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APPENDIX 7: MASS BALANCES AND EMPIRICAL EUTROPHICATION MODEL UPDATE

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MASS BALANCES AND EMPIRICAL EUTROPHICATION MODEL UPDATE

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1. INTRODUCTION

The development and structure of a mass-balance modeling framework for Onondaga Lake is described in previous lake monitoring reports (Ecologic et al., 2006). 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, non-point, 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 et al, 2006).
(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 data through 2007. Computations are linked directly to the AMP long-term water quality and hydrologic database (Figure 1). Recent mass balances for key water quality components are summarized. Long-term trends in total loads (point, non-point), inflow concentrations, and outflow concentrations are documented using revised statistical methods.

With improvements to the monitoring program made since initiation of the AMP in 1999, the accuracy and precision of the load estimates and power for detecting trends has steadily improved. In this update, nine out of the ten years in the base period typically used to evaluate recent trends (1998-2007) reflect AMP improvements.

With implementation of point-source phosphorus controls, non-point loads have become increasingly important as factors driving eutrophication-related water quality in the Lake. A separate section analyzes spatial and year-to-year variations in non-point loads of phosphorus and other constituents from the Lake tributaries, as they relate to land use and rainfall.

As discussed in the previous annual report (Ecologic, 2007), the steady increase in precipitation over the past decade significantly complicates the interpretation of apparent trends in the tributary loading data. Since annual runoff and non-point source loads are correlated with precipitation, any decreases in long-term-average loads or improvements in lake water quality resulting from the control program would have been at least partially masked by increases in non-point load attributed to rainfall. Potential refinements in the trend analysis methodology to account for variations in rainfall are explored. These include using a longer period of record (vs. ten years) and statistical adjustment to remove rain-driven variations. The apparent decreasing trend in non-point total phosphorus load identified in the 2006 report (3.1 +/- 1.2 % per year over 1990-2006) is further explored by applying the revised methods to data for other constituents and from individual tributaries. While the trend analysis is complicated by the increasing trend in rainfall, analysis of data from 1998-2007 indicates a significant decreasing trend in the combined phosphorus load from urban watersheds, an increasing trend in load from the lower subwatershed of Harbor Brook, but no trend in the combined non-point load from all tributaries.

The report updates the empirical eutrophication model that was initially developed based upon data thru 1999 (Ecologic, 2000) and subsequently updated to include data through 2000 (Ecologic, 2001) and 2005 (Ecologic, 2006). 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 concentration 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 the responses of summer-average lake concentrations and algal bloom frequencies to reductions in external phosphorus loads potentially resulting from future implementation of point-source and non-point-source control measures.

As further reductions in phosphorus loads from METRO were accomplished in 2006-2007 to achieve an average annual inflow concentration of 0.12 ppm, lake phosphorus concentrations decreased and algal productivity became increasingly phosphorus-limited (Figure 2). While declining trends in mixed-layer and hypolimnetic phosphorus concentrations indicate that the Lake had not fully responded to the recent load reductions and further reductions in non-point loads are planned, Lake water quality conditions in 2006-2007 were substantially closer to those likely to result from full implementation of planned control measures, as compared with at and before the beginning of the AMP. Adding data from these two years to the calibration dataset substantially improves the accuracy and precision of the model for use in evaluating the ultimate assimilative capacity and evaluating further control measures to achieve water quality goals. Further analysis of magnitudes and trends in non-point source loads also provides as improved basis for evaluating the load reductions potentially resulting from BMP's and CSO controls.

2. HYDROLOGY

Yearly variations in precipitation and lake inflow volume are summarized in Figure 3. Over the 1990-2007 period, yearly runoff from the Onondaga Lake watershed varied from 31 to 75 cm and was strongly correlated with precipitation (r = 0.91). Runoff and precipitation were slightly above average in 2007. Runoff was 60 cm, as compared with the 18-year mean of 53 cm. Precipitation was 106 cm, as compared with a mean of 99 cm. Precipitation gradually increased from ~80 to ~110 cm/yr while runoff increased from ~30 to ~60 cm/yr over the 1998-2007 period. As discussed below, this complicates the interpretation of apparent trends in loading.

3. MASS BALANCES

Historical variations in the mass balances of primary water quality components over the 1990-2006 period are summarized in the following figures:

Figure 4	Total Inflow & Outflow Concentrations
Figure 5	Total Inflow & Outflow Loads
Figure 6	Total Non-point & 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.

The following tables describe lake mass balances for various constituents in the most recent 5-year period (2003-2007), as provided in previous annual reports:

Table 1	Chloride
Table 2	Total Nitrogen
Table 3	Ammonia Nitrogen
Table 4	Total Phosphorus
Table 5	Soluble Reactive Phosphorus

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 considered most representative of net discharge from the Lake exceeded inflow loads by 3.6% ± 2.1% in 2003-2007 (Table 1). This compares with 5.7+/- 2.1% in the previous 5-year interval and 0.4 +/- 3.4% in last 2 years 2006-2007. An apparent increasing trend in the chloride load from the lower portion of Onondaga Creek (between the Dorwin and Kirkpatrick monitoring sites) may be responsible for the gradual convergence of the chloride balance, although the loading trend analysis is uncertain because of increases in precipitation (see below). In 2003-2007, the chloride load to this reach accounted for 34% of the total load to the Lake (Table 1). Chloride export from this subwatershed averaged 1,237 mt/km^2-yr, as compared with 144 mt/km^2-yr for all other subwatersheds combined. Trends in the sodium balance are similar (Figure 5). Salt springs enter the lower reach of Onondaga Creek between the Dorwin and Kirkpatrick sites (Kappel, 2003). Increases in road salt contributions associated with increasing precipitation may also contribute to increasing chloride and sodium loads.

As a consequence of treatment improvements, annual total phosphorus concentrations in the Metro discharge varied from 0.12 to 0.54 ppm in the 5-year mass balance period, but averaged 0.12 ppm in both 2006 and 2007. Supplemental total phosphorus balances for 2006-2007 and 1998-2007 are listed in Tables 6 and 7, respectively. The former is representative of point-source loads reflecting the current Metro treatment level. The latter reflects a wider range of precipitation and runoff concentrations that would be representative of average non-point loads in the past 10 years. That period is used below as a baseline for evaluating load reduction scenarios using the phosphorus mass-balance. Total phosphorus balances for each period are summarized below:

TP Load (metric tons / yr)	1998-2007	2006-2007	1998-2007*
Total Non-point	26.4	29.3	26.4
Industrial	0.4	0.2	0.2
Metro Discharge (Outfall 1)	27.5	10.7	10.7
Metro Bypass (Outfall 2)	2.3	1.5	1.5
Total	56.8	42.0	38.8

The 2006-2007 non-point load was above the 1998-2007 average because of high precipitation (Figure 3). The third column(*) combines 1998-2007 non-point with 2006-2007 Metro and industrial loads. This is representative of the long-term average loads with the existing Metro treatment capabilities. The combined Metro discharge accounted for 31% of the total load, as compared with 52% in 1998-2007.

4. NON-POINT SOURCES

With non-point sources currently accounting for ~69% of the long-term average phosphorus load to the Lake, implementation of non-point source controls will be important to achieving further load reductions and improvements in Lake water quality. Spatial variations in runoff and non-point phosphorus loads from each subwatershed are shown in Figure 7. These results are based upon water and phosphorus balances for 1998-2007 listed in Table 7. Comparisons are made across subwatersheds with respect to drainage area, total flow, load, concentration, runoff (flow per unit watershed area), and export (load per unit watershed area).

As described in the previous annual report (Ecologic, 2007), mass balances have been expanded to reflect runoff and non-point loads from different subwatersheds. Paired monitoring sites on Harbor Brook (upstream = Velasko, downstream = Hiawatha) and Onondaga Creek (upstream = Dorwin, downstream = Kirkpatrick) provide a basis for partitioning the load from each tributary into two components (Upper vs. Lower subwatersheds). In each case, the Upper subwatershed is generally representative of rural (undeveloped, agricultural) land uses, while the Lower subwatershed is generally representative of urban land uses. Similarly, the Ninemile Creek watershed is primarily rural and the Ley Creek watershed is primarily urban.

Total flows and loads from the Upper (~Rural) and Lower (~Urban) watersheds are included in the mass balance tables. A third category ("Net Urban") reflects the estimated Lower watershed contribution above that expected if the unit area export coefficient were equal to that measured in the Upper watershed (i.e. rural background load). The net load is estimated by applying the export coefficient (load per unit) from the Upper watersheds (total = 554 Km^2) to the drainage area of the Lower basins (126 km^2). The net load from the Lower basins is thus computed as the measured load minus 0.23 times the measured load from the Upper basins. The same algorithm is used to compute subwatershed runoff volume.

The upper/rural and lower/urban watershed categories are also considered in the trend analyses described below. The lower watershed load estimates are less precise because they are computed by difference and thus reflect uncertainty in loads measured at both the upstream and downstream monitoring sites. The partitioning of Onondaga Creek is approximate because loads at the downstream site are computed from concentrations measured at Kirkpatrick Street and flows measured at Spencer Street since 1998. While the rural vs. urban classifications are simplifications because each subwatershed contains a mix of land uses, the framework provides approximate estimates of the total and net contributions from the urban watersheds that would potentially benefit from implementation of CSO and urban runoff controls in the lower watersheds. This information is useful for evaluating potential benefits of and responses to BMPs and CSO controls implemented in various locations.

As shown in Figure 7, runoff from individual subwatersheds varied from 20 to 68 cm/yr. Phosphorus export rate from the three urban watersheds averaged 60 kg/km^2-yr and ranged from 54 to 115 kg/km^2-yr, as compared with a mean of 31 kg/km^2-yr and range of 15 to 27 kg/km^2-yr for the rural watersheds. Considering the mix of land uses in each category, these export coefficients are reasonably consistent with values estimated for the Oneida Lake watershed by the Ecologic(2007b): 7 to 28 kg/km2-yr for undeveloped areas, 40 to 70 kg/km2-yr for medium-high density urban areas, 45 kg/km2-yr for pasture, and 210 kg/km2-yr for cropland. They are also similar to values tabulated by the Coon & Reddy (2008). Similarly, the Onondaga Lake urban watersheds had higher runoff concentrations (mean = 98 ppb, range = 65–571 ppb), as compared with rural watersheds (mean = 60 ppb, range = 43–65 ppb). Overall, urban watersheds accounted for 29% of the total non-point load, rural watersheds accounted for 65%, and ungauged areas accounted for 6%. The net phosphorus load from the lower/urban watersheds (above rural background) accounted for 14% of the total non-point load.

Each of the three urban watersheds (Ley, lower Harbor, lower Onondaga) contributed equally to the total load (3.4-3.6 mt/yr), even though the lower Harbor watershed is about half the size of the others. Further investigation of potential causes for the unusually high P export from the lower Harbor watershed is recommended, particularly given the apparent increasing trend in load described below (Table 10, Figure 10).

Similar non-point source breakdowns for other water quality components are listed in Table 8. In most cases, export coefficients are higher for the lower/urban watersheds. Excess fertilizer in agricultural runoff probably accounts for the similar rural and urban export coefficients for total and nitrate nitrogen.

5. TRENDS IN PHOSPHORUS

Data from the most recent ten-year period have typically been used to test AMP hypotheses regarding decreases in load or concentration resulting from implementation of control measures. As discussed above and in the previous annual report (Ecologic, 2007), the increase in precipitation over the 1998-2007 period significantly complicates causal interpretation of trends in the tributary loading data (Figure 3). Precipitation and year are highly correlated in this period (r=0.78). Similarly, total runoff and non-point load are each correlated with precipitation (r=0.84 and r= 0.75), as well as with year (r = 0.74 and r=0.58, respectively). Any decreases in long-term-average loads or improvements in lake water quality resulting from the control program could have been partially masked by increases in non-point load attributed to rainfall. As a consequence, tests of AMP hypotheses regarding load reductions and lake improvements over the 1998-2007 period are weak and likely to be conservative; i.e. any improving trends might have been more pronounced had there not been an increasing trend in precipitation over this period.

Power for detecting trends is improved by considering a longer base period (1990-2007) that includes precipitation cycles (Figure 3). Rainfall and year are less correlated over this period (r = 0.02), as compared with 1998-2007 (r = 0.78). One disadvantage of using a longer time frame is that apparent trends may vary within the 18-year period. Improvements in the monitoring program made over this period could also impact the trend analysis. As demonstrated in the previous annual report (Ecologic, 2007), the power for detecting trends can also be increased by statistical adjustment of the data to account for rain-driven variations (Hirsch et al, 1982; Walker, 2000).

A decreasing trend in the rainfall-adjusted phosphorus non-point load (-3.1 +/- 1.2%/yr) over the 1990-2006 period was identified in the previous annual report. Similar results are obtained when the same methodology is applied to the 1990-2007 data (Figure 8). The 2007 data fall on 1990-2006 regression lines relating load to precipitation and adjusted load year. As recommended in the previous report, the trend and methodology are further explored below by analyzing data from individual sources, other constituents, and other time frames.

Figure 9 applies a slightly different methodology to total non-point runoff, phosphorus load, and flow-weighted-mean concentration over the 1990-2007 period. A multiple regression model relating the logarithm of the observed value to year and precipitation is fit to each time series. For each variable, the trend hypothesis is tested by determining whether the regression coefficient for year is significantly different from zero ($p < 0.05$ for one-tailed hypothesis). The regression models explain 80% of the variance in runoff, 72% of the variance in load, and 56% of the variance in concentration. Each variable is positively correlated with rainfall. There is no apparent trend in runoff volume, but decreasing trends in total non-point load (-3.1 +/- 1.1 %/yr) and concentration (-3.7 +/- 1.0 %/yr). One limitation of the methodology is that the trends are assumed to be linear. This has the effect of reducing the power of the test for detecting sudden reductions in load potentially resulting from implementation of a control measure at a specific date. This may not be a major limitation, however, because of the time scales required for BMP's to be implemented and become fully effective, both at the mouths of the tributaries and in the outflow from the Lake.

The same methodology is applied to 1990-2007 data from individual sources and the Lake outflow in Table 9. Adjusted load time series are shown in Figure 10. In each case, the trend hypothesis is tested with and without adjusting for precipitation using the equations given in Figure 9. Because there is no net trend in precipitation during this period, conclusions regarding the presence or absence of trends are relatively insensitive to precipitation adjustment, although adjustment increases the power of the trend hypothesis test by decreasing variability in the time series. With precipitation adjustment, results indicate slight (~1%/yr) decreasing trends in flow at Harbor Brook and Onondaga Creek sites and an 8%/yr decreasing trend in Trib5A flow. Reductions in non-point P load and concentrations are indicated for most point and non-point sources and for the lake outflow. In contrast, increasing trends in phosphorus load and concentration are indicated for the lower portion of Harbor Brook (between the Velasko and Hiawatha monitoring sites).

Trends in phosphorus load over the 1990-2007 period are expressed both in percent per year and in kilograms/year (Table 9). The latter reveals the extent to which trends in individual sources contribute to trends in the total non-point and overall loads. The apparent trend in total non-point load (-1,012+/- 373 kg/yr) accounts for 20% of the trend in total inflow load (-4,880 +/- 732 kg/yr), which primarily reflects reductions in Metro load over the 1990-2007 period. No trends in load are indicated for Ninemile Creek and the upper portion of Onondaga Creek. Most of the apparent trends in non-point load are attributed to urban subwatersheds (Ley Creek and lower portion of Onondaga Creek). The apparent increasing trend in phosphorus load from the lower Harbor Brook watershed (43 +/- 8 kg/yr) offsets a portion of the decreasing trend in load from all non-point sources combined (-1,012 +/- 373 kg/yr).

The analysis of non-point phosphorus loads for 1990-2007 is repeated for 1998-2007 in Figure 11 and Table 10. Because of the increasing trend in precipitation during this period (Figure 3), conclusions regarding the presence or absence of trends in load for individual sources are sensitive to precipitation adjustment. Without adjustment, increasing trends in flow are indicated for most of the mass balance terms (Table 10). This is likely to be a consequence of the increasing precipitation. With adjustment, increasing trends in flow are indicated only for the Harbor Brook sites and a decreasing trend is indicated for Trib5A. Similarly, adjustment for precipitation removes most of the apparent trends in load. Exceptions include a decrease in load from Trib5A and increase in load from Harbor Brook, both of which are consistent with corresponding decreasing trends in flow. A decreasing trend in the adjusted total load from all urban watersheds combined is also indicated (-6.0 +- 2.5 %/yr). Rainfall adjustment removes most of the apparent trends in concentration, with the exceptions of decreasing trends for the total inflow, Ley Creek, and the combined inflows from the urban watersheds.

Results suggest that most of the apparent decreasing trend in total non-point P load over the 1990-2007 period occurred prior to 1998. Even with adjustments for precipitation, however, trend analysis results for 1998-2007 are uncertain because the increasing trend in precipitation causes the model regression coefficients to be correlated. While a trend in the total non-point load is not indicated for 1998-2007, decreasing trends in phosphorus load (6%/yr) and concentration (7%/yr) are indicated for the combined inflows from the urban subwatersheds. Lower Harbor Brook exhibits increasing trends in flow and load, but no apparent trend in phosphorus concentration. No trends in phosphorus load or concentration are indicated for the upper/rural watersheds.

Despite the fact that the lowest inflow phosphorus loads and concentrations occurred in 2006-2007 with the Metro discharge concentration reduced to 0.12 ppm, significant (linear) trends in the Metro load, total lake inflow load, and outflow loads are not indicated for the 1998-2007 period. This reflects the fact that Metro loads peaked in 2003-2004 and was closely tracked in the lake outflow (Figures 5 & 6). This "blip" in the load time series makes it difficult to identify long-term declining trends in point-source and total loads within the 1998-2007 interval.

As compared with loads, flow-weighted-mean concentrations tend to be less variable and less correlated with rainfall. As a consequence, the likelihood of detecting a trend of a given magnitude is greater for concentration than for load. The long-term flow-weighted-mean concentrations can be used as a surrogate for the long-term-average load if the flow regime is assumed to be stable. Results of Seasonal Kendall Tests applied to concentration data from individual monitoring sites should also be considered in evaluating trends in the tributaries. While they are not flow-weighted and also confounded with trends in precipitation, they are likely to be more powerful because they are based upon the individual samples (vs. annual flow-weighted-means), do not assume a linear trend, and are more robust to outliers in the data. Results of these tests for 1998-2007 indicate decreasing trends in phosphorus concentration at the Lake outflow and Ley Creek sites and increasing trends at the Dorwin (upper Onondaga Creek) and Hiawatha (total Harbor Brook) sites. These results are reasonably consistent with the observed trends in rainfall-adjusted load and flow-weighted-mean concentration. There also indications of increasing trends in the adjusted load and flow-weighted mean concentration at the Dorwin site in 1998-2007, although they are not strong enough to be statistically significant.

The correlation between rainfall and non-point P loads developed from 1998-2007 data (Figure 11) can be used as a baseline for evaluating future measured loads relative to a management goal. Suppose, for example, that a goal of reducing the long-term average non-point load by 20% relative to the 1998-2007 were established. The load vs. rainfall regression model can be used to develop a confidence interval for the measured load in any future year that would be consistent with achieving the goal, considering the precipitation in that year. Similar methods are used to measure BMP performance in Florida agricultural watersheds (Walker, 2000). As compared with testing for linear trends in load or flow-weighted concentration, comparison of data from each year with 10-year baseline values may be more useful for evaluating responses to future load-reduction measures. Adjusting for precipitation in each year increases the power of such comparisons. This concept is recommended for further development in the AMP statistical framework and/or future yearly reports.

6. TRENDS IN OTHER CONSTITUENTS

Ten-year trends in load and concentration for other nutrient and inorganic constituents are listed in Tables 11 and 12, respectively. Results are shown with and without adjustment for precipitation using the multiple regression technique described above (Figure 9). Table 13 lists adjusted trends in load expressed in mass units (i.e. kg/yr vs. %/yr). Shaded cells indicate tests that are potentially impacted by detection limits for Ammonia N and Nitrite N at two sites with relatively low concentrations (Velasko and Dorwin). Trend analyses for BOD-5, TSS, and SRP in the lake tributaries are not shown because they are also potentially impacted by variations in analytical methods and detection limits. Similar to the results for phosphorus, many of the apparent trends in load and concentration are removed when adjustments are made for precipitation. Results of the latter tests are discussed below. While the multiple regression technique increases the power of the tests for trends in the long-term means, all results are subject to uncertainty because the technique does not necessarily eliminate the confounding effect of the trend in precipitation over the 1998-2007 period. Addition of data from future drought years to the time series will provide a basis for distinguishing between trends and variations driven by precipitation.

Decreasing trends in load and concentration are indicated for nitrogen species (TKN, Ammonia N, Nitrite N) in the Metro discharge, total inflow, and total outflow. Decreasing trends in ammonia concentration and/or load are also indicated for all of the non-point inflows to the Lake. At sites with relatively low ammonia concentrations (Velasko, Dorwin), these trends are likely to be artifacts of the decrease in the ammonia detection limit from 0.1 to 0.03 ppb over this period. Since these data are used to compute the net loads from the lower subwatersheds of Harbor Brook and Onondaga Creek, those results are suspect also. Results for other sites with concentrations in a higher range would not be impacted by the decrease in detection limit.

Both with respect to concentration and load, increasing trends in sodium and chloride are indicated for the total inflow and for the inflow from each tributary except for Ninemile Creek. On a mass basis, the trend in load from the lower Onondaga Creek watershed accounts for most of the trend in the total inflow load (Table 13). Despite the apparent trends in inflow loads for sodium and chloride, no trends in outflow loads are indicated.

Increases in flow are indicated at each Harbor Brook site. These are associated with increases in loads of total phosphorus, total nitrogen, nitrate, inorganic species (alkalinity, calcium, chloride, sodium) at the Hiawatha site. Similarly, decreases in Trib5A loads reflect an apparent decrease in flow.

Apparent increasing trends in silica concentration and load in the Lake outflow are not paired with corresponding trends in the lake inflow. This may be an indirect consequence of reduced algal productivity in the Lake resulting from decreases in phosphorus load. If diatom growth were increasingly limited by phosphorus levels, silica uptake by diatoms and subsequent sedimentation would also to decrease. Increases in lake nitrate concentrations would also be expected from this mechanism, although masked in Onondaga Lake by the decreases in nitrogen loads.

7. EUTROPHICATION MODEL

7.1 Introduction

This section updates empirical eutrophication model framework described in previous reports (Ecologic, 2000, 2001, 2005). The model structure is depicted Figure 12. Following the protocol established in previous updates, the model is re-calibrated to data from the last 5 water years (2003-2007) and tested against data collected prior to that (1991-2002). While small adjustments are made to a few model coefficients in this update, the overall calibration is not significantly different that based upon 2001-2005 data (Ecologic, 2006). Lake conditions in 2006-2007 are successfully simulated using the model structure and calibrations developed in the previous update.

Models of this type are widely used for eutrophication assessment because of their limited data requirements and demonstrated ability to predict eutrophication-related water quality components within defined error distributions (Canfield & Bachman, 1981; Reckhow & Chapra, 1983; Wilson & Walker, 1989; Walker, 2006). While all mechanisms controlling lake phosphorus and algal response are not directly considered, effects of simplifying assumptions in the model structure are embedded in the calibrated coefficients and error distributions. Quantification of the latter allows characterization of the uncertainty associated with model forecasts and which is particularly useful in a TMDL context (Margin of Safety etc, Walker 2001, 2003). While a-priori calibrations are typically based upon data from collections of lakes, site-specific calibration reduces the potential impacts of simplifying assumptions and improves the accuracy and precision of model forecasts. The latter features depend on the extent to which future scenarios differ from conditions under which the model was calibrated and tested.

Compared with previous model updates, calibration conditions are much closer those expected when the ultimate water quality goals are attained. Figure 2 shows TP concentrations in the upper (0 – 3 m and lower (9 – 12 m) layers at the Lake South station between 1990 and 2007. Declining trends were especially evident in the bottom layer, where concentrations peaked in late summer and subsequently declined in fall as the thermocline eroded and bottom waters became entrained in the upper layer. Peak lower-layer TP concentrations were 40-80 ppb in 2006 -2007, as compared with 100-300 ppb in 1990-2005. In the summer of 2007, the upper-layer TP concentration ranged from 21 to 44 ppb, the lowest in the 1991-2007 period of record.

7.2 Data Set Development

Average total nitrogen and phosphorus for the calibration period (2003-2007) are listed in Tables 2 and 4, respectively. Yearly loads and observed lake data used in model calibration and testing are listed in Table 14. 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 on a water- year basis.

Average lake nutrient concentrations in each summer have been computed using June-September samples collected at the Lake South station between 0 and 3 meters. Summer means and standard errors have been 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. Seasonal dynamics in lake TP and chlorophyll-a concentrations have been considered in selecting an averaging period for the lake responses (i.e. the definition of “summer”). Seasonal variations in upper-layer phosphorus, chlorophyll, and transparency over the 1998-2007 period are plotted in Figure 13. TP concentrations generally tend to decline from April to June due to algal uptake and sedimentation, then increase in late September and October as the thermocline erodes and phosphorus in the enriched hypolimnion is transported to the upper layer (Figure 2). The previous model version was calibrated to trophic state indicator data collected between June and August. That averaging period was used to reflect the summer stratified period and limit effects of lake mixing events in early fall on the phosphorus calibration. The latter events cause TP increases that have relatively little impact on summer-average algal productivity. June-August also corresponded to the averaging period typically used to assess lake condition relative to the state's guidance value for Total P (20 ppb).

Subsequent to the previous model update, June-September was adopted under the AMP as the official averaging period for assessing lake conditions relative to long-term water quality goals (Ecologic, 2007). Accordingly, the model calibration period has been changed to reflect that period. Extension of the averaging period from June-August to June-September has the advantage of capturing that portion of the growing season occurring in September, as evident in elevated chlorophyll-a and low transparency levels (Figure 13). While phosphorus increases in late September are evident in some years, these occurred prior to the substantial decreases in bottom P concentrations in 2006-2007 (Figure 2). One exception is the September 30, 2003 sampling event, which has been excluded from the calibration dataset because of turnover impacts evident in a lake P concentration about twice those measured in all previous events that year.

Chlorophyll-a concentrations are based upon photic zone samples (1999-2007), epilimnion composites (1993-1998), and 0-3 meter average grab samples (1991-1992). Based upon paired data from 1999-2005, photic zone chlorophyll-a data collected during in June-September exceeded epilimnetic composites by an average of 10.2%. This reflects that the fact that epilimnion composites often extended below the photic zone, where lower algal densities may have been lower. Accordingly, the 1993-1998 epilimnetic values have been increased by 10.2% for consistency with the 1999-2007 values. No adjustment has been to the 1991-1992 grab-sample chlorophyll-a data because there are no paired photic zone measurements.

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 (Figure 1). 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). Results for the 9-meter depth have been used for model testing.

7.3 Assumptions

This section examines key assumptions in the phosphorus balance model with respect to vertical gradients, horizontal gradients, seasonal variations, and year-to-year variations. While simplifying assumptions have desirable effects of reducing data requirements and the number of calibrated parameters, they create a risk of bias in model forecasts, particularly if the model is applied under conditions that are significantly different from those present during the model calibration and testing periods. To some extent, effects of deviations from assumptions are embedded in the calibrated coefficients and reflected in the defined error distributions. Diagnostic checks (residuals analysis) provide a basis for evaluating model biases related to simplifying assumptions. Parallel application of the detailed Lake model (QEA, 2006) in evaluating management alternatives will be useful for evaluating the robustness of management decisions to modeling approach.

The model does not attempt to simulate the substantial vertical gradients in the water column P concentration evident in Figure 2. It does not assume that the water column is well-mixed vertically, but that net sedimentation of phosphorus per unit area is proportional to the upper-layer TP concentration. This is consistent with the notion that P uptake by algae and subsequent sedimentation is a primary mechanism for P removal. Effects of vertical gradients and mixing between the upper and lower layers are minimized by calibrating to data from the stratified period. Residual effects are embedded in the calibrated parameters (settling rate and ratio of summer to annual flow-weighted mean outflow concentration) and in the error distributions characterized by model calibration and testing datasets.

Figure 14 shows TP and chloride time series at the Lake South (0 -3 m), Lake North (0-3 m), and Outlet (3.7 m) sites. There is good agreement across these sites for each variable and year. This supports the model's assumption that horizontal variations in water quality are small relative to seasonal and year-to-year variations. The occasional negative divergence of the outlet chloride from the lake values may reflect intrusion events from the Seneca River that penetrate to lower depths at the outlet.

Total phosphorus loads from the tributaries and point sources are assumed to have the equal impacts on the summer mixed-layer TP concentrations. There are three mechanisms that could decrease the relative impacts of the tributary loads:

1. Density currents transporting saline tributary inflows (Onondaga & Ninemile Creeks) below the upper mixed layer.
2. Differences in bio-availability related to phosphorus speciation; and
3. Seasonal variations in the relative magnitude of tributary and point-source loads.

To the extent that these mechanisms are important, the model will tend to under-estimate lake sensitivity to reductions in point-source loads and over-estimate sensitivity to reductions in non-point loads. While only the SRP fraction is immediately available for algal uptake, portions if not most of the dissolved organic and particulate P loads are eventually made available through decomposition processes occurring in the water column and recycling from bottom sediments occurring over various time scales. Model residuals (Figure 17) are reasonably independent of phosphorus load speciation, the fraction of load attributed to the Metro discharges, and the seasonal distribution of loads. This suggests that net effects of these mechanisms are small relative to other sources of variability in the model residuals.

Salinities measured in the lake thermocline tend to be slightly elevated relative to surface and bottom layers during the summer. This is evidence of “plunging inflows” from creeks with elevated salinity (Onondaga and Ninemile) and subsequent transport through the Lake as density currents below the mixed layer. The phosphorus load associated with these flows in June-September when density currents are evident averaged 18% of the total annual non-point load and 8% of the total load to the Lake in 1998-2007. Lake vertical profiles show that the summer thermocline salinity bulge is typically 10% above surface and bottom values, whereas the inflowing creek salinities typically exceed the lake mixed- layer values by 200% in Onondaga Creek and 100% in Ninemile Creek. Considerable dilution of the saline inflows apparently occurs as they enter the lake before the density currents develop. There are no indications of positive divergence in the outlet chloride concentrations relative to the mixed layer values which would be expected if a significant fraction of the saline inflows passed through the Lake without mixing into the upper per layer (Figure 14). Similarly, positive divergence of the lake outlet over the upper mixed layer values is not evident in sodium or conductivity data. While density currents are evident in the profundal zone, it is possible that they are destroyed when reaching the littoral zone at the northern end of the lake and recycled back into the lake surface waters instead of passing directly to through the outlet.

Declining trends in inflow (Figure 5), lake surface, and lake bottom concentrations (Figure 2) 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. Peak fall-overturn concentrations declined from ~0.3 to ~0.04 ppm between 1995 and 2007 (Figure 2) which corresponds to an average trend of -2.8 metric tons / year in the phosphorus stored in the lake, assuming a total lake volume (128 $x10^6$ m^3). This is approximately 5% of the average inflow load and 7% of the average outflow load over the same period. Corresponding percentages for 2007 alone were 13% and 21%, respectively. This indicates that the Lake was still responding to the sharp reductions in load that occurred over the 2006-2007 period. As a consequence of this, the steady-state model calibration is likely to be conservative; i.e. over-estimate the long-term average Lake P concentration likely to result from a given loading regime.

Depletion of surface SRP concentrations in the summer is a sign that algal productivity is limited by phosphorus, a key assumption in the model components predicting mean chlorophyll-a and related trophic state indicators. Summer SRP concentrations in the upper layer were frequently at or below detection in 1998-2007, with exception of 2004, when loads from Metro were high relative to the other years (Figure 5). Figure 15 plots summer mean SRP vs. TP concentrations in 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.

7.4 Model Structure and Calibration

The model structure is depicted in Figure 12. Major components and calibrations to 2003-2007 data are summarized below:

- Yearly flow-weighted-mean outflow TP and TN concentrations are predicted from inflow loads and flows using a simple first-order model that assumes that the net nutrient removal per unit area is proportional to the mean concentration in the upper mixed layer (Vollenweider, 1969; Chapra, 1975). The calibrated coefficients (“effective settling rates”) are 22.9 m/yr for TP and 15.9 m/yr for TN.

- Summer lake TP and TN concentrations are assumed to be fixed percentages of the yearly flow-weighted-mean outflow concentrations. The calibrated percentages are 59% for phosphorus and 100% for nitrogen.

- Chlorophyll-a is predicted using the Jones & Bachman (1976) regression equation for phosphorus-limited lakes. As expected, the model over-predicts chlorophyll-a and related trophic state indicators in years prior to ~1998 when phosphorus concentrations were above growth-limiting levels. Convergence between the data and predictions occurred as TP and SRP concentrations decreased in the recent decade (Figure 15).

- Other trophic response variables (Secchi Depth, organic nitrogen, utilized phosphorus (TP - SRP), and HOD rates) are predicted from predicted chlorophyll-a using empirical models derived from other lake and reservoir datasets, as extracted from the BATHTUB model (Walker, 1985; 2006).

- Bloom frequencies (% of daily chlorophyll-a concentrations exceeding 15 or 30 ppb, adopted AMP metrics (Ecologic, 2007), are computed from predicted mean chlorophyll-a concentrations using a log-normal frequency distribution model (Walker, 1984; 2006) and calibrated temporal coefficient of variation (Figure 18).

- Frequencies of Secchi Depths less than 1.5 meters and 1.2 meters (also adopted AMP metrics) are predicted using a log-normal frequency distribution and a calibrated temporal coefficient of variation (Figure 19).

Updated model equations coefficients and equations are listed in Table 15. Observed and predicted time series for primary variables in the model network are shown in Figure 16. Prediction intervals in Figure 16 are based upon residual standard errors computed from 1998-2007 data. For each sub-model, the 10-year residual standard error is less than or equal to the error for the 5-year model calibration period. Therefore, the calibrations hold up when applied to data from different periods.

The phosphorus balance model calibrated to 2003-2007 data performs reasonably well when applied to data from previous years. The calibrated net settling rate (22.9 m/yr) compares with a range of 19.9 to 22.9 m/yr in previous model updates. Residual standard errors (11% for outflow P and 14% for Lake P) reflect the combined effects of factors not considered in the model structure and uncertainty in the data related to limited precision of the yearly inflow loads, yearly outflow outflows, and summer-mean concentrations computed from the biweekly measurements. Figure 17 indicates that phosphorus residuals (observed-predicted concentrations) are reasonably independent of several factors related to model assumptions, including year, areal water loading, phosphorus loading, average inflow concentration, ratio Metro load to total load, ratio of SRP to total P load, ratio of Total Dissolved P to Total P load, and fraction of the total annual load occurring between May and September. Any effects of variations in phosphorus speciation or differential response to Metro vs. tributary loading appear to be small relative to the inherent residual variations.

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 external load reductions would be reflected in the model residual time series (Figure 17). Reasonable agreement between observed and predicted lake and outlet P time series over this period with significant reductions in external load (Figure 16) suggests that effects of net phosphorus releases from bottom sediments are small relative to variations in 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.

While there is good agreement between observed and predicted outflow TN concentrations, summer TN concentrations are significantly under-predicted in 2007 (Figure 16). The calibrated settling rate (15.69 m/yr) compares with a range of 14.2-30.5 m/yr in previous model updates. Most of the variance in settling rate reflects an error in the outflow total nitrogen load time series used in the previous calibration to 2001-2005 data (Ecologic, 2006). That error resulted in a high settling rate (30.5 m/yr) as compared with 14.2 to 15.5 m/yr for the other calibration periods. Performance of the total nitrogen model is limited by the shift in load speciation from reduced to oxidized forms associated with nitrification of the Metro discharge over the past decade. In addition, decreases in nitrogen removal by phytoplankton are expected as productivity becomes increasing limited by phosphorus levels. This factor may explain the positive nitrogen residual in 2007, the year with the lowest lake P concentration. While the model tracks outflow N concentrations (Figure 16), a simple first-order model that ignores nitrogen speciation and coupling with phosphorus does not appear to be sufficient. The nitrogen model is included here only for comparison with phosphorus and is not particularly relevant to evaluating management scenarios, since total nitrogen concentrations are not a factor with respect to compliance with water quality standards.

Aside from SRP depletion (Figure 15), another pattern consistent with the increased importance of phosphorus limitation is the convergence of observed and predicted chlorophyll-a concentrations in recent years (1999-2007, Figure 16), 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 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).

Coefficients of determination (R^2) for the 10-year interval are relatively high for nutrient concentrations (0.57 to 0.84) as compared with chlorophyll-a and related trophic state indicators (0 – 0.59). This reflects the fact that year-to-year variations in chlorophyll-a have been relatively low relative to the inherent error distributions in recent years as growth has become increasing limited by phosphorus. Error coefficients of variation (CV's) are generally below typical values for empirical models of this type. Table 16 compares results with error CV's associated with the original BATHTUB calibration based upon data from 40 reservoirs (Walker, 1985). The error CV's reflect the combined influences of sampling variations (uncertainty in loads and measured lake variables) and model error. Further analysis could be performed to separate these sources of error. Without separation, the current model over-estimates the uncertainty associated with model forecasts.

7.5 Model Applications

The Excel workbook (OLEEM.XLS) for applying the model has been revised to reflect the updated calibration. The workbook facilitates application of the model to user-defined loading scenarios (Tables 16 & 17). 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. Model updates and documentation are posted at http://www.wwwalker.net/onondaga .

The AMP hypotheses include numerical criteria for measuring lake-restoration progress, expressed in terms of summer-mean Total P (< 20 ppb, NYSDEC guidance value), frequency of chlorophyll-a values exceeding 15 ppb (< 15%), and frequency of Secchi depths < 1.2 meters (0%). Yearly simulations provide a basis for predicting the percent of years conforming to these and other eutrophication-related criteria for specific management actions. Accordingly, the workbook has been enhanced to simulate yearly time series, as well as a specified average loading regime. This enables characterization of both year-to-year variability and uncertainty in model projections, features which are useful in a TMDL context (Walker, 2001; 2003).

The predicted response of each trophic state indicator to variations in phosphorus load and concentrations is shown in Figure 13, as derived from the OLEEM.XLS. The 80% prediction intervals (10^{th}, 50^{th}, 90^{th} percentiles) for an average hydrologic year are shown for each variable. Response curves are shown relative to mean loads and phosphorus concentrations in 1998-2007 and 2006-2007. The latter period represents the status-quo with the Metro discharge concentration at 0.12 ppm, although non-point loads in 2006-2007 were above the 1998-2007 average because of high precipitation (Figure 3).

The model has been applied to forecast lake responses to various management scenarios involving combinations of Metro effluent P levels and non-point source load controls. Results are based upon simulations of Water years 1998-2007. As discussed above

(Section 7.5), this period reflects a wide range of annual precipitation and reasonably stable non-point loads when adjusted for variations in precipitation. Forecasts for scenarios stored in the model workbook are summarized below:

	TP Load	Inflow TP Conc ppb		Nonpoint	Lake TP	Chl-a	Algal Bloom Freq		Secchi	Secchi Excurs.Freq	
Scenario	mt/yr	Metro	Non-Point	Reduc %	ppb	ppb	> 15 ppb	> 30 ppb	m	< 1.2 m	< 1.5 m
Base 1998-2007	56.4	306	67	0%	44	21	66%	15%	1.7	12%	37%
Metro =120	39.5	120	67	0%	31	12	25%	2%	2.0	4%	19%
Metro=120, NPS=50	33.1	120	50	25%	26	9	11%	0%	2.1	3%	15%
Metro=120, NPS=40	29.2	120	40	40%	23	8	6%	0%	2.1	2%	12%
Metro=120, NPS=30	25.4	120	30	55%	20	6	2%	0%	2.2	2%	10%
Metro=20	30.3	20	67	0%	24	8	7%	0%	2.1	2%	13%
Metro =120, NPS=50	24.1	20	50	25%	19	6	1%	0%	2.2	2%	10%
Metro Diverted	26.3	120	67	0%	24	8	7%	0%	2.1	2%	13%
Metro Div, NPS=50	19.9	120	50	25%	18	5	1%	0%	2.2	1%	9%

The first scenario uses measured yearly inflows and loads for each source averaged over the 1998-2007 baseline period. The remaining scenarios use the same hydrologic base period with hypothetical values for Metro and non-point source phosphorus concentrations. Except for the diversion scenarios, Metro bypass flows and loads are assumed to be unchanged relative to 1998-2007 baseline conditions. The load from this source (2.2 mt/yr) accounted for 4% of the total baseline load and 5.6% of the total load with Metro operating at 0.12 ppm. Addressing bypass loads is an additional control measure not considered in the scenarios but potentially evaluated with the model. It is possible that these loads will be reduced as a consequence of CSO controls.

The projections differ only slightly from those generated by previous model calibrations (Ecologic, 2001, 2005). Chlorophyll-a and Secchi exceedance frequencies are reduced substantially with Metro operating at 0.12 ppm. Lake P concentrations approach the 20 ppb criterion for scenarios involving control of Metro load (either by diversion or by achieving the 2012 effluent P level of 20 ppb) and ~20% reduction in non-point load.

Forecasts for scenarios without further reductions in non-point load relative to the 1998-2007 baseline may be conservative; i.e. over-estimate lake TP concentrations and exceedance frequencies. A decreasing trend (-5.9 +/- 2.5 %/yr) in the combined load from urban watersheds is apparent over the 1998-2007 period when adjusted for rainfall variations (Tables 10-11). A decreasing trend in flow-weighted mean concentration for the total non-point inflow may also exist, but is not strong enough to be statistically significant (-1.5 +/- 1.6 %/yr, p=.37, Figure 11) and is potentially masked by inherent variability in the data. The apparent decreasing trend in flow and load from TRIB-5A (Table 10, Figure 20) is also ignored in simulations of future scenarios; this source accounted for only 0.6% of the load over the 1998-2007 period (Table 7).

As discussed above, the model assumes that the Lake responds equally to point and non-point loads. Figure 17 shows that phosphorus residuals are independent of the fraction of total annual load attributed to Metro (treated + bypass) over a range of 0.25 to 0.75. Since the last four scenarios listed above involve extrapolation of the model below that range, they are subject to greater uncertainty. If non-point loads actually have less impact than Metro loads due to density currents and/or bio-availability differences, simulation results for those scenarios would also be conservative. The model workbook includes an additional algorithm for testing the sensitivity of the forecasts to alternative assumptions regarding the bio-availability of the phosphorus loads from each tributary.

Simulation of long-term hydrologic records could be performed using yearly non-point loads predicted from regressions calibrated to the historical data Tracking of future measured non-point loads and lake conditions relative to the prediction intervals of the models developed from 1998-2007 data (Figures 9 & 16) would provide a basis for evaluating future trends and responses to additional non-point controls and other management measures while adjusting for year-to-year variations related to precipitation. Similar tracking methodologies have been developed for Everglades watersheds and wetlands (Walker, 2000).

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List of Tables

Table 1 Chloride Balance for 2003-2007

Variable: Chloride   Average for Years: 2003 thru 2007

							Percent of Total Inflow			Drain.		Export
	Flow	Load	Std Error	Conc	RSE	Sampl	Flow	Load	Error	Area	Runoff	mt/
Term	10^6 m3	mt	mt	ppm	%	per yr	%	%	%	km2	cm	km2
Metro Effluent	93.26	37889	1960	406	5%	44	17%	18%	30%			
Metro Bypass	1.89	785	136	416	17%	4	0%	0%	0%			
East Flume	0.76	388	16	509	4%	27	0%	0%	0%			
Trib 5A	1.34	508	11	378	2%	27	0%	0%	0%			
Harbor Brook	12.65	3375	216	267	6%	29	2%	2%	0%	31.4	40.3	107.6
Ley Creek	42.50	14579	1410	343	10%	29	8%	7%	15%	66.1	64.3	220.6
Ninemile Creek	172.94	51853	812	300	2%	30	31%	25%	5%	298.1	58.0	173.9
Onondaga Creek	191.70	85315	2089	445	2%	28	34%	42%	34%	285.1	67.2	299.2
Nonpoint Gauged	419.79	155122	2657	370	2%	117	75%	76%	54%	680.7	61.7	227.9
Nonpoint Ungauged	28.59	10566	1430	370	14%		5%	5%	16%	46.4	61.7	227.9
NonPoint Total	448.38	165687	3017	370	2%	117	80%	81%	70%	727.0	61.7	227.9
Industrial	2.11	896	20	425	2%	55	0%	0%	0%			
Municipal	95.15	38675	1965	406	5%	47	17%	19%	30%			
Total External	545.64	205258	3600	376	2%	219	98%	100%	100%	727.0	75.0	282.3
Precipitation	12.46	12	1	1	9%		2%	0%	0%	11.7	106.5	1.1
Total Inflow	558.10	205270	3600	368	2%	219	100%	100%	100%	738.7	75.5	277.9
Evaporation	8.86						2%			11.7	75.7	
Outflow	549.24	212668	2543	387	1%		98%	104%	50%	738.7	74.3	287.9
Retention	0.00	-7398	4408		60%		0%	-3.6%				
Alternative Estimates of Lake Outflow												
Outlet 12 Feet	549.24	212668	2543	387	1%	27	98%	104%	50%	738.7	74.3	287.9
Outlet 2 Feet	549.24	193864	4328	353	2%	27	98%	94%	144%	738.7	74.3	262.4
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	11.33	2599	88	230	3%	29	2%	1%		27.0	42.0	96.4
Downstream - Hiawatha	12.65	3375	216	267	6%	29	2%	2%		31.4	40.3	107.6
Local Inflow	1.33	776	233	584	30%		0%	0%		4.4	30.2	176.0
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	149.66	16393	292	110	2%	41	27%	8%		229.4	65.2	71.5
Downstream - Kirkpatrick	191.70	85315	2089	445	2%	28	34%	42%		285.1	67.2	299.2
Local Inflow	42.04	68922	2109	1640	3%		8%	34%		55.7	75.4	1236.7
Nonpoint Source Summary - Gauged Watersheds							Percent of Total Gauged Watershed					
Total Watershed	419.79	155122	2657	370	2%		100%	100%		680.7	61.7	227.9
Upper/Rural Watersheds	333.93	70845	868	212	1%		80%	46%		554.5	60.2	127.8

Table 2 Total Nitrogen Balance for 2003-2007

Variable: Total Nitrogen   Average for Years: 2003 thru 2007

							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	93.26	1145344	29278	12281	3%	100	17%	60%	83%			
Metro Bypass	1.89	21446	856	11354	4%	4	0%	1%	0%			
East Flume	0.76	4576	123	6002	3%	27	0%	0%	0%			
Trib 5A	1.34	2036	124	1514	6%	27	0%	0%	0%			
Harbor Brook	12.65	27231	903	2152	3%	27	2%	1%	0%	31.4	40.3	868
Ley Creek	42.50	54871	2476	1291	5%	27	8%	3%	1%	66.1	64.3	830
Ninemile Creek	172.94	290722	7813	1681	3%	27	31%	15%	6%	298.1	58.0	975
Onondaga Creek	191.70	296228	7782	1545	3%	27	34%	15%	6%	285.1	67.2	1039
Nonpoint Gauged	419.79	669053	11338	1594	2%	109	75%	35%	12%	680.7	61.7	983
Nonpoint Ungauged	28.59	45571	6181	1594	14%		5%	2%	4%	46.4	61.7	983
NonPoint Total	448.38	714624	12913	1594	2%	109	80%	37%	16%	727.0	61.7	983
Industrial	2.11	6612	175	3138	3%	54	0%	0%	0%			
Municipal	95.15	1166790	29291	12262	3%	104	17%	61%	83%			
Total External	545.64	1888026	32011	3460	2%	267	98%	99%	100%	727.0	75.0	2597
Precipitation	12.46	23665	2123	1900	9%		2%	1%	0%	11.7	106.5	2023
Total Inflow	558.10	1911691	32082	3425	2%	267	100%	100%	100%	738.7	75.5	2588
Evaporation	8.86						2%			11.7	75.7	
Outflow	549.24	1428717	29221	2601	2%		98%	75%	83%	738.7	74.3	1934
Retention	0.00	482974	43395		9%		0%	25%				
Alternative Estimates of Lake Outflow												
Outlet 12 Feet	549.24	1428717	29221	2601	2%	26	98%	75%	83%	738.7	74.3	1934
Outlet 2 Feet	549.24	1334439	29254	2430	2%	26	98%	70%	83%	738.7	74.3	1806
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	11.33	24142	1343	2132	6%	27	2%	1%		27.0	42.0	896
Downstream - Hiawatha	12.65	27231	903	2152	3%	27	2%	1%		31.4	40.3	868
Local Inflow	1.33	3089	1618	2325	52%		0%	0%		4.4	30.2	701
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	149.66	246055	26049	1644	11%	34	27%	13%		229.4	65.2	1073
Downstream - Kirkpatrick	191.70	296228	7782	1545	3%	27	34%	15%		285.1	67.2	1039
Local Inflow	42.04	50173	27187	1194	54%		8%	3%		55.7	75.4	900
Nonpoint Source Summary - Gauged Watersheds							Percent of Total Gauged Watershed					
Total Watershed	419.79	669053	11338	1594	2%		100%	100%		680.7	61.7	983

Table 3 Ammonia Nitrogen Balance for 2003-2007

Variable: Ammonia Nitrogen Average for Years: 2003 thru 2007

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 %	Error %	Drain. Area km2	Runoff cm	Export kg/ km2
Metro Effluent	93.26	147553	2952	1582	2%	361	17%	64%	40%			
Metro Bypass	1.89	10058	593	5325	6%	42	0%	4%	2%			
East Flume	0.76	356	19	467	5%	27	0%	0%	0%			
Trib 5A	1.34	214	9	159	4%	27	0%	0%	0%			
Harbor Brook	12.65	1033	97	82	9%	28	2%	0%	0%	31.4	40.3	32.9
Ley Creek	42.50	12367	817	291	7%	27	8%	5%	3%	66.1	64.3	187.1
Ninemile Creek	172.94	39121	3247	226	8%	27	31%	17%	49%	298.1	58.0	131.2
Onondaga Creek	191.70	15006	917	78	6%	28	34%	6%	4%	285.1	67.2	52.6
Nonpoint Gauged	419.79	67528	3473	161	5%	109	75%	29%	56%	680.7	61.7	99.2
Nonpoint Ungauged	28.59	4599	665	161	14%		5%	2%	2%	46.4	61.7	99.2
NonPoint Total	448.38	72127	3536	161	5%	109	80%	31%	58%	727.0	61.7	99.2
Industrial	2.11	571	21	271	4%	55	0%	0%	0%			
Municipal	95.15	157611	3011	1656	2%	403	17%	68%	42%			
Total External	545.64	230309	4644	422	2%	567	98%	99%	100%	727.0	75.0	316.8
Precipitation	12.46	1246	112	100	9%		2%	1%	0%	11.7	106.5	106.5
Total Inflow	558.10	231554	4646	415	2%	567	100%	100%	100%	738.7	75.5	313.4
Evaporation	8.86						2%			11.7	75.7	
Outflow	549.24	204982	8839	373	4%		98%	89%	362%	738.7	74.3	277.5
Retention	0.00	26572	9985		38%		0%	11%				
Alternative Estimates of Lake Outflow												
Outlet 12 Feet	549.24	204982	8839	373	4%	27	98%	89%	362%	738.7	74.3	277.5
Outlet 2 Feet	549.24	186838	9113	340	5%	27	98%	81%	385%	738.7	74.3	252.9
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	11.33	587	42	52	7%	28	2%	0%		27.0	42.0	21.8
Downstream - Hiawatha	12.65	1033	97	82	9%	28	2%	0%		31.4	40.3	32.9
Local Inflow	1.33	446	106	336	24%		0%	0%		4.4	30.2	101.3
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	149.66	8100	403	54	5%	40	27%	3%		229.4	65.2	35.3
Downstream - Kirkpatrick	191.70	15006	917	78	6%	28	34%	6%		285.1	67.2	52.6
Local Inflow	42.04	6906	1002	164	15%		8%	3%		55.7	75.4	123.9
Nonpoint Source Summary - Gauged Watersheds							Percent of Total Gauged Watershed					
Total Watershed	419.79	67528	3473	161	5%		100%	100%		680.7	61.7	99.2

Table 4 Total Phosphorus Balance for 2003-2007

Variable: Total Phosphorus Average for Years: 2003 thru 2007

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	93.26	26266	333	282	1%	361	17%	45%	3%			
Metro Bypass	1.89	2088	74	1106	4%	42	0%	4%	0%			
East Flume	0.76	118	8	155	7%	27	0%	0%	0%			
Trib 5A	1.34	145	5	108	4%	28	0%	0%	0%			
Harbor Brook	12.65	1111	149	88	13%	29	2%	2%	1%	31.4	40.3	35.4
Ley Creek	42.50	3573	375	84	10%	29	8%	6%	4%	66.1	64.3	54.1
Ninemile Creek	172.94	9173	669	53	7%	30	31%	16%	12%	298.1	58.0	30.8
Onondaga Creek	191.70	13236	1724	69	13%	28	34%	23%	79%	285.1	67.2	46.4
Nonpoint Gauged	419.79	27094	1893	65	7%	117	75%	47%	95%	680.7	61.7	39.8
Nonpoint Ungauged	28.59	1845	280	65	15%		5%	3%	2%	46.4	61.7	39.8
NonPoint Total	448.38	28940	1913	65	7%	117	80%	50%	97%	727.0	61.7	39.8
Industrial	2.11	263	9	125	4%	55	0%	0%	0%			
Municipal	95.15	28355	341	298	1%	403	17%	49%	3%			
Total External	545.64	57557	1944	105	3%	575	98%	99%	100%	727.0	75.0	79.2
Precipitation	12.46	374	34	30	9%		2%	1%	0%	11.7	106.5	31.9
Total Inflow	558.10	57931	1944	104	3%	575	100%	100%	100%	738.7	75.5	78.4
Evaporation	8.86						2%			11.7	75.7	
Outflow	549.24	37264	1080	68	3%		98%	64%	31%	738.7	74.3	50.4
Retention	0.00	20667	2224		11%		0%	36%				
Alternative Estimates of Lake Outflow												
Outlet 12 Feet	549.24	37264	1080	68	3%	27	98%	64%	31%	738.7	74.3	50.4
Outlet 2 Feet	549.24	36098	1141	66	3%	27	98%	62%	34%	738.7	74.3	48.9
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	11.33	481	150	43	31%	29	2%	1%		27.0	42.0	17.9
Downstream - Hiawatha	12.65	1111	149	88	13%	29	2%	2%		31.4	40.3	35.4
Local Inflow	1.33	630	212	474	34%		0%	1%		4.4	30.2	143.0
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	149.66	10155	1762	68	17%	41	27%	18%		229.4	65.2	44.3
Downstream - Kirkpatrick	191.70	13236	1724	69	13%	28	34%	23%		285.1	67.2	46.4
Local Inflow	42.04	3081	2465	73	80%		8%	5%		55.7	75.4	55.3
Nonpoint Source Summary - Gauged Watersheds							Percent of Total Gauged Watershed					
Total Watershed	419.79	27094	1893	65	7%		100%	100%		680.7	61.7	39.8

Table 5 Soluble Reactive Phosphorus Balance for 2003-2007

Variable: Soluble Reactive P Average for Years: 2003 thru 2007

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 %	Error %	Drain. Area km2	Runoff cm	Export kg / km2
Metro Effluent	93.26	8033	784	86	10%	30	17%	62%	84%			
Metro Bypass	1.89	443	179	235	40%	4	0%	3%	4%			
East Flume	0.76	45	5	60	10%	27	0%	0%	0%			
Trib 5A	1.34	45	3	33	6%	27	0%	0%	0%			
Harbor Brook	12.65	408	43	32	11%	29	2%	3%	0%	31.4	40.3	13.0
Ley Creek	42.50	571	36	13	6%	29	8%	4%	0%	66.1	64.3	8.6
Ninemile Creek	172.94	1478	180	9	12%	30	31%	11%	4%	298.1	58.0	5.0
Onondaga Creek	191.70	1550	215	8	14%	28	34%	12%	6%	285.1	67.2	5.4
Nonpoint Gauged	419.79	4007	287	10	7%	117	75%	31%	11%	680.7	61.7	5.9
Nonpoint Ungauged	28.59	273	42	10	15%		5%	2%	0%	46.4	61.7	5.9
NonPoint Total	448.38	4280	290	10	7%	117	80%	33%	11%	727.0	61.7	5.9
Industrial	2.11	90	5	43	6%	55	0%	1%	0%			
Municipal	95.15	8476	805	89	9%	33	17%	65%	88%			
Total External	545.64	12847	855	24	7%	205	98%	99%	100%	727.0	75.0	17.7
Precipitation	12.46	187	17	15	9%		2%	1%	0%	11.7	106.5	16.0
Total Inflow	558.10	13033	855	23	7%	205	100%	100%	100%	738.7	75.5	17.6
Evaporation	8.86						2%			11.7	75.7	
Outflow	549.24	19271	1864	35	10%		98%	148%	475%	738.7	74.3	26.1
Retention	0.00	-6237	2051		33%		0%	-48%				
Alternative Estimates of Lake Outflow												
Outlet 12 Feet	549.24	19271	1864	35	10%	27	98%	148%	475%	738.7	74.3	26.1
Outlet 2 Feet	549.24	17722	1204	32	7%	27	98%	136%	198%	738.7	74.3	24.0
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	11.33	123	18	11	15%	29	2%	1%		27.0	42.0	4.6
Downstream - Hiawatha	12.65	408	43	32	11%	29	2%	3%		31.4	40.3	13.0
Local Inflow	1.33	285	47	214	16%		0%	2%		4.4	30.2	64.6
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	149.66	784	111	5	14%	32	27%	6%		229.4	65.2	3.4
Downstream - Kirkpatrick	191.70	1550	215	8	14%	28	34%	12%		285.1	67.2	5.4
Local Inflow	42.04	766	242	18	32%		8%	6%		55.7	75.4	13.7
Nonpoint Source Summary - Gauged Watersheds							Percent of Total Gauged Watershed					
Total Watershed	419.79	4007	287	10	7%		100%	100%		680.7	61.7	5.9

Table 6 Total Phosphorus Balance for 2006-2007

Variable: Total Phosphorus Average for Years: 2006 thru 2007

							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	87.90	10659	242	121	2%	361	16%	25%	1%			
Metro Bypass	1.17	1483	74	1263	5%	48	0%	4%	0%			
East Flume	0.65	102	12	158	12%	27	0%	0%	0%			
Trib 5A	0.64	64	3	99	5%	27	0%	0%	0%			
Harbor Brook	13.47	1375	275	102	20%	28	2%	3%	1%	31.4	42.9	43.8
Ley Creek	41.55	3170	515	76	16%	27	8%	8%	2%	66.1	62.9	48.0
Ninemile Creek	172.98	9173	1202	53	13%	36	31%	22%	13%	298.1	58.0	30.8
Onondaga Creek	193.36	13721	3006	71	22%	27	35%	33%	81%	285.1	67.8	48.1
Nonpoint Gauged	421.36	27439	3289	65	12%	117	76%	65%	98%	680.7	61.9	40.3
Nonpoint Ungauged	28.70	1869	457	65	24%		5%	4%	2%	46.4	61.9	40.3
NonPoint Total	450.06	29308	3321	65	11%	117	81%	70%	99%	727.0	61.9	40.3
Industrial	1.29	166	13	129	8%	54	0%	0%	0%			
Municipal	89.08	12142	253	136	2%	409	16%	29%	1%			
Total External	540.42	41616	3330	77	8%	580	98%	99%	100%	727.0	74.3	57.2
Precipitation	13.20	396	56	30	14%		2%	1%	0%	11.7	112.8	33.8
Total Inflow	553.62	42012	3331	76	8%	580	100%	100%	100%	738.7	74.9	56.9
Evaporation	8.86						2%			11.7	75.7	
Outflow	544.76	22862	1036	42	5%		98%	54%	10%	738.7	73.7	30.9
Retention	0.00	19150	3488		18%		0%	46%				
Alternative Estimates of Lake Outflow												
Outlet 12 Feet	544.76	22862	1036	42	5%	26	98%	54%	10%	738.7	73.7	30.9
Outlet 2 Feet	544.76	23983	1200	44	5%	26	98%	57%	13%	738.7	73.7	32.5
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	11.40	478	206	42	43%	28	2%	1%		27.0	42.3	17.7
Downstream - Hiawatha	13.47	1375	275	102	20%	28	2%	3%		31.4	42.9	43.8
Local Inflow	2.07	897	344	433	38%		0%	2%		4.4	47.0	203.5
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	149.77	10397	2549	69	25%	53	27%	25%		229.4	65.3	45.3
Downstream - Kirkpatrick	193.36	13721	3006	71	22%	27	35%	33%		285.1	67.8	48.1
Local Inflow	43.59	3324	3941	76	119%		8%	8%		55.7	78.2	59.7
Nonpoint Source Summary - Gauged Watersheds							Percent of Total Gauged Watershed					
Total Watershed	421.36	27439	3289	65	12%		100%	100%		680.7	61.9	40.3
Upper/Rural Watersheds	334.15	20048	2825	60	14%		79%	73%		554.5	60.3	36.2
Lower/Urban Watersheds	87.21	7391	3989	85	54%		21%	27%		126.2	69.1	58.6
Net Urban	11.13	2827		254			3%	10%		126.2	8.8	22.4

Upper Watersheds: Ninemile + Onondaga(Dorwin) + Harbor(Velasko) - Primarily Rural / Agric Land Uses
Lower Watersheds: Lower Watershed = Ley + Onondaga(Kirkpatrick-Dorwin) + Harbor (Hiawatha - Velasko) - Primarily Urban Land Uses
Net Urban: Net Contribution of Lower Watersheds above Rural Background Loads

Lake Overflow Rate	46.56 m/yr	Calib. Settling Rate	39.0 m/yr
Lake Residence Time	0.23 years	Calib. Retention Coef	46%

RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Error % = Percent of Variance in Total Inflow Load Estimate

Table 7 Total Phosphorus Balance for 1998-2007

Variable: Total Phosphorus Average for Years: 1998 thru 2007

							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	91.31	27477	224	301	1%	363	18%	48%	4%			
Metro Bypass	2.04	2279	53	1118	2%	46	0%	4%	0%			
East Flume	0.57	93	4	163	5%	28	0%	0%	0%			
Trib 5A	2.08	258	6	124	3%	28	0%	0%	0%			
Harbor Brook	10.56	922	89	87	10%	31	2%	2%	1%	31.4	33.7	29.4
Ley Creek	38.54	3567	278	93	8%	31	8%	6%	6%	66.1	58.3	54.0
Ninemile Creek	148.53	8317	390	56	5%	30	30%	15%	11%	298.1	49.8	27.9
Onondaga Creek	167.10	11864	1004	71	8%	32	34%	21%	76%	285.1	58.6	41.6
Nonpoint Gauged	364.73	24671	1116	68	5%	123	73%	43%	94%	680.7	53.6	36.2
Nonpoint Ungauged	24.84	1680	178	68	11%		5%	3%	2%	46.4	53.6	36.2
NonPoint Total	389.57	26351	1130	68	4%	123	78%	46%	96%	727.0	53.6	36.2
Industrial	2.66	352	8	132	2%	55	1%	1%	0%			
Municipal	93.35	29756	230	319	1%	409	19%	52%	4%			
Total External	485.57	56459	1154	116	2%	587	98%	99%	100%	727.0	66.8	77.7
Precipitation	11.55	347	22	30	6%		2%	1%	0%	11.7	98.7	29.6
Total Inflow	497.12	56805	1154	114	2%	587	100%	100%	100%	738.7	67.3	76.9
Evaporation	8.86						2%			11.7	75.7	
Outflow	488.27	35944	747	74	2%		98%	63%	42%	738.7	66.1	48.7
Retention	0.00	20862	1375		7%		0%	37%				
Alternative Estimates of Lake Outflow												
Outlet 12 Feet	488.27	35944	747	74	2%	26	98%	63%	42%	738.7	66.1	48.7
Outlet 2 Feet	488.27	33873	758	69	2%	26	98%	60%	43%	738.7	66.1	45.9
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	9.68	418	97	43	23%	31	2%	1%		27.0	35.9	15.5
Downstream - Hiawatha	10.56	922	89	87	10%	31	2%	2%		31.4	33.7	29.4
Local Inflow	0.88	505	132	570	26%		0%	1%		4.4	20.1	114.5
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	129.49	8419	920	65	11%	38	26%	15%		229.4	56.4	36.7
Downstream - Kirkpatrick	167.10	11864	1004	71	8%	32	34%	21%		285.1	58.6	41.6
Local Inflow	37.61	3445	1362	92	40%		8%	6%		55.7	67.5	61.8
Nonpoint Source Summary - Gauged Watersheds							Percent of Total Gauged Watershed					
Total Watershed	364.73	24671	1116	68	5%		100%	100%		680.7	53.6	36.2
Upper/Rural Watersheds	287.69	17154	1004	60	6%		79%	70%		554.5	51.9	30.9
Lower/Urban Watersheds	77.03	7516	1397	98	19%		21%	30%		126.2	61.0	59.5
Net Urban	11.53	3611		313			3%	15%		126.2	9.1	28.6

Upper Watersheds: Ninemile + Onondaga(Dorwin) + Harbor(Velasko) - Primarily Rural / Agric Land Uses
Lower Watersheds: Lower Watershed = Ley + Onondaga(Kirkpatrick-Dorwin) + Harbor (Hiawatha - Velasko) - Primarily Urban Land Uses
Net Urban: Net Contribution of Lower Watersheds above Rural Background Loads

Lake Overflow Rate	41.73 m/yr	Calib. Settling Rate	24.2 m/yr	RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time	0.26 years	Calib. Retention Coef	37%	Error % = Percent of Variance in Total Inflow Load Estimate

Table 8 Summary of NonPoint Source Loads, 1998-2007

	Flow	Total Phosphorus	Total Dissolved P	Soluble Reactive P	Total Nitrogen	Total Kjeldahl N	Ammonia Nitrogen	Nitrate Nitrogen	5-Day BOD	Total Org Carbon	Filtered Total Org C	Chloride	Sodium
Annual Loads	hm3	kg	kg	kg	kg	kg	kg	kg	mt	mt	mt	mt	mt
Ley	39	3567	1167	568	53037	34782	12867	17406	109	264	242	12827	7586
Ninemile	149	8317	3135	1147	251349	97559	39456	150481	321	491	407	51595	16980
Harbor - Upper	10	418	200	91	20460	3915	622	16417	22	21	19	2198	1195
Harbor - Lower	1	505	174	197	1968	1889	540	37	5	6	6	588	341
Harbor - Total	11	922	375	288	22429	5804	1162	16454	27	27	24	2786	1536
Onondaga - Upper	129	8419	1751	642	202897	58531	8310	132214	269	368	337	14969	9218
Onondaga - Lower	38	3445	1197	643	53113	24474	7998	37122	128	96	81	59873	37164
Onondaga - Total	167	11864	2948	1286	256011	83006	16308	169337	397	464	417	74841	46382
Total Nonpoint Gauged	365	24671	7625	3289	582825	221150	69792	353677	854	1246	1091	142049	72484
Rural Watersheds	288	17154	5086	1881	474707	160005	48388	299112	612	880	762	68762	27393
Urban Watersheds	77	7516	2539	1409	108118	61145	21404	54565	242	366	329	73287	45091
Net Urban	12	3611	1381	981	39	24715	10387	-13536	103	165	155	57632	38854
Unit Area Loads	cm	kg /km2	kg /km2	kg /km2	kg/km2	kg/km2	kg/km2	kg /km2	mt/km2	mt/km2	mt/km2	mt/km2	mt/km2
Ley	58	54	18	9	802	526	195	263	1.7	4.0	3.7	194	115
Ninemile	50	28	11	4	843	327	132	505	1.1	1.6	1.4	173	57
Harbor - Upper	36	16	7	3	759	145	23	609	0.8	0.8	0.7	82	44
Harbor - Lower	20	115	40	45	447	429	122	8	1.2	1.3	1.3	134	77
Harbor - Total	34	29	12	9	715	185	37	525	0.9	0.9	0.8	89	49
Onondaga - Upper	56	37	8	3	884	255	36	576	1.2	1.6	1.5	65	40
Onondaga - Lower	67	62	21	12	953	439	144	666	2.3	1.7	1.4	1074	667
Onondaga - Total	59	42	10	5	898	291	57	594	1.4	1.6	1.5	262	163
Total Nonpoint Gauged	54	36	11	5	856	325	103	520	1.3	1.8	1.6	209	106
Rural Watersheds	52	31	9	3	856	289	87	539	1.1	1.6	1.4	124	49
Urban Watersheds	61	60	20	11	856	484	170	432	1.9	2.9	2.6	581	357
Net Urban	9	29	11	8	0	196	82	-107	0.8	1.3	1.2	457	308
Percent of Total Gauged NonPoint Load													
Ley	11%	14%	15%	17%	9%	16%	18%	5%	13%	21%	22%	9%	10%
Ninemile	41%	34%	41%	35%	43%	44%	57%	43%	38%	39%	37%	36%	23%
Harbor - Upper	3%	2%	3%	3%	4%	2%	1%	5%	3%	2%	2%	2%	2%
Harbor - Lower	0%	2%	2%	6%	0%	1%	1%	0%	1%	0%	1%	0%	0%
Harbor - Total	3%	4%	5%	9%	4%	3%	2%	5%	3%	2%	2%	2%	2%
Onondaga - Upper	36%	34%	23%	20%	35%	26%	12%	37%	31%	30%	31%	11%	13%
Onondaga - Lower	10%	14%	16%	20%	9%	11%	11%	10%	15%	8%	7%	42%	51%
Onondaga - Total	46%	48%	39%	39%	44%	38%	23%	48%	46%	37%	38%	53%	64%
Total Nonpoint Gauged	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Rural Watersheds	79%	70%	67%	57%	81%	72%	69%	85%	72%	71%	70%	48%	38%
Urban Watersheds	21%	30%	33%	43%	19%	28%	31%	15%	28%	29%	30%	52%	62%
Net Urban	3%	15%	18%	30%	0%	11%	15%	-4%	12%	13%	14%	41%	54%
FWM Concentrations		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppm	ppm	ppm	ppm	ppm
Ley	-	93	30	15	1376	902	334	452	2.8	6.8	6.3	333	197
Ninemile	-	56	21	8	1692	657	266	1013	2.2	3.3	2.7	347	114
Harbor - Upper	-	43	21	9	2114	405	64	1696	2.3	2.2	1.9	227	124
Harbor - Lower	-	570	197	223	2226	2136	610	41	5.9	6.6	6.4	665	385
Harbor - Total	-	87	35	27	2124	549	110	1558	2.6	2.6	2.3	264	145
Onondaga - Upper	-	65	14	5	1567	452	64	1021	2.1	2.8	2.6	116	71
Onondaga - Lower	-	92	32	17	1412	651	213	987	3.4	2.6	2.1	1592	988
Onondaga - Total	-	71	18	8	1532	497	98	1013	2.4	2.8	2.5	448	278
Total Nonpoint Gauged	-	68	21	9	1598	606	191	970	2.3	3.4	3.0	389	199
Rural Watersheds	-	60	18	7	1650	556	168	1040	2.1	3.1	2.6	239	95
Urban Watersheds	-	98	33	18	1404	794	278	708	3.1	4.7	4.3	951	585
Net Urban	-	313	120	85	3	2143	901	-1176	8.9	14.3	13.4	4997	3369

Table 9 Trends in Total Phosphorus for Each Mass Balance Term, 1990-2007

	Flow						Load								Concentration					
	Mean	Rainfall	Trend % / yr		p Levels		Mean	Rainfall	Trend (kg/yr)		Trend % / yr		p Levels		Mean	Rainfall	Trend % / yr		p Levels	
Source	hm3/yr	Correl	A	B	A	B	kg/yr	Correl	Mean	Std Error	A	B	A	B	ppb	Correl	A	B	A	B
Metro	91.9	0.42			0.55	0.50	38983	-0.03	-3394	628	-9	-9	0.00	0.00	424	-0.09	-9	-8	0.00	0.00
Bypass	3.3	0.28			0.26	0.25	5349	0.26	-462	190	-9	-9	0.03	0.03	1633	0.03	-4	-4	0.00	0.00
E Flume	0.9	0.63			0.43	0.29	143	0.63	-7	4		-5	0.17	0.07	164	-0.35			0.13	0.13
Trib5A	2.6	-0.31	-8	-8	0.00	0.00	213	-0.22		6			0.77	0.79	83	0.05	7	7	0.00	0.00
Harbor/Velasko	9.2	0.82		1	0.17	0.02	493	0.72	-14	8		-3	0.26	0.09	54	0.40	-4	-4	0.02	0.01
Harbor/Lower	1.1	0.46			0.82	0.77	341	0.17	43	8	13	13	0.00	0.00	325	-0.25	14	14	0.03	0.03
Harbor/Hiawatha	10.2	0.84		1	0.30	0.08	828	0.67	27	13		3	0.13	0.05	81	0.33			0.15	0.15
Onondaga/Dorwin	125.6	0.83		1	0.30	0.09	10277	0.78		174			0.50	0.25	82	0.60	-3	-3	0.09	0.03
Onondaga/Lower	36.6	0.88		1	0.29	0.04	5722	0.40	-448	128	-8	-8	0.01	0.00	156	0.16	-9	-9	0.00	0.00
Onond./Kirkpatrick	162.2	0.86		1	0.29	0.05	15999	0.72	-617	219		-4	0.11	0.01	99	0.42	-5	-5	0.00	0.00
Ley/Park	39.3	0.86			0.93	0.76	4616	0.55	-203	61	-4	-4	0.02	0.00	117	0.16	-4	-4	0.00	0.00
Ninemile/Rt48	148.5	0.88			0.78	0.68	9222	0.82		92			0.40	0.11	62	0.40	-2	-2	0.06	0.04
NonPoint Gauged	360.3	0.89			0.56	0.27	30665	0.76	-947	350		-3	0.15	0.02	85	0.40	-4	-4	0.01	0.00
Total Gauged	458.9	0.89			0.69	0.49	75353	0.40	-4750	723	-6	-6	0.00	0.00	164	-0.01	-7	-7	0.00	0.00
Total NonPoint	384.8	0.89			0.56	0.27	32753	0.76	-1012	373		-3	0.15	0.02	85	0.40	-4	-4	0.01	0.00
Total Industrial	3.4	0.02	-7	-7	0.00	0.00	356	0.21		8			0.22	0.22	104	0.26	4	4	0.01	0.01
Total Municipal	95.1	0.62		-1	0.11	0.04	44332	0.02	-4023	724	-9	-9	0.00	0.00	466	-0.05	-9	-9	0.00	0.00
Total Inflow	495.0	0.89			0.68	0.48	77790	0.41	-4808	732	-6	-6	0.00	0.00	157	0.00	-6	-6	0.00	0.00
NP_Rural	283.3	0.87			0.53	0.27	19992	0.82		245			0.44	0.15	71	0.57	-2	-3	0.05	0.02
NP_Urban	77.0	0.92			0.70	0.45	10679	0.52	-593	156	-5	-6	0.01	0.00	139	0.18	-6	-6	0.00	0.00
Outlet2	486.1	0.89			0.68	0.47	43440	0.41	-2050	504	-5	-5	0.00	0.00	89	-0.06	-5	-5	0.00	0.00
Outlet12	486.1	0.89			0.68	0.47	48570	0.27	-2802	623	-6	-6	0.00	0.00	100	-0.16	-6	-6	0.00	0.00

Methods: A = without adjustment for annual precipitation, B = with adjustment for precipitation using equations listed in Figure 9.

Shaded cells indicate trend slopes significantly different from zero at $p < 0.10$ for two-tailed and $p < 0.05$ for one-tailed hypothesis.

Table 10 Trends in Total Phosphorus for Each Mass Balance Term, 1998-2007

	Flow						Load								Concentration					
	Mean	Rainfall	Trend Slopes		p Levels		Mean	Rainfall	Trend kg /y		Trend Slopes		p Levels		Mean	Rainfall	Trend Slopes		p Levels	
Source	hm3/yr	Correl	A	C	A	B	kg	Correl	Mean	SE	A	C	A	C	ppb	Correl	A	C	A	C
Metro	91.3	0.30			0.78	0.57	27477	-0.42		2256	-11		0.05	0.15	301	-0.47	-11		0.04	0.14
Bypass	2.0	-0.36			0.34	0.80	2279	-0.29		154			0.38	0.72	1118	0.26			0.76	0.72
E Flume	0.6	0.67	13		0.01	0.13	93	0.60		6	9		0.06	0.43	163	-0.41	-4		0.05	0.12
Trib5A	2.1	-0.67	-17	-17	0.00	0.03	258	-0.72	-40	20	-19	-16	0.00	0.08	124	-0.59			0.27	0.70
Harbor/Velasko	9.7	0.79	6	4	0.00	0.08	418	0.36		25			0.69	0.56	43	-0.13			0.29	0.24
Harbor/Lower	0.9	0.69	28		0.04	0.47	505	0.38	84	22	11	17	0.01	0.01	570	-0.60			0.21	0.87
Harbor/Hiawatha	10.6	0.81	7	5	0.00	0.05	922	0.59	74	29	7	8	0.00	0.04	87	-0.17			0.85	0.41
Onondaga/Dorwin	129.5	0.81	5		0.01	0.41	8419	0.59		434	8		0.04	0.29	65	0.16			0.32	0.34
Onondaga/Lower	37.6	0.97	4		0.01	0.48	3445	-0.07		234			0.26	0.14	92	-0.41	-10		0.05	0.13
Onond./Kirkpatrick	167.1	0.86	5		0.01	0.39	11864	0.62		328	3		0.10	0.71	71	-0.41			0.28	0.80
Ley/Park	38.5	0.76	4		0.04	0.67	3567	0.24		111			0.69	0.13	93	-0.46	-4	-6	0.00	0.01
Ninemile/Rt48	148.5	0.81	5		0.03	0.68	8317	0.71		183			0.13	0.83	56	-0.67	-3		0.03	0.34
NonPoint Gauged	364.7	0.84	5		0.01	0.50	24671	0.75		454	3		0.08	0.99	68	-0.64	-2		0.04	0.37
Total Gauged	460.7	0.83	4		0.02	0.59	54779	-0.15		2288			0.23	0.19	119	-0.61	-7	-7	0.01	0.09
Total NonPoint	389.6	0.84	5		0.01	0.50	26351	0.75		485	3		0.08	0.99	68	-0.64	-2		0.04	0.37
Total Industrial	2.7	-0.58	-10	-10	0.01	0.07	352	-0.60		20	-10		0.02	0.16	132	-0.26			0.75	0.72
Total Municipal	93.3	0.26			0.87	0.56	29756	-0.42		2336	-10		0.06	0.17	319	-0.48	-10		0.04	0.15
Total Inflow	497.1	0.83	4		0.02	0.58	56805	-0.13		2298			0.26	0.19	114	-0.62	-7	-7	0.01	0.08
NP_Rural	287.7	0.82	5		0.02	0.53	17154	0.70		521	5		0.03	0.44	60	-0.28			0.79	0.61
NP_Urban	77.0	0.92	4		0.01	0.44	7516	0.03	-444	190		-6	0.26	0.05	98	-0.56	-6	-7	0.01	0.07
Outlet2	488.3	0.83	4		0.02	0.59	33873	-0.01		1683			0.63	0.49	69	-0.53	-6		0.06	0.31
Outlet12	488.3	0.83	4		0.02	0.59	35944	-0.18		1902			0.30	0.34	74	-0.61	-8		0.02	0.19

Methods: A = without adjustment for annual precipitation, B = with adjustment for precipitation using equations listed in Figure 9

Shaded cells indicate trend slopes significantly different from zero at $p < 0.10$ for two-tailed and $p < 0.05$ for one-tailed hypothesis.

Table 11 Trends in Load, 1998-2007

Load Trends (% / yr) 1998 to 2007 Precip Trend = 3.0 +/- 0.9 cm/yr

Term	FLOW	TP	TN	TKN	NH3N	NO2N	NO3N	TOC	TOC_F	TIC	SIO2	ALK	CA	CL	NA
Metro		-11		-23	-32	-23	11	-5	-5				3	4	
Bypass			-8	-8	-9										
E Flume	13	9	11			10	14	11	11	13	10	13	14	15	16
Trib5A	-17	-19	-24	-17	-17	-20	-27	-15	-15	-15	-15	-14	-17	-19	-20
Harbor/Velasko	6		6	5	-4	4	6	7	6	6	5	7	5	6	8
Harbor/Lower	28	11					56			14	13	13	31	12	10
Harbor/Hiawatha	7	7	7	4	-5		8	7	7	7	7	7	6	7	8
Onondaga/Dorwin	5	8	7	7		11	5			6	7	6	7	3	4
Onondaga/Lower	4					-6	7		11	5	5	5	6	6	6
Onond./Kirkpatrick	5	3	5	4		8	5			6	6	6	7	6	6
Ley/Park	4					-3		4	4	4	4	4	4	6	7
Ninemile/Rt48	5						6		6	6	6	6	2		
NonPoint Gauged	5	3	4			4	5	6	6	6	6	6	4	3	5
Total Gauged	4			-13	-23	-13	9			5	5	5	4	3	4
Total NonPoint	5	3	4			4	5	6	6	6	6	6	4	3	5
Total Industrial	-10	-10	-6	-7	-8	6	-7	-7	-8	-8	-7	-7	-10	-9	-6
Total Municipal		-10		-22	-30	-23	11	-5	-5				3	4	
Total Inflow	4			-13	-22	-12	9			5	5	5	4	3	4
NP_Rural	5	5	6			6	5	6	6	6	6	6	3		
NP_Urban	4					-4	6	6	6	5	4	5	6	6	6
Outlet2	4			-8	-16	-4	10			5	11	5	5	4	5
Outlet12	4			-10	-19	-6	9			5	12	5	4	2	3

Load Trends (% / yr), Adjusted for Variations in Rainfall

Term	FLOW	TP	TN	TKN	NH3N	NO2N	NO3N	TOC	TOC_F	TIC	SIO2	ALK	CA	CL	NA
Metro				-24	-35	-27		-5	-6						
Bypass															
E Flume															14
Trib5A	-17	-16	-24	-17	-17	-21	-26	-17	-16	-15	-15	-15	-17	-19	-20
Harbor/Velasko	4		4		-6									7	8
Harbor/Lower		17												12	
Harbor/Hiawatha	5	8	6				6					5	4	8	9
Onondaga/Dorwin						10									
Onondaga/Lower													4	7	7
Onond./Kirkpatrick													3	6	6
Ley/Park						-5								8	8
Ninemile/Rt48					-6										
NonPoint Gauged					-5									3	5
Total Gauged				-15	-24	-14								3	4
Total NonPoint					-5									3	5
Total Industrial	-10		-9	-10	-12		-10	-10	-10				-11		
Total Municipal				-23	-32	-27		-5	-6						
Total Inflow				-14	-23	-13								3	4
NP_Rural					-6										
NP_Urban		-6									2		4	7	7
Outlet2				-11	-18	-6					12				
Outlet12				-13	-19	-8					14				

Trend magnitudes shown for results with $p < .10$ for two-tailed hypothesis, $p<05$ for one-tailed hypothesis.
Shaded cells, trend analysis potentially impacted by variations in detection limits.

Table 12 Trends in Flow-Weighted-Mean Concentration, 1998-2007

Concentration Trends (%/Yr) Precip Trend = 3.0 +/- 0.9 cm/yr

Term		TP	TN	TKN	NH3N	NO2N	NO3N	TOC	TOC_F	TIC	SIO2	ALK	CA	CL	NA
Metro		-11	-3	-24	-32	-24	11	-5	-5				3	4	
Bypass			-4	-4	-5							2			
E Flume		-4	-2	-9	-14				-3		-4				2
Trib5A			-7				-10			2	2	3			-3
Harbor/Velasko					-9							1			
Harbor/Lower				-29	-34	-35	28	-21	-18						
Harbor/Hiawatha					-12	-5									
Onondaga/Dorwin					-9					1		1	1	-2	-2
Onondaga/Lower		-10		-6		-10				1			2		
Onond./Kirkpatrick					-8					1		1	1		
Ley/Park		-4	-3	-4	-6	-7							1		3
Ninemile/Rt48		-3		-3	-7	-4				1		1	-3	-6	-4
NonPoint Gauged		-2		-2	-7					1		1	-1		
Total Gauged		-7	-4	-17	-27	-17			-3			1			
Total NonPoint		-2		-2	-7					1		1	-1		
Total Industrial				2		16				2	2	2			4
Total Municipal		-10	-3	-23	-30	-23	11	-5	-5				3	3	
Total Inflow		-7	-4	-17	-26	-16			-3			1			
NP_Rural					-7					1		1	-2	-5	-3
NP_Urban		-6		-5	-6	-8				1		1	2		
Outlet2		-6	-2	-12	-20	-8	6			1	7	1	1		
Outlet12		-8	-3	-14	-23	-10	5			1	8	1		-2	

Concentration Trends, Adjusted for Variations in Rainfall (%/Yr)

Term		TP	TN	TKN	NH3N	NO2N	NO3N	TOC	TOC_F	TIC	SIO2	ALK	CA	CL	NA
Metro			-4	-23	-34	-26		-4	-5				2	5	5
Bypass			-4	-4	-5										
E Flume			-4	-11	-19				-4		-6				3
Trib5A			-7				-9			1		2			-3
Harbor/Velasko					-10									3	4
Harbor/Lower							37								
Harbor/Hiawatha					-8					-1				3	4
Onondaga/Dorwin					-9										
Onondaga/Lower													4	6	6
Onond./Kirkpatrick					-5								2	4	
Ley/Park		-6	-4	-6	-4	-6							1	7	7
Ninemile/Rt48					-7									-3	
NonPoint Gauged					-6										
Total Gauged		-7	-3	-16	-25	-15								2	3
Total NonPoint					-6										
Total Industrial						13				1		1			
Total Municipal			-4	-22	-31	-26		-5	-5				2	5	5
Total Inflow		-7	-3	-15	-24	-14								2	3
NP_Rural					-7									-2	
NP_Urban		-7		-4									3	6	6
Outlet2			-2	-12	-19	-7					11		1		2
Outlet12			-3	-14	-20	-9					13				

Trend magnitudes shown for results with p < .10 for two-tailed hypothesis, p<05 for one-tailed hypothesis.
Shaded cells, trend analysis potentially impacted by variations in detection limits.

Table 13 Trends in Load, Mass Units, 1998-2007

Load Trends (mass / yr) , Adjusted for Variations in Rainfall   Precip Trend = 3.0 +/- 0.9 cm/yr

Term	FLOW	TP	TN	TKN	NH3N	NO2N	NO3N	TOC	TOC_F	TIC	SIO2	ALK	CA	CL	NA
Units	hm3	kg	kg	kg	kg	kg	kg	mt	mt	mt	mt	mt	mt	mt	mt
Metro				-125166	-120025	-6660		-45	-43						
Bypass															
E Flume															31
Trib5A	-0.35	-40	-860	-184	-58	-15	-649	-1	-1	-12	-2	-46	-47	-159	-81
Harbor/Velasko	0.37		914		-40									144	98
Harbor/Lower		84												69	
Harbor/Hiawatha	0.52	74	1342				1058					114	92	210	137
Onondaga/Dorwin						299									
Onondaga/Lower													315	4086	2443
Onond./Kirkpatrick													618	4384	2618
Ley/Park						-44								1020	634
Ninemile/Rt48					-2191										
NonPoint Gauged					-3205									4499	3293
Total Gauged				-113219	-101904	-4701								5904	4115
Total NonPoint					-3423									4805	3517
Total Industrial	-0.27		-654	-183	-82		-485	-1	-1				-38		
Total Municipal				-124351	-114449	-6628		-49	-47						
Total Inflow				-112654	-101400	-4581								6211	4340
NP_Rural					-2808										
NP_Urban		-444									9		432	5213	3140
Outlet2				-57743	-51999	-1555					179				
Outlet12				-74649	-63372	-2287					203				

Trend magnitudes shown for results with p < .10 for two-tailed hypothesis, p<05 for one-tailed hypothesis.

Shaded cells, trend analysis potentially impacted by variations in detection limits.

Table 14 Yearly Data Used for Model Calibration & Testing

Phosphorus Balance

Water Year	Net Inflow hm3	Metro+ Bypass kg	Total Load kg	Outflow Load kg	Inflow P P Conc ppb	Outflow P Conc ppb	HLR m/yr	Res Time Yrs	Settling Rate m/yr	Lake P Conc ppb	SE ppb
1991	545	53056	97121	55123	178	101	46.5	0.23	35.5	61.5	4.8
1992	483	67573	108270	49880	224	103	41.3	0.26	48.4	63.6	11.6
1993	572	65756	168104	102535	294	179	48.9	0.22	31.3	125.2	15.7
1994	484	56071	81212	66203	168	137	41.3	0.26	9.4	98.2	31.8
1995	298	45061	62085	49542	209	166	25.4	0.43	6.4	70.8	8.4
1996	488	48734	98479	65066	202	133	41.7	0.26	21.4	69.1	6.1
1997	450	38423	79475	52948	176	118	38.5	0.28	19.3	56.9	6.0
1998	475	38388	69667	39197	147	82	40.6	0.27	31.6	54.7	4.7
1999	315	31559	54752	33412	174	106	26.9	0.41	17.2	56.0	5.3
2000	485	29953	58512	37741	121	78	41.5	0.26	22.8	43.5	3.4
2001	412	21357	47493	31423	115	76	35.3	0.31	18.0	38.9	7.4
2002	422	22059	45608	29530	108	70	36.1	0.30	19.7	41.5	3.3
2003	486	36510	62473	40235	129	83	41.6	0.26	23.0	66.6	1.5
2004	593	49786	87229	55931	147	94	50.7	0.21	28.4	59.0	4.1
2005	513	26301	53056	42727	103	83	43.8	0.25	10.6	35.6	1.3
2006	558	12037	46376	30244	83	54	47.7	0.23	25.4	40.7	5.1
2007	571	11239	39527	24318	69	43	48.8	0.22	30.5	25.1	2.1
2003-2007	544	27174	57732	38691	106	71	46.5	0.23	22.9	45.4	7.6

Nitrogen Balance

Water Year	Net Inflow hm3	Metro+ Bypass kg	Total Load kg	Outflow Load kg	Inflow P P Conc ppb	Outflow N Conc ppb	HLR m/yr	Res Time Yrs	Settling Rate m/yr	Lake N Conc ppb	SE ppb
1991	545	1755992	2560250	1962682	4701	3604	46.5	0.23	14.2	4364	168
1992	483	1672009	2418004	1880217	5002	3889	41.3	0.26	11.8	4418	305
1993	572	1387500	2724153	2046168	4759	3575	48.9	0.22	16.2	3701	128
1994	484	1766085	2462262	1947854	5090	4027	41.3	0.26	10.9	4153	274
1995	298	1837802	2209321	1357467	7421	4559	25.4	0.43	16.0	5157	302
1996	488	1847815	2676295	1973197	5489	4047	41.7	0.26	14.8	3873	182
1997	450	1636220	2304162	1603544	5116	3560	38.5	0.28	16.8	3661	180
1998	475	1691731	2340156	1658378	4925	3490	40.6	0.27	16.7	3573	204
1999	315	1252391	1663682	1041103	5287	3309	26.9	0.41	16.1	3378	172
2000	485	1133824	1823711	1448012	3759	2985	41.5	0.26	10.8	2396	78
2001	412	1051118	1638335	1214090	3972	2944	35.3	0.31	12.3	2863	123
2002	422	929115	1478285	1070365	3500	2534	36.1	0.30	13.8	1951	182
2003	486	1112245	1883052	1285293	3873	2644	41.6	0.26	19.3	2549	110
2004	593	1242461	2127565	1568221	3587	2644	50.7	0.21	18.1	2403	128
2005	513	1229985	1935767	1459464	3774	2845	43.8	0.25	14.3	2584	116
2006	558	1074588	1790093	1373718	3207	2461	47.7	0.23	14.5	2477	124
2007	571	1054030	1769335	1397105	3101	2449	48.8	0.22	13.0	2951	49
2003-2007	544	1142662	1901163	1416760	3494	2603	46.5	0.23	15.9	2593	95

Chlorophyll-a Photic Zone or 0-3 m averages

Water Year	Sample Dates	Mean ppb	Std Dev ppb	SE ppb	CV -	Freq > 15 -	Freq > 20 -	Freq > 30 -	Freq > 40 -	Freq > 60 -
1991	20	30.0	25.2	5.6	0.84	60%	50%	45%	30%	10%
1992	18	16.3	10.6	2.5	0.65	56%	28%	17%	0%	0%
1993	9	18.8	19.3	6.4	1.03	33%	33%	33%	11%	0%
1994	9	33.3	42.5	14.2	1.28	44%	44%	44%	44%	22%
1995	9	7.9	4.7	1.6	0.59	0%	0%	0%	0%	0%
1996	8	34.0	28.4	10.0	0.83	75%	75%	63%	13%	13%
1997	9	13.5	13.2	4.4	0.98	44%	11%	11%	11%	0%
1998	12	19.4	10.1	2.9	0.52	50%	33%	17%	0%	0%
1999	19	26.4	18.0	4.1	0.68	74%	58%	42%	21%	5%
2000	17	21.9	16.6	4.0	0.76	59%	53%	24%	12%	0%
2001	17	27.3	25.7	6.2	0.94	47%	41%	35%	29%	18%
2002	18	25.8	15.1	3.6	0.59	72%	61%	28%	22%	0%
2003	17	37.2	28.9	7.0	0.78	76%	71%	53%	29%	18%
2004	18	25.5	13.2	3.1	0.52	67%	61%	39%	22%	0%
2005	17	12.8	4.1	1.0	0.32	35%	0%	0%	0%	0%
2006	17	17.4	5.9	1.4	0.34	53%	41%	0%	0%	0%
2007	17	9.6	5.7	1.4	0.59	6%	6%	0%	0%	0%
2003-2007	17	21	12	4.6	0.51	47%	36%	18%	10%	4%

Secchi Depth

Water Year	Sample Dates	Mean m	Std Dev m	SE m	CV -	Freq < 1.2 -	Freq < 1.5 -	HOD (mg/m^2-day) < 6 m	< 9 m	< 12 m
1991	7	1.44	1.02	0.39	0.71	57%	71%	1602	1484	1333
1992	9	1.99	1.33	0.44	0.67	0%	22%	1966	1795	1521
1993	9	2.31	1.24	0.41	0.53	11%	22%			
1994	9	2.13	1.01	0.34	0.48	33%	33%			
1995	8	1.99	0.58	0.20	0.29	0%	13%	1393	1364	1270
1996	8	1.56	0.95	0.33	0.61	38%	75%	1477	1354	1191
1997	9	2.97	2.09	0.70	0.70	0%	11%	1095	970	873
1998	9	1.82	0.60	0.20	0.33	22%	33%	927	922	899
1999	18	1.72	1.14	0.27	0.66	28%	44%	1699	1455	1196
2000	17	2.08	0.82	0.20	0.40	6%	24%	1041	988	888
2001	17	2.38	1.29	0.31	0.54	18%	41%	1146	1073	909
2002	16	1.96	0.72	0.18	0.37	0%	25%	1085	988	876
2003	17	1.35	0.49	0.12	0.36	35%	65%	968	946	860
2004	18	1.72	0.33	0.08	0.19	6%	17%	1160	1186	1073
2005	17	1.81	0.45	0.11	0.25	0%	24%	900	794	644
2006	17	1.71	0.34	0.08	0.20	12%	18%	1114	1145	1051
2007	17	2.14	0.75	0.18	0.35	6%	18%	984	866	723
2003-2007	17	1.75	0.47	0.08	0.27	12%	28%	1025	987	870

Nutrient Species

	Total Org. Carbon		Organic N		Inorganic N		TP - SRP		SRP	
Water Year	Mean ppm	SE ppm	Mean ppb	SE ppb	Mean ppb	SE ppb	Mean ppb	SE ppb	Mean ppb	SE ppb
1991	6.4	0.47	1034	167	3330	140	58	4.8	3.1	0.1
1992	5.7	0.18	1303	126	3115	213	51	11.0	12.3	4.7
1993	5.3	0.21	941	80	2760	169	96	8.7	29.2	8.7
1994	9.3	4.52	1055	248	3098	137	80	32.3	18.3	6.0
1995	4.8	0.38	1015	154	4142	183	51	5.2	19.9	8.4
1996	6.0	0.34	1018	131	2855	177	62	5.1	7.2	1.9
1997	4.6	0.10	917	61	2745	155	48	3.5	9.0	3.4
1998	4.7	0.12	671	98	2901	200	51	4.4	4.2	0.9
1999	4.7	0.17	915	124	2463	190	50	5.4	5.5	1.7
2000	4.5	0.09	658	25	1739	70	39	3.9	4.6	1.1
2001	4.3	0.15	766	68	2098	177	36	7.4	3.0	0.0
2002	4.4	0.10	751	38	1200	201	39	3.3	3.0	0.0
2003	5.1	0.28	873	72	1676	95	62	1.4	4.5	0.8
2004	5.9	0.26	682	22	1721	140	48	3.3	10.8	3.8
2005	4.5	0.14	608	19	1976	114	33	1.3	3.1	0.1
2006	3.9	0.06	626	27	1852	122	38	5.1	3.0	0.0
2007	3.7	0.07	536	21	2414	32	22	2.1	3.0	0.0
2003-2007	4.6	0.40	692	57	1848	133	40	6.8	4.3	1.5

SE = Standard Error of Mean
Lake Summary Statistics from for South Station, 0-3 m for Grabs or Epil Composites, June-September

Table 15 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/m²-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 =	22.9	m/yr

Calibrated to 2003-2007

Period	2003-2007	1998-2007	1991-2007
Residual CV	0.12	0.11	0.17
R^2	0.85	0.80	0.78

Lake Surface Total P:

Reference: Walker (1978), Sas (1989)

$P = F_P P_O$

F_P = 0.59 Calibrated to 2004-2007

Period	2003-2007	1998-2007	1991-2007
Residual CV	0.20	0.14	0.18
R^2	0.71	0.74	0.81

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 =	15.9	m/yr

Calibrated to 2003-2007

Period	2003-2007	1998-2007	1991-2007
Residual CV	0.04	0.05	0.05
R^2	0.50	0.84	0.94

Lake Summer Total N:

$N = F_N$ No

F_N = 1.00 Calibrated to 2003-2007

Period	2003-2007	1998-2007	1991-2007
Residual CV	0.15	0.13	0.13
R^2	0.00	0.57	0.77

Lake Photic Zone Chlorophyll-a:

Reference: Jones & Bachman (1976)

$B = 0.081 P^{1.46}$

not recalibrated

Period	2003-2007	1998-2007
Residual CV	0.33	0.32
R^2	0.63	0.00

Algal Bloom Frequencies:

Reference: BATHTUB Walker (1984; 2004)

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 = SD / Mean
C_B =	0.508 Calibrated to 2003-2007

Lake Secchi Depth:

Reference: BATHTUB, Walker (1985; 2004)

$S = 1 / (a + b B)$

a =	0.4014	1/m
b =	0.0091	m^2/mg

Calibrated to 2003-2007

Period	2003-2007	1998-2007
Residual CV	0.14	0.17
R^2	0.24	0.00

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 1.5 m)
S_S =	Standard Deviation of ln (Secchi)
S_S =	$[\ln (1 + C_S^2)]^{1/2}$
C_S =	Within-Year Temporal CV = 0.27
	Calibrated to 2003-2007

Lake Summer Total P - SRP:

Reference: BATHTUB, Walker (1985; 2004)

TP - SRP = -4.1 + 1.78 B + 23.7a

Not recalibrated

Period	2003-2007	1998-2007
Residual CV	0.23	0.17
R^2	0.62	0.59

Lake Summer Organic Nitrogen:

Reference: BATHTUB, Walker (1985; 2004)

TON = K (157 + 22.8 B + 75.3 a)

K = 2003-2007 Calibration = 1.1

	2003-2007	1998-2007
Residual CV	0.19	0.20
R^2	0.00	0.00

Hypolimnetic Oxygen Depletion Rate:

Reference: BATHTUB, Walker (1985; 2004)

$HOD = 240 B^{0.45}$

not recalibrated

Period	2003-2007	1998-2007
Residual CV	0.22	0.19
R^2	0.00	0.00

Table 16 Model Inputs & Outputs

Lake Features		
Lake Area	km2	11.7
Mean Hypol Depth	m	7.02
Stratified Period	days	183
Spring DO Conc	ppm	12

Coefficients Calibrated to 2003-2007 Data		
P Settling Rate	m/yr	22.900
Summer UML / Outflow P	-	0.59
Total N Setting Rate	m/yr	15.900
Summer UML / Outflow N		0.996
Chla/P Slope	-	1.4600
Chla/P Intercept	-	0.081
Non-Algal Turbidity	1/m	0.401
Secchi/Chla Slope	m2/mg	0.009
Organic N Calib Factor		1.100
Chla Temporal CV	-	0.508
Secchi Temporal CV	-	0.269

Error Coefficients of Variation for Yearly Simulations, 1998-2007		**BATHTUB Calib***
Outflow P Error CV	0.105	0.364
Summer Epil P Error CV	0.139	0.272
Outflow N CV	0.051	0.230
Summer Epil N CV	0.128	0.219
Chl-a Error CV	0.318	0.350
Secchi Error CV	0.172	0.281
HOD Error CV	0.194	0.205
Organic N Error CV	0.200	0.253
TP-OP Error CV	0.173	0.350

Predicted Values			Confidence Intervals for Long-Term Means				Year-to-Year Variations		Observed Mean 1998 - 2007	
			50%	10%	90%		10%	90%		
Output Variable		Units	Mean	Low	High	Std Error	Low	High	Mean	Std Error
Outflow P Conc		ppb	75	72	79	2.5	47	102	76	5.8
Lake P Conc		ppb	44	41	47	1.9	40	86	46	4.0
Mean Chl-a		ppb	20.5	17.6	23.9	2.1	10	32	22	2.5
Algal Bloom Frequencies										
	>	15	66%	54%	77%		16%	91%	54%	7%
	>	20	43%	31%	55%		5%	77%	43%	7%
	>	30	15%	9%	24%		1%	45%	24%	6%
	>	40	5%	3%	9%		0%	23%	14%	4%
	>	60	1%	0%	2%		0%	6%	4%	2%
Mean Secchi Depth		m	1.7	1.6	1.8	0.1	1.4	2.0	1.9	0.09
Secchi Interval Frequencies										
	<	1.2	12%	19%	7%		3%	28%	13%	4%
	<	1.5	37%	49%	26%		16%	60%	31%	5%
	<	2.0	77%	86%	67%		54%	91%	64%	5%
Oxygen Depletion Rate		mg/m^2-day	1087	990	1195	66.7	773	1352	1036	60
Oxygen Depletion Rate		mg/m3-day	155	141	170	9.5	110	193	148	9
Days Hypol. DO < .5 ppm		days	0	0	11		79	123	50	
Days Hypol. DO < 2 ppm		days	0	15	33		92	131	68	
Days Hypol. DO < 5 ppm		days	49	66	78		119	147	102	
Organic N		ppb	721	654	794	45.6	466	1002	708	37
Total P - SRP		ppb	42	39	46	2.3	24	62	42	4

* Error coefficients for BATHTUB original calibration dataset based upon data from 40 reservoirs (Walker, 1985) shown for comparison with values for Onondaga Lake
Error CV's are for yearly predictions (lower for long-term means).

Table 17 Model Interface for Evaluating Management Scenarios

Onondaga Lake Empirical Eutrophication Model — Version: April 27, 2009

Select Scenario:

- Base 1998-2007
- Metro =120
- Metro=120, NPS=50
- Metro=120, NPS=40
- Metro=120, NPS=30
- Metro=20
- Metro =120, NPS=50
- Metro Diverted
- Metro Div, NPS=50
- Metro =120, Model 2
- Metro =120, NPS=40, Model 2

Scenario Index	Detailed Output	Yearly Simulation
Save Scenario	P Load Response	Documen-tation
Delete Scenario	Lake P Response	Sheet Index

User input cells are red

Press 'Ctrl-I' to return here from other worksheets

Define Historical Baseline Period: 1998 2007

Scenario Name: Metro =120

	Metro =120			Historical Baseline: 1998 - 2007			Percent Reduction		
	Flow cfs	TP ppb	TP Load kg/yr	Flow cfs	TP ppb	TP Load kg/yr	Flow cfs	TP ppb	TP Load kg/yr
Metro Effluent	102.1	120	10,957	102.1	306	27,919	0%	61%	61%
Metro Bypass	2.2	1118	2,228	2.2	1118	2,228	0%	0%	0%
East Flume	0.6	165	93	0.6	165	93	0%	0%	0%
Trib 5A	2.4	122	261	2.4	122	261	0%	0%	0%
Harbor Brook	11.6	86	891	11.6	86	891	0%	0%	0%
Ley Creek	42.6	94	3,575	42.6	94	3,575	0%	0%	0%
Ninemile Creek	163.9	55	8,076	163.9	55	8,076	0%	0%	0%
Onondaga Creek	184.4	69	11,449	184.4	69	11,449	0%	0%	0%
Nonpoint Ungauged	27.4	67	1,634	27.4	67	1,634	0%	0%	0%
Precipitation	10.8	30	290	10.8	30	290	0%	0%	0%
Evaporation	9.9			9.9			0%		
NonPoint Total	429.9	67	25,625	429.9	67	25,625	0%	0%	0%
Total Municipal	104.3	141	13,185	104.3	323	30,147	0%	56%	56%
Total Industrial	3.0	131	354	3.0	131	354	0%	0%	0%
Total External	537.3	82	39,164	537.3	117	56,126	0%	30%	30%
Total Inflow	548.1	80	39,454	548.1	115	56,416	0%	30%	30%
Outflow	538.2	53	25,345	538.2	76	36,341			30%
Retention			14,109			20,074			

Output Variable		Predicted	Std Error	Observed	Std Error	Percent Reduction
Outflow TP ppb	ppb	53	1.7	76	5.8	30%
Lake Total P	ppb	31	1.4	46	4.0	33%
Mean Chlorophyll-a	ppb	12.2	1.2	22.3	2.5	45%
Mean Secchi	m	2.0	0.1	1.9	0.1	-4%

Yearly Simulation

Scenario: Metro =120

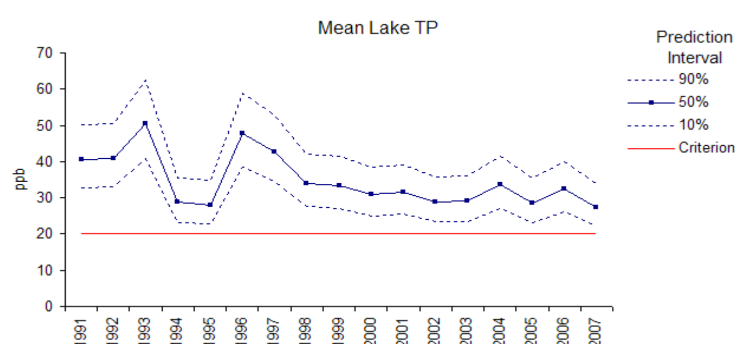
Select Scenario

- Base 1998-2007
- Metro =120
- Metro=120, NPS=50
- Metro=120, NPS=40
- Metro=120, NPS=30
- Metro=20
- Metro =120, NPS=50
- Metro Diverted
- Metro Div, NPS=50
- Metro =120, Model 2
- Metro =120, NPS=40, Model 2

Go To Input Sheet

Plot Variable

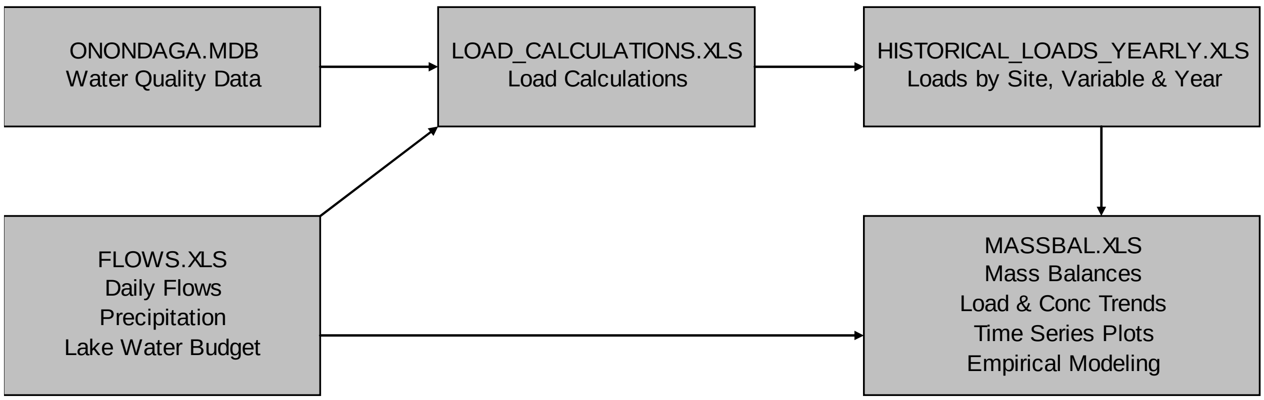
- Outflow TP Conc
- Mean Lake TP
- Mean Chlorophyll-a
- Freq Chla > 15 ppb
- Freq Chla > 20 ppb
- Freq Chla > 30 ppb
- Freq Chla > 40 ppb
- Freq Chla > 60 ppb
- Mean Secchi Depth
- Freq Secchi < 1.2 m
- Freq Secchi < 1.5 m
- Freq Secchi < 2.0 m
- Area O2 Depletion Rate
- Vol. O2 Depletion Rate
- Days Hypol. DO < .5 ppm
- Days Hypol. DO < 2 ppm
- Days Hypol. DO < 5 ppm
- Organic Nitrogen
- Total P - SRP



Criterion = AMP Goal or Guidance Value for Long-Term Mean

List of Figures

Figure 1
Mass Balance Computations Integrated with AMP Long-Term Database



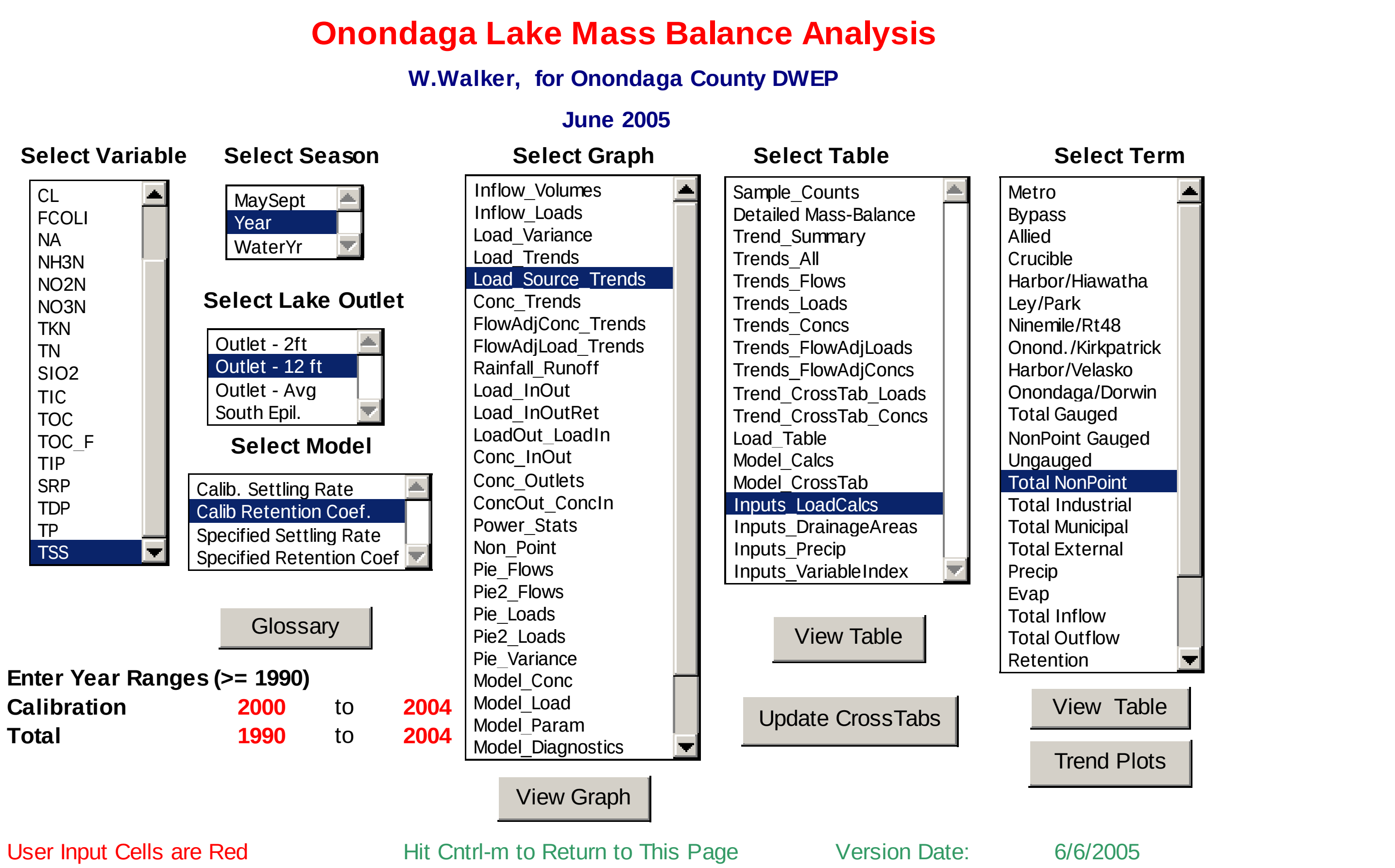
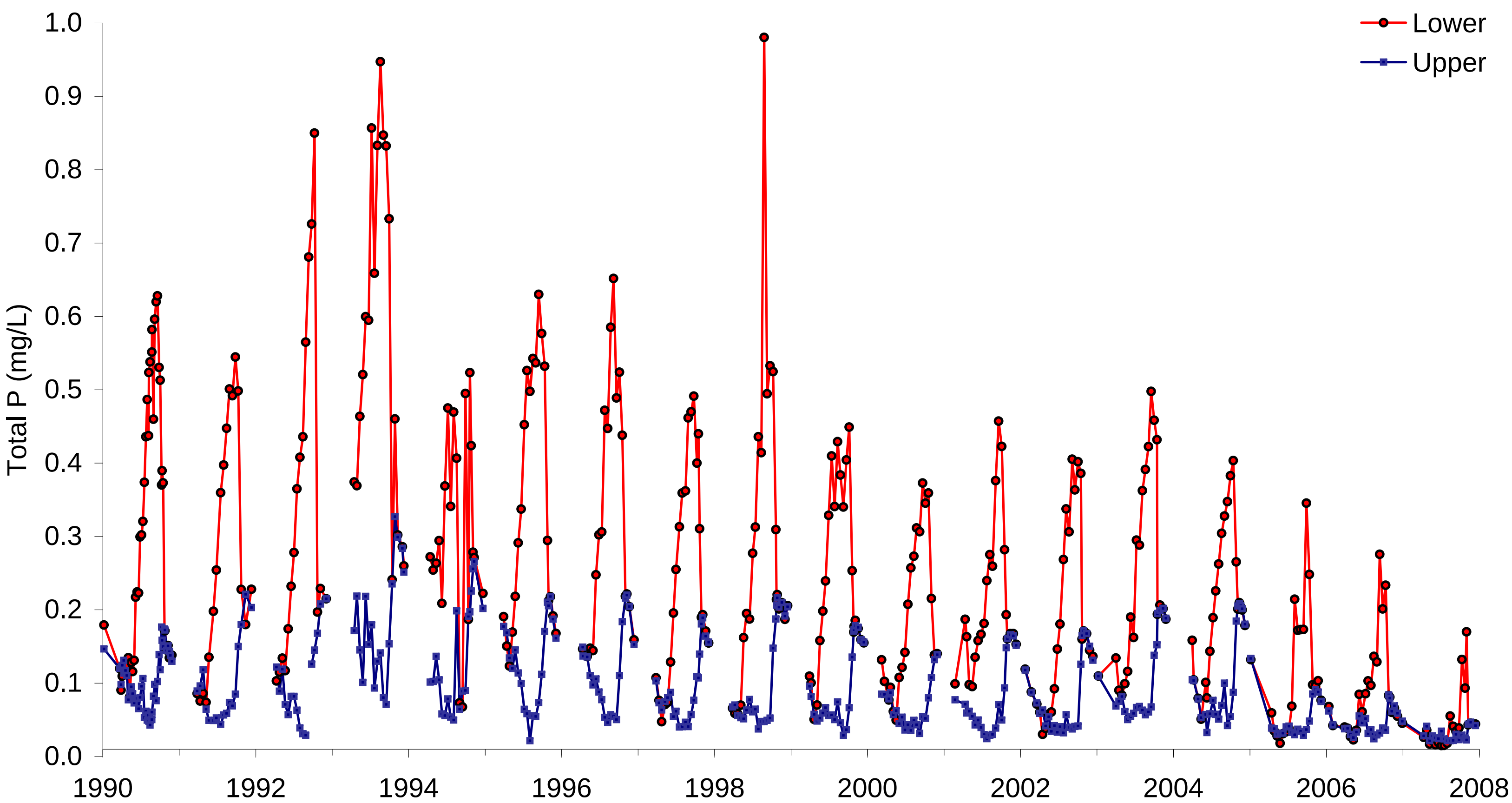
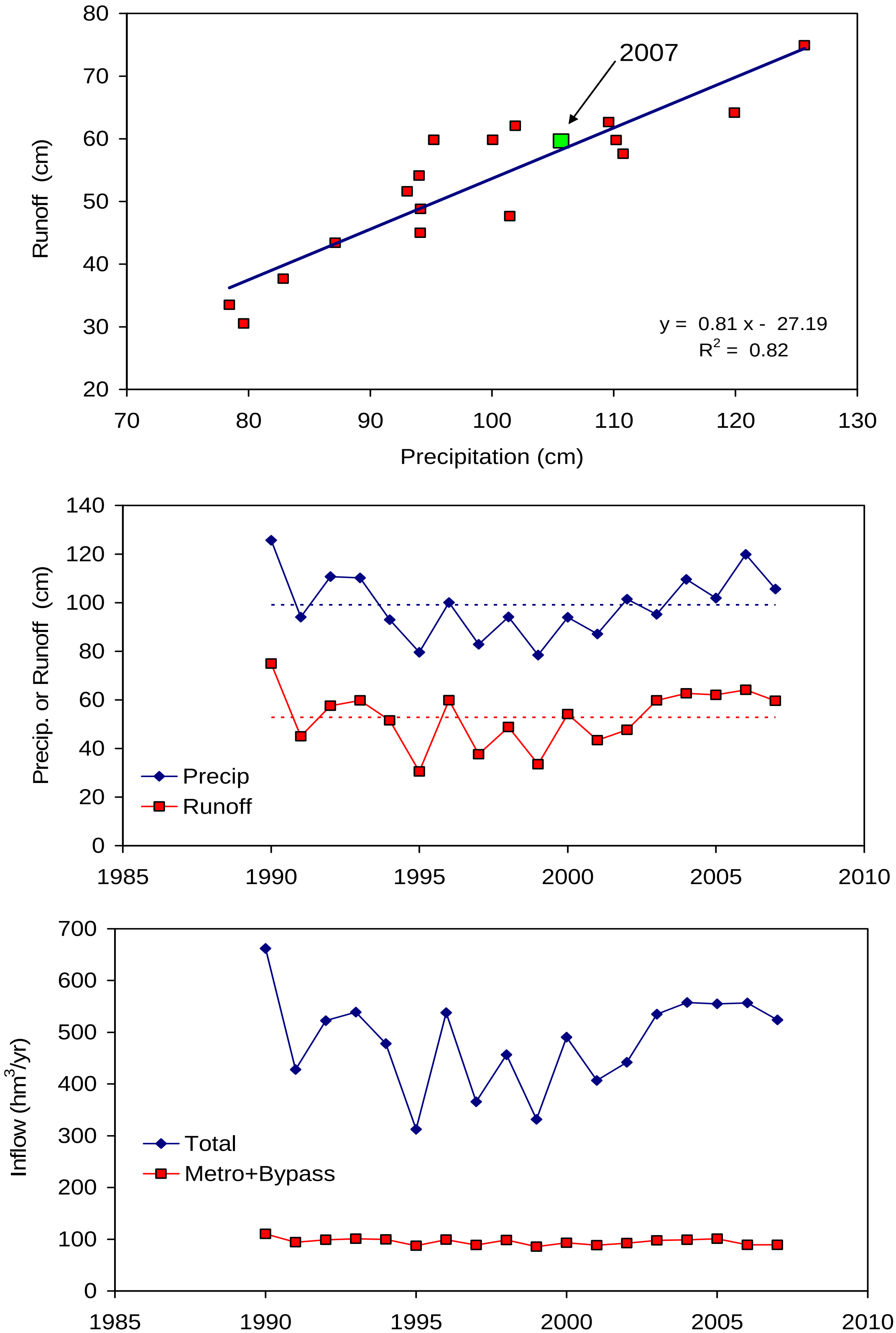


Figure 2
Long-Term Trends in Lake Phosphorus Concentration



Lower 9 - 18 meters, South Deep station
Upper 0 - 3 meters

Figure 3
Precipitation, Runoff, & Lake Inflow Volumes



X Axis: Calendar Year

Figure 4
Long-Term Variations in Total Inflow & Outflow Concentrations

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

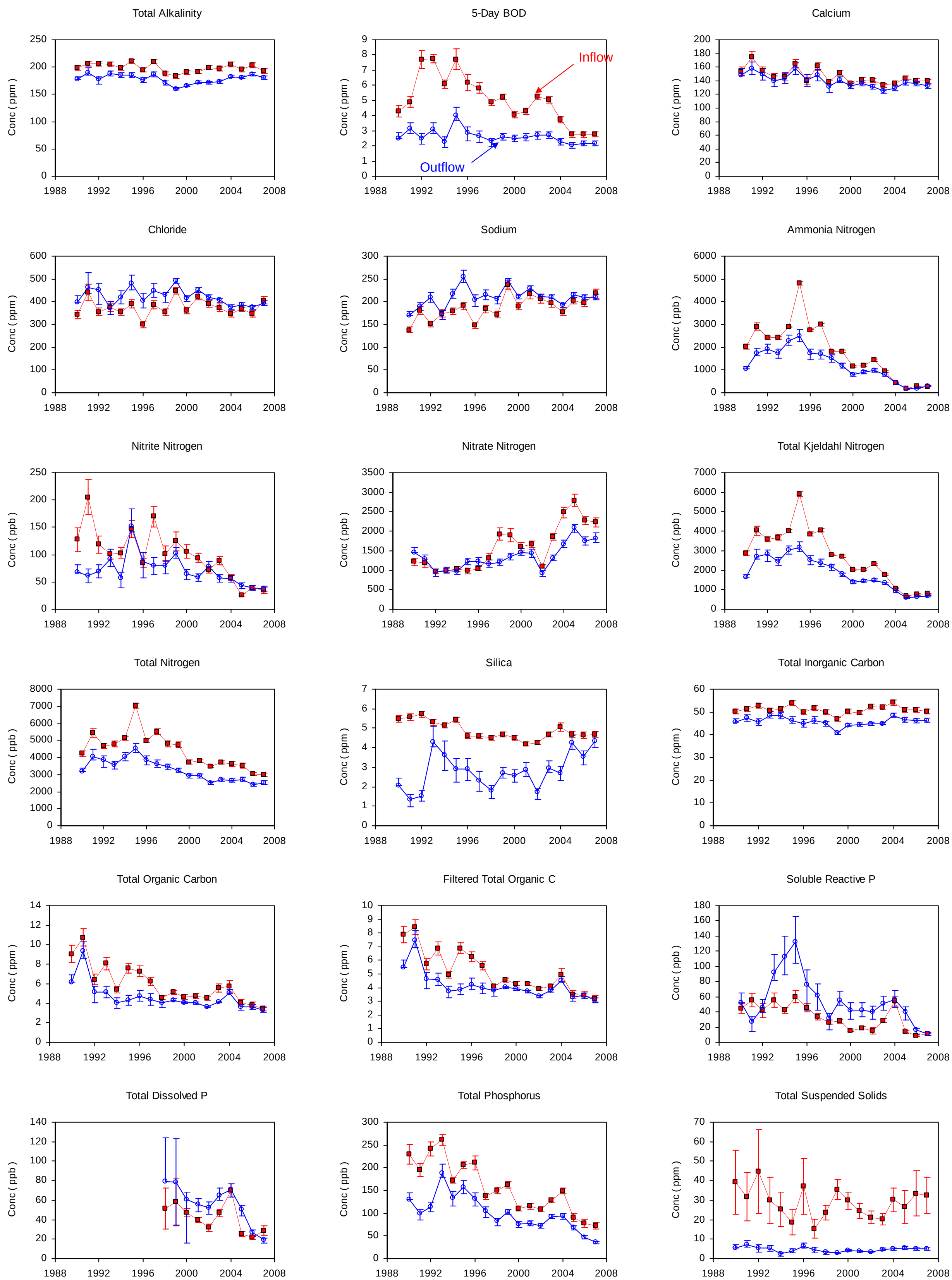


Figure 5
Long-Term Variations in Total Inflow & Outflow Loads

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

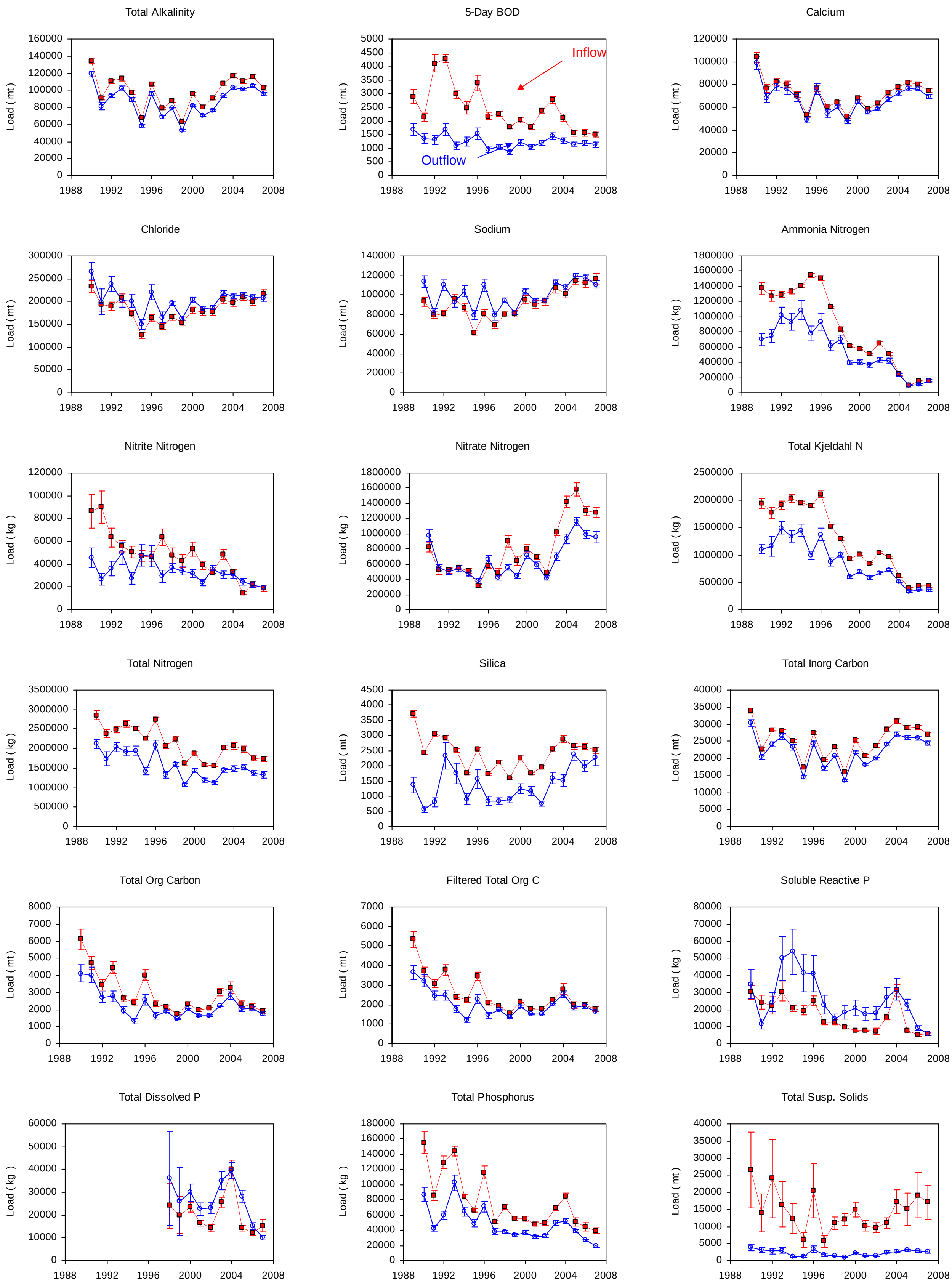


Figure 6

Long-Term Variations in NonPoint & Metro Loads

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

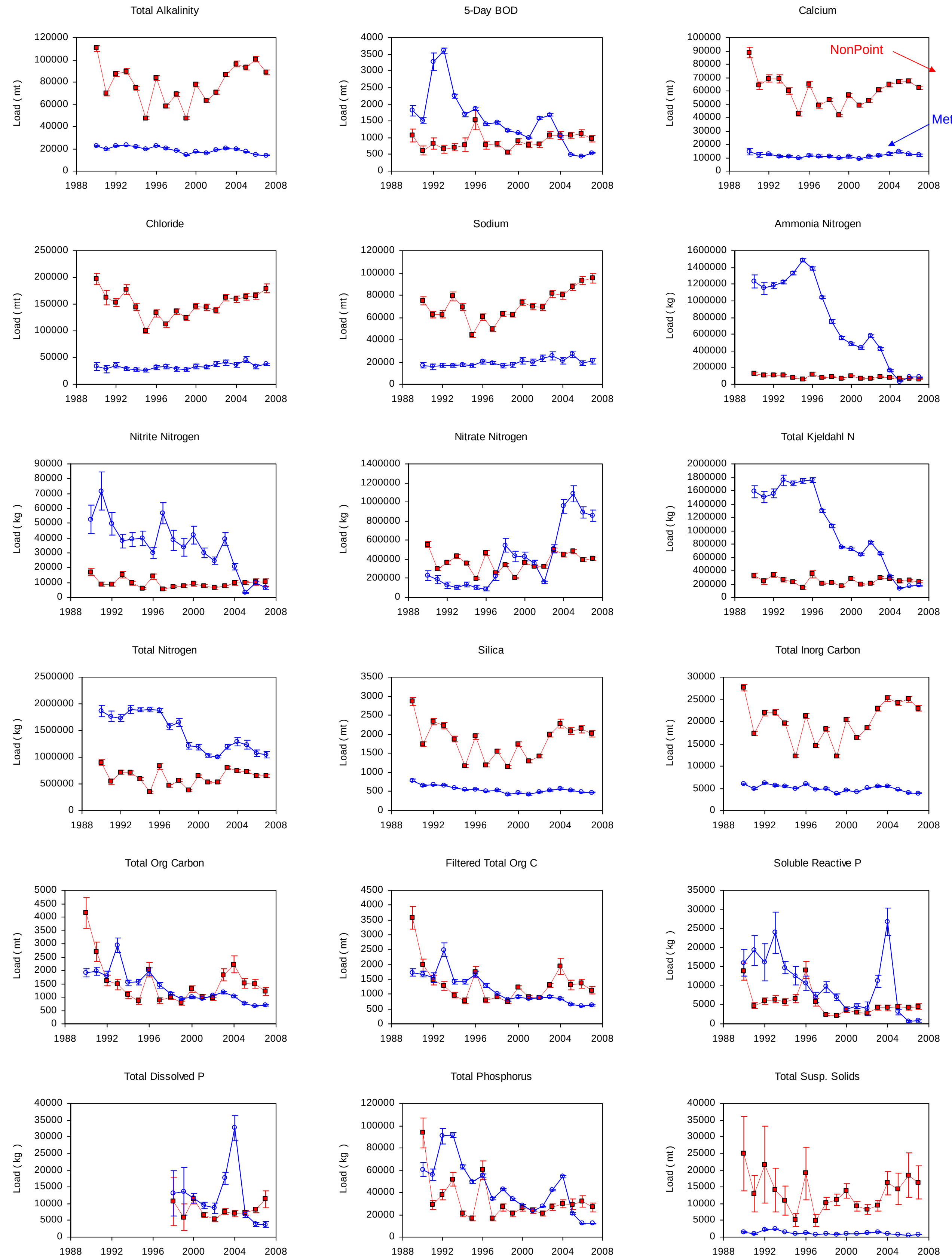


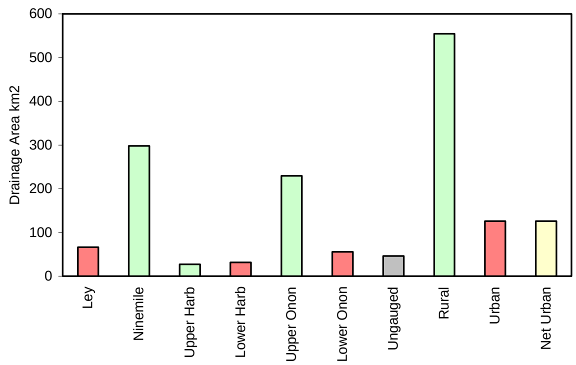
Figure 7 Spatial Variations in NonPoint Phosphorus Loads

Variable: Total Phosphorus

Period: 1998 - 2007

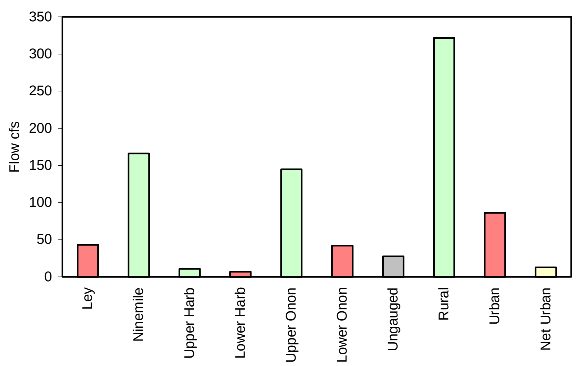
Total Values

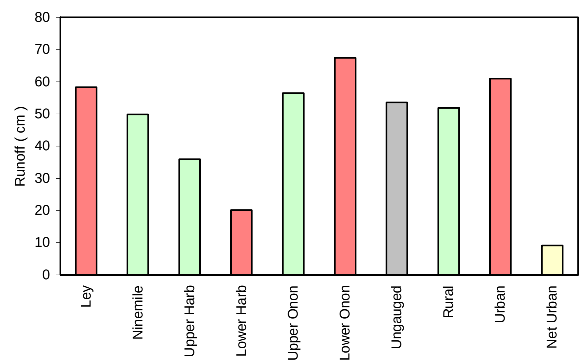
Unit Area Values

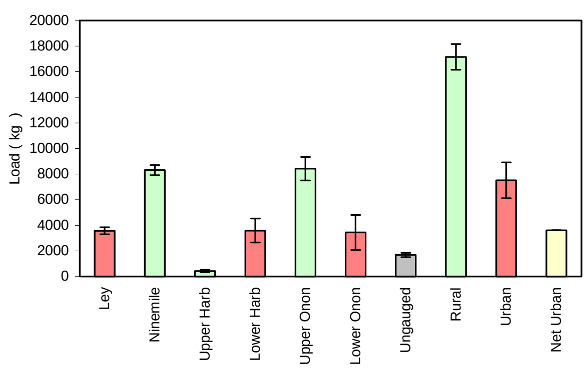


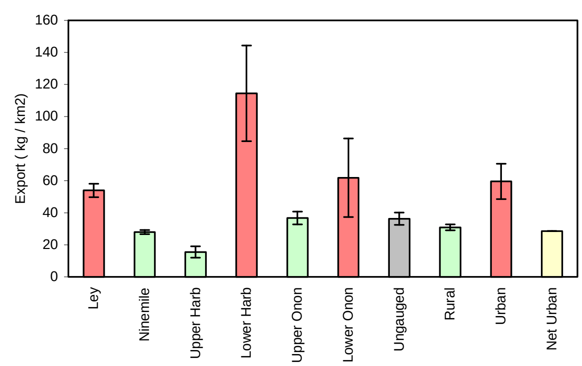
Label	Description
Ley	Above Park
Ninemile	Above Lakeland
Upper Harb	Above Velasko
Lower Harb	Between Velasko & Hiawatha
Upper Onon	Above Dorwin
Lower Onon	Between Dorwin & Kirkpatrick
Ungauged	Ungauged Watershed (Estimated)

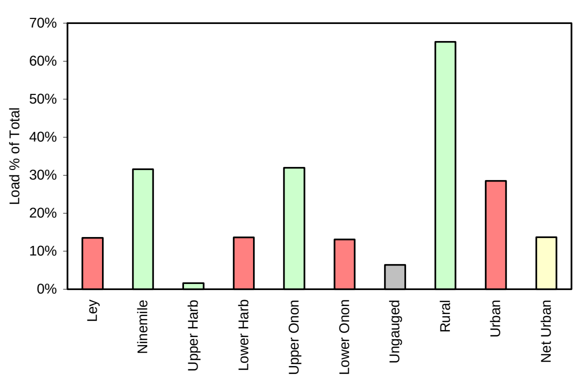
Red	Lower Watersheds (~ Urban)
Green	Upper Watersheds (~ Rural)
Yellow	Net From Lower/Urban Areas vs. Rural Background











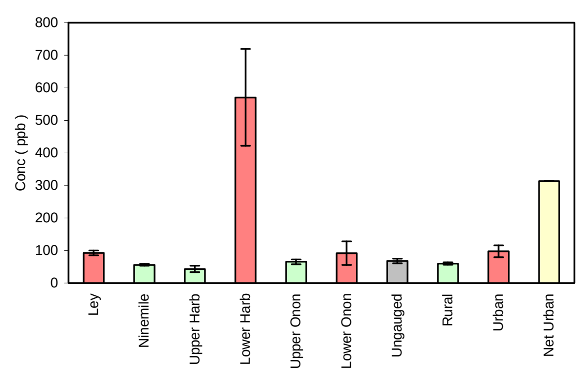
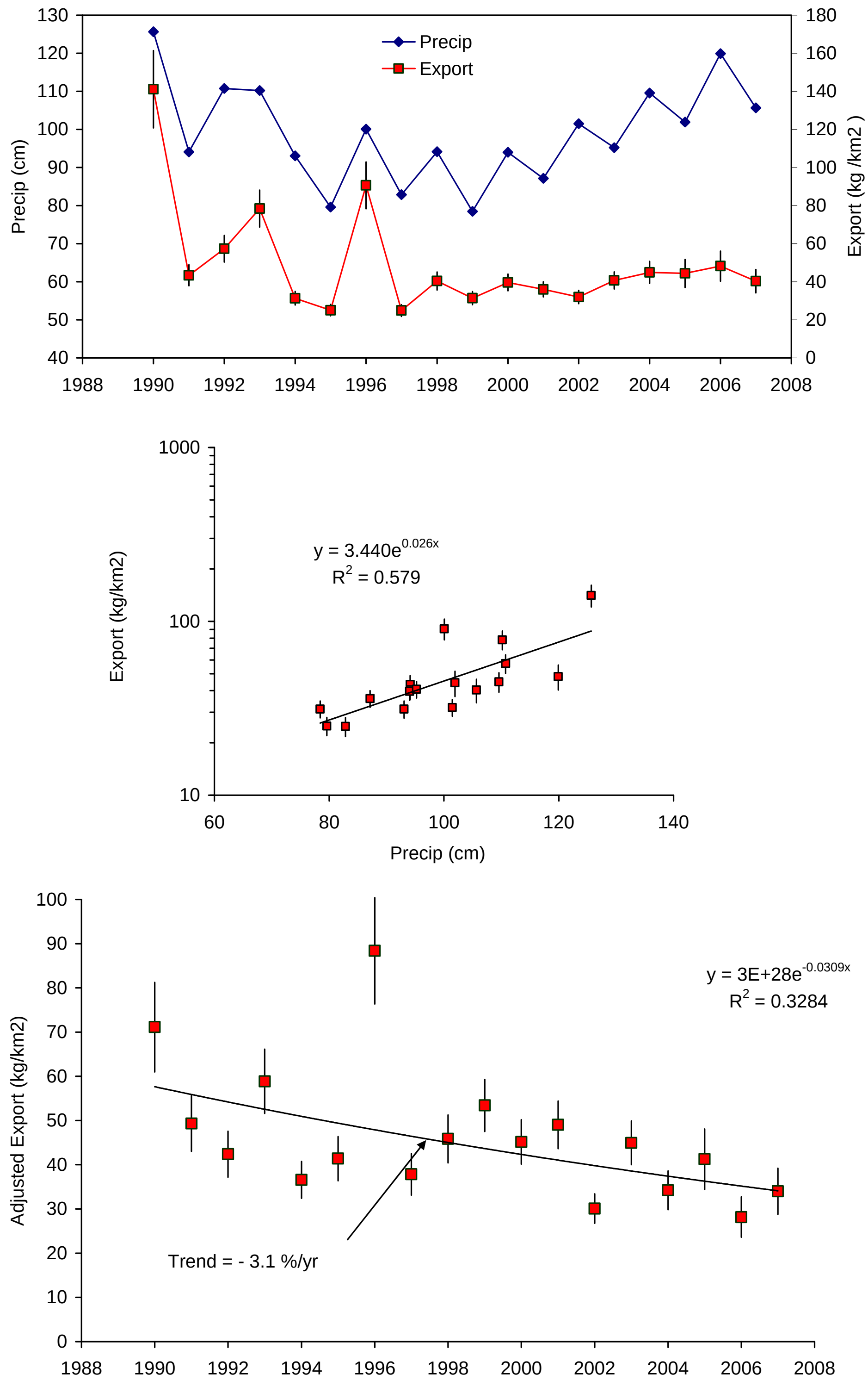


Figure 8 Adjustment of NonPoint P Loads for Variations in Rainfall



P_Export = Total Nonpoint Load (kg/yr) / Watershed Area (km2)

Precip = Hancock Airport Precipitation (cm)

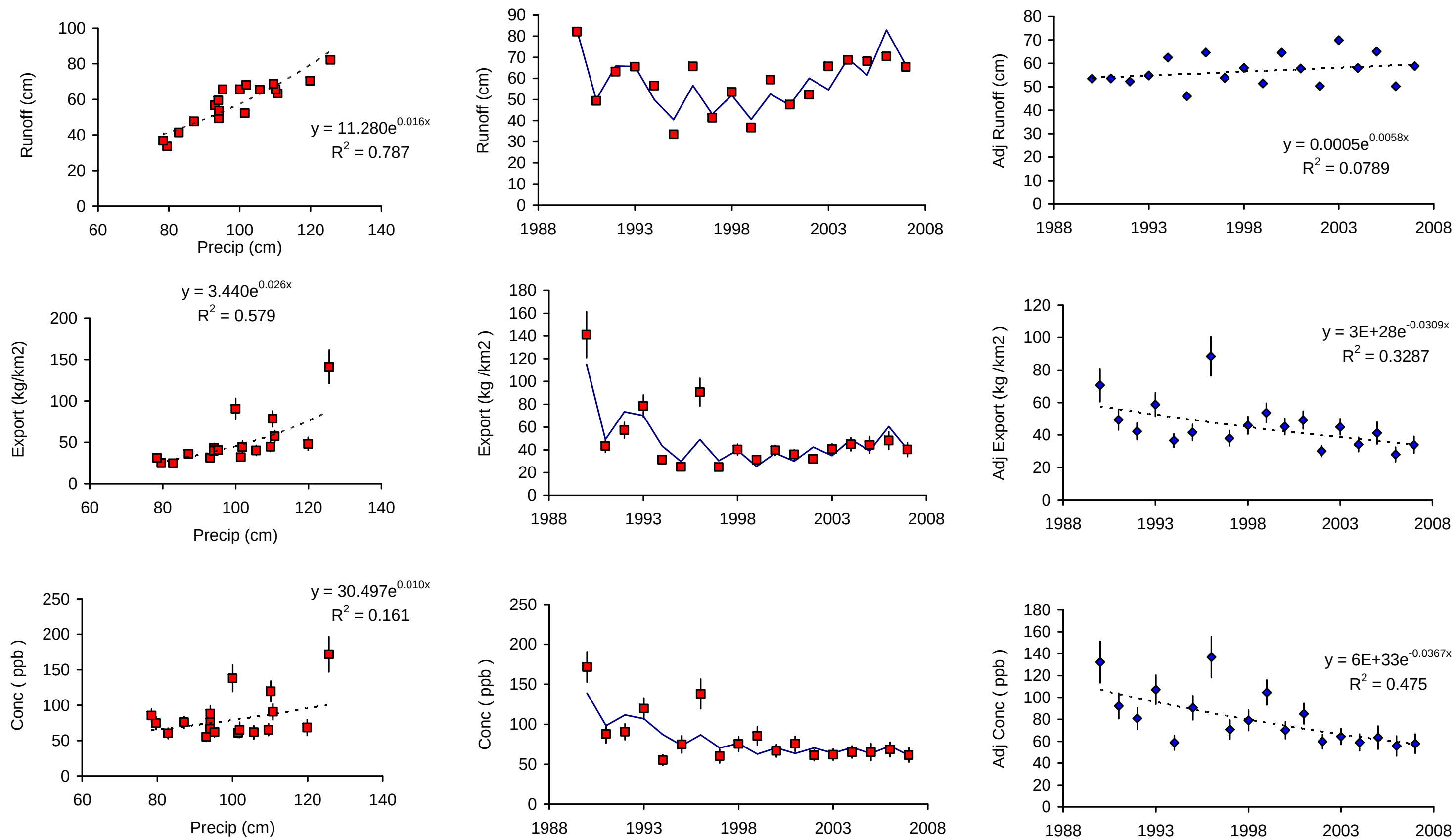
Adjusted_P_Export = P_Export Adjusted for Yearly Variations in Precipitation

Adjusted_P_Export = Measured_P_Export x Exp [.026 x (Mean_Precip - Precip)]

Trend in Adjusted_P_Export (% per year) = -3.1% +/- 1.1% p= 0.016

Figure 9 Trends in Nonpoint Runoff, Total P Load, & Concentration, 1990-2007

Correlations with Precipitation | Observed & Predicted Time Series | Adjusted for Variations in Precipitation



Dashed Line = Regression vs. Precip
Vertical Bars = +/- 1 Standard Error of Measured Yearly Value

Solid Line = Regression vs. Year and Precip

Dashed Line = Regressionof Adjusted Value vs. Year

Regression Model: Ln (Y) = A0 + A1 Year + A2 Precip   Years: 18

Adjustment to Mean Precip: Ln (Yadjusted) = Ln (Y) + A2 (Mean_Precip - Precip)   Mean_Precip = 99 cm/yr

	Ln Runoff vs. Precip & Year			Ln Export vs. Precip & Year			Ln Conc vs. Precip & Year		
	Coef	SE	p	Coef	SE	p	Coef	SE	p
A0	-9.22861			62.94281			76.77659		
A1 (Yr)	0.00583	0.00515	0.27	-0.03089	0.01140	0.02	-0.03672	0.00997	0.00
A2 (Precip)	0.01623	0.00210	0.00	0.02607	0.00465	0.00	0.00984	0.00407	0.03
R^2	0.80350			0.71735			0.55930		
Std Error	0.11324			0.25089			0.21942		

Summary of Trends (Percent / Year)

	Trend	p
Runoff	0.6%	0.27
Export	-3.1%	0.02
Conc	-3.7%	0.00

Figure 10 Trends in Rainfall-Adjusted Phosphorus Loads from Individual Sources, 1990-2007

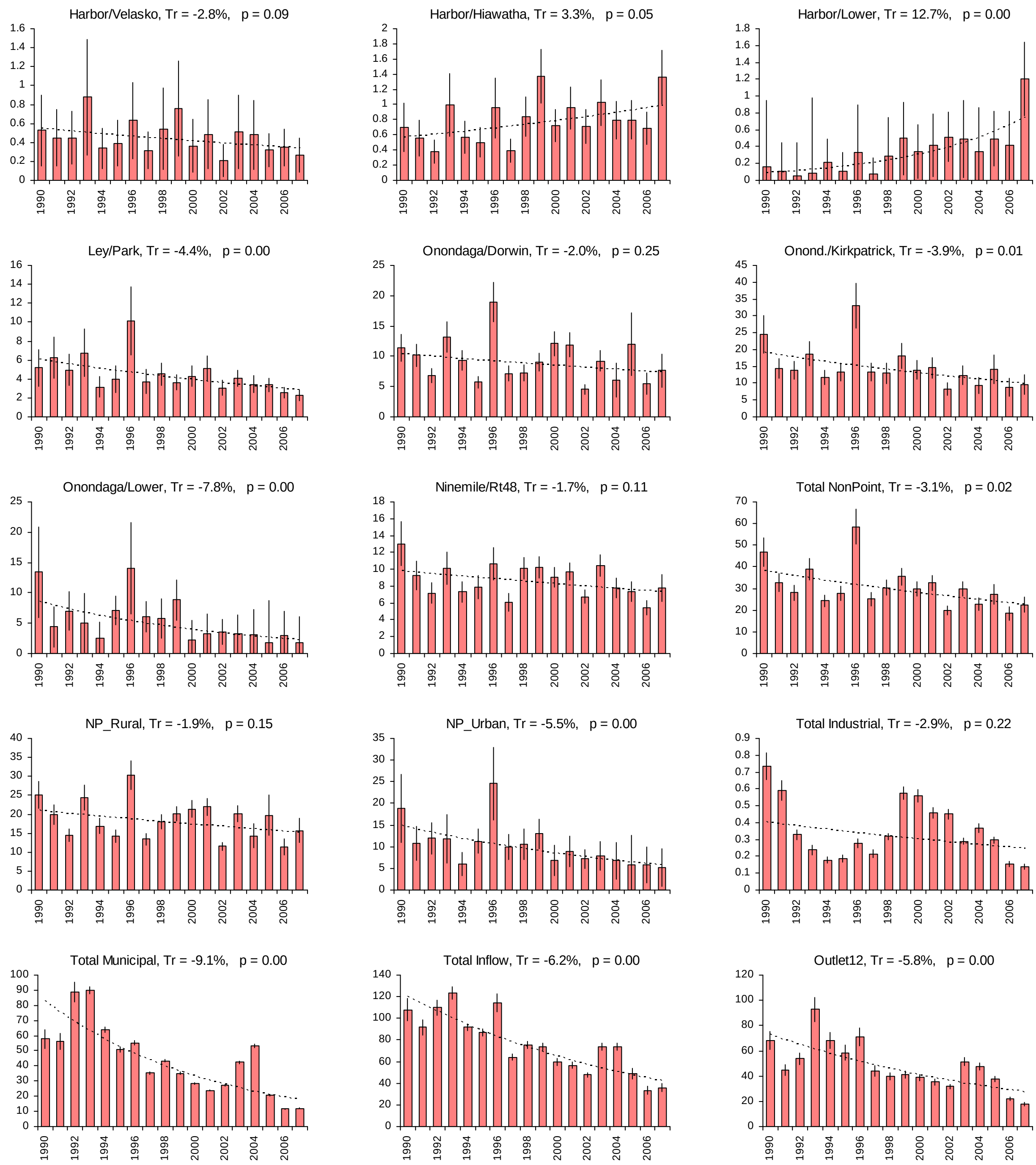
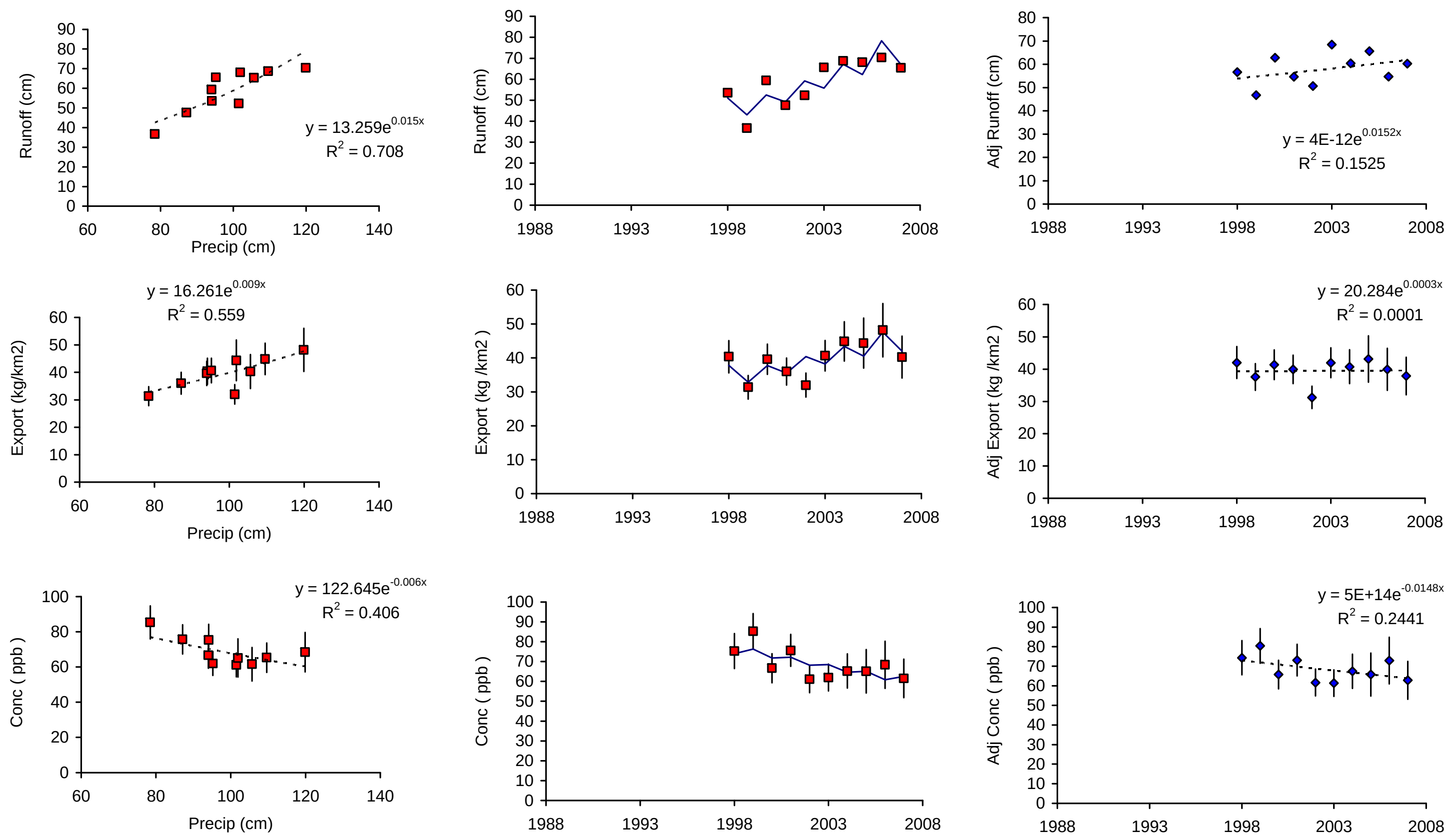


Figure 11 Trends in Nonpoint Runoff, Total P Load, and Concentration, 1998-2007

Correlations with Precipitation | Observed & Predicted Time Series | Adjusted for Variations in Precipitation



Dashed Line = Regression vs. Precip
Vertical Bars = +/- 1 Standard Error of Measured Yearly Value

Solid Line = Regression vs. Year and Precip

Dashed Line = Regressionof Adjusted Value vs. Year

Regression Model: Ln (Y) = A0 + A1 Year + A2 Precip   Years: 10

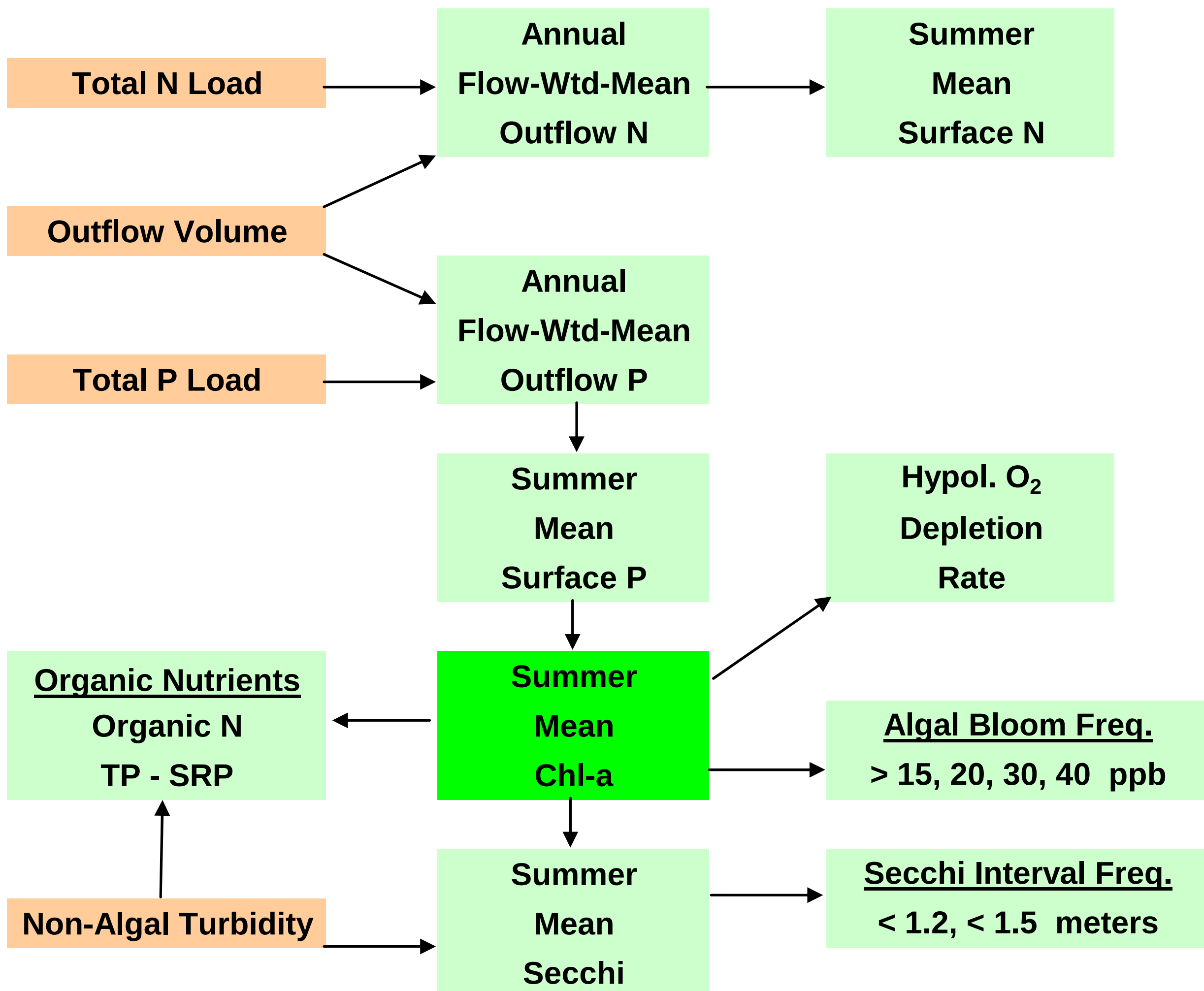
Adjustment to Mean Precip: Ln (Yadjusted) = Ln (Y) + A2 (Mean_Precip - Precip)   Mean_Precip = 99 cm/yr

	Ln Runoff vs. Precip & Year			Ln Export vs. Precip & Year			Ln Conc vs. Precip & Year		
	Coef	SE	p	Coef	SE	p	Coef	SE	p
A0	-27.48206			2.13101			34.21824		
A1 (Yr)	0.01516	0.02139	0.50	0.00033	0.01842	0.99	-0.01483	0.01562	0.37
A2 (Precip)	0.01186	0.00553	0.07	0.00890	0.00476	0.10	-0.00296	0.00404	0.49
R^2	0.72751			0.55938			0.47408		
Std Error	0.12274			0.10568			0.08961		

Summary of Trends (Percent / Year)

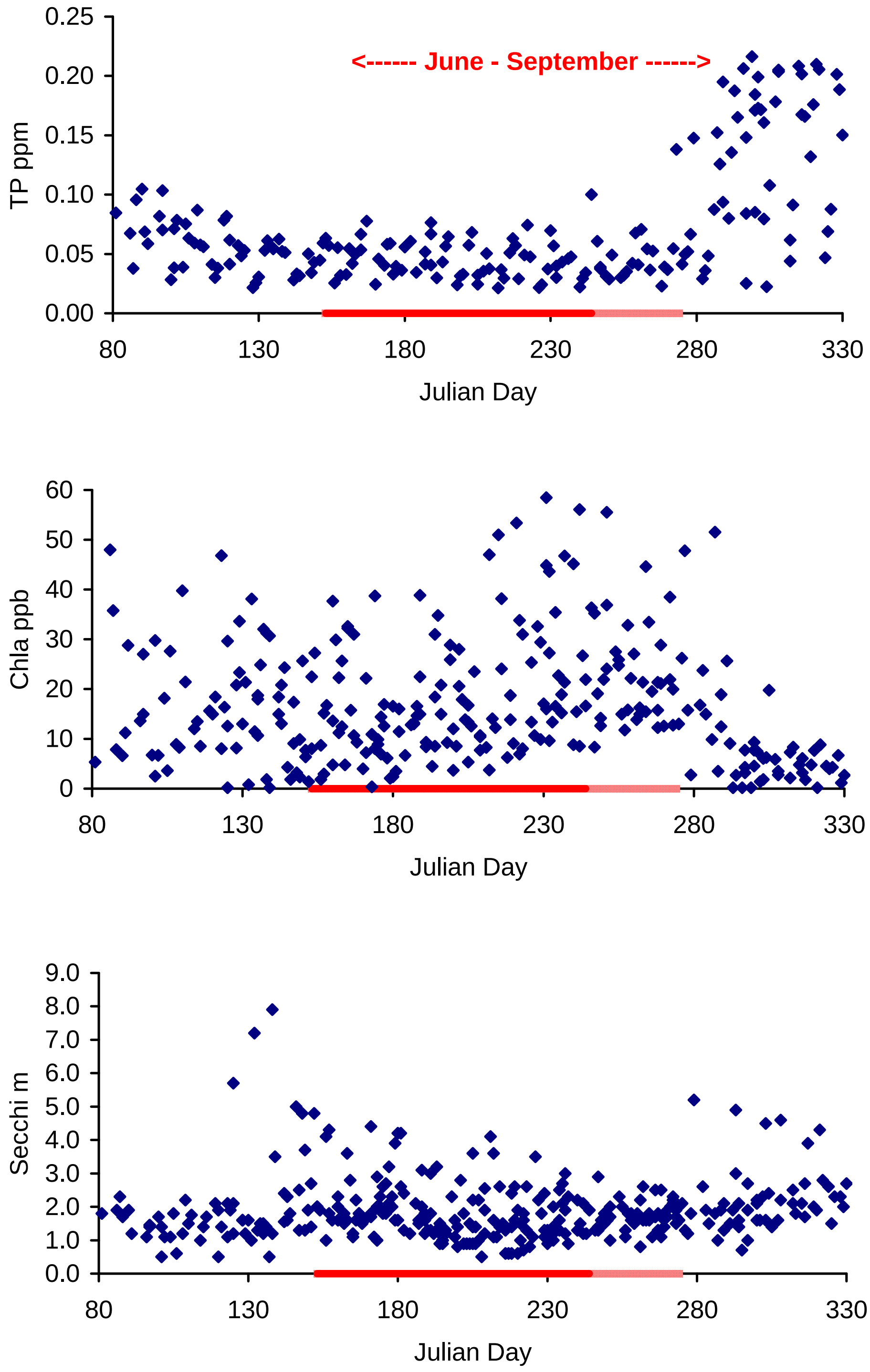
	Trend	p
Runoff	1.5%	0.50
Export	0.0%	0.99
Conc	-1.5%	0.37

Figure 12 Onondaga Lake Empirical Eutrophication Model



Adapted from BATHTUB (Walker, 2006)

Figure 13 Seasonal Variations in Trophic State Indicators



Red bars show June-September averaging period.
Data from Lake South Upper Mixed Layer, 1998 - 2007

Figure 14 Total Phosphorus & Chloride in Lake Upper Mixed Layer & Outlet

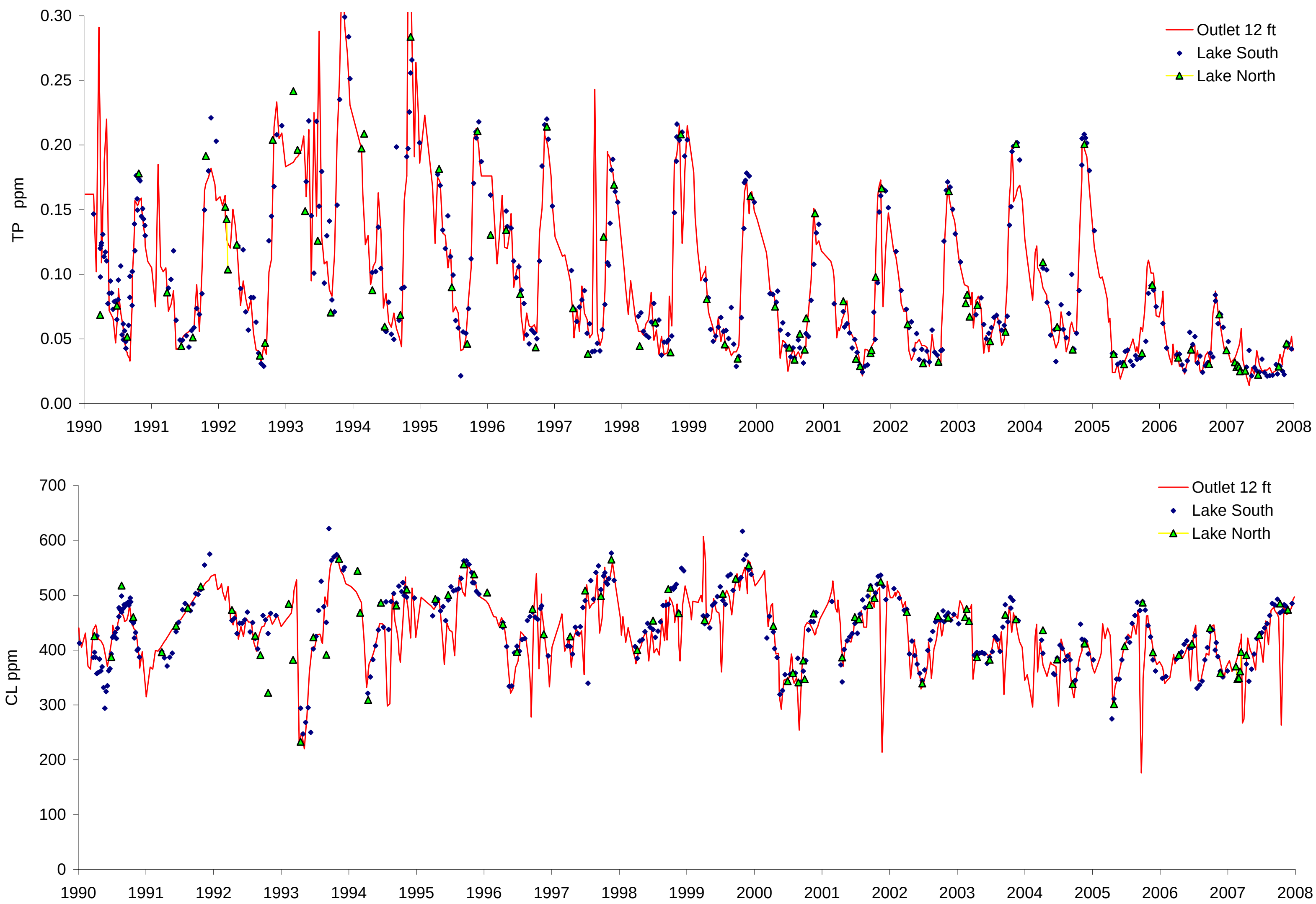


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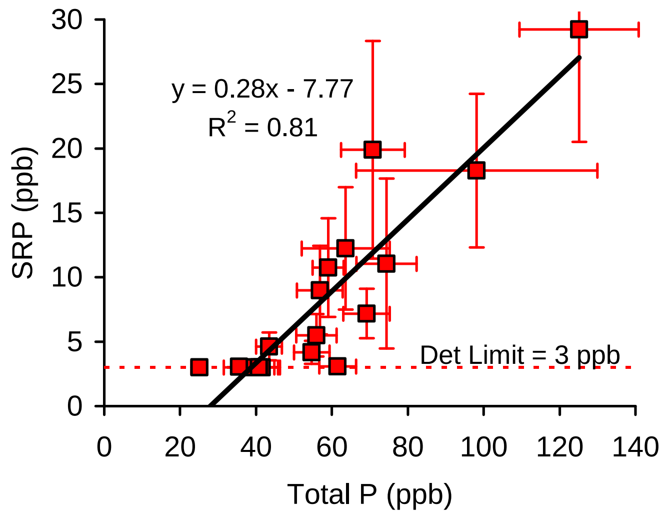
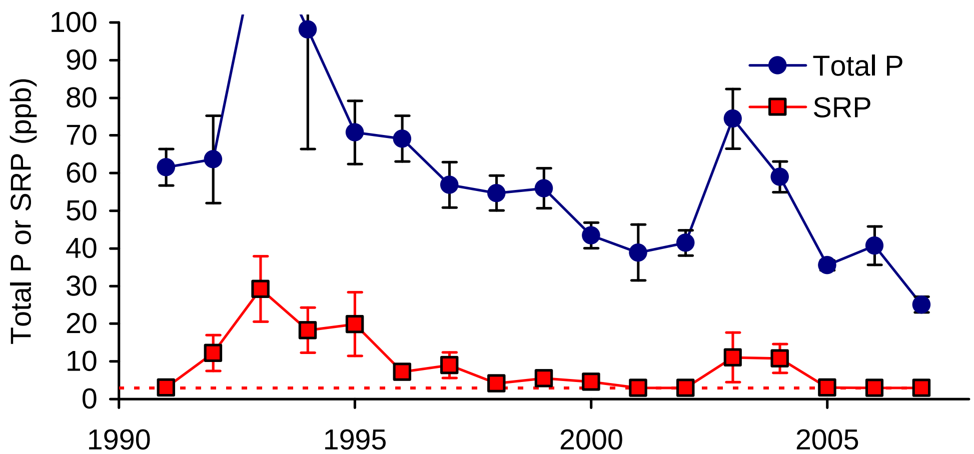
Figure 15 Soluble Reactive P vs. Total P Concentrations

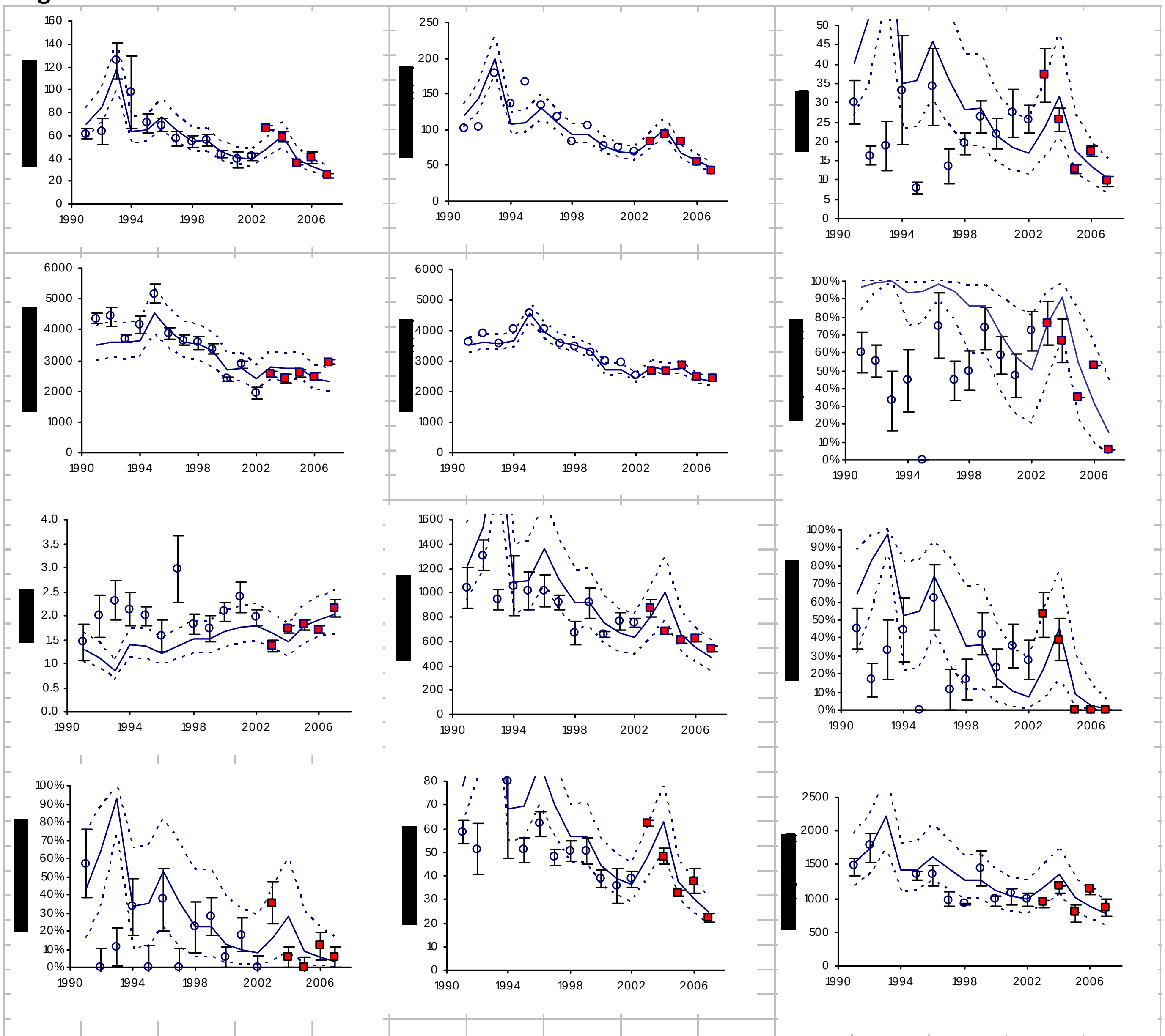




June-September Means, 0-3 meters, Lake South Station

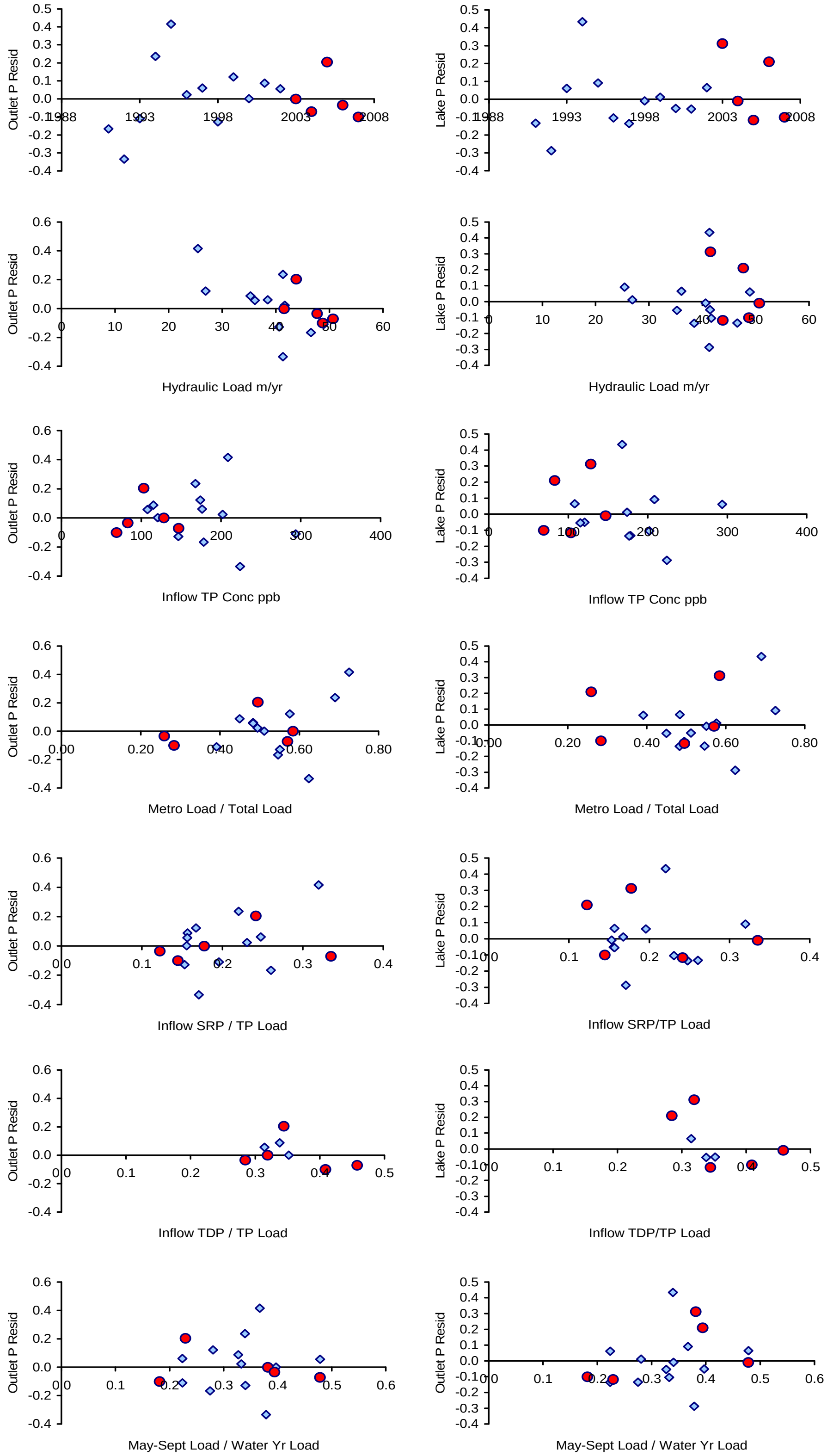
Error bars show mean +/- 1 standard error

Figure 16 Observed and Predicted Time Series



Square Symbols = Calibration Period; Observed Means +/- 1 Std Error Lines = 80% Prediction Intervals

Figure 17 Phosphorus Residuals vs. Various Factors



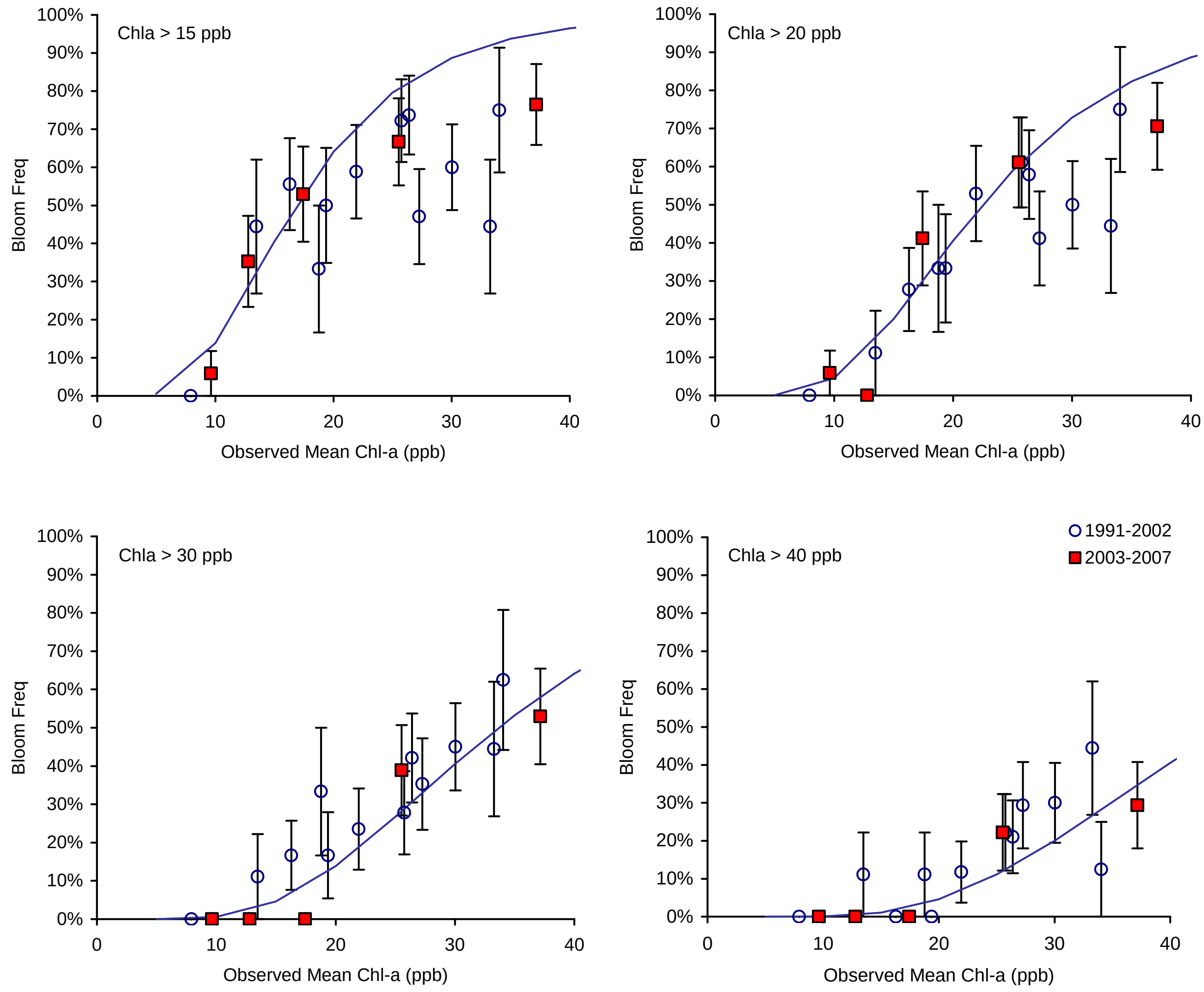
Residual = Observed - Predicted Concentration

Red circles = calibration period (2003 - 2007)

Red symbols = calibration period (2003-2007)

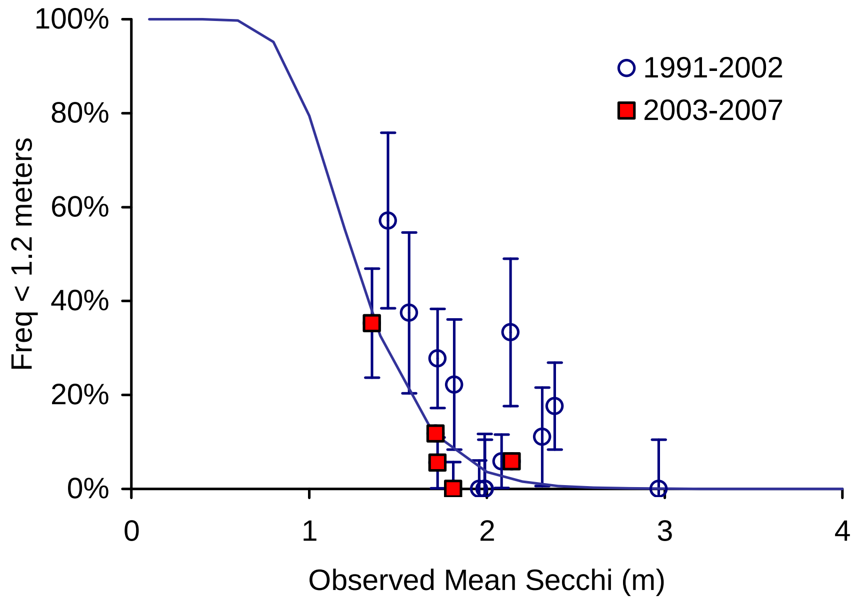
Residual = LN (observed/predicted concentration)

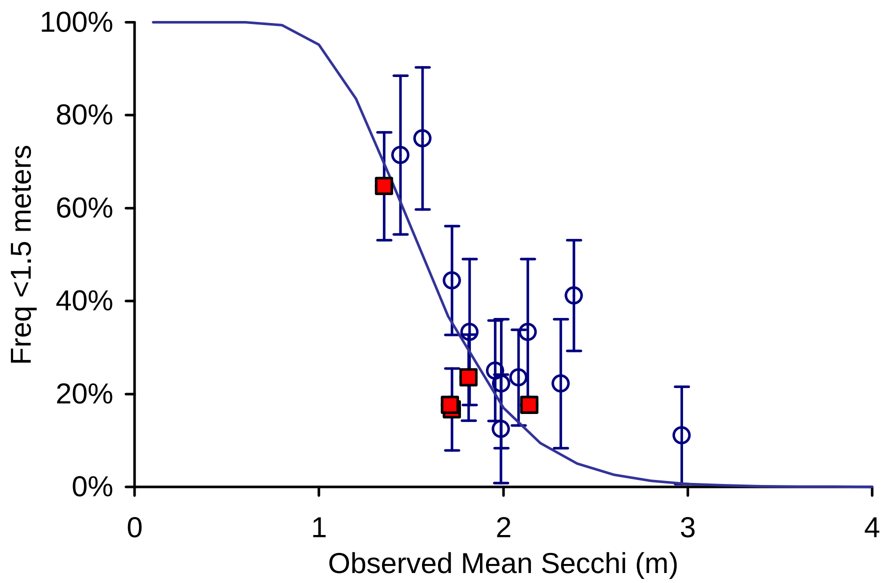
Figure 18 Algal Bloom Frequencies vs. Observed Mean Chlorophyll-a



Under-prediction of bloom frequencies in 1991-2002 is associated with decreases in chlorophyll-a variance, alweife populations, and late summer clearing events after 2003.

Figure 19 Secchi Interval Frequencies vs. Mean Secchi Depth





Under-prediction of exursion frequencies in 1991-2002 is associated with decreases in secchi depth variance, alweife populations, and late summer clearing events after 2003.

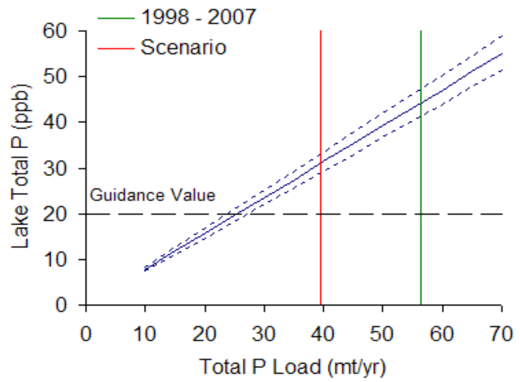
Model: Log-Normal Frequency Distribution, CV = 0.27

Months: 6 thru 9

Figure 20   Predicted Lake Responses to Reductions in Phosphorus Load

Onondaga Lake Empirical Eutrophication Model
Scenario: Metro =120

Responses to Phosphorus Load & Concentration
Historical Baseline: 1998 - 2007



		Scenario	Baseline
Outflow Volume	cfs	538	538
Total P Load	kg/yr	39.5	56.4
Lake TP	ppb	31	46

Dashed lines show 80% prediction intervals for long-term mean
Vertical Lines = Scenario & Historical Averages