Calibration and Testing of a Eutrophication Analysis Procedure for Vermont Lakes

Final Report

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by

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INTRODUCTION

The Lake Eutrophication Analysis Procedure (LEAP) is a system which can be used for predicting lake trophic status and related water quality conditions, given certain land use, morphometric, and hydrologic information (Walker, 1979,82). Control pathways are indicated in Figure 1. Regional calibration and testing of the framework are required prior to application in a planning context. A previous report (Walker, 1981) summarized data on 15 lakes to be used in calibrating the framework for use in Vermont. This provided opportunities for the AEC to review the data base and to suggest any corrections or refinements, particularly with respect to land use information. Preliminary testing was also conducted to identify needs for modification or recalibration of the existing models. Results indicated that the system could be improved by modifying it to account for: (1) differences in phosphorus export between watersheds with sedimentary and glacial till soils; and (2) effects of internal phosphorus loading (recycling) on the lake phosphorus balance and productivity.

In subsequent work, the model structure has been modified to account for the above factors. The data base has also been refined, based upon AEC feedback. This report presents the modified data base, describes the structure and calibration of the refined framework, and tests the methodology using data from three additional lakes which were not employed in calibration.

DATA BASE

Table 1 lists the lakes used for model calibration and testing. The range of spring total phoshorus values is 6 to 113 mg/m3, which reflects a wide range of trophic status from oligotrophic to highly eutrophic. The three lakes selected for model testing (Halls, Shadow, and Sunset) are at the lower end of the range of spring phosphorus values, although measurements of other trophic state indicators (chlorophyll, transparency, and oxygen depletion) suggest that the productivity of Halls is well within the range of the calibration lakes

Figure 1

LEAP Control Pathways

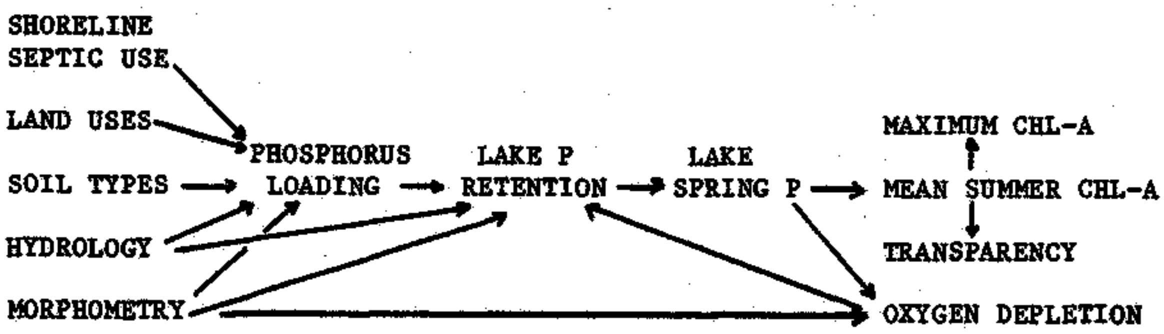


Table 1
Lakes Included in Study

Lake	County	Hydrologic Unit	River Basin	Spring Total P (mg/m3)	Symbol*
Model Calibration Lakes					
Bomoseen	Rutland	02010001	Poultney	15	Bo
Carmi	Franklin	02010007	Pike	20	Ca
Cedar	Addison	02010002	Lewis	17	Ce
Curtis	Washington	02010003	Winooski	12	Cu
Elmore	Lamoille	02010005	Lamoille	12	El
Fairfield	Franklin	02010007	Missisquoi	20	Fa
Harveys	Caledonia	01080103	Stevens	14	Hv
Hortonia	Rutland	02010001	Poultney	12	Ho
Iroquois	Chittenden	02010003	LaPlatte	30	Ir
Morey	Orange	01080104	Connect.	27	Mo
Parker	Orleans	01110000	Barton	15	Pa
St Catherines	Rutland	02010001	Poultney	12	SC
Shelburne	Chittenden	02010003	Winooski	113	Sh
Star	Rutland	02010002	Otter	14	St
Winona	Addison	02010002	Lewis	26	Wi
Model Testing Lakes					
Halls	Orange	01080104	Connect.	10	Ha
Shadow	Orleans	01110000	Barton	6	Sh
Sunset	Rutland	02010001	Poultney	6	Su

* Symbol used to identify lakes in plots

(see Appendix A). The two-character symbols listed in Table 1 are used on subsequent plots.

Appendix A contains a compilation of land use, water quality, morphometric, and other data used in model calibration and testing. As described in the previous report, three separate sets of land use estimates have been provided for each lake by the AEC: (1) based upon Landsat, (2) based upon regional planning maps, and (3) a "best" set, based upon AEC review of (1), (2), aerial photos, and knowledge of the watersheds. In many cases, there are wide variances between estimates (1) and (2). Landsat estimates are more recent, but generally do not pick up low-density residential areas. Many planning maps are outdated, do not reflect decreasing trends in agriculture, and may use various alternative definitions for land use categories. The "best" estimates have been used in calibration and testing. To provide indications of the sensitivity to land use estimates, the framework has been applied to each set of estimates for each lake. In some cases, the feasibility of applying the framework may be significantly limited by the accuracy of the land use estimates. Direct estimation of land uses from recent aerial photos should be considered for future applications.

Hydrologic data are important LEAP inputs. Average annual streamflows are required for estimating lake phosphorus loading and hydraulic residence time. Since none of the study lakes are directly gauged, regional streamflow estimates must be used. Table 2 contains a compilation of average streamflow data from 31 USGS gauges in Vermont. By matching hydrologic unit codes, the table can be used to estimate a runoff rate (meters/yr) for any lake in the state. The averages in the table are derived from the period of record at each gauge. Future updating of the table to include only the last ten years of record would be advisable, in order to factor out any effects of recent trends in land use and/or climate.

CALIBRATION

Some of the LEAP submodels may be influenced by regional factors which are not directly accounted for in the framework. The effects of

Table 2
Summary of Average Streamflow Data from USGS Gauges in Vermont

River	Hydrologic Unit	Drainage Area km2	Flow m3/sec	Period of Record	Mean Runoff m/yr
Lake Memphremagog Basin					
black north	01010000	316	5.69	29	.57
clyde	01010000	368	7.31	61	.63
Connecticut River Basin					
connecticut	01080101	6848	133.00	31	.61
wells	01080103	254.9	3.97	40	.49
east orange br	01080103	23.18	.44	22	.60
ompompanoosuc	01080103	337	5.47	40	.51
mink	01080104	11.91	.21	18	.56
ayers	01080105	79	1.31	40	.52
white	01080105	1790	33.45	65	.59
black	01080106	409	8.21	51	.63
ottauquechee	01080106	572	11.21	50	.62
williams	01080107	267	4.90	40	.58
saxtons	01080107	187	3.40	40	.57
west	01080107	798	17.84	56	.71
Lake Champlain Basin					
poultney	02010001	484	7.05	52	.46
otter	02010002	795	15.60	52	.62
otter	02010002	1627	27.81	64	.54
jail branch	02010003	100.8	1.54	50	.48
winooski no br	02010003	179.2	3.80	47	.67
winooski	02010003	1028	16.60	61	.51
winooski	02010003	2704	48.00	52	.56
dog	02010003	197.1	3.46	46	.55
mad	02010003	360	7.22	52	.63
little	02010003	287	6.74	45	.74
lamoille	02010005	803	15.09	54	.59
lamoille	02010005	1777	34.81	51	.62
missisquoi	02010007	339	7.65	49	.71
missisquoi	02010007	1241	26.11	64	.66
batten kill	02020003	394	9.63	52	.77
wallomsac	02020003	287	6.29	49	.69

these factors can be offset by empirically adjusting the appropriate coefficients so that estimated water quality conditions match the observed values in the calibration lakes. The potential need for calibration is the price that must be paid for using empirical models. More complex, theoretical models may have more generality but are difficult to implement because of demanding input data requirements. Because each of the LEAP submodels has been developed and calibrated using a much larger lake or watershed data base than used in this study, re-structuring or re-calibration should be done with caution and supported, where possible, with independent evidence.

In preliminary testing (Walker, 1981), the original system was found to under-predict phosphorus concentrations in lakes with watersheds with soils of sedimentary (vs. glacial) origin, including Shelburne (75% sedimentary), Winona (50%), and Fairfield (15%). The system has been modified to include the following land use categories:

Land Use	Soil Origin	Nominal Export Concentration (mg-P/m3)
(1) undeveloped	glacial	15
(2) undeveloped	sedimentary	45
(3) untilled agric.	glacial	30
(4) untilled agric.	sedimentary	90
(5) tilled agric.	glacial	57
(6) tilled agric.	sedimentary	171
(7) urban	all	137

Export concentrations for sedimentary areas are assumed to be three times those for glacial areas, within a given land use category. The export concentrations for glacial watersheds were originally calibrated to data from 116 watersheds in the Northeast (Meta Systems, 1978). The need for recalibration is consistent with previous findings that export from forested and agricultural lands are two to five times greater in unglaciated areas of the Midwest, as compared with the Northeast (Meta Systems, 1978). Dillon and Kirchner (1975) found that mean export values from sedimentary watersheds were higher by about a factor of 2.5. The effects of soil origin are attributed primarily to differences in drainage characteristics and soil phosphorus concentrations. For each soil type, the export concentration for untilled agriculture has been set at twice the respective undeveloped value, as indicated by Likens (1974) for New York watersheds.

The original LEAP framework included the following model for phosphorus retention or trapping, based upon data from over 100 northern temperate lakes and reservoirs (Walker, 1977):

$$1-Rp = P/Pi = 1/(1 + .82\ T^{.45})$$

where,

Rp = phosphorus retention coefficient
P = lake spring phosphorus (mg/m3)
Pi = average inflow total phosphorus (mg/m3)
T = mean hydraulic residence time (years)

Some modifications may be required for Vermont lakes, since the model was originally calibrated using average annual outflow concentrations in place of spring values and was not tested for the potential effects of internal loading.

Preliminary testing (Walker, 1981) indicated that some of the lakes may be influenced by internal phosphorus supplies because prediction errors (residuals) were strongly correlated with the length hypolimnetic anaerobic period. Based upon additional studies using the refined data base, the following formulation has been selected for representing the apparent effects of oxygen depletion on internal phosphorus loading or recycling:

$$Pest = Pi\ /\ (1 + .82\ T^{.45})$$

$$Pobs/Pest = .7\ \exp(6\ HODv\ Ah\ /\ As)$$

where,

Pest = spring P estimated from original retention function
Pobs = observed spring P (mg/m3)
HODv = volumetric oxygen depletion rate (g/m3-day)
Ah = hypolimnetic surface area (km2)
As = lake surface area (km2)

Figure 2 depicts the above relationship for the calibration lakes, using observed volumetric oxygen depletion rates. Figure 3 shows the same relationship, using HODv's which are estimated from the observed phosphorus values, mean depth, and mean hypolimnetic depth using the oxygen depletion submodel of LEAP (see Appendix B). In each case, inflow phosphorus values (Pi) have been estimated from the refined phosphorus export submodel described above.

HODv reflects the potential for the development of reducing conditions in the hypolimnion and subsequent release of phosphorus from bottom sediments. The fate of this released phosphorus is difficult to predict because of complexities in iron/phosphorus/sediment chemistry and vertical mixing. Observations from Lake Morey (to the right in Figures 2 and 3) indicate considerable hypolimnetic accumulations of phosphorus and that the amount of phosphorus released into the mixed layer at fall overturn is comparable to the estimated annual external loading (Walker, 1979). The ratio of hypolimnetic area to lake surface area is an important factor governing the transfer of phosphorus to and from hypolimnetic waters. For a given HODv, a lake with a higher Ah/As ratio would tend to have a greater potential for internal recycling. Since HODv increases with lake phosphorus concentration, the above formulation suggests a non-linear response to phosphorus loading which is explored in more detail below (see TESTING). Calculation of spring phosphorus concentration involves an iterative procedure which has been incorporated into the model subroutine. A mass balance constraint requiring the estimated spring P to be less than the inflow concentration has also been included, but implemented only in the case of one lake (Shelburne).

Figure 4 shows the calibration of the submodel for predicting summer maximum chlorophyll-a as a function of summer mean chlorophyll-a. The slope of the relationship (1.16) indicates that algal populations are somewhat more variable at higher mean chlorophyll levels. Note that for a given lake and year, the observed maximum value depends upon sampling frequency, i.e., weekly sampling will almost always detect a higher maximum than monthly sampling, though, on the average, the

Figure 2

Phosphorus Prediction Errors vs.
Observed Oxygen Depletion Rate

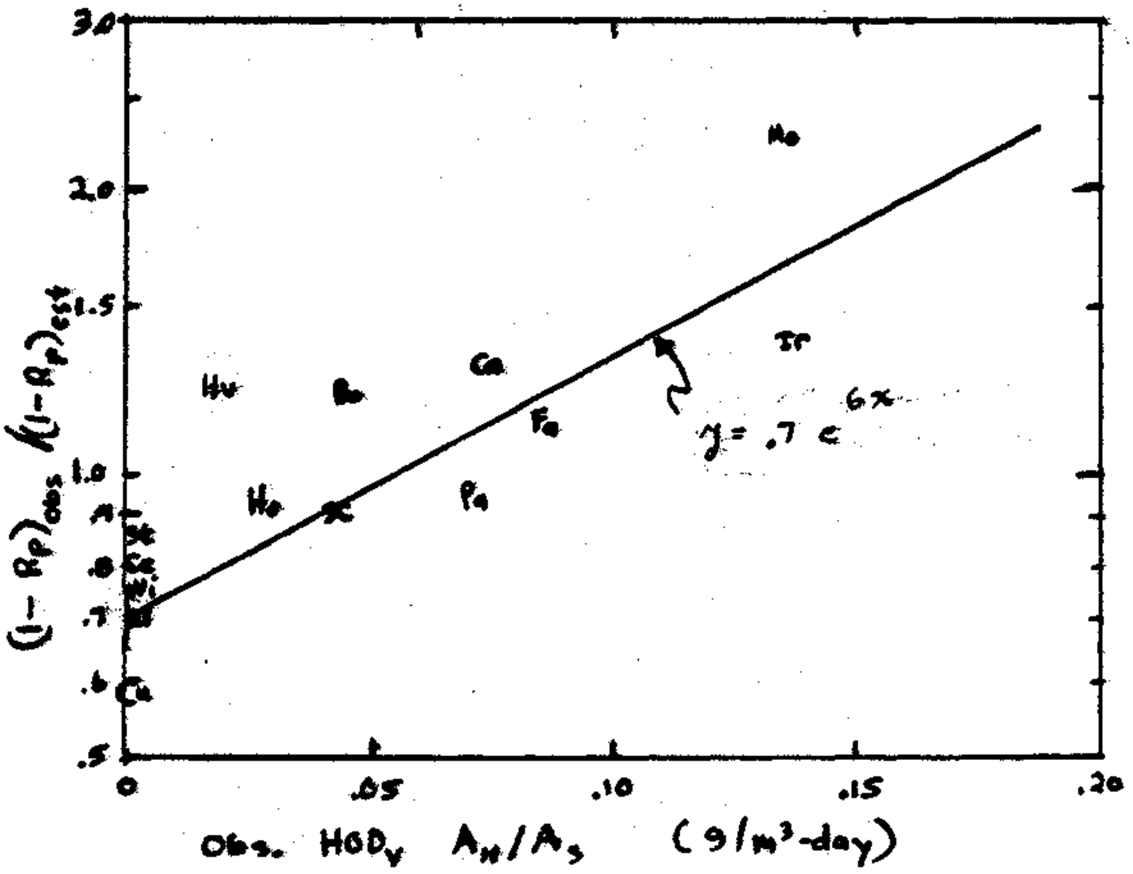


Figure 3

Phosphorus Prediction Errors vs.
Estimated Oxygen Depletion Rate

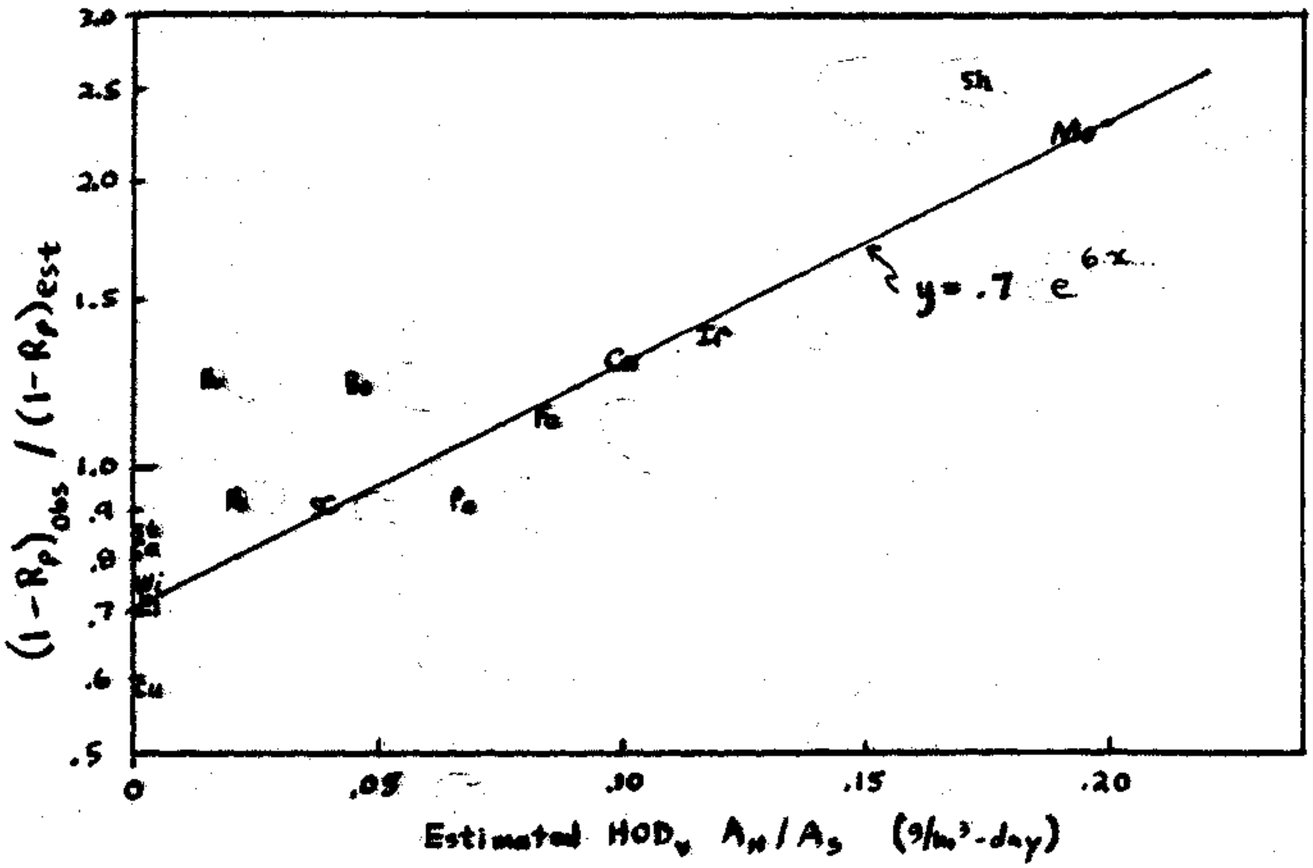


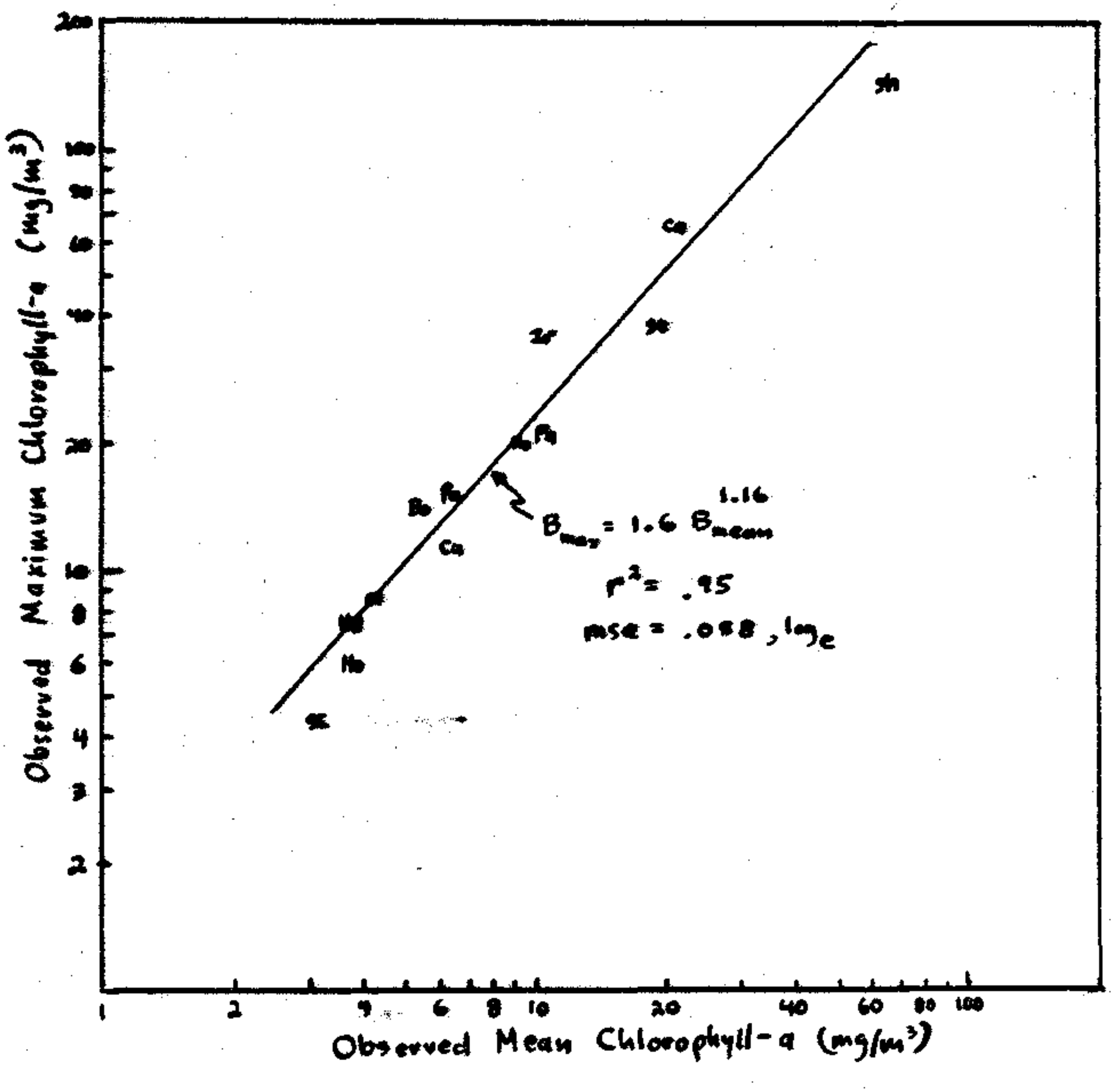
Table 7
Summary of Model Error Statistics

Statistic	Spring P	Mean Chl-a	Maximum Chl-a	Secchi	Areal HOD	Vol HOD
N	18	16	16	16	12	12
Obs. Variance	.437	.872	1.080	.598	.186	1.086
Res Mean	.071	.147	.151	-.084	.120	.120
Res Std Dev	.257	.534	.592	.319	.303	.303
Res Mean Sq	.067	.288	.349	.102	.097	.097
Res Mean Sq*	.069	.176	.252	.100	.097	.097
t	1.172	1.101	1.020	-1.053	1.372	1.372
MAD	.19	.19	.28	.11	.16	.16
R-Squared	.85	.67	.68	.83	.48	.91
R-Squared*	.84	.80	.77	.83	.48	.91

all statistics on natural log scales
* excluding Star Lake
t = t-test for bias (none are significant at p<.10)
MAD = median absolute deviation (residual)

Figure 4

Observed Maximum Chlorophyll vs.
Mean Chlorophyll



observed means will be equal. Use of the 95th percentile in place of the maximum would eliminate the dependence on sampling frequency, but would require additional raw data compilation and analysis. The maximum values predicted by the model in Figure 4 correspond to monitoring programs which are similar to those conducted in the calibration lakes.

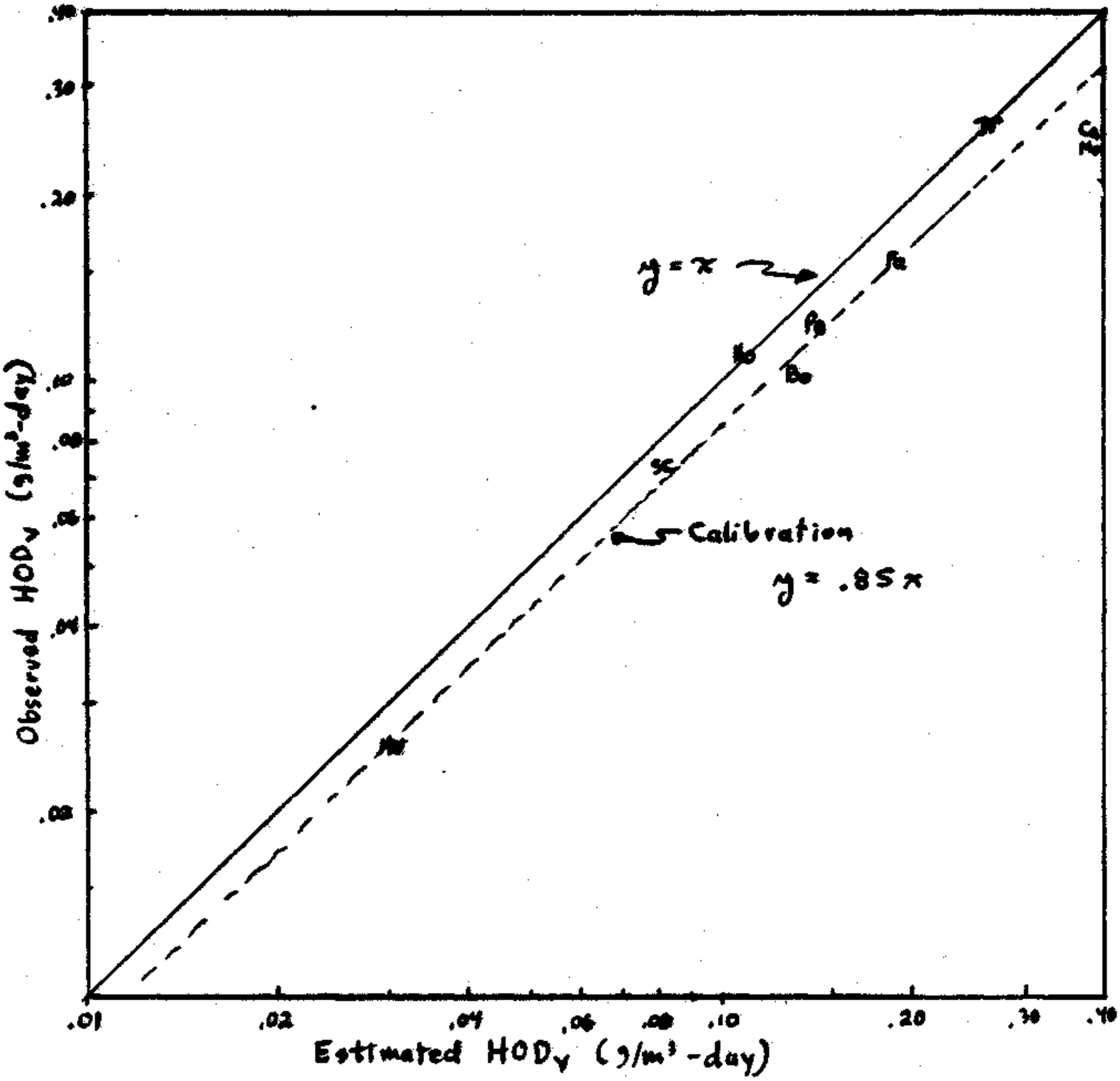
The oxygen depletion submodel predicts areal and volumetric hypolimnetic oxygen depletion rates as functions of spring phosphorus, mean depth, and mean hypolimnetic depth (Walker, 1979). Since the original model was based upon summer phosphorus measurements, re-calibration seems appropriate. Figure 5 plots observed HODv's against HODv's estimated from observed spring phosphorus. Observed values average 85% of those predicted. This adjustment has been added to the oxygen depletion submodel.

Morphometric characteristics of the hypolimnion (thermocline depth, surface area, mean depth) are important input variables which may not be available in some applications. A series of submodels to permit estimation of these characteristics as a function of lake maximum depth, mean depth, and surface area has been incorportated into the model subroutine. These are described in Appendix B. If the input thermocline depth is zero, the lake is assumed to be unstratified and all morphometric and oxygen depletion calculations are bypassed. If the input thermocline depth is less than zero, the value is assumed to be missing and the morphometric variables are estimated. If the estimated thermocline depth is greater than the maximum depth, the lake is assumed to be unstratified. Measured morphometric values can be input directly and have been used exclusively in the model testing conducted below.

The flexibility for using different coefficients to represent the chlorophyll/transparency relationship for each lake has been included (Appendix B). The intercept may vary with color or non-algal suspended solids concentrations. The slope may vary with algal type and distribution, although a constant value (.025 m2/mg) has been assumed for model testing purposes. Observed chlorophyll and transparency data could be used to estimate separate coefficients for each lake, although caution should be exercised. Some lakes have metalimnetic algal

Figure 5

Observed vs. Estimated
Oxygen Depletion Rate



populations (Harveys, Morey, and probably St Catherines) and most of the chlorophyll is located below the Secchi depth. In these lakes, observed transparency will tend to be greater than predicted. Use of surface grab samples for chlorophyll (as opposed to depth-integrated sampling to twice the Secchi depth) would provide better data from calibrating the relationship, though LEAP has been calibrated to predict depth-integrated chlorophyll values. Nonalgal light extinction is dominant in some lakes (such as Elmore) and would make it difficult to estimate the slope parameter.

The key relationships included in the calibrated system are summarized in Appendix B. Appendix C lists the computer program used for implementing the model, in the form of a BASIC subroutine appropriate for use with the generalized modelling software provided previously. Table 3 lists lake-specific input variables required for implementation of the model framework. Table 4 summarizes the model parameters, i.e., the input values which are held constant across lakes. Model output variables are listed in Table 5.

The distinction between the variables in Tables 3 and 4 reflect data availability and model generality. As more variables are included in the former, the model becomes more difficult to implement because of increasing lake-specific data requirements. On the other hand, as fewer variables are included in the former, the generality of the model and parameter estimates are stressed and the risk of prediction error increases. The variables included in Table 4 have been held constant for model testing purposes, though some or all could be varied from lake-to-lake in future applications, depending upon data availability (e.g., chlorophyll-secchi relationships, measured septic system loadings, etc.).

It is difficult to compare direct measurements of total phosphorus loading with those predicted by the framework because of the effort, expense, and variability associated with the former and because the predicted loadings are probably better defined as "available" phosphorus than as total phosphorus estimates. The calibration factor in the phosphorus retention function (.7) may reflect a consistent bias in the

Table 3

Lake-Specific Model Input Variables

Variable	Units	Notes
1 Undev Non-Sedimentary	acres	undeveloped, glacial soils
2 Undev Sedimentary	acres	undeveloped, lake plain soils
3 Untilled Non-Sedimentary	acres	untilled agriculture
4 Untilled Sedimentary	acres	
5 Tilled Non-Sedimentary	acres	tilled agriculture
6 Tilled Sedimentary	acres	
7 Urban Area	acres	all urban land uses, soil types
8 Lake Surface Area	acres	
9 Upstr Lake Ret. Factor	acres	(a)
10 Mean Depth	m	
11 Basin Mean Depth	m	mean depth of hypolimnetic basin (a)
12 Maximum Depth	m	
13 Thermocline Depth	m	unstratified if = 0, unknown if < 0
14 Hypolimnion Depth	m	optional (c)
15 Hypol. Surface Area	acres	optional (c)
16 Annual Runoff	m/yr	regional streamflow, see Table (2)
17 Shoreline Septic Use	cap/yr	est. from residence and resort data
18 Extra P Load	kg/yr	optional add. P load = 0 for testing
19 Chl/Secchi Intercept	1/m	nominal value .08 1/m
20 Obs Spring P	mg/m3	optional observed data (= 0 if missing)
21 Obs Mean Chl-a	mg/m3	"
22 Obs Max Chl-a	mg/m3	"
23 Obs Secchi Depth	m	"
24 Obs HOD	g/m2-day	"
25 Dummy	-	not used

(a) accounts for P retention by upstream lakes, see Appendix B

(b) equals mean depth, except in lakes with large shallow bays (Hortonia, Bomoseen), see Walker, 1981

(c) optional input values, estimated from other morphometric variables if input as zero and thermocline depth less than maximum depth

Table 4

Model Input Variables Constant Across Lakes

Variable	Units	Mean	S.D.	Notes
26 Inflow Conc of Upst L.	mg/m3	15	3	(a),(b)
27 Septic P Factor	kg/cap-y	.05	.01	(a)
28 Spring DO	g/m3	12	1	(a)
29 Undev Non-Sedimen P	mg/m3	15	3	phosphorus export conc
30 Undev Sedimentary P	mg/m3	45	9	"
31 Untilled Non-Sedimen P	mg/m3	30	6	"
32 Untilled Sedimentary P	mg/m3	90	18	"
33 Tilled Non-Sedimen P	mg/m3	57	6.3	"
34 Tilled Sedimentary P	mg/m3	171	19	"
35 Urban P	mg/m3	139	31	"
36 Atmos P Load	kg/km2-yr	20	10	atmospheric loading
37 Internal Load Parameter	-	6	0	(c)
38 Chl/Secchi Slope	m2/mg	.025	0	(a)
39 M Error - Watershed	-	1	.30	model error variable(d)
40 M Error - P Retention	-	1	.20	"
41 M Error - Mean Chl-a/P	-	1	.30	"
42 M Error - Max Chl/Mean Chl	-	1	.10	"
43 M Error - Secchi/Chl-a	-	1	.20	"
44 M Error - HOD/P	-	1	.20	"

(a) parameters which could be adjusted from lake to lake, given adequate data; for example, the chlorophyll/secchi slope (28) could be calibrated separately for each lake, based upon observed chlorophyll and transparency data

(b) average inflow P concentration of upstream lakes, which are assumed to have undeveloped watersheds, since most are in remote areas; adjust upward if upstream lakes have developed and/or sedimentary watersheds (not the case in those used for calibration and testing)

(c) parameter used in computing internal phosphorus load; set equal to zero to eliminate internal load; use 8.0 for alternative internal loading function (see TESTING)

(d) model error terms have not been calibrated

Table 5

Model Output Variables

Variable	Units	Notes
1 External P Load	kg/yr	total external load (2-6)
2 Undeveloped P Load	kg/yr	adjusted for upstream lake effect
3 Agricultural P Load	kg/yr	input from tilled+untilled land uses
4 Urban P Load	kg/yr	input from urban land uses
5 Atmospheric P Load	kg/yr	direct atmospheric input
6 Septic P Load	kg/yr	input from shoreline residences *
7 Net Internal P Load	kg/yr	estimated from P retention model
8 Inflow P Concentration	mg/m3	external P load/annual discharge
9 Overflow Rate	m/yr	annual discharge/lake area
10 Hydraulic Residence Time	yr	lake volume/annual discharge
11 1 - P Retention Coef.	-	estimated from ~~equation (??)~~ App. B
12 P Spring	mg/m3	spring phosphorus concentration
13 Chlorophyll-a	mg/m3	mean, estimated from Spring P
14 Max. Chlorophyll-a	mg/m3	estimated from mean Chl-a
15 Secchi Depth	m	estimated from mean Chl-a
16 Areal HOD	g/m2-day	estimated from Spring P and mean depth
17 Hypolimnetic Depth	m	input, or estimated from other variables
18 Hypolimnetic Area	acres	" (see Table 3)
19 Thermocline Depth	m	estimated if input value < 0
20 Volumetric HOD	g/m3-day	est. from HOD and Hypolimnetic Depth
21 Days of Oxygen Supply	days	est. from HOD, Spring DO, and Hyp. Depth
22 Trophic State Disc. Score	-	Walker (1977), based upon EPA/NES data
23 Prob(Eutrophic)	-	probability of eutrophic classification
24 Prob(Mesotrophic)	-	probability of mesotrophic class.
25 Prob(Oligotrophic)	-	probability of oligotrophic class.
26 Error - P Spring	-	log(observed/predicted), base e
27 Error - Chl-a	-	"
28 Error - Chl Max	-	"
29 Error - Secchi	-	"
30 Error - HOD	-	"

* also includes other direct loading (input variable 18)

export concentrations, as well as bias in the lake model. The net effect of this coefficient, however, is an unbiased estimate of lake concentration, which is of direct concern.

TESTING

The calibrated version of LEAP has been tested using the following procedures:

(1) plotting and statistical analysis of observed and predicted water quality conditions

(2) plotting of residuals (errors) to test for association with various lake and watershed characteristics

(3) interpretation of outliers

The above procedures have been implemented using an expanded data set which includes eighteen lakes, three of which were not used in calibration. Appendix D lists model inputs and outputs, using the "best" set of land use values for each study lake. Appendix E presents charts of observed and predicted conditions, indicating year-to-year variability in observed lake water quality in relation to the prediction variability induced by alternative sets of land use estimates. Appendix E also presents a brief discussion of the model fit for each lake. Phosphorus and Chlorophyll residuals are plotted in Appendix F.

Observed and predicted water quality conditions are listed in Table 6 and plotted in Figures 6-11. Residual histograms are presented in Figure 12. Since both the measurements and the predictions tend to be log-normally distributed, residuals are expressed as the natural logarithm of the ratio of observed to predicted response. In the limit of small errors, this is equal to the fraction error, i.e., a residual of +.1 indicates that the observed response exceeds the predicted response by 10%. One consequence of this transformation is that the error significance is somewhat inflated for oligotrophic lakes, where the measured levels are lower and the potential effects of analytical errors are higher on a percentage basis.

Table 7 summarizes the results of statistical analyses of the observations and residuals. The model framework explains 85% of the

Table 6

Observations, Predictions and Residuals

lake	e-chlx	chlmax	r-chlx	e-pspr	pspr	r-pspr
Bomoseen	9.315	14.832	0.465	10.783	14.834	0.319
Carmi	16.719	64.992	1.358	18.612	19.959	0.070
Cedar	13.019	-	-	14.737	17.129	0.150
Curtis	12.929	11.500	-0.117	14.642	12.154	-0.186
Elmore	10.403	8.454	-0.207	11.954	12.477	0.043
Fairfield	20.924	21.647	0.034	22.947	19.967	-0.139
Harveys	6.656	7.155	0.072	7.880	13.842	0.563
Hortonia	8.314	6.000	-0.326	9.698	11.668	0.185
Iroquois	28.397	36.742	0.258	30.512	29.720	-0.026
Morey	14.941	20.456	0.314	16.758	27.073	0.480
Parker	17.277	15.684	-0.097	19.190	15.330	-0.225
St Cather	9.612	4.400	-0.781	11.104	11.755	0.057
Shelburne	77.666	140.712	0.594	78.027	112.607	0.367
Star	9.744	37.229	1.340	11.246	13.719	0.199
Winona	24.279	-	-	26.362	25.938	-0.016
Halls	12.881	12.800	-0.006	14.592	10.100	-0.368
Shadow	6.169	7.389	0.181	7.340	5.578	-0.275
Sunset	4.659	2.411	-0.659	5.649	6.117	0.080
hold						

lake	e-secchi	secchi	r-secchi	e-chl	chla	r-chl
Bomoseen	5.070	4.636	-0.089	4.689	5.373	0.136
Carmi	3.625	1.839	-0.679	7.833	21.790	1.023
Cedar	4.215	-	-	6.290	-	-
Curtis	4.232	3.800	-0.108	6.252	6.300	0.008
Elmore	3.038	3.234	0.062	5.166	4.224	-0.201
Fairfield	3.140	2.852	-0.096	9.537	10.453	0.092
Harveys	5.977	6.652	0.107	3.492	3.568	0.021
Hortonia	5.373	4.927	-0.087	4.244	3.673	-0.144
Iroquois	2.553	2.653	0.038	12.466	10.511	-0.171
Morey	3.884	4.719	0.195	7.098	9.516	0.293
Parker	3.552	3.795	0.066	8.062	6.211	-0.261
St Cather	4.987	6.384	0.247	4.820	3.184	-0.415
Shelburne	1.200	0.488	-0.900	30.133	75.764	0.922
Star	1.217	0.849	-0.360	4.878	19.774	1.400
Winona	2.844	-	-	10.866	-	-
Halls	4.241	3.800	-0.110	6.232	6.500	0.042
Shadow	6.186	7.019	0.126	3.267	3.824	0.158
Sunset	7.471	9.490	0.239	2.554	1.473	-0.550
hold						

Table 6 (continued)

lake	e-hod	hod	e-vhod	vhod	r-hod
Bomoseen	0.324	0.380	0.090	0.106	0.160
Carmi	0.294	0.238	0.312	0.253	-0.209
Cedar	0.000	-	0.000	-	-
Curtis	0.000	-	0.000	-	-
Elmore	0.000	-	0.000	-	-
Fairfield	0.517	0.450	0.182	0.158	-0.139
Harveys	0.235	0.426	0.014	0.026	0.594
Hortonia	0.275	0.410	0.076	0.113	0.398
Iroquois	0.511	0.587	0.222	0.255	0.139
Morey	0.437	0.506	0.219	0.253	0.146
Parker	0.460	0.400	0.151	0.131	-0.140
St Cather	0.344	0.405	0.063	0.075	0.163
Shelburne	0.514	-	0.367	-	-
Star	0.000	-	0.000	-	-
Winona	0.000	-	0.000	-	-
Halls	0.204	0.180	0.157	0.138	-0.123
Shadow	0.220	0.427	0.014	0.027	0.662
Sunset	0.172	0.140	0.012	0.010	-0.207

Figure 6

Observed vs. Estimated
Spring Phosphorus

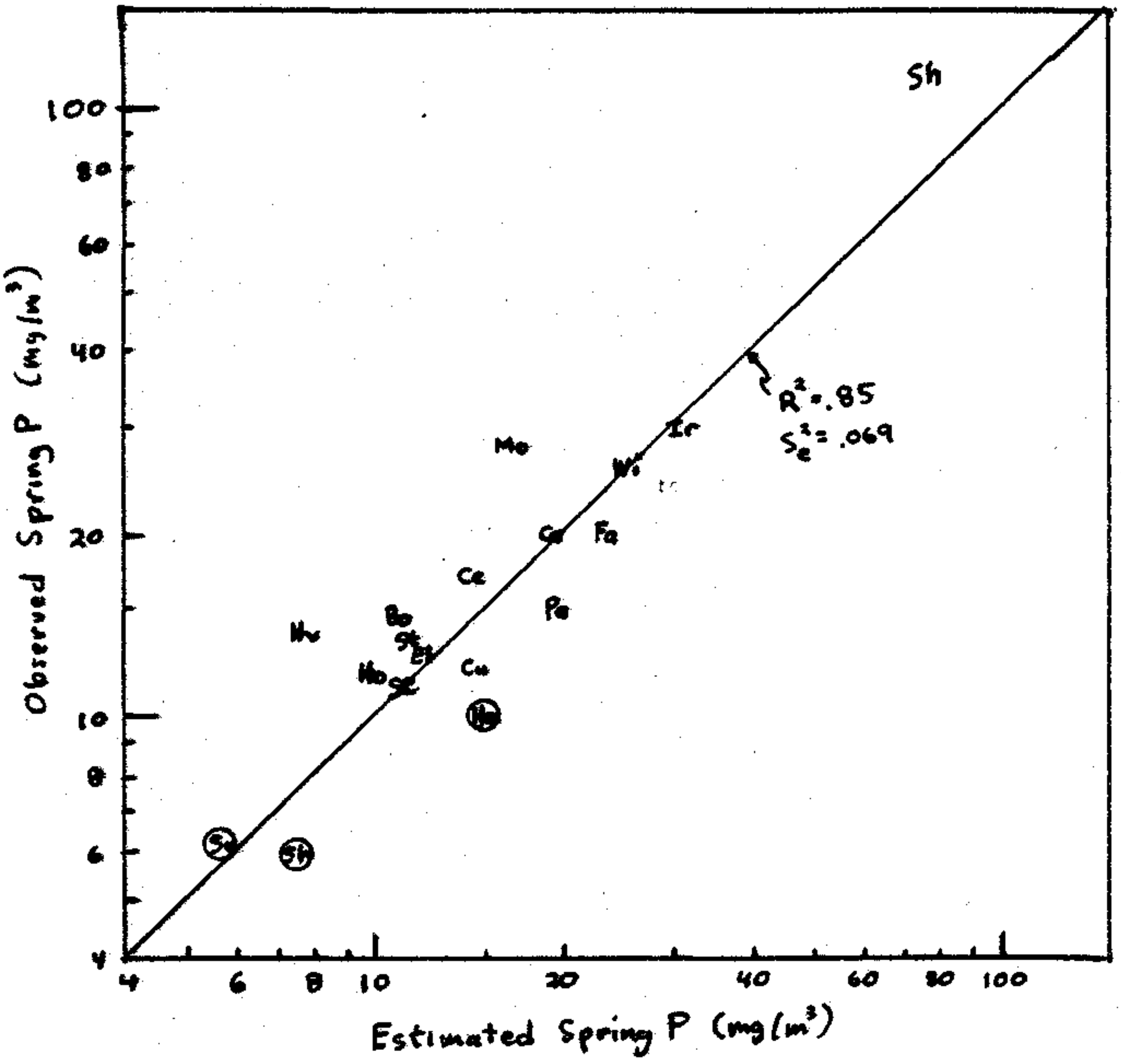


Figure 7

Observed vs. Estimated
Mean Chlorophyll-a

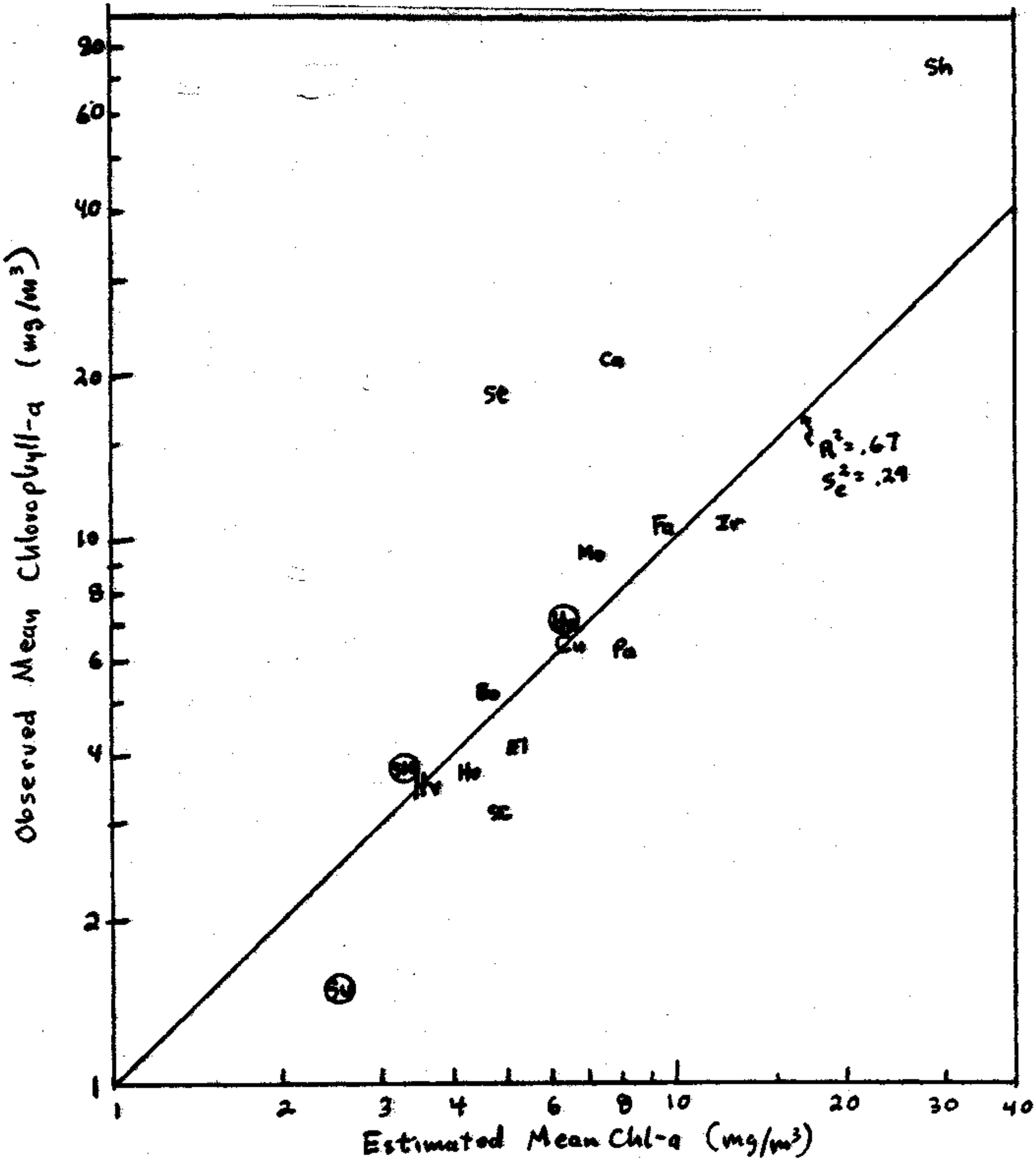


Figure 8

Observed vs. Estimated
Maximum Chlorophyll-a

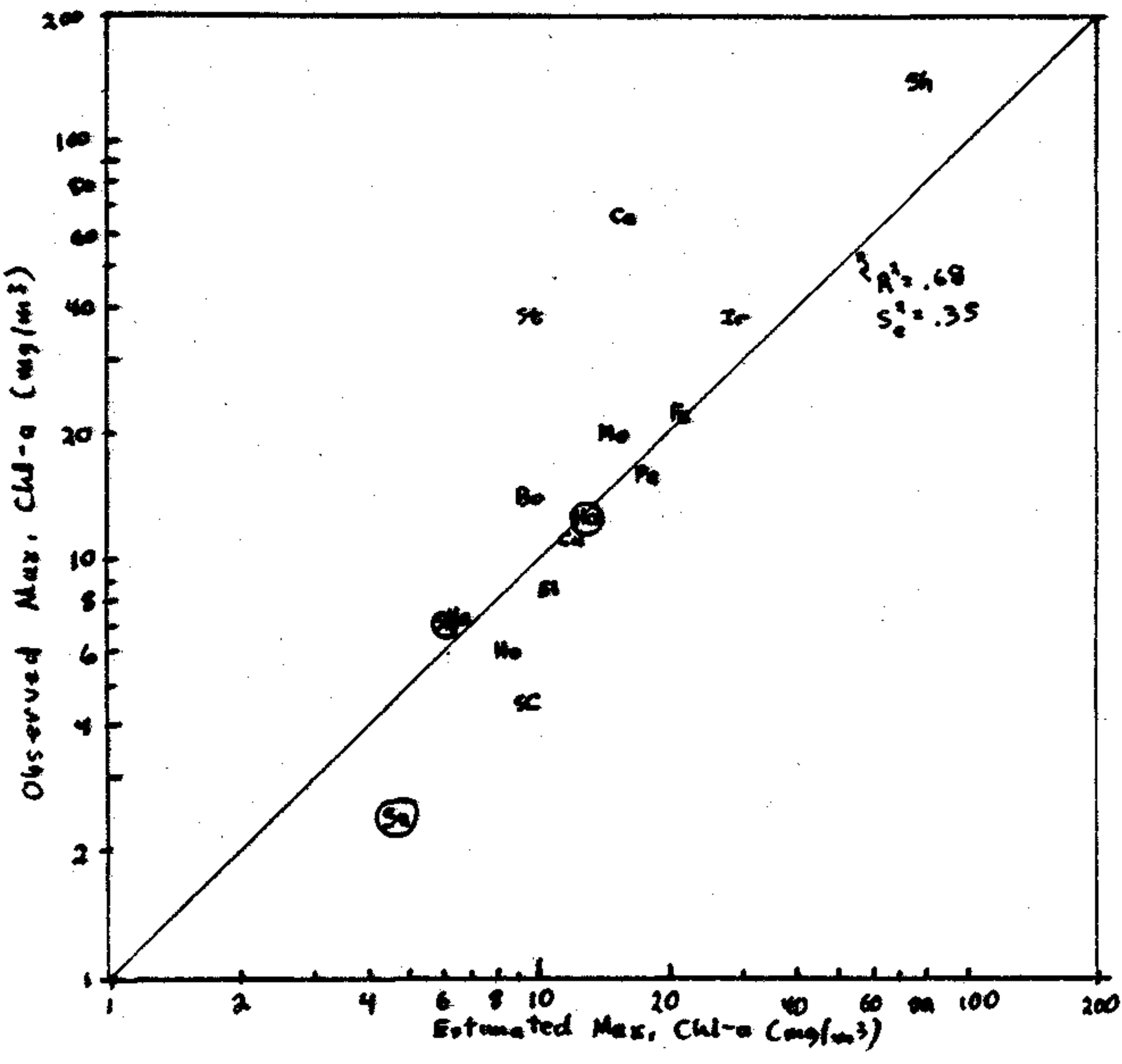


Figure 9

Observed vs. Estimated Transparency

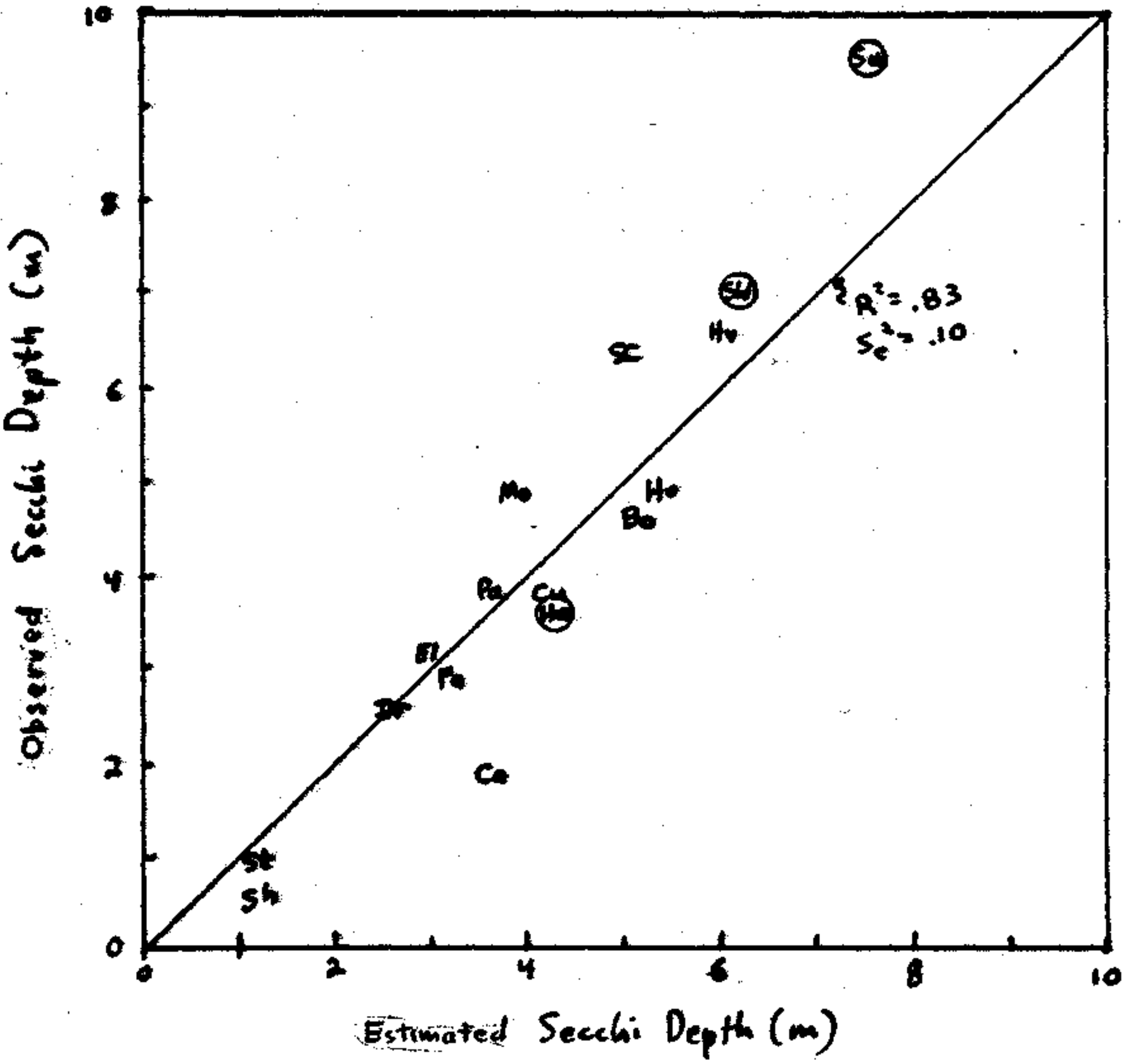


Figure 10

Observed vs. Estimated Areal HOD

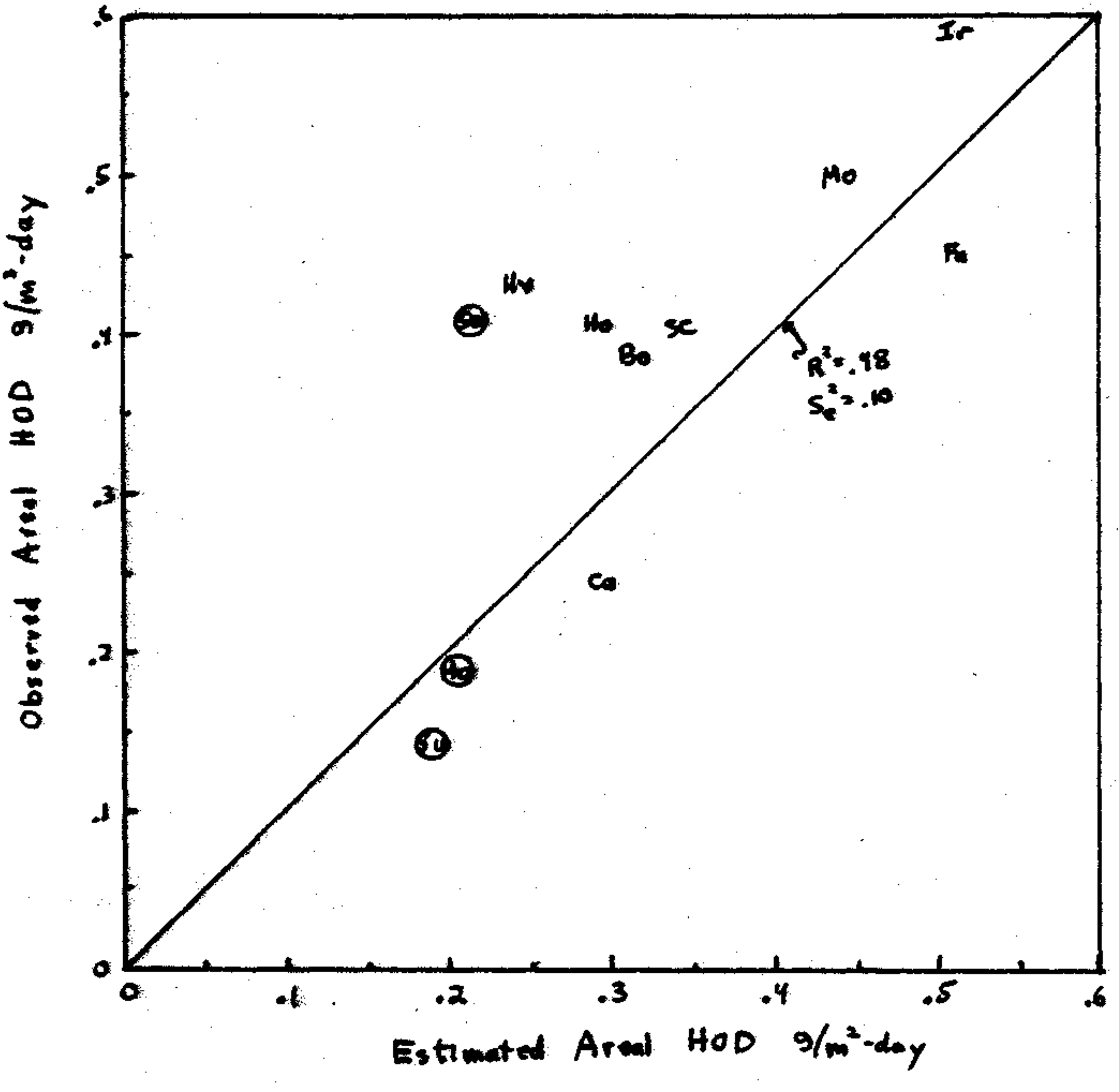


Figure 11

Observed vs. Estimated Volumetric HOD

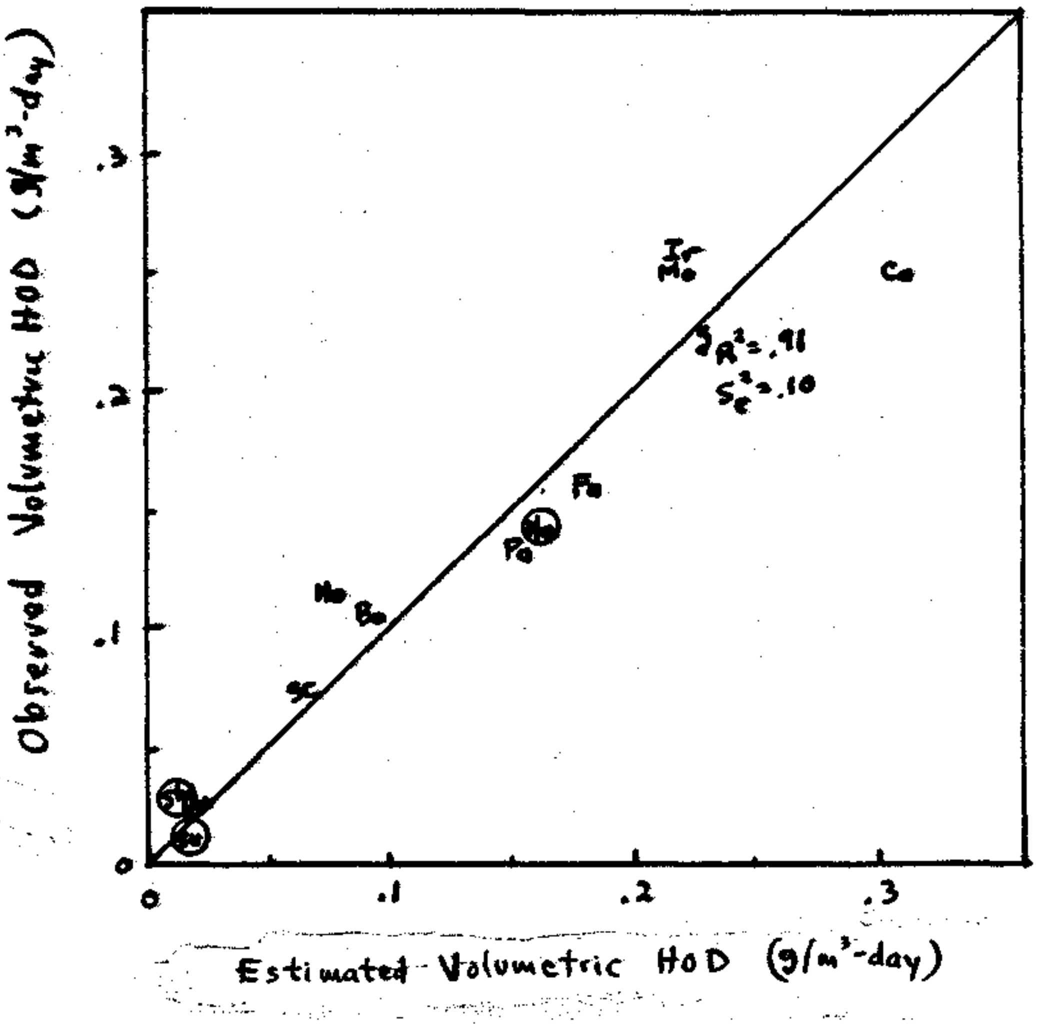


Figure 12

Histograms of Model Residuals

```
histogram of      -pspr

   1.60
   1.40
   1.20
   1.00
   0.80
   0.60
   0.40 Hv Mo
   0.20 Bo Sh
  -0.00 Ca Ce El Ho SC St Su
  -0.20 Cu Fa Ir Wi
  -0.40 Pa Ha Sw
  -0.60
  -0.80
  -1.00
  -1.20
```

```
histogram of      -chl

   1.60
   1.40
   1.20 St
   1.00 Ca
   0.80 Sh
   0.60
   0.40
   0.20 Mo
  -0.00 Bo Cu Fa Hv Ha Sw
  -0.20 Ho Ir
  -0.40 El Pa
  -0.60 SC Su
  -0.80
  -1.00
  -1.20
```

```
histogram of      -chlx

   1.60
   1.40
   1.20 Ca St
   1.00
   0.80
   0.60
   0.40 Bo Sh
   0.20 Ir Mo
  -0.00 Fa Hv Sw
  -0.20 Cu Pa Ha
  -0.40 El Ho
  -0.60
  -0.80 SC Su
  -1.00
  -1.20
```

```
histogram of      -hod

   1.60
   1.40
   1.20
   1.00
   0.80
   0.60 Sw
   0.40 Hv
   0.20 Ho
  -0.00 Bo Ir Mo SC
  -0.20 Fa Pa Ha
  -0.40 Ca Su
  -0.60
  -0.80
  -1.00
  -1.20
```

```
histogram of      -secchi

   1.60
   1.40
   1.20
   1.00
   0.80
   0.60
   0.40
   0.20 SC Su
  -0.00 El Hv Ir Mo Pa Sw
  -0.20 Bo Cu Fa Ho Ha
  -0.40 St
  -0.60
  -0.80 Ca
  -1.00 Sh
  -1.20
```

variance in the observed spring phosphorus values and between 48% and 91% in the other lake response measurements. The relatively low R-Squared for areal HOD (48%) is attributed to the relatively low variance in the observed HOD values (.186 vs. .437-1.086 for the other variables). The volumetric HOD has a high R-Squared (91%) and is of greater significance than the areal HOD because it is more directly related to variations in hypolimnetic oxygen concentrations.

Mean squared residuals range from .067 for total phosphorus to .349 for maximum chlorophyll-a. The corresponds to a range of .26 to .59 in standard error. Median absolute errors, less sensitive to the individual outliers discussed below, range from .11 for transparency to .28 for maximum chlorophyll-a. Transparency is generally the easiest variable to predict in an empirical modelling framework (Walker, 1981b), because it has a limited range and appears to be a fairly robust measurement. Fortunately, it is also the most significant to users of recreational lakes. Maximum chlorophyll errors are expected to be greater because they are more subject to sampling variability than are the mean response variables, i.e., the seasonal maximum concentration estimated from a limited number of samples is less statistically reliable than the seasonal mean.

Appendix E contains a discussion and interpretation of the fit for each lake. As discussed for Star Lake, the chlorophyll/phosphorus relationship used in LEAP may not be appropriate for extremely shallow (mean depth 1.5 meters) and/or rapidly flushed lakes, so a second set of error statistics excluding Star has been added to Table 7.

Examination of Figures 7-9 reveals that the summer algal densities may be somewhat more sensitive to spring phosphorus than is represented in the model framework. There is a tendancy for observed values to be lower than predicted on left sides of these plots and higher than predicted on the right sides. The key relationship responsible for this is the spring phosphorus/ mean summer chlorophyll-a model, which has been taken from the Vermont classification survey report (VAEC,1980):

$$B = .5\ P^{.94}$$

where,

B = mean summer chlorophyll (mg/m3)
P = spring phosphorus (mg/m3)

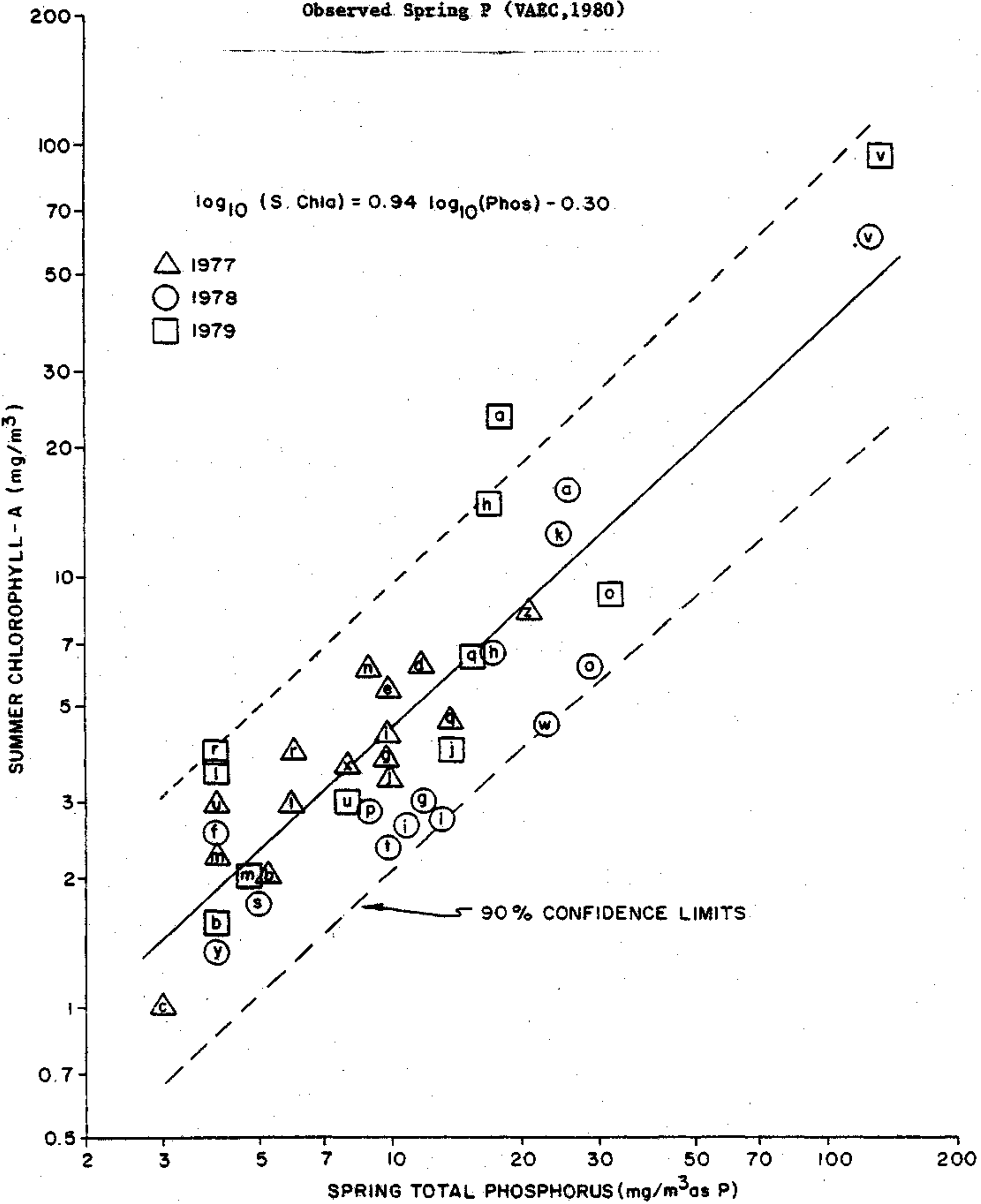
As shown in Figure 13, this relationship was derived from a larger data base of 40 Vermont lakes, including 13 of the lakes studied here. Using a steeper function (say, .21 in place of .5 and 1.21 in place of .94) would eliminate the patterns apparent in Figures 7-9. Based upon Figure 13, however, the above modification may not be appropriate for other Vermont lakes, depending upon confidence in the data from the lakes not studied here. If indicated by future analyses of other lake data, the function could be easily modified in the program subroutine.

Appendix F contains plots of phosphorus and chlorophyll residuals against various lake and watershed characteristics. These have been produced and reviewed in order to identify any significant trends or patterns which may indicate possibilities for reducing prediction error by incorporating additional factors into the framework. The individual lake characteristics (as discussed in Appendix E) should be considered in interpreting the residual plots. As discussed above, modification of the phosphorus/chlorophyll relationship could improve some of the chlorophyll over-predictions (Shelburne, Carmi, Morey) and under-predictions (Shadow, St Catherines). These potential changes should also be considered in reviewing Appendix F. Plots and relationships seeming worthy of comment are discussed below.

Plots of phosphorus residuals against forest type variables (fraction conifer, hardwood, and mixed) indicate that conifer forests may have a somewhat lower export concentration than the 15 mg/m3 assumed for undeveloped land. The three lakes with the most negative residuals (Halls, Shadow, and Parker) all have greater than 45% coniferous forests. Harvey's Lake, however, has both a high percentage of coniferous forest and a positive residual, which might be attributed to the effects of South Peacham Brook, as discussed in Appendix E, or to some other unique feature of the lake. This effect may be related to a lower cycling phosphorus via needle-fall (vs. leaf-fall) in conifer forests and/or to the fact that conifer forests tend to be located in

Figure 13

Observed Chlorophyll-a vs.
Observed Spring P (VAEC,1980)



well-drained soils (which have lower runoff potential). Corresponding effects of coniferous forests on chlorophyll residuals are not indicated, however.

Phosphorus and chlorophyll residuals may be positively correlated with the ratio of wetland area to total drainage area. This is more evident if the responses of Morey, Harveys, and Star are interpreted independently of wetlands (see discussions in Appendix E). While it is possible that wetlands could export more phosphorus than forested areas, the effect could also be explained by the tendancy for wetlands to export organic color which interferes with phosphorus and chlorophyll measurements (Carlson and Shapiro,1981). The effect is also difficult to distinguish from the possible coniferous forest effect discussed above, since the watersheds with higher percentages of coniferous forests would tend to have lower precentages of wetlands and better drainage.

The factors discussed above have maximum effects of +/- 20% and could be easily incorporated into the model framework by including additional watershed categories. Since both the forest type and the wetlands effects are consistent with a general effect of soil drainage properties, the potentials for using hydrologic soil group as an additional independent variable could also be investigated. This would involve augmenting the data base to characterize each watershed in a matrix of hydrologic soil group vs. land use. The soils information is readily available, but would have to be overlayed on land use maps. While the existing framework appears to be adequate for explaining most of the lake-to-lake variations in phosphorus, chlorophyll, transparency, and oxygen depletion, the potential for improving the watershed model using an expanded data base should be considered in the future.

The modification of the phosphorus retention function to account for the effects of hypolimnetic oxygen depletion on internal phosphorus cycling has not been severely tested because the lakes in the testing data set are relatively unproductive and do not have the internal loading potential of Morey, Iroquois, Carmi, or Shelburne. Data from other mesotrophic or eutrophic, stratified lakes would provide a better basis for testing the formulation. As a result of work by the Connecticut Agricultural Experiment Station (Norvell et al., 1979), there is a good data set on land use, lake morphometry, and lake water quality for 33 Connecticut lakes. This data set would be particularly useful as a basis for further testing.

One important feature of the model is that it indicates a nonlinear response of lake phoshorus levels to external loading. Table 8 summarizes the results of sensitivity and error analysis calculations for predicted spring phoshorus levels. Note that both the sensitivity coefficients and the error variances are much higher for lakes with higher internal loading potential. Some of this high sensitivity results from the somewhat arbitary selection of an exponential function to fit the data in Figure 2.

Figure 14 plots the estimated spring P level as a function of total external loading for a hypothetical lake with the same morphometric and hydrologic characteristics as Lake Iroquois. The curve is concave upwards, in contrast to the linear relationship (constant retention coefficient) more generally assumed in lake models. The nonlinearity of the model also increases with loading, as shown by the sensitivity coefficients (percent increase in spring P for a 1% increase in external loading) plotted in Figure 14. At low loadings, oxygen depletion is of little consequence and the sensitivity coefficient is near one. The sensitivity coefficient increases with loading, especially as the loading approaches about 230 kg/yr, where the coefficient exceeds five. One unfortunate consequence of this sensitivity is that it magnifies the effects of errors in loading estimates and lake morphometric characteristics. At a sensitivity coefficient of 5, for example, the variance in the predicted lake concentration is 25 times the variance of the loading estimate. This is an undesirable characteristic if the framework is to be used to provide robust assessments of lake conditions, given uncertain watershed and morphometric information.

The dramatic increase in sensitivity reflects the use of the exponential function in the phosphorus retention function:

Table 8
Estimated Lake Sensitivities to External Phosphorus Loading

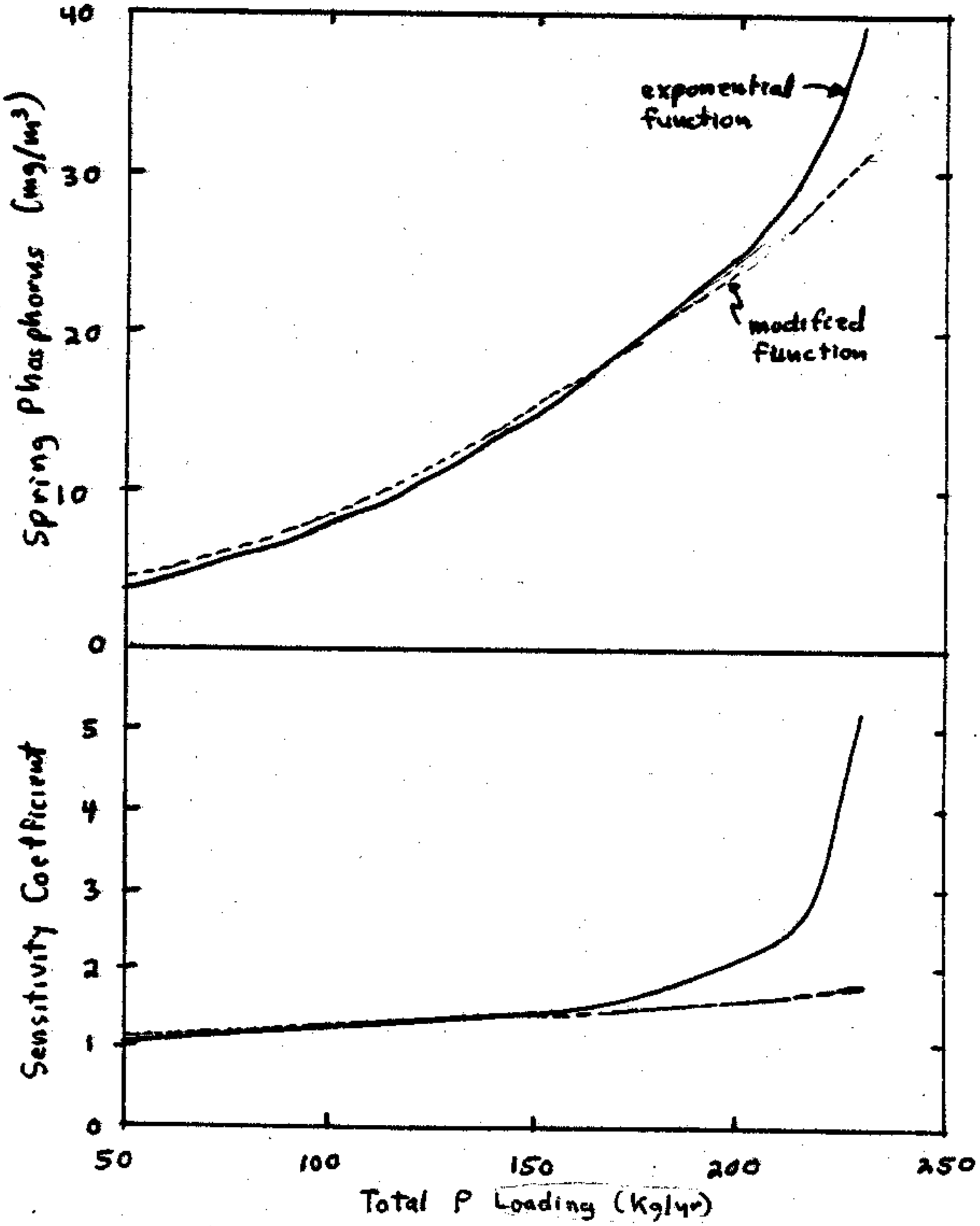
Lake	Observed Spring P	Observed HODv	HODv x Ah/Ae	External Load Sensitivity*	CV(P)
Bomoseen	15	.11	.044	1.27	.44
Carmi	20	.25	.073	2.05	.71
Cedar	17	0	0	1.00	.34
Curtis	12	0	0	1.00	.35
Elmore	12	0	0	1.00	.36
Fairfield	20	.16	.084	2.24	.80
Harveys	14	.026	.019	1.06	.37
Hortonia	12	.11	.027	1.12	.39
Iroquois	30	.26	.138	3.25	1.19
Morey	27	.25	.136	3.07	1.09
Parker	15	.13	.073	1.92	.70
St Catherines	12	.075	.043	1.26	.42
Shelburne	112	-	-	1.00	.40
Star	14	0	0	1.00	.35
Winona	26	0	0	1.00	.36
Halls	10	.095	.044	1.46	.49
Shadow	6	.027	.026	1.08	.39
Sunset	6	.010	.008	1.06	.38

* percent increase in lake spring phosphorus for a 1 percent increase in external phosphorus loading, estimated from LEAP first-order sensitivity analysis procedure

** coefficient of variation of spring total P estimate, estimated from LEAP error analysis procedure

Figure 14

Simulated Lake Responses
to External P Loading



$$1\text{-}Rp = .7 \exp(6\ HODv\ Ah/Ae) / (1 + .82\ T^{.45})$$

The following function also provides an adequate fit of the observed phosphorus retention data:

$$1\text{-}Rp = .7\ (1 + 8\ HODv\ Ah/Ae) / (1 + .82\ T^{.45})$$

The dashed lines in Figure 14 indicate that the predicted lake response is nearly identical to that derived from the above function, but the sensitivity coefficient is much more stable. Tests of this alternative function indicate that prediction errors for phosphorus and other lake response variables are not significantly different from the original formulation. The modified formulation has much better error stability and should probably be used in place of the exponential function, subject to further evaluations.

Because of the above problems with error stability, it has not been possible to calibrate or test the model error terms (input variables 39-44). Additional analysis would be required to achieve this. The LEAP sensitivity analysis procedure can still be used to estimate and compare the sensitivities of predictions to various input variables, but the predicted confidence ranges are not reliable. Until the error analysis terms can be properly calibrated, predicted confidence ranges should be calculated from the model error statistics in Table 7, with awareness that the confidence ranges are likely to be wider for lakes with higher internal loading potential. For spring phosphorus, the error statistics in Table 7 refer to the average of four to six years of data for each lake. Higher error variance would be expected for comparisons with data from individual years. A refined error analysis scheme could also be developed to account for the effects of year-to-year variability on the predicted confidence ranges and error statistics for individual lakes and years.

CONCLUSIONS

(1) The calibrated LEAP framework is a potentially useful tool for managing Vermont lakes which can be implemented without excessive data requirements.

(2) When predictions are compared with measurements made in 18 Vermont lakes, the prodecure explains 85%, 67%, 83%, and 91% of the variance in spring phosphorus, mean summer chlorophyll, mean transparency, and volumetric hypolimnetic oxygen depetion rate, respectively.

(3) The model may under-predict chlorophyll levels in extremely shallow lakes (mean depth < 2 meters). Excluding data from one lake in this category (Star), the procedure explains 80% of the mean chlorophyll variance.

(4) Median absolute prediction errors are 19%, 19%, 11%, and 16% for phosphorus, chlorophyll, transparency, and oxygen depletion, respectively. These errors are smaller than the year-to-year variability observed within lakes.

(5) Reductions in chlorophyll and transparency error variance could be achieved by using a steeper chlorophyll/phosphorus relationship for these lakes. This potential modification should be further tested on data from other lakes.

(6) Residuals analyses indicate that additional variance could be explained by modifying the framework to account for the effects of variations in forest types, wetlands, and/or soil drainage characteristics on phosphorus export.

(7) The phosphorus retention function accounts for the effects of hypolimnetic oxygen depletion on phosphorus cycling within lakes and suggests a non-linear response of spring phosphorus levels to external loadings in stratified lakes. Additional testing of this function should be undertaken, using data from other lakes in Vermont or elsewhere in New England.

(8) Owing to the extreme sensitivity of the retention function for some lakes, it has not been possible to calibrate the error analysis parameters used in LEAP. The calibration could be achieved through analysis of an expanded data set and slight modification of the retention function.

(9) Routine measurements of summer phosphorus concentrations, in addition to spring phosphorus, summer chlorophyll, and summer transparency, would provide a better data base for assessing eutrophication in Vermont lakes, especially for those which have short hydraulic residence times and/or significant internal recycling of phosphorus.

(10) Direct estimates of land uses from recent areal photos should be considered, in addition to Landsat and planning maps, as sources of watershed information for future implementations of LEAP.

REFERENCES

Carlson, R.E. and J. Shapiro, "Dissolved Humic substances: A Major Source of Error in Fluorometric Analyses Involving Lake Waters", Limnology and Oceanography , Vol. 26, No. 4, pp. 785-799, July 1981.

Dillon, P.J. and B. Kirchner, "The Effects of Geology and Land Use on the Export of Phosphorus from Watersheds", Water Research , Vol. 9, pp. 135-148, 1975.

Likens, G.E., "Water and Nutrient Budgets for Cayuga Lake, New York", Cornell University Water Resources and Marine Sciences Center, Technical Report No. 82, March 1974.

Meta Systems, Inc., "Land Use-Nutrient Export Relationships in the Northeast", in "A Preliminary Analysis of the Potential Impacts of Watershed Development on the Eutrophication of Lake Chamberlain", prepared for New Haven Water Company, Connecticut, June 1978.

Morse, J.W. and P.H. Flanders, "Primary Productivity Study of Three Vermont Lakes", Vermont Agency of Environmental Conservation, Department of Water Resources, Water Quality Surveillance Series No.2, 1971.

Norvell, W.A, C.R. Frink, and D.E. Hill, "Phosphorus in Connecticut Lakes Predicted by Land Use", Proc. Natl. Acad. Sci. U.S.A. , Vol. 76, No. 11, pp. 5426-5429, November 1979.

Vermont Agency of Environmental Conservation, "A Prelimimary Investigation of the Water Quality Relationships in Lake Morey", Department of Water Resources, Water Quality Division, December 1979.

Vermont Agency of Environmental Conservation, "Vermont Lake Classification Survey", Department of Water Resources and Environmental Engineering, Water Quality Division, Montpelier, December 1980.

Vermont Agency of Environmental Conservation, "Harvey's Lake Diagnostic/ Feasibility Study", Interim Report, Department of Water Resources and Environmental Engineering, Water Quality Division, Montpelier, January 1981.

Walker, W.W., "Use of Hypolimnetic Oxygen Depletion Rate as a Trophic State Index for Lakes", Water Resources Research , Vol. 15, No. 6, pp. 1463-1470, December 1979.

Walker, W.W., "A Lake Eutrophication Analysis Procedure Applied to Lake Morey", prepared for the Vermont Department of Water Resources, Water Quality Division, Lakes Program, August 1980.

Walker, W.W., "A Sensitivity and Error Analysis Framework for Lake Eutrophication Modelling", Water Resources Bulletin , March 1982.

Walker, W.W., "Calibration of LEAP to Vermont Lakes: Data Base Summary", prepared for Vermont Agency of Environmental Conservation, Water Quality Division, December 1981.

Walker, W.W., "Empirical Methods for Predicting Eutrophication in Impoundments: Phase II Model Testing", prepared for the Office of the Chief, Corps of Engineers, U.S. Army, Waterways Experiment Station, Vicksburg, Mississippi, draft, 1981b.

APPENDIX A

Lake Data Base

Lake Water Quality Data by Year

Lake	yr	pspr	chla	chlmax	secchi	hoda
Bomoseen	77	14	-	-	-	-
Bomoseen	78	15	7.40	22.00	4.20	0.38
Bomoseen	79	19	4.40	10.00	5.00	0.38
Bomoseen	80	12	4.00	-	5.50	-
Bomoseen	81	15	6.40	-	4.00	-
Carmi	77	18	-	-	-	0.21
Carmi	78	25	19.80	64.00	2.20	-
Carmi	79	18	27.50	66.00	1.70	-
Carmi	80	17	23.00	-	1.70	-
Carmi	81	23	18.00	-	1.80	0.27
Cedar	77	21	-	-	-	-
Cedar	78	11	-	-	-	-
Cedar	79	19	-	-	-	-
Cedar	80	14	-	-	-	-
Cedar	81	24	-	-	-	-
Curtis	77	13	6.30	11.50	3.80	-
Curtis	78	17	-	-	-	-
Curtis	79	10	-	-	-	-
Curtis	80	8	-	-	-	-
Curtis	81	15	-	-	-	-
Elmore	77	10	3.87	8.40	3.30	-
Elmore	78	12	2.99	7.60	3.30	-
Elmore	79	12	4.14	8.00	3.20	-
Elmore	80	14	5.20	10.00	2.90	-
Elmore	81	15	5.40	-	3.50	-
Fairfield	78	17	6.70	14.20	4.30	-
Fairfield	79	17	14.90	33.00	2.23	-
Fairfield	80	25	13.00	-	3.00	-
Fairfield	81	22	9.20	-	2.30	0.45
Harveys	77	10	3.42	7.00	6.90	-
Harveys	78	11	2.68	5.20	6.80	-
Harveys	79	14	3.40	8.00	6.10	0.39
Harveys	80	15	5.30	9.00	7.00	0.39
Harveys	81	22	3.50	-	6.50	0.51
Hortonia	77	9	-	-	-	0.32
Hortonia	78	11	-	-	-	-
Hortonia	79	13	2.70	6.00	5.20	0.50
Hortonia	80	12	3.60	6.00	5.00	-
Hortonia	81	14	5.10	-	4.60	0.43
Iroquois	77	41	9.40	-	2.60	-
Iroquois	78	25	12.16	54.00	2.50	0.51
Iroquois	79	26	9.90	25.00	2.60	0.63
Iroquois	80	30	8.10	-	3.70	-
Iroquois	81	29	14.00	-	2.10	0.63

Lake Water Quality Data by Year (ct)

Lake	yr	pspr	chla	chlmax	secchi	hoda
Morey	75	26	-	-	6.00	-
Morey	77	17	-	-	-	-
Morey	78	29	6.15	21.40	5.50	-
Morey	79	32	9.26	20.00	5.00	0.53
Morey	80	20	12.00	20.00	3.30	0.46
Morey	81	48	12.00	-	4.30	0.53
Parker	77	14	4.73	12.30	3.70	-
Parker	78	10	-	-	-	-
Parker	79	18	6.75	20.00	4.47	-
Parker	80	16	7.90	-	3.80	-
Parker	81	21	5.90	-	3.30	0.40
St Cather	77	10	-	-	-	-
St Cather	78	10	2.33	4.40	7.90	-
St Cather	79	11	3.00	-	5.90	0.42
St Cather	80	12	3.00	-	6.60	-
St Cather	81	17	4.90	-	5.40	0.39
Shelburne	77	147	-	-	-	-
Shelburne	78	128	59.30	132.00	0.70	-
Shelburne	79	135	96.80	150.00	0.34	-
Shelburne	80	99	-	-	-	-
Shelburne	81	72	-	-	-	-
Star	78	10	-	-	-	-
Star	79	7	17.00	33.00	0.90	-
Star	80	22	23.00	42.00	0.80	-
Star	81	23	-	-	-	-
Winona	77	40	-	-	-	-
Winona	78	22	-	-	-	-
Winona	79	20	-	-	-	-
Winona	80	29	-	-	-	-
Winona	81	23	-	-	-	-
Halls	77	10	4.40	7.10	3.60	-
Halls	78	10	-	-	-	-
Halls	79	5	-	-	3.60	-
Halls	80	9	12.00	23.00	3.70	0.23
Halls	81	23	5.20	-	4.20	-
Shadow	77	5	-	-	-	-
Shadow	78	9	-	-	-	0.57
Shadow	79	4	4.70	9.10	7.30	-
Shadow	80	6	3.40	6.00	6.40	0.57
Shadow	81	5	3.50	-	7.40	0.24
Sunset	78	4	1.40	2.90	9.60	0.13
Sunset	79	10	1.40	2.30	9.50	0.17
Sunset	80	5	1.50	2.10	9.90	0.13
Sunset	81	7	1.60	-	9.00	-

Geometric Mean Observed Lake Water Quality Variables

lake	pspr	chla	chlmax	secchi	hoda
Bomoseen	14.83	5.37	14.83	4.64	0.38
Carmi	19.96	21.79	64.99	1.84	0.24
Cedar	17.13	-	-	-	-
Curtis	12.15	6.30	11.50	3.80	-
Elmore	12.48	4.22	8.45	3.23	-
Fairfield	19.97	10.45	21.65	2.85	0.45
Harveys	13.84	3.57	7.15	6.65	0.43
Hortonia	11.67	3.67	6.00	4.93	0.41
Iroquois	29.72	10.51	36.74	2.65	0.59
Morey	27.07	9.52	20.46	4.72	0.51
Parker	15.33	6.21	15.68	3.79	0.40
St Cather	11.75	3.18	4.40	6.38	0.40
Shelburne	112.61	75.76	140.71	0.49	-
Star	13.72	19.77	37.23	0.85	-
Winona	25.94	-	-	-	-
Halls	10.10	6.50	12.80	3.80	0.18
Shadow	5.58	3.82	7.39	7.02	0.43
Sunset	6.12	1.47	2.41	9.49	0.14

Depth Variables *

lake	zmean	zbasin	zmax	ztherm	zhyp
Bomoseen	8.2	9.9	19.8	10.0	3.6
Carmi	5.4	5.4	10.1	8.0	0.9
Cedar	1.9	1.9	4.0	0.0	0.0
Curtis	3.3	3.3	9.8	0.0	0.0
Elmore	3.5	3.5	5.2	0.0	0.0
Fairfield	7.2	7.2	12.8	8.0	2.8
Harveys	20.0	20.0	44.2	10.0	16.4
Hortonia	5.6	8.9	18.3	11.0	3.6
Iroquois	5.8	5.8	11.3	7.5	2.3
Morey	8.3	8.3	13.1	9.0	2.0
Parker	7.6	7.6	14.7	8.0	3.1
St Cather	10.7	10.7	19.5	10.0	5.4
Shelburne	3.6	3.6	7.9	4.0	1.4
Star	1.5	1.5	2.4	0.0	0.0
Winona	1.0	1.0	2.7	0.0	0.0
Halls	5.0	5.0	9.2	7.0	1.3
Shadow	20.9	20.9	42.4	10.0	15.7
Sunset	18.6	18.6	36.0	8.0	14.5

* all depths in meters

Land Uses and Soil Types

use:	undeveloped		untilled ag.		tilled ag.		urban
lake soil:	ns	s	ns	s	ns	s	s,ns
Bomoseen LS	19722	0	1072	0	236	0	236
Bomoseen PM	18265	0	1566	0	646	0	1391
Bomoseen XX	17855	0	1474	0	614	0	1323
Carmi LS	3803	0	1606	0	925	0	0
Carmi PM	3651	0	900	0	1962	0	131
Carmi XX	3626	0	1606	0	871	0	231
Cedar LS	427	0	113	0	98	0	0
Cedar PM	229	0	29	0	338	0	44
Cedar XX	360	0	133	0	115	0	30
Curtis LS	748	0	83	0	9	0	0
Curtis PM	420	0	74	0	203	0	148
Curtis XX	492	0	248	0	27	0	73
Elmore LS	5074	0	164	0	111	0	0
Elmore PM	3581	0	441	0	607	0	202
Elmore XX	4304	0	655	0	167	0	223
Fairfield LS	2730	281	0	170	0	113	0
Fairfield PM	2586	211	0	98	0	270	232
Fairfield XX	2495	291	0	170	0	113	225
Harveys LS	4652	0	312	0	54	0	0
Harveys PM	3590	0	451	0	715	0	153
Harveys XX	3852	0	914	0	155	0	97
Hortonia LS	3837	0	125	0	45	0	0
Hortonia PM	3135	0	446	0	132	0	257
Hortonia XX	3481	0	214	0	89	0	223
Iroquois LS	1534	0	486	0	193	0	0
Iroquois PM	1191	0	0	0	599	0	222
Iroquois XX	1292	0	486	0	193	0	242
Morey LS	4461	0	51	0	51	0	0
Morey PM	4074	0	499	0	0	0	128
Morey XX	3925	0	459	0	51	0	128
Parker LS	4811	0	313	0	54	0	0
Parker PM	2219	0	689	0	1998	0	102
Parker XX	2644	0	2101	0	325	0	108
St Cath LS	6237	0	210	0	74	0	74
St Cath PM	4819	0	444	0	962	0	370
St Cath XX	5119	0	880	0	298	0	298

units: acres

(contined)

Land Uses and Soil Types (ct)

use:	undeveloped		untilled ag.		tilled ag.		urban
lake soil:	ns	s	ns	s	ns	s	s,ns
Shelburne LS	86	1428	399	1722	0	788	49
Shelburne PM	359	1094	0	143	0	2569	143
Shelburne XX	386	1679	0	1471	0	788	148
Star LS	620	0	11	0	7	0	14
Star PM	612	0	92	0	6	0	22
Star XX	544	0	82	0	6	0	20
Winona LS	1021	872	0	333	0	77	26
Winona PM	890	522	0	484	0	170	50
Winona XX	993	569	0	579	0	134	54
Halls LS	443	0	17	0	11	0	6
Halls PM	493	0	0	0	22	0	123
Halls XX	393	0	50	0	6	0	28
Shadow LS	3304	0	36	0	36	0	0
Shadow PM	2560	0	106	0	389	0	283
Shadow XX	2787	0	429	0	71	0	89
Sunset LS	949	0	36	0	12	0	0
Sunset PM	773	0	5	0	0	0	73
Sunset XX	893	0	32	0	12	0	60

units: acres

LS = Landsat Estimate
PM = Planning Map Estimate
XX = "Best" Estimate

Other Lake Variables

Lake	surface area acres	hypol. area acres	Fu acres	runoff m/yr	Us cap/yr	a 1/m
Bomoseen	2363.79	988.00	3560.00	0.46	717.97	0.08
Carmi	1375.79	395.20	150.98	0.68	679.43	0.08
Cedar	113.62	0.00	0.00	0.58	61.50	0.08
Curtis	76.57	0.00	0.00	0.60	60.00	0.08
Elmore	224.77	0.00	190.97	0.60	313.68	0.20
Fairfield	464.36	247.00	0.00	0.68	150.00	0.08
Harveys	346.00	247.00	0.00	0.55	223.70	0.08
Hortonia	449.54	108.68	1237.82	0.46	348.00	0.08
Iroquois	205.01	111.15	0.00	0.60	196.50	0.08
Morey	538.46	288.99	0.00	0.56	382.80	0.08
Parker	239.59	133.38	62.99	0.60	156.00	0.08
St Cather	852.15	491.53	316.96	0.46	814.42	0.08
Shelburne	449.54	210.00	0.00	0.60	0.00	0.08
Star	56.81	0.00	0.00	0.58	12.00	0.70
Winona	234.65	0.00	0.00	0.58	10.50	0.08
Halls	84.00	29.60	6.20	0.55	76.50	0.08
Shadow	199.00	187.00	573.00	0.60	183.00	0.08
Sunset	195.00	152.00	439.00	0.46	48.00	0.07

Fu = upstream lake P retention factor
Us = shoreline septic system use
a = secchi/chlorophyll intercept

Additional Morphometric and Watershed Data

lake	shoreline develop. ratio	drainage area acres	......forest types.....			wetland fraction
			conifer	hardwood	mixed	
Bomoseen	3.155	23630	0.123	0.691	0.186	.057
Carmi	1.531	7710	0.046	0.698	0.256	.077
Cedar	1.108	752	0.249	0.501	0.250	.037
Curtis	2.594	917	0.307	0.580	0.113	.010
Elmore	1.247	5574	0.341	0.582	0.077	.049
Fairfield	1.861	3758	0.129	0.776	0.095	.042
Harveys	1.387	5364	0.540	0.368	0.092	.052
Hortonia	2.644	4457	0.136	0.654	0.210	.048
Iroquois	1.610	2418	0.180	0.689	0.131	.055
Morey	1.463	5101	0.216	0.705	0.079	.004
Parker	1.383	5418	0.506	0.382	0.112	.016
St Cather	2.402	7447	0.169	0.687	0.144	.022
Shelburne	1.552	4922	0.205	0.539	0.256	.132
Star	1.264	709	0.379	0.436	0.185	.031
Winona	1.201	2564	0.188	0.681	0.131	.143
Halls	1.790	561	0.510	0.340	0.160	.016
Shadow	1.320	3575	0.480	0.460	0.060	.039
Sunset	1.090	1192	0.200	0.560	0.240	.022

total drainage area for "best" land use estimates
forest types = fractions of total forested area
wetland fraction = wetland area/ total drainage area

APPENDIX B

Summary of Key Models Used in LEAP

			Subscripts	
Symbols	Variable	Unit	Input	Output
Ah	Hypolimnetic Area	km2	15	18
Ai	Watershed area for land use/soil type i	km2	1-7	
As	Lake Surface Area	km2	8	
Awu	Watershed Area of Upstream Lake	km2		
Alu	Surface Area of Upstream Lake	km2		
B	Mean Chlorophyll-a	mg/m3		13
Bmax	Maximum Chlorophyll-a	mg/m3		14
Ci	Export concentration for wat. type 1	mg/m3	29-35	
Cu	Inflow concentration of upstream lakes	mg/m3	26	
DOsp	Spring Overturn D.O.	g/m3	28	
Fu	Upstream lake P retention factor	km2	9	
HODa	Areal HOD	g/m2-day		16
HODv	Volumetric HOD	g/m3-day		20
Ip	Trophic State Index			
La	Atmospheric P loading	kg/km2-yr	36	
Qr	Regional Runoff Rate	m/yr	16	
Qs	Surface Overflow Rate	m/yr		9
Pi	Average Inflow Total P Conc.	mg/m3		8
P	Lake Spring Phosphorus	mg/m3		12
Rp	P Retention Coefficient	-		11
Rseas	Number of Seasonal Shoreline Residences	-		
Rperm	Number of Permanent Shoreline Residences	-		
S	Mean Secchi Depth	m		15
T	Hydraulic Residence Time	yr		10
Tdo	Days of Oxygen Supply	days		21
Uday	Day Use of Resorts/Parks	cap-days/yr		
Unit	Overnight Use of Resorts/Parks	cap-days/yr		
Us	Total Use of Shoreline Septic Syst.	capita/yr	17	
Wi	Net Internal P Loading	kg/yr		7
Wo	Other Direct Loading	kg/yr	18	
Ws	Shoreline Septic Loading	kg/yr		6
Wx	Total External P Loading	kg/yr		1
Z	Mean Depth	m	10	
Zb	Basin Mean Depth	m	11	
Zh	Mean Hypolimnetic Depth	m	14	17
Zt	Thermocline Depth	m	13	19
Zx	Maximum Depth	m	12	

Summary of Key Models Used in LEAP (continued)

(1) Total External Loading: mass balance, export concentrations estimated from EPA/NES watersheds in Northeast (Meta Systems, 1978); exports for sedimentary soils 3 x glacial

$$Wx = Qr\ Sum[Ai\ Ci] - Qr\ Fu\ Cu + Ws + Wo + As\ La$$

(Sum = sum over land use/soil types)

(2) Phosphorus loading from shoreline septic systems (Walker, 1981): mass balance, based upon use intensity
net P loading of .05 kg/capita-yr (input variable 27) corresponds to approx. 90% treatment efficiency at .5 kg/cap-yr input to systems under detergent ban

$$Ws = .05\ Us$$

$$Us = 3\ (.5\ Rseas + Rperm) + (.5\ Uday + Unit)/365$$

(assumes average of 3 people/shoreline residence)

(3) Phosphorus retention by upstream lakes and reservoirs (Walker, 1981): mass balance, using settling velocity model (12 m/yr)

$$Fu = Sum\ [\ 12\ Awu\ Alu / (12\ Alu + Qr\ Awu)\ ]$$

(Sum = sum over all upstream lakes and reservoirs)

(4) Phosphorus Retention: Walker(1977), modified to account for internal loading and calibrated to study lakes (Fig. 2-3)

$$Fr = .7 / (1 + .82\ T^{.45})$$

$$Fi = \exp\ [\ 6\ HODv\ Ah/As\ ]\ ,\ \text{maximum}\ 1/Fr$$

$$1 - Rp = Fr\ Fi$$

$$Wi = Wx\ Fr\ (Fi - 1)$$

Summary of Key Models Used in LEAP (continued)

(5) Chlorophyll-a, Vermont AEC (1980):

$$B = .5\, P^{.94}$$

(6) Max Chlorophyll-a, fit of data from study lakes (Fig. 4):

$$Bmax = 1.6\, B^{1.16}$$

(7) Secchi Depth, Walker (1981b):

$$1/S = a + b\, B$$

a = .08 1/m (input var. 19)
b = .025 m2/mg (input var. 38)

(8) Oxygen Depletion: Walker(1979), calibrated for Spring P:

$$Fm = -3.58 + 1.98 \log_e(Zb) - .38\, [\log_e(Zb)]^2$$

$$Ip = -15.6 \overset{20}{+} \log_e(P)$$

$$HODa = .85\; 10^{(Fm\, +\, .02\, Ip)}$$

(.85 = calibration factor for spring P/HOD relationship in Vermont lakes (see Figure 5))

$$HODv = HODa/Zh$$

$$Tdo = DOsp/HODv$$

Summary of Key Models Used in LEAP (continued)

(9) Hypolimnetic Morphometry:
used if Zt, Zh and Ah are not input
fits of data from study lakes

$Zt = 5.25\ As^{.08}\ Zx^{.16}$, (least squares fit, $R^2 = .61$, $SE^2 = .01$)

$f = (Zx - Zt) / Zx$

$c = .83\ (Zx/Z - 1)$, .83 = calibration factor for study lakes

$Ah = A_s f^c$

$Zh = Zb\ f$

APPENDIX C

```
3500 'LEAP model subroutine January 1982
3505 'initialize constants.................................................
3510 F1=1/247      :'convert acres to km2
3520 T2=1E-06      :'convergence criterion for internal load
3523 Z9=-1         :'missing value code for error calcs
3525 'end of initialization................................................
3530 A1=X(1)+X(2)+X(3)+X(4)+X(5)+X(6)+X(7)           :'total watershed
3540 Y(2)=(X(1)*X(29)+X(2)*X(30)-X(9)*X(26))*F1*X(39)*X(16) :'undev p load
3550 Y(3)=(X(3)*X(31)+X(4)*X(32)+X(5)*X(33)+X(6)*X(34))*F1*X(39)*X(16) :'agric p
3560 Y(4)=X(39)*X(16)*X(7)*X(35)*F1                  :'urban p
3570 Y(5)=X(8)*X(36)*F1                              :'atmos load
3580 Y(6)=X(17)*X(27)+X(18)                          :'septic
3600 P1=0:V1=1                                       :'initialize
3610 Y(9)=(A1+X(8))*X(16)/X(8)                       :'overflow rate
3620 Y(10)=X(10)/Y(9)                                :'residence time
3630 V2=.7/(1+.82*(Y(10)^.45))                       :'retention
3635 Y(1)=Y(2)+Y(3)+Y(4)+Y(5)+Y(6)                   :'total load
3640 Y(8)=Y(1)/((A1+X(8))*X(16)*F1)                  :'inflow conc
3657 Y(11)=V1*V2                                     :'internal load adjustment
3670 Y(12)=Y(11)*Y(8)*X(40)                          :'p spring
3680 'hypolimnetic morphometry.................................................
3690 IF X(13)<>0 THEN 3704
3700 FOR J6=16 TO 21:Y(J6)=0:NEXT J6:GOTO 3880       :'unstratified
3704 IF X(13)>0 THEN Y(19)=X(13):GOTO 3710           :'use input thermocline
3705 Y(19)=5.17*((F1*X(8))^.077)*(X(12)^.164)        :'estimate thermocline
3706 IF Y(19)>=X(12) THEN 3700                       :'check if stratified
3710 Z5=X(11):IF Z5>18 THEN Z5=LOG(18) ELSE Z5=LOG(Z5)
3712 Z5=-3.58+1.976*Z5-.3846*Z5*Z5                   :'morpho factor for hod
3740 IF X(14)>0 THEN Y(17)=X(14):GOTO 3770
3750 Y(17) = X(11)*(X(12)-Y(19))/(X(12))             :'hypolimnetic depth
3770 IF X(15)>0 THEN Y(18)=X(15):GOTO 3794
3780 B1=.84*(X(12)/X(10)-1)
3790 Y(18)=X(8)*((((X(12)-Y(19))/X(12))^B1))         :'estimate hypol area
3791 'iteration to determine internal load.....................................
3792 Y(11)=V1*V2                                     :'internal load adjustment
3793 Y(12)=Y(11)*Y(8)*X(40)                          :'p spring
3794 Z3=-15.6+20*LOG(Y(12))                          :'tsi
3796 Y(16)= X(44)*(10^(.0204*Z3+Z5))*.85             :'hod
3800 Y(20)=Y(16)/Y(17)                               :'volumetric hod
3822 V1=EXP(X(37)*Y(20)*Y(18)/X(8))       :'internal load param,X(37)=6
3823 rem V1=1+X(37)*Y(20)*Y(18)/X(8)      :'alternative, X(37)=8
3824 IF (V1*V2)>1 THEN V1=1/V2
3825 REM PRINT "iteration: pspring=";Y(12);" 1-rp=";Y(11):'optional print
3850 T1=(Y(12)-P1)/Y(12)                             :'test for convergence
3860 IF ABS(T1)> T2 THEN P1=Y(12):GOTO 3792          :'iterate
3870 REM end of iteration ...................................................
3875 Y(21)=X(28)*Y(17)/Y(16)                         :'days of oxygen supply
3880 Y(13)=X(41)*.5*(Y(12)^.94)                      :'chla
3890 Y(14)=1.6*X(42)*(Y(13)^1.14)                    :'chla-max
3900 Y(15)=X(43)/(X(38)*Y(13)+X(19))                 :'secchi depth
3925 Y(7)=Y(1)*V2*(V1-1)                             :'net internal load
```

```
3926 'trophic state probabilities............................................
3927 P3=V1*Y(1)/(F1*X(8))                                  :'areal load
3930 Z3=Y(12)/X(40)                                        LakeP/
3940 Y(22) = 1E-03*(Z3^.82)*(P3^.18)                       :'discriminant score
3950 Z3 = -(Y(22)^(-.25))
3960 Y(23) = EXP(-18.51-20.49*Z3)
3970 Y(24) = EXP(-36.77-29.33*Z3)
3980 Y(25) = EXP(-53.8-35.65*Z3)
3990 Z3 = Y(23)+Y(24)+Y(25)
4000 Y(23) = Y(23)/Z3                                       :'prob(eutrophic)
4010 Y(24) = Y(24)/Z3                                       :'prob(mesotrophic)
4020 Y(25) = Y(25)/Z3                                       :'prob(oligotrophic)
4025 'prediction error statistics..............................................
4030 FOR J6=1 TO 5
4040 IF X(19+J6)<=0 THEN Y(25+J6)=Z9:GOTO 4060             :'set to missing if no obs.
4052 Y(25+J6)=LOG(X(19+J6)/Y(11+J6))                       :'log error
4060 NEXT J6
4070 RETURN
```

APPENDIX D

Model Inputs and Outputs by Lake

```
CASE: Bomoseen
INPUT                                          MEAN
 1 Undev Non-Sedim acres                  17855.200
 2 Undev Sedimentary  acres                   0.000
 3 Untilled Non-Sedim  acres               1474.000
 4 Untilled Sedimentary  acres                0.000
 5 Tilled Non-Sedim  acres                  614.000
 6 Tilled Sedimentary  acres                  0.000
 7 Urban Area  acres                       1323.000
 8 Lake Surface Area  acres                2363.790
 9 Upstr Lake Ret Fac  acres               3560.000
10 Mean Depth  m                              8.200
11 Basin Mean Depth  m                        9.900
12 Maximum Depth  m                          19.800
13 Thermocline Depth  m                      10.000
14 Hypolimnion Depth  m                       3.600
15 Hypol Surface Area acres                 988.000
16 Runoff  m/yr                               0.460
17 Shoreline Septic Use  cap/yr             717.969
18 Extra P Load  kg/yr                        0.000
19 Chl/Secchi Intercept (1/m)                 0.080
20 Obs Spring P  mg/m3                       14.834
21 Obs Mean Chl-a  mg/m3                      5.373
22 Obs Max Chl-a  mg/m3                      14.832
23 Obs Secchi Depth  m                        4.636
24 Obs HOD  g/m2-day                          0.380

OUTPUT                                         MEAN
 1 External P Load kg/yr                   1116.650
 2 Undeveloped P Load  kg/yr                399.340
 3 Agricultural P Load  kg/yr               147.532
 4 Urban P Load  kg/yr                      342.480
 5 Atmospheric P Load  kg/yr                191.400
 6 Septic P Load  kg/yr                      35.898
 7 Net Internal P Load kg/yr                 95.791
 8 Inflow P Conc  mg/m3                      25.374
 9 Overflow Rate  m/yr                        4.598
10 Residence Time  yr                         1.783
11 1 - P Retent Coef                          0.425
12 P Spring  mg/m3                           10.783
13 Chlorophyll-a  mg/m3                       4.689
14 Max Chl-a  mg/m3                           9.315
15 Secchi Depth  m                            5.070
16 Oxygen Depl Rate  g/m2-day                 0.324
17 Hypol Depth  m                             3.600
18 Hypol Area acres                         988.000
19 Days of O2 Supply                        133.470
20 Volumetric HOD g/m3-day                    0.090
21 P Residence Time  yrs                      0.758
22 TS Discr Score                             0.017
23 Prob(Eutrophic)                            0.001
24 Prob(Mesotrophic)                          0.398
25 Prob(Oligotrophic)                         0.601
26 Error - P Spring                           0.319
27 Error - Chl-a                              0.136
28 Error - Chl Max                            0.465
29 Error - Secchi                            -0.089
30 Error - HOD                                0.160
```

```
CASE: Carmi
INPUT                                        MEAN
 1 Undev Non-Sedim acres                 3626.210
 2 Undev Sedimentary  acres                 0.000
 3 Untilled Non-Sedim  acres             1606.000
 4 Untilled Sedimentary  acres              0.000
 5 Tilled Non-Sedim  acres                871.000
 6 Tilled Sedimentary  acres                0.000
 7 Urban Area  acres                      231.000
 8 Lake Surface Area  acres              1375.790
 9 Upstr Lake Ret Fac  acres              150.978
10 Mean Depth  m                            5.440
11 Basin Mean Depth  m                      5.440
12 Maximum Depth  m                        10.100
13 Thermocline Depth  m                     8.000
14 Hypolimnion Depth  m                     0.940
15 Hypol Surface Area acres               395.200
16 Runoff  m/yr                             0.680
17 Shoreline Septic Use  cap/yr           679.434
18 Extra P Load  kg/yr                      0.000
19 Chl/Secchi Intercept (1/m)               0.080
20 Obs Spring P  mg/m3                     19.959
21 Obs Mean Chl-a  mg/m3                   21.790
22 Obs Max Chl-a  mg/m3                    64.992
23 Obs Secchi Depth  m                      1.839
24 Obs HOD  g/m2-day                        0.238

OUTPUT                                       MEAN
 1 External P Load kg/yr                  646.602
 2 Undeveloped P Load  kg/yr              143.512
 3 Agricultural P Load  kg/yr             269.321
 4 Urban P Load  kg/yr                     88.397
 5 Atmospheric P Load  kg/yr              111.400
 6 Septic P Load  kg/yr                    33.972
 7 Net Internal P Load kg/yr              164.416
 8 Inflow P Conc  mg/m3                    30.463
 9 Overflow Rate  m/yr                      3.811
10 Residence Time  yr                       1.428
11 1 - P Retent Coef                        0.611
12 P Spring  mg/m3                         18.612
13 Chlorophyll-a  mg/m3                     7.833
14 Max Chl-a  mg/m3                        16.719
15 Secchi Depth  m                          3.625
16 Oxygen Depl Rate  g/m2-day               0.294
17 Hypol Depth  m                           0.940
18 Hypol Area acres                       395.200
19 Days of O2 Supply                       38.431
20 Volumetric HOD g/m3-day                  0.312
21 P Residence Time  yrs                    0.872
22 TS Discr Score                           0.029
23 Prob(Eutrophic)                          0.031
24 Prob(Mesotrophic)                        0.812
25 Prob(Oligotrophic)                       0.156
26 Error - P Spring                         0.070
27 Error - Chl-a                            1.023
28 Error - Chl Max                          1.358
29 Error - Secchi                          -0.679
30 Error - HOD                             -0.209
```

```
CASE: Cedar
INPUT                                      MEAN
 1 Undev Non-Sedim acres                360.380
 2 Undev Sedimentary  acres               0.000
 3 Untilled Non-Sedim  acres            133.000
 4 Untilled Sedimentary  acres            0.000
 5 Tilled Non-Sedim  acres              115.000
 6 Tilled Sedimentary  acres              0.000
 7 Urban Area  acres                     30.000
 8 Lake Surface Area  acres             113.620
 9 Upstr Lake Ret Fac  acres              0.000
10 Mean Depth  m                          1.925
11 Basin Mean Depth  m                    1.925
12 Maximum Depth  m                       4.000
13 Thermocline Depth  m                   0.000
14 Hypolimnion Depth  m                   0.000
15 Hypol Surface Area acres               0.000
16 Runoff  m/yr                           0.580
17 Shoreline Septic Use  cap/yr          61.500
18 Extra P Load  kg/yr                    0.000
19 Chl/Secchi Intercept (1/m)             0.080
20 Obs Spring P  mg/m3                   17.129
21 Obs Mean Chl-a  mg/m3                 -1.000
22 Obs Max Chl-a  mg/m3                  -1.000
23 Obs Secchi Depth  m                   -1.000
24 Obs HOD  g/m2-day                     -1.000

OUTPUT                                     MEAN
 1 External P Load kg/yr                 59.522
 2 Undeveloped P Load  kg/yr             12.694
 3 Agricultural P Load  kg/yr            24.762
 4 Urban P Load  kg/yr                    9.792
 5 Atmospheric P Load  kg/yr              9.200
 6 Septic P Load  kg/yr                   3.075
 7 Net Internal P Load kg/yr              0.000
 8 Inflow P Conc  mg/m3                  33.708
 9 Overflow Rate  m/yr                    3.839
10 Residence Time  yr                     0.501
11 1 - P Retent Coef                      0.437
12 P Spring  mg/m3                       14.737
13 Chlorophyll-a  mg/m3                   6.290
14 Max Chl-a  mg/m3                      13.019
15 Secchi Depth  m                        4.215
16 Oxygen Depl Rate  g/m2-day             0.000
17 Hypol Depth  m                         0.000
18 Hypol Area acres                       0.000
19 Days of O2 Supply                      0.000
20 Volumetric HOD g/m3-day                0.000
21 P Residence Time  yrs                  0.219
22 TS Discr Score                         0.022
23 Prob(Eutrophic)                        0.006
24 Prob(Mesotrophic)                      0.638
25 Prob(Oligotrophic)                     0.357
26 Error - P Spring                       0.150
27 Error - Chl-a                         -1.000
28 Error - Chl Max                       -1.000
29 Error - Secchi                        -1.000
30 Error - HOD                           -1.000
```

```
CASE: Curtis
INPUT                                            MEAN
 1 Undev Non-Sedim acres                      492.430
 2 Undev Sedimentary  acres                     0.000
 3 Untilled Non-Sedim  acres                  248.000
 4 Untilled Sedimentary  acres                  0.000
 5 Tilled Non-Sedim  acres                     27.000
 6 Tilled Sedimentary  acres                    0.000
 7 Urban Area  acres                           73.000
 8 Lake Surface Area  acres                    76.570
 9 Upstr Lake Ret Fac  acres                    0.000
10 Mean Depth  m                                3.324
11 Basin Mean Depth  m                          3.324
12 Maximum Depth  m                             9.800
13 Thermocline Depth  m                         0.000
14 Hypolimnion Depth  m                         0.000
15 Hypol Surface Area acres                     0.000
16 Runoff  m/yr                                 0.600
17 Shoreline Septic Use  cap/yr                60.000
18 Extra P Load  kg/yr                          0.000
19 Chl/Secchi Intercept (1/m)                   0.080
20 Obs Spring P  mg/m3                         12.154
21 Obs Mean Chl-a  mg/m3                        6.300
22 Obs Max Chl-a  mg/m3                        11.500
23 Obs Secchi Depth  m                          3.800
24 Obs HOD  g/m2-day                           -1.000

OUTPUT                                           MEAN
 1 External P Load kg/yr                       73.603
 2 Undeveloped P Load  kg/yr                   17.943
 3 Agricultural P Load  kg/yr                  21.811
 4 Urban P Load  kg/yr                         24.649
 5 Atmospheric P Load  kg/yr                    6.200
 6 Septic P Load  kg/yr                         3.000
 7 Net Internal P Load kg/yr                    0.000
 8 Inflow P Conc  mg/m3                        33.042
 9 Overflow Rate  m/yr                          7.186
10 Residence Time  yr                           0.463
11 1 - P Retent Coef                            0.443
12 P Spring  mg/m3                             14.642
13 Chlorophyll-a  mg/m3                         6.252
14 Max Chl-a  mg/m3                            12.929
15 Secchi Depth  m                              4.232
16 Oxygen Depl Rate  g/m2-day                   0.000
17 Hypol Depth  m                               0.000
18 Hypol Area acres                             0.000
19 Days of O2 Supply                            0.000
20 Volumetric HOD g/m3-day                      0.000
21 P Residence Time  yrs                        0.205
22 TS Discr Score                               0.024
23 Prob(Eutrophic)                              0.011
24 Prob(Mesotrophic)                            0.723
25 Prob(Oligotrophic)                           0.265
26 Error - P Spring                            -0.186
27 Error - Chl-a                                0.008
28 Error - Chl Max                             -0.117
29 Error - Secchi                              -0.108
30 Error - HOD                                 -1.000
```

```
CASE: Elmore
INPUT                                    MEAN
 1 Undev Non-Sedim acres             4304.230
 2 Undev Sedimentary  acres             0.000
 3 Untilled Non-Sedim  acres          655.000
 4 Untilled Sedimentary  acres          0.000
 5 Tilled Non-Sedim  acres            167.000
 6 Tilled Sedimentary  acres            0.000
 7 Urban Area  acres                  223.000
 8 Lake Surface Area  acres           224.770
 9 Upstr Lake Ret Fac  acres          190.972
10 Mean Depth  m                        3.487
11 Basin Mean Depth  m                  3.487
12 Maximum Depth  m                     5.200
13 Thermocline Depth  m                 0.000
14 Hypolimnion Depth  m                 0.000
15 Hypol Surface Area acres             0.000
16 Runoff  m/yr                         0.600
17 Shoreline Septic Use  cap/yr       313.678
18 Extra P Load  kg/yr                  0.000
19 Chl/Secchi Intercept (1/m)           0.200
20 Obs Spring P  mg/m3                 12.477
21 Obs Mean Chl-a  mg/m3                4.224
22 Obs Max Chl-a  mg/m3                 8.454
23 Obs Secchi Depth  m                  3.234
24 Obs HOD  g/m2-day                   -1.000

OUTPUT                                   MEAN
 1 External P Load kg/yr              329.912
 2 Undeveloped P Load  kg/yr          149.876
 3 Agricultural P Load  kg/yr          70.856
 4 Urban P Load  kg/yr                 75.296
 5 Atmospheric P Load  kg/yr           18.200
 6 Septic P Load  kg/yr                15.684
 7 Net Internal P Load kg/yr            0.000
 8 Inflow P Conc  mg/m3                24.366
 9 Overflow Rate  m/yr                 14.879
10 Residence Time  yr                   0.234
11 1 - P Retent Coef                    0.491
12 P Spring  mg/m3                     11.954
13 Chlorophyll-a  mg/m3                 5.166
14 Max Chl-a  mg/m3                    10.403
15 Secchi Depth  m                      3.038
16 Oxygen Depl Rate  g/m2-day           0.000
17 Hypol Depth  m                       0.000
18 Hypol Area acres                     0.000
19 Days of O2 Supply                    0.000
20 Volumetric HOD g/m3-day              0.000
21 P Residence Time  yrs                0.115
22 TS Discr Score                       0.022
23 Prob(Eutrophic)                      0.006
24 Prob(Mesotrophic)                    0.650
25 Prob(Oligotrophic)                   0.344
26 Error - P Spring                     0.043
27 Error - Chl-a                       -0.201
28 Error - Chl Max                     -0.207
29 Error - Secchi                       0.062
30 Error - HOD                         -1.000
```

```
CASE: Fairfield
INPUT                                      MEAN
 1 Undev Non-Sedim acres               2494.940
 2 Undev Sedimentary  acres             290.700
 3 Untilled Non-Sedim  acres              0.000
 4 Untilled Sedimentary  acres          170.000
 5 Tilled Non-Sedim  acres                0.000
 6 Tilled Sedimentary  acres            113.000
 7 Urban Area  acres                    225.000
 8 Lake Surface Area  acres             464.362
 9 Upstr Lake Ret Fac  acres              0.000
10 Mean Depth  m                          7.233
11 Basin Mean Depth  m                    7.233
12 Maximum Depth  m                      12.800
13 Thermocline Depth  m                   8.000
14 Hypolimnion Depth  m                   2.840
15 Hypol Surface Area acres             247.000
16 Runoff  m/yr                           0.680
17 Shoreline Septic Use  cap/yr         150.000
18 Extra P Load  kg/yr                    0.000
19 Chl/Secchi Intercept (1/m)             0.080
20 Obs Spring P  mg/m3                   19.967
21 Obs Mean Chl-a  mg/m3                 10.453
22 Obs Max Chl-a  mg/m3                  21.647
23 Obs Secchi Depth  m                    2.852
24 Obs HOD  g/m2-day                      0.450

OUTPUT                                     MEAN
 1 External P Load kg/yr                365.564
 2 Undeveloped P Load  kg/yr            139.044
 3 Agricultural P Load  kg/yr            95.318
 4 Urban P Load  kg/yr                   86.101
 5 Atmospheric P Load  kg/yr             37.600
 6 Septic P Load  kg/yr                   7.500
 7 Net Internal P Load kg/yr            104.633
 8 Inflow P Conc  mg/m3                  35.334
 9 Overflow Rate  m/yr                    5.503
10 Residence Time  yr                     1.314
11 1 - P Retent Coef                      0.649
12 P Spring  mg/m3                       22.947
13 Chlorophyll-a  mg/m3                   9.537
14 Max Chl-a  mg/m3                      20.924
15 Secchi Depth  m                        3.140
16 Oxygen Depl Rate  g/m2-day             0.517
17 Hypol Depth  m                         2.840
18 Hypol Area acres                     247.000
19 Days of O2 Supply                     65.901
20 Volumetric HOD g/m3-day                0.182
21 P Residence Time  yrs                  0.854
22 TS Discr Score                         0.037
23 Prob(Eutrophic)                        0.129
24 Prob(Mesotrophic)                      0.814
25 Prob(Oligotrophic)                     0.057
26 Error - P Spring                      -0.139
27 Error - Chl-a                          0.092
28 Error - Chl Max                        0.034
29 Error - Secchi                        -0.096
30 Error - HOD                           -0.139
```

```
CASE: Harveys
INPUT                                        MEAN
 1 Undev Non-Sedim acres                 3852.000
 2 Undev Sedimentary  acres                 0.000
 3 Untilled Non-Sedim  acres              914.000
 4 Untilled Sedimentary  acres              0.000
 5 Tilled Non-Sedim  acres                155.000
 6 Tilled Sedimentary  acres                0.000
 7 Urban Area  acres                       97.000
 8 Lake Surface Area  acres               346.000
 9 Upstr Lake Ret Fac  acres                0.000
10 Mean Depth  m                           20.000
11 Basin Mean Depth  m                     20.000
12 Maximum Depth  m                        44.200
13 Thermocline Depth  m                    10.000
14 Hypolimnion Depth  m                    16.400
15 Hypol Surface Area acres               247.000
16 Runoff  m/yr                             0.550
17 Shoreline Septic Use  cap/yr           223.700
18 Extra P Load  kg/yr                      0.000
19 Chl/Secchi Intercept (1/m)               0.080
20 Obs Spring P  mg/m3                     13.842
21 Obs Mean Chl-a  mg/m3                    3.568
22 Obs Max Chl-a  mg/m3                     7.155
23 Obs Secchi Depth  m                      6.652
24 Obs HOD  g/m2-day                        0.426

OUTPUT                                       MEAN
 1 External P Load kg/yr                  278.614
 2 Undeveloped P Load  kg/yr              128.660
 3 Agricultural P Load  kg/yr              80.730
 4 Urban P Load  kg/yr                     30.023
 5 Atmospheric P Load  kg/yr               28.016
 6 Septic P Load  kg/yr                    11.185
 7 Net Internal P Load kg/yr                5.612
 8 Inflow P Conc  mg/m3                    23.326
 9 Overflow Rate  m/yr                      8.527
10 Residence Time  yr                       2.346
11 1 - P Retent Coef                        0.338
12 P Spring  mg/m3                          7.880
13 Chlorophyll-a  mg/m3                     3.492
14 Max Chl-a  mg/m3                         6.656
15 Secchi Depth  m                          5.977
16 Oxygen Depl Rate  g/m2-day               0.235
17 Hypol Depth  m                          16.400
18 Hypol Area acres                       247.000
19 Days of O2 Supply                      836.096
20 Volumetric HOD g/m3-day                  0.014
21 P Residence Time  yrs                    0.792
22 TS Discr Score                           0.014
23 Prob(Eutrophic)                          0.000
24 Prob(Mesotrophic)                        0.220
25 Prob(Oligotrophic)                       0.779
26 Error - P Spring                         0.563
27 Error - Chl-a                            0.021
28 Error - Chl Max                          0.072
29 Error - Secchi                           0.107
30 Error - HOD                              0.594
```

```
CASE: Hortonia
INPUT                                         MEAN
 1 Undev Non-Sedim acres                  3481.460
 2 Undev Sedimentary  acres                  0.000
 3 Untilled Non-Sedim  acres               214.000
 4 Untilled Sedimentary  acres               0.000
 5 Tilled Non-Sedim  acres                  89.000
 6 Tilled Sedimentary  acres                 0.000
 7 Urban Area  acres                       223.000
 8 Lake Surface Area  acres                449.542
 9 Upstr Lake Ret Fac  acres              1237.820
10 Mean Depth  m                             5.592
11 Basin Mean Depth  m                       8.900
12 Maximum Depth  m                         18.300
13 Thermocline Depth  m                     11.000
14 Hypolimnion Depth  m                      3.630
15 Hypol Surface Area acres                108.680
16 Runoff  m/yr                              0.460
17 Shoreline Septic Use  cap/yr            348.000
18 Extra P Load  kg/yr                       0.000
19 Chl/Secchi Intercept (1/m)                0.080
20 Obs Spring P  mg/m3                      11.668
21 Obs Mean Chl-a  mg/m3                     3.673
22 Obs Max Chl-a  mg/m3                      6.000
23 Obs Secchi Depth  m                       4.927
24 Obs HOD  g/m2-day                         0.410

OUTPUT                                        MEAN
 1 External P Load kg/yr                   195.608
 2 Undeveloped P Load  kg/yr                62.677
 3 Agricultural P Load  kg/yr               21.404
 4 Urban P Load  kg/yr                      57.727
 5 Atmospheric P Load  kg/yr                36.400
 6 Septic P Load  kg/yr                     17.400
 7 Net Internal P Load kg/yr                 8.386
 8 Inflow P Conc  mg/m3                     23.566
 9 Overflow Rate  m/yr                       4.561
10 Residence Time  yr                        1.226
11 1 - P Retent Coef                         0.412
12 P Spring  mg/m3                           9.698
13 Chlorophyll-a  mg/m3                      4.244
14 Max Chl-a  mg/m3                          8.314
15 Secchi Depth  m                           5.373
16 Oxygen Depl Rate  g/m2-day                0.275
17 Hypol Depth  m                            3.630
18 Hypol Area acres                        108.680
19 Days of O2 Supply                       158.221
20 Volumetric HOD g/m3-day                   0.076
21 P Residence Time  yrs                      0.505
22 TS Discr Score                            0.015
23 Prob(Eutrophic)                           0.000
24 Prob(Mesotrophic)                          0.278
25 Prob(Oligotrophic)                        0.722
26 Error - P Spring                          0.185
27 Error - Chl-a                            -0.144
28 Error - Chl Max                          -0.326
29 Error - Secchi                           -0.087
30 Error - HOD                               0.398
```

```
CASE: Morey
INPUT                                     MEAN
 1 Undev Non-Sedim acres              3924.540
 2 Undev Sedimentary  acres              0.000
 3 Untilled Non-Sedim  acres           459.000
 4 Untilled Sedimentary  acres           0.000
 5 Tilled Non-Sedim  acres              51.000
 6 Tilled Sedimentary  acres             0.000
 7 Urban Area  acres                   128.000
 8 Lake Surface Area  acres            538.460
 9 Upstr Lake Ret Fac  acres             0.000
10 Mean Depth  m                         8.301
11 Basin Mean Depth  m                   8.301
12 Maximum Depth  m                     13.100
13 Thermocline Depth  m                  9.000
14 Hypolimnion Depth  m                  2.000
15 Hypol Surface Area acres            288.990
16 Runoff  m/yr                          0.560
17 Shoreline Septic Use  cap/yr        382.800
18 Extra P Load  kg/yr                   0.000
19 Chl/Secchi Intercept (1/m)            0.080
20 Obs Spring P  mg/m3                  27.073
21 Obs Mean Chl-a  mg/m3                 9.516
22 Obs Max Chl-a  mg/m3                 20.456
23 Obs Secchi Depth  m                   4.719
24 Obs HOD  g/m2-day                     0.506

OUTPUT                                    MEAN
 1 External P Load kg/yr               274.355
 2 Undeveloped P Load  kg/yr           133.466
 3 Agricultural P Load  kg/yr           37.810
 4 Urban P Load  kg/yr                  40.338
 5 Atmospheric P Load  kg/yr            43.600
 6 Septic P Load  kg/yr                 19.140
 7 Net Internal P Load kg/yr            97.927
 8 Inflow P Conc  mg/m3                 23.723
 9 Overflow Rate  m/yr                   5.305
10 Residence Time  yr                    1.565
11 1 - P Retent Coef                     0.706
12 P Spring  mg/m3                      16.758
13 Chlorophyll-a  mg/m3                  7.097
14 Max Chl-a  mg/m3                     14.941
15 Secchi Depth  m                       3.884
16 Oxygen Depl Rate  g/m2-day            0.437
17 Hypol Depth  m                        2.000
18 Hypol Area acres                    288.990
19 Days of O2 Supply                    54.908
20 Volumetric HOD g/m3-day               0.219
21 P Residence Time  yrs                 1.105
22 TS Discr Score                        0.027
23 Prob(Eutrophic)                       0.025
24 Prob(Mesotrophic)                     0.796
25 Prob(Oligotrophic)                    0.180
26 Error - P Spring                      0.480
27 Error - Chl-a                         0.293
28 Error - Chl Max                       0.314
29 Error - Secchi                        0.195
30 Error - HOD                           0.146
```

```
CASE: Iroquois
INPUT                                   MEAN
 1 Undev Non-Sedim acres            1291.990
 2 Undev Sedimentary  acres            0.000
 3 Untilled Non-Sedim  acres         486.000
 4 Untilled Sedimentary  acres         0.000
 5 Tilled Non-Sedim  acres           193.000
 6 Tilled Sedimentary  acres           0.000
 7 Urban Area  acres                 242.000
 8 Lake Surface Area  acres          205.010
 9 Upstr Lake Ret Fac  acres           0.000
10 Mean Depth  m                       5.776
11 Basin Mean Depth  m                 5.776
12 Maximum Depth  m                   11.300
13 Thermocline Depth  m                7.500
14 Hypolimnion Depth  m                2.300
15 Hypol Surface Area acres          111.150
16 Runoff  m/yr                        0.600
17 Shoreline Septic Use  cap/yr      196.500
18 Extra P Load  kg/yr                 0.000
19 Chl/Secchi Intercept (1/m)          0.080
20 Obs Spring P  mg/m3                29.720
21 Obs Mean Chl-a  mg/m3              10.511
22 Obs Max Chl-a  mg/m3               36.742
23 Obs Secchi Depth  m                 2.653
24 Obs HOD  g/m2-day                   0.587

OUTPUT                                  MEAN
 1 External P Load kg/yr             217.353
 2 Undeveloped P Load  kg/yr          47.077
 3 Agricultural P Load  kg/yr         62.140
 4 Urban P Load  kg/yr                81.712
 5 Atmospheric P Load  kg/yr          16.600
 6 Septic P Load  kg/yr                9.825
 7 Net Internal P Load kg/yr          92.197
 8 Inflow P Conc  mg/m3               37.005
 9 Overflow Rate  m/yr                 7.077
10 Residence Time  yr                  0.816
11 1 - P Retent Coef                   0.825
12 P Spring  mg/m3                    30.512
13 Chlorophyll-a  mg/m3               12.466
14 Max Chl-a  mg/m3                   28.396
15 Secchi Depth  m                     2.553
16 Oxygen Depl Rate  g/m2-day          0.511
17 Hypol Depth  m                      2.300
18 Hypol Area acres                  111.150
19 Days of O2 Supply                  54.033
20 Volumetric HOD g/m3-day             0.222
21 P Residence Time  yrs               0.673
22 TS Discr Score                      0.051
23 Prob(Eutrophic)                     0.413
24 Prob(Mesotrophic)                   0.573
25 Prob(Oligotrophic)                  0.014
26 Error - P Spring                   -0.026
27 Error - Chl-a                      -0.171
28 Error - Chl Max                     0.258
29 Error - Secchi                      0.038
30 Error - HOD                         0.139
```

```
CASE: Parker
INPUT                                      MEAN
 1 Undev Non-Sedim acres               2644.410
 2 Undev Sedimentary  acres               0.000
 3 Untilled Non-Sedim  acres           2101.000
 4 Untilled Sedimentary  acres            0.000
 5 Tilled Non-Sedim  acres              325.000
 6 Tilled Sedimentary  acres              0.000
 7 Urban Area  acres                    108.000
 8 Lake Surface Area  acres             239.590
 9 Upstr Lake Ret Fac  acres             62.991
10 Mean Depth  m                          7.611
11 Basin Mean Depth  m                    7.611
12 Maximum Depth  m                      14.700
13 Thermocline Depth  m                   8.000
14 Hypolimnion Depth  m                   3.050
15 Hypol Surface Area acres             133.380
16 Runoff  m/yr                           0.600
17 Shoreline Septic Use  cap/yr         156.000
18 Extra P Load  kg/yr                    0.000
19 Chl/Secchi Intercept (1/m)             0.080
20 Obs Spring P  mg/m3                   15.330
21 Obs Mean Chl-a  mg/m3                  6.211
22 Obs Max Chl-a  mg/m3                  15.684
23 Obs Secchi Depth  m                    3.795
24 Obs HOD  g/m2-day                      0.400

OUTPUT                                     MEAN
 1 External P Load kg/yr                355.836
 2 Undeveloped P Load  kg/yr             94.060
 3 Agricultural P Load  kg/yr           198.109
 4 Urban P Load  kg/yr                   36.466
 5 Atmospheric P Load  kg/yr             19.400
 6 Septic P Load  kg/yr                   7.800
 7 Net Internal P Load kg/yr             99.956
 8 Inflow P Conc  mg/m3                  27.037
 9 Overflow Rate  m/yr                   13.568
10 Residence Time  yr                     0.561
11 1 - P Retent Coef                      0.710
12 P Spring  mg/m3                       19.190
13 Chlorophyll-a  mg/m3                   8.062
14 Max Chl-a  mg/m3                      17.277
15 Secchi Depth  m                        3.552
16 Oxygen Depl Rate  g/m2-day             0.460
17 Hypol Depth  m                         3.050
18 Hypol Area acres                     133.380
19 Days of O2 Supply                     79.563
20 Volumetric HOD g/m3-day                0.151
21 P Residence Time  yrs                  0.398
22 TS Discr Score                         0.036
23 Prob(Eutrophic)                        0.104
24 Prob(Mesotrophic)                      0.827
25 Prob(Oligotrophic)                     0.068
26 Error - P Spring                      -0.225
27 Error - Chl-a                         -0.261
28 Error - Chl Max                       -0.097
29 Error - Secchi                         0.066
30 Error - HOD                           -0.140
```

```
CASE: St Cather
INPUT                                  MEAN
 1 Undev Non-Sedim acres           5118.850
 2 Undev Sedimentary  acres           0.000
 3 Untilled Non-Sedim  acres        880.000
 4 Untilled Sedimentary  acres        0.000
 5 Tilled Non-Sedim  acres          298.000
 6 Tilled Sedimentary  acres          0.000
 7 Urban Area  acres                298.000
 8 Lake Surface Area  acres         852.150
 9 Upstr Lake Ret Fac  acres        316.955
10 Mean Depth  m                     10.723
11 Basin Mean Depth  m               10.723
12 Maximum Depth  m                  19.500
13 Thermocline Depth  m              10.000
14 Hypolimnion Depth  m               5.420
15 Hypol Surface Area acres         491.530
16 Runoff  m/yr                       0.460
17 Shoreline Septic Use  cap/yr     814.423
18 Extra P Load  kg/yr                0.000
19 Chl/Secchi Intercept (1/m)         0.080
20 Obs Spring P  mg/m3               11.755
21 Obs Mean Chl-a  mg/m3              3.184
22 Obs Max Chl-a  mg/m3               4.400
23 Obs Secchi Depth  m                6.384
24 Obs HOD  g/m2-day                  0.405

OUTPUT                                 MEAN
 1 External P Load kg/yr            401.805
 2 Undeveloped P Load  kg/yr        134.142
 3 Agricultural P Load  kg/yr        80.800
 4 Urban P Load  kg/yr               77.142
 5 Atmospheric P Load  kg/yr         69.000
 6 Septic P Load  kg/yr              40.721
 7 Net Internal P Load kg/yr         30.369
 8 Inflow P Conc  mg/m3              28.972
 9 Overflow Rate  m/yr                4.020
10 Residence Time  yr                 2.667
11 1 - P Retent Coef                  0.383
12 P Spring  mg/m3                   11.104
13 Chlorophyll-a  mg/m3               4.820
14 Max Chl-a  mg/m3                   9.612
15 Secchi Depth  m                    4.987
16 Oxygen Depl Rate  g/m2-day         0.344
17 Hypol Depth  m                     5.420
18 Hypol Area acres                 491.530
19 Days of O2 Supply                189.066
20 Volumetric HOD g/m3-day            0.063
21 P Residence Time  yrs              1.022
22 TS Discr Score                     0.018
23 Prob(Eutrophic)                    0.001
24 Prob(Mesotrophic)                  0.422
25 Prob(Oligotrophic)                 0.577
26 Error - P Spring                   0.057
27 Error - Chl-a                     -0.415
28 Error - Chl Max                   -0.781
29 Error - Secchi                     0.247
30 Error - HOD                        0.163
```

```
CASE: Shelburne
INPUT                                      MEAN
 1 Undev Non-Sedim acres               386.460
 2 Undev Sedimentary  acres           1679.000
 3 Untilled Non-Sedim  acres             0.000
 4 Untilled Sedimentary  acres        1471.000
 5 Tilled Non-Sedim  acres               0.000
 6 Tilled Sedimentary  acres           788.000
 7 Urban Area  acres                   148.000
 8 Lake Surface Area  acres            449.540
 9 Upstr Lake Ret Fac  acres             0.000
10 Mean Depth  m                         3.607
11 Basin Mean Depth  m                   3.607
12 Maximum Depth  m                      7.900
13 Thermocline Depth  m                  4.000
14 Hypolimnion Depth  m                  1.400
15 Hypol Surface Area acres            210.000
16 Runoff  m/yr                          0.600
17 Shoreline Septic Use  cap/yr          0.000
18 Extra P Load  kg/yr                   0.000
19 Chl/Secchi Intercept (1/m)            0.080
20 Obs Spring P  mg/m3                 112.607
21 Obs Mean Chl-a  mg/m3                75.764
22 Obs Max Chl-a  mg/m3               140.712
23 Obs Secchi Depth  m                   0.488
24 Obs HOD  g/m2-day                    -1.000

OUTPUT                                     MEAN
 1 External P Load kg/yr               932.907
 2 Undeveloped P Load  kg/yr           197.616
 3 Agricultural P Load  kg/yr          648.918
 4 Urban P Load  kg/yr                  49.972
 5 Atmospheric P Load  kg/yr            36.400
 6 Septic P Load  kg/yr                  0.000
 7 Net Internal P Load kg/yr           531.315
 8 Inflow P Conc  mg/m3                 78.027
 9 Overflow Rate  m/yr                   6.569
10 Residence Time  yr                    0.549
11 1 - P Retent Coef                     1.000
12 P Spring  mg/m3                      78.027
13 Chlorophyll-a  mg/m3                 30.133
14 Max Chl-a  mg/m3                     77.666
15 Secchi Depth  m                       1.200
16 Oxygen Depl Rate  g/m2-day            0.514
17 Hypol Depth  m                        1.400
18 Hypol Area acres                    210.000
19 Days of O2 Supply                    32.688
20 Volumetric HOD g/m3-day               0.367
21 P Residence Time  yrs                 0.549
22 TS Discr Score                        0.127
23 Prob(Eutrophic)                       0.970
24 Prob(Mesotrophic)                     0.030
25 Prob(Oligotrophic)                    0.000
26 Error - P Spring                      0.367
27 Error - Chl-a                         0.922
28 Error - Chl Max                       0.594
29 Error - Secchi                       -0.900
30 Error - HOD                          -1.000
```

```
CASE: Star
INPUT                                      MEAN
 1 Undev Non-Sedim acres                544.190
 2 Undev Sedimentary  acres               0.000
 3 Untilled Non-Sedim  acres             82.000
 4 Untilled Sedimentary  acres            0.000
 5 Tilled Non-Sedim  acres                6.000
 6 Tilled Sedimentary  acres              0.000
 7 Urban Area  acres                     20.000
 8 Lake Surface Area  acres              56.810
 9 Upstr Lake Ret Fac  acres              0.000
10 Mean Depth  m                          1.477
11 Basin Mean Depth  m                    1.477
12 Maximum Depth  m                       2.400
13 Thermocline Depth  m                   0.000
14 Hypolimnion Depth  m                   0.000
15 Hypol Surface Area acres               0.000
16 Runoff  m/yr                           0.580
17 Shoreline Septic Use  cap/yr          12.000
18 Extra P Load  kg/yr                    0.000
19 Chl/Secchi Intercept (1/m)             0.700
20 Obs Spring P  mg/m3                   13.719
21 Obs Mean Chl-a  mg/m3                 19.774
22 Obs Max Chl-a  mg/m3                  37.229
23 Obs Secchi Depth  m                    0.849
24 Obs HOD  g/m2-day                     -1.000

OUTPUT                                     MEAN
 1 External P Load kg/yr                 37.475
 2 Undeveloped P Load  kg/yr             19.168
 3 Agricultural P Load  kg/yr             6.580
 4 Urban P Load  kg/yr                    6.528
 5 Atmospheric P Load  kg/yr              4.600
 6 Septic P Load  kg/yr                   0.600
 7 Net Internal P Load kg/yr              0.000
 8 Inflow P Conc  mg/m3                  22.510
 9 Overflow Rate  m/yr                    7.239
10 Residence Time  yr                     0.204
11 1 - P Retent Coef                      0.500
12 P Spring  mg/m3                       11.246
13 Chlorophyll-a  mg/m3                   4.878
14 Max Chl-a  mg/m3                       9.744
15 Secchi Depth  m                        1.217
16 Oxygen Depl Rate  g/m2-day             0.000
17 Hypol Depth  m                         0.000
18 Hypol Area acres                       0.000
19 Days of O2 Supply                      0.000
20 Volumetric HOD g/m3-day                0.000
21 P Residence Time  yrs                  0.102
22 TS Discr Score                         0.018
23 Prob(Eutrophic)                        0.001
24 Prob(Mesotrophic)                      0.455
25 Prob(Oligotrophic)                     0.544
26 Error - P Spring                       0.199
27 Error - Chl-a                          1.400
28 Error - Chl Max                        1.340
29 Error - Secchi                        -0.360
30 Error - HOD                           -1.000
```

```
CASE: Winona
INPUT                                        MEAN
 1 Undev Non-Sedim acres                   993.350
 2 Undev Sedimentary  acres                569.000
 3 Untilled Non-Sedim  acres                 0.000
 4 Untilled Sedimentary  acres             579.000
 5 Tilled Non-Sedim  acres                   0.000
 6 Tilled Sedimentary  acres               134.000
 7 Urban Area  acres                        54.000
 8 Lake Surface Area  acres                234.650
 9 Upstr Lake Ret Fac  acres                 0.000
10 Mean Depth  m                             1.019
11 Basin Mean Depth  m                       1.019
12 Maximum Depth  m                          2.700
13 Thermocline Depth  m                      0.000
14 Hypolimnion Depth  m                      0.000
15 Hypol Surface Area acres                  0.000
16 Runoff  m/yr                              0.580
17 Shoreline Septic Use  cap/yr             10.500
18 Extra P Load  kg/yr                       0.000
19 Chl/Secchi Intercept (1/m)                0.080
20 Obs Spring P  mg/m3                      25.938
21 Obs Mean Chl-a  mg/m3                    -1.000
22 Obs Max Chl-a  mg/m3                     -1.000
23 Obs Secchi Depth  m                      -1.000
24 Obs HOD  g/m2-day                        -1.000

OUTPUT                                       MEAN
 1 External P Load kg/yr                   308.434
 2 Undeveloped P Load  kg/yr                95.114
 3 Agricultural P Load  kg/yr              176.170
 4 Urban P Load  kg/yr                      17.625
 5 Atmospheric P Load  kg/yr                19.000
 6 Septic P Load  kg/yr                      0.525
 7 Net Internal P Load kg/yr                 0.000
 8 Inflow P Conc  mg/m3                     51.229
 9 Overflow Rate  m/yr                       6.338
10 Residence Time  yr                        0.161
11 1 - P Retent Coef                         0.515
12 P Spring  mg/m3                          26.362
13 Chlorophyll-a  mg/m3                     10.866
14 Max Chl-a  mg/m3                         24.279
15 Secchi Depth  m                           2.844
16 Oxygen Depl Rate  g/m2-day                0.000
17 Hypol Depth  m                            0.000
18 Hypol Area acres                          0.000
19 Days of O2 Supply                         0.000
20 Volumetric HOD g/m3-day                   0.000
21 P Residence Time  yrs                     0.083
22 TS Discr Score                            0.041
23 Prob(Eutrophic)                           0.201
24 Prob(Mesotrophic)                         0.762
25 Prob(Oligotrophic)                        0.037
26 Error - P Spring                         -0.016
27 Error - Chl-a                            -1.000
28 Error - Chl Max                          -1.000
29 Error - Secchi                           -1.000
30 Error - HOD                              -1.000
```

```
CASE: Halls
INPUT                                     MEAN
 1 Undev Non-Sedim acres               393.000
 2 Undev Sedimentary  acres              0.000
 3 Untilled Non-Sedim  acres            50.000
 4 Untilled Sedimentary  acres           0.000
 5 Tilled Non-Sedim  acres               6.000
 6 Tilled Sedimentary  acres             0.000
 7 Urban Area  acres                    28.000
 8 Lake Surface Area  acres             84.000
 9 Upstr Lake Ret Fac  acres             6.200
10 Mean Depth  m                         5.000
11 Basin Mean Depth  m                   5.000
12 Maximum Depth  m                      9.200
13 Thermocline Depth  m                  7.000
14 Hypolimnion Depth  m                  1.300
15 Hypol Surface Area acres             29.600
16 Runoff  m/yr                          0.550
17 Shoreline Septic Use  cap/yr         76.500
18 Extra P Load  kg/yr                   0.000
19 Chl/Secchi Intercept (1/m)            0.080
20 Obs Spring P  mg/m3                  10.100
21 Obs Mean Chl-a  mg/m3                 6.500
22 Obs Max Chl-a  mg/m3                 12.800
23 Obs Secchi Depth  m                   3.800
24 Obs HOD  g/m2-day                     0.180

OUTPUT                                    MEAN
 1 External P Load kg/yr                36.314
 2 Undeveloped P Load  kg/yr            12.919
 3 Agricultural P Load  kg/yr            4.102
 4 Urban P Load  kg/yr                   8.666
 5 Atmospheric P Load  kg/yr             6.802
 6 Septic P Load  kg/yr                  3.825
 7 Net Internal P Load kg/yr             5.139
 8 Inflow P Conc  mg/m3                 29.070
 9 Overflow Rate  m/yr                   3.673
10 Residence Time  yr                    1.361
11 1 - P Retent Coef                     0.502
12 P Spring  mg/m3                      14.592
13 Chlorophyll-a  mg/m3                  6.232
14 Max Chl-a  mg/m3                     12.881
15 Secchi Depth  m                       4.241
16 Oxygen Depl Rate  g/m2-day            0.204
17 Hypol Depth  m                        1.300
18 Hypol Area acres                     29.600
19 Days of O2 Supply                    76.612
20 Volumetric HOD g/m3-day               0.157
21 P Residence Time  yrs                 0.683
22 TS Discr Score                        0.022
23 Prob(Eutrophic)                       0.006
24 Prob(Mesotrophic)                     0.653
25 Prob(Oligotrophic)                    0.341
26 Error - P Spring                     -0.368
27 Error - Chl-a                         0.042
28 Error - Chl Max                      -0.006
29 Error - Secchi                       -0.110
30 Error - HOD                          -0.123
```

```
CASE: Shadow
INPUT                                        MEAN
 1 Undev Non-Sedim acres                 2787.000
 2 Undev Sedimentary  acres                 0.000
 3 Untilled Non-Sedim  acres              429.000
 4 Untilled Sedimentary  acres              0.000
 5 Tilled Non-Sedim  acres                 71.000
 6 Tilled Sedimentary  acres                0.000
 7 Urban Area  acres                       89.000
 8 Lake Surface Area  acres               199.000
 9 Upstr Lake Ret Fac  acres              573.000
10 Mean Depth  m                           20.900
11 Basin Mean Depth  m                     20.900
12 Maximum Depth  m                        42.400
13 Thermocline Depth  m                    10.000
14 Hypolimnion Depth  m                    15.700
15 Hypol Surface Area acres               187.000
16 Runoff  m/yr                             0.600
17 Shoreline Septic Use  cap/yr           183.000
18 Extra P Load  kg/yr                      0.000
19 Chl/Secchi Intercept (1/m)               0.080
20 Obs Spring P  mg/m3                      5.578
21 Obs Mean Chl-a  mg/m3                    3.824
22 Obs Max Chl-a  mg/m3                     7.389
23 Obs Secchi Depth  m                      7.019
24 Obs HOD  g/m2-day                        0.427

OUTPUT                                       MEAN
 1 External P Load kg/yr                  177.080
 2 Undeveloped P Load  kg/yr               80.672
 3 Agricultural P Load  kg/yr              41.094
 4 Urban P Load  kg/yr                     30.051
 5 Atmospheric P Load  kg/yr               16.113
 6 Septic P Load  kg/yr                     9.150
 7 Net Internal P Load kg/yr                4.846
 8 Inflow P Conc  mg/m3                    20.391
 9 Overflow Rate  m/yr                     10.779
10 Residence Time  yr                       1.939
11 1 - P Retent Coef                        0.360
12 P Spring  mg/m3                          7.340
13 Chlorophyll-a  mg/m3                     3.267
14 Max Chl-a  mg/m3                         6.169
15 Secchi Depth  m                          6.186
16 Oxygen Depl Rate  g/m2-day               0.220
17 Hypol Depth  m                          15.700
18 Hypol Area acres                       187.000
19 Days of O2 Supply                      855.626
20 Volumetric HOD g/m3-day                  0.014
21 P Residence Time  yrs                    0.698
22 TS Discr Score                           0.014
23 Prob(Eutrophic)                          0.000
24 Prob(Mesotrophic)                        0.193
25 Prob(Oligotrophic)                       0.807
26 Error - P Spring                        -0.275
27 Error - Chl-a                            0.158
28 Error - Chl Max                          0.181
29 Error - Secchi                           0.126
30 Error - HOD                              0.662
```

```
CASE: Sunset
INPUT                                      MEAN
 1 Undev Non-Sedim acres                893.000
 2 Undev Sedimentary  acres               0.000
 3 Untilled Non-Sedim  acres             32.000
 4 Untilled Sedimentary  acres            0.000
 5 Tilled Non-Sedim  acres               12.000
 6 Tilled Sedimentary  acres              0.000
 7 Urban Area  acres                     60.000
 8 Lake Surface Area  acres             195.000
 9 Upstr Lake Ret Fac  acres            439.000
10 Mean Depth  m                         18.600
11 Basin Mean Depth  m                   18.600
12 Maximum Depth  m                      36.000
13 Thermocline Depth  m                   8.000
14 Hypolimnion Depth  m                  14.500
15 Hypol Surface Area acres             152.000
16 Runoff  m/yr                           0.460
17 Shoreline Septic Use  cap/yr          48.000
18 Extra P Load  kg/yr                    0.000
19 Chl/Secchi Intercept (1/m)             0.070
20 Obs Spring P  mg/m3                    6.117
21 Obs Mean Chl-a  mg/m3                  1.473
22 Obs Max Chl-a  mg/m3                   2.411
23 Obs Secchi Depth  m                    9.490
24 Obs HOD  g/m2-day                      0.140

OUTPUT                                     MEAN
 1 External P Load kg/yr                 49.466
 2 Undeveloped P Load  kg/yr             12.683
 3 Agricultural P Load  kg/yr             3.062
 4 Urban P Load  kg/yr                   15.532
 5 Atmospheric P Load  kg/yr             15.789
 6 Septic P Load  kg/yr                   2.400
 7 Net Internal P Load kg/yr              0.677
 8 Inflow P Conc  mg/m3                  22.283
 9 Overflow Rate  m/yr                    2.812
10 Residence Time  yr                     6.615
11 1 - P Retent Coef                      0.254
12 P Spring  mg/m3                        5.649
13 Chlorophyll-a  mg/m3                   2.554
14 Max Chl-a  mg/m3                       4.659
15 Secchi Depth  m                        7.471
16 Oxygen Depl Rate  g/m2-day             0.172
17 Hypol Depth  m                        14.500
18 Hypol Area acres                     152.000
19 Days of O2 Supply                   1010.650
20 Volumetric HOD g/m3-day                0.012
21 P Residence Time  yrs                  1.677
22 TS Discr Score                         0.009
23 Prob(Eutrophic)                        0.000
24 Prob(Mesotrophic)                      0.026
25 Prob(Oligotrophic)                     0.974
26 Error - P Spring                       0.080
27 Error - Chl-a                         -0.550
28 Error - Chl Max                       -0.659
29 Error - Secchi                         0.239
30 Error - HOD                           -0.207


[illegible] [illegible]UT [illegible]ES
```

APPENDIX E

Charts of Observed and Predicted Lake Responses and Discussions

```
     0         Spring Phosphorus (mg/m3)                        35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                    0   781     9
est:            L     PX

     0         Mean Chlorophyll-a (mg/m3)                       25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:         09    1 8
est:       L   PX

     0         Maximum Chlorophyll-a (mg/m3)                    50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:            9             8
est:       L   PX

     0         Mean Transparency (m)                            8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                              18     9   0
est:                                     PX       L

     0         Oxygen Depletion Rate (g/m3-day)                 .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:               89
est:         L   PX

     LAKE: Bomoseen
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Model under-predicts spring P, though chlorophyll-a and transparency are in reasonable agreement. Aquatic weeds may play a role in utilization of phosphorus. Under-prediction may be related to relatively high percentage of wetlands in watershed. Land use estimates are reasonably close.

```
     0         Spring Phosphorus (mg/m3)                        35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                            079       1  8
est:                        L     X      P

     0         Mean Chlorophyll-a (mg/m3)                       25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                          1   8       0    9
est:               L  X  P

     0         Maximum Chlorophyll-a (mg/m3)                    50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                                          98
est:               L    X   P

     0         Mean Transparency (m)                            8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:            901 8
est:                        P  X   L

     0         Oxygen Depletion Rate (g/m3-day)                 .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                 7         1
est:                                      L       X        P

     LAKE: Carmi
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Phosphorus and oxygen depletion predictions are OK. Chlorophyll and transparency data indicate substantial under-prediction of summer algal populations. Carmi is an outlier on the observed chlorophyll-a vs. observed spring P plot and chlorophyll-a levels tend to rise sharply in eary summer. Summer phosphorus concentrations are likely to be considerably greater than the spring values and may be related to internal loadings. Better chlorophyll and transparency predictions could be achieved by using a steeper phosphorus/chlorophyll relationship. Under-prediction may be also related to relatively high percentage of wetlands in watershed.

```
     0         Spring Phosphorus (mg/m3)                        35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                  8     0       9   7    1
est:                    L    X        P

     0         Mean Chlorophyll-a (mg/m3)                       25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:            L  X    P

     0         Maximum Chlorophyll-a (mg/m3)                    50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:            L  X     P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:                         P     X   L

     0         Oxygen Depletion Rate (g/m3-day)                 .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:

     LAKE: Cedar
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

There is reasonable agreement in spring phosphorus; no other response measurements are available.

```
     0         Spring Phosphorus (mg/m3)                         35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:              0  9    7   1   8
est:              L           X          P

     0         Mean Chlorophyll-a (mg/m3)                        25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                7
est:         L      X     P

     0         Maximum Chlorophyll-a (mg/m3)                     50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:              7
est:         L      X       P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                             7
est:                         P      X          L

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:

     LAKE: Curtis
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Agreement is reasonable for all variables. Slight over-prediction of P might be attributed to the elogated nature of the lake, which would tend to increase trapping efficiency for sediment and nutrients and to cause lake conditions to be sensitive to the geographical distribution of intensive land uses within the watershed. Variance between LS and PM relatively large, owing to differences in estimated urban land use.

```
     0         Spring Phosphorus (mg/m3)                         35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                 7  89  01
est:              L     X  P

     0         Mean Chlorophyll-a (mg/m3)                        25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:       8 79 01
est:         L  XP

     0         Maximum Chlorophyll-a (mg/m3)                     50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:         8790
est:        L   X P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                     0  7891
est:                     PX  L

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:

     LAKE: Elmore
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

There is good agreement for all response variables and little difference between LS and PM.

```
     0         Spring Phosphorus (mg/m3)                         35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                             89      1    0
est:                         L             X             P

     0         Mean Chlorophyll-a (mg/m3)                        25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                8     1        0   9
est:               L      X       P

     0         Maximum Chlorophyll-a (mg/m3)                     50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                 8                     9
est:               L         X        P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                91    0         8
est:                  P    X       L

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                       1
est:                  L        X        P

     LAKE: Fairfield
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Agreement is reasonable for all variables. Model indicates that internal loading is significant. The variance between LS and PM is wide.

```
     0         Spring Phosphorus (mg/m3)                         35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                 78     90          1
est:          L  X  P

     0         Mean Chlorophyll-a (mg/m3)                        25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:      8 791 0
est:      L X P

     0         Maximum Chlorophyll-a (mg/m3)                     50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:      8 790
est:      LX P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                             9  1  780
est:                                        P   X     L

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:   901
est: LPX

     LAKE: Harveys
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Spring Phosphorus concentrations are substantially under-predicted, though agreement is good for chlorophyll-a and transparency. Year-to-year variability in observed spring P is large (10-22 mg/m3). P error could be partially attributed to loading from South Peacham Brook, which discharges to the lake outlet but has been observed to backflow into the lake during high-flow periods (VAEC,1981). South Peacham has a drainage area of 7826 acres, compared with the lake watershed of 5255 acres used in the above calculations, and has a higher percentage of cropland. Predicted spring phosphorus concentration (7.9 mg/m3) lies between the mean observed spring P (14 mg/m3) and the summer, epilimnetic concentrations observed in 1980 (3-8 mg/m3). The lake has metalimnetic algal populations, which are a factor in interpreting the relationship between chlorophyll and transparency.

```
     0         Spring Phosphorus (mg/m3)                        35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:               7  8 0 9 1
est:           L    X P

     0         Mean Chlorophyll-a (mg/m3)                       25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:      9 0   1
est:       L  XP

     0         Maximum Chlorophyll-a (mg/m3)                    50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:       90
est:      L  X P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                  1  0 9
est:                                      P X       L

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:             7   1  9
est:       L   XP

     LAKE: Hortonia
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Agreement is resaonable for all variables. Slight under-prediction of spring P and oxygen depletion might be attributed to morphometric complexity, since the lake has a large, shallow, southern bay and a deep, northern hypolimnetic basin. The nutrient retention efficiencies of these basins are likely to be different, which would make the lake conditions somewhat sensitive to the geographical distributions of intensive land uses within the watershed. The above analysis assumes a thermocline depth of 11 meters. Re-examination of the data indicates that a thermocline depth of 9 meters may be more representative, though this change has little influence on the predicted responses.

```
     0         Spring Phosphorus (mg/m3)                         35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                          8 9    1 0        7
est:                       L                            X       P

     0         Mean Chlorophyll-a (mg/m3)                        25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                   0  79     8   1
est:              L              X          P

     0         Maximum Chlorophyll-a (mg/m3)                     50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                              9                             8
est:              L                   X             P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:               1  879      0
est:              P    X            L

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                 8       91
est:               L                 X           P

     LAKE: Iroquois
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Agreement is reasonable for all variables. Model indicates significance of internal loading. The wide variance between LS and PM is attributed to differences in urban land use and to the high loading sensitivity.

```
     0         Spring Phosphorus (mg/m3)                        35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                             7    0         5    8    9     1
est:                  L        PX

     0         Mean Chlorophyll-a (mg/m3)                       25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:              8       9     01
est:           L    PX

     0         Maximum Chlorophyll-a (mg/m3)                    50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                        980
est:           L     PX

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                        0       1    9   8   5
est:                             XP      L

     0         Oxygen Depletion Rate (g/m3-day)                 .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                  0    91
est:                     L         PX

     LAKE: Morey
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Model underpredicts lake productivity, based upon phosphorus, chlorophyll, and oxygen depletion. Agreement is good for transparency because of metalimnetic algal populations. Internal loading is significant. The above predictions assume an export factor of .05 kg/cap-yr for shoreline septic systems, which translates into a septic loading of 19 kg/yr. The lake shoreline is steep and soils are generally thin. An independent analysis (VDWR,1979) indicates a most likely septic loading of 75 kg/yr. If this value is used in place of the above, the predicted phosphorus concentration is 28 mg/m3, compared with the observed mean value of 27 mg/m3.

```
     0         Spring Phosphorus (mg/m3)                        35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                 8      7  0  9     1
est:                L               X                           P

     0         Mean Chlorophyll-a (mg/m3)                       25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:           7  1 9 0
est:          L        X               P

     0         Maximum Chlorophyll-a (mg/m3)                    50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:              7         9
est:          L         X                    P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                        1  70    9
est:                P         X             L

     0         Oxygen Depletion Rate (g/m3-day)                 .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                   1
est:            L         X                  P

     LAKE: Parker
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

The "best" land use estimates tend to overpredict lake productivity slightly, although there is extremely wide variance between LS and PM. Prediction accuracy is limited by accuracy of land use information. Over-prediction of phosphorus may be related to high percentage of coniferous forest.

```
     0         Spring Phosphorus (mg/m3)                         35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                 7890        1
est:              L    X  P

     0         Mean Chlorophyll-a (mg/m3)                        25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:     8 90  1
est:        L  X P

     0         Maximum Chlorophyll-a (mg/m3)                     50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:     8
est:        L  X P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                        1   9    0         8
est:                                 P   X     L

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:          19
est:       L X P

     LAKE: St Cather
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

There is good agreement in spring phosphours and oxygen depletion. Agreement in chlorophyll and transparency would be improved by using a steeper phosphorus/chlorophyll regression, since the lake in the lower range of phosphorus values.

```
     0         Spring Phosphorus (mg/m3)                         150
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                            1          0            8  9  7
est:                               LX            P

     0         Mean Chlorophyll-a (mg/m3)                        100
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                    8                     9
est:                  LX     P

     0         Maximum Chlorophyll-a (mg/m3)                     150
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                                     8       9
est:                               LX             P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:  9  8
est:      P LX

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:                                                        LX  P

     LAKE: Shelburne
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

This is the most eutrophic lake in the data set because of its sedimentary, agricultural watershed and the estimated significance of internal loading. Soil types (Vergennes clay) are relatively unique, poorly drained and erodible and there is a high percentage of wetlands. Phosphorus export coefficients may be underestimated. Because its watershed and water quality conditions are unique among Vermont lakes, a low weight has been attached to data from this lake in calibrating the framework. The data are very weak in terms of oxygen and temperature profiles. A graph of data from August, 1968 (Morse and Flanders,1971) indicates a thermocline depth of 4 meters and anoxic conditions below that level. Profiles from 1969, however, do not indicate vertical stratification. Thus, there is a question as to whether or not the lake should be considered stratified for modeling purposes. Predictions are not very sensitive to assumed thermocline level, but if unstratified conditions are assumed, the predicted productivities are considerably lower than the above. Better agreement could be achieved in chlorophyll and transparency by using a steeper phosphorus/chlorophyll relationship, since the lake is at the upper end of phosphorus values.

```
     0         Spring Phosphorus (mg/m3)                         35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:            9    8                   0 1
est:                 L PX

     0         Mean Chlorophyll-a (mg/m3)                        25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                        9               0
est:          LPX

     0         Maximum Chlorophyll-a (mg/m3)                     50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                       9           0
est:          LPX

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:      90
est:         LPX

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:

     LAKE: Star
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Star Lake ranks second lowest in mean depth (1.5 meters) and hydraulic residence time (.2 years). While there is reasonable agreement between mean observed and predicted spring phosphorus concentrations, the observed year-to-year variability is extremely high (7-23 mg/m3). Considering the shallowness of this lake, it may be subject to anaerobic conditions during winters of prolonged ice-cover, which would promote internal phosphorus cycling. The relatively rapid flushing rate would also tend to increase year-to-year and seasonal variability in phosphorus and productivity. The lake is an outlier on the observed chlorophyll vs. observed phosphorus plot. Under-prediction of summer productivity (as measured by chlorophyll and transparency) might be related to shallowness (recycling) or to high flushing rate. Summer phosphorus concentrations are likely to be considerably higher than spring values.

```
     0         Spring Phosphorus (mg/m3)                  35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                  9  8 1         0          7
est:                                     L       XP

     0         Mean Chlorophyll-a (mg/m3)                 25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:                      L   PX

     0         Maximum Chlorophyll-a (mg/m3)              50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:                        L    PX

     0         Mean Transparency (m)                      8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:                    PX  L

     0         Oxygen Depletion Rate (g/m3-day)           .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:
est:

     LAKE: Winona
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

yrs

Winona has the lowest mean depth (1.5 meters) and lowest hydraulic residence time (.16 meters). Like Star, the variability in observed spring phosphorus is large (20-40 mg/m3). There are no chlorophyll or transparency data, however, to indicate whether summer productivity responds similarly to Star (see previous page).

```
     0         Spring Phosphorus (mg/m3)                        35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:        9      0 78                    1
est:                  L      X                            P

     0         Mean Chlorophyll-a (mg/m3)                       25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:          7 1               0
est:           L  X                P

     0         Maximum Chlorophyll-a (mg/m3)                    50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:        7                  0
est:           L   X                   P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                           790 1
est:                  P            X     L

     0         Oxygen Depletion Rate (g/m3-day)                 .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                          0
est:                  L    X                         P

     LAKE: Halls
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Testing lake (not used in model calibration)

The model tends to over-predict spring phosphorus concentration, although the year-to-year variability in observed values is large and there is a wide variance between LS and PM land use estimates. Over-prediction of phosphorus may be related to high percentage of coniferous forest. Agreement is good for chlorophyll, transparency, and oxygen depletion.

```
     0         Spring Phosphorus (mg/m3)                         35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:      9 710    8
est:         L  X     P

     0         Mean Chlorophyll-a (mg/m3)                        25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:        01 9
est:     L X   P

     0         Maximum Chlorophyll-a (mg/m3)                     50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:       0  9
est:     L X   P

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                                0     91
est:                                     P        X      L

     0         Oxygen Depletion Rate (g/m3-day)                  .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:  1  80
est: LXP

     LAKE: Shadow
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Testing lake (not used in model calibration)

Shadow Lake is oligotrophic and is the second least productive of the lakes in the data set. Agreement is reasonable for all variables. Slight over-prediction of phosphorus may be related to high percentage of coniferous forest.

```
     0         Spring Phosphorus (mg/m3)                        35
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:      8 0   1    9
est:      L  XP

     0         Mean Chlorophyll-a (mg/m3)                       25
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:   8901
est:    L PX

     0         Maximum Chlorophyll-a (mg/m3)                    50
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:  980
est:   L PX

     0         Mean Transparency (m)                             8
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs:                                                         1098
est:                                                       PX   L

     0         Oxygen Depletion Rate (g/m3-day)                 .4
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
obs: 890
est: LPX

     LAKE: Sunset
     obs: observed (symbol=last digit of year)
     est: estimated (L=Landsat,P=Planning Map,X=Best)
```

Testing lake (not used in model calibration)

Sunset is the least productive of the study lakes, based upon observed chlorophyll and transparency data. Phosphorus trapping by upstream lakes is an important factor regulating nutrient loadings. While there is good agreement for spring phosphorus, summer productivity is over-predicted, based upon chlorophyll and transparency measurements. While the precentage error in mean chlorophyll-a is large (42%), the absolute error is small (1.1 mg/m3) in relation to potential analytical errors at the low chlorophyll levels and the lake is correctly ranked by the model framework as the least productive of the study lakes. Agreement in chlorophyll and transparency would be improved by using a steeper chlorophyll/phosphorus relationship.

APPENDIX F

Plots of Phosphorus and Chlorophyll Residuals

Symbol	Meaning	
r-pspr	phosphorus residual	(loge(observed/predicted))
r-chl	mean chlorophyll residual	"
af-und	undeveloped, glacial watershed area/drainage area	
af-undlp	undeveloped, sedimentary watershed area/drainage area	
af-unt	untilled agric., glacial watershed area/drainage area	
af-untlp	untilled agric., sedimentary watershed area/drainage area	
af-tld	tilled, glacial watershed area/drainage area	
af-tldlp	tilled, sedimentary watershed area/drainage area	
af-urban	urban watershed area/drainage area	
af-lake	lake surface area/drainage area	
af-ulakf	upstream lake retention factor/drainage area	
af-wetl	wetland area/drainage area	
ff-conif	conifer forest/total forest area	
ff-hdwd	hardwood forest/total forest area	
ff-mixed	mixed forest/total forest area	
lf-und	undeveloped loading/total external loading	
lf-agr	agricultural loading/total external loading	
lf-urb	urban loading/total external loading	
lf-septic	septic system loading/total external loading	
lf-atm	atmospheric loading/total external loading	
lf-inter	net internal loading/total external loading	
sarea	lake surface area (acres)	
log(t)	log(hydraulic residence time, (yr))	
log(qs)	log(surface overflow rate, (m/yr))	
runoff	regional runoff rate (m/yr)	
shordev	shoreline development ratio	
zx	maximum depth (m)	
zmean	mean depth (m)	
zx/zmean	maximum depth/mean depth	
ztherm	thermocline depth (m)	
zhyp	mean hypolimnetic depth (m)	

```
r-pspr (lake)  vs. af-und
  0.563|                                              Hv
  0.514|
  0.465|                                                 Mo
  0.416|
  0.367|Sh
  0.318|                                                Bo
  0.269|
  0.220|                                                 St
  0.171|                             Ce                   Ho
  0.122|
  0.073|                            Ca             SC   Su
  0.024|                                                 El
        ----------------------------------------------------
 -0.025|                      Wi         Ir
 -0.074|
 -0.123|                                          Fa
 -0.172|                                 Cu
 -0.221|                             Pa
 -0.270|                                                  Sw
 -0.319|
 -0.368|                                            Ha
        +---------+---------+---------+---------+---------+--
      0.079     0.219     0.360     0.500     0.641     0.781
```

```
r-chl (lake)  vs. af-und
  1.400|                                                 St
  1.297|
  1.194|
  1.092|
  0.989|                            Ca
  0.886|Sh
  0.784|
  0.681|
  0.579|
  0.476|
  0.373|
  0.271|                                                 Mo
  0.168|                                                BoSw
  0.065|                                          FaHaHv
        -----------------------------------------------------
 -0.037|                                 Cu
 -0.140|                                Ir                 Ho
 -0.242|                             Pa                   El
 -0.345|
 -0.448|                                           SC
 -0.550|                                                Su
        +---------+---------+---------+---------+---------+--
      0.079     0.219     0.360     0.500     0.641     0.781
```

```
r-pspr (lake)  vs. af-undlp
   0.563|Hv
   0.514|
   0.465|Mo
   0.416|
   0.367|                                                 Sh
   0.318|Bo
   0.269|
   0.220|St
   0.171|CeHo
   0.122|
   0.073|CaSCSu
   0.024|El
  -0.025|Ir                              Wi
  -0.074|
  -0.123|          Fa
  -0.172|Cu
  -0.221|Pa
  -0.270|Sw
  -0.319|
  -0.368|Ha
         +---------+---------+---------+---------+---------+--
       0.000     0.068     0.136     0.205     0.273     0.341
```

```
r-chl (lake)  vs. af-undlp
   1.400|St
   1.297|
   1.194|
   1.092|
   0.989|Ca
   0.886|                                                 Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|Mo
   0.168|BoSw
   0.065|HvHa      Fa
  -0.037|Cu
  -0.140|HoIr
  -0.242|ElPa
  -0.345|
  -0.448|SC
  -0.550|Su
         +---------+---------+---------+---------+---------+--
       0.000     0.068     0.136     0.205     0.273     0.341
```

```
r-pspr (lake)  vs. af-unt
   0.563|                      Hv
   0.514|
   0.465|            Mo
   0.416|
   0.367|Sh
   0.318|        Bo
   0.269|
   0.220|               St
   0.171|      Ho               Ce
   0.122|
   0.073|   Su          SC          Ca
   0.024|               El
  -0.025|Wi                        Ir
  -0.074|
  -0.123|Fa
  -0.172|                                   Cu
  -0.221|                                                  Pa
  -0.270|               Sw
  -0.319|
  -0.368|           Ha
          +---------+---------+---------+---------+---------+
       0.000     0.078     0.155     0.233     0.310     0.388
```

```
r-chl (lake)  vs. af-unt
   1.400|               St
   1.297|
   1.194|
   1.092|
   0.989|                           Ca
   0.886|Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|            Mo
   0.168|        Bo     Sw
   0.065|Fa         Ha         Hv
  -0.037|                                   Cu
  -0.140|      Ho                  Ir
  -0.242|               El                                 Pa
  -0.345|
  -0.448|               SC
  -0.550|   Su
          +---------+---------+---------+---------+---------+
       0.000     0.078     0.155     0.233     0.310     0.388
```

```
r-pspr (lake)  vs. af-untlp
   0.563|Hv
   0.514|
   0.465|Mo
   0.416|
   0.367|                                                   Sh
   0.318|Bo
   0.269|
   0.220|St
   0.171|CeHo
   0.122|
   0.073|CaSCSu
   0.024|El
  -0.025|Ir                                    Wi
  -0.074|
  -0.123|       Fa
  -0.172|Cu
  -0.221|Pa
  -0.270|Sw
  -0.319|
  -0.368|Ha
         +---------+---------+---------+---------+---------+--
       0.000     0.060     0.120     0.179     0.239     0.299
```

```
r-chl (lake)  vs. af-untlp
   1.400|St
   1.297|
   1.194|
   1.092|
   0.989|Ca
   0.886|                                                   Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|Mo
   0.168|BoSw
   0.065|HvHa    Fa
  -0.037|Cu
  -0.140|HoIr
  -0.242|ElPa
  -0.345|
  -0.448|SC
  -0.550|Su
         +---------+---------+---------+---------+---------+--
       0.000     0.060     0.120     0.179     0.239     0.299
```

```
r-pspr (lake)  vs. af-tld
   0.563|         Hv
   0.514|
   0.465|   Mo
   0.416|
   0.367|Sh
   0.318|        Bo
   0.269|
   0.220|   St
   0.171|       Ho                                          Ce
   0.122|
   0.073|   Su         SC                       Ca
   0.024|          El
  -0.025|Wi                Ir
  -0.074|
  -0.123|Fa
  -0.172|          Cu
  -0.221|                    Pa
  -0.270|      Sw
  -0.319|
  -0.368|   Ha
         +---------+---------+---------+---------+---------+-
       0.000     0.031     0.061     0.092     0.122     0.153
```

```
r-chl (lake)  vs. af-tld
   1.400|   St
   1.297|
   1.194|
   1.092|
   0.989|                                     Ca
   0.886|Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|   Mo
   0.168|      SwBo
   0.065|Fa Ha     Hv
  -0.037|          Cu
  -0.140|       Ho                 Ir
  -0.242|          El        Pa
  -0.345|
  -0.448|             SC
  -0.550|   Su
         +---------+---------+---------+---------+---------+-
       0.000     0.031     0.061     0.092     0.122     0.153
```

```
r-pspr (lake)  vs. af-tldlp
   0.563|Hv
   0.514|
   0.465|Mo
   0.416|
   0.367|                                                  Sh
   0.318|Bo
   0.269|
   0.220|St
   0.171|CeHo
   0.122|
   0.073|CaSCSu
   0.024|El
  -0.025|Ir              Wi
  -0.074|
  -0.123|         Fa
  -0.172|Cu
  -0.221|Pa
  -0.270|Sw
  -0.319|
  -0.368|Ha
         +---------+---------+---------+---------+---------+--
       0.000     0.032     0.064     0.096     0.128     0.160
```

```
r-chl (lake)  vs. af-tldlp
   1.400|St
   1.297|
   1.194|
   1.092|
   0.989|Ca
   0.886|                                                  Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|Mo
   0.168|BoSw
   0.065|HvHa     Fa
  -0.037|Cu
  -0.140|HoIr
  -0.242|ElPa
  -0.345|
  -0.448|SC
  -0.550|Su
         +---------+---------+---------+---------+---------+--
       0.000     0.032     0.064     0.096     0.128     0.160
```

```
r-pspr (lake)  vs. af-urban
   0.563|Hv
   0.514|
   0.465|    Mo
   0.416|
   0.367|       Sh
   0.318|                       Bo
   0.269|
   0.220|      St
   0.171|             Ce    Ho
   0.122|
   0.073|       Ca    SC     Su
   0.024|             El
  -0.025|  Wi                                              Ir
  -0.074|
  -0.123|                         Fa
  -0.172|                                      Cu
  -0.221| Pa
  -0.270|    Sw
  -0.319|
  -0.368|                   Ha
         +---------+---------+---------+---------+---------+
       0.018     0.034     0.051     0.067     0.084     0.100
```

```
r-chl (lake)  vs. af-urban
   1.400|      St
   1.297|
   1.194|
   1.092|
   0.989|       Ca
   0.886|       Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|    Mo
   0.168|    Sw                  Bo
   0.065|Hv                 Ha    Fa
  -0.037|                                      Cu
  -0.140|                   Ho                             Ir
  -0.242| Pa          El
  -0.345|
  -0.448|-------------SC------------------------------------
  -0.550|                    Su
         +---------+---------+---------+---------+---------+
       0.018     0.034     0.051     0.067     0.084     0.100
```

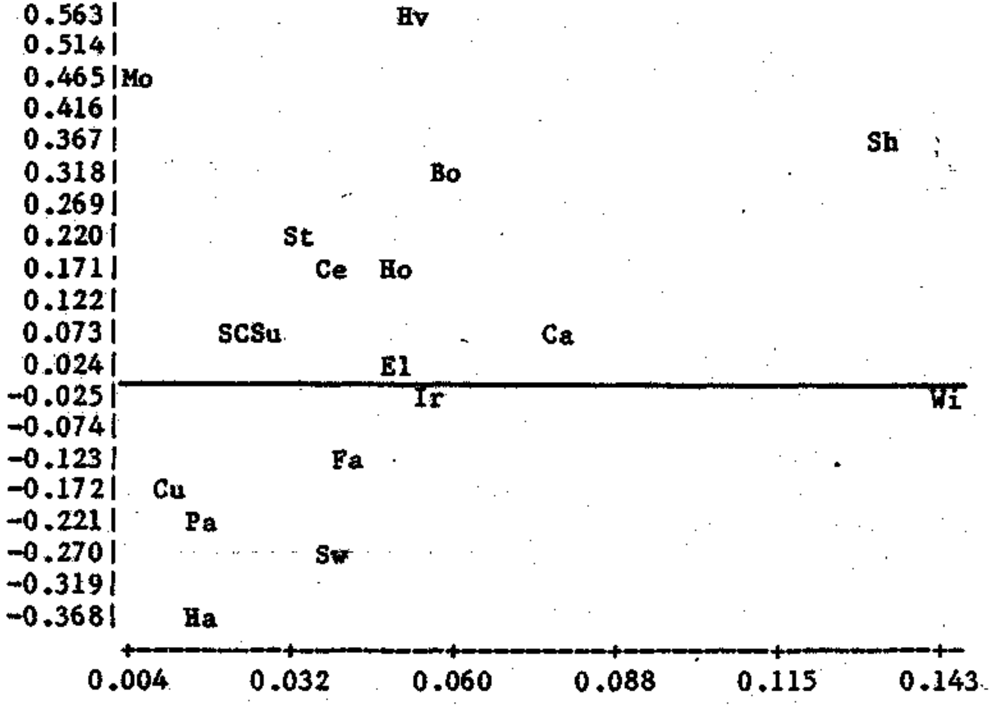
```
r-pspr (lake)  vs. af-lake
   0.563|         Hv
   0.514|
   0.465|                        Mo
   0.416|
   0.367|                  Sh
   0.318|                      Bo
   0.269|
   0.220|              St
   0.171|                      Ho                Ce
   0.122|
   0.073|                           SC                Su   Ca
   0.024|El
  -0.025|                Ir Wi
  -0.074|
  -0.123|                              Fa
  -0.172|                Cu
  -0.221| Pa
  -0.270|      Sw
  -0.319|
  -0.368|                                        Ha
         +---------+---------+---------+---------+---------+
       0.040     0.068     0.096     0.123     0.151     0.178
```

```
r-chl (lake)  vs. af-lake
   1.400|              St
   1.297|
   1.194|
   1.092|
   0.989|                                                  Ca
   0.886|                  Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                        Mo
   0.168|      Sw              Bo
   0.065|         Hv                   Fa              Ha
  -0.037|                Cu
  -0.140|                Ir    Ho
  -0.242|El Pa
  -0.345|
  -0.448|                           SC
  -0.550|                                             Su
         +---------+---------+---------+---------+---------+
       0.040     0.068     0.096     0.123     0.151     0.178
```

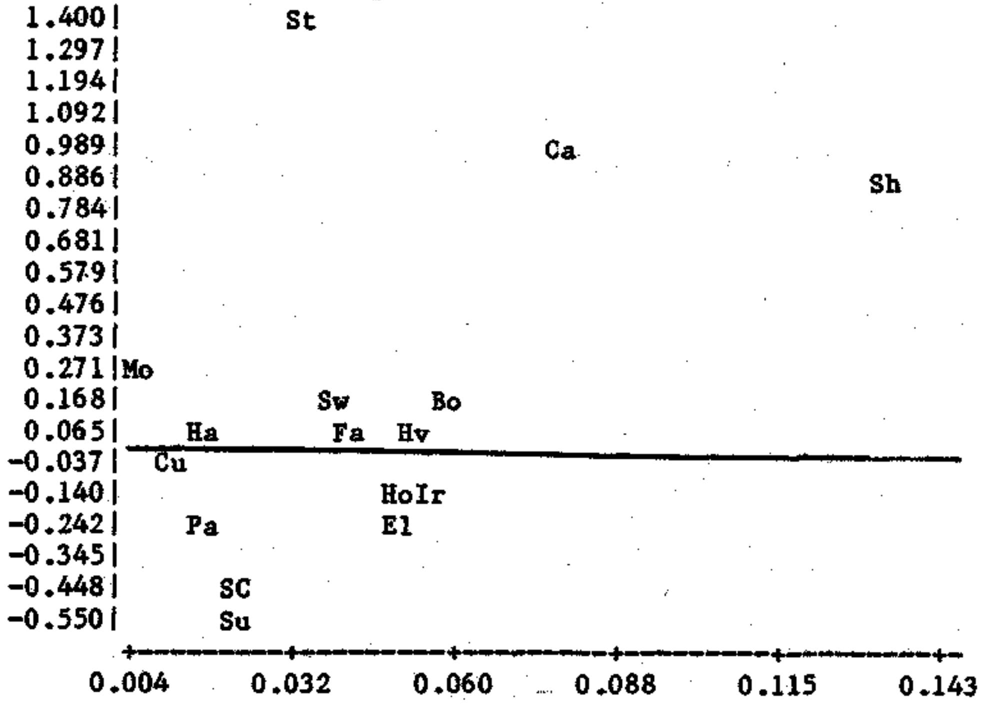
```
r-pspr (lake)  vs. af-ulakf
   0.563|Hv
   0.514|
   0.465|Mo
   0.416|
   0.367|Sh
   0.318|                    Bo
   0.269|
   0.220|St
   0.171|Ce                                    Ho
   0.122|
   0.073|   Ca SC                                          Su
   0.024|     El
  -0.025|IrWi
  -0.074|
  -0.123|Fa
  -0.172|Cu
  -0.221|  Pa
  -0.270|                      Sw
  -0.319|
  -0.368|  Ha
         +---------+---------+---------+---------+---------+
       0.000     0.074     0.147     0.221     0.295     0.368
```

```
r-chl (lake)  vs. af-ulakf
   1.400|St
   1.297|
   1.194|
   1.092|
   0.989|   Ca
   0.886|Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|Mo
   0.168|                    BoSw
   0.065|FaHvHa
  -0.037|Cu
  -0.140|Ir                                    Ho
  -0.242|  Pa El
  -0.345|
  -0.448|      SC
  -0.550|                                                  Su
         +---------+---------+---------+---------+---------+
       0.000     0.074     0.147     0.221     0.295     0.368
```

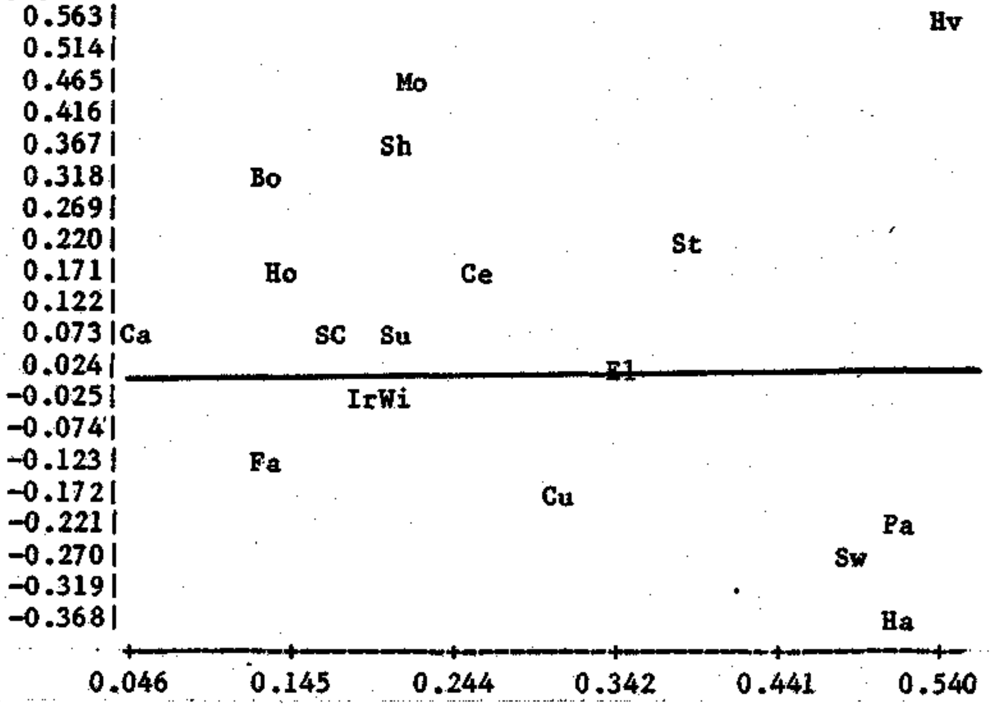
r-pspr (lake) vs. af-wet1



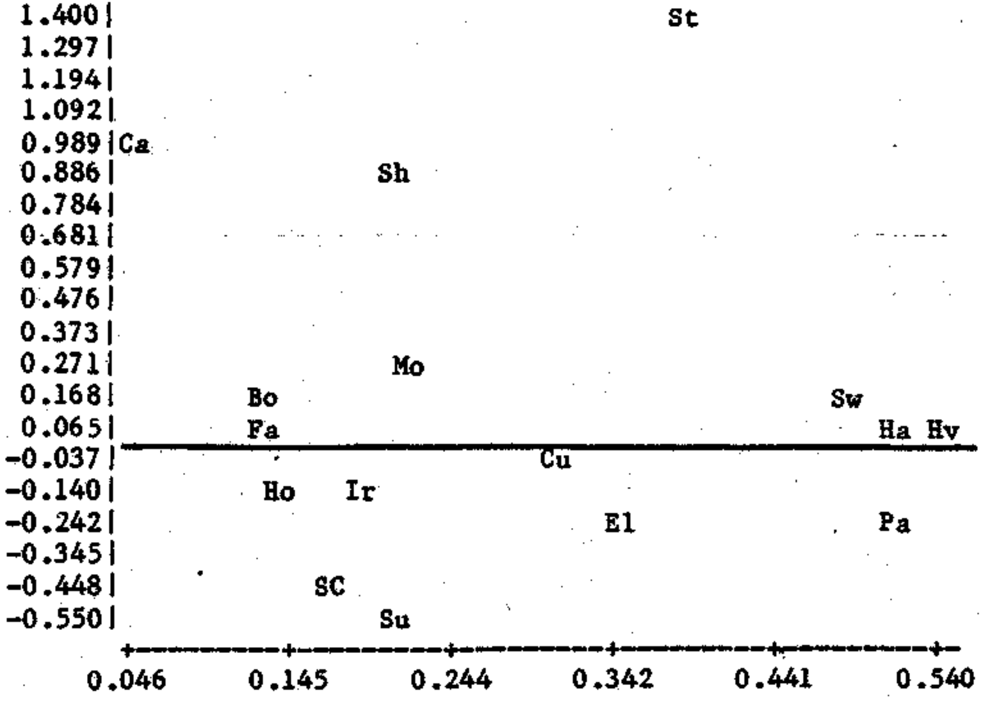
r-chl (lake) vs. af-wet1



r-pspr (lake) vs. ff-conif



r-chl (lake) vs. ff-conif



```
r-pspr (lake)  vs. ff-hdwd
   0.563|  Hv
   0.514|
   0.465|                                         Mo
   0.416|
   0.367|                      Sh
   0.318|                                       Bo
   0.269|
   0.220|          St
   0.171|                 Ce                Ho
   0.122|
   0.073|                        Su              Ca SC
   0.024|                           El
  -0.025|                                       Ir Wi
  -0.074|
  -0.123|                                                 Fa
  -0.172|                           Cu
  -0.221|    Pa
  -0.270|             Sw
  -0.319|
  -0.368|Ha
         +---------+---------+---------+---------+---------+-
       0.340     0.427     0.514     0.602     0.689     0.776
```

```
r-chl (lake)  vs. ff-hdwd
   1.400|          St
   1.297|
   1.194|
   1.092|
   0.989|                                        Ca
   0.886|                      Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                                         Mo
   0.168|             Sw                        Bo
   0.065|Ha Hv                                            Fa
  -0.037|                           Cu
  -0.140|                                   Ho  Ir
  -0.242|    Pa                     El
  -0.345|
  -0.448|                                       SC
  -0.550|                        Su
         +---------+---------+---------+---------+---------+-
       0.340     0.427     0.514     0.602     0.689     0.776
```

```
r-pspr (lake)  vs. ff-mixd
   0.563|        Hv
   0.514|
   0.465|     Mo
   0.416|
   0.367|                                                  Sh
   0.318|                                Bo
   0.269|
   0.220|                                St
   0.171|                                      Ho        Ce
   0.122|
   0.073|                     SC                       Su  Ca
   0.024|    El
  -0.025|                  IrWi
  -0.074|
  -0.123|         Fa
  -0.172|              Cu
  -0.221|             Pa
  -0.270|Sw
  -0.319|
  -0.368|                          Ha
         +---------+---------+---------+---------+---------+-
       0.060     0.099     0.138     0.178     0.217     0.256
```

```
r-chl (lake)  vs. ff-mixd
   1.400|                                St
   1.297|
   1.194|
   1.092|
   0.989|                                                  Ca
   0.886|                                                  Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|     Mo
   0.168|Sw                              Bo
   0.065|         Fa Hv            Ha
  -0.037|              Cu
  -0.140|                  Ir                  Ho
  -0.242|    El       Pa
  -0.345|
  -0.448|                     SC
  -0.550|                                              Su
         +---------+---------+---------+---------+---------+-
       0.060     0.099     0.138     0.178     0.217     0.256
```

```
r-pspr (lake)  vs. lf-und
   0.563|                                         Hv
   0.514|
   0.465|                                              Mo
   0.416|
   0.367|Sh
   0.318|                        Bo
   0.269|
   0.220|                                                  St
   0.171|Ce                Ho
   0.122|
   0.073|  Ca   Su           SC
   0.024|                                        El
  -0.025| Ir             Wi
  -0.074|
  -0.123|                            Fa
  -0.172|     Cu
  -0.221|         Pa
  -0.270|                                         Sw
  -0.319|
  -0.368|                        Ha
         +---------+---------+---------+---------+---------+
       0.212     0.272     0.332     0.392     0.452     0.511
```

```
r-chl (lake) vs. lf-und
   1.400|                                                  St
   1.297|
   1.194|
   1.092|
   0.989|  Ca
   0.886|Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                                              Mo
   0.168|                        Bo               Sw
   0.065|                        Ha  Fa             Hv
  -0.037|     Cu
  -0.140| Ir               Ho
  -0.242|         Pa                             El
  -0.345|
  -0.448|                    SC
  -0.550|       Su
         +---------+---------+---------+---------+---------+
       0.212     0.272     0.332     0.392     0.452     0.511
```

```
r-pspr (lake)  vs. lf-agr
   0.563|                  Hv
   0.514|
   0.465|      Mo
   0.416|
   0.367|                                                  Sh
   0.318|      Bo
   0.269|
   0.220|         St
   0.171|    Ho                      Ce
   0.122|
   0.073|Su         SC               Ca
   0.024|____________El______________________________________
  -0.025|                  Ir                    Wi
  -0.074|
  -0.123|                Fa
  -0.172|                  Cu
  -0.221|                                       Pa
  -0.270|             Sw
  -0.319|
  -0.368|    Ha
         +---------+---------+---------+---------+---------+
       0.062     0.189     0.315     0.442     0.569     0.696
```

```
r-chi (lake)  vs. lf-agr
   1.400|         St
   1.297|
   1.194|
   1.092|
   0.989|                            Ca
   0.886|                                                  Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|      Mo
   0.168|      Bo     Sw
   0.065|    Ha          FaHv
  -0.037|__________________Cu__________________________________
  -0.140|    Ho            Ir
  -0.242|            El                         Pa
  -0.345|
  -0.448|           SC
  -0.550|Su
         +---------+---------+---------+---------+---------+
       0.062     0.189     0.315     0.442     0.569     0.696
```

```
r-pspr (lake)  vs. lf-urb
   0.563|        Hv
   0.514|
   0.465|              Mo
   0.416|
   0.367|Sh
   0.318|                                       Bo
   0.269|
   0.220|                   St
   0.171|                 Ce                  Ho
   0.122|
   0.073|             Ca      SC                 Su
   0.024|                           El
  -0.025| Wi                                               Ir
  -0.074|
  -0.123|                            Fa
  -0.172|                                            Cu
  -0.221|        Pa
  -0.270|                  Sw
  -0.319|
  -0.368|                             Ha
         +---------+---------+---------+---------+---------+
       0.054     0.118     0.183     0.247     0.311     0.376
```

```
r-chl (lake)  vs. lf-urb
   1.400|                   St
   1.297|
   1.194|
   1.092|
   0.989|             Ca
   0.886|Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|              Mo
   0.168|                  Sw                   Bo
   0.065|        Hv                  Fa Ha
  -0.037|                                            Cu
  -0.140|                                     Ho           Ir
  -0.242|        Pa                 El
  -0.345|
  -0.448|                     SC
  -0.550|                                        Su
         +---------+---------+---------+---------+---------+
       0.054     0.118     0.183     0.247     0.311     0.376
```

```
r-pspr (lake)  vs. lf-septic
   0.563|                    Hv
   0.514|
   0.465|                                   Mo
   0.416|
   0.367|Sh
   0.318|                Bo
   0.269|
   0.220|         St
   0.171|                          Ce               Ho
   0.122|
   0.073|                        SuCa                      SC
   0.024|________________________El___________________________
  -0.025| Wi                   Ir
  -0.074|
  -0.123|           Fa
  -0.172|                    Cu
  -0.221|           Pa
  -0.270|                          Sw
  -0.319|
  -0.368|                                                    Ha
          +---------+----------+---------+----------+---------+
       0.000     0.021      0.042      0.063     0.084     0.105
```

```
r-chl (lake)  vs. lf-septic
   1.400|         St
   1.297|
   1.194|
   1.092|
   0.989|                          Ca
   0.886|Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                                   Mo
   0.168|                Bo        Sw
   0.065|           Fa       Hv                               Ha
  -0.037|____________________Cu__________________________________
  -0.140|                      Ir                    Ho
  -0.242|           Pa           El
  -0.345|
  -0.448|                                                   SC
  -0.550|                        Su
          +---------+----------+---------+----------+---------+
       0.000     0.021      0.042      0.063     0.084     0.105
```

```
r-pspr (lake) vs. lf-atm
    0.563|          Hv
    0.514|
    0.465|                    Mo
    0.416|
    0.367|Sh
    0.318|                       Bo
    0.269|
    0.220|              St
    0.171|                    Ce   Ho
    0.122|
    0.073|                       CaSC                      Su
    0.024|  El
   -0.025|   Wi Ir
   -0.074|
   -0.123|          Fa
   -0.172|       Cu
   -0.221|  Pa
   -0.270|        Sw
   -0.319|
   -0.368|                         Ha
         +---------+---------+---------+---------+---------+-
       0.039     0.095     0.151     0.207     0.263     0.319
```

```
r-chl (lake) vs. lf-atm
    1.400|               St
    1.297|
    1.194|
    1.092|
    0.989|                        Ca
    0.886|Sh
    0.784|
    0.681|
    0.579|
    0.476|
    0.373|
    0.271|                     Mo
    0.168|         Sw             Bo
    0.065|           FaHv           Ha
   -0.037|        Cu
   -0.140|       Ir                 Ho
   -0.242|   ElPa
   -0.345|
   -0.448|                        SC
   -0.550|                                                  Su
          +---------+---------+---------+---------+---------+
        0.039     0.095     0.151     0.207     0.263     0.319
```

```
r-pspr (lake)  vs. 1f-inter
   0.563|  Hv
   0.514|
   0.465|                               Mo
   0.416|
   0.367|                                                  Sh
   0.318|        Bo
   0.269|
   0.220|St
   0.171|Ce  Ho
   0.122|
   0.073| Su    SC             Ca
   0.024|El
  -0.025|Wi                                   Ir
  -0.074|
  -0.123|                         Fa
  -0.172|Cu
  -0.221|                         Pa
  -0.270|  Sw
  -0.319|
  -0.368|            Ha
         +---------+---------+---------+---------+---------+
       0.000     0.114     0.228     0.342     0.456     0.570
```

```
r-chl (lake)  vs. 1f-inter
   1.400|St
   1.297|
   1.194|
   1.092|
   0.989|                      Ca
   0.886|                                                  Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                               Mo
   0.168|  Sw    Bo
   0.065|  Hv        Ha           Fa
  -0.037|Cu
  -0.140|    Ho                               Ir
  -0.242|El                       Pa
  -0.345|
  -0.448|       SC
  -0.550| Su
         +---------+---------+---------+---------+---------+
       0.000     0.114     0.228     0.342     0.456     0.570
```

```
r-pspr (lake)  vs. sarea
   0.563|      Hv
   0.514|
   0.465|          Mo
   0.416|
   0.367|         Sh
   0.318|                                          Bo
   0.269|
   0.220|St
   0.171| Ce      Ho
   0.122|
   0.073|   Su          SC          Ca
   0.024|    El
  -0.025|   Ir Wi
  -0.074|
  -0.123|         Fa
  -0.172|Cu
  -0.221|    Pa
  -0.270|   Sw
  -0.319|
  -0.368| Ha
         +---------+---------+---------+---------+---------+-
      56.810   518.206   979.602  1441.000  1902.390  2363.790
```

```
r-chl (lake)  vs. sarea
   1.400|St
   1.297|
   1.194|
   1.092|
   0.989|                             Ca
   0.886|         Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|          Mo
   0.168|   Sw                                        Bo
   0.065| Ha    Hv Fa
  -0.037|Cu
  -0.140|   Ir     Ho
  -0.242|    ElPa
  -0.345|
  -0.448|                Sc
  -0.550|   Su
         +---------+---------+---------+---------+---------+-
      56.810   518.206   979.602  1441.000  1902.390  2363.790
```

```
r-pspr (lake)  vs. log(t)
   0.563|                                    Hv
   0.514|
   0.465|                               Mo
   0.416|
   0.367|                 Sh
   0.318|                                Bo
   0.269|
   0.220|   St
   0.171|               Ce          Ho
   0.122|
   0.073|                             Ca       SC          Su
   0.024|     El
  -0.025|Wi                    Ir
  -0.074|
  -0.123|                            Fa
  -0.172|              Cu
  -0.221|                 Pa
  -0.270|                                 Sw
  -0.319|
  -0.368|                             Ha
         +---------+---------+---------+---------+---------+
      -1.828    -1.084    -0.341     0.403     1.146     1.889
```

```
r-chl (lake)  vs. log(t)
   1.400|   St
   1.297|
   1.194|
   1.092|
   0.989|                             Ca
   0.886|                 Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                               Mo
   0.168|                                Bo Sw
   0.065|                            Fa Ha   Hv
  -0.037|              Cu
  -0.140|                      Ir   Ho
  -0.242|     El          Pa
  -0.345|
  -0.448|                                      SC
  -0.550|                                                  Su
         +---------+---------+---------+---------+---------+
      -1.828    -1.084    -0.341     0.403     1.146     1.889
```

```
r-pspr (lake)  vs. log(qs)
   0.563|                                 Hv
   0.514|
   0.465|                   Mo
   0.416|
   0.367|                         Sh
   0.318|               Bo
   0.269|
   0.220|                            St
   0.171|         Ce    Ho
   0.122|
   0.073|Su       CaSC
   0.024| _________________________________________________El
  -0.025|                        Wi  Ir
  -0.074|
  -0.123|                    Fa
  -0.172|                            Cu
  -0.221|                                               Pa
  -0.270|                                        Sw
  -0.319|
  -0.368|        Ha
         +---------+---------+---------+---------+---------+
       1.034     1.367     1.700     2.034     2.367     2.700
```

```
r-chl (lake)  vs. log(qs)
   1.400|                            St
   1.297|
   1.194|
   1.092|
   0.989|         Ca
   0.886|                         Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                   Mo
   0.168|               Bo                       Sw
   0.065|________Ha__________Fa___________Hv__________________
  -0.037|                            Cu
  -0.140|               Ho           Ir
  -0.242|                                               Pa El
  -0.345|
  -0.448|           SC
  -0.550|Su
         +---------+---------+---------+---------+---------+
       1.034     1.367     1.700     2.034     2.367     2.700
```

```
r-pspr (lake)  vs. runoff
   0.563|                    Hv
   0.514|
   0.465|                       Mo
   0.416|
   0.367|                                Sh
   0.318|Bo
   0.269|
   0.220|                           St
   0.171|Ho                         Ce
   0.122|
   0.073|SCSu                                              Ca
   0.024|________________________________El________________
  -0.025|                           Wi   Ir
  -0.074|
  -0.123|                                                  Fa
  -0.172|                                Cu
  -0.221|                                Pa
  -0.270|                                Sw
  -0.319|
  -0.368|                    Ha
         +---------+---------+---------+---------+---------+
       0.460     0.504     0.548     0.592     0.636     0.680
```

```
r-chl (lake)  vs. runoff
   1.400|                           St
   1.297|
   1.194|
   1.092|
   0.989|                                                  Ca
   0.886|                                Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                       Mo
   0.168|Bo                              Sw
   0.065|                    HvHa                          Fa
  -0.037|________________________________Cu________________
  -0.140|Ho                              Ir
  -0.242|                                ElPa
  -0.345|
  -0.448|SC
  -0.550|Su
         +---------+---------+---------+---------+---------+
       0.460     0.504     0.548     0.592     0.636     0.680
```

```
r-pspr (lake)  vs. shordev
    0.563|       Hv
    0.514|
    0.465|         Mo
    0.416|
    0.367|           Sh
    0.318|                                                    Bo
    0.269|
    0.220|    St
    0.171|Ce                                     Ho
    0.122|
    0.073|Su         Ca                    SC
    0.024|____El___________________________________________________
   -0.025|   Wi         Ir
   -0.074|
   -0.123|                    Fa
   -0.172|                                     Cu
   -0.221|       Pa
   -0.270|      Sw
   -0.319|
   -0.368|                  Ha
          +---------+----------+---------+---------+----------+-
        1.090     1.503      1.916     2.329      2.742     3.155
```

```
r-chl (lake)  vs. shordev
    1.400|    St
    1.297|
    1.194|
    1.092|
    0.989|           Ca
    0.886|           Sh
    0.784|
    0.681|
    0.579|
    0.476|
    0.373|
    0.271|         Mo
    0.168|      Sw                                            Bo
    0.065|_______Hv_________HaFa__________________________________
   -0.037|                                     Cu
   -0.140|              Ir                       Ho
   -0.242|    El Pa
   -0.345|
   -0.448|                                 SC
   -0.550|Su
          +---------+----------+---------+---------+----------+-
        1.090     1.503      1.916     2.329      2.742     3.155
```

```
r-pspr (lake)  vs. zx
   0.563|                                                 Hv
   0.514|
   0.465|             Mo
   0.416|
   0.367|       Sh
   0.318|                     Bo
   0.269|
   0.220|St
   0.171|  Ce               Ho
   0.122|
   0.073|         Ca         SC                  Su
   0.024|   El
  -0.025|Wi         Ir
  -0.074|
  -0.123|            Fa
  -0.172|         Cu
  -0.221|               Pa
  -0.270|                                                Sw
  -0.319|
  -0.368|        Ha
         +---------+---------+---------+---------+---------+--
       2.400    10.760    19.120    27.480    35.840    44.200
```

```
r-chl (lake)  vs. zx
   1.400|St
   1.297|
   1.194|
   1.092|
   0.989|         Ca
   0.886|       Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|             Mo
   0.168|                     Bo                         Sw
   0.065|        Ha  Fa                                   Hv
  -0.037|         Cu
  -0.140|           Ir      Ho
  -0.242|   El          Pa
  -0.345|
  -0.448|                    SC
  -0.550|                                        Su
         +---------+---------+---------+---------+---------+--
       2.400    10.760    19.120    27.480    35.840    44.200
```

```
r-pspr (lake)  vs. zmean
   0.563|                                                 Hv
   0.514|
   0.465|                   Mo
   0.416|
   0.367|       Sh
   0.318|                   Bo
   0.269|
   0.220| St
   0.171|  Ce        Ho
   0.122|
   0.073|           Ca            SC                  Su
   0.024|      El
  -0.025|Wi          Ir
  -0.074|
  -0.123|                Fa
  -0.172|      Cu
  -0.221|                 Pa
  -0.270|                                                   Sw
  -0.319|
  -0.368|          Ha
         +---------+---------+---------+---------+---------+-
       1.019     4.995     8.971    12.948    16.924    20.900
```

```
r-chl (lake)  vs. zmean
   1.400| St
   1.297|
   1.194|
   1.092|
   0.989|            Ca
   0.886|       Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|                   Mo
   0.168|                   Bo                              Sw
   0.065|          Ha    Fa                               Hv
  -0.037|      Cu
  -0.140|            HoIr
  -0.242|      El         Pa
  -0.345|
  -0.448|                         SC
  -0.550|                                             Su
         +---------+---------+---------+---------+---------+-
       1.019     4.995     8.971    12.948    16.924    20.900
```

```
r-pspr (lake)  vs. zx/zm
   0.563|                    Hv
   0.514|
   0.465|  Mo
   0.416|
   0.367|                    Sh
   0.318|                          Bo
   0.269|
   0.220|    St
   0.171|                Ce                                Ho
   0.122|
   0.073|          Ca SC Su
   0.024|El__________________________________________________
  -0.025|             Ir                  Wi
  -0.074|
  -0.123|        Fa
  -0.172|                                         Cu
  -0.221|            Pa
  -0.270|               Sw
  -0.319|
  -0.368|          Ha
         +---------+---------+---------+---------+---------+
       1.491     1.848     2.204     2.560     2.916     3.272
```

```
r-chl (lake)  vs. zx/zm
   1.400|    St
   1.297|
   1.194|
   1.092|
   0.989|          Ca
   0.886|                    Sh
   0.784|
   0.681|
   0.579|
   0.476|
   0.373|
   0.271|  Mo
   0.168|               Sw         Bo
   0.065|        FaHa        Hv
  -0.037|_________________________________________Cu_________
  -0.140|             Ir                                   Ho
  -0.242|El          Pa
  -0.345|
  -0.448|         SC
  -0.550|            Su
         +---------+---------+---------+---------+---------+
       1.491     1.848     2.204     2.560     2.916     3.272
```

```
r-pspr (lake)  vs. ztherm
  0.563|                                             Hv
  0.514|
  0.465|                                         Mo
  0.416|
  0.367|                  Sh
  0.318|                                             Bo
  0.269|
  0.220|St
  0.171|Ce                                                Ho
  0.122|
  0.073|                                    CaSu     SC
  0.024|El
 -0.025|Wi                                Ir
 -0.074|
 -0.123|                                    Fa
 -0.172|Cu
 -0.221|                                    Pa
 -0.270|                                             Sw
 -0.319|
 -0.368|                                Ha
        +---------+---------+---------+---------+---------+-
      0.000     2.200     4.400     6.600     8.800    11.000
```

```
r-chl (lake)  vs. ztherm
  1.400|St
  1.297|
  1.194|
  1.092|
  0.989|                                    Ca
  0.886|                  Sh
  0.784|
  0.681|
  0.579|
  0.476|
  0.373|
  0.271|                                         Mo
  0.168|                                             BoSw
  0.065|                                Ha  Fa       Hv
 -0.037|Cu
 -0.140|                                  Ir              Ho
 -0.242|El                                  Pa
 -0.345|
 -0.448|                                             SC
 -0.550|                                    Su
        +---------+---------+---------+---------+---------+-
      0.000     2.200     4.400     6.600     8.800    11.000
```

```
r-pspr (lake)  vs. zhyp
  0.563|                                                  Hv
  0.514|
  0.465|      Mo
  0.416|
  0.367|    Sh
  0.318|           Bo
  0.269|
  0.220|St
  0.171|Ce         Ho
  0.122|
  0.073|   Ca            SC                          Su
  0.024|El
 -0.025|Wi     Ir
 -0.074|
 -0.123|         Fa
 -0.172|Cu
 -0.221|         Pa
 -0.270|                                                Sw
 -0.319|
 -0.368|    Ha
        +---------+---------+---------+---------+---------+
      0.000     3.280     6.560     9.840    13.120    16.400
```

```
r-chl (lake)  vs. zhyp
  1.400|St
  1.297|
  1.194|
  1.092|
  0.989|   Ca
  0.886|     Sh
  0.784|
  0.681|
  0.579|
  0.476|
  0.373|
  0.271|       Mo
  0.168|            Bo                                   Sw
  0.065|     Ha   Fa                                       Hv
 -0.037|Cu
 -0.140|        Ir  Ho
 -0.242|El        Pa
 -0.345|
 -0.448|                  SC
 -0.550|                                             Su
        +---------+---------+---------+---------+---------+
      0.000     3.280     6.560     9.840    13.120    16.400
```