Update of Statistical Framework for the Onondaga Lake Ambient Monitoring Program
Phase I – Water Quality Monitoring

Prepared for

Department of Water Environment Protection
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By

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Introduction

The Onondaga Lake Ambient Monitoring Program (AMP, Onondaga County, 1998) is designed to support future decisions on wastewater and watershed management. These decisions will be based in part upon changes detected in Onondaga Lake, its tributaries, and the Seneca River over the next several years, as a variety of control programs are implemented. Decisions may also rely upon comparisons of monitored conditions with water quality standards or management goals. The ability to detect such changes and the reliability of such comparisons depend in part upon the design of the monitoring program. Decisions should not be made based upon the monitoring results without an adequate understanding of the sources and magnitudes of variability in the data.

Previous reports (Walker, 1998, 1999, 2000) describe the development and implementation of a statistical framework with the following intended functions:

- Identifying and quantifying sources of variability in the data;
- Evaluating uncertainty associated with summary statistics;
- Formulating and testing specific hypotheses; and
- Refining monitoring program designs;

The framework has been implemented in two phases. Phase I focuses on water quality monitoring (Walker, 1999). Phase II focuses on biological monitoring (Walker, 2000). This report updates the Phase I analysis to reflect data collected through 2000 and the current AMP design. Future updates and refinements over the course of the AMP will help to ensure that data-collection efforts are cost-effective and that the resulting database is adequate to support future management decisions.

Phase I is specifically concerned with the following water-quality components that are important from a management perspective:

- Total Phosphorus
- Total Nitrogen
- Total Kjeldahl Nitrogen
- Ammonia Nitrogen
- Chlorophyll-a
- Transparency
- Fecal Coliform Bacteria

Although they are biological measurements, chlorophyll-a, and fecal coliforms are considered under Phase I because they are typically measured simultaneously with the water quality components listed above.

Analyses, conclusions, and recommendations of the previous Phase I report (Walker, 1999) are updated with respect to topics listed below:

- Variance Components
- Precision & Power for Trend Detection
- Tributary Loadings & Lake Mass Balances
- Chlorophyll-a & Bacteria Sampling Frequencies
- Sampling Methodology for Chlorophyll-a
- Lake Near-shore & Storm-Event Monitoring
- Lake Vertical Profile Monitoring

Subsequent sections summarize conclusions and recommended refinements to the AMP design for 2002 and following years.

Data Compilation

The analysis is based upon data collected under Onondaga County's monitoring program between January 1993 and December 2000. Although the entire database extends back to 1968, data collected after 1992 most closely reflect the AMP design, sampling procedures, and analytical methods. Although data from January 1993 - July 1998 were not formally collected under the AMP, inclusion of these data provides a longer period of record to support estimation of variance components and evaluation of trends. Table 1 summarizes AMP designs for relevant water quality measurements during 2000.

Onondaga County has supplied monitoring datasets described in yearly lake monitoring reports (e.g., EcoLogic et al., 2001). Biweekly data have been supplemented with daily NPDES permit monitoring data for the Metro discharge and bypass between 1995 and 2000. The tributary data include both biweekly and storm-event sampling. Daily flow-weighted-mean concentrations have been computed for each station and date to support load computations and estimation of variance components.

Given the apparent skewness in the distributions of these measurements, statistical analyses have been conducted on logarithmic scales. For purposes of display and computation of variance components, values below the detection limit have been set equal to detection limit. When a high percentage of observations are below detection, this procedure may cause under-estimation of variance and over-estimation of means. This is a potential issue for bacteria (in general) and ammonia in some tributaries.

Variance Components

Variance component models (Snedecor & Cochran, 1989) explicitly represent the sources and magnitudes of variability in monitoring data. They provide a basis for estimating the uncertainty associated with yearly and long-term summary statistics and for estimating the power of trend tests or other hypothesis tests (Walker, 1998). Given data collected at a given location over a number of years, total measurement variance can be partitioned into the following components:

- **Year** (attributed to variations in climate, hydrology or other factors operating at a yearly time step)
- **Date** (variations within a given year attributed to season, weather, etc.)
- **Depth** (random variations with depth at a given location)
- **Replicate** (attributed to sampling & analytical variations)

Calibration of the model involves application of a nested analysis of variance (Snedecor & Cochran, 1989) to data from several years of monitoring. Walker (1998; 1999) describes relevant equations and data-reduction procedures.

The model describes variations at a given location. It does not include a spatial component because the objective of the monitoring program is not to characterize spatially-averaged conditions in the lake or tributary. Historical and AMP sampling strategies utilize data from the Lake South station to track long-term trends in the pelagic zone (deep, stratified region). A separate network of near-shore stations provides a basis for evaluating spatial variations in parameters that are most relevant to recreational uses along the shoreline (transparency and bacteria). The latter network is evaluated separately below.

The feasibility of resolving each variance component depends upon the design of the monitoring program used for calibration. Yearly, date, and replicate variance components can be estimated for tributary data and for lake transparency, total nitrogen, and bacteria data. Yearly, date, depth, and replicate components can be estimated for lake phosphorus, TKN, and ammonia data. Estimation of the depth component requires multiple grab samples within each mixed layer (epilimnion, hypolimnion). The depth component for total nitrogen cannot be resolved because nitrate and nitrite nitrogen are measured in epilimnetic and hypolimnetic composites instead of discrete grabs. This is not a significant limitation because TKN typically accounts for ~90% of the total nitrogen in the lake samples and the depth variance component for TKN is not significantly different from zero. Replicate variance components can be estimated from duplicate samples routinely collected under normal QA/QC protocols.

In using variance components to estimate the precision of yearly or long-term summary statistics or to estimate power for trend detection (Walker, 1998), variations at each level are assumed to be random. It is necessary to remove non-random (deterministic) variations from the historical data prior to estimating variance components. Fixed seasonal effects (i.e. seasonal patterns consistent from year to year) have been removed by subtracting monthly medians (computed from all years) from each sample. Long-term trends have been removed by regressing yearly medians against year.

Consistent with assumptions made in the initial Phase 1 analysis (Walker, 1999), effects of serial correlation across sampling dates are ignored in estimating variance components. This results in conservative estimates of precision and power for detecting trends. Serial correlation coefficients computed for filtered (de-trended and de-seasoned) time series are small for most variables and stations. Serial correlation across yearly geometric means would work in the opposite direction (i.e., tend to cause over-estimation of power for detecting trends) but would require longer data sets (~ 20 years) to evaluate. This factor is considered, however, in the Seasonal Kendall Test (Hirsch & Slack, 1984) used in tracking trends under the AMP (EcoLogic et al, 2001).

Vertical gradients within the sampled layer represent another type of non-random variation. To partially control for this, the analysis is conducted separately for the epilimnion (0-6 meters) and hypolimnion (10-18 meters). The 9-meter sampled depth is not included because it is sometimes located within or below the thermocline. It is possible that vertical gradients are present on some sampling dates within each of these depth intervals (particularly, in the hypolimnion). Ignoring these gradients causes over-estimation of the depth variance component and generates conservative estimates of precision (i.e., over-estimates relative standard errors). Because precision and power for trend detection are controlled primarily by the year and date variance components, assumptions regarding vertical structure have a relatively small impact on the results.

Variance component analyses have been performed for two depth intervals in the lake (Epilimnion & Hypolimnion) and for each of the primary tributary monitoring stations using data from 1993-2000. Lake data have been restricted to May through September (growing season). This restriction is justified based upon incomplete sampling during other months and upon the assumption that conditions during this season are most likely to drive future management decisions with respect to nutrients and trophic state. Variance components are listed for each station and variable in Table 2.

The accuracy of the variance component estimates is limited when a high percentage of measurements is at or below the detection limit (Table 2). This occurs in the case of ammonia nitrogen at some tributary stations (Dorwin, Kirkpatrick, Velasko, Hiawatha, Crucible). Following previous recommendations (Walker, 1999), the detection limit for ammonia N was decreased from 0.1 to 0.05 ppb in 1999. This will improve precision and power for tracking ammonia levels in the tributaries. It will also provide improved estimates of variance components in future updates of the statistical framework. As discussed below (see Lake Vertical Profile Monitoring), it is likely that further decreases in the detection limit will be needed to track future trends in lake ammonia concentrations.

Precision & Power for Detecting Trends in Concentration

Calibrated variance components are used to evaluate the following indicators of precision and power that can be viewed as performance measures (PM's) for the monitoring program (Walker, 1998;1999):

1. Relative Standard Error (RSE) of Yearly Geometric Mean
2. RSE of Long-Term Geometric Mean Computed from 5 Years of Data
3. Probability of Detecting a 25% Step Change over a 10 Year Period
4. Probability of Detecting a 5%/Year Linear Trend Over a 10-year Period
5. Step Change Detectable with 80% Confidence over a 10-year Period
6. Trend Detectable with 80% Confidence over a 10-year Period

For PM's 3-6, "detecting" means rejecting the null hypothesis in one-tailed t-test or regression slope test at a significance level of 0.05. PM 1 depends upon the date and random variance components and can be controlled by modifying sampling frequencies (number of sampling dates per year and/or number of samples per date/depth interval). The remaining PM's depend upon the precision of the yearly geometric means (PM 1) and year-to-year variance components. The latter are inherent characteristics of the lake/watershed and are independent of the monitoring program design. For this reason, results for PM 1 (RSE of the yearly geometric mean) are emphasized.

The AMP (Onondaga County, 1998, p. 39) discusses a target value of 20% for the relative error of population means measured under the AMP. It also indicates that it may not be feasible to attain this goal for each parameter monitored, depending upon inherent variability. A 20% RSE for the yearly geometric mean is used below as an approximate criterion for evaluating the adequacy of the AMP design.

Table 3 lists precision and power estimates for the current AMP design computed from variance components listed in Table 2. Sensitivities to sampling intensity (e.g., sampling dates per year, number replicates) are listed in Table 4. Precision, power for detecting step changes, and power for detecting trends are displayed in Figures 1, 2, and 3, respectively. Consistent with results derived from 1993-1997 data (Walker, 1999), the expected RSE's of yearly geometric means are well below the 20% criterion for transparency and nutrient concentrations (total phosphorus, total nitrogen, total Kjeldahl nitrogen, ammonia nitrogen) and between 20 and 30% for biological measurements (chlorophyll-a and fecal coliforms). The latter values are consistent with estimates for other biological parameters (Walker, 2000).

As discussed above, the methodology assumes that variations are random within each stratum. The procedure used to remove trends and fixed seasonal effects does not remove all of the deterministic variations in lake ammonia and TKN levels. This results from strong seasonality and nonlinear trends induced by recent increased nitrification rates at Metro. These factors are reflected in the relatively high serial correlation coefficients for these parameters in the lake epilimnion (0.64 and 0.51, respectively, Table 2). It is likely that estimates of precision and power are conservative (i.e., actual RSE's and detectable trends are lower than those listed in Tables 3 & 4).

Precision of Tributary Loadings & Lake Mass Balances

The existing lake mass-balance software (Walker, 1999; Ecologic et al, 2001) has been applied to estimate precision in tracking tributary loadings and lake mass balances under historical and current AMP designs. Figure 4 shows trends in the flow-weighted-mean concentrations of total phosphorus in the lake inflows (non-point, municipal (Metro Effluent + Bypass), total) and lake outflow (12-foot station) over the 1986-2000 period. Precision is indicated by error bars associated with each yearly value and by a separate plot of relative standard error. Dashed lines show long-term trends estimated by linear regression. RSE values are 2-8% for total inflow concentration (and load) and 6-14% for outflow concentration. This level of precision is consistent with the AMP goal (RSE <20%) and appears to be adequate to support tracking long-term trends. Similar conclusions are reached for nitrogen species (Figures 5-7).

Chlorophyll-a & Bacteria Sampling Frequencies

The current AMP design involves weekly sampling for chlorophyll-a and bacteria at the Lake South station between May and September. Based upon variance components computed from 1993-1997 data, an increase in sampling frequency from biweekly to weekly was previously recommended (Walker, 1999). Updated variance component estimates support this recommendation. With weekly sampling, the estimated RSE for chlorophyll-a is 24%, as compared with 34% biweekly sampling. Corresponding values for fecal coliforms are 27% and 38%, respectively. Continued sampling at a weekly frequency is recommended for these parameters.

The 1993-1997 database did not allow estimation of replicate variance components for chlorophyll-a and fecal coliforms (Walker, 1999). To fill these data gaps, duplicate chlorophyll-a samples (epilimnetic composites) were collected monthly between May and September at the Lake South station in 2000. Duplicate fecal coliform samples were collected monthly at the Lake South station in 1999. Eight pairs of duplicate fecal coliform samples also were collected at the mouth of Onondaga Creek during storm events in 2000. Paired samples are plotted in Figure 8.

Relative standard deviations among replicates were 13% for chlorophyll-a and 46% for fecal coliforms. Sampling variance accounts for 1% and 13%, respectively, of the total error variance in the annual geometric means for these parameters. Accordingly, routine collection of replicates would not provide significant improvements in precision.

Continued collection of replicate samples for these parameters is recommended for consistency with normal QA/QC methods applied to other water quality parameters. Because of the relatively high percentage of fecal coliform counts at or below the detection limit at the Lake South station (5 cfu/ 100 ml), it would be preferable to collect duplicates at a near-shore lake station during storm events, as well as a tributary station, to characterize sampling error over a range of bacteria densities.

Under the 2000 tributary and storm event monitoring program, approximately 10% of the fecal coliform results were reported as minimum values (e.g. >6000 cfu/100 ml). Minimum values ranged from 200 to 60,000 cfu/100 ml. Performing bacteria counts on a wider range of dilutions in samples suspected of having high values (based upon location and/or turbidity, for example) would reduce the frequency of these results and increase power for detecting trends.

Chlorophyll-a Sampling Methods

Walker (1999) recommended coincident vertically-integrated sampling over the both epilimnion (surface to thermocline) and photic zone (2 x Secchi Depth). The former is consistent with the sample collection method for phytoplankton. The latter would be more sensitive to surface algal blooms and more directly correlated with transparency. Chlorophyll-a results using both sampling methods are plotted in Figure 9. Epilimnetic and photic-zone composites are similar on most days, particularly when the two depth intervals coincide. A paired t-test indicates that the photic zone values average 9% ± 3% higher ($p < .01$). On a few occasions, photic zone values exceeded the epilimnetic values by a factor of 2 or more.

Based upon these results, it would not be appropriate to assume that epilimnetic composites are always representative of surface values. Photic zone values are typically used for evaluation of trophic state. It would be acceptable to drop the epilimnetic composites if the phytoplankton sampling could be conducted in the photic zone or if correlating chlorophyll-a with phytoplankton counts is not considered an important objective for the biological assessment.

The depths of epilimnetic and photic-zone composites are routinely reported in log books, but not in the long-term database. While these depth intervals can be inferred from temperature profiles and transparency data, it would be preferable to specifically record composite sample depth intervals in the database. The same recommendation applies to epilimnetic and hypolimnetic composites for other water quality components.

Lake Near-Shore & Storm-Event Monitoring

The long-term monitoring record at the Lake South station provides a basis for tracking water-quality trends in the pelagic zone (deep, stratified region of the Lake). The AMP also includes a network of near-shore monitoring stations to track transparency and bacteria levels in the vicinity of recreational areas under dry- and wet-weather conditions. A variety of spatial and temporal patterns are evident in the 1999-2000 data collected under this program (Figure 10). Mean transparency and geometric mean bacteria counts (fecal coliforms, enterococci, and E-coli) are shown for each station in dry and wet weather. (E-coli counts have been dropped from the AMP based upon recent USEPA guidance). Dry-weather results reflect 34 sampling events from the weekly periodic sampling program. Wet-weather results reflect 22 sampling events and 13 storm events. Error bars indicate means (or geometric means) ± 1 standard error. The 8 near-shore stations are arranged in a north-to-south direction and compared with results from the south pelagic station.

Stations at the south end of the lake have significantly lower transparency and higher bacteria counts, compared with the north and pelagic stations. Fecal coliform and enterococci levels at the north end of the Lake tend to be higher in storm event samples, as compared with weekly periodic samples. The monitoring program is sufficiently intensive to detect these significant spatial and temporal patterns, which are generally consistent with expected responses to nutrient, suspended solids, and bacteria loadings from tributaries at the south end of the Lake.

During wet weather, bacteria counts at southern stations (Ley Creek, Harbor Brook, & Metro) were about an order of magnitude higher than those measured at northern stations (Ninemile, Lake Park, Willow Bay, Maple Bay). The latter were generally at or below the detection limit. The southern stations were not monitored in dry weather (periodic weekly surveys). The Bloody Brook site (midway between Ley Creek and Onondaga Lake Park) was sampled during only 3 storm events; this station may be important for evaluating transport along the northeastern shoreline. Consistent sampling of the Bloody Brook stations and three southern stations would provide a basis for detecting wet/dry weather differences and an improved basis for detecting trends in the region of the lake that is most likely to improve in response to future management measures.

Because significant dilution and die-off occur as bacteria are transported into the pelagic zone, the Lake South station serves as a control. Significant differences in transparency or bacteria counts between wet and dry weather are not apparent at this location. Only 10 storm-event samples were collected at the Lake South station, as compared with 19-21 at the near-shore stations. Routine inclusion of the Lake South station in the storm-event monitoring network would provide a consistent control for characterizing spatial variations and for modeling dynamic responses to storm events.

Transparency appears to be less responsive to storm events, as compared with bacteria. OCWEP staff indicate that some of the near-shore transparency values represent minimum values because the Secchi disk reached the bottom. Documentation of such occurrences in the data files (in addition to log books) is recommended to provide an improved basis for data interpretation and analysis.

Compared with transparency, turbidity measurements would provide an improved basis for tracking the loadings and transport of particulate contaminants in the Lake following storm events. Turbidity is often used as a surrogate for suspended solids and potential bacterial contamination in water supplies (USEPA, 1991). Given the effort involved in sample collection under this program and relative simplicity of turbidity measurements, it is likely that they could be added to the program without a large marginal cost. Accordingly, it is recommended that wet and dry-weather turbidity measurements be added to the tributary and lake monitoring programs under both the periodic and wet-weather sampling schedules. Turbidity baselines would also be useful in the event that continuous monitoring is determined to be an effective means of tracking transport dynamics.

A more detailed analysis of the near-shore monitoring data on a storm-event basis may reveal data limitations and suggest further refinements to the monitoring program. Correlations between bacteria levels and antecedent rainfall may provide a basis for factoring out some of the variability in the data and thereby increasing power for detecting long-term changes. Deterministic modeling efforts (Canale et al., 1993) would be useful for integrating the data, testing hypotheses regarding lake dynamics, and projecting responses to management measures.

Lake Vertical Profile Monitoring

The historical sampling plan for the Lake South station has involved collecting 7 discrete samples at 3-meter intervals and a biweekly frequency for most parameters. This design extends back to 1968 for several parameters (Walker, 1991). A variety of procedures have been used to compute summer-average concentrations in the upper mixed layer (Ecologic et al., 2001). Recent data for two key parameters are examined below to evaluate potential sensitivity of average values to the range of depths included.

Recent trends in ammonia nitrogen at each depth are plotted in Figure 11. It is apparent that the discrete sampling plan provides a basis for characterizing vertical variations on each date, as well as seasonal and long-term trends at each depth. Based upon paired t-tests applied to June-September data, there is no significant difference in the average concentrations at 0 and 3 meters. Vertical gradients are apparent at depths below 3 meters on most sampling dates.

The ammonia detection limit was decreased from 0.1 to 0.05 ppm in 1999 (Figure 11). This reduction was recommended to support tracking of tributary concentrations and loads (Walker, 1999). Significant decreasing trends in ammonia concentration are indicated at all lake depths and are consistent with decreasing trends in ammonia loads (Figure 7). Concentrations in the upper mixed layer approached the 0.05 ppm detection limit in 1999-2000. It is apparent that a further decrease in the detection limit would be required to track lake responses to future reductions in ammonia load. Detection limits in the 0.01-0.02 range seem to be adequate for the next few years. Further adjustments may be necessary, depending upon future lake responses and upon whether resolution at lower levels is necessary in order to evaluate compliance with water quality standards.

Recent trends in total phosphorus are plotted in Figure 12. The upper panels show results at each depth over the entire year. The bottom panel shows results for 0, 1, 3, and 6 meter samples between June and September. The latter reflects data potentially considered in computing a summer-average concentration in the upper mixed layer for comparison with the NYSDEC phosphorus criterion (20 ppb).

Paired t-tests indicate there are no significant differences among average total phosphorus concentrations measured at the 0, 3, and 6 meter depths. Samples within this depth range can be included in the mixed-layer average without biasing results. Supplementary total phosphorus samples collected at 1 meter for consistency with the NYSDEC phosphorus criterion can be considered replicates of the 0-, 3-, and 6-meter samples. Phosphorus concentrations at or below 9 meters frequently exceed the 0-6 meter values and should not be included in the upper-mixed-layer averages. Since regular seasonal patterns are evident within the 0-6 meter range, the computation of summer averages would be more sensitive to the range of months considered than to the range of depths. Discrete samples within the mixed layer provide a degree of replication (and higher precision) that seems desirable for important parameters. Given the additional objective of maintaining a consistent design for tracking long-term trends, there is no reason for changing the lake profile sampling strategy.

Conclusions

1. Variance components estimated from 1993-2000 data are similar to those estimated previously based upon 1993-1997 data (Walker, 1999).

2. The existing AMP design meets the precision goal (Relative Standard Error or RSE < 20%) for tracking concentrations and loads of major water quality components.

3. Precision for chlorophyll-a (24%) and fecal coliforms (27%) is substantially improved with weekly sampling and is consistent with precision for other biological indicators.

4. Yearly nutrient loading estimated developed from AMP data have RSE values that are generally < 10% for total phosphorus and <5% for nitrogen species.

5. Epilimnetic chlorophyll-a composites may fail to detect surface blooms on some dates. Photic zone composites are more representative of surface conditions and more directly related to variations in transparency.

6. The lake near-shore monitoring program provides a basis for identifying significant spatial (north vs. south, littoral vs. pelagic) and temporal (dry-weather vs. wet-weather) variations in transparency and bacteria. Recommended refinements to the program are summarized below, based upon analysis of 1999-2000 data.

7. The historical sampling plan for the lake south station (biweekly at 7 discrete depths) provides good resolution of vertical gradients, seasonal variations, and long-term trends The water column can be considered well-mixed over the 0-3 meter range with respect to ammonia concentrations and over the 0-6 meter range with respect to total phosphorus. Samples within these depth intervals can be treated as replicates in computing mixed-layer averages for comparison with water quality and trophic state criteria.

Recommendations

Based upon the data analyses described above, the following recommendations are made for the 2002 lake and tributary monitoring plan:

1. Continue bacteria and chlorophyll-a monitoring at a weekly sampling frequency.

2. Drop fecal coliform duplicates at the Lake South station and substitute duplicates at a near-shore station (storm event samples).

3. Improve precision in fecal coliform counts by including a wider range of dilutions in samples suspected of having higher counts (based upon turbidity and location, for example).

4. Continue photic-zone sampling for chlorophyll-a; drop epilimnetic composites if not required for consistency with phytoplankton samples (depending upon needs for biological assessment),

5. Collect duplicate chlorophyll-a samples (photic-zone composites) at a frequency consistent with other water quality parameters.

6. Measure turbidity at lake near-shore stations (weekly & storm-event) and at creek mouths (biweekly & storm event) to provide an additional basis for evaluating contaminant transport along the lake shoreline in response to storm events and future control measures.

7. Monitor the Lake South station (along with near-shore stations) for transparency, bacteria, and turbidity under both weekly and storm-event programs.

8. Add near-shore stations at the south end of the Lake (Ley, Metro, Harbor) to the weekly sampling program for transparency, bacteria, and turbidity.

9. Consistently include the Bloody Brook station in the storm-event and weekly monitoring programs.

10. Conduct more detailed analysis & modeling of data from the lake near-shore storm-event monitoring program to test specific hypotheses regarding responses to storm events and to identify additional data needs.

11. Document in the database transparencies that are under-estimated because the Secchi disk reading is limited by the lake bottom.

12. Routinely record depth intervals for composite samples (epilimnetic, hypolimnetic, photic) in the database.

13. Reduce ammonia detection limit from 0.05 ppm to 0.01 – 0.02 ppm for lake samples.

14. Formulate specific hypotheses to be tested using the water quality data around specific management goals; evaluate power for testing these hypotheses in future updates of the statistical framework.

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Table 1
Year 2000 AMP Design for Relevant Water Quality Parameters

Variable	Frequency	Method	Depths	Tributaries
Lake South Deep Station				
Total Phosphorus Total Kjeldahl Nitrogen Ammonia Nitrogen	biweekly	grab	0,3,6,9,12,15,18 m	biweekly
Nitrite Nitrogen Nitrate Nitrogen	biweekly	composite	0-9, 12-18 m	biweekly
Chlorophyll-a	weekly	composite	0-9 m & Photic Zone	-
Transparency	weekly	-	surface	-
Fecal Coliform Bacteria Enterococci E Coli	weekly	grab	surface	biweekly
Lake Near-Shore Stations				
Fecal Coliform Bacteria	weekly (4 sites)		surface	
Transparency	5 storms (8 sites)			

Notes:

Lake Monitoring at South station (described above) supplemented with quarterly at North station

Duplicate samples collected regularly at Lake South (6 meters depth) and Lake Outlet (2 feet).

Duplicate samples collected monthly for chlorophyll-a (epi-composites) , lake south station, may-sept

Total P also analyzed at 1 meter depth, Lake South, June-September.

Metro effluent and bypass data supplemented with daily NPDES permit monitoring data.

AMP also specifies sampling of 5 high-flow events per year at each tributary site.

METRO & BYPASS samples collected daily under NPDES program (TP, TKN, Ammonia N)

Tributary flows monitored daily except lake outlet stations.

Table 2
Variance Components Estimated from 1993-2000 Data

Station	Variable	Samples	% <= Detec.Limit	Geometric Mean	Years (SY)	Dates (SD)	Depths (SZ)	Replicates (SR)	Total (ST)	Serial Correl Coef
EPIL	CHLA	114	8%	18.58	0.213	1.095		0.126	1.123	0.364
EPIL	SECCHI	109	0%	1.93	0.039	0.526		0.000	0.527	0.512
EPIL	TP	293	0%	0.11	0.006	0.277	0.230	0.100	0.374	0.072
HYPO	TP	264	0%	0.72	0.242	0.361	0.384	0.100	0.589	0.419
OUTLET12	TP	187	0%	0.16	0.069	0.269		0.100	0.295	0.229
OUTLET2	TP	213	0%	0.13	0.106	0.390		0.100	0.416	0.126
METRO	TP	2257	0%	0.53	0.098	0.392		0.100	0.416	0.701
DORWIN	TP	255	0%	0.05	0.210	0.693		0.100	0.731	0.186
KIRKPAT	TP	227	0%	0.05	0.217	0.793		0.100	0.828	0.083
VELASKO	TP	210	0%	0.04	0.260	0.746		0.100	0.796	0.064
HIAWATHA	TP	220	0%	0.04	0.343	0.674		0.100	0.763	0.101
PARK	TP	210	0%	0.10	0.101	0.494		0.100	0.514	0.329
RT48	TP	234	0%	0.05	0.089	0.538		0.100	0.554	0.122
CRUCIBLE	TP	206	0%	0.03	0.334	0.557		0.100	0.657	0.263
EFLUME	TP	231	0%	0.27	0.017	0.331		0.100	0.346	0.211
EPIL	TN	99	0%	4.53	0.130	0.084		0.057	0.165	0.167
HYPO	TN	88	0%	4.81	0.156	0.107		0.057	0.197	0.508
OUTLET12	TN	187	0%	4.34	0.091	0.127		0.057	0.167	0.225
OUTLET2	TN	213	0%	3.22	0.000	0.369		0.057	0.374	0.032
METRO	TN	220	0%	20.19	0.110	0.222		0.057	0.254	0.358
DORWIN	TN	202	0%	1.17	0.106	0.293		0.057	0.317	0.139
KIRKPAT	TN	210	0%	1.29	0.028	0.209		0.057	0.218	0.125
VELASKO	TN	203	0%	1.81	0.076	0.138		0.057	0.167	0.191
HIAWATHA	TN	207	0%	1.79	0.023	0.221		0.057	0.230	0.133
PARK	TN	195	0%	1.52	0.065	0.392		0.057	0.402	0.270
RT48	TN	206	0%	1.63	0.000	0.230		0.057	0.237	0.012
CRUCIBLE	TN	206	0%	2.51	0.101	0.433		0.057	0.448	-0.015
EFLUME	TN	231	0%	9.58	0.074	0.266		0.057	0.282	0.008
EPIL	TKN	264	0%	4.11	0.195	0.220	0.000	0.126	0.320	0.509
HYPO	TKN	264	0%	5.41	0.190	0.117	0.145	0.126	0.295	0.380
OUTLET12	TKN	187	0%	3.49	0.129	0.254		0.126	0.312	0.473
OUTLET2	TKN	213	0%	2.02	0.000	0.456		0.126	0.473	0.040
METRO	TKN	1499	0%	22.51	0.235	0.439		0.126	0.514	0.827
DORWIN	TKN	223	10%	0.30	0.102	0.542		0.126	0.566	0.001
KIRKPAT	TKN	227	3%	0.39	0.000	0.534		0.126	0.549	0.069
VELASKO	TKN*	207	12%	0.26	0.033	0.609		0.126	0.623	-0.022
HIAWATHA	TKN	221	4%	0.27	0.122	0.661		0.126	0.684	0.071
PARK	TKN	210	0%	0.99	0.036	0.449		0.126	0.468	0.298
RT48	TKN	206	0%	0.76	0.020	0.311		0.126	0.336	0.121
CRUCIBLE	TKN	206	0%	0.45	0.135	0.362		0.126	0.406	0.121
EFLUME	TKN	231	0%	4.31	0.074	0.359		0.126	0.388	0.197
EPIL	NH3N	264	4%	3.17	0.150	0.502	0.202	0.160	0.584	0.674
HYPO	NH3N	264	0%	5.07	0.223	0.179	0.165	0.160	0.367	0.414
OUTLET12	NH3N	187	2%	2.56	0.231	0.469		0.160	0.547	0.481
OUTLET2	NH3N	213	3%	1.48	0.000	0.671		0.160	0.690	0.041
METRO	NH3N	2252	0%	22.36	0.260	0.388		0.160	0.494	0.906
DORWIN	NH3N*	202	82%	0.11	0.041	0.186		0.160	0.249	0.068
KIRKPAT	NH3N*	210	60%	0.11	0.072	0.306		0.160	0.353	0.122
VELASKO	NH3N*	203	81%	0.12	0.114	0.235		0.160	0.306	0.145
HIAWATHA	NH3N*	207	46%	0.12	0.108	0.437		0.160	0.478	-0.011
PARK	NH3N	195	4%	0.38	0.000	0.542		0.160	0.565	0.295
RT48	NH3N	206	5%	0.38	0.102	0.472		0.160	0.508	-0.008
CRUCIBLE	NH3N*	206	38%	0.13	0.088	0.332		0.160	0.379	0.172
EFLUME	NH3N	231	0%	3.26	0.126	0.637		0.160	0.669	0.240
EPIL	FCOLI*	111	48%	13.60	0.284	1.205		0.462	1.321	-0.015
HYPO	FCOLI*									
OUTLET12	FCOLI*	118	19%	22.12	0.000	0.946		0.462	1.053	-0.020
OUTLET2	FCOLI*	191	27%	19.14	0.000	1.052		0.462	1.149	0.073
METRO	FCOLI*	751	14%	47.32	0.314	1.307		0.462	1.421	0.233
DORWIN	FCOLI*	224	16%	106.42	0.101	1.383		0.462	1.462	0.185
KIRKPAT	FCOLI	224	0%	1657.89	0.000	1.284		0.462	1.365	0.299
VELASKO	FCOLI	209	5%	169.27	0.550	1.230		0.462	1.424	0.071
HIAWATHA	FCOLI	222	0%	446.08	0.455	1.525		0.462	1.657	0.235
PARK	FCOLI	205	0%	911.14	0.000	1.281		0.462	1.362	0.158
RT48	FCOLI	204	5%	83.81	0.000	1.233		0.462	1.317	-0.043
CRUCIBLE	FCOLI*	207	37%	21.40	0.236	1.217		0.462	1.323	0.048
EFLUME	FCOLI	204	1%	9217.88	0.404	1.404		0.462	1.532	0.160

* Accuracy of Estimates Limited; More than 10% of Samples <= Detection Limit

Table 3
Precision & Power Estimates

		Current AMP Design			Precision			Power for Detecting Step Change				Power for Detection Trend			
Station	Variable	Dates Per Year	Depths/Date	Reps per Depth	RSE of Yearly Geo Mean	RSE of Long-Term Mean	Expected Yr-to-Yr CV	Prob (Detec. 25% Change)	Prob (Detec/ 50% Change)	Change Detec. with 50% Conf	Change Detec. with 80% Conf	Prob (Detec. 5%/yr Trend)	Prob (Detect. 10%/yr Trend)	Trend Detect. with 50% Conf	Trend Detect. with 80% Conf
EPIL	CHLA	22	1	1	24%	14%	32%	28%	73%	37%	55%	34%	83%	6%	10%
EPIL	SECCHI	22	1	1	11%	5%	12%	91%	100%	14%	21%	96%	100%	2%	4%
EPIL	TP	11	3	1	9%	4%	9%	98%	100%	11%	17%	99%	100%	2%	3%
HYPO	TP	11	3	1	13%	12%	27%	34%	83%	32%	48%	42%	91%	6%	8%
OUTLET12	TP	26	1	1	6%	4%	9%	98%	100%	10%	15%	99%	100%	2%	3%
OUTLET2	TP	26	1	1	8%	6%	13%	85%	100%	16%	23%	92%	100%	3%	4%
METRO	TP	365	1	1	2%	4%	10%	97%	100%	12%	18%	99%	100%	2%	3%
DORWIN	TP	30	1	1	13%	11%	25%	40%	89%	29%	43%	50%	95%	5%	7%
KIRKPAT	TP	30	1	1	15%	12%	26%	37%	86%	31%	45%	45%	93%	5%	8%
VELASKO	TP	30	1	1	14%	13%	29%	31%	78%	35%	51%	38%	87%	6%	9%
HIAWATHA	TP	30	1	1	12%	16%	36%	23%	62%	43%	63%	28%	73%	7%	11%
PARK	TP	30	1	1	9%	6%	14%	84%	100%	16%	24%	91%	100%	3%	4%
RT48	TP	30	1	1	10%	6%	13%	85%	100%	16%	23%	92%	100%	3%	4%
CRUCIBLE	TP	26	1	1	11%	16%	35%	24%	65%	41%	61%	29%	75%	7%	11%
EFLUME	TP	26	1	1	7%	3%	7%	100%	100%	8%	12%	100%	100%	1%	2%
EPIL	TN	11	1	1	3%	6%	13%	85%	100%	16%	23%	92%	100%	3%	4%
HYPO	TN	11	1	1	4%	7%	16%	72%	99%	19%	28%	82%	100%	3%	5%
OUTLET12	TN	26	1	1	3%	4%	10%	97%	100%	11%	17%	99%	100%	2%	3%
OUTLET2	TN	26	1	1	7%	3%	7%	100%	100%	8%	13%	100%	100%	2%	2%
METRO	TN	365	1	1	1%	5%	11%	94%	100%	13%	19%	97%	100%	2%	3%
DORWIN	TN	30	1	1	5%	5%	12%	91%	100%	14%	21%	96%	100%	2%	4%
KIRKPAT	TN	30	1	1	4%	2%	5%	100%	100%	6%	8%	100%	100%	1%	1%
VELASKO	TN	30	1	1	3%	4%	8%	99%	100%	10%	14%	100%	100%	2%	2%
HIAWATHA	TN	30	1	1	4%	2%	5%	100%	100%	6%	8%	100%	100%	1%	1%
PARK	TN	30	1	1	7%	4%	10%	97%	100%	11%	17%	99%	100%	2%	3%
RT48	TN	30	1	1	4%	2%	4%	100%	100%	5%	8%	100%	100%	1%	1%
CRUCIBLE	TN	26	1	1	9%	6%	13%	85%	100%	16%	23%	92%	100%	3%	4%
EFLUME	TN	26	1	1	5%	4%	9%	98%	100%	11%	16%	99%	100%	2%	3%
EPIL	TKN	11	3	1	7%	9%	21%	52%	96%	24%	36%	63%	98%	4%	6%
HYPO	TKN	11	3	1	5%	9%	20%	56%	97%	23%	34%	67%	99%	4%	6%
OUTLET12	TKN	26	1	1	6%	6%	14%	82%	100%	16%	24%	90%	100%	3%	4%
OUTLET2	TKN	26	1	1	9%	4%	9%	98%	100%	11%	17%	99%	100%	2%	3%
METRO	TKN	365	1	1	2%	11%	24%	43%	91%	28%	41%	52%	96%	5%	7%
DORWIN	TKN	30	1	1	10%	6%	14%	80%	100%	17%	25%	89%	100%	3%	4%
KIRKPAT	TKN	30	1	1	10%	4%	10%	96%	100%	12%	18%	99%	100%	2%	3%
VELASKO	TKN*	30	1	1	11%	5%	12%	91%	100%	14%	21%	96%	100%	2%	4%
HIAWATHA	TKN	30	1	1	12%	8%	17%	66%	99%	20%	30%	77%	100%	4%	5%
PARK	TKN	30	1	1	9%	4%	9%	98%	100%	11%	16%	99%	100%	2%	3%
RT48	TKN	30	1	1	6%	3%	6%	100%	100%	8%	11%	100%	100%	1%	2%
CRUCIBLE	TKN	26	1	1	8%	7%	15%	75%	99%	18%	27%	84%	100%	3%	5%
EFLUME	TKN	26	1	1	7%	5%	11%	95%	100%	12%	18%	98%	100%	2%	3%
EPIL	NH3N	11	3	1	16%	10%	22%	48%	94%	26%	38%	59%	98%	4%	7%
HYPO	NH3N	11	3	1	7%	10%	23%	44%	92%	27%	40%	54%	96%	5%	7%
OUTLET12	NH3N	26	1	1	10%	11%	25%	39%	88%	29%	44%	48%	94%	5%	8%
OUTLET2	NH3N	26	1	1	14%	6%	14%	84%	100%	16%	24%	91%	100%	3%	4%
METRO	NH3N	365	1	1	2%	12%	26%	37%	86%	31%	45%	45%	93%	5%	8%
DORWIN	NH3N*	30	1	1	4%	3%	6%	100%	100%	7%	11%	100%	100%	1%	2%
KIRKPAT	NH3N*	30	1	1	6%	4%	10%	97%	100%	11%	17%	99%	100%	2%	3%
VELASKO	NH3N*	30	1	1	5%	6%	13%	88%	100%	15%	22%	94%	100%	3%	4%
HIAWATHA	NH3N*	30	1	1	8%	6%	14%	83%	100%	16%	24%	91%	100%	3%	4%
PARK	NH3N	30	1	1	10%	5%	10%	96%	100%	12%	18%	98%	100%	2%	3%
RT48	NH3N	30	1	1	9%	6%	14%	83%	100%	16%	24%	91%	100%	3%	4%
CRUCIBLE	NH3N*	26	1	1	7%	5%	11%	93%	100%	13%	20%	97%	100%	2%	3%
EFLUME	NH3N	26	1	1	13%	8%	18%	63%	98%	21%	31%	74%	99%	4%	5%
EPIL	FCOLI*	22	1	1	28%	18%	40%	21%	55%	46%	69%	25%	66%	8%	12%
HYPO	FCOLI*														
OUTLET12	FCOLI*	26	1	1	21%	9%	21%	52%	96%	24%	36%	63%	98%	4%	6%
OUTLET2	FCOLI*	26	1	1	23%	10%	23%	46%	93%	26%	39%	56%	97%	5%	7%
METRO	FCOLI*	26	1	1	27%	19%	42%	20%	52%	49%	72%	23%	62%	8%	13%
DORWIN	FCOLI*	30	1	1	27%	13%	28%	32%	81%	34%	50%	40%	89%	6%	9%
KIRKPAT	FCOLI	30	1	1	25%	11%	25%	40%	89%	29%	43%	49%	94%	5%	8%
VELASKO	FCOLI	30	1	1	24%	27%	60%	13%	30%	71%	105%	15%	37%	12%	18%
HIAWATHA	FCOLI	30	1	1	29%	24%	54%	15%	35%	63%	94%	17%	43%	11%	16%
PARK	FCOLI	30	1	1	25%	11%	25%	40%	89%	29%	43%	49%	94%	5%	8%
RT48	FCOLI	30	1	1	24%	11%	24%	42%	90%	28%	42%	51%	95%	5%	7%
CRUCIBLE	FCOLI*	26	1	1	26%	16%	35%	24%	65%	41%	61%	30%	76%	7%	11%
EFLUME	FCOLI	26	1	1	29%	22%	50%	16%	40%	58%	86%	19%	49%	10%	15%

AMP Objective: Relative Standard Error (RSE) of Yearly Mean <=20%
RSE of Long-Term Geometric Mean Estimated from 5 Years of Data
Power for Detecting Step Change & Trend Evaluted for 10 years of Monitoring with Hypothesis Tests Conducted at 5% & 10% for 1-Tailed & 2-Tailed Tests
* Accuracy of Estimates Limited; More than 10% of Samples <= Detection Limit

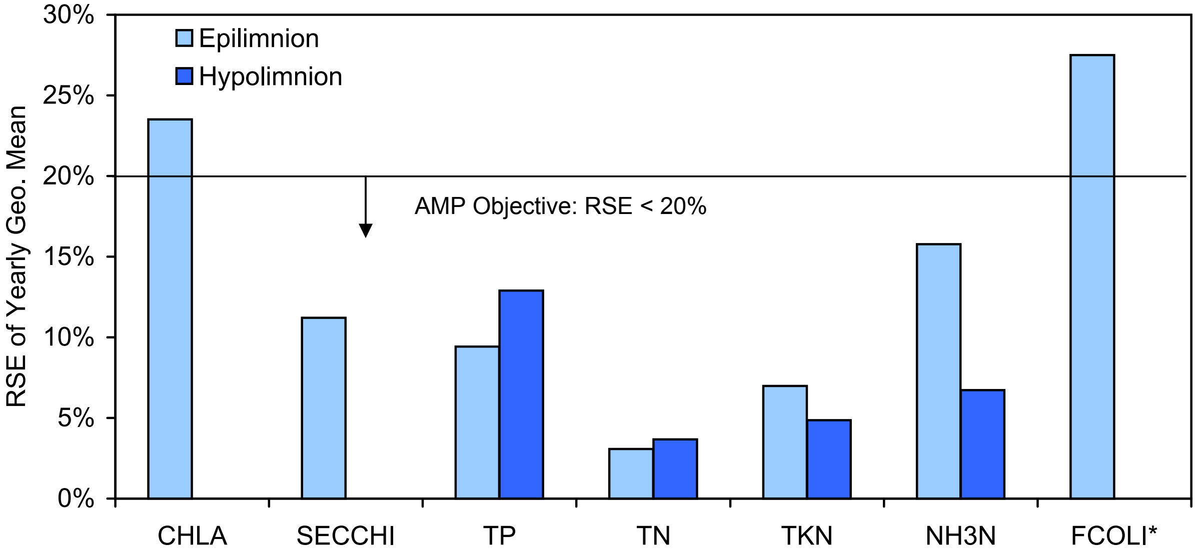
Table 4
Sensitivity of Precision to Monitoring Frequency

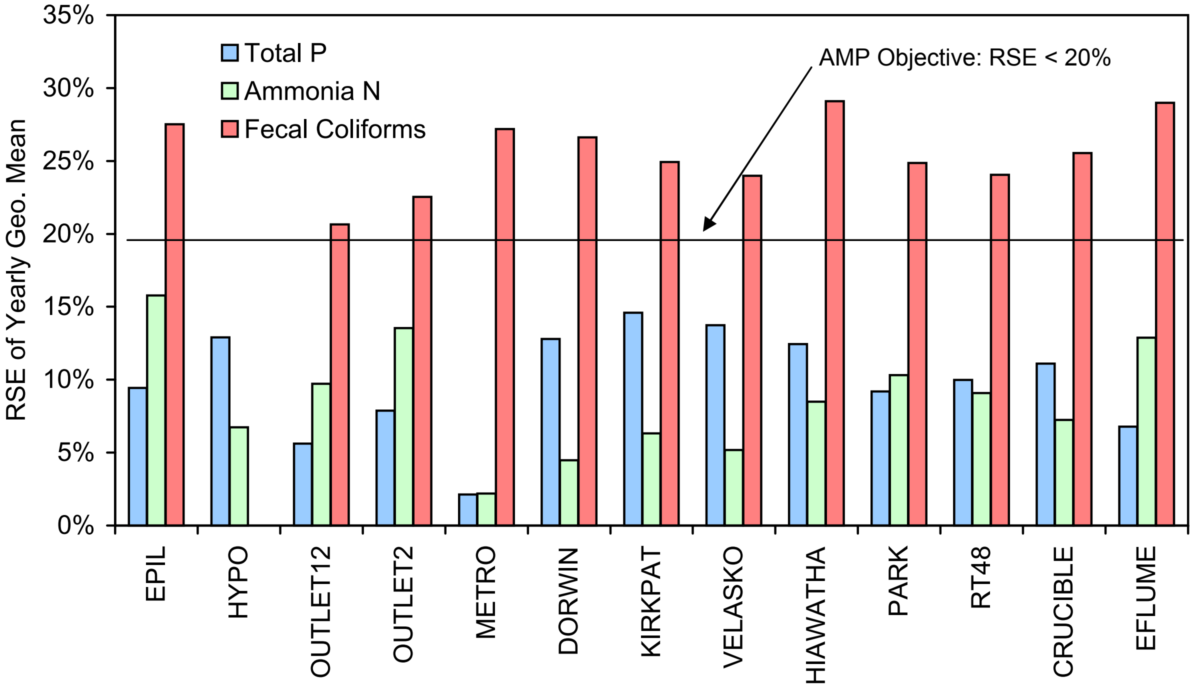
		Current AMP Design			Precision of Yearly Geo. Mean				Precision of Long-Term Geometric Mean				
Station	Variable	Dates Per Year	Depths/Date	Reps per Depth	Current Design	RSE- 2X Reps	RSE - 2X Depths	RSE - 2X Dates	Current Design	RSE LT - 2X Reps	RSE LT - 2X Depths	RSE LT - 2X Dates	RSE LT - 2X Years
EPIL	CHLA	22	1	1	24%	23%		17%	14%	14%		12%	10%
EPIL	SECCHI	22	1	1	11%	11%		8%	5%	5%		4%	4%
EPIL	TP	11	3	1	9%	9%	9%	7%	4%	4%	4%	3%	3%
HYPO	TP	11	3	1	13%	13%	12%	9%	12%	12%	12%	12%	9%
OUTLET12	TP	26	1	1	6%	5%		4%	4%	4%		4%	3%
OUTLET2	TP	26	1	1	8%	8%		6%	6%	6%		5%	4%
METRO	TP	365	1	1	2%	2%		1%	4%	4%		4%	3%
DORWIN	TP	30	1	1	13%	13%		9%	11%	11%		10%	8%
KIRKPAT	TP	30	1	1	15%	15%		10%	12%	12%		11%	8%
VELASKO	TP	30	1	1	14%	14%		10%	13%	13%		12%	9%
HIAWATHA	TP	30	1	1	12%	12%		9%	16%	16%		16%	12%
PARK	TP	30	1	1	9%	9%		7%	6%	6%		5%	4%
RT48	TP	30	1	1	10%	10%		7%	6%	6%		5%	4%
CRUCIBLE	TP	26	1	1	11%	11%		8%	16%	16%		15%	11%
EFLUME	TP	26	1	1	7%	7%		5%	3%	3%		2%	2%
EPIL	TN	11	1	1	3%	3%		2%	6%	6%		6%	4%
HYPO	TN	11	1	1	4%	3%		3%	7%	7%		7%	5%
OUTLET12	TN	26	1	1	3%	3%		2%	4%	4%		4%	3%
OUTLET2	TN	26	1	1	7%	7%		5%	3%	3%		2%	2%
METRO	TN	365	1	1	1%	1%		1%	5%	5%		5%	3%
DORWIN	TN	30	1	1	5%	5%		4%	5%	5%		5%	4%
KIRKPAT	TN	30	1	1	4%	4%		3%	2%	2%		2%	2%
VELASKO	TN	30	1	1	3%	3%		2%	4%	4%		3%	3%
HIAWATHA	TN	30	1	1	4%	4%		3%	2%	2%		2%	2%
PARK	TN	30	1	1	7%	7%		5%	4%	4%		4%	3%
RT48	TN	30	1	1	4%	4%		3%	2%	2%		1%	1%
CRUCIBLE	TN	26	1	1	9%	9%		6%	6%	6%		5%	4%
EFLUME	TN	26	1	1	5%	5%		4%	4%	4%		4%	3%
EPIL	TKN	11	3	1	7%	7%	7%	5%	9%	9%	9%	9%	7%
HYPO	TKN	11	3	1	5%	5%	4%	3%	9%	9%	9%	9%	6%
OUTLET12	TKN	26	1	1	6%	5%		4%	6%	6%		6%	4%
OUTLET2	TKN	26	1	1	9%	9%		7%	4%	4%		3%	3%
METRO	TKN	365	1	1	2%	2%		2%	11%	11%		11%	7%
DORWIN	TKN	30	1	1	10%	10%		7%	6%	6%		6%	5%
KIRKPAT	TKN	30	1	1	10%	10%		7%	4%	4%		3%	3%
VELASKO	TKN*	30	1	1	11%	11%		8%	5%	5%		4%	4%
HIAWATHA	TKN	30	1	1	12%	12%		9%	8%	8%		7%	5%
PARK	TKN	30	1	1	9%	8%		6%	4%	4%		3%	3%
RT48	TKN	30	1	1	6%	6%		4%	3%	3%		2%	2%
CRUCIBLE	TKN	26	1	1	8%	7%		5%	7%	7%		6%	5%
EFLUME	TKN	26	1	1	7%	7%		5%	5%	5%		4%	3%
EPIL	NH3N	11	3	1	16%	16%	15%	11%	10%	10%	10%	8%	7%
HYPO	NH3N	11	3	1	7%	6%	6%	5%	10%	10%	10%	10%	7%
OUTLET12	NH3N	26	1	1	10%	9%		7%	11%	11%		11%	8%
OUTLET2	NH3N	26	1	1	14%	13%		10%	6%	6%		4%	4%
METRO	NH3N	365	1	1	2%	2%		2%	12%	12%		12%	8%
DORWIN	NH3N*	30	1	1	4%	4%		3%	3%	3%		2%	2%
KIRKPAT	NH3N*	30	1	1	6%	6%		4%	4%	4%		4%	3%
VELASKO	NH3N*	30	1	1	5%	5%		4%	6%	6%		5%	4%
HIAWATHA	NH3N*	30	1	1	8%	8%		6%	6%	6%		6%	4%
PARK	NH3N	30	1	1	10%	10%		7%	5%	5%		3%	3%
RT48	NH3N	30	1	1	9%	9%		6%	6%	6%		5%	4%
CRUCIBLE	NH3N*	26	1	1	7%	7%		5%	5%	5%		5%	4%
EFLUME	NH3N	26	1	1	13%	13%		9%	8%	8%		7%	6%
EPIL	FCOLI*	22	1	1	28%	27%		19%	18%	17%		15%	12%
HYPO	FCOLI*												
OUTLET12	FCOLI*	26	1	1	21%	20%		15%	9%	9%		7%	7%
OUTLET2	FCOLI*	26	1	1	23%	22%		16%	10%	10%		7%	7%
METRO	FCOLI*	26	1	1	27%	26%		19%	19%	18%		16%	13%
DORWIN	FCOLI*	30	1	1	27%	26%		19%	13%	12%		10%	9%
KIRKPAT	FCOLI	30	1	1	25%	24%		18%	11%	11%		8%	8%
VELASKO	FCOLI	30	1	1	24%	23%		17%	27%	27%		26%	19%
HIAWATHA	FCOLI	30	1	1	29%	28%		21%	24%	24%		22%	17%
PARK	FCOLI	30	1	1	25%	24%		18%	11%	11%		8%	8%
RT48	FCOLI	30	1	1	24%	23%		17%	11%	10%		8%	8%
CRUCIBLE	FCOLI*	26	1	1	26%	25%		18%	16%	15%		13%	11%
EFLUME	FCOLI	26	1	1	29%	28%		20%	22%	22%		20%	16%

Effect of Doubling Number of Replicates Per Depth, Depths per Date, or Dates Per Year on Precision of Yearly Geometric Mean
Precision Expressed as Relative Standard Error (Standard Error / Mean)
Precision of Long-Term Geometric Mean Computed from 5 Years of Data
* Accuracy of Estimates Limited; More than 10% of Samples <= Detection Limit

List of Figures

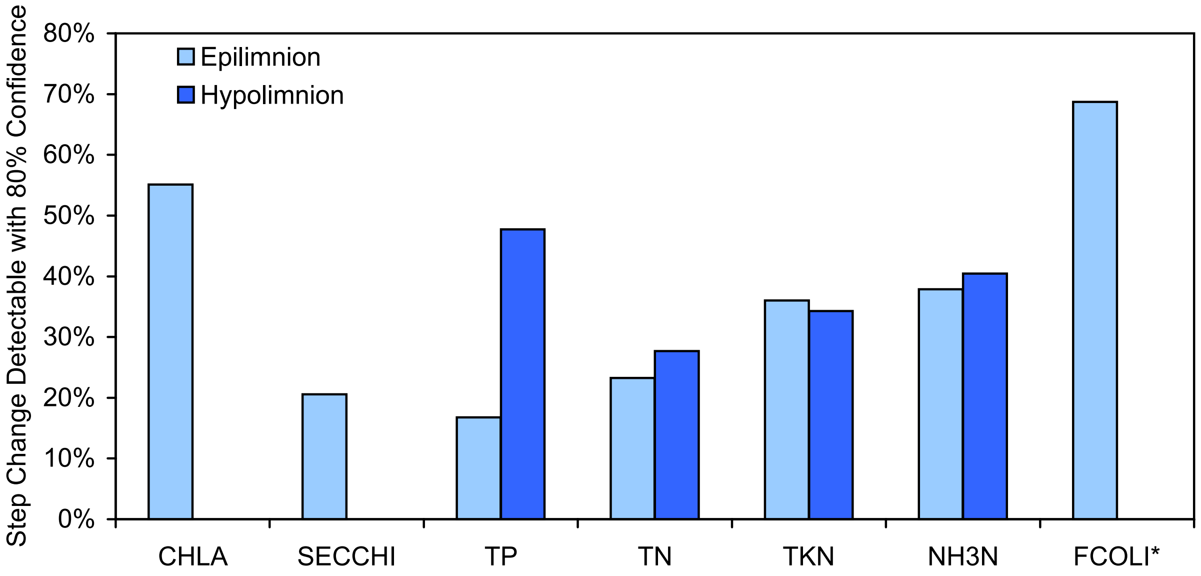
Figure 1
Precision Estimates for Lake & Tributary Stations

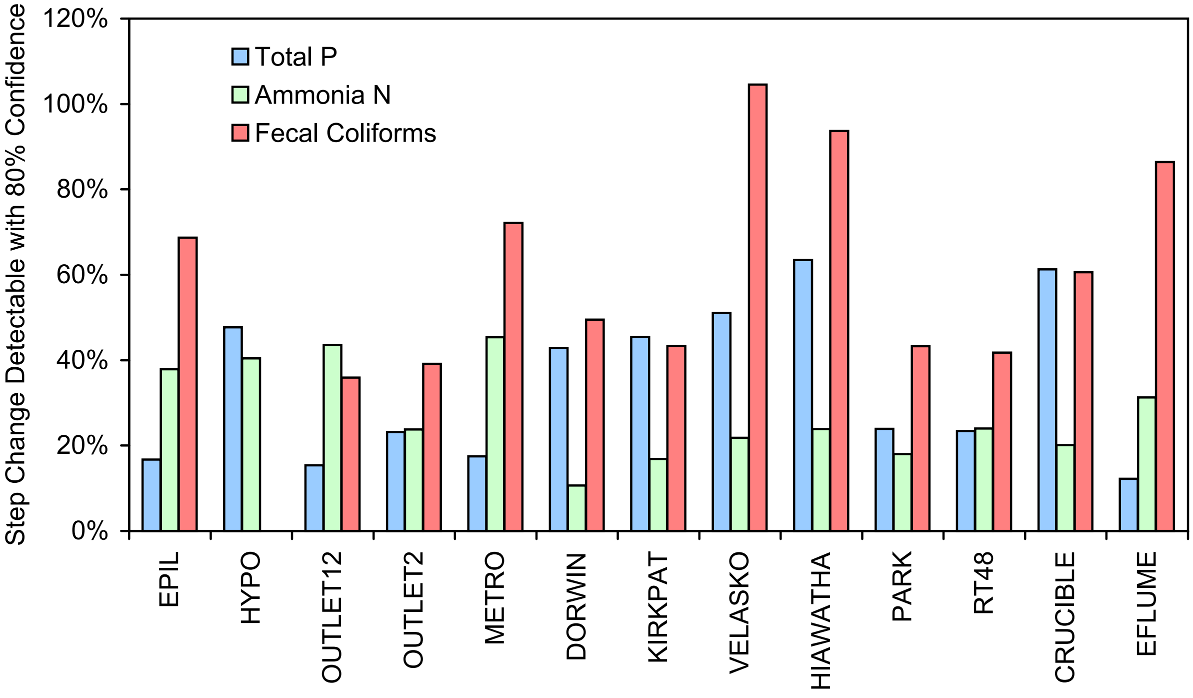




Precision Estimates for May-Sept. Geo. Means (Lake South Station) & Jan-Dec. Geo. Means (Tributary Strations)
RSE's for Total N & TKN lower than those shown above for TP, NH3N, & Fecal Coli

Figure 2
Power for Detecting Step Changes

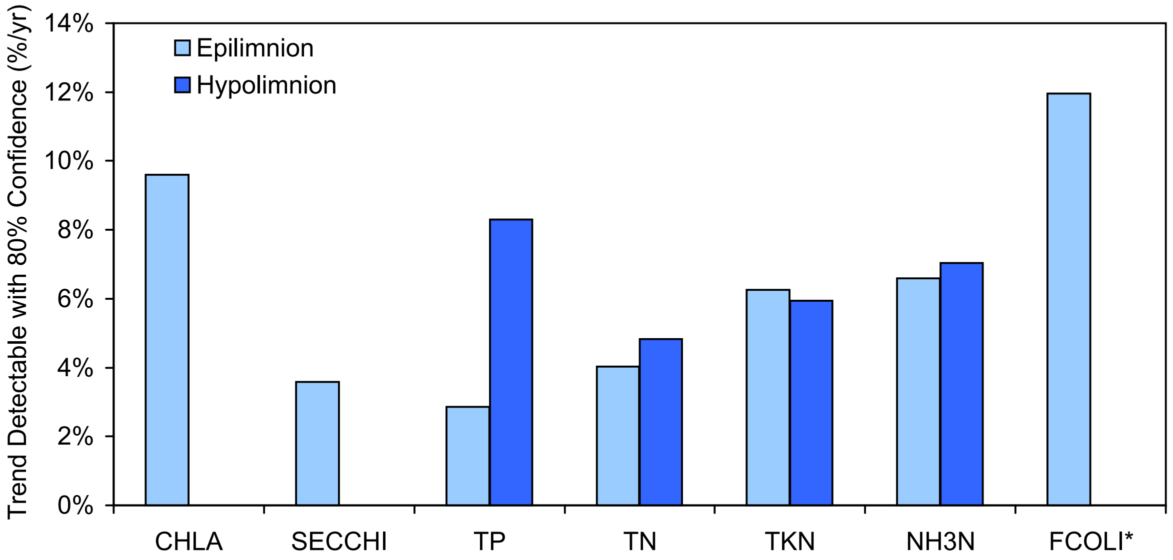


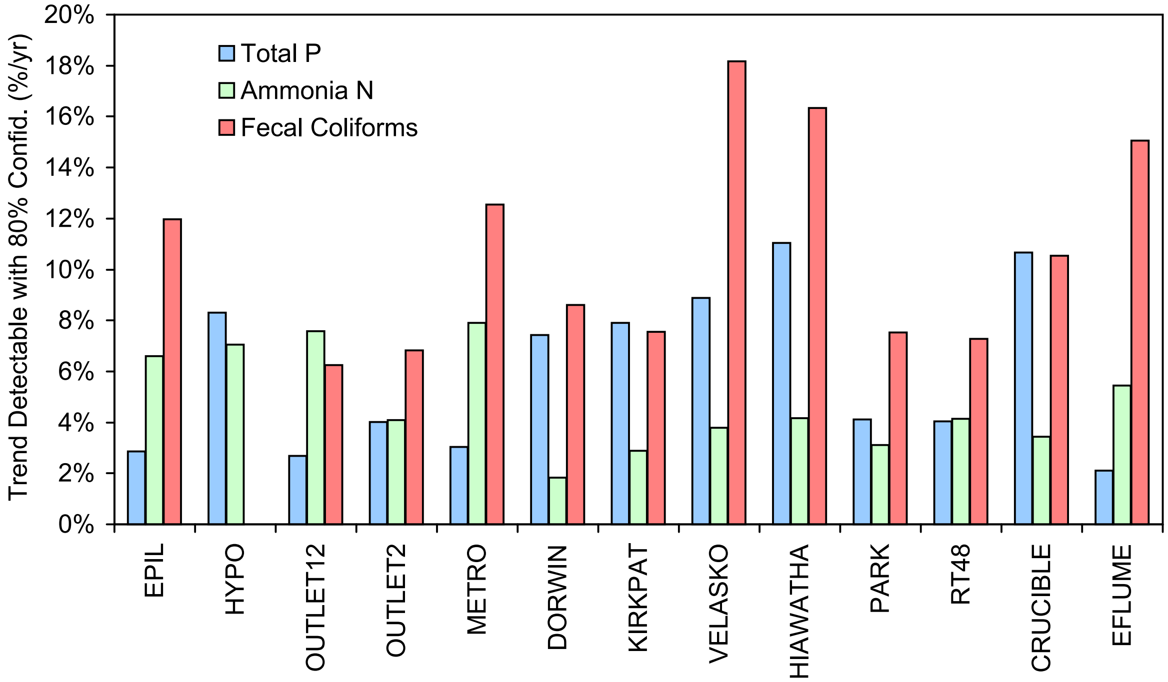


Power for Detecting Step Change Based upon 10 Years of Data (5 Before & 5 After Hypothetical Step Change)
Using t-test at 5%/10% Significance Level for 1-Tailed & 2-Tailed Hypotheses, Respectively

Figure 3

Power for Detecting Trends

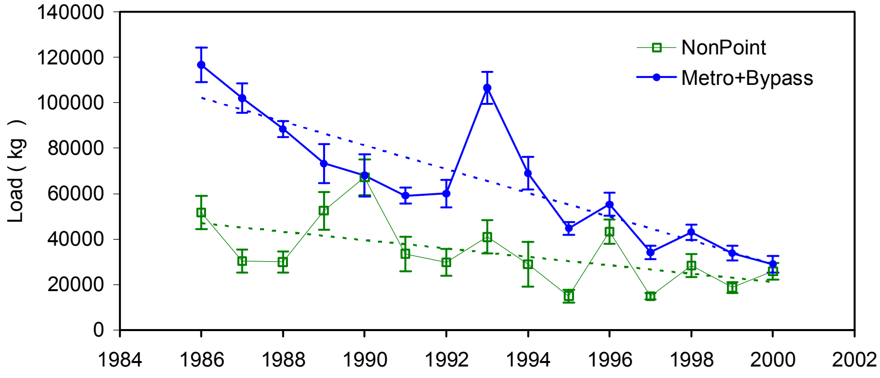


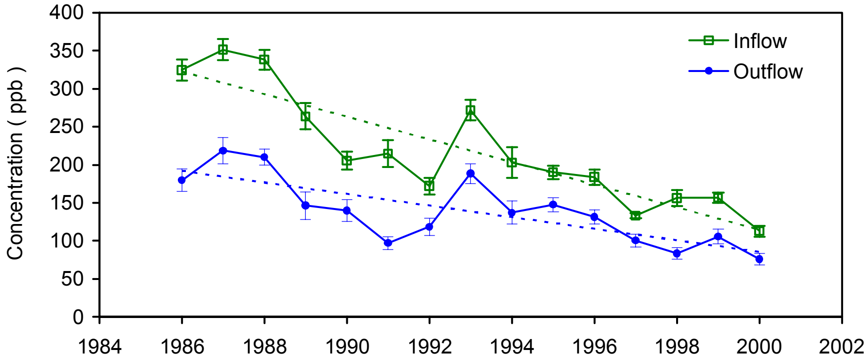


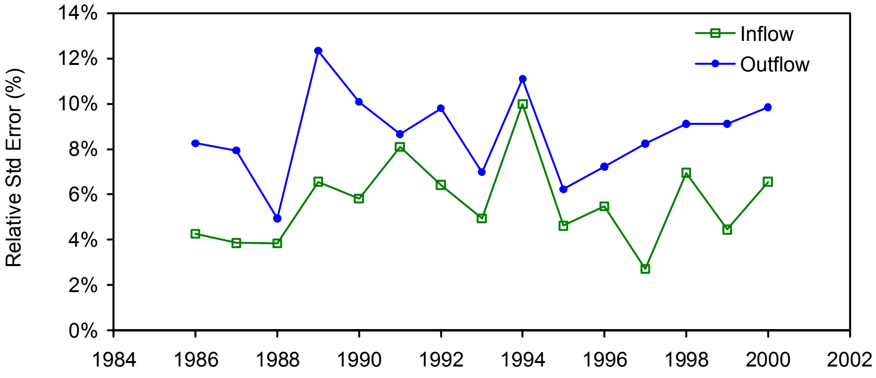
Power for Detecting Linear Trend upon 10 Years of Data
Regression of Yearly Geometric Means at 5%/10% Significance Level for 1-Tailed & 2-Tailed Hypotheses, Respectively

Figure 4
Total Phosphorus Balances

Long-Term Trends in Lake Mass Balances
Variable: **Total Phosphorus** **Season: Year**







Error Bars Show Mean Estimate +/- 1 Standard Error
Dashed Lines Show Trend Estimated by Linear Regression

Pooled Estimates for 1996-2000:

Mass-Balance Term	Metro	Nonpoint	Total In	Outflow
Relative Standard Error of Yearly Value*	2%	13%	5%	9%
Detrended Year-to-Year CV	14%	24%	15%	16%
Trend Detectable with 80% Conf. (%/yr)**	4%	7%	5%	5%
Change Detectable with 80% Confidence**	24%	41%	26%	28%

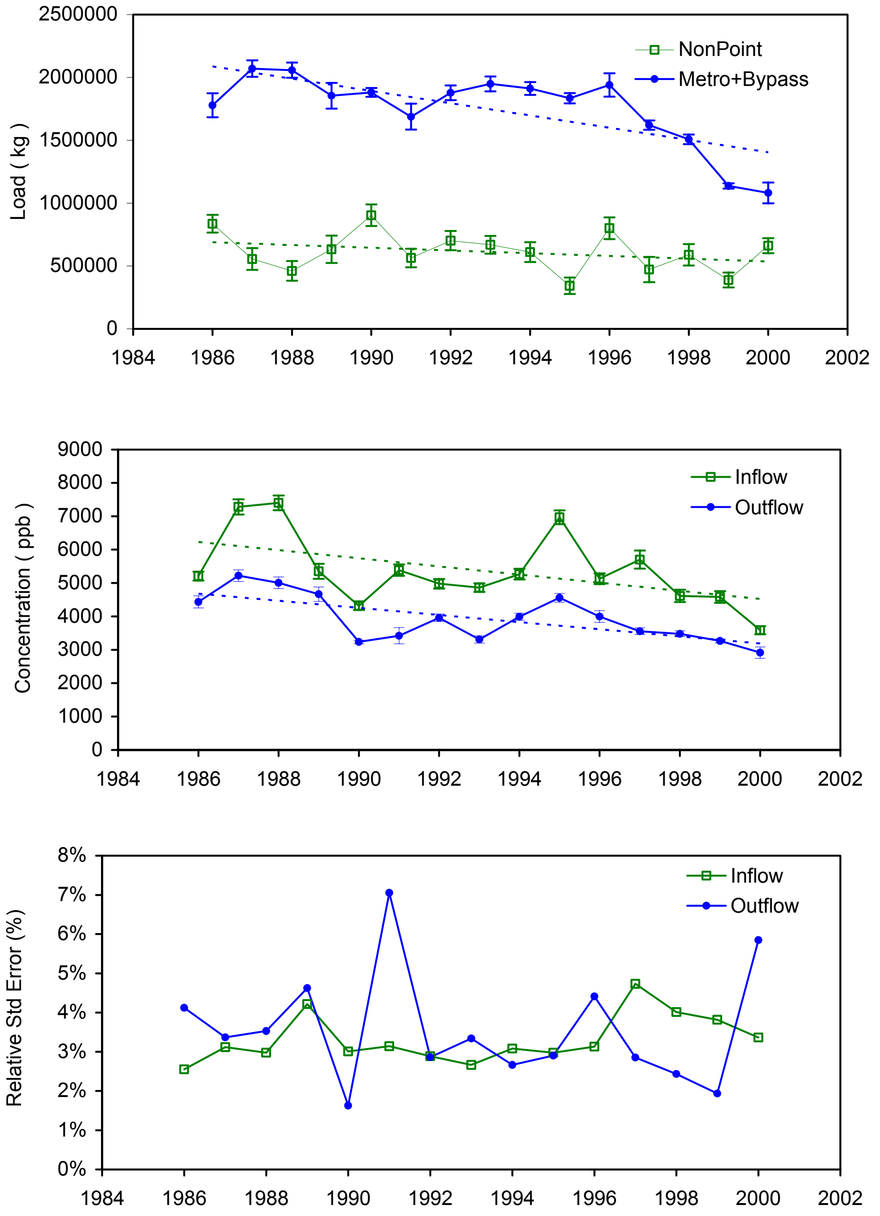
* AMP Precision Goal is RSE < 20%

** Power statistics evaluated for hypothetical trend tests with 10 years of data & 10% significance level (1-Tailed) or 5% significance level (2-Tailed)

Figure 5
Total Nitrogen Balances

Long-Term Trends in Lake Mass Balances

Variable: Total Nitrogen Season: Year



Error Bars Show Mean Estimate +/- 1 Standard Error
Dashed Lines Show Trend Estimated by Linear Regression

Pooled Estimates for 1996-2000:

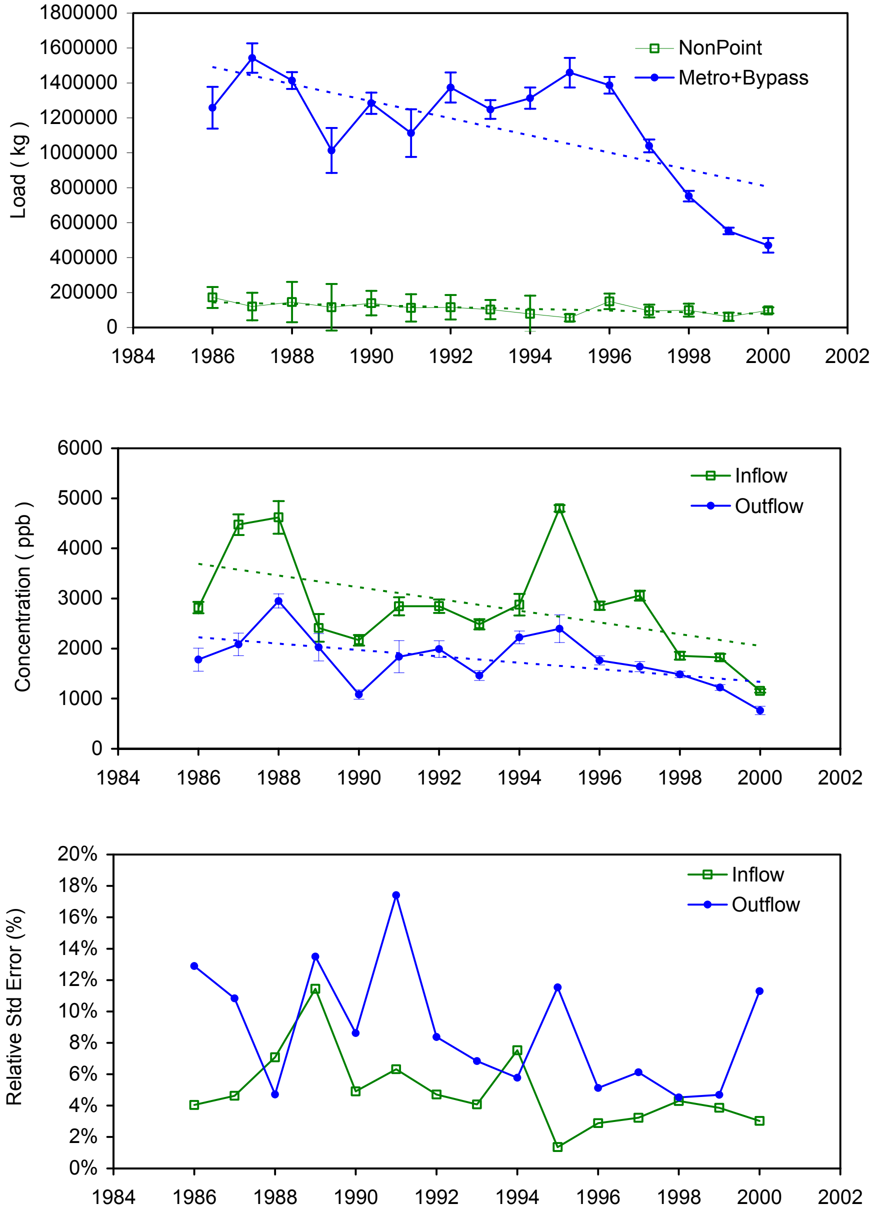
Mass-Balance Term	Metro	Nonpoint	Total In	Outflow
Relative Standard Error of Yearly Value*	5%	6%	4%	3%
Detrended Year-to-Year CV	3%	4%	10%	3%
Trend Detectable with 80% Conf. (%/yr)**	1%	1%	3%	1%
Change Detectable with 80% Confidence**	5%	7%	18%	5%

* AMP Precision Goal is RSE < 20%

** Power statistics evaluated for hypothetical trend tests with 10 years of data & 10% significance level (1-Tailed) or 5% significance level (2-Tailed)

Figure 6
TKN Balances

Long-Term Trends in Lake Mass Balances
Variable: Total Kjeldahl Nitrogen Season: Year



Error Bars Show Mean Estimate +/- 1 Standard Error
Dashed Lines Show Trend Estimated by Linear Regression

Pooled Estimates for 1996-2000:

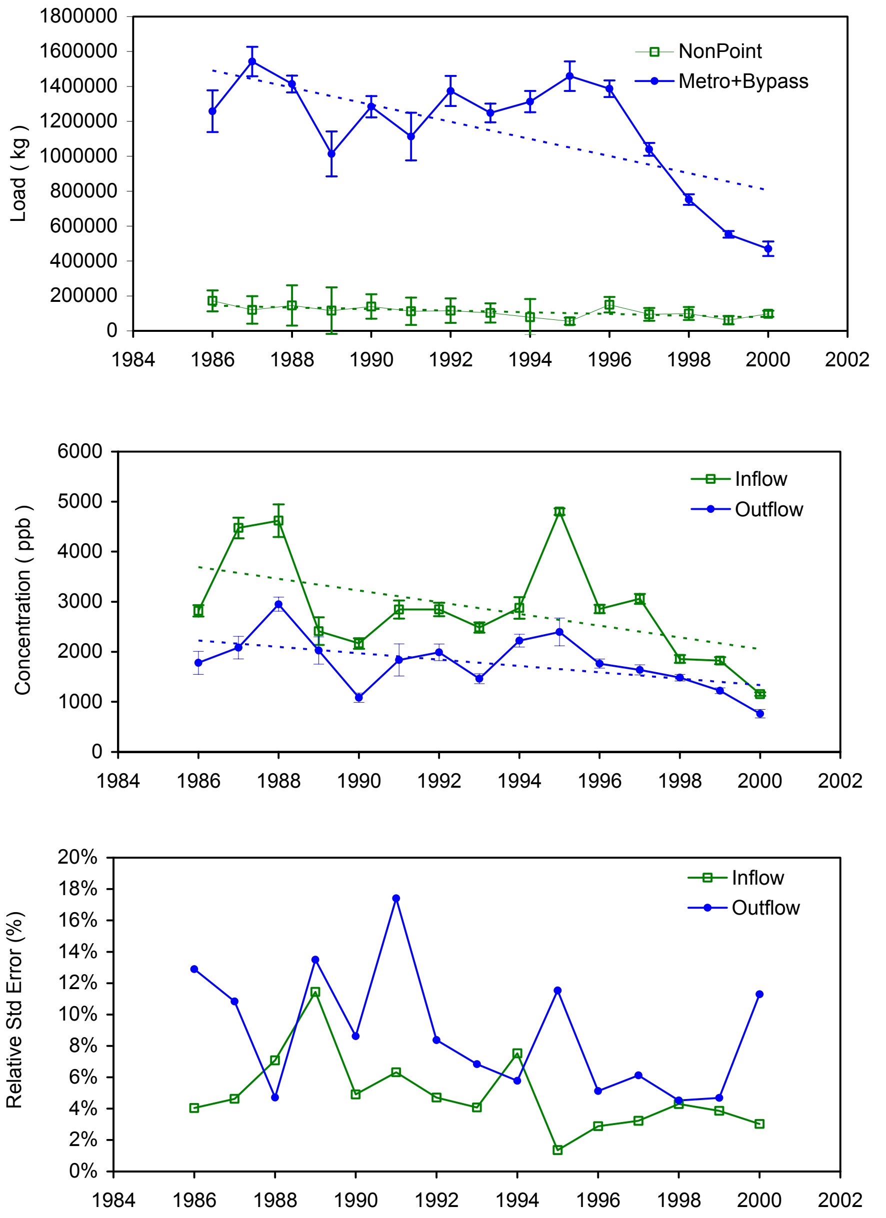
Mass-Balance Term	Metro	Nonpoint	Total In	Outflow
Relative Standard Error of Yearly Value*	3%	9%	3%	5%
Detrended Year-to-Year CV	6%	8%	13%	4%
Trend Detectable with 80% Conf. (%/yr)**	2%	2%	4%	1%
Change Detectable with 80% Confidence**	11%	13%	22%	8%

* AMP Precision Goal is RSE < 20%

** Power statistics evaluated for hypothetical trend tests with 10 years of data & 10% significance level (1-Tailed) or 5% significance level (2-Tailed)

Figure 7
Ammonia Balances

Long-Term Trends in Lake Mass Balances
Variable: Ammonia Nitrogen Season: Year



Error Bars Show Mean Estimate +/- 1 Standard Error
Dashed Lines Show Trend Estimated by Linear Regression

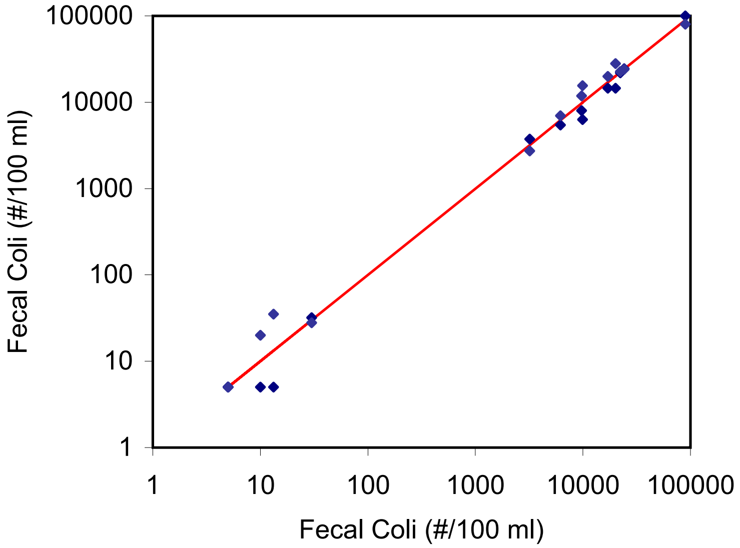
Pooled Estimates for 1996-2000:

Mass-Balance Term	Metro	Nonpoint	Total In	Outflow
Relative Standard Error of Yearly Value*	3%	17%	3%	6%
Detrended Year-to-Year CV	10%	7%	16%	9%
Trend Detectable with 80% Conf. (%/yr)**	3%	2%	5%	3%
Change Detectable with 80% Confidence**	18%	12%	28%	16%

* AMP Precision Goal is RSE < 20%

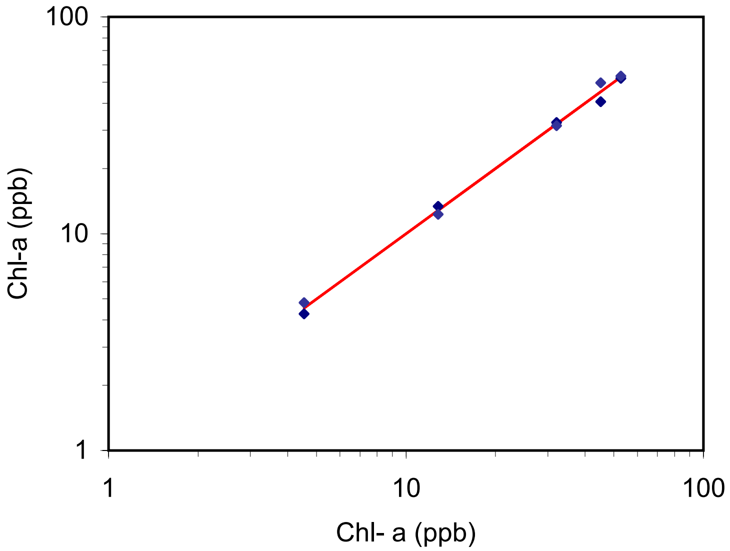
** Power statistics evaluated for hypothetical trend tests with 10 years of data & 10% significance level (1-Tailed) or 5% significance level (2-Tailed)

Figure 8
Replicate Fecal Coliform & Chl-a Measurements



Replicate Standard Deviation = 46%

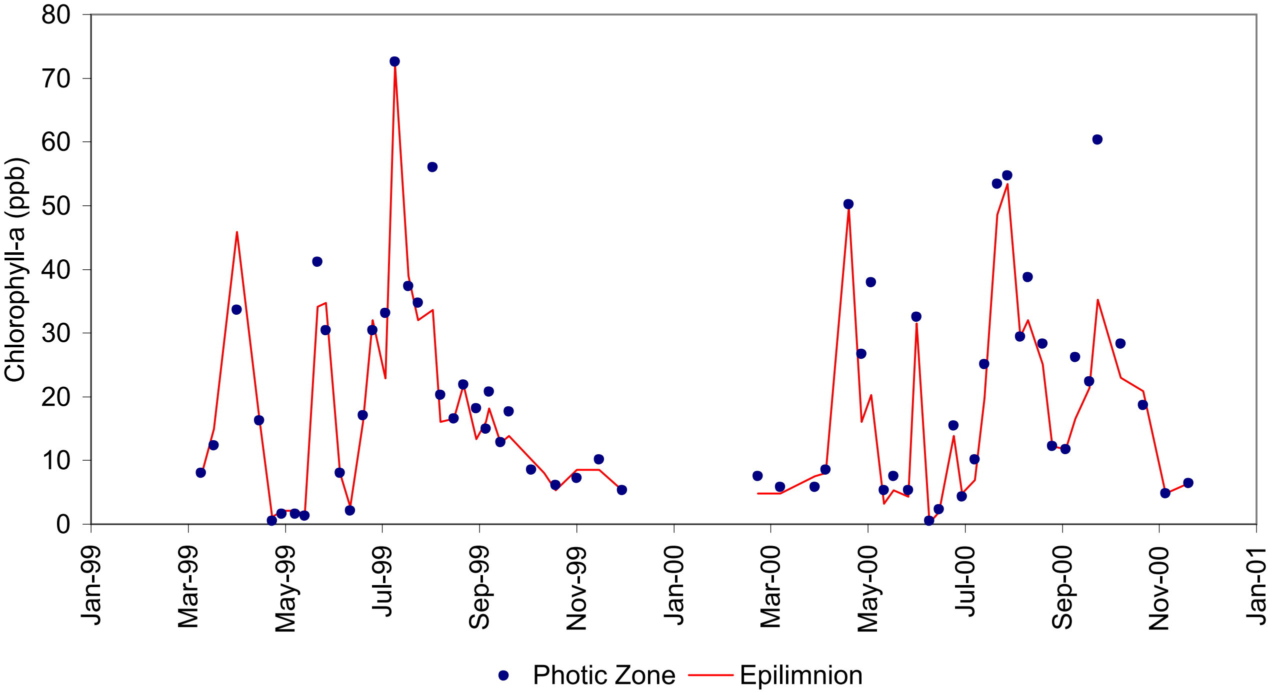
Percent of Variance in Yearly Geometric Mean = 13%

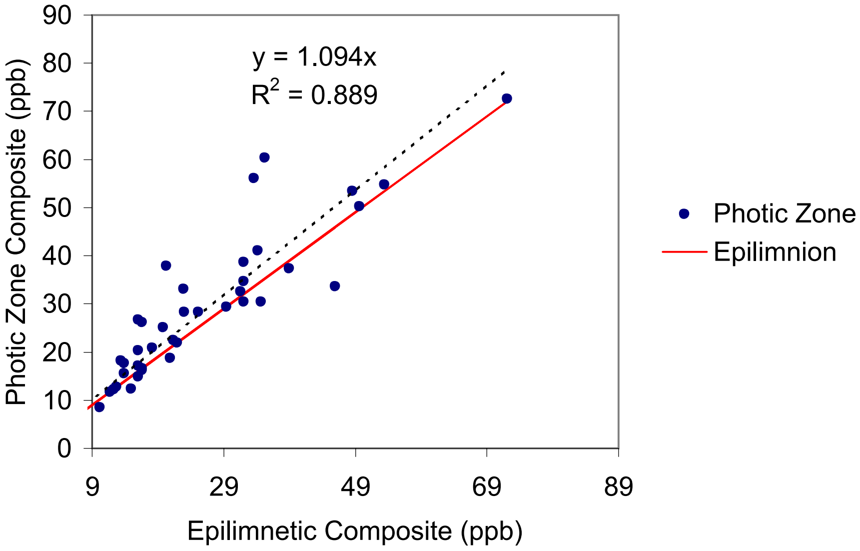


Replicate Standard Deviation = 13%

Percent of Variance in Yearly Geometric Mean = 1%

Figure 9
Comparison of Epilimnetic & Photic-Zone Composite Chlorophyll-a Samples
Lake South Station, 1999-2000

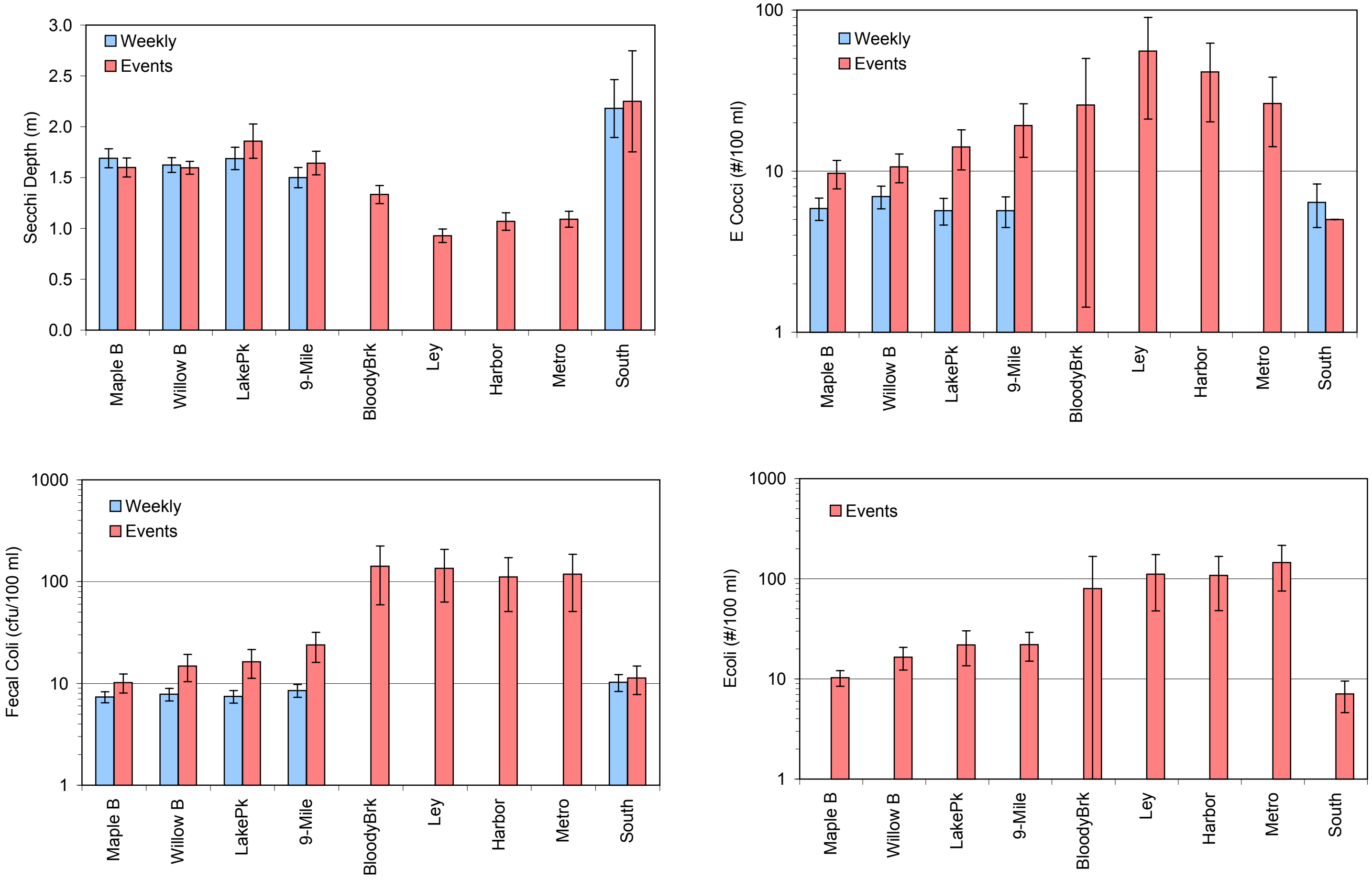




Paired t-Test Using Ln-Transformed Values:

Mean Difference =	9.1 +/- 3.4%
t =	2.69
p =	0.009

Figure 10
Transparency & Bacteria Data from Nearshore Lake Stations, 1999-2000



Lakeshore Sites Arranged in North --> South Direction
Secchi Depths: Arithmetic Means +/- 1 Std Error
Fecal Coliforms: Geometric Means +/- 1 Std Error
Values with >=3 Observations Plotted
Weekly = Periodic (Dry-Weather) Monitoring
Event = Storm Event (Wet-Weather) Monitoring
Lower Detection Limit for Bacteria Samples = 5 Organisms/100 ml

Sample Counts

		Maple B	Willow B	LakePk	9-Mile	BloodyBrk	Ley	Harbor	Metro	South
Secchi	Weekly	34	34	32	32	0	0	2	0	34
	Event	22	22	22	21	3	22	22	22	10
Fcoli	Weekly	34	34	32	32	0	0	2	0	36
	Event	22	22	22	21	3	20	19	20	10

Figure 11
Lake South Ammonia Nitrogen Time Series

All Depths & Months

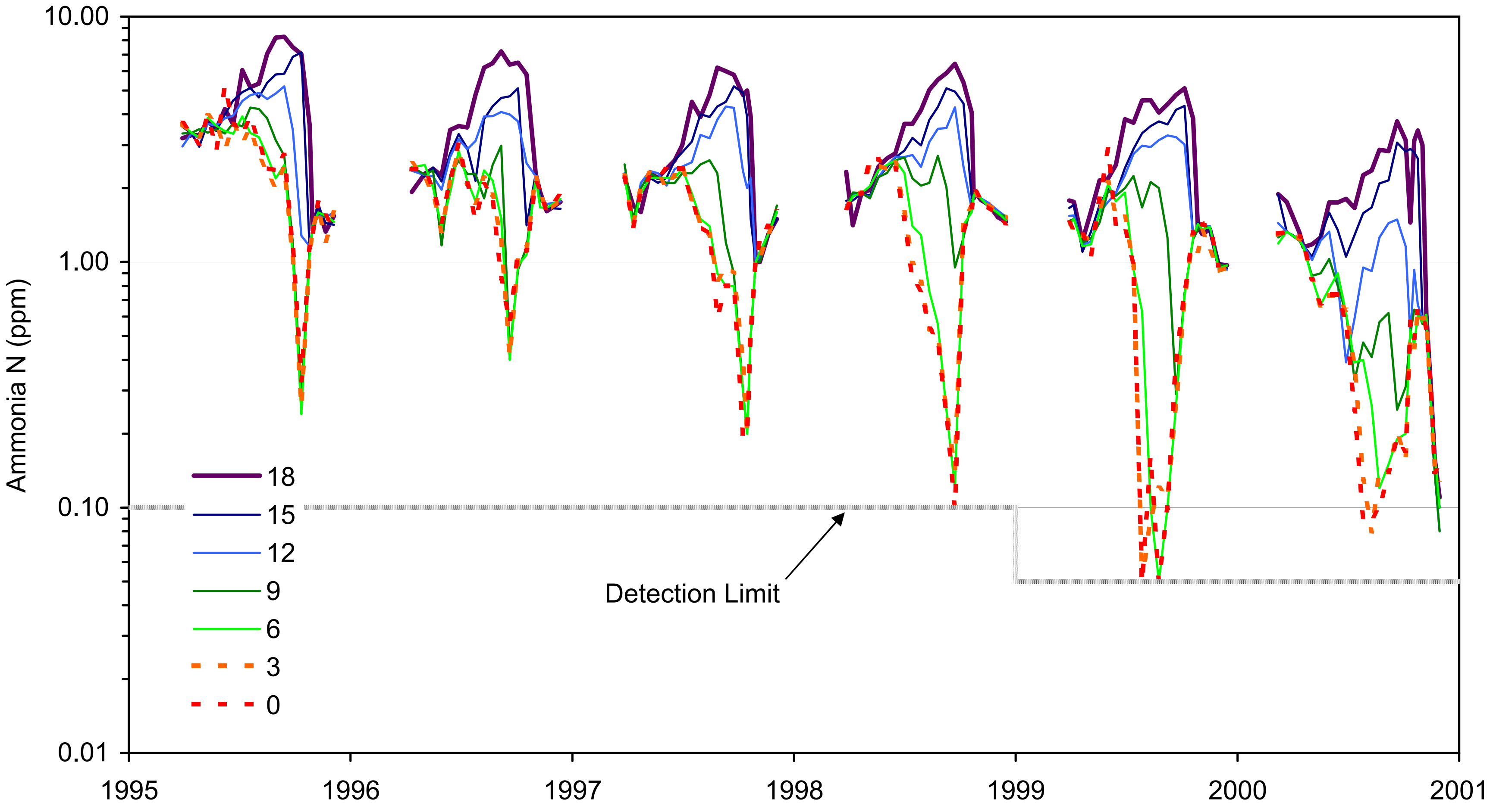
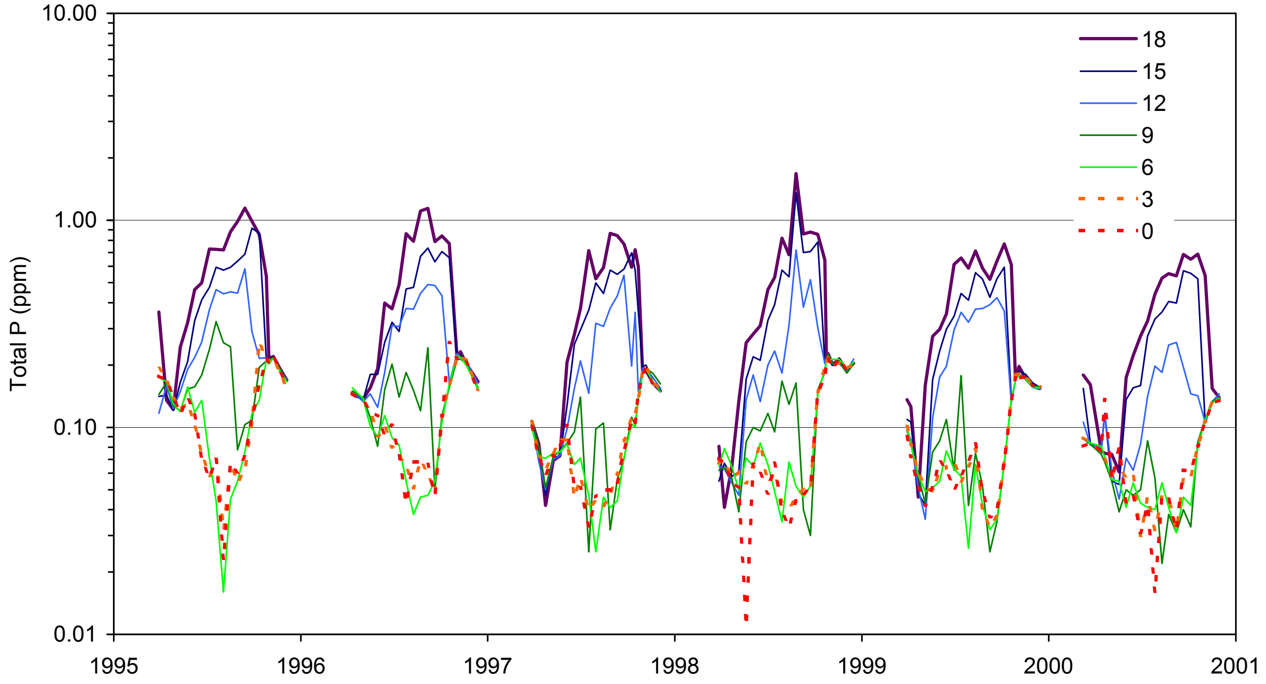


Figure 12
Lake South Total P Time Series

All Depths & Months



Upper Mixed Layer, 0-6 meter Samples, June-September