CHAPTER 9: MASS-BALANCE MODELING

9.1 OVERVIEW

Chapter 3 describes 1998 load calculations for each tributary and water-quality component. This chapter integrates these results into a mass-balance framework for the Lake as a whole (Figure 9-1). Mass balances provide important information on sources controlling water quality, foundations for empirical and mechanistic modeling, and bases for tracking watershed and lake responses to implementation of control measures. Interactive software has been developed to perform the following functions for a user-specified water quality component and season (calendar year, water year, growing season):

- Summarize water and mass balances for specified year or year range;
- Estimate the uncertainty (standard error) of each mass-balance term;
- Refine the monitoring program design to reduce uncertainty in load estimates;
- Track trends in each mass-balance term (individual sources, total inputs & outputs);
- Calibrate empirical mass-balance models to forecast responses of lake outflow concentrations and loads to variations in inflow volumes and loads.

The software is currently set up to analyze 1986-1998 data for the following monitored water quality components:

- Phosphorus species (total, total inorganic, ortho)
- Nitrogen species (total, kjeldahl, nitrate, nitrite, ammonia)
- Carbon species (total organic, total inorganic)
- Biochemical Oxygen Demand
- Total Suspended Solids
- Inorganic species (chloride, sodium, calcium, alkalinity)
- Fecal Coliforms

With future database updates, the trend-analysis functions will be useful for evaluating the effectiveness of point-source and nonpoint-source controls implemented in the watershed over the next several years, measured in terms of reductions in lake input loads and outflow concentrations. It is not within the scope of this chapter to document all features of the software in detail. The following sections describe the methodology, software structure, and mass-balance models for chlorides, total phosphorus, and total nitrogen.

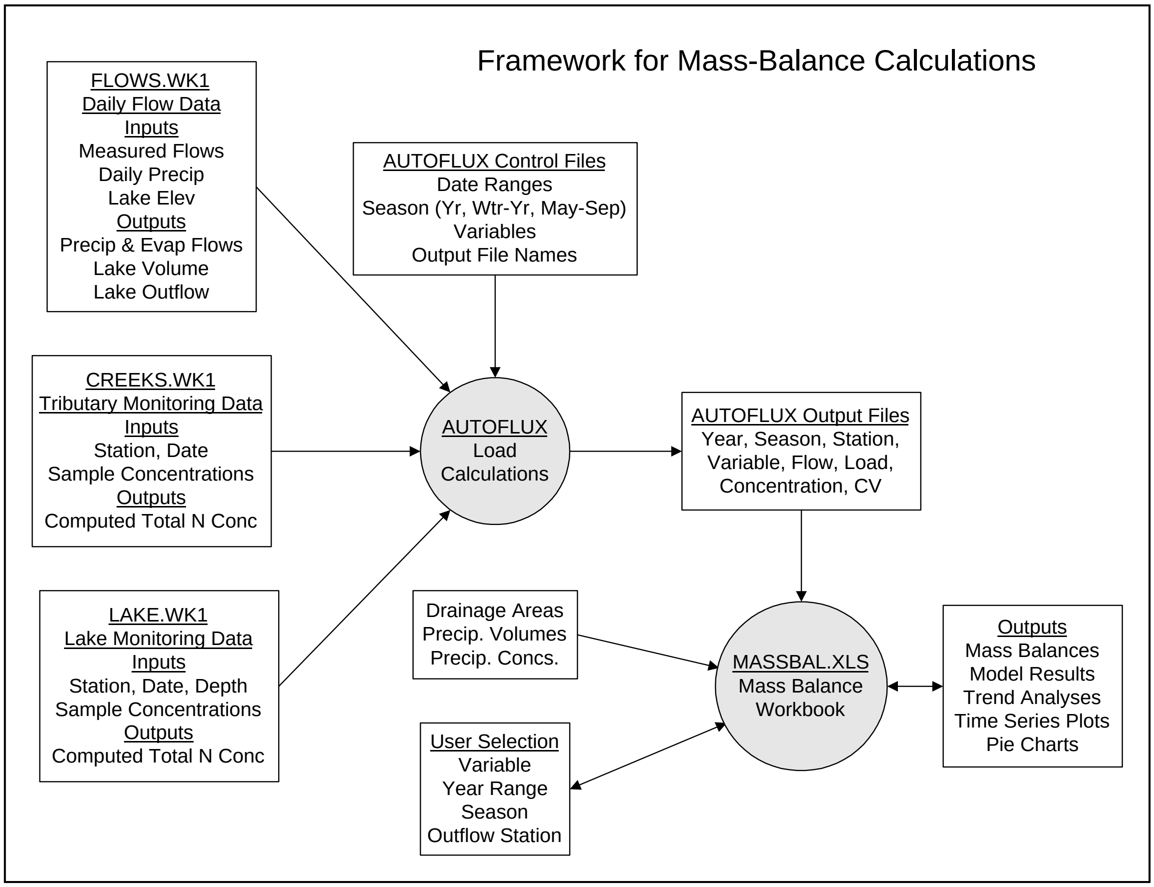


FIGURE 9-1: Framework for Mass-Balance Calculations

9.2 METHODOLOGY

Basic data for the calculations are stored in three worksheet files:

- FLOWS.WK1 - daily measured flows (creeks, point sources, precipitation), measured elevations, & calculated flows (ungauged inputs, outflows).
- CREEKS.WK1 - tributary & point-source concentration data (1985-1998)
- LAKE.WK1 - lake concentration data (1968-1998)

The data worksheets are in formats that are compatible with AUTOFLUX (used in Chapter 3 for load calculations), FLUX (interactive software for load calculations, Walker (1996)), and TRENDS (used in Chapters 3 & 4 for trend analyses).

Daily water balances are computed in FLOWS.WK1. Table 9-1 describes the algorithm

TABLE 9-1: Water Balance Algorithm

Outflow = Inflows + Precipitation - Evaporation - Increase in Storage
Inflows:
Tributaries
Gauged: Onondaga, Harbor, Ley, Ninemile
Ungauged ~ 0.051 x Gauged
Industrial
Allied / East Flume, Crucible
Municipal
Metro Effluent & Bypass

Precipitation:
Daily Precipitation x Lake Area
Daily Precip. from Hancock Airport (~38 in/yr)

Evapotranspiration:
Daily Evaporation x Lake Area
Regional Average Monthly Evaporation Data (~27 inches/yr)
(VanderLeden et al., 1990)

Increase in Storage:
Daily Increase in Elevation x Lake Area

Outflow Time Series Smoothed (7 Day Rolling Average) for computing daily lake outflow volumes.

Based upon drainage areas reported by the USGS (Table 9-2), about 14.3 mi^2 of the watershed is ungauged (above Lake and below USGS gauges). Gauged watershed inflows are multiplied by the ungauged/gauged drainage area ratio (.051) to estimate ungauged inflows and loads. Development of a GIS coverage for the watershed (e.g., Figure 1-5) is recommended to refine drainage area estimates above each gauge and above the lake as a whole.

TABLE 9-2: Drainage Areas

	USGS Station Number	Drainage Area (mi^2)
Onondaga/Spencer	04240010	110.0
Ley/Park	04240120	29.9
Harbor/Hiawatha	04240105	11.3
Ninemile/Lakeland	04240300	115.0
Ungauged	(calculated)	14.3
Lake		4.5
Total	04240495	285.0
Onondaga/Dorwin	04239000	88.5
Harbor /Velasko	04240100	10.0

AUTOFLUX (Walker, 1995) computes loads for each monitored inflow, season, year, and water-quality component. Three alternative estimates of lake outflow loads are computed by pairing daily outflow volumes with monitored concentrations at each of three locations (Outlet @ 2 feet, Outlet @ 12 feet, Lake South Epilimnion (<9 meters). In years following elimination of saline discharges from the Allied Chemical facility, yearly chloride balances (see below) are tightest using the Outlet @ 2 feet. AUTOFLUX generates ASCII output files that are subsequently pasted into the Excel-97 workbook used for mass-balance calculations and analysis (MASSBAL.XLS, Figure 9-1).

Data inputs to the load-calculation workbook include:

- AUTOFLUX output files (see above)
- Drainage area estimates (Table 9-2)
- Precipitation volumes for each year and season (from Hancock Airport)
- Rainfall concentrations for estimating atmospheric inputs (Table 9-3)

The workbook is currently stoked with results for 1986-1998, three seasons (calendar year, water year, May-September), and variables listed in Section 9.1. Pending results of further data screening for 1990-1997, concentration outliers detected by AUTOFLUX at the 0.01 significance level have been excluded from load calculations. Future data can be pasted into the workbook to update the calculations.

To facilitate long-term trend analyses, missing historical data have been estimated as follows:

- **Total P, All Terms, 1986-1989**. Estimated from Total Inorganic Phosphorus loads using TP/TIP ratios for each term derived from years when both TP and TIP were measured (between 1990 & 1997, depending on term).
- **All Variables, Crucible, 1992**. Estimated using concentrations measured in 1991.
- **Metro Bypass, All Variables, 1986-1992**. Estimated using measured flows in each year and flow-weighted-mean concentrations measured in 1994-1998. A search for 1986-1992 bypass concentration data is recommended.

Although tributary concentration data are available for 1985, the flow record is incomplete. Compilation of daily flows for Metro effluent and bypass would enable mass-balance computations for 1985. Load estimates for 1985 currently in the workbook use 1986 daily flows for the effluent and bypass.

Nominal estimates of rainfall concentration for each water quality component are listed in Table 9-3. These values can be refined with additional literature review. The concentrations represent bulk atmospheric deposition (wetfall + dryfall). Precipitation volumes are multiplied by these concentrations to calculate atmospheric loads. Computed mass balances are generally insensitive to these values because atmospheric loads are generally small in relation to inputs from the watershed and point sources.

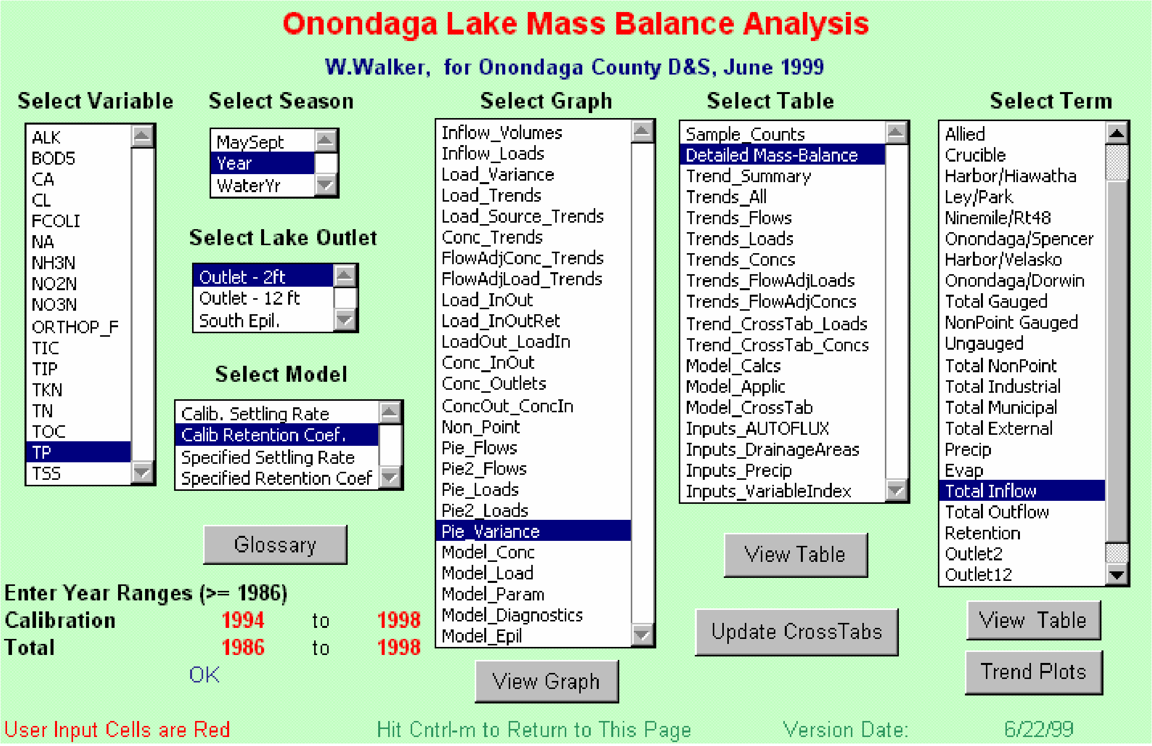
TABLE 9-3: Assumed Rainfall Concentrations

Variable	Conc.	Units
Total Alkalinity	5	ppm
5-Day Biochemical Oxygen Demand	0	ppm
Calcium	5	ppm
Chloride	1	ppm
Fecal Coliforms	0	cells/liter
Sodium	1	ppm
Ammonia Nitrogen	100	ppm
Nitrite Nitrogen	100	ppb
Nitrate Nitrogen	800	ppb
Soluble Reactive Phosphorus	15	ppb
Total Inorganic Carbon	1000	ppm
Total Inorganic Phosphorus	20	ppb
Total Kjeldahl Nitrogen	1000	ppm
Total Nitrogen	1900	ppm
Total Organic Carbon	1000	ppb
Total Phosphorus	30	ppb
Total Suspended Solids	1	ppm

9.3 MASS-BALANCE WORKBOOK

Mass-Balance analysis is performed in an Excel-97 workbook "MASSBAL.XLS". The workbook control panel is shown in Figure 9-2. The scope of the calculations is defined by selecting each of the following:

- Water quality variable
- Season (May-September, Calendar Year, or Water Year)
- Lake Outlet Station (Outlet @ 2 feet, Outlet @ 12 feet, or Lake South Epilimnion)
- Model Formulation (Constant Settling Rate, or Constant Retention Coefficient, each calibrated to a selected date range or specified by the user)
- Calibration Year Range (used in model calibration & detailed mass-balance table)
- Total Year Range (used in model testing & trend analyses)



Onondaga Lake Mass Balance Analysis

W.Walker, for Onondaga County D&S, June 1999

Select Variable: TP

Select Season: Year

Select Lake Outlet: Outlet - 2ft

Select Model: Calib Retention Coef.

Select Graph: Pie_Variance

Select Table: Detailed Mass-Balance

Select Term: Total Inflow

Enter Year Ranges (>= 1986)

Calibration 1994 to 1998

Total 1986 to 1998

User Input Cells are Red

Hit Cntrl-m to Return to This Page

Version Date: 6/22/99

FIGURE 9-2: MASSBAL.XLS Control Panel

With the scope selected, a variety of graphs and tables can be viewed. To view a graph, select the desired graph name from the list and then click the 'View Graph' button. Hit 'Cntrl-m' to return to the control panel after viewing any graph or table. A brief description of each graph format (Table 9-4) and table format (Table 9-5) can be accessed by clicking the 'Glossary' button on the control panel.

TABLE 9-4 : List of Output Graphs

Graph	**Description**
Inflow_Volumes	Bar Chart of Inflow Volumes in Each Source Category
Inflow_Loads	Bar Chart of Inflow Loads in Each Source Category
Load_Variance	Bar Chart of Load Variances in Each Source Category
Load_Trends	Trends in Total Inflow & Total Outflow Loads
Load_Source_Trends	Trends in Municipal & Non-Point Loads
Conc_Trends	Trends in Total Inflow & Total Outflow Concentrations
FlowAdjConc_Trends	Trends in Total Inflow & Total Outflow Flow-Adjusted Concs
FlowAdjLoad_Trends	Trends in Total Inflow & Total Outflow Flow-Adjusted Loads
Load_InOut	Bar Chart of Total Inflow & Total Outflow Loads
Load_InOutRet	Bar Chart of Total Inflow Loads , Outflow Loads, and Retention
LoadOut_LoadIn	Scatter Plot of Outflow Loads vs. Inflow Loads
Conc_InOut	Bar Chart of Total Inflow & Outflow Concs
Conc_Outlets	Bar Chart of Total Inflow & Outflow Concs for Alt. Outlets
ConcOut_ConcIn	Scatter Plot of Outflow Concs vs. Inflow Concs
Non_Point	Unit Area Flows, Loads, & Concs. for Each Watershed
Pie_Flows	Pie Chart of Inflow Volumes by Source
Pie2_Flows	Pie Chart of Inflow Volumes by Source Category
Pie_Loads	Pie Chart of Inflow Loads by Source
Pie2_Loads	Pie Chart of Inflow Loads by Source Category
Pie_Variance	Pie Chart of Inflow Load Variance by Source Category
Model_Conc	Observed & Predicted Outflow Concentrations
Model_Load	Observed & Predicted Outflow Loads
Model_Param	Water Load, Setting Rates, Retention Coef.
Model_Diagnostics	Model Residuals Plots
Model_Epil	Summer Epilimnetic Total Phosphorus or Total Nitrogen Model

TABLE 9-5 : List of Output Tables

Table	Description
Sample_Counts	Number of Samples vs. Station & Year
Detailed Mass-Balance	Complete Water & Mass Balance
Trend_Summary	Summary of Trends in Major Mass-Balance Terms
Trends_All	Summary of Trends in Flows, Loads, & Concs for Each Term
Trends_Flows	Trend Analysis Details - Flows
Trends_Loads	Trend Analysis Details - Loads
Trends_Concs	Trend Analysis Details - Concentrations
Trends_FlowAdjLoads	Trend Analysis Details - Flow-Adjusted Loads
Trends_FlowAdjConcs	Trend Analysis Details - Flow-Adjusted Concentrations
Trend_CrossTab_Loads	Summary of Load Trends vs. Variable & Mass-Balance Term
Trend_CrossTab_Concs	Summary of Conc. Trends vs. Variable & Mass-Balance Term
Model_Calcs	Mass-Balance Model Calculations
Model_Applic	Apply Mass-Balance Model to Hypothetical Load Scenario
Model_CrossTab	Summary of Model Results vs. Variable & Model Formulation
Inputs_AUTOFLUX	AUTOFLUX Output Data
Inputs_DrainageAreas	Input Drainage Areas
Inputs_Precip	Input Precipitation Data
Inputs_VariableIndex	Input Variable Names & Rainfall P Concs.

9.3 TREND ANALYSIS METHODS

The "Select Term" menu on the far right of the control panel (Figure 9-2) lists yearly time series and performs a trend analysis any term of the mass balance. Trend analyses for total inputs and total outputs can also be viewed from graph and table menu. Trends are evaluated via linear regression against year. Tests are performed for flow, load, concentration, flow-adjusted load, and flow-adjusted concentration.

Flow-adjusted values remove a portion of the hydrologic variability from the time series. In situations where load or concentration are significantly correlated with flow, adjusted values may provide an improved basis for detecting trends, expressed in terms of higher power and less risk that hydrologic variations will be mistakenly interpreted as long-term trends (Hirsch et al., 1982). This is particularly true for loads, since correlations between load and flow are generally stronger than correlations between concentration and flow.

Flow-adjusted concentrations are computed as follows:

$$C_a = C + b_c (Q_m - Q)$$

where,

C_a = flow-adjusted concentration for current year (ppb)
C = measured flow-weighted-mean concentration for current year (ppb)
b_c = slope of concentration vs. flow regression
Q = average flow for current year (10^6 m^3/yr)
Q_m = average flow for entire time series (10^6 m^3/yr)

Measured yearly concentrations are adjusted to average flow conditions based upon the slope of the concentration vs. flow regression. Future investigation of alternative forms for the concentration vs. flow regression (e.g., log-scale or polynomial) is suggested. Analogous equations are used to compute flow-adjusted loads.

If there is a long-term trend in flow over the tested year interval, flow-adjusted results should be interpreted cautiously. In this situation, the correlation between flow and year makes it difficult to distinguish their effects on concentration or load. The above procedures for filtering out apparent flow-related variations will also tend to filter out any long-term trends and cause a Type II error (failure to detect a real trend). Lake inflow volumes and loads between 1986 and 1998 are shown in Figures 9-3 and 9-4, respectively. Because of the high flow in 1990 and low-to-average flows in 1995, 1997, and 1998, distinguishing flow effects from long-term trend would be relatively difficult for trend analyses between 1990 and 1998. In such situations, the unadjusted concentration time series is probably more reliable as a trend indicator.

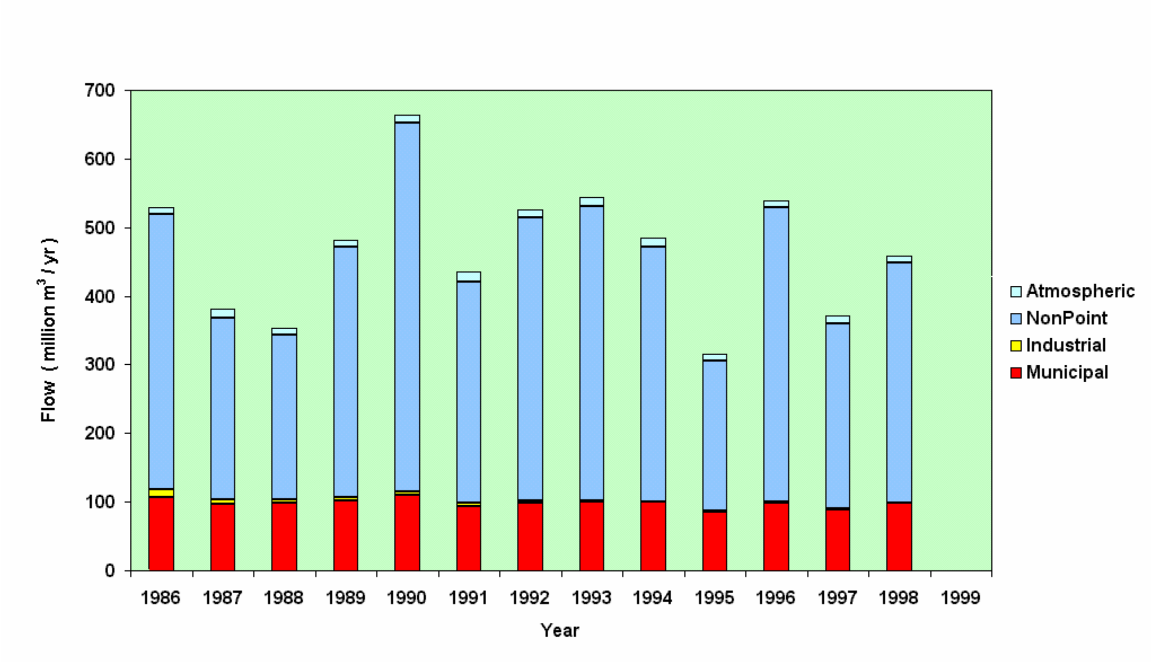


FIGURE 9-3: Long-Term Variations in Lake Inflow Volume

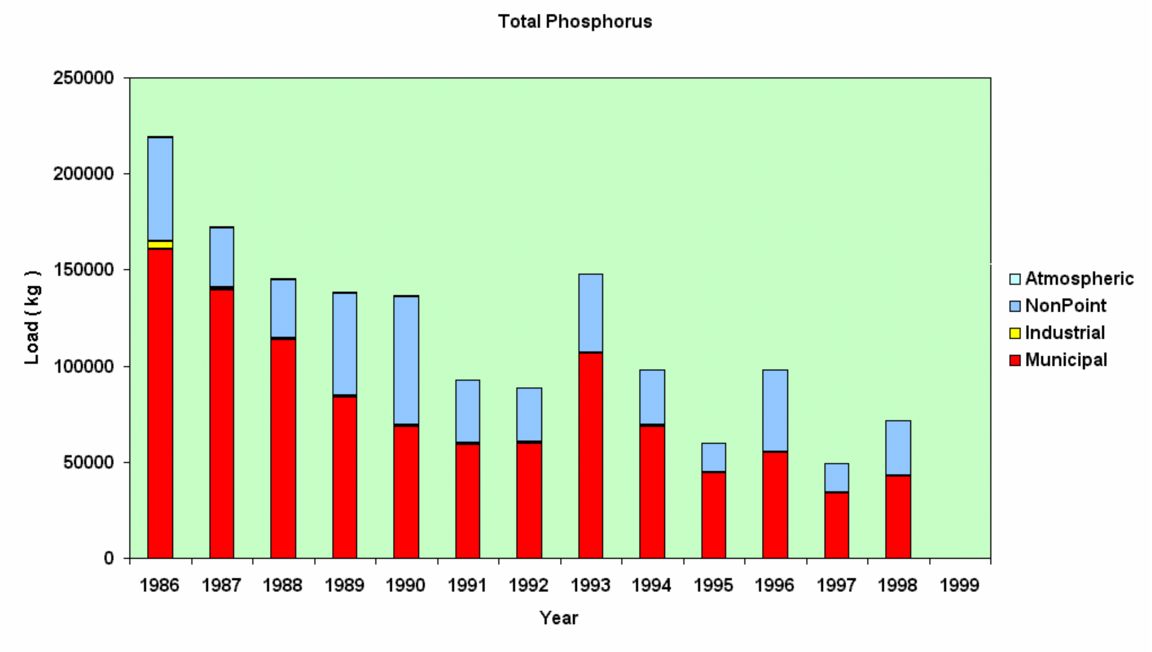


FIGURE 9-4: Long-Term Variations in Total Phosphorus Load

The 'Trend CrossTab' table summarizes significant trends in each variable and mass-balance term. These tables must be manually updated if the year interval for trend analysis or the outlet definition is changed. Updating is accomplished by clicking the 'Update CrossTabs' button (Figure 9-2). Tables 9-6 and 9-7 show trend crosstabs for concentrations and loads between 1986 and 1998. Values in the table represent trend magnitudes (% per year) that are significant at $p < .10$ (two-tailed test).

9.4 MASS-BALANCE MODELING

The software facilitates calibration and testing of empirical mass-balance models for predicting lake outflow concentrations as a function of inflow volumes and loads. The following alternative model formulations are considered:

Constant Settling Velocity (Chapra & Tarapchak, 1976):

$$C_o = C_i \ Q_s \ / \ (Q_s + U)$$

Constant Retention Coefficient (Dillion & Rigler, 1975):

$$C_o = C_i (1 - R)$$

where,

C_o = Lake outflow concentration (ppb)
C_i = Average inflow concentration = W_i / Qo
W_i = Inflow load (kg/yr)
Q_o = Lake outflow (10^6 m^3/yr)
Q_s = Water load (m/yr) = Q_o / A
R = Retention coefficient
U = Net Settling Velocity (m/yr)

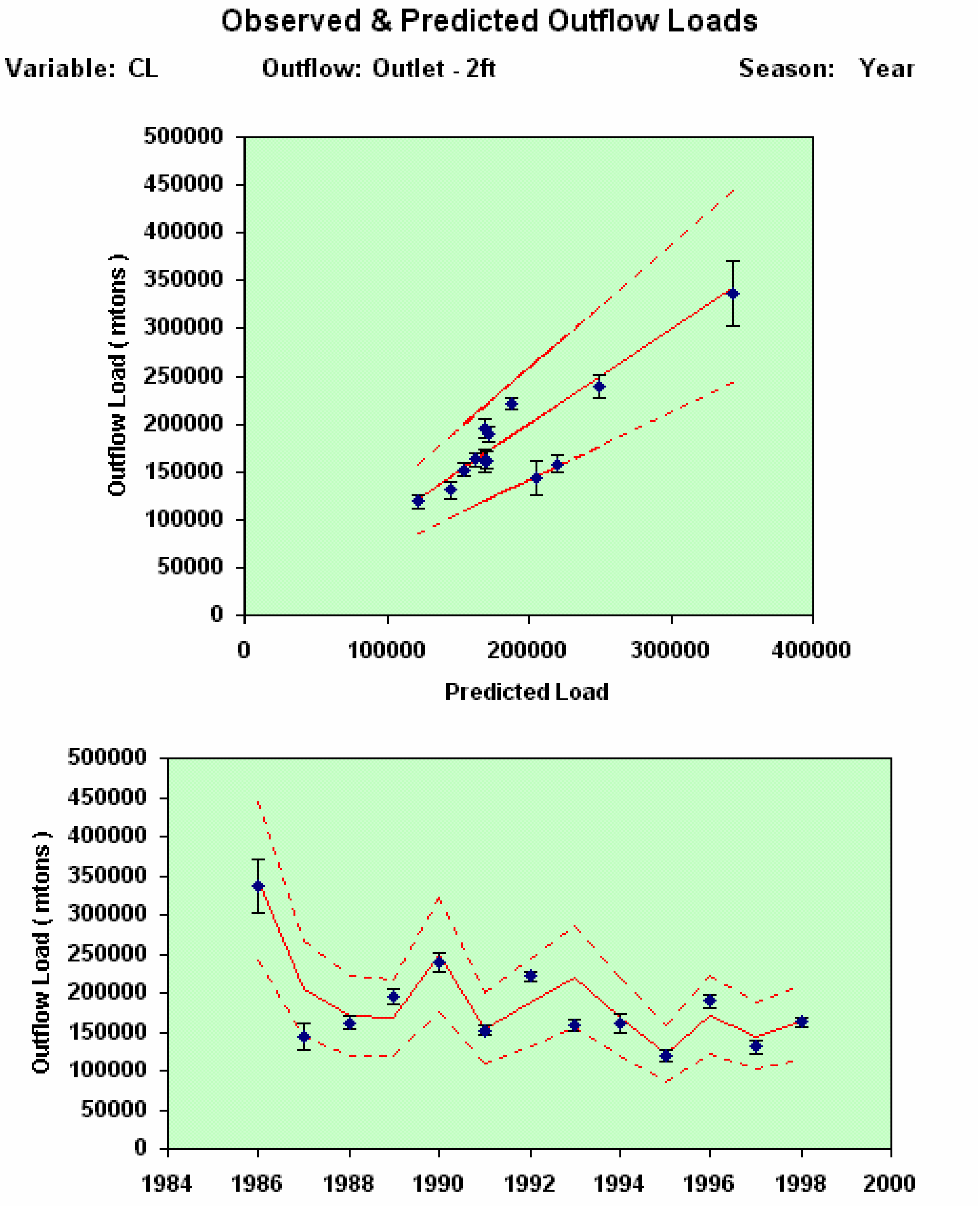
The empirical parameters (U or R) can be calibrated to average mass balances for the specified calibration years or estimated independently by user.

Model performance for predicting outflow concentration or load over the entire period is measured by the explained variance (r^2) and residual standard error, expressed as a percentage of the predicted value (CV%). In applications to phosphorus & nitrogen discussed below, models are calibrated to the most recent five-year period (1994-1998) and tested against 1986-1998 yearly time series. Predictions for 1986-1993 provide independent verification of the models calibrated to average 1994-1998 mass-balances. Model output is represented in tables and figures labeled "model_" (e.g., 'model_concs' shows observed & predicted outflow concentrations, along with calibrated parameters and performance measures).

For both phosphorus and nitrogen, there is some possibility that the lake response to nonpoint loads is different from its response to point-source loads. This would be reflected in terms of different retention coefficients or settling velocities for each source category. Unfortunately, testing this hypothesis is not straight-forward because year-year-variations in the ratio of point-source to nonpoint-source loads are strongly correlated with year-to-year variations in flow. Point sources tend to represent a lower percentage of the total load during wet years. This makes it difficult to distinguish effects of hydrologic variations from differential responses to point vs. nonpoint loads. Residuals from the models discussed below are generally uncorrelated with point/nonpoint load ratios. Further investigations of this aspect are recommended, however.

9.5 CHLORIDE BALANCE MODEL

Assuming that chlorides are conservative, input and output loads should be approximately equal. Comparing input and output loads provides a basis for testing the testing the overall water balance and testing the scheme for estimating ungauged flows and loads. The 1994-1998 chloride balance is listed in Table 9-8. In this period, total input and output loads differ by 1% using the 2-foot samples to compute outflow loads, as compared with 20% using the 20-foot outlet samples and 18% using the Lake South epilimnetic concentrations. Lack of consistent year-round sampling limits the usefulness of the Lake South data for computing outflow loads. Observed and predicted yearly outflow chloride loads are shown in Figure 9-5, based upon the mass-balance model with an assumed settling velocity of 0.0 m/yr. The model explains 78% of the observed outflow load time series with a residual standard error of 16%. Based upon these results, 2-foot outlet samples are used below in developing phosphorus and nitrogen balances.



Observed Std Dev	57503	Predicted 90% Confidence Intervals			
Residual Std Dev	28134	Model:	Specified Settling Rate		
R-Squared	76%	Parameter Value	0.0 m/yr		
Residual CV%	16%	Calib. Ret. Coef.	1%		
P	0.002	Calibration Pd:	1994	to	1998

FIGURE 9-5: Observed & Predicted Outflow Chloride Loads

9.6 PHOSPHORUS BALANCE MODEL

Table 9-9 lists the total phosphorus balance for the 1994-1998 period. The lake retained 41.6% of the input phosphorus load, corresponding to an average settling of 25.9 m/yr. Figure 9-6 shows observed and predicted yearly-average outflow concentrations for 1986-1998 using the retention coefficient calibrated to 1994-1998 data (41.6%). The constant-retention model (r^2 = 86%, residual CV = 16%) performs slightly better than the constant settling-rate model (r^2 = 79%, residual CV = 21%). As discussed above (see 9.2), total phosphorus concentrations and loads for 1986-1989 have been estimated from total inorganic phosphorus values. The resulting equation for predicting yearly-average outflow phosphorus concentration is:

$$P_o = P_I (1 - R) = 0.584 \; P_I$$

90% Confidence Interval = $[0.42 \text{ to } 0.75] \; P_I$

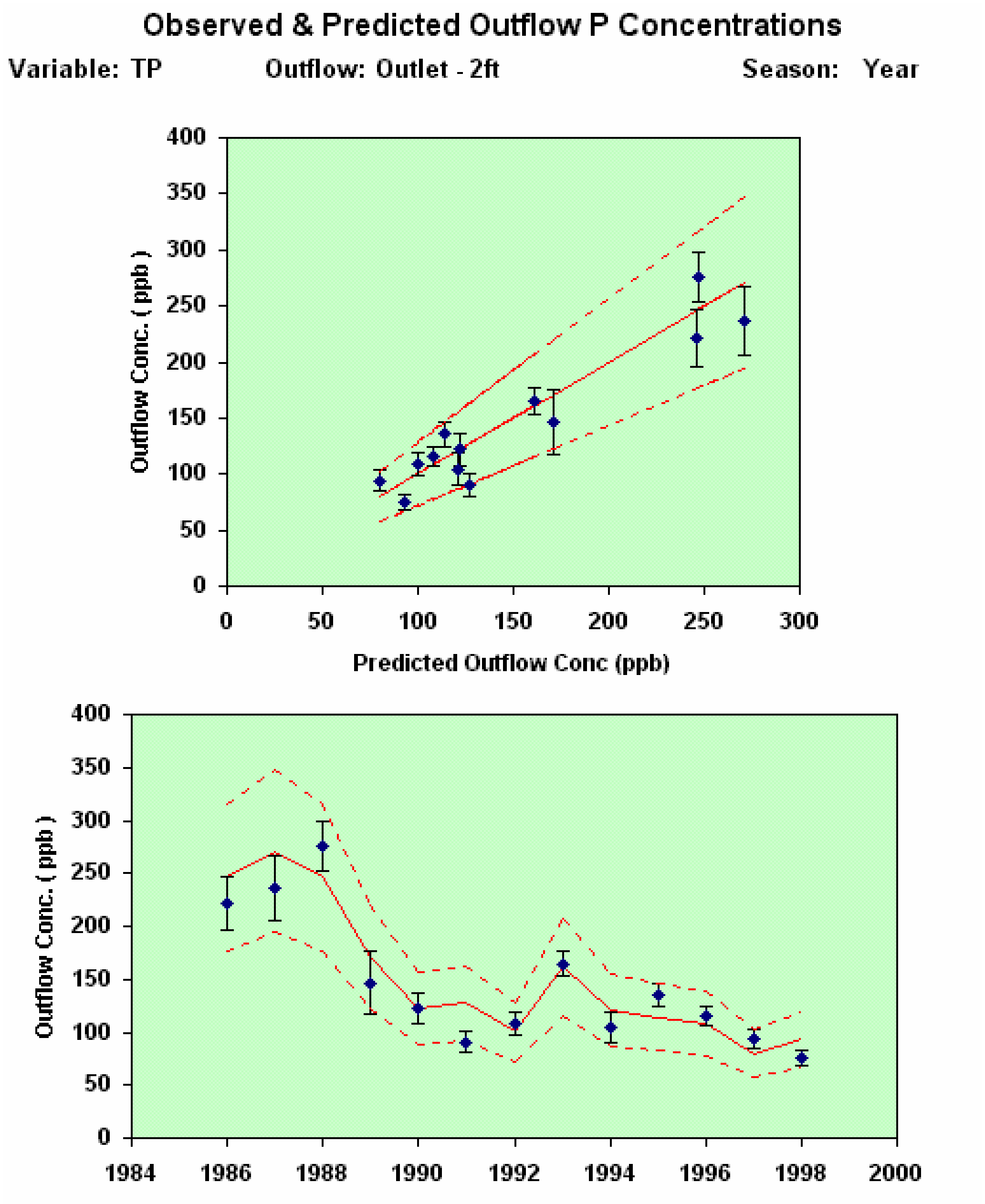
Summer epilimnetic phosphorus concentrations are of primary concern for evaluating lake trophic state. Observed values have been computed using 0 to 6 meter samples collected from June through September at the Lake South station. Sample results have been averaged by date before computing a mean and standard error for each year. Table 9-10 lists summer-mean epilimnetic concentrations for each year between 1986-1998, along with annual phosphorus balance terms.

The yearly phosphorus-balance model can be extended to predicted summer epilimnetic concentrations using an equation of the following form:

$$P_s = k \; P_o = k (1 - R) P_i$$

where,

P_s = summer epilimnetic total phosphorus concentration (ppb)
k = proportionality constant = 0.657 (calibrated)



Observed Std Dev	62.3	Predicted 90% Confidence Intervals			
Residual Std Dev	21.5	Model:	Calib Retention Coef.		
R-Squared	88%	Parameter Value	0.42		
Residual CV%	16%	Calib. Ret. Coef.	42%		
Significance Level	0.000	Calibration Pd:	1994	to	1998

FIGURE 9-6: Observed & Predicted Outflow Total P Concentrations

TABLE 9-10: Summary of Lake Phosphorus Balances, 1986-1998

Summary of Lake Phosphorus Balances

Calendar Years 1986-1998

	Outflow	Inflow Load		Metro+Bypass Load		Inflow Conc	Outflow Conc @ 2 ft		Lake South Epil. June-Sept, 0-6 m Concentration	
Year	10^6 m3	kg	RSE%	kg	RSE%	ppb	ppb	RSE%	ppb	RSE%
1986	520.1	219291	5%	160823	7%	422	221	11%	188	8%
1987	372.0	172524	5%	139721	6%	464	237	13%	157	6%
1988	344.2	145301	5%	113725	5%	422	276	8%	170	8%
1989	472.8	138328	8%	83672	11%	293	146	20%	108	21%
1990	654.7	136496	7%	68521	10%	208	122	12%	88	14%
1991	427.0	93004	8%	59151	11%	218	91	11%	61	9%
1992	516.6	88792	7%	60056	9%	172	109	10%	62	18%
1993	535.4	148006	5%	106586	6%	276	165	7%	132	12%
1994	475.5	98233	10%	68941	11%	207	104	13%	87	11%
1995	307.0	60025	5%	44741	3%	196	136	8%	72	13%
1996	530.1	98179	5%	55265	3%	185	116	8%	68	10%
1997	362.6	49448	3%	34160	2%	136	94	10%	56	10%
1998	449.9	71681	7%	43021	2%	159	75	9%	55	8%
94-98	425.0	75513	6%	49226	4%	178	104	10%	67.8	10%

RSE = relative standard error = standard error / mean

Note: Total P values for 1986-1989 estimated from Total Inorganic P values.

With k and R values calibrated to 1994-1998 data, the resulting equation is:

$$P_s = 0.657 \ (1 - 0.416) \ = 0.384 \ P_{I,}$$

$$90\% \text{ Confidence Interval} = [0.28 \text{ to } 0.49] \ P_I$$

Observed and predicted summer P concentrations for 1986-1998 are shown in Figure 9-7 (r^2 = 90%, Residual CV = 16%).

If the settling-velocity model is used to predict the yearly outflow concentration, the equation for predicting summer epilimnetic P concentration is:

$$P_s \ = \ k \ P_i \ Q_s \ / \ (Q_s + \ U) \ = \ 0.662 \ P_i \ Q_s / (Q_s + 25.9)$$

At the average surface overflow rate in 1994-1998 (Q_s = 36.3 m/yr, Table 9-10), this model is identical to the retention coefficient formulation. Observed and predicted time series are shown in Figure 9-8 (r^2 = 92%, CV = 13%). The settling-velocity model performs slightly better than the retention-coefficient model for predicting summer epilimnetic concentrations. Further analysis and/or future data may help to determine whether there is any significant difference between these models.

By selecting the 'Model_Applic' table on the control panel, the user can run the calibrated mass-balance model on a hypothetical loading scenario (Table 9-11). The screen shows the lake water and mass balance for the calibration period. Hypothetical percentage reductions in inflow volumes and/or loads can be specified. The program recalculates the water and mass balance and applies the calibrated models to predict 90% confidence intervals for annual-average outflow and summer epilimnetic concentrations. The probability that the summer epilimnetic value is below a user-specified criterion is also estimated.

The scenario in Table 9-11 assumes a 20% reduction in nonpoint phosphorus concentrations and 100 % reduction in the municipal load (complete diversion of flow).

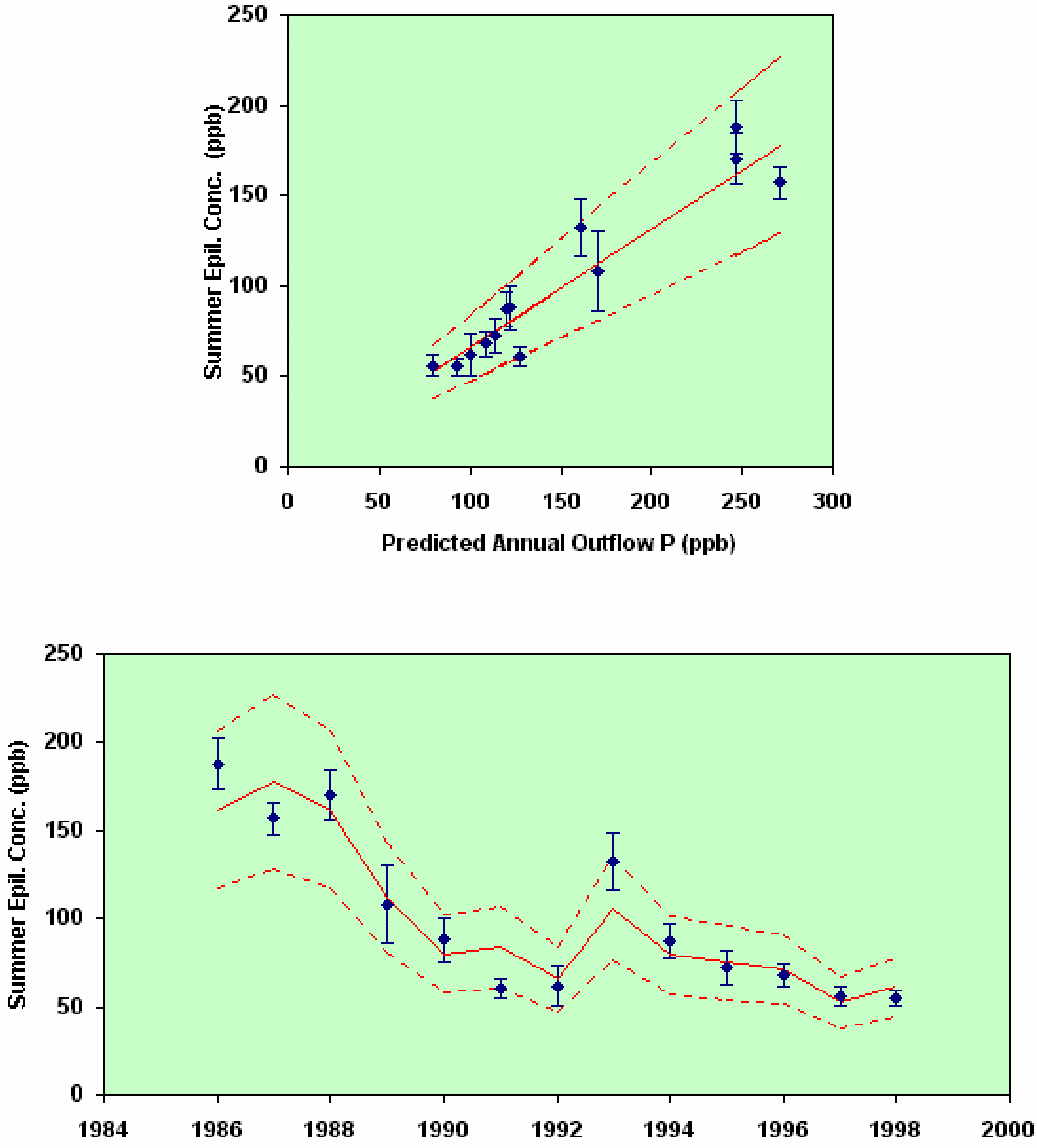
The 20% reduction brings the nonpoint inflow concentration down to 63 ppb, which is similar to values measured at stations with less-developed watersheds (e.g., Onondaga Creek @ Dorwin or Ninemile Creek, Table 9-9). The net reduction in total load amounts to 72% relative to 1994-1998 conditions. The model predicts an average summer concentration of 25 ppb, a 90 % confidence interval of 18 to 31 ppb, and a 13% chance that the summer-mean concentration would be below the 20 ppb criterion. Since this is probably close to a background scenario (without point sources or urban runoff), results suggest that a summer-mean concentration of 20 ppb is not likely to be achievable with source controls alone.

Setting realistic goals for the Lake requires consideration of inherent lake and watershed characteristics (drainage area, land use, lake area, depth, flushing rate. etc.). The ecoregion concept has been shown to be useful in this type of effort (Wilson & Walker, 1989). The goal should also reflect the lake-specific relationships between phosphorus concentrations and more direct measures of use impairment (e.g., transparency, algal bloom frequency, hypolimnetic oxygen depletion, etc.). For example, since more than 80% of the summer transparency measurements between 1994-1998 were better than the 1.2-meter bathing criterion, it does not appear likely that a phosphorus concentration of 20 ppb is needed to satisfy the transparency criterion.

Development of empirical models linking lake phosphorus to transparency and other direct measures of trophic state and use impairment would provide a more complete picture of lake responses to alternative load scenarios. The lake mass-balance model could be linked with a phosphorus export model for predicting nonpoint inputs as a function of watershed land use to provide an improved basis evaluating background (undeveloped) loads and corresponding lake water quality conditions (Walker, 1982). Important perspectives on year-to-year variations could also be gained by applying the model to yearly time series.

Observed & Predicted Summer Epilimnetic Concentrations

Variable: Total Phosphorus Model: Calib Retention Coef.

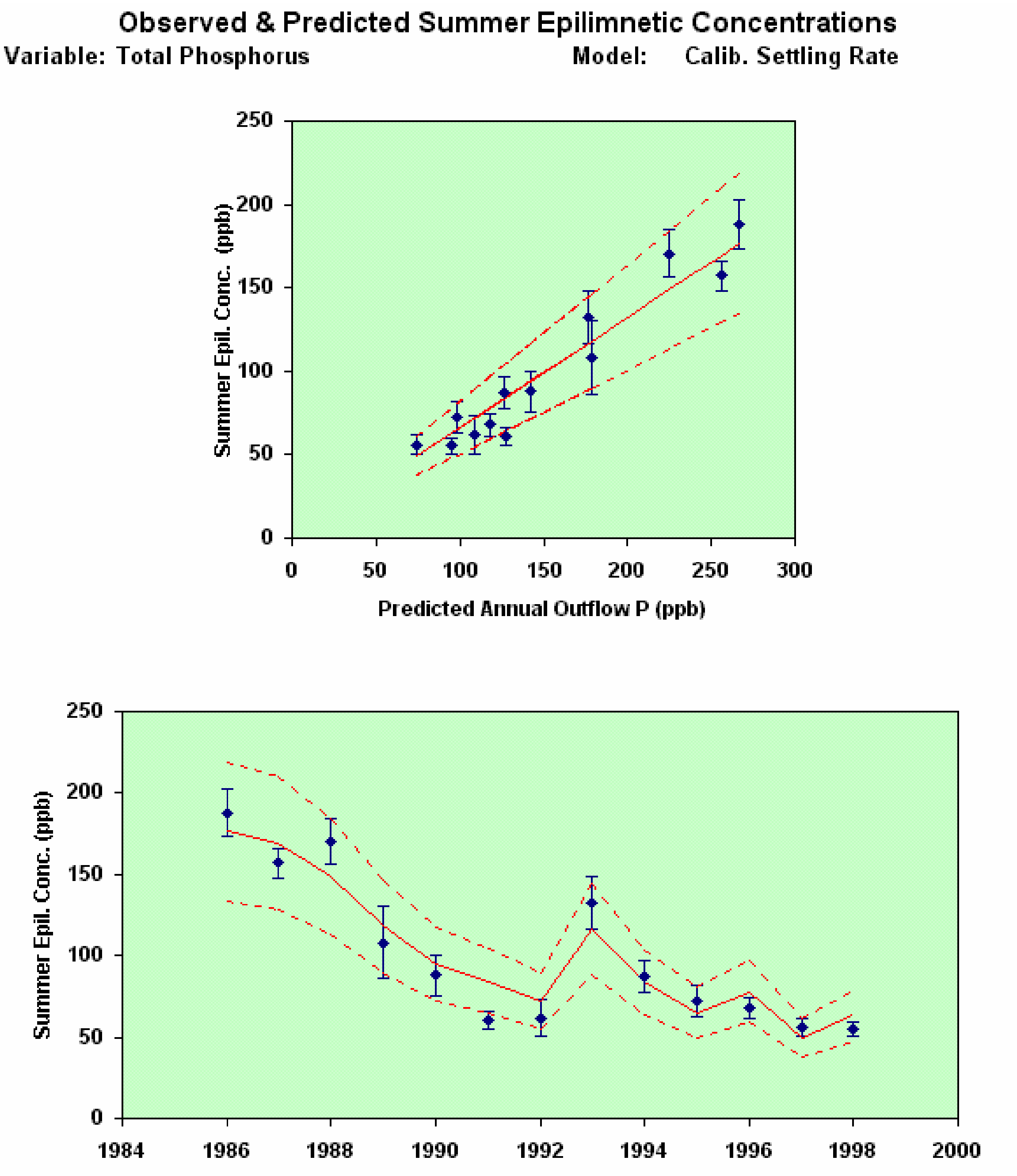


Model: Cs = 0.657 Co
Co = Ci (1 - R)
R = 0.42

Calibration Period: 1994 to 1998
R^2 90%
Residual CV 16% p = 0.000

Cs = June-September, Epilimnion
Co = Annual Average Outflow Conc.
Ci = Annual Average Inflow Conc.
Qs = Overflow Rate (m/yr)
U = Settling Rate (m/yr)
R = Retention Coef.
Model: Calib Retention Coef.

FIGURE 9-7: Observed & Predicted Summer P , Retention Coefficient Model



Model:	Cs =	0.662 Co		Cs =	June-September, Epilimnion
	Co =	Ci Qs / (Qs + U)		Co =	Annual Average Outflow Conc.
	U =	25.86 m/yr		Ci =	Annual Average Inflow Conc.
				Qs =	Overflow Rate (m/yr)
Calibration Period:		1994 to 1998		U =	Settling Rate (m/yr)
R^2		92%		R =	Retention Coef.
Residual CV		13%	p = 0.000	Model:	Calib. Settling Rate

FIGURE 9-8: Observed & Predicted Summer P , Settling Velocity Model

9.8 NITROGEN BALANCE MODELS

Model formulations and calibration procedures identical to those described above for phosphorus have also been applied to predict outflow and epilimnetic total nitrogen concentrations. Average nitrogen balances of the 1994-1998 calibration period are listed in Table 9-12. The settling velocity model performs slightly better than retention coefficient model.

The calibrated equation for yearly outflow total nitrogen concentration (Figure 9-9) is:

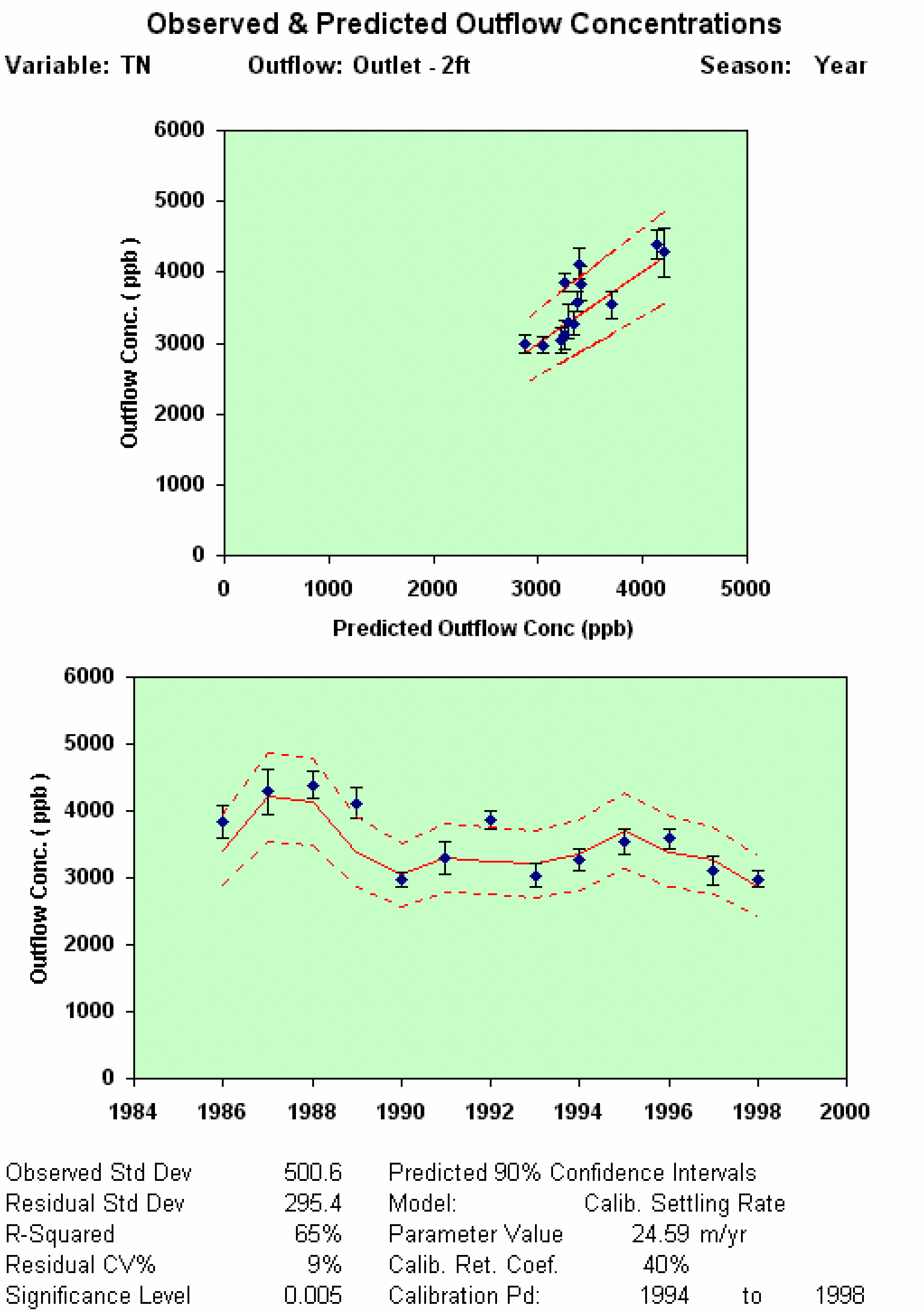
$$N_o = N_i \; Q_s / (Q_s + 24.6), \qquad r^2 = 65\%, \text{ Resid.CV} = 9\%$$

The calibrated equation for June-September epilimnetic concentration (Figure 9-10) is:

$$N_s = 1.213 \; N_i \; Q_s / (Q_s + 24.6), \qquad r^2 = 56\%, \text{ Resid.CV} = 9\%$$

The nitrogen models have substantially lower r^2 values than the phosphorus models described above ($r^2 >= 90\%$). The lower residual CV's for nitrogen (9% vs. 13%) reflect that fact that total nitrogen concentrations are inherently less variable.

Since algal productivity in the lake is clearly not nitrogen limited, total nitrogen models are of limited use for predicting the trophic state of Onondaga Lake. It is likely that algal uptake and sedimentation accounts for significant portion of the nitrogen losses from the water column. To the extent that algal productivity is controlled by phosphorus under existing and future conditions, it is possible that the retention coefficient (or settling velocity) for total nitrogen will decrease if control measures are successful in reducing lake phosphorus concentrations. Given the relative complexity of the nitrogen cycle, more detailed mechanistic models are required to predict individual nitrogen species which are of direct concern with respect to water quality standards unrelated to eutrophication (e.g., nitrite and ammonia).

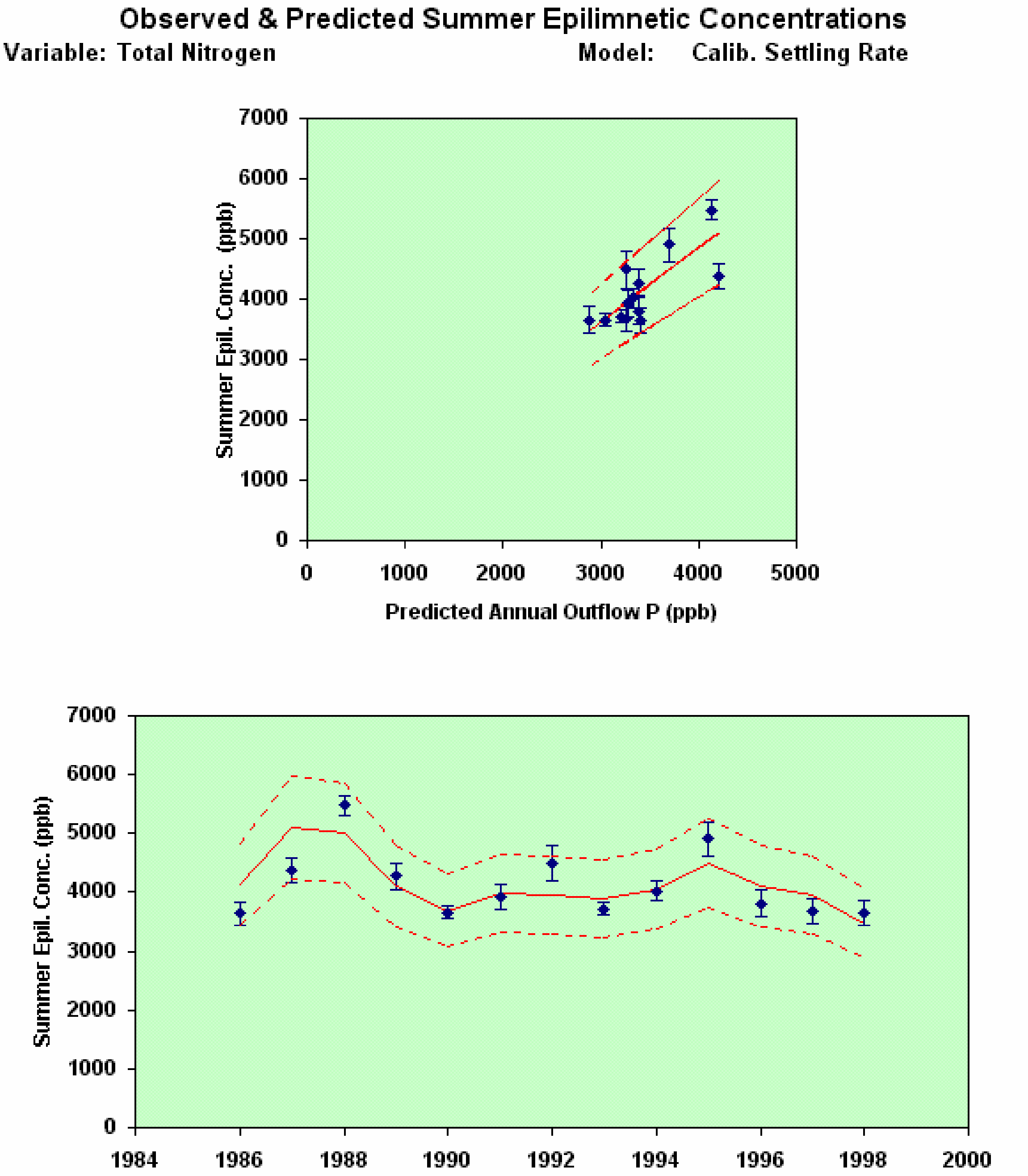


Observed & Predicted Outflow Concentrations

Variable: TN   Outflow: Outlet - 2ft   Season: Year

Observed Std Dev	500.6	Predicted 90% Confidence Intervals			
Residual Std Dev	295.4	Model:	Calib. Settling Rate		
R-Squared	65%	Parameter Value	24.59 m/yr		
Residual CV%	9%	Calib. Ret. Coef.	40%		
Significance Level	0.005	Calibration Pd:	1994	to	1998

FIGURE 9-9: Observed & Predicted Outflow N Concentrations



Model: Cs = 1.213 Co
Co = Ci Qs / (Qs + U)
U = 24.59 m/yr

Calibration Period: 1994 to 1998
R^2 56%
Residual CV 9% p = 0.011

Cs = June-September, Epilimnion
Co = Annual Average Outflow Conc.
Ci = Annual Average Inflow Conc.
Qs = Overflow Rate (m/yr)
U = Settling Rate (m/yr)
R = Retention Coef.
Model: Calib. Settling Rate

FIGURE 9-10: Observed & Predicted Summer Epilimnetic N Concentrations

9.9: REFERENCES

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Chapter 9 - DRAFT

W. Walker

June 22, 1999

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