# Adaptation of MINLEAP to Lakes in Itasca County

prepared for

Minnesota Department of Natural Resources

By

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The Minnesota Lake Eutrophication Analysis Procedure (MINLEAP, Wilson & Walker, 1989) was developed to predict eutrophication indices based upon information readily available for most lakes (watershed area, lake area, mean depth, and ecoregion). The model was calibrated to data from minimally-impacted lakes in each of four ecoregions in Minnesota. It provided a simple screening tool for predicting a baseline water quality condition that is consistent with other regional lakes and adjusted for lake-specific features (watershed size, morphometry). Comparison of measured lake conditions with the baseline conditions predicted by the model provided a means of identifying lakes potentially impacted by anthropogenic sources.

The following modifications and enhancements were made to MINLEAP under the current project:

1. Translation of model code from Basic to Excel;

2. Linkage to an Access database containing observed water quality and an Excel data table containing other model input variables. The database can accommodate up to 2000 lakes. This facilitates use of the model for regional as well as individual lake assessments.

3. Calibration and testing of the model equations against data from 163 lakes in the Northern Lakes & Forests ecoregion, most of which are in Itasca County; calibration involved:
   a. adjustment of loading factors for lakes on the Canadian shield;
   b. adjustment of P retention factors for polymictic lakes;
   c. alternative model for predicting Secchi depth as a function of chlorophyll-a concentration (optional)

4. Addition of algorithms for evaluating lake sensitivity to shoreline development, expressed in terms of percentage change in trophic state variables potentially resulting from full development of shoreline relative to ecoregion baseline conditions.

5. Addition of algorithms for ranking lakes with respect to sensitivity or other model input/output variables;

6. Addition of indices of hypolimnetic oxygen depletion (probability of anoxic classification (Reckhow & Chapra, 1983) and percent of measurements below 2 ppm)

7. Provision for evaluating lake response to a hypothetical scenario (user-specified number of shoreline loads and/or additional P load). The scenario is compared with the ecoregion baseline, existing development, and full development scenarios.

The model is interactive and operated from a menu located on an Excel worksheet (Figure 1). The Appendix contains model documentation (also provided as a worksheet in the model workbook) and calibration charts.

Following is a list of model limitations and potential enhancements:

1. MINLEAP develops lake phosphorus balances and applies empirical models to predict trophic indices (Wilson & Walker, 1989). Simplicity and minimal input requirements are necessary to allow broad application using information that is generally available. This type of model is generally more accurate for relative predictions (sensitivity, ranking) as compared with absolute predictions for individual lakes.

2. The Appendix summarizes uncertainty associated with predictions of trophic state indicators (residual standard errors as a percentage of predicted value). Generally, standard errors are lower than those reported by Wilson & Walker (1989) for the original statewide application of MINLEAP. Standard errors decrease as the number of sampling dates increase; this suggests that a significant portion of the residual variance is attributed to measurement variability as opposed to model error. Residual variance decreases as the minimum number of sampling dates decrease from 1 to 10 per lake. Additional testing indicates that variance does not decrease significantly for sampling dates above 10. This indicates that there is considerable benefit to sampling lakes on at least 10 dates (preferably spaced over 3 years or so) to support lake assessments, but that is not a requirement for applying the model.

3. Residual errors for chlorophyll-a and transparency are strongly correlated with residual error for total phosphorus; this suggests that model errors in predicting lake phosphorus concentration (sensitive to watershed loading and lake P retention) are relatively important.

4. Lot P loads are estimated based upon user-specified average lot dimensions and loading factors for runoff and septic tank effluents. Nominal parameter estimates for lot loading factors are initially specified. Detailed assessments of individual lakes and developments may require more complex models that consider additional site-specific factors (lot dimensions, population, age of septic system, set-back from lake, impervious vs. pervious area, soil types, soil depth, slope, buffer zones, BMP's etc.). Because most of the lakes in this dataset are minimally impacted, it is not possible to test the accuracy of the initially

assumed lot loading factors against observed lake conditions. Regional or lake-specific loading factors can be independently estimated and entered into the lake database for use in assessments and ranking. Testing sensitivity to assumed loading factors is recommended in applying the model to individual lakes and in developing regional rankings.

5. Since most of the lakes are minimally impacted, model testing results (Appendix) are reasonably insensitive to assumed lot loading factors. Lakes with at least 3 sampling dates for trophic indicators were used in testing the models against observed data. Predictions for the existing lot counts were used in model testing, otherwise predictions for ecoregion baseline predictions were used.

6. Consistent with the original version of MINLEAP, baseline P loads are estimated from watershed area and ecoregion average runoff rates and stream P concentrations. Each lake is assumed to be independent. In watersheds with multiple linked lakes, the potential impacts of phosphorus trapping in upstream lakes and of development in the watersheds of upstream lakes are ignored. Significant modifications to the model structure and database would be required to account for such factors.

7. While only 34 lakes had both land use and observed water quality data (>= 3 sampling dates), the percentage of the watershed in wetlands is weakly correlated with model residual errors for chlorophyll-a (positive , $r^2 = 0.16$) and for Secchi depth (negative, $r^2 = 0.10$); i.e. lakes with watersheds having higher wetland percentages tend to have observed chlorophyll-a values that are greater than predicted and observed Secchi Depths that are lower than predicted. Phosphorus residuals are uncorrelated with wetland percentage, however. Reasons for these apparent correlations are unknown, but they explain small proportions of the total residual variance. Further investigation using an expanded database is recommended.

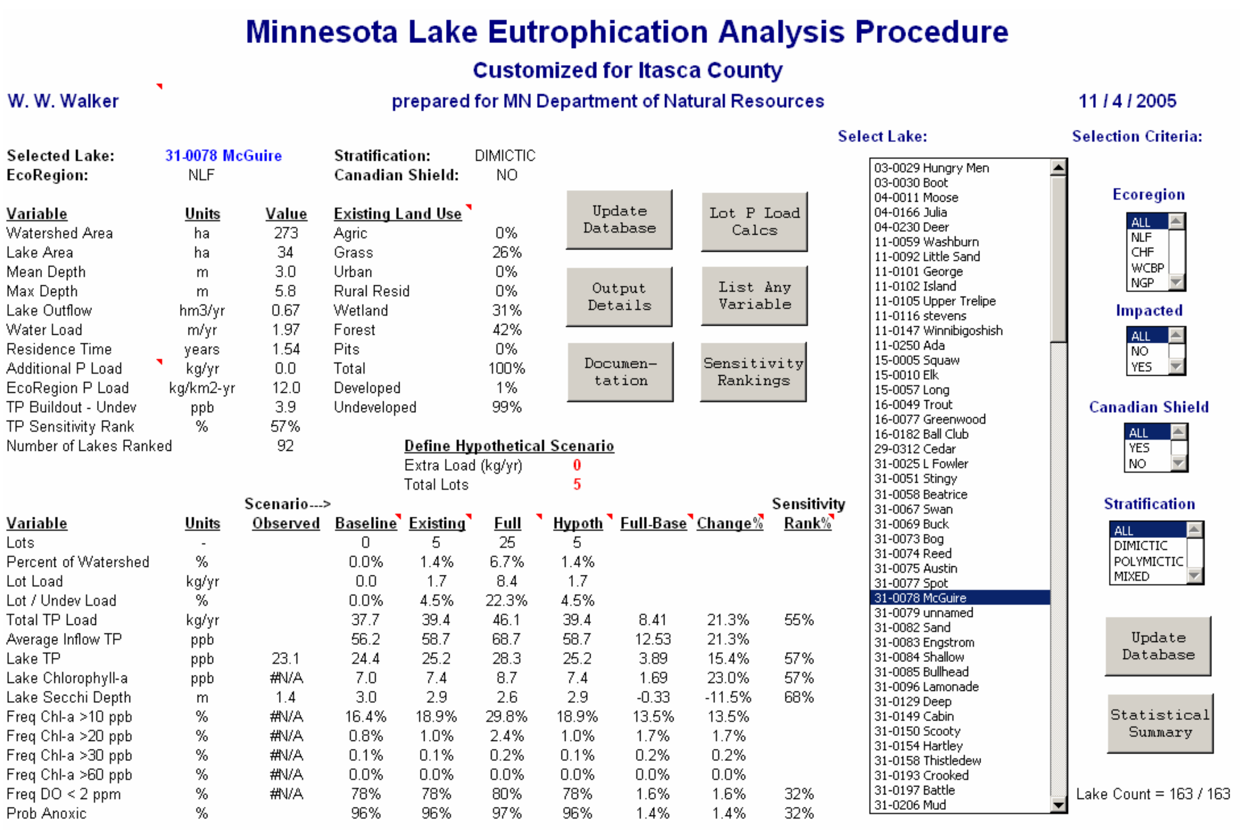
8. Further testing and refinement of the oxygen depletion models against an expanded dataset is recommended. Reckhow’s equation for predicting oxic vs. anoxic classification in northern lakes is included, but not specifically tested against data from these lakes. This would require greater monitoring frequencies (at least monthly) than are typical of the lake datasets provided. The model for predicting the percentage of hypolimnetic DO measurements less than 2 ppm was calibrated to a limited set of 10 lakes, but requires further testing on expanded datasets with higher monitoring frequencies.

References

Wilson, B. and W. Walker, “Development of Lake Assessment Methods Based upon the Aquatic Ecoregion Concept”, Lake & Reservoir Mgt, Vol, 5, No. 2, pp 11-22, 1989.

Reckhow K. & S. Chapra, Engineering Approaches for Lake Management, Volume 1, 1983, page 242.

Figure 1 – Program Menu



**Minnesota Lake Eutrophication Analysis Procedure**

**Customized for Itasca County**

W. W. Walker

prepared for MN Department of Natural Resources

11 / 4 / 2005

| | | | | |
|---|---|---|---|---|
| **Selected Lake:** | 31-0078 McGuire | | **Stratification:** | DIMICTIC |
| **EcoRegion:** | NLF | | **Canadian Shield:** | NO |

| Variable | Units | Value | Existing Land Use | |
|---|---|---|---|---|
| Watershed Area | ha | 273 | Agric | 0% |
| Lake Area | ha | 34 | Grass | 26% |
| Mean Depth | m | 3.0 | Urban | 0% |
| Max Depth | m | 5.8 | Rural Resid | 0% |
| Lake Outflow | hm3/yr | 0.67 | Wetland | 31% |
| Water Load | m/yr | 1.97 | Forest | 42% |
| Residence Time | years | 1.54 | Pits | 0% |
| Additional P Load | kg/yr | 0.0 | Total | 100% |
| EcoRegion P Load | kg/km2-yr | 12.0 | Developed | 1% |
| TP Buildout - Undev | ppb | 3.9 | Undeveloped | 99% |
| TP Sensitivity Rank | % | 57% | | |
| Number of Lakes Ranked | | 92 | | |

Update Database | Lot P Load Calcs | Output Details | List Any Variable | Documen-tation | Sensitivity Rankings

**Define Hypothetical Scenario**

| | |
|---|---|
| Extra Load (kg/yr) | 0 |
| Total Lots | 5 |

| Variable | Units | Scenario---> Observed | Baseline | Existing | Full | Hypoth | Full-Base | Change% | Sensitivity Rank% |
|---|---|---|---|---|---|---|---|---|---|
| Lots | - | | 0 | 5 | 25 | 5 | | | |
| Percent of Watershed | % | | 0.0% | 1.4% | 6.7% | 1.4% | | | |
| Lot Load | kg/yr | | 0.0 | 1.7 | 8.4 | 1.7 | | | |
| Lot / Undev Load | % | | 0.0% | 4.5% | 22.3% | 4.5% | | | |
| Total TP Load | kg/yr | | 37.7 | 39.4 | 46.1 | 39.4 | 8.41 | 21.3% | 55% |
| Average Inflow TP | ppb | | 56.2 | 58.7 | 68.7 | 58.7 | 12.53 | 21.3% | |
| Lake TP | ppb | 23.1 | 24.4 | 25.2 | 28.3 | 25.2 | 3.89 | 15.4% | 57% |
| Lake Chlorophyll-a | ppb | #N/A | 7.0 | 7.4 | 8.7 | 7.4 | 1.69 | 23.0% | 57% |
| Lake Secchi Depth | m | 1.4 | 3.0 | 2.9 | 2.6 | 2.9 | -0.33 | -11.5% | 68% |
| Freq Chl-a >10 ppb | % | #N/A | 16.4% | 18.9% | 29.8% | 18.9% | 13.5% | 13.5% | |
| Freq Chl-a >20 ppb | % | #N/A | 0.8% | 1.0% | 2.4% | 1.0% | 1.7% | 1.7% | |
| Freq Chl-a >30 ppb | % | #N/A | 0.1% | 0.1% | 0.2% | 0.1% | 0.2% | 0.2% | |
| Freq Chl-a >60 ppb | % | #N/A | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | |
| Freq DO < 2 ppm | % | #N/A | 78% | 78% | 80% | 78% | 1.6% | 1.6% | 32% |
| Prob Anoxic | % | | 96% | 96% | 97% | 96% | 1.4% | 1.4% | 32% |

**Select Lake:**

03-0029 Hungry Men
03-0030 Boot
04-0011 Moose
04-0166 Julia
04-0230 Deer
11-0059 Washburn
11-0092 Little Sand
11-0101 George
11-0102 Island
11-0105 Upper Trelipe
11-0116 stevens
11-0147 Winnibigoshish
11-0250 Ada
15-0005 Squaw
15-0010 Elk
15-0057 Long
16-0049 Trout
16-0077 Greenwood
16-0182 Ball Club
29-0312 Cedar
31-0025 L Fowler
31-0051 Stingy
31-0058 Beatrice
31-0067 Swan
31-0069 Buck
31-0073 Bog
31-0074 Reed
31-0075 Austin
31-0077 Spot
31-0078 McGuire
31-0079 unnamed
31-0082 Sand
31-0083 Engstrom
31-0084 Shallow
31-0085 Bullhead
31-0096 Lamonade
31-0129 Deep
31-0149 Cabin
31-0150 Scooty
31-0154 Hartley
31-0158 Thistledew
31-0193 Crooked
31-0197 Battle
31-0206 Mud

**Selection Criteria:**

Ecoregion: ALL, NLF, CHF, WCBP, NGP

Impacted: ALL, NO, YES

Canadian Shield: ALL, YES, NO

Stratification: ALL, DIMICTIC, POLYMICTIC, MIXED

Update Database | Statistical Summary

Lake Count = 163 / 163

**MINLEAP_ITASCA Documentation** **William. W. Walker, Jr., Ph.D** http://www.wwwalker.net **Version:** **11 / 4 / 2005**

Adaptation of MINLEAP (Wilson & Walker, 1989) to facilitate regional evaluations of lake sensitivity to shoreline development.
Lakes are ranked based upon change in trophic response variables with full buildout vs. undeveloped (ecoregion baseline)
Program operates from 'Model" worksheet (press Ctrl-m to go there from any other worksheet). User input cells are red.

The LakeIndex sheet contains a master list of all lakes & associated features (morphometry, land use, lots, etc..)
Subsets of data can be selected for analysis from the 'Selection Criteria' boxes on the menu (Ecoregion, Mixing, Impacted, Canadian Shield)
Click the 'Update Database' button to extract the selected records (copied to Output Sheet) and update all database fields.
Up to 2000 lakes can be included in the database.

**TP Load Components**

Ecoregion background (original MINLEAP calibration)
Shoreline Lots (computed from number of lots and loading factors (runoff, septic tanks) defined on the 'LotLoads' sheet)
Additional P Load - user defined in the Lake Index (does not apply to the Undeveloped scenario)
Atmospheric Load

( Although land use data are contained in the LakeIndex, these are not used in the computations. )

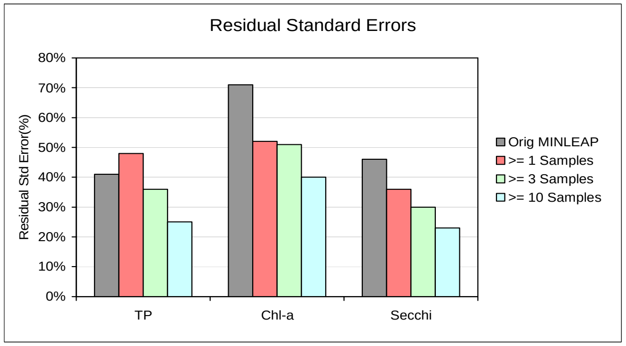
**Development Scenarios**

| | |
|---|---|
| Observed | Observed data; retrieved from 'WaterQualityData' sheet |
| Undev | Predicted for undeveloped watershed - ecoregion background load - estimated from original MINLEAP calibration |
| Existing | Predicted for existing development - number of shoreline lots - from LakeIndex sheet |
| Full | Predicted for full buildout buildout - number of shoreline lots - from LakeIndex sheet |
| Hypoth | Hypothetical scenario (user enters a supplemental P load (kg/yr) and/or total number of shoreline lots) |

**Calibration**

Based upon model testing results, the following adjustments to the original MINLEAP calibrations :
- The Ecoregion background stream concentration for Canadian Shield lakes was reduced by 30% (calib factor = 0.7)
- Phosphorus Sedimentation in Polymitic lakes was reduced by 50% (calib factor = 0.5)

These adjustments were necessary to give unbiased predictions ot TP, Chl-a, & Secchi in the calibration lakes.
The calibration factors are defined on the Model sheet (Rows 83 - 90)
A secchi vs. chlorophyll-a model borrowed from BATHTUB (Walker 2004) provides a slighly better fit and is included as an option to the original MINLEAP equation.
The secchi model is selected in row 89 of the Models sheet and described in the Fig_ObsTSI sheet.
Predicted values used in calibration are based on existing development scenario; if existing lots are not defined in LakeIndex, the Undev scenario was used.
Indicators of oxygen depletion have been added. These have not been extensively tested on regional data. See 'Fig_Oxygen' sheet.
Calibration charts for various subsets of data are shown in a separate document (minleap_itasca_calibrations.pdf)
Residual standard errors are generally lower than those derived from the original MINLEAP dataset, especially as the minimum number of sampling dates increases:



| Menu Button | Function |
|---|---|
| Update Database | extracts selected lakes from the index and updates all database fields; run only if input data, lake selection criteria, or assumptions are changed |
| Lot P Load Calcs | jumps to 'LotLoads' sheet |
| Sensitivtity Ranking | jumps to 'Ranking' sheet |
| List Any Variable | jumps to 'ListAny' sheet |
| Output Details | jumps to 'Output' sheet, containing all variables for each selected lake, & points to currently selected lake |
| Summary | jumps to 'Summary' sheet |
| Documentation | jumps here |

| Sheet | Description | Type | Access Query | Comments |
|---|---|---|---|---|
| Model | Basic Calculations for a Single Lake | Main | | main program menu |
| LotLoads | Assumptions & Computations of P Load from Shoreline Lots | Output | | |
| Ranking | Lake Sensitivity Ranking | Output | | |
| ListAny | List & Sort Lake Data Based upon Any Variable | Output | | |
| Output | Combined Output for All Selected Lakes | Output | | |
| Summary | Statistical Summary of Inputs & Outputs for Selected Lakes | Output | | |
| Documentation | This page | Documentation | | |
| | | | | |
| LakeIndex | Central Index of All Lakes with Morphometry, Lot Info, Etc | Input | | |
| WaterQualityData | Observed TP, Chla, Secchi by Lake, May-Sept, Depth < 2.1 m | Input | minleap_tp_chla_secchi | original MINLEAP data appended |
| OxygenData | Observed DO data by Lake, July-Sept, Depth > 5 meters | Input | minleap_oxygen | |
| | | | | |
| Fig_Calib | Observed & Predicted TP, CHl-a, Secchi Values | Calibration/Testing Results for Currently Selected Lakes | | |
| Fig_Oxygen | Observed & Predicted Frequencies DO < 2 ppm | "" | | |
| Fig_ObsTSI | Correlations Among Observed TSI's | "" | | |
| Fig_Resid_TP | Residual TP Concs (Ln (Obs/Predicted) ) vs. Lake Features | "" | | |
| Fig_Resid_Chla | Residual Chl-a Depths (Ln (Obs/Predicted) ) vs. Lake Features | "" | | |
| Fig_Resid_Secchi | Residual Secchi Depths (Ln (Obs/Predicted) ) vs. Lake Features | "" | | |
| Fig_Resid_Correl | Correlations Among Model Residuals | | | |

**Database Notes**

Most of the input data tables were initially created using Queries in the supporting Access Database ('minleap_itasca.mdb').
Additional lake data from the original MINLEAP database are appended to the lake index & water quality data tables

The LakeIndex sheet can be updated/edited manually. To add new lakes, insert a new row or add one to the bottom.
The formula for calculating the number of lots at full buildout (column S) should be copied to any new records.
Lakes are indexed by ID Code (e.g. '31-0005'). There should be only one record per ID code
It makes sense to sort the LakeIndex by ID Code (but not necessary) to make it easier to find on the program menu

The WaterQualityData and OxygenData tables can be edited manually or copied from the Access Queries supplied.
After updating the source data tables in the Access database, the query output tables (minleap_tp_chla_secchi & minleap_oxygen)
These tables can be sorted in any order and do not have to contain data for each lake in the LakeIndex.
In the queries, observed water quality values are computed by first averaging the data by date, then averaging across dates.
This places equal weight on each sampling date in computing the lake average value.

Generally a bad idea to DELETE rows at the bottom of any input table. CLEAR the cells instead (select cells with mouse, then hit 'DEL' key).

**Reference**

Wilson, B. & W. Walker, "Development of Lake Assessment Methods Based upon the Aquatic Ecoregion Concept", Lake& Reservoir Mgt, Vol. 5, No. 2, pp. 11-22, 1989.
http://www.wwwalker.net/pdf/ecoreg.pdf

## Computation of P Load from Shoreline Lots

no user inputs on this page

**Assumed Lot Dimensions**

| | | | | | |
|---|---|---|---|---|---|
| Lot Frontage on Lake | 200 | ft | blue cells are input values specified in Lake Index | | |
| Lot Depth | 400 | ft | | | |
| Equivalent Lot Size | 0.74 | hectares = | 1.84 | acres | |

**Runoff Load**

| | | | |
|---|---|---|---|
| Unit Area Runoff Load from Lot | 30 | kg/km$^2$-yr | Values for Twin Cities area are summarized below |

**Septic Load**

| | | | |
|---|---|---|---|
| P Input to Septic System | 0.66 | kg/capita-yr | LCM Value = 0.66 * |
| Yearly Average Inhabitants / Lot | 2.0 | capita / lot | |
| Load Attenuation in Soils between Tank & Lake | 90% | | LCM assumes 100% for setback > 300 m * |

| **Summary of Results** | kg/km$^2$/yr | kg/lot-yr | | | Lots | Shoreline (m) |
|---|---|---|---|---|---|---|
| Lot Runoff | 30.0 | 0.223 | | Total Shoreline Length | | 7952 |
| Septic Systems | 17.8 | 0.132 | | Buildable Shoreline | 105 | 6381 |
| Total P Export from Lot | 47.8 | 0.355 | | Existing | 93 | 5671 |
| Ecoregion Background | 12.0 | 0.089 | | Remaning Capacity | 11.6 | 710 |
| Incremental Load from Lot | 35.8 | 0.266 | above background | Existing % of Max | 89% | 89% |

| **Results for Current Lake** | | 31-0084 Shallow | | |
|---|---|---|---|---|
| Development | | Baseline | Existing | Full |
| Number of Lots | | 0.0 | 93.0 | 104.6 |
| Lot Runoff | kg/yr | 0.0 | 20.7 | 23.3 |
| Septic System | kg/yr | 0.0 | 12.3 | 13.8 |
| Total from Lot | kg/yr | 0.0 | 33.0 | 37.2 |
| Net from Lot | kg/yr | 0.0 | 24.8 | 27.8 |
| Ecoregion Background | kg/yr | 36.6 | 36.6 | 36.6 |
| Additional P Load | kg/yr | 0.0 | 0.0 | 0.0 |
| Atmospheric | kg/yr | 32.6 | 32.6 | 32.6 |
| Total to Lake | kg/yr | 69.2 | 94.0 | 97.1 |
| Net Lot / Total | % | 0.0% | 26.3% | 28.7% |

**Sensitivity of Predicted Lake P to Assumptions**

Lake P Conc (ppb) for 2-fold variation in runoff & septic loads

Full Buildout Lots = 105

| | | Septic Tank Scale Factor | | |
|---|---|---|---|---|
| | | 0.5 | 1.0 | 2.0 |
| Runoff | 0.5 | 11.2 | 11.8 | 12.9 |
| Scale | 1.0 | 12.1 | **12.7** | 13.8 |
| Factor | 2.0 | 13.9 | 14.4 | 15.4 |
| Lake P Range (ppb) | | 11.2 | to | 15.4 |
| Percent of Median | | 88.0% | to | 121.3% |

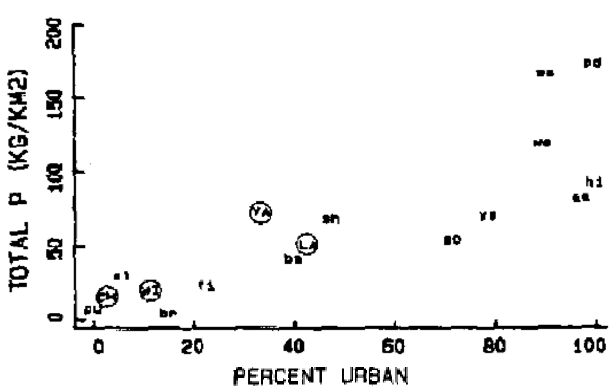
**Notes**

It is impossible to generalize about runoff & septic P loads from shoreline lots without more detailed information.
Nominal parameter estimates for runoff & septic tank loading factors are initially specified in the Lake Index.
Sensitivity to assumed runoff & septic loads is shown in the table on the lower right.
Users can test sensitivity to alternative assumptions for runoff and septic load parameters by modifying entries in Lake Index

**References**


* LCM = Ontario Lakeshore Capacity Model
Paterson, A. M., P. J. Dillon, N. J. Hutchinson, M. N. Futter, B. J. Clark, R. B. Mills, R.A. Reid, & W.A. Scheider
"A review of the components, coefficients, and technical assumptions of Ontario's Lakeshore Capacity Model"
Draft Manuscript submitted to Lake & Reservoir Management, 2004.

Unit Area P Export vs. Percent Urban Land Use
Walker, W.W., "Urban Non-Point Source Impacts on a Surface Water Supply",
Proc. EPA Conf On Non-Point Sources, Kansas City, 'EPA-440/5-85-001, May 1985.
http://www.wwwalker.net/pdf/urbannps.pdf


Circled - May-September, Vadnais Lake area watersheds, St. Paul.
Others are yearly values for other Twin Cities Area watersheds
Most watersheds had storm & sanitary sewers, so probably overestimate runoff loads for low-density residential lots without storm sewers & reasonab
set back from shoreline .

# MINLEAP for Itasca County
# Documentation & Calibration Charts

W. Walker

November 4, 2005

| Figure | Description |
|---|---|
| 1 | Correlations Among Observed TP, Chl-a, & Secchi, >=1 Sampling Date Per Lake |
| 2 | Correlations Among Observed TP, Chl-a, & Secchi, >=3 Sampling Dates Per Lake |
| 3 | Correlations Among Observed TP, Chl-a, & Secchi, >= 10 Sampling Dates Per Lake |
| 4 | Calibration Charts - Minimum 1 Sampling Date Per Lake |
| 5 | Calibration Charts - Minimum 3 Sampling Dates Per Lake |
| 6 | Calibration Charts - Minimum 10 Sampling Dates Per Lake |
| 7 | Calibration Charts - Canadian Shield Lakes |
| 8 | Calibration Charts - Polymictic Lakes |
| 9 | Phosphorus Residuals |
| 10 | Chlorophyll-a Residuals |
| 11 | Secchi Residuals |
| 12 | Correlations Among Model Residuals |
| 13 | Oxygen Models |

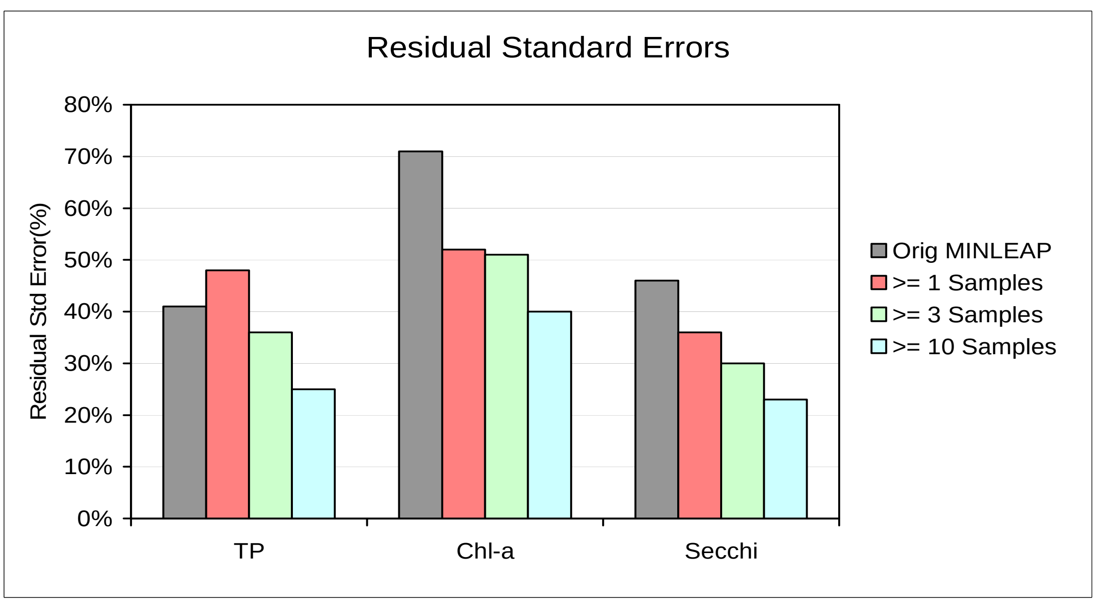
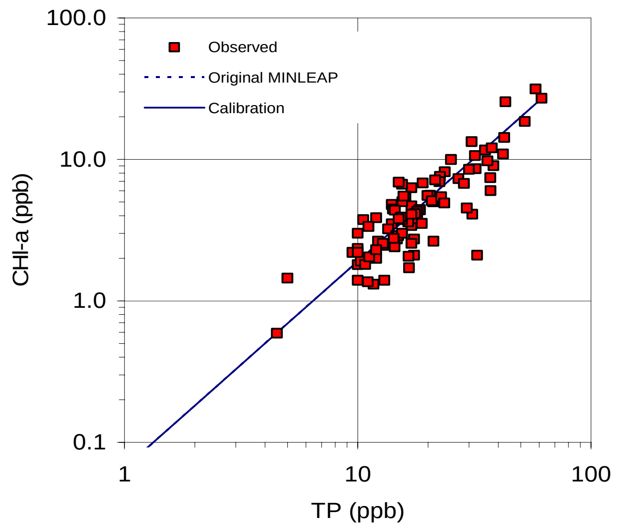
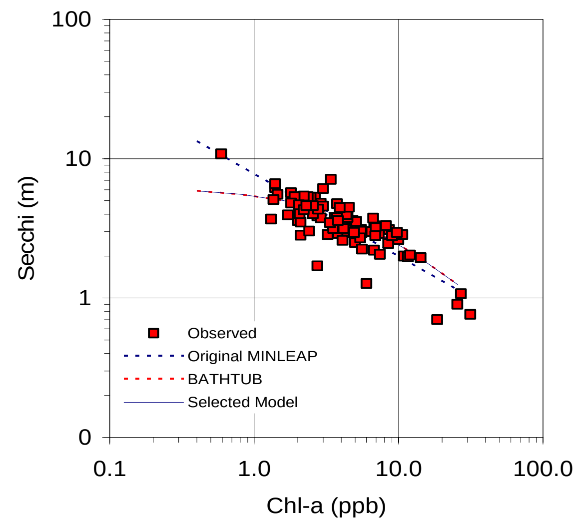


**Figure 1** **Correlations Among Observed TP, Chl-a, & Secchi Values** **Minimum 1 Sample Per Lake**




Residual Statistics
Residual = ln (Observed / Predicted ) Values

| Model | Chla vs. P | Secchi vs. Chla |
|---|---|---|
| Minimum Samples | 1 | 1 |
| Number of Lakes | 91 | 86 |
| Ln Residual Mean | -0.07 | -0.08 |
| Standard Deviation | 0.39 | 0.26 |
| RMS Error | 0.39 | 0.27 |
| t-test for Bias | -1.61 | -2.85 |
| p for H0: Mean = 0 | 0.11 | 0.01 |

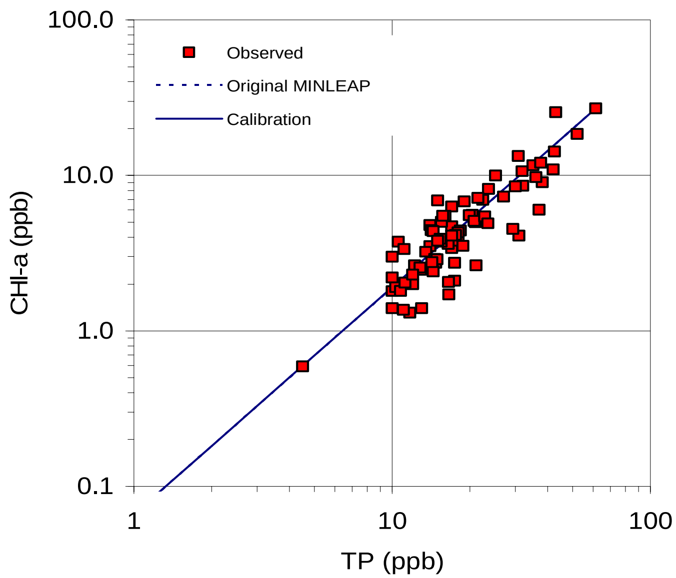
Model Selected = 2 BATHTUB

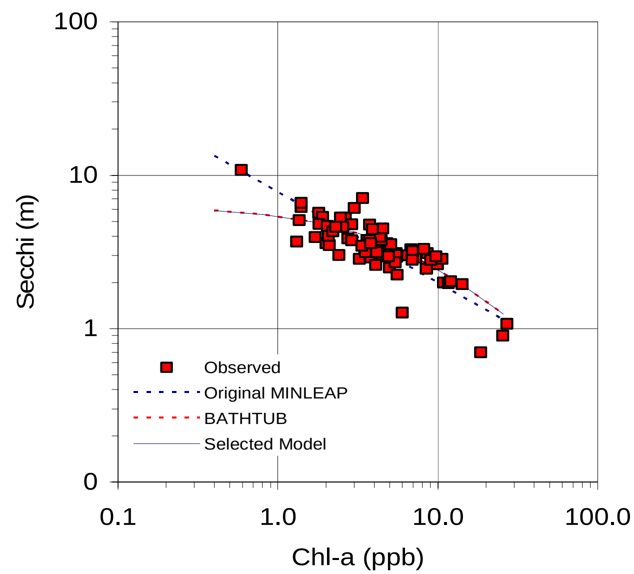
Original MINLEAP Regression

| | |
|---|---|
| Calib Fac | 1 |
| Slope | 1.46 |
| Intercept | 0.0661 |

| Original MINLEAP Regression | | BATHTUB | |
|---|---|---|---|
| Secchi = F A Chla^B | | 1/ Secchi = A + B Chl-a | |
| Calib Fac (F | 1 | | |
| Slope (B) | -0.59 | 0.025 | |
| Intercept (A | 7.76 | 0.16 | calibrated |

**Figure 2** **Correlations Among Observed TP, Chl-a, & Secchi Values** **Minimum 3 Samples Per Lake**




Residual Statistics
Residual = ln (Observed / Predicted ) Values

| Model | Chla vs. P | Secchi vs. Chla |
|---|---|---|
| Minimum Samples | 3 | 3 |
| Number of Lakes | 78 | 73 |
| Ln Residual Mean | -0.07 | -0.07 |
| Standard Deviation | 0.34 | 0.25 |
| RMS Error | 0.35 | 0.26 |
| t-test for Bias | -1.81 | -2.29 |
| p for H0: Mean = 0 | 0.07 | 0.03 |

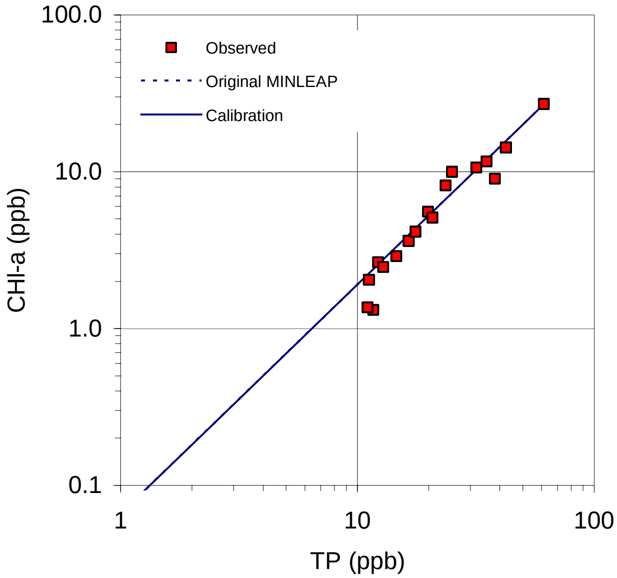
Model Selected = 2 BATHTUB

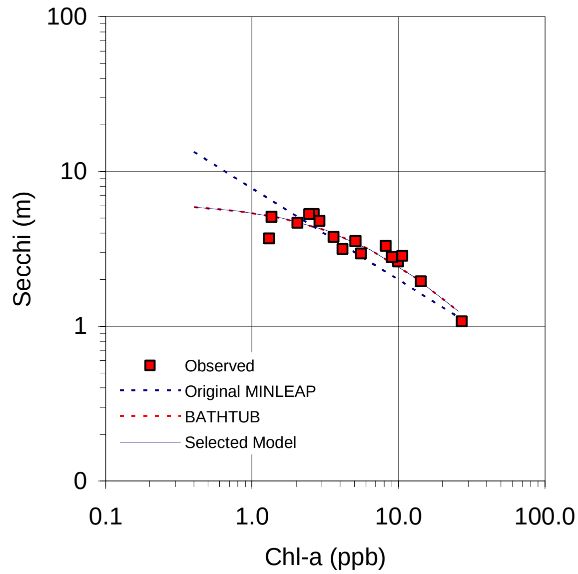
Original MINLEAP Regression

| | |
|---|---|
| Calib Fac | 1 |
| Slope | 1.46 |
| Intercept | 0.0661 |

| Original MINLEAP Regression | | BATHTUB | |
|---|---|---|---|
| Secchi = F A Chla^B | | 1/ Secchi = A + B Chl-a | |
| Calib Fac (F | 1 | | |
| Slope (B) | -0.59 | 0.025 | |
| Intercept (A | 7.76 | 0.16 | calibrated |

**Figure 3** **Correlations Among Observed TP, Chl-a, & Secchi Values** **Minimum 10 Samples Per Lake**




Residual Statistics
Residual = ln (Observed / Predicted ) Values

| Model | Chla vs. P | Secchi vs. Chla |
|---|---|---|
| Minimum Samples | 10 | 10 |
| Number of Lakes | 17 | 16 |
| Ln Residual Mean | -0.09 | 0.01 |
| Standard Deviation | 0.23 | 0.15 |
| RMS Error | 0.25 | 0.15 |
| t-test for Bias | -1.64 | 0.26 |
| p for H0: Mean = 0 | 0.12 | 0.80 |

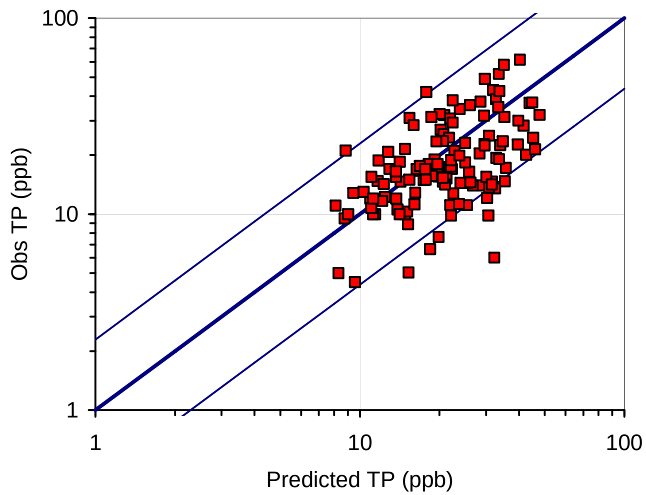
Model Selected = 2 BATHTUB

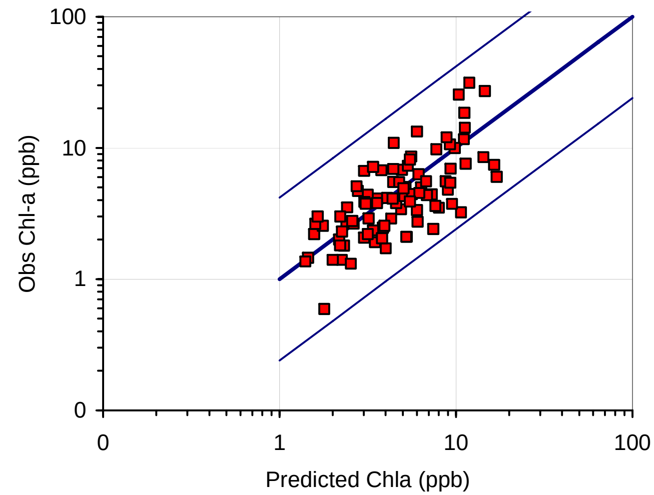
Original MINLEAP Regression

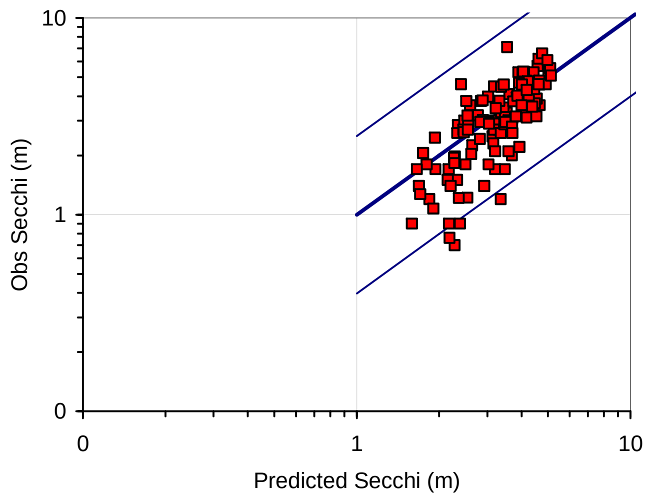
| | |
|---|---|
| Calib Fac | 1 |
| Slope | 1.46 |
| Intercept | 0.0661 |

| Original MINLEAP Regression | | BATHTUB | |
|---|---|---|---|
| Secchi = F A Chla^B | | 1/ Secchi = A + B Chl-a | |
| Calib Fac (F | 1 | | |
| Slope (B) | -0.59 | 0.025 | |
| Intercept (A | 7.76 | 0.16 | calibrated |

**Figure 4** **Calibration Charts** **Minimum 1 Sampling Date Per Lake**



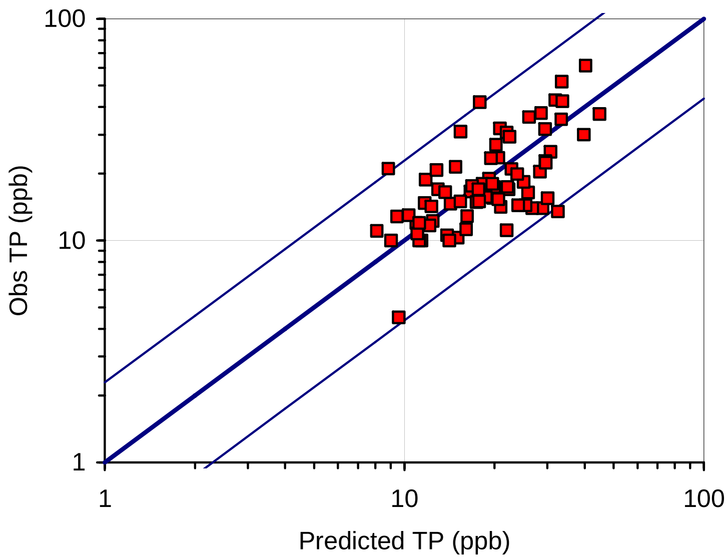



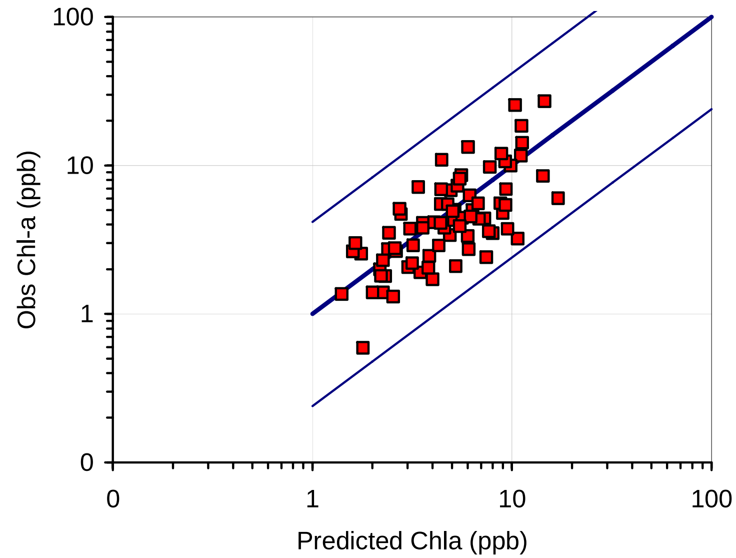

Residual Error Statistics

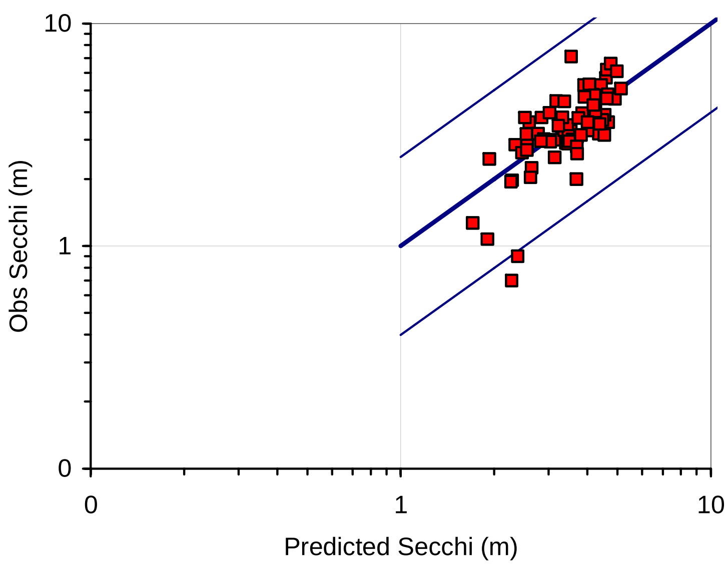
| | TP | Chl-a | Secchi |
|---|---|---|---|
| Residual Std Errors (ln (Observed / Predicted) values) | | | |
| Original MINLEAP | 0.41 | 0.71 | 0.46 |
| These Data | 0.48 | 0.53 | 0.36 |
| Min Sample Dates/Lake | 1 | 1 | 1 |
| | | | |
| Number of Lakes | 129 | 90 | 122 |
| Ln Residual Mean | -0.16 | -0.10 | -0.10 |
| Standard Deviation | 0.46 | 0.52 | 0.35 |
| RMS Error | 0.48 | 0.53 | 0.36 |
| t-test for Bias | -4.01 | -1.77 | -3.32 |
| p for H0: Mean = 0 | 0.00 | 0.08 | 0.00 |
| | | | |
| Calibration Factors | | | |
| Default | 1.00 | 1.00 | 1.00 |
| Polymictic | 0.50 | 1.00 | 1.00 |

Lines = 90% Conf Interval for Original MINLEAP Calib

**Figure 5** **Calibration Charts** **Minimum 3 Sampling Dates Per Lake**



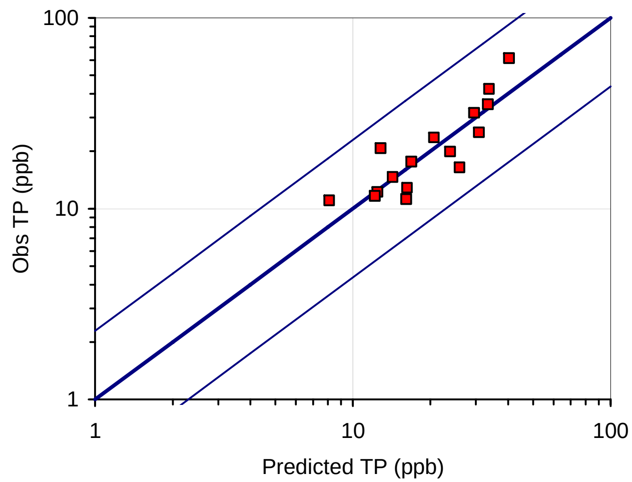



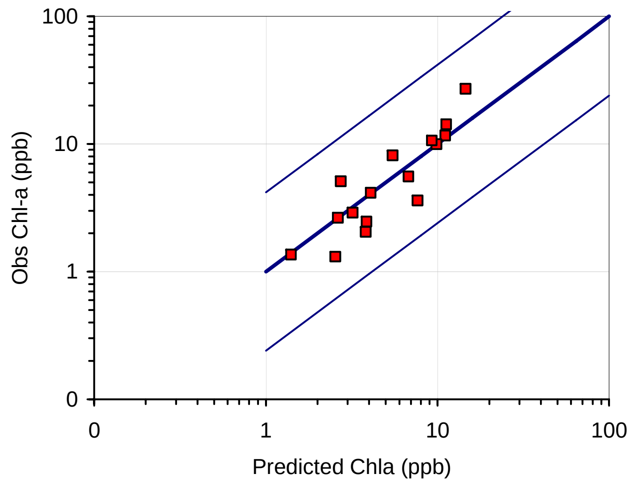



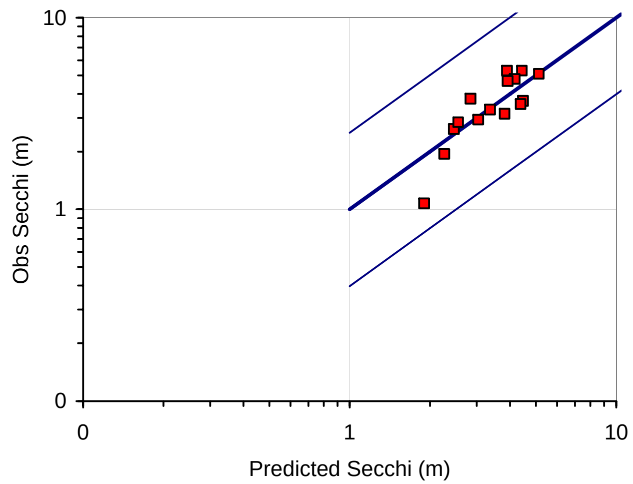

Residual Error Statistics

| | TP | Chl-a | Secchi |
|---|---|---|---|
| Residual Std Errors (ln (Observed / Predicted) values) | | | |
| Original MINLEAP | 0.41 | 0.71 | 0.46 |
| These Data | 0.36 | 0.52 | 0.31 |
| Min Sample Dates/Lake | 3 | 3 | 3 |
| | | | |
| Number of Lakes | 77 | 77 | 72 |
| Ln Residual Mean | -0.04 | -0.12 | -0.02 |
| Standard Deviation | 0.36 | 0.50 | 0.31 |
| RMS Error | 0.36 | 0.52 | 0.31 |
| t-test for Bias | -0.93 | -2.11 | -0.64 |
| p for H0: Mean = 0 | 0.36 | 0.04 | 0.53 |
| | | | |
| Calibration Factors | | | |
| Default | 1.00 | 1.00 | 1.00 |
| Polymictic | 0.50 | 1.00 | 1.00 |

**Figure 6** **Calibration Charts** **Minimum 10 Sampling Dates Per Lake**



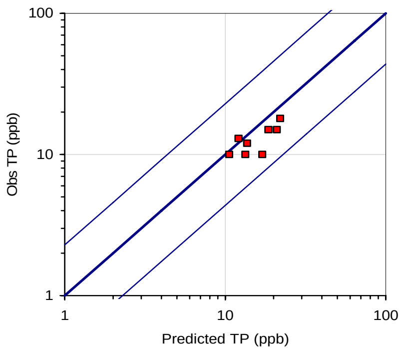

Residual Error Statistics

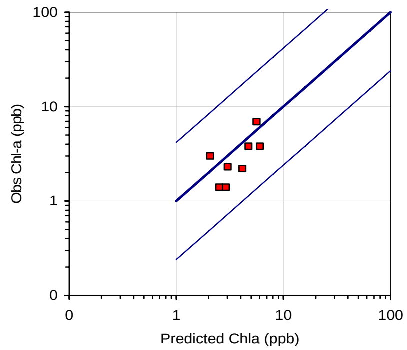
| | TP | Chl-a | Secchi |
|---|---|---|---|
| Residual Std Errors (ln (Observed / Predicted) values) | | | |
| Original MINLEAP | 0.41 | 0.71 | 0.46 |
| These Data | 0.27 | 0.42 | 0.23 |
| Min Sample Dates/Lake | 10 | 10 | 10 |
| | | | |
| Number of Lakes | 16 | 16 | 15 |
| Ln Residual Mean | 0.02 | -0.04 | -0.01 |
| Standard Deviation | 0.26 | 0.42 | 0.23 |
| RMS Error | 0.27 | 0.42 | 0.23 |
| t-test for Bias | 0.27 | -0.43 | -0.13 |
| p for H0: Mean = 0 | 0.79 | 0.68 | 0.90 |
| | | | |
| Calibration Factors | | | |
| Default | 1.00 | 1.00 | 1.00 |
| Polymictic | 0.50 | 1.00 | 1.00 |

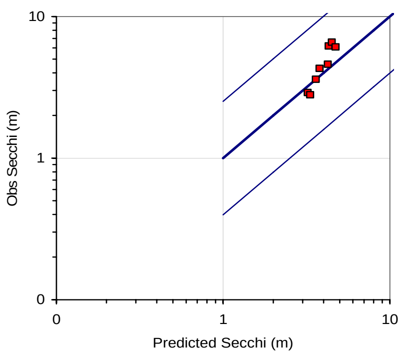
Lines = 90% Conf Interval for Original MINLEAP Calib

## Figure 7 Calibration Charts Canadian Shield Lakes

### Before Calibration



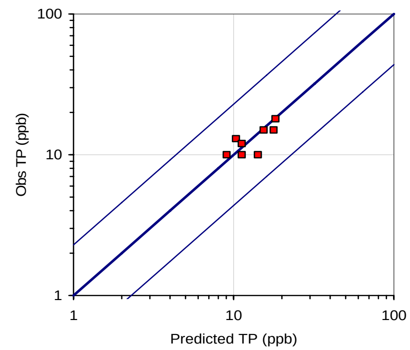



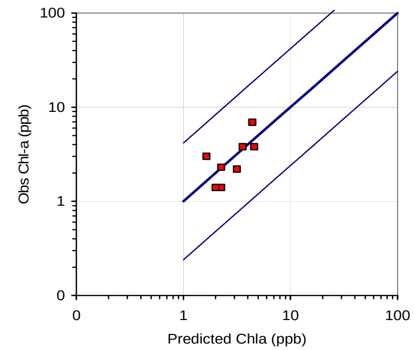

Residual Error Statistics

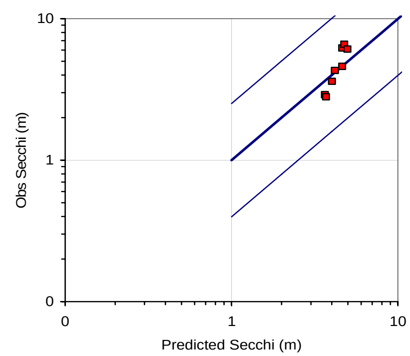
| | TP | Chl-a | Secchi |
|---|---|---|---|
| Residual Std Errors (ln (Observed / Predicted) values) | | | |
| Original MINLEAP | 0.41 | 0.71 | 0.46 |
| These Data | 0.28 | 0.49 | 0.24 |
| Min Sample Dates/Lake | 1 | 1 | 1 |
| | | | |
| Number of Lakes | 8 | 8 | 8 |
| Ln Residual Mean | -0.21 | -0.29 | 0.12 |
| Standard Deviation | 0.18 | 0.40 | 0.21 |
| RMS Error | 0.28 | 0.49 | 0.24 |
| t-test for Bias | -3.26 | -2.05 | 1.60 |
| p for H0: Mean = 0 | 0.02 | 0.09 | 0.16 |
| | | | |
| Calibration Factors | | | |
| Default | 1.00 | 1.00 | 1.00 |
| Polymictic | 0.50 | 1.00 | 1.00 |

Lines = 90% Conf Interval for Original MINLEAP Calib

### After Calibration (Eco Region Stream P Reduced by 30% )



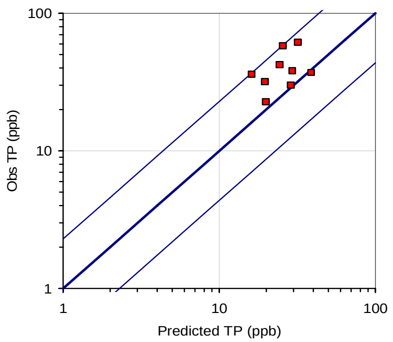

Residual Error Statistics

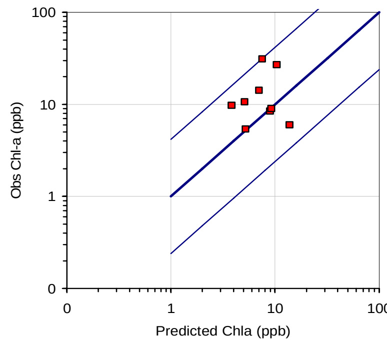
| | TP | Chl-a | Secchi |
|---|---|---|---|
| Residual Std Errors (ln (Observed / Predicted) values) | | | |
| Original MINLEAP | 0.41 | 0.71 | 0.46 |
| These Data | 0.18 | 0.39 | 0.23 |
| Min Sample Dates/Lake | 1 | 1 | 1 |
| | | | |
| Number of Lakes | 8 | 8 | 8 |
| Ln Residual Mean | -0.03 | -0.03 | 0.03 |
| Standard Deviation | 0.18 | 0.39 | 0.23 |
| RMS Error | 0.18 | 0.39 | 0.23 |
| t-test for Bias | -0.55 | -0.24 | 0.36 |
| p for H0: Mean = 0 | 0.60 | 0.82 | 0.73 |
| | | | |
| Calibration Factors | | | |
| Default | 1.00 | 1.00 | 1.00 |
| Polymictic | 0.50 | 1.00 | 1.00 |

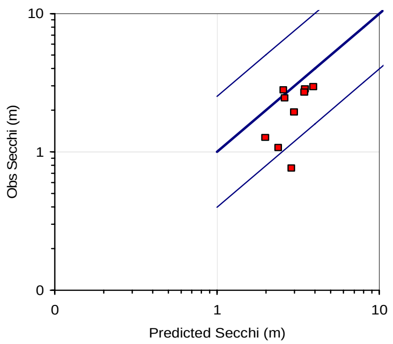
Lines = 90% Conf Interval for Original MINLEAP Calib

## Figure 8 Calibration Charts Polymictic Lakes

### Before Calibration



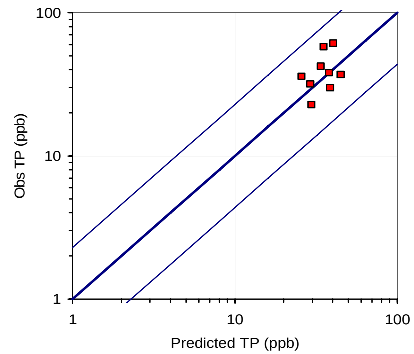



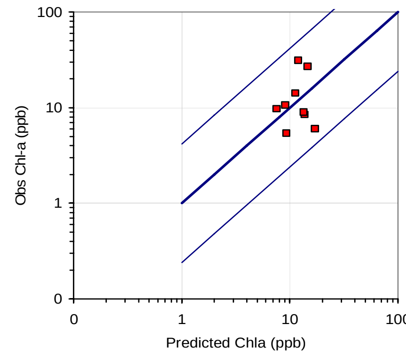

Residual Error Statistics

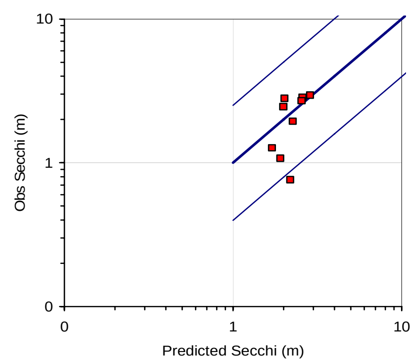
| | TP | Chl-a | Secchi |
|---|---|---|---|
| Residual Std Errors (ln (Observed / Predicted) values) | | | |
| Original MINLEAP | 0.41 | 0.71 | 0.46 |
| These Data | 0.52 | 0.82 | 0.59 |
| Min Sample Dates/Lake | 1 | 1 | 1 |
| Number of Lakes | 9 | 9 | 9 |
| Ln Residual Mean | 0.41 | 0.43 | -0.41 |
| Standard Deviation | 0.33 | 0.70 | 0.43 |
| RMS Error | 0.52 | 0.82 | 0.59 |
| t-test for Bias | 3.79 | 1.86 | -2.88 |
| p for H0: Mean = 0 | 0.01 | 0.10 | 0.02 |
| Calibration Factors | | | |
| Default | 1.00 | 1.00 | 1.00 |
| Polymictic | 1.00 | 1.00 | 1.00 |

Lines = 90% Conf Interval for Original MINLEAP Calib

### After Calibration (P Sedimentation Rate Reduced by 50%)




Residual Error Statistics

| | TP | Chl-a | Secchi |
|---|---|---|---|
| Residual Std Errors (ln (Observed / Predicted) values) | | | |
| Original MINLEAP | 0.41 | 0.71 | 0.46 |
| These Data | 0.31 | 0.63 | 0.46 |
| Min Sample Dates/Lake | 1 | 1 | 1 |
| Number of Lakes | 9 | 9 | 9 |
| Ln Residual Mean | 0.10 | -0.02 | -0.15 |
| Standard Deviation | 0.29 | 0.63 | 0.43 |
| RMS Error | 0.31 | 0.63 | 0.46 |
| t-test for Bias | 1.00 | -0.11 | -1.03 |
| p for H0: Mean = 0 | 0.35 | 0.91 | 0.34 |
| Calibration Factors | | | |
| Default | 1.00 | 1.00 | 1.00 |
| Polymictic | 0.50 | 1.00 | 1.00 |

Lines = 90% Conf Interval for Original MINLEAP Calib

**Figure 9** **Phosphorus Residuals = Ln ( Observed / Predicted ) Concentrations** **Minimum 3 Samples Per Lake**

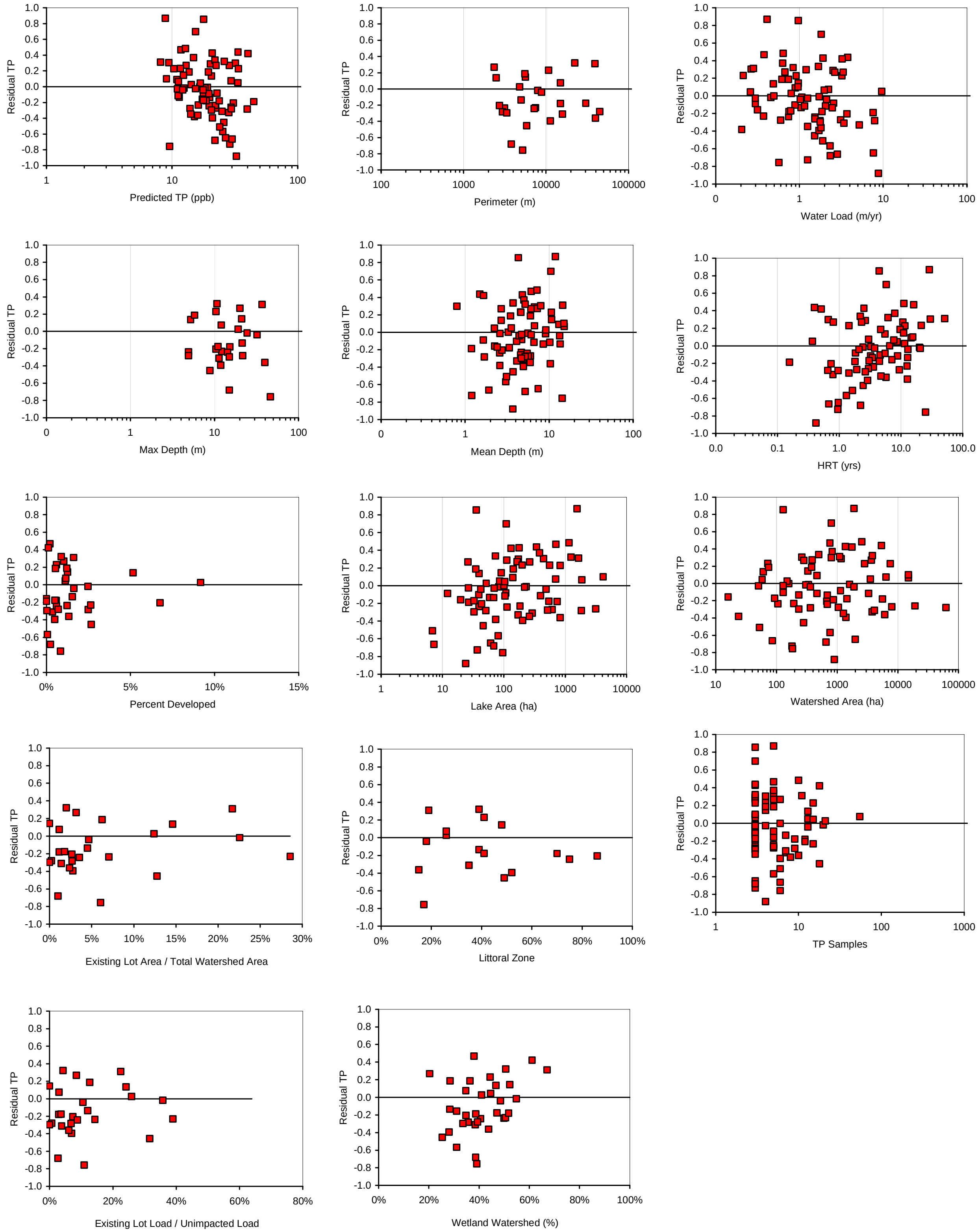


**Figure 10 Chlorophyll-a Residuals = Ln ( Observed / Predicted ) Concentrations Minimum 3 Samples Per Lake**

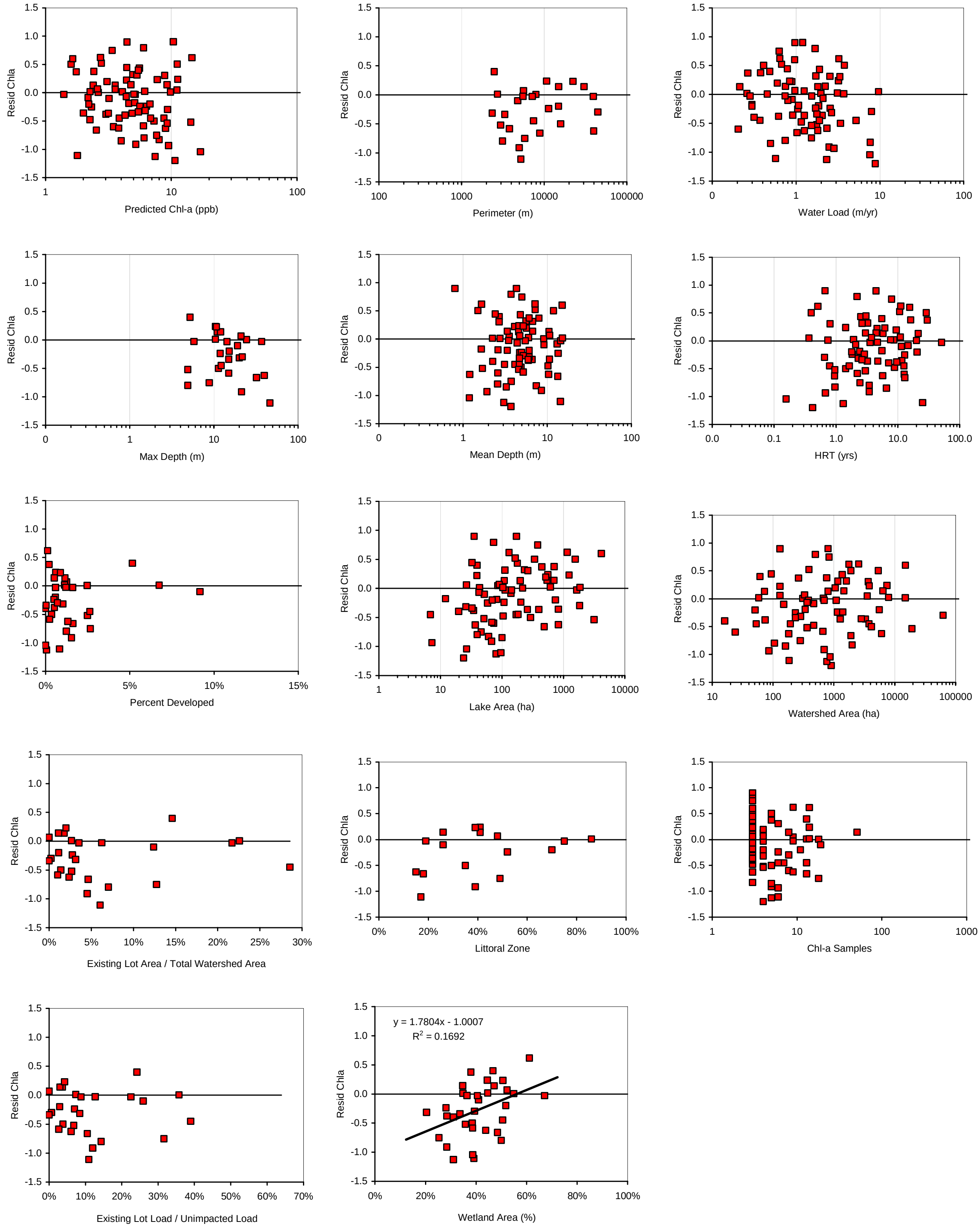


**Figure 11** **Secchi Residuals = Ln ( Observed / Predicted ) Values** **Minimum 3 Samples Per Lake**

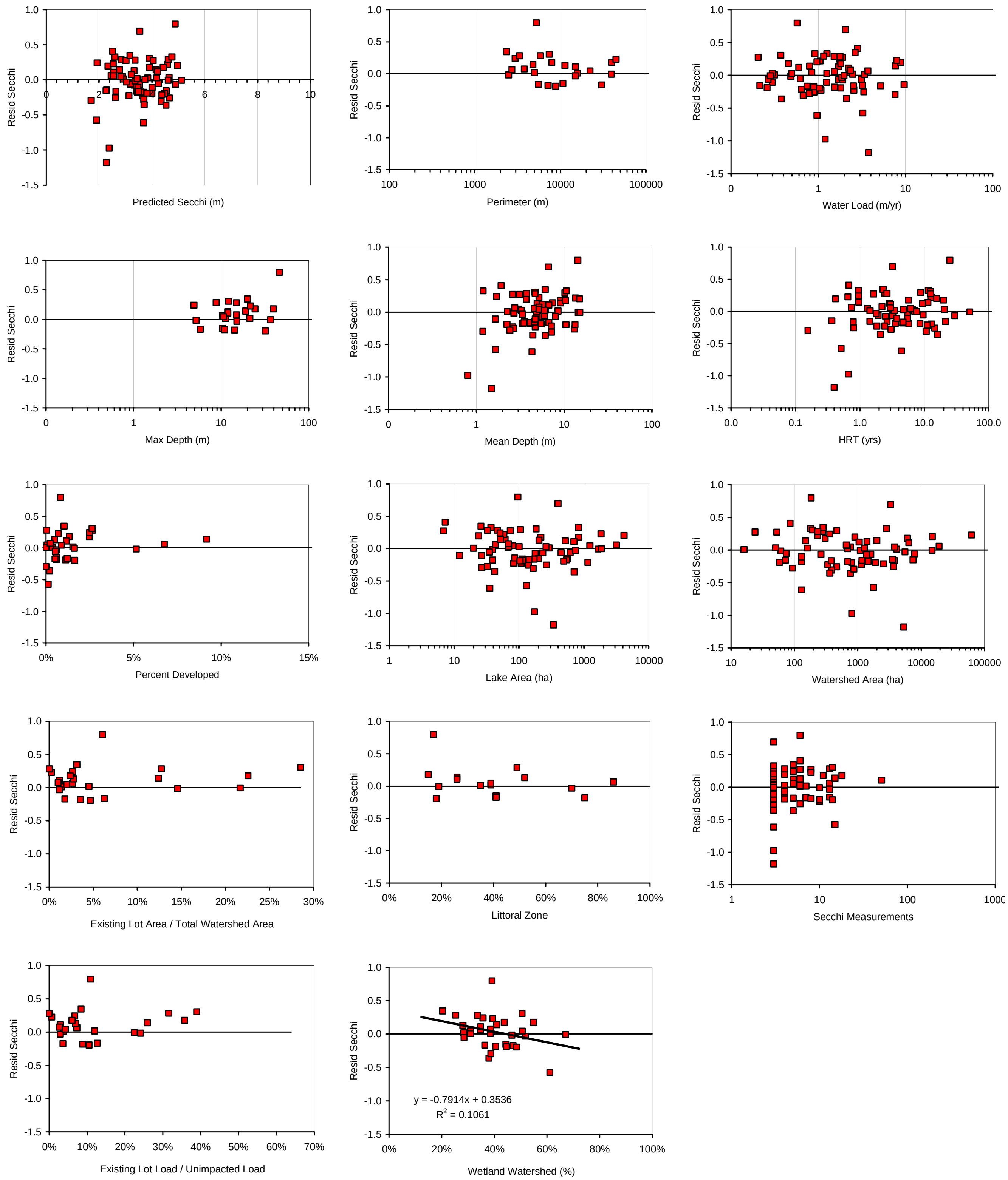
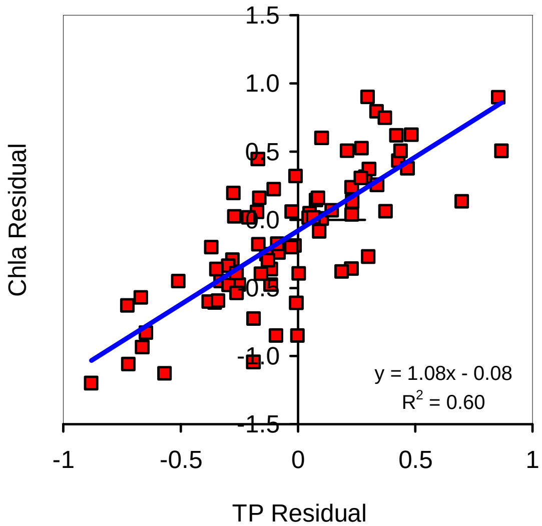
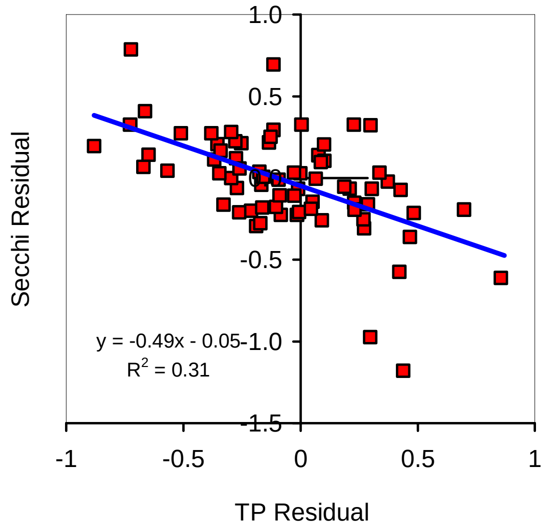
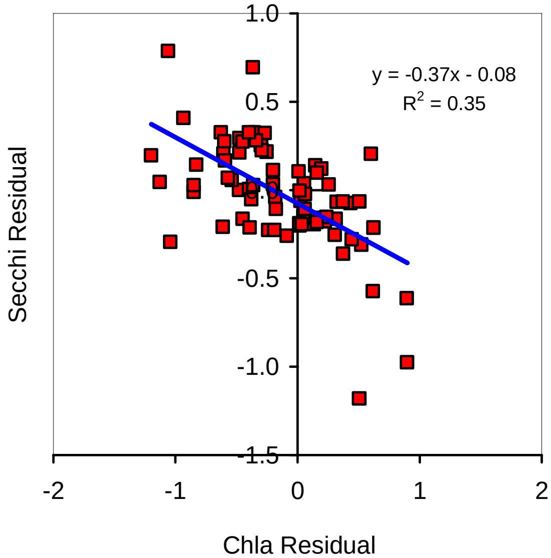


**Figure 12 Correlations Among Model Residuals Minimum 3 Samples Per Lake**

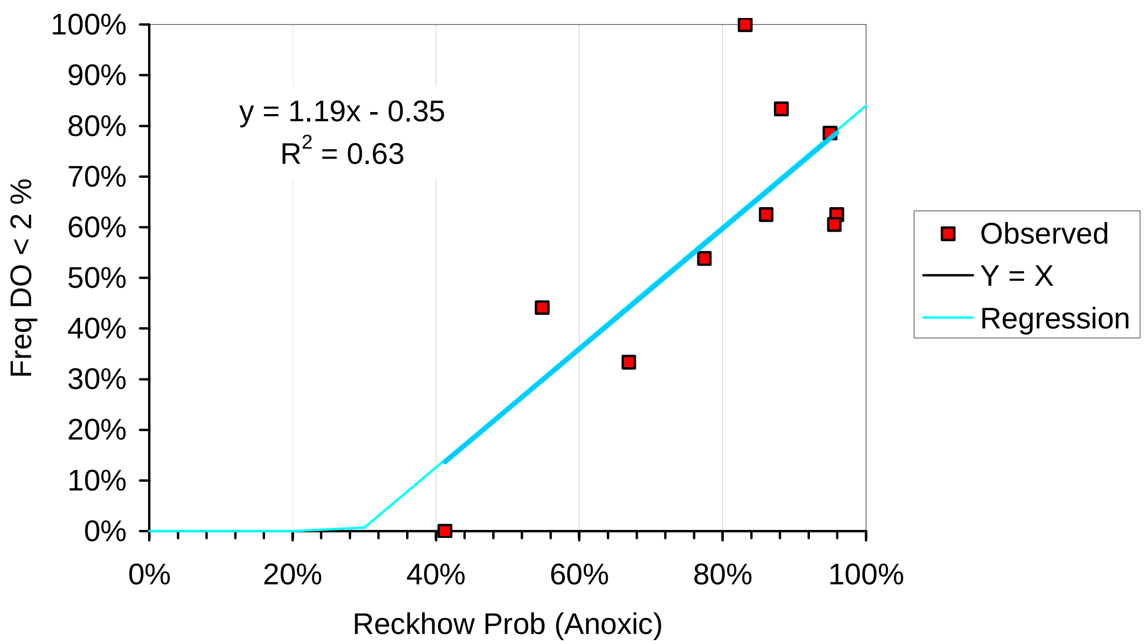



Strong correlations among model residuals indicate that most of the uncertainty in predicting lake trophic state can be attributed to uncertainty in predicting lake P concentration. The latter reflects uncertainty in predicting lake P loads & retention with the lake.

**Figure 13** **Oxygen Models**




Probability (Anoxic):

Reckhow & Chapra, "Engineering Approaches for Lake Management, Volume 1, 1983, page 242
Lake "Anoxic" if a single hypolimnetic measurement had a DO < 1 ppm
Northern Temperate Lakes (Z > 3 m, Z/Qs > 0.25 yr, Qs > 1 m/yr, Qs < 50 m/yr ) *
Prob( Anoxic ) = $1 - 1 / (10^5 Z^{-2.49} L^2 Qs^{-1.78} + 1)$
L = Load (g/$m^2$-yr), Qs = water load (m/yr), Z = mean depth (m)
* not predicted if data are outside of this range
While applicable to lakes in this region, it has not been tested specifically against Itasca lakes.

Frequency of DO values < 2 ppm ( computed in Access Query "minleap_oxygen" )

Percent of Samples < 2 ppm
July -Sept, Depth > 5 meters
Require at least 3 sampling dates for computation
Equation:

Freq (DO<20) = A + B Prob(Anoxic)

Further Refinement & Testing of Oxygen Models is recommended.

Calibration - coefficients will differ from above figure above if database is changed vs. the 11/4/2005 version
Slope (B) 1.19
Intercept (A) -0.35 $r^2$ = 0.63, n = 10

11/19/2005