VARIABILITY OF TROPHIC STATE INDICATORS IN VERMONT LAKES AND IMPLICATIONS FOR LEAP ERROR ANALYSES

prepared for

Vermont Agency of Environmental Conservation
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by

William W. Walker, Jr.
Environmental Engineer
1127 Lowell Road
Concord, MA 01742
617-369-8061

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This report develops refined estimates of LEAP error terms, based upon the general approach outlined previously (Walker, W.W., "Structure and Calibration of an Error Analysis Framework for the Vermont Lake Eutrophication Analysis Procedure", 1982). The major refinement incorporated below is consideration of the effects of within-year and among-year variability in observed lake water quality on the accuracies of observed mean values. Results provide a useful framework for designing monitoring programs as well as a basis for estimation of LEAP model error terms.

Lay monitoring data from the 98 STORET stations listed in the Appendix have been used as a basis for the analysis. Since variations among stations within a given lake would depend upon site-specific characteristics (morphometry, nutrient loading distributions, stations locations, etc.), each station is treated separately below. This permits a focus on temporal variance components. LEAP is designed to predict long-term average conditions and temporal variability imposes limitations on the accuracy of observed mean values derived from limited sampling data.

Table 1 presents results of nested analyses of variance for spring total P, summer chlorophyll-a, and summer transparency. The conceptual model described previously divides measurement variance into three components: (1) among lakes (stations); (2) among years, within lakes; and (3) among samples, within years. Because spring phosphorus measurements were generally conducted only once per year, it is impossible to distinguish components (2) and (3) and they are lumped in Table 1. Within-year variations in phosphorus are treated separately below. Two sets of ANOVA's are given in Table 1. One uses uses all non-missing observations for each variable and examines all three variance components. The second is based upon station-year means and includes only station-years with non-missing values for phosphorus, chlorophyll-a, and transprency; this permits assessment of covariance components (Table 2).

The analysis indicates that among-lake (or among-station) variance dominates all three measurements and accounts for 73%, 56%, and 76% of the total observed variance in phosphorus, chlorophyll, and transparency when all data are considered. The among-sample variance component is strongest in the case of chlorophyll-a (.19 or 33%); this reflects seasonal variations in algal populations, as well as sampling and analytical errors, and indicates, for example, that an average of 19 samples per summer would be required to estimate a yearly-mean value to within a coefficient of variation of 10%. Diagnostic plots indicate that the among-sample standard deviation in log(chlorophyll) increases with mean chlorophyll-a level from about .38 to .55; while this may reflect a tendancy for algal populations to be more variable in more eutrophic systems, the pooled estimate (.44) is adequate for the present purposes. Covariance among the three variables is generally stronger among stations than among years (Table 2). The year-to-year component is more strongly influenced by measurement and sampling errors, which would not be expected to correlate as strongly across variables. Another possible factor is that wet years may tend to have higher phosphorus levels (because of increased runoff) but lower chlorophyll concentrations (because of lower light intensities and temperatures).

Limited data from four lakes are available to estimate within-year variance in spring phosphorus concentrations (Table 3). Based upon the average coefficient of variation, a pooled estimate for the within-year component is .063 (natural log scales) and accounts for 66% of the year/sample variance component estimated in Table 1.

Table 4 summarizes the estimated variance components for each variable and computes estimated variances, coefficients of variation, and 90% confidence factors for long-term means of each variable as a function of monitoring years. The within-year sampling regime (m) corresponds approximately to the lay monitoring design (1 phosphorus, 12 chlorophyll, and 12 secchi measurements per year). The variance components and formula can be used to assess alternative sampling designs. Generally, the variance in the long-term mean is greatest for phosphorus because only one sample is taken per year and the within-year variance component is appreciable. Increasing within-year sampling frequency (even to 2 samples/year) may be cost-effective for determining long-term means in spring phosphorus.

As shown in Table 5, a portion of the year-to-year variance in each measurement is not random, but associated with specific years, i.e., the yearly effects are correlated across stations. Fixed yearly effects are statistically significant for each variable and account for a total of 23.1%, 3.3%, and 2.0% of the total within-station variance of phosphorus, chlorophyll, and transparency. They are of practical significance only in the case of phosphorus. Duncan's Multiple Range Test applied to yearly means suggests an increasing trend in phosphorus ranging from a mean of 8.2 in 1979 to 12.3 in 1982. Except for the slightly lower chlorophyll-a mean in 1979 (3.82 vs. mean of 4.10 for other years), the apparent trend in phosphorus is not correlated with trends in the other measurements.

Applied to the total estimated within-station phosphorus variance component of .095 (V(Y) + V(W) in Table 4), the fixed yearly effects account for 23.1% or .022; this, in turn, accounts for 68.8% of the estimated among-year variance component for phosphorus (.032). Thus, about two thirds of the year-to-year variance in spring phosphorus during these four years was not random but associated with specific years. This suggests a deterministic component which may be related to hydrologic or climatologic variations which influence all lakes, changes in laboratory or sampling procedures, or actual trends in concentration attributed to increases in nutrient loadings. Additional analysis (particularly vs. streamflow data) may shed additional light on the the sources of these variations. The non-random nature of the year-to-year phosphorus variations raises a question, however, as to the applicability of the estimated variance components in future years and warrants continued study. In applying these results to estimate error terms for future LEAP applications, we are assuming the the lake conditions and sampling procedures in 1979-82 period were reasonably representative.

The above results can be used to estimate the model and data error components of LEAP submodels following the general approach outlined previously. Table 6 lists the estimated data error variances for the 18 calibration lakes, based upon the variance components listed in Table 4 and the average monitoring program designs for these lakes. Table 7 estimates the model error variances by difference from the total and data error variance, considering the effects of error propagation through the model network. The total error variances (V(R)) in Table 7 correspond to use of the linear form of the LEAP internal loading function. While they are slightly greater than the errors derived from the exponential function, the linear function is recommended because of sensitivity considerations. Resulting input standard deviations for the model error terms in LEAP are listed in Table 8.

Table 9 lists observed and predicted phosphorus concentrations for LEAP applications to 18 calibration lakes and the 24 additional lakes compiled by VDWR. Monitoring years and estimated variance components are also listed. A major distinction between the first and second set of lakes is apparent in terms of sampling frequency; the latter were generally sampled less frequently and LEAP error variance would be expected to be greater for these lakes. Based upon the error terms estimated above, observations and predictions differ by more than two standard errors for Morey in the first group. Under-prediction in this case is attributed primarily to unusual iron/sulfur chemistry leading to enhanced internal recycling of phosphorus. The effects of unusual outlet hydraulic conditions leading to increased phosphorus loadings may be responsible for the under-prediction in the case of Harvey's Lake (t = 1.99). In the second group of lakes, t values exceed 2.0 in 3 cases. Northeast Developer's "pond" is a relatively new, artificial impoundment and is atypical of the natural lakes used in model development. Internal recycling may be more efficient than predicted in Valley because the lake is permanently stratified. The deviation of Hosmer (t=2.7) is unexplained.

Excluding Northeast Developer's and Valley on the basis of their atypical characteristics, the total error variance in the second set of lakes is .111. This compares well with the average data and model variance components (Vtotal in Table 9) of .108 for the same set of lakes. Calculated error statistics for the second set of lakes support the error terms estimated from the calibration lakes and indicate that the general magnitudes of deviations in the second set are expected based upon sampling frequency and model error considerations. The numbers of lakes in the second set with chlorophyll and transparency data are inadequate as a basis to test the error terms for these variables.

One limitation of the error analysis is that the estimated variance components and their effects on the accuracies of lake-mean values assume that the samples are statistically independent. Some autocorrelation would be expected in chlorophyll and transparency samples taken at a weekly frequency. Additional analysis would be required to quantify this and its effects on the error analysis. Generally, serial correlation would tend to become increasingly important at relatively high sampling freqencies and would tend to decrease the value of high-frequency sampling for determination of summer-mean values. Serial correlation is not likely to influence the spring phosphorus estimates, however.

Minor code modifications and procedures to permit consideration of errors in the observed means in LEAP applications have been described previously. By considering both model and data error components, LEAP can be used to identify lakes which have unusual watershed, loading, or internal recycling characteristics leading to high phosphorus levels. These would be logical candidates for further direct investigation. Deviations of Harvey's, Morey, Valley, and Northeast Developer's are all positive and explained independently of the model. More detailed investigation of Hosmer may lead to an explanation for its deviation (also positive). In this sense, LEAP can be used as a screening tool to identify problem lakes.

Another type of application would involve projecting impacts of changes in nutrient loadings and/or land use on water quality. If data are available for the lake in question, the model error terms (means) can be calibrated so that water quality observations and predictions match, similar to the approach demonstrated for Lake Morey. If the model is calibrated in this way, however, the error term standard deviations estimated above are no longer valid. Because of the calibration, projections would be more accurate than predicted based upon the error terms. While there is no good way of assessing model error in this type of application, the error analysis routine can still be used to assess the effects of uncertainty in the model input variables on predictions.

Table 1

Results of Nested Analyses of Variance

		All Data				Yearly-Means*		
	DOF	MS	VC	Percent	DOF	MS	VC	Percent
Spring Total P								
Total	285	.451	.456	100.0	134	.355	.355	100.0
Station	84	1.241	.334	73.1	57	.705	.265	74.0
Year/Sample	201	.122	.122	26.9	77	.095	.095	26.1
Chlorophyll-a								
Total	2620	.573	.578	100.0	134	.414	.419	100.0
Station	64	14.288	.324	56.3	57	.875	.345	83.1
Year	87	1.236	.058	10.4	77	.069	.069	17.0
Sample	2469	.191	.191	33.3				
Secchi Depth								
Total	3521	.276	.281	100.0	134	.255	.255	100.0
Station	93	8.300	.212	76.1	57	.557	.228	90.0
Year	203	.302	.022	8.0	77	.027	.027	10.3
Sample	3225	.045	.045	15.9				

DOF = Degrees of Freedom
MS = Mean Square
VC = Variance Component
Percent = VC as Percent of Total
all components on natural log scales
* including only station-years with non-missing values for all variables

$cv^2 = .191$
$cv \sim .4$

Table 2

Nested Analysis of Covariance

	DOF	VC-X	VC-Y	CC-XY	R	Bg	Br
X = Chl-a Y = Secchi - including within-year variations							
Total	1919	.607	.342	-.251	-.551	-.75	-.41
Station	64	.353	.267	-.210	-.685	-.87	-.60
Year	87	.056	.027	-.013	-.346	-.69	-.24
Sample	1768	.198	.049	-.032	-.324	-.50	-.16
X = Chl-a Y = Secchi (yearly means)							
Total	134	.417	.256	-.235	-.720	-.78	-.56
Station	57	.346	.229	-.223	-.794	-.82	-.65
Year	77	.071	.027	-.014	-.335	-.61	-.20
X = Total P Y = Chl-a (yearly means)							
Total	134	.357	.417	.237	.613	1.08	.66
Station	57	.265	.346	.221	.730	1.14	.83
Year	77	.093	.071	.016	.199	.87	.17
X = Total P Y = Secchi (yearly means)							
Total	134	.357	.256	-.115	-.379	-.85	-.32
Station	57	.265	.229	-.120	-.486	-.93	-.45
Year	77	.093	.027	.003	.069	.53	.03

DOF = Degrees of Freedom
VC-X, VC-Y = Variance Component of X and Y
CC-XY = Covariance Component of X and Y
R = Covariance Component Correlation
Bg = geometric regression slope
Br = regression slope
all components on natural log scales

Table 3
Within-Year Variance of Spring Phosphorus in Four Vermont Lakes

Lake	Year	N	Mean	Standard Deviation	Coef. of Variation
Harveys	79	9	11.7	2.3	.20
Keiser	79	8	5.5	1.9	.34
Morey	79	10	36.2	7.8	.22
Peacham	79	8	6.3	1.6	.25
				mean	.25

Estimated Within-Year Variance Component = $.25^2$ = .063
(natural log scales)

Table 4

Estimation of Variances in Observed Means as a Function of Sample Years

Sample	Variances of Means*			Coefs. of Variation			90% Confidence Fac.		
Years	P	Chl-a	Secchi	P	Chl-a	Secchi	P	Chl-a	Secchi
1	.0950	.0739	.0258	.3082	.2719	.1605	1.852	1.722	1.378
2	.0475	.0370	.0129	.2179	.1922	.1135	1.546	1.469	1.255
3	.0317	.0246	.0086	.1780	.1570	.0926	1.427	1.369	1.204
4	.0238	.0185	.0064	.1541	.1359	.0802	1.361	1.312	1.174
5	.0190	.0148	.0052	.1378	.1216	.0718	1.317	1.275	1.154
6	.0158	.0123	.0043	.1258	.1110	.0655	1.286	1.249	1.140
7	.0136	.0106	.0037	.1165	.1028	.0607	1.262	1.228	1.129
8	.0119	.0092	.0032	.1090	.0961	.0567	1.244	1.212	1.120
9	.0106	.0082	.0029	.1027	.0906	.0535	1.228	1.199	1.113
10	.0095	.0074	.0026	.0975	.0860	.0507	1.215	1.188	1.107

* natural log scales

Coef. of Variation = $\text{Variance}^{.5}$

90% Confidence Factor = F90 = exp(2 CV)

Ye/F90 < Y < Ye x F90 at 90% confidence level

Y = actual mean , Ye = estimated mean

Variance of Means Computed from:

$$V(O) = V(Y)/n + V(W)/ (n\ m)$$

where,

V(O) = variance of observed long-term mean
V(Y) = between-year variance component
V(W) = within-year variance component
n = number of years
m = number of samples per year

Variable	P	Chl-a	Secchi
V(Y)	.032	.058	.022
V(W)	.063	.191	.045
m	1	12	12

Table 5
Test for Fixed Yearly Effects on Trophic State Indicators

	Total P		Chlorophyll-a		Transparency	
Source	DOF	SS	DOF	SS	DOF	SS
Total	285	24.74	2620	282.27	3521	184.14
Station	84	19.66**	64	172.39**	93	145.57**
Year	3	1.07**	3	3.58**	3	.76**
Error	198	3.56	2553	106.30	3425	37.81
Year/(Error+Year)		23.1%		3.3%		2.0%
Fixed Yearly Means:						
1982		1.090 A*		.607 A		.661 A
1981		1.035 B		.619 A		.648 B
1980		.955 C		.613 A		.646 B
1979		.915 C		.582 B		.652 AB
Range		.180		.025		.015

DOF = degrees of freedom
SS = sum of squares
** Effect significant at $p < .01$
* Means followed by same letter are not significantly different at $p < .05$, based upon Duncan's multiple range test
all statistics on base-10 log scales

Table 6

Estimated Data Error Components for LEAP Calibration Lakes

Variable	V(Y)	n	V(W)	m	V(O)
Spring P	.032	5	.063	1	.019
Mean Chlorophyll-a	.058	4	.191	12	.019
Maximum Chlorophyll-a *	.083	4	-	-	.021
Mean Transparency	.022	4	.045	12	.006
Oxygen Depletion Rate *	.020	2	-	-	.010

V(Y) = year-to-year variance component
n = average number sample-years per lake
V(W) = within-year variance component
m = average number os samples/year
V(O) = error variance in mean estimate = V(Y) / n + V(n)/ (n m)

* developed previously (Walker ,1982)

all variances expressed on natural log scales

Table 7

Model Error Components

Model	Error Term	V(R)	V(O)	V(M)	V(M) Components
39/40	Spring Phosphorus	.075	.019	.056	.028 (Watershed, 39)
					.028 (Retention, 40)
41	Phosphorus/Chl-a	.197	.019	.178	$.94^2$ x .056 (Spring P)
					.129 (P/Chl-a, 41)
42	Mean Chl-a/Max Chl-a	.287	.021	.266	1.16^2 x .178 (Mean Chl-a)
					.026 (Mean/Max Chl-a, 42)
43	Mean Chl-a/Secchi	.107	.006	.101	$.65^2$ x .178 (Mean Chl-a)
					.026 (Mean Chl-a/Secchi, 43)
44	Phosphorus/HOD	.105	.010	.095	$.91^2$ x .056 (Spring P)
					.049 (P/HOD, 44)

V(R) = total variance of residuals, excluding Star Lake (outlier) for mean and maximum chlorophyll-a

V(O) = average observed data error component (Table ?)

V(M) = estimated total model error = V(R) - V(O)

V(M) Components = breakdown of model error, sum = V(M)

All variances on natural log scale

Table 8

Summary of Calibrated Error Terms for LEAP Input

Variable	Mean	Standard Deviation
39 Watershed Model Error	1.0	.17
40 Retention Model Error	1.0	.17
41 P/Chl-a Model Error	1.0	.36
42 Mean Chl-a/Max Chl-a Model Error	1.0	.16
43 Mean Chl-a/Secchi Model Error	1.0	.16
44 Phosphorus/HOD Model Error	1.0	.21

Notes:

Standard Deviations estimated from square roots of variance terms estimated in Table ?;

Standard Deviations of input variables 1-38 should be set to 0.0.

Table 9
Spring Phosphorus Residuals

Lake	Error	Obs.	Est.	Years	V(O)	Vtotal	t
Bomoseen	0.271	2.697	2.426	5	0.019	0.075	0.989
Carmi	0.065	2.994	2.928	5	0.019	0.075	0.239
Cedar	0.150	2.841	2.690	5	0.019	0.075	0.549
Curtis	-0.186	2.498	2.684	5	0.019	0.075	-0.680
Elmore	0.043	2.524	2.481	5	0.019	0.075	0.156
Fairfield	-0.127	2.994	3.121	4	0.024	0.080	-0.448
Harveys	0.545	2.628	2.083	5	0.019	0.075	1.989
Hortonia	0.154	2.457	2.303	5	0.019	0.075	0.563
Iroquois	0.061	3.392	3.331	5	0.019	0.075	0.222
Morey	0.555	3.299	2.743	6	0.016	0.072	2.072 *
Parker	-0.241	2.730	2.971	5	0.019	0.075	-0.879
St Cather	0.009	2.464	2.455	5	0.019	0.075	0.035
Shelburne	0.367	4.724	4.357	5	0.019	0.075	1.340
Star	0.199	2.619	2.420	4	0.024	0.080	0.704
Winona	-0.016	3.256	3.272	5	0.019	0.075	-0.059
Halls	-0.417	2.313	2.729	5	0.019	0.075	-1.522
Shadow	-0.298	1.719	2.017	5	0.019	0.075	-1.087
Sunset	0.063	1.811	1.748	4	0.024	0.080	0.222
Harriman	0.389	3.135	2.746	2	0.048	0.103	1.209
Bliss	0.128	2.485	2.357	3	0.032	0.088	0.433
Long	-0.236	3.091	3.327	2	0.048	0.103	-0.733
Round	-0.027	3.178	3.205	1	0.095	0.151	-0.070
Sodom	-0.311	2.398	2.709	1	0.095	0.151	-0.802
Lily-Vernon	-0.168	2.639	2.807	2	0.048	0.103	-0.522
Colby	0.023	2.398	2.375	2	0.048	0.103	0.070
Runnemede	-0.515	2.565	3.080	4	0.024	0.080	-1.823
Mill-Windsor	-0.136	2.565	2.701	4	0.024	0.080	-0.482
Shippee	-0.191	2.197	2.388	1	0.095	0.151	-0.490
Lowell	-0.099	1.792	1.891	2	0.048	0.103	-0.308
Lower Sunset	0.277	2.773	2.496	1	0.095	0.151	0.712
Brownington	-0.061	2.303	2.364	2	0.048	0.103	-0.189
Derby	0.247	3.045	2.798	3	0.032	0.088	0.834
Ewell	0.498	2.833	2.335	4	0.024	0.080	1.764
Sadawga	-0.370	2.303	2.672	4	0.024	0.080	-1.309
Tildys	0.334	3.045	2.710	2	0.048	0.103	1.038
Chipman	-0.436	2.303	2.739	1	0.095	0.151	-1.123
Danby	-0.240	2.303	2.543	1	0.095	0.151	-0.619
Northeast Dev.	0.659	3.091	2.432	2	0.048	0.103	2.049 *
Paran	-0.345	2.565	2.910	3	0.032	0.088	-1.167
Hosmer	0.798	3.280	2.482	3	0.032	0.088	2.695 *
Ticklenaked	-0.119	3.178	3.297	5	0.019	0.075	-0.433
Valley	1.044	3.258	2.214	4	0.024	0.080	3.696 *

Error = Obs. - Est.
Obs. = observed mean spring P (natural log, mg/m3)
Est. = estimated mean spring P (natural log, mg/m3)
Years = number of monitored years
V(O) = estimated variance of observed P = .095 / Years
Vtotal = estimated variance of residual = V(O) + .056
t = Error / square root of Vtotal = test for deviation
* Observations and Predictions differ by more than 2 standard errors, considering both model and data error components

APPENDIX

STORET Station Codes Used in Analysis

PRIM.	SEC.	BASIN	LAKE
503776	9ARR1	LAMOILLE RIVER	ARROWHEAD MT
503777	9ARR2	LAMOILLE RIVER	
503778	9ARR3	LAMOILLE RIVER	
503779	9ARR4	LAMOILLE RIVER	
504813	9AVB1	ST. FRANCIS RIVER	AVERILL
504814	9AVB2	ST. FRANCIS RIVER	
503105	9BEE1	CASTLETON RIVER	BEEBE
503117	9BEE2	CASTLETON RIVER	
503006	9BIG1	WALLOOMSAC RIVER	BIG POND
503007	9BIG2	WALLOOMSAC RIVER	
503112	9BOM1	CASTLETON RIVER	BOMOSEEN
503109	9BOM2	CASTLETON RIVER	
503089	9BUR1	HUBBARDTON RIVER	BURR
503118	9BUR2	HUBBARDTON RIVER	
503512	9CAR1	PIKE RIVER	CARMI
503526	9CAR2	PIKE RIVER	
503784	9CAS1	GREENSBORO BROOK	CASPIAN
503787	9CAS2	GREENSBORO BROOK	
504254	9COL1	WEST RIVER	COLE
504255	9COL2	WEST RIVER	
504939	9DER1	CLYDE RIVER	DERBY
504850	9DER2	CLYDE RIVER	
503179	9DUN1	LEICESTER RIVER	DUNMORE
503182	9DUN2	LEICESTER RIVER	
503180	9DUN3	LEICESTER RIVER	
504926	9ECH1	CLYDE RIVER	ECHO
504858	9ECH2	CLYDE RIVER	
503796	9ELM1	LAMOILLE RIVER	ELMORE
503797	9ELM2	LAMOILLE RIVER	
503193	9FER1	OTTER CREEK	FERN
503194	9FER2	OTTER CREEK	
503680	9FRD1	BLACK CREEK	FAIRFIELD
503681	9FRD2	BLACK CREEK	
504533	9FRL1	OMPOMPANOOSUC RIVER	FAIRLEE
504532	9FRL2	OMPOMPANOOSUC RIVER	
503080	9GLE1	OTTER CREEK	GLEN
503079	9GLE2	OTTER CREEK	
503898	9GRE1	KINGSBURY BRANCH	GREENWOOD
503894	9GRE2	KINGSBURY BROOK	
504536	9GRO1	WELLS RIVER	GROTON
504537	9GRO2	WELLS RIVER	
504702	9HAL1	CONNECTICUT RIVER	HALLS
504703	9HAL2	CONNECTICUT RIVER	
504526	9HAR1	PEACHAM BROOK	HARVEYS
504540	9HAR2	PEACHAM BROOK	
503082	9HOR1	HUBBARDTON RIVER	HORTONIA
503091	9HOR2	HUBBARDTON RIVER	

PRIM.	SEC.	BASIN	LAKE
503507	9IR01	LAPLATTE RIVER	IROQUOIS
503537	9IR02	LAPLATTE RIVER	
503508	9IR03	LAPLATTE RIVER	
504863	9ISL1	CLYDE RIVER	ISLAND POND
504857	9ISL2	CLYDE RIVER	
504625	9JOE1	JOES BROOK	JOES
504626	9JOE2	JOES BROOK	
504701	9MAI1	PAULS STREAM	MAIDSTONE
504709	9MAI2	PAULS STREAM	
504541	9MAR1	STEVENS RIVER	MARTINS
504529	9MAR2	STEVENS RIVER	
503687	9MET1	MISSISSQUOI RIVER	METCALF
503697	9MET2	MISSISSQUOI RIVER	
504705	9MOR1	CONNECTICUT RIVER	MOREY
504707	9MOR2	CONNECTICUT RIVER	
503895	9NEL1	KINGSBURY BRANCH	NELSON
503897	9NEL2	KINGSBURY BRANCH	
504153	9NIN1	BLACK RIVER	NINEVAH
504158	9NIN2	BLACK RIVER	
504905	9PAR1	ROARING BROOK	PARKER
504908	9PAR2	ROARING BROOK	
503141	9PIN1	OTTAUQUECHEE RIVER	PINNEO
503142	9PIN2	OTTAUQUECHEE RIVER	
503003	9PRN1	WALLOOMSAC RIVER	PARAN
503004	9PRN2	WALLOOMSAC RIVER	
504356	9RAP1	N. BRANCH DEERFIELD	RAPONDA
504359	9RAP2	N. BRANCH DEERFIELD	
504155	9RES1	BLACK RIVER	RESCUE
504157	9RES2	BLACK RIVER	
504869	9SAL1	CLYDE RIVER	SALEM
504865	9SAL2	CLYDE RIVER	
504889	9SEY1	ECHO LAKE	SEYMOUR
504872	9SEY2	ECHO LAKE	
504915	9SHA1	BARTON RIVER	SHADOW
504843	9SHA2	BARTON RIVER	
503084	9SNS1	HUBBARDTON RIVER	SUNSET
503104	9SNS2	HUBBARDTON RIVER	
503183	9STA1	MILL RIVER	STAR
503184	9STA2	MILL RIVER	
503094	9STC1	MILL BROOK	— ~~CATH~~ ST CATHERINE
503116	9STC2	MILL BROOK	
503899	9VAL1	KINGSBURY BRANCH	VALLEY
503900	9VAL2	KINGSBURY BRANCH	
504922	9WIL1	BARTON RIVER	WILLOUGHBY
504920	9WIL2	BARTON RIVER	
503887	9WOO1	KINGSBURY BRANCH	WOODBURY
503888	9WOO2	KINGSBURY BRANCH	
504151	9WOW1	OTTAUQUECHEE RIVER	WOODWARD
504160	9WOW2	OTTAUQUECHEE RIVER	

STRUCTURE AND CALIBRATION OF AN ERROR ANALYSIS FRAMEWORK FOR THE VERMONT LAKE EUTROPHICATION ANALYSIS PROCEDURE

prepared for

Vermont Agency of Environmental Conservation
Water Quality Division
Lakes Program
Montpelier, Vermont

by

William W. Walker, Jr.
Environmental Engineer
1127 Lowell Road
Concord, MA 01742
617-369-8061

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The structure, calibration, and use of the error calculation routine in LEAP are based upon first-order error analysis concepts. An "error" is defined as a "residual", or difference between an observed and predicted lake condition (phosphorus, chlorophyll-a, transparency, or oxygen depletion rate). Figure 1 summarizes the pathways involved in calculating the mean and variance of each lake response variable and residual. Because both the measurement and the model errors tend to be multiplicative and to increase with the corresponding mean estimate, they are best expressed on a logarithmic scale. According to fundamental error analysis concepts, the total residual variance can be partitioned into the following sources:

$$V(R) = V(I) + V(M) + V(O)$$

where,

$V(R)$ = total residual variance

$V(I)$ = variance attributed to uncertainty in model input variables and parameter estimates

$V(M)$ = variance attributed to model error

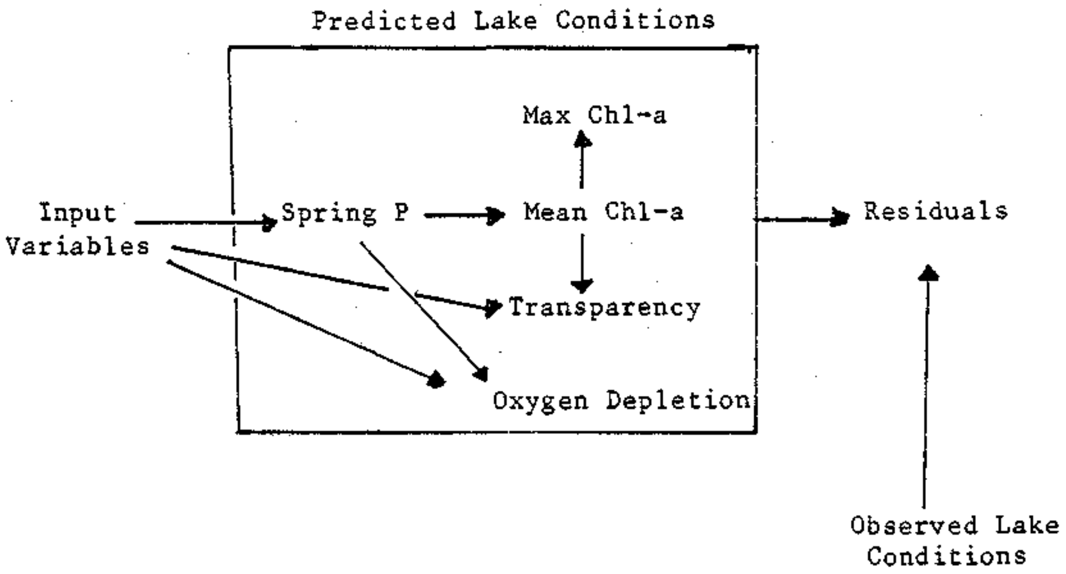
$V(O)$ = variance attributed to measurement errors in the observed lake response variable

Note that the variance of a predicted value is given by the sum of the first two terms and that the last term is included only when comparing observed and predicted lake conditions. In the Vermont LEAP subroutine, V(I) terms are calculated from the standard deviations specified for each input variable (subscripts 1 - 38). These values should reflect the uncertainty in each input variable, which would tend to be lake- and data-specific. V(M) terms are calculated from the standard deviations specified for each model error variable (subscripts 39 - 44) and would tend to be constant across lakes.

For these types of models, previous work (Walker, 1977, 1982b) indicates that the error "balance" tends to be dominated by the model (V(M)) and data (V(O)) terms. Because the V(I) terms are lake- and information-specific, it is necessary initially to ignore them in calibrating the other terms based upon observed and predicted lake

Figure 1

LEAP Pathways



conditions. The V(I) terms can still be included in LEAP applications, although, in general, they will be relatively small.

LEAP predictions correspond to long-term-average lake conditions. V(O) errors reflect errors in observed lake conditions based upon limited sampling. In order to estimate the V(O) terms, it is convenient to employ the following nested analysis of variance (Snedecor and Cochran, 1972):

$$V(O) = V(Y) / n + V(W) / (n m)$$

where,

V(Y) = between-year variance component
V(W) = within-year variance component
n = number of sampling years
m = average number of observations within each sample-year

Each of the above terms is specific for each observed variable. The second term in the above equation incorporates analytical error, field sample collection error, and statistical sampling error; the last is attributed to temporal variablity in lake conditions within a given year. For an "adequate" sampling design, the second term should be small in relation to the first; this is because "m" is relatively large. For example, a pooled estimate of V(Y) for chlorophyll in Vermont Lakes is .074 on a natural log scale (Walker, 1981). Previous analysis of within-year variance in chlorophyll at 258 stations in Corps of Engineer reservoirs suggests a typical V(W) value of .32 (Walker, 1982c); this value is conservative (high) because it is based upon a sampling regime which includes some spring and fall samples. For a one-year, weekly, June-August, sampling regime (n=1,m=12), terms of the above equation are .074 and .027, respectively. Definition of a within-year variance component for spring phosphorus is indeterminant. Because of these considerations, variance in the observations is approximately represented by considering V(Y) only, although this could be refined by analysis of time series data from Vermont lakes. Table 1 summarizes pooled estimates of V(Y), n, and V(O) for each response variable, based

Table 1

Pooled Estimates of Year-to-Year Variance in Observed Lake Conditions

Variable	V(Y)	n	V(O)
Spring P	.080	5	.016
Mean Chlorophyll-a	.074	4	.019
Maximum Chlorophyll-a	.083	4	.021
Transparency	.035	4	.009
Oxygen Depletion Rate	.020	2	.010

V(Y) = pooled estimate of year-to-year variance
n = average number sample-years per lake
V(O) = error variance in mean estimate = V(Y) / n

all variances expressed in natural logarithms
based upon ANOVA´s conducted on LEAP calibration lakes
(Walker,1981b)

upon analyses of variance for the LEAP calibration lakes (Walker, 1981).

Figure 2 summarizes LEAP residual distributions for the calibration lakes. Given V(0) estimates, the model error terms can be estimated by difference from the residual error variance. In this exercise, model error terms must be "tracked" through the network. For example, the model error for chlorophyll is the cumulative effect of model errors in predicting watershed phosphorus export, lake phosphorus retention, and the lake phosphorus/chlorophyll relationship. For multiplicative models, the model error variance terms are additive on a logarithmic scale, although average sensitivity or slope must also be considered using the standard first-order error analysis procedure. For example, the chlorophyll-a model error is tracked using the following scheme:

$$\log(B) = a + b \log(P)$$

$$V(MB) = b^2 V(MP) + V(MB/P)$$

where,

a,b = regression coefficients for phosphorus/chlorophyll relationship

V(MB) = total model error for chlorophyll

V(MP) = total model error for spring phosphorus

V(MB/P) = model error term for phosphorus/chlorophyll relationship

For models of more complex structure, an average sensitivity (b) is employed in variance tracking, based upon analytic differentiation of the model at average values of the lake response variables.

Results of the error tracking exercise are summarized in Table 2. Because observed phosphorus loadings are not available for Vermont lakes, it is not possible to separate the spring phosphorus model error into its two components (watershed export and lake phosphorus retention). In this case, the variance is assumed to be partitioned equally between the two sources; this assumption is of no consequence to model applications because the variance in predicted lake conditions reflects only the sum of these error terms and not their relative

Figure 2

LEAP Error Distributions

```
r-pspr                                                        frequency    percentage
minimum of interval                                            int  cum    int   cum
     0.600                                                      0    18    0.0 100.0
     0.400 Hv Mo                                                2    18   11.1 100.0
     0.200 Sh Bo                                                2    16   11.1  88.9
     0.000 St Ho Ce Su Ca SC El                                 7    14   38.9  77.8
    -0.200 Wi Ir Fa Cu                                          4     7   22.2  38.9
    -0.400 Pa Sh Ha                                             3     3   16.7  16.7
    -0.600                                                      0     0    0.0   0.0
 <h>
```

```
univariate statistics for: r-pspr

number of cases =     18            missing values =     0
mean =                .070957       maximum =            .563368
variance =            .0659931      upper hinge =        .228787
std deviation =       .256891       median =             .0634172
mean square =         .0673617      lower hinge =       -.150874
coef of variation = 3.62038         minimum =           -.367914
std error of mean = .0605498        h-spread =           .379661
t-test for m=0  =    1.17188        prob(>t) =           .256484
skewness coef. =      .190726       large-sample z =     .330347
kurtosis coef. =    -.653719        large-sample z =    -.566137
sum of squares =     1.21251        cor. sum of sqs =   1.12188
av absolute dev =     .197199       av absolute value = .208169

   five lowest values             five highest values
   16 Halls            -0.368     14 Star              0.199
   17 Shadow           -0.275      1 Bomoseen          0.319
   11 Parker           -0.225     13 Shelburne         0.367
    4 Curtis           -0.186     10 Morey             0.480
    6 Fairfield        -0.139      7 Hveys             0.563
<h>
```

```
r-chl                                                         frequency    percentage
minimum of interval                                            int  cum    int   cum
     1.400                                                      0    16    0.0 100.0
     1.200 St                                                   1    16    6.3 100.0
     1.000 Ca                                                   1    15    6.3  93.8
     0.800 Sh                                                   1    14    6.3  87.5
     0.600                                                      0    13    0.0  81.3
     0.400                                                      0    13    0.0  81.3
     0.200 Mo                                                   1    13    6.3  81.3
    -0.000 Sh Bo Fa Ha Hv Cu                                    6    12   37.5  75.0
    -0.200 Ho Ir                                                2     6   12.5  37.5
    -0.400 El Pa                                                2     4   12.5  25.0
    -0.600 SC Su                                                2     2   12.5  12.5
```

```
univariate statistics for: r-chl

number of cases =     16            missing values =     2
mean =                .147021       maximum =           1.39954
variance =            .285535       upper hinge =        .259324
std deviation =       .534354       median =             .0318102
mean square =         .289304       lower hinge =       -.193642
coef of variation = 3.63456         minimum =           -.550281
std error of mean =  .133589        h-spread =           .452966
t-test for m=0  =    1.10055        prob(>t) =           .288517
skewness coef. =     1.09054        large-sample z =    1.78084
kurtosis coef. =      .321237       large-sample z =     .262289
sum of squares =     4.62886        cor. sum of sqs =   4.28302
av absolute dev =     .382537       av absolute value = .364798

   five lowest values             five highest values
   16 Sunset           -0.550     15 Shadow            0.158
   11 SC               -0.415      9 Morey             0.293
   10 Parker           -0.261     12 Shelburne         0.922
    4 Elmore           -0.201      2 Carmi             1.023
    8 Iroquois         -0.171     13 Star              1.400
```

```
r-chlx                                                                      frequency    percentage
minimum of interval                                                          int   cum    int    cum
    1.400                                                                     0    16     0.0  100.0
    1.200 Ca St                                                               2    16    12.5  100.0
    1.000                                                                     0    14     0.0   87.5
    0.800                                                                     0    14     0.0   87.5
    0.600                                                                     0    14     0.0   87.5
    0.400 Sh Bo                                                               2    14    12.5   87.5
    0.200 Mo Ir                                                               2    12    12.5   75.0
   -0.000 Sh Hv Fa                                                            3    10    18.8   62.5
   -0.200 Ha Pa Cu                                                            3     7    18.8   43.8
   -0.400 El Ho                                                               2     4    12.5   25.0
   -0.600                                                                     0     2     0.0   12.5
   -0.800 Su SC                                                               2     2    12.5   12.5


 univariate statistics for: r-chlx

 number of cases =    16            missing values =     2
 mean =               .151378       maximum =            1.35772
 variance =           .350952       upper hinge =        .427412
 std deviation =      .592412       median =             .0531025
 mean square =        .351933       lower hinge =        -.184901
 coef of variation =  3.91346       minimum =            -.781423
 std error of mean =  .148103       h-spread =           .612313
 t-test for m=0  =    1.02211       prob(>t) =           .324216
 skewness coef. =     .669165       large-sample z =     1.09274
 kurtosis coef. =     .136169       large-sample z =     .111182
 sum of squares =     5.63092       cor. sum of sqs =    5.26428
 av absolute dev =    .431285       av absolute value =  .425639

     five lowest values             five highest values
     11 SC             -0.781       9 Morey          0.314
     16 Sunset         -0.659       1 Bomoseen       0.465
      7 Hortonia       -0.326      12 Shelburne      0.594
      4 Elmore         -0.207      13 Star           1.340
      3 Curtis         -0.117       2 Carmi          1.358


 r-secchi                                                                   frequency    percentage
 minimum of interval                                                         int   cum    int    cum
     0.400                                                                    0    16     0.0  100.0
     0.200 SC Su                                                              2    16    12.5  100.0
     0.000 Mo Sh Hv Pa El Ir                                                  6    14    37.5   87.5
    -0.200 Ho Bo Fa Cu Ha                                                     5     8    31.3   50.0
    -0.400 St                                                                 1     3     6.3   18.8
    -0.600                                                                    0     2     0.0   12.5
    -0.800 Ca                                                                 1     2     6.3   12.5
    -1.000 Sh                                                                 1     1     6.3    6.3


 univariate statistics for: r-secchi

 number of cases =    16            missing values =     2
 mean =              -.0842503      maximum =            .246913
 variance =           .101904       upper hinge =        .121528
 std deviation =      .319225       median =            -.0242718
 mean square =        .102634       lower hinge =       -.109284
 coef of variation =-3.78901        minimum =           -.90007
 std error of mean = .0798062       h-spread =           .230812
 t-test for m=0  =   -1.05569       prob(>t) =           .308559
 skewness coef. =    -1.39145       large-sample z =    -2.27223
 kurtosis coef. =     1.15726       large-sample z =     .944899
 sum of squares =     1.64214       cor. sum of sqs =    1.52857
 av absolute dev =    .219372       av absolute value =  .219372

     five lowest values             five highest values
     12 Shelburne      -0.900       6 Hveys          0.107
      2 Carmi          -0.679      15 Shadow         0.126
     13 Star           -0.360       9 Morey          0.195
     14 Halls          -0.110      16 Sunset         0.239
      3 Curtis         -0.108      11 SC             0.247
```

```
r-hod                                                          frequency    percentage
minimum of interval                                              int  cum    int    cum
     0.800                                                         0   12    0.0  100.0
     0.600 Sh                                                      1   12    8.3  100.0
     0.400 Hv                                                      1   11    8.3   91.7
     0.200 Ho                                                      1   10    8.3   83.3
     0.000 SC Bo Mo Ir                                             4    9   33.3   75.0
    -0.200 Ha Fa Pa                                                3    5   25.0   41.7
    -0.400 Su Ca                                                   2    2   16.7   16.7


univariate statistics for: r-hod

number of cases =     12          missing values =      6
mean =                .120334      maximum =            .662295
variance =            .0917856     upper hinge =        .338888
std deviation =       .302961      median =             .142411
mean square =         .098617      lower hinge =       -.139607
coef of variation =  2.51767       minimum =           -.209161
std error of mean =   .0874574     h-spread =           .478495
t-test for m=0  =    1.37591       prob(>t) =           .194138
skewness coef. =      .569876      large-sample z =     .805927
kurtosis coef. =    -.897996       large-sample z =    -.634979
sum of squares =     1.1834        cor. sum of sqs =   1.00964
av absolute dev =     .236635      av absolute value = .256691

   five lowest values              five highest values
    2 Carmi          -0.209         1 Bomoseen         0.160
   12 Sunset         -0.207         9 SC               0.163
    8 Parker         -0.140         5 Hortonia         0.398
    3 Fairfield      -0.139         4 Hveys            0.594
   10 Halls          -0.123        11 Shadow           0.662
```

Table 2

Model Error Components

Model	Error Term	V(R)	V(O)	V(M)	V(M) Components
39/40	Spring Phosphorus	.069	.016 .019	.053 .049	.026 (Watershed, 39) .027 (Retention, 40)
41	Phosphorus/Chl-a	.176	.019	.158	$.94^2 \times .053$ (Spring P) .111 (P/Chl-a, 41)
42	Mean Chl-a/Max Chl-a	.252	.021	.231	$1.16^2 \times .158$ (Mean Chl-a) .018 (Mean/Max Chl-a, 42)
43	Mean Chl-a/Secchi	.100	.009	.091	$.65^2 \times .158$ (Mean Chl-a) .024 (Mean Chl-a/Secchi, 43)
44	Phosphorus/HOD	.097	.010	.087	$.91^2 \times .053$ (Spring P) .043 (P/HOD, 44)

V(R) = total variance of residuals, excluding Star Lake (outlier) for mean and maximum chlorophyll-a

V(O) = average observed data error component (Table 1)

V(M) = estimated total model error = V(R) - V(O)

V(M) Components = breakdown of model error, sum = V(M)

All variances on natural log scale

Table 3

Summary of Calibrated Error Terms for LEAP Input

Variable	Mean	Standard Deviation
39 Watershed Model Error	1	.16
40 Retention Model Error	1	.16
41 P/Chl-a Model Error	1	.33
42 Mean Chl-a/Max Chl-a Model Error	1	.13
43 Mean Chl-a/Secchi Model Error	1	.15
44 Phosphorus/HOD Model Error	1	.21

Notes:

Standard Deviations estimated from square roots of variance terms estimated in Table 2;

Standard Deviations of input variables 1-38 should be set to 0.0.

magnitudes. Corresponding input values for the model error terms are specified in Table 3.

With a slight modification of the LEAP model subroutine, it can be readily employed to test whether a given lake conforms to the model structure and calibration. Output variables 26-30 were originally used to compare observed and predicted lake conditions on log scales. Because of the structure of the LEAP error analysis framework, it is necessary to express these comparisons as ratios, rather than log ratios; i.e., the "LOG" transformation in line 4052 of the subroutine should be removed in order to provide a means for hypothesis testing. The effects of variance in the observed conditions (V(O)) can be incorporated by specifying non-zero standard deviations for input variables 20-24. These standard deviations can be estimated from the number of sampling years and the pooled estimates of year-to-year variance given in Table 1. For example, for a lake with a mean chlorophyll-a of 4.4 mg/m3 based upon 3 years of sampling, the input standard deviation for variable 21 would be:

$$S(21) = 4.4\ (.074\ /\ 3\ )^{.5} = .69$$

With these modifications, output from the LEAP error analysis procedure will include estimates of mean, standard deviation, minimum(2.5%) and maximum(97.5%) for each observed/predicted comparison (output variables 26-30). The mean equals the ratio of the observed to the predicted response and would therefore equal 1.0 in the case of perfect fit. If the estimated range (min to max) does not include 1.0, then the probability that the lake conforms to LEAP (or vice-versa) is less than 5%. This range reflects the combined effects of model error (V(M)), input data errors (V(I), if any are specified), and observed response (V(O)) error. A lake which does not "conform" would be considered atypical of the lakes used in LEAP calibration. It would also be possible to modify the model code to permit direct probability calculations.

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Calibration of LEAP to Vermont Lakes

Interim Report:

Data Base Summary
Preliminary Model Testing

prepared for

Vermont Agency of Environmental Conservation
Water Quality Division
Montpelier, Vermont

by

William W. Walker, Jr., Ph.D.
Environmental Engineer
1127 Lowell Road
Concord, Massachusetts 01742

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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, 1979,81). Regional calibration and testing of the framework are required prior to application in a planning context. This report summarizes the data base which has been established for 15 Vermont lakes using information provided by the Agency of Environmental Conservation (AEC). With slight modifications, the original version of LEAP has been applied to each of the 15 lakes and the results compared with observed water quality data. The purposes of this report are to provide:

(1) a concise data summary of the model input variables and observed water quality conditions to be used in model calibration and testing

(2) opportunity for the AEC to review the data base and suggest any corrections or refinements

(3) indications of model sensitivity to key variables which may need better definition

(4) indications of the types of model changes which may be required in order to improve the framework

Following review of this report and refinements in the data base, modifications in the model structure will be made to account for important factors which are not currently considered in LEAP. Results indicate two such factors: (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. A second report will describe the final data base and the structure, calibration, and testing of the refined model framework.

Appendices to this report contain the following:

A data base tables
B LEAP subroutine and variable definitions
C model predictions and sensitivity analyses
D charts of observed and predicted lake conditions
E analyses of variance in observed lake water quality

The following sections describe the modified model and discuss key results.

LEAP MODIFICATIONS

Before preliminary testing, the original LEAP framework has been modified to include the following:

(1) additional land use categories, to conform with the land use data base;
(2) a means of accounting for phosphorus retention by upstream lakes or reservoirs;
(3) a phosphorus input term for shoreline septic systems;
(4) modifications of the oxygen depletion rate calculation to account for the effects of multi-basin lakes;
(5) modification of the function used to calculate summer chlorophyll based upon spring phosphorus concentration;
(6) modification of the function used to calculate transparency to account for variations in non-algal turbidity or color;
(7) expansion of the list of output variables to include loading components;
(8) provision of alternative means for estimating mean hypolimnetic depths required for oxygen depletion calculations.

Each of these changes is discussed below. Sensitivity analyses indicate that none of the changes are very substantial in terms of impact on predicted productivities of the study lakes. The original phosphorus export and retention coefficients, which are derived from much larger watershed and lake data bases, have been retained. Thus, we are essentially testing the original model framework.

The watershed of each lake has been classified according to nine land use categories, in accordance with the types of data available from planning maps and landsat:

(1) lake surface area
(2) upstream lake surface area
(3) wetlands (exclusive of upstream lakes)
(4) conifer forest
(5) hardwood forest
(6) mixed forest
(7) untilled agriculture
(8) tilled agriculture
(9) urban

The model framework has been modified to permit specification of a separate export concentration for each land use category. In preliminary testing, categories (2) through (7) have been treated as non-contributing areas (the "forested" category in the original LEAP framework, with an export concentration of 15 mg/m3). Category (8) corresponds to the old "agricultural" classification, with an export concentration of 57 mg/m3, since the data base used to develop the original export function treated "agricultural" and "cleared-unproductive" separately (Omernik, 1977). Category (9) is unchanged, with an export concentration of 139 mg/m3.

The land use data file (Appendix A) contains three sets of land use distributions for each lake, keyed by the following symbols:

(1) LS = based upon Landsat
(2) PM = based upon planning map

(3) XX = "best"

The last category is based upon the first two and subjective assessments provided by the AEC for each lake. Land use distributions have been adjusted so that the total watershed area equals the value specified in the classification survey report (Vermont AEC, 1980). The adjustment procedure has used direct estimates for landuse categories (1), (2), (3), (7), (8), and (9). Total forested area ((4)+(5)+(6)) has been calculated by difference from the total watershed area and the above categories. Finally, forested areas have been partitioned among the conifer, hardwood, and forested categories using percentages calculated from landsat data, since forest types are generally not available from planning maps. Appendix A lists the estimated land use breakdowns by lake and source, with areas expressed in acres and as fractions of the respective total watershed areas.

The framework has also been modified to account for phosphorus retention by upstream lakes or reservoirs. Surface and drainage areas of upstream lakes and reservoirs were provided by the AEC for each study lake. Using the settling velocity model (Chapra, 1975), the amount of phosphorus trapped by each upstream lake can be calculated from the following system of equations:

$$WT = QR\ CI\ AW\ U\ /\ (U + QS)$$

$$QS = QR\ AW\ /\ AL$$

or,

$$WT = QR\ CI\ FU$$

$$FU = AW\ AL\ U\ /\ (AL\ U + QR\ AW)$$

where,

WT = P load trapped by upstream lake (kg/yr)

QR = average runoff rate = .6 m/yr

CI = average inflow concentration of upstream lake (mg/m3)

AW = watershed area of upstream lake (km2)
U = phosphorus settling velocity = 12 m/yr
AL = upstream lake surface area (km2)
QS = surface overflow rate of upstream lake (m/yr)
FU = adjustment factor for P retention in upstream lake (km2)

The parameters CI and FU are input for each lake. Since upstream lakes are generally remote from intensive uses, inflow concentrations are initially assumed to equal the forested value (CI = 15 mg/m3), although this parameter could be adjusted if there are significant agricultural or urban uses above a given upstream lake. FU values have been calculated from the surface and drainage areas of each upstream lake and summed to provide a model input value for each study lake. In the model subroutine, the estimated WT value is subtracted from the total undeveloped loading in constructing the lake phosphorus budget. Calculations are generally insensitive to the upstream lake factors. Bomoseen had the highest value (15.95 km2 vs. a total watershed area of 95.7 km2)

The phosphorus input from shoreline septic systems is estimated from the following equation:

$$WS = US\ FS$$

where,

WS = septic input (kg/yr)
US = septic system use factor (annual population equivalents)
FS = septic phosphorus export factor (kg/capita-yr)

US and FS are model input variables for each lake. A nominal value of .05 kg/capita-yr has been used in preliminary calculations. This is based upon .5 kg/cap-yr input to systems (under phosphorus detergent ban) and an assumed 90% treatment efficiency. On the average, the assumed FS value may be a bit low. FS values can be adjusted from lake to lake, based upon soil suitability, setbacks, age, etc.. Future work will consider alternative values.

Septic system use, US, is estimated from the following:

$$WS = 3\ (.5\ \text{R-SEAS} + \text{R-PERM}) + \ (.5\ \text{USE-DAY} + \text{USE-NT})/365$$

where,

R-SEAS = number of seasonal shoreline residences
R-PERM = number of year-round shoreline residences
USE-DAY = day use of resorts/parks (capita-days)
USE-NT = night use of resorts/parks (capita-days)

The above scheme assumes an average of 3 people per dwelling. Appendix A lists the above residence and use factors for each lake, along with the calculated annual population equivalent. residence counts were not available for a few lakes. Approximate estimates have been derived by counting structures on USGS or lake contour maps, increasing the total by 20% (based upon average relationship between map count and tabulated values for other lakes), and assuming that 75% of the residences are seasonal. Septic contributions calculated in the above way account for a maximum of 9.4% of the total phosphorus loadings for the study lakes (St. Catherine) and results are generally insensitive to this loading component. The assumed FS value may be biased on the low side, however, and needs further investigation.

The scheme for calculating oxygen depletion rate is based upon its relationship with mean depth and phosphorus concentration (Walker,1979). The mean depth used in this calculation should reflect the morphometry of the stratified portion of the lake. Use of the nominal mean depth will give biased predictions in lakes which have more than one hypolimnetic basin or relatively large, shallow, isolated embayments. For example, Lake Quinsigamond, Massachusetts, has three separate hypolimnetic basins. Depletion rates vary by a factor of two among the basins but there is little variation in surface water quality. The model has been shown to apply using mean depths calculated separately for each basin (Walker, 1981).

Accordingly, an additional input term ("basin mean depth") has been included in the LEAP framework for use in oxygen depletion rate calculations. Based upon a review of contour maps of the study lakes, only Hortonia is considered to have a basin mean depth which is substantially different from the nominal mean depth. Roughly half of the surface area is in the southwest portion of the lake (maximum depth 15 ft) which is remote from the stratified northeastern portion (maximum depth 60 ft). In this case, the basin mean depth is estimated at 8.9 m, as compared with the nominal mean depth of 5.6 m. In all other study lakes, the basin mean depths equal the nominal mean depths.

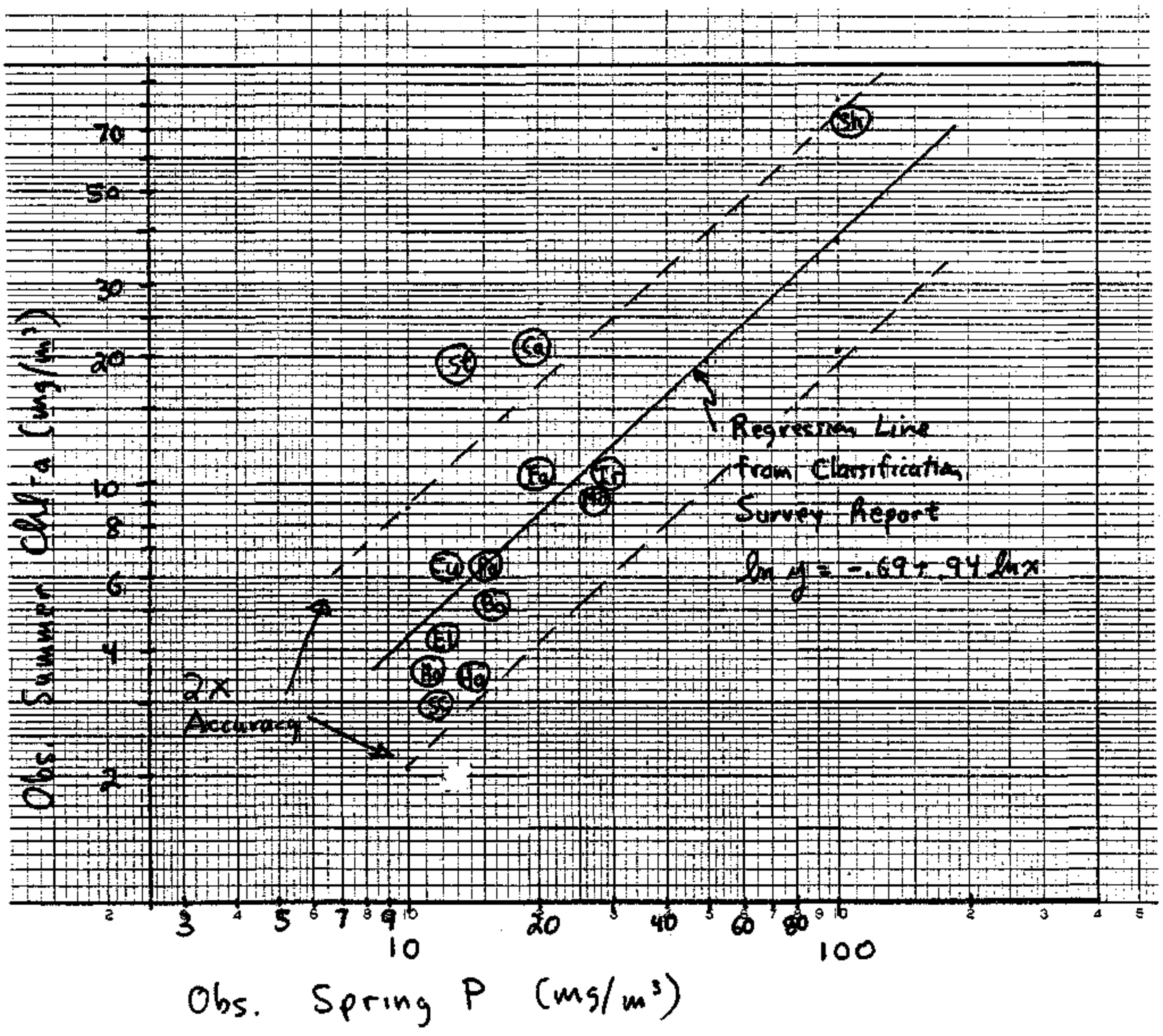
The function relating spring phosphorus to summer chlorophyll has been replaced by the regression equation published in the classification survey report (Vermont AEC, 1980). Figure 1 plots observed chlorophyll vs. observed spring phosphorus values for the study lakes, in relation to the regression equation. The chlorophyll productivities of Star and Carmi are considerably greater than the predicted values. In these cases, the observed summer chlorophyll/spring phosphorus ratio exceeds 1, which is roughly the algal physiologic ratio. This indicates that seasonal or internal loadings are significant in these lakes and that summer phosphorus values would be more representative of trophic status than spring overturn values. The model tends to over-predict the chlorophyll values in lakes with meta- or hypolimnetic algal populations (Harveys, St Catherine, Hortonia, Morey). This may be related to the sampling difficulties which are present when most of the chlorophyll is located within a relatively narrow depth range. While sampling and year-to-year variablities influence the scatter in Figure 1, variabilities in the observed chlorophyll/phosphorus relationships impose limitations on the accuracy of chlorophyll predictions derived from the LEAP framework.

The transparency function has been modified to provide a means of incorporating the effects of non-algal turbidity and color:

$$1/S = A0 + A1\ B$$

Figure 1

Observed Summer Chlorophyll-a vs. Observed Spring Phosphorus



where,

S = mean summer secchi depth (m)
$A0$ = non-algal turbidity/color term (1/m)
$A1$ = chlorophyll sensitivity = .025 m^2/mg
B = mean summer chlorophyll-a (mg/m^3)

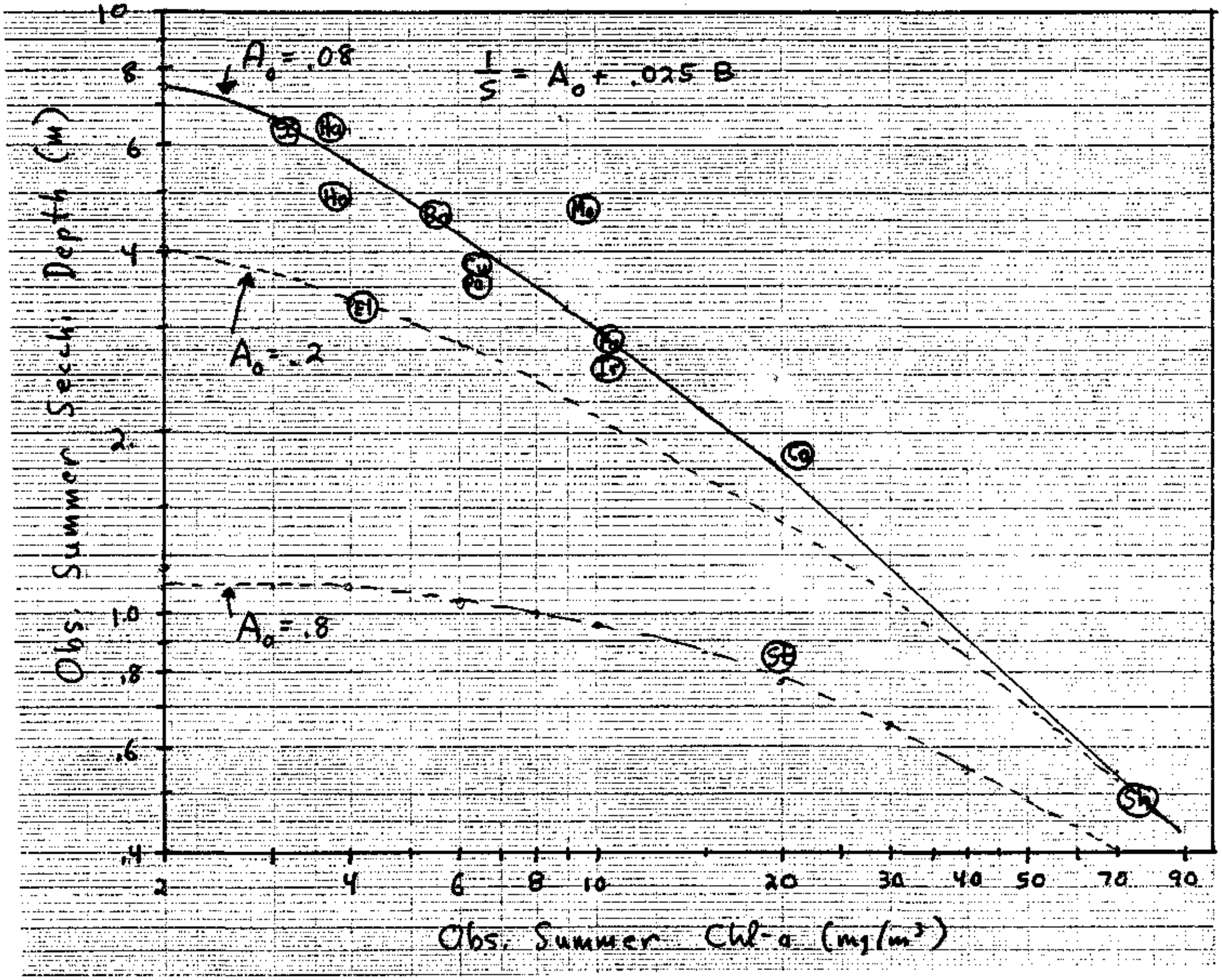
The function is similar to those developed for Harveys Lake (Vermont AEC, 1981) and for Corps of Engineer reservoirs (Walker, 1981). The intercept term, A0, can be increased in lakes with high non-algal turbidity or color. One Platinum-Cobalt Unit of true color is the equivalent of about .003 1/m in A0.

Observed chlorophyll and transparency data (Figure 2) indicate that Star Lake (A0=.68) and Elmore (A0=.2) have somewhat higher non-algal light extinction coefficients then the others. A nominal value of .08 1/m has been used for all lakes in preliminary testing. Observed Secchi and chlorophyll data can be used to adjust A0 in lake applications. Predicted transparencies are sensitive to A0 only relatively unproductive lakes, in which transparency is relatively insensitive to chlorophyll. The model will give biased transparency predictions in lakes with substantial metalimnetic or hypolimnetic algal populations, depending upon how chlorophyll samples are taken. A positive bias is apparent for Morey, in which case most of the chlorophyll is located below the Secchi depth.

In addition to the above modifications, the output variable list has been expanded to include an itemized accounting of the loading components (undeveloped, agricultural, urban, septic, and atmospheric). This provides insight into factors controlling the nutrient budget of each lake. Mean hypolimnetic depths required for oxygen depletion calculation can be input directly (as derived from hypsiographs). Anticipating that detailed hypsiographs would not be available for many future applications, an option has been included to permit estimation of mean hypolimnetic depth based upon input values for mean depth, maximum

Figure 2

Observed Summer Secchi Depth vs. Observed Summer Chlorophyll-a



depth, and thermocline depth. The calculation procedure assumes that lake surface area and volume vary as single term power functions in total depth. If the input value for mean hypolimnetic depth is zero, the estimation procedure is used. If both the mean hypolimnetic depth and the thermocline depth are zero, the lake is assumed to be unstratified and oxygen depletion calculations are by-passed.

DATA BASE

The data base is assembled in a series of tables in Appendix A. The following should be considered in reviewing the data:

(1) Observed water quality data have been tabulated by lake and year, based upon information in the classification survey report, STORET printout, lake reports, and the tabulated 1981 data. Where possible, missing chlorophyll and transparency values have been filled with lay monitoring data. Hypolimnetic oxygen depletion rates have been re-calculated for all lakes, based upon profiles derived from STORET and the hypsiographs, and using a consistent averaging procedure. Thermocline depths are based upon the Cornett/Rigler definition. The depletion rates tabulated in the Harveys Lake report (1981) are probably biased on the low side, because profiles measured after the bottom of the hypolimnion reached anoxic conditions were apparently included in the slope estimation procedure.

(2) The morphometric file includes two estimates for mean depth: one derived from the classification survey report, and the other, from the hypsiographs. In most cases, aggreement is reasonable, with the exception of Harveys, and, perhaps, Winona and Carmi. These values need further checking. Aside from Harveys and Bomoseen, hypsiographs values have been used in the model testing described below.

(3) Total drainage areas have been taken directly from the classification survey report. Is this the most reliable source?

(4) Runoff rates (back-calculated from residence times, mean depths, drainage areas, and surface areas in the classification survey report) seem highly variable, with range from .31 to .89 m/yr. Previous experience indicates that long-term-average runoff rates in New England are rarely outside of the .5 to .75 m/yr range. These values need checking.

(5) Any additional insights that could be provided with regard to the "best" land use estimates would be helpful, particularly for lakes with large variances between landsat and the planning maps. Based upon the charts in Appendix C, problem lakes in this regard include Cedar, Curtis, Iroquois, Park, and Shelburne. Tilled and urban land uses are the most important for export calculations.

(6) The ANOVA's in Appendix E should be reviewed. Relatively high within-lake (year-to-year) variability may indicate problems with measurements in certain lakes and years. For example, the year-to-year variance in spring phosphorus is .35 for Star Lake, in relation to an average year-to-year variance of .08 for all lakes.

PRELIMINARY TESTING

To provide preliminary indications of error and sensitivity, the revised model has been applied to each lake. The distributions of predicted variables and sensitivity analyses for spring phosphorus concentrations are tabulated in Appendix C. These calculations are based upon the "best" set of land use estimates for each lake. Appendix D contains a series of charts comparing observed values of spring phosphorus, mean chlorophyll, maximum chlorophyll, transparency, and oxygen depletion rate with predicted values for each set of land use estimates. Symbols in the charts are used to identify different sampling years and different land use estimates. Review of the charts provides insights into year-to-year variability in observed conditions, sensitivity to assumed land use distributions, and differences between observed and predicted distributions. Comments on the results and/or data base are indicated below the chart for each lake.

Figure 3 contains stem-and-leaf diagrams of residuals for each of the six response variables. Uniform scales have been used to permit direct comparisons of the error distributions on a natural logarithmic scale. While the LEAP framework provides direct error estimates, factor of two accuracy is generally a "rule-of-thumb" for empirical lake models (Vollenweider and Kerekes, 1981). These are indicated for each variable in Figure 3 (+/- .7 log units).

Table 1 summarizes error statistics calculated from the observed and predicted lake characteristics. For reasons discussed below, Shelburne Pond is not typical of the other Vermont lakes or of the lakes used in development of LEAP and has been excluded from the error statistic calculations. Analyses of variance have been conducted on the observed lake data to provide indications of year-to-year variability in relation to lake-to-lake variability. Details on the ANOVA calculations are given in Appendix E. ANOVA's indicate that differences among lakes are strongest in the case of TDO (F = 57.8) and weakest in the case of HOD (F = 5.0). The strength of the TDO variations is due primarily to differences in mean hypolimnetic depths, rather than productivity.

Within-lake (i.e. year-to-year) variance ranges from .02 for HOD to .088 for Chl-max This type of variability imposes limitations on the accuracies of the observed mean values used in model testing. The pooled error variance of the observed means is appreciable in relation to the total error variance only for the oxygen statistics, which have much lower total error variance than the other variables. Thus, the observed data base appears to be adequate for model testing - we cannot attribute lack of fit exclusively to measurement errors or variability in observed lake conditions, although they may be important for certain lakes and variables.

For spring phosphorus, the key variable in the framework, the error variance estimated by LEAP (.12) is comparable to the observed error variance (.11). Thus, the residual spread in Figure 3 (excluding Shelburne) is consistent with data from other lakes and watersheds used

Figure 3

LEAP Error Distributions

```
stem-and-leaf diagram for r-pspr

* >1.60 She
   1.40
   1.20
   1.00
   0.80 ------  2x Accuracy
   0.60 Mor
   0.40 Iro
   0.20 Fai Har Win
  -0.00 Bom Car
  -0.20 Hor Par St  Sta
  -0.40 Ced Elm
  -0.60 Cur
  -0.80 -----
  -1.00
  -1.20
  -1.40
  -1.60
```

```
stem-and-leaf diagram for r-chla

  >1.60 She
   1.40
   1.20
   1.00 Car Sta
   0.80
   0.60 --------  2x Accuracy
   0.40 Fai Mor
   0.20 Iro
  -0.00
  -0.20 Bom Har Par
  -0.40 Cur
  -0.60 Elm Hor St
  -0.80
  -1.00
  -1.20
  -1.40
  -1.60
```

```
stem-and-leaf diagram for r-chlmax

  >1.60 She
   1.40 Car
   1.20
   1.00
   0.80 Sta
   0.60 Iro Mor --  2x Accuracy
   0.40 Fai
   0.20 Bom
  -0.00 Par
  -0.20 Har
  -0.40
  -0.60 Cur Elm ---
  -0.80 Hor
  -1.00 St
  -1.20
  -1.40
  -1.60
```

* ln (observed/predicted)

ct

```
stem-and-leaf diagram for r-secchi

    1.60
    1.40
    1.20
    1.00
    0.80 - - - - - - -  2x Accuracy
    0.60
    0.40
    0.20 Har St
   -0.00 Bom Cur Hor Mor
   -0.20 Elm Par
   -0.40 Fai Iro
   -0.60 - - - - - -
   -0.80 Car
   -1.00
   -1.20
   -1.40
   -1.60 She Sta
```

Figure 3

LEAP Error Distributions (continued)

```
stem-and-leaf diagram for r-hod

    1.60
    1.40
    1.20
    1.00
    0.80 - - - - - -  2x Accuracy
    0.60
    0.40
    0.20 Mor
   -0.00 Fai Har Iro
   -0.20 Bom Car Hor Par St
   -0.40
   -0.60 - - - - - -
   -0.80
   -1.00
   -1.20
   -1.40
   -1.60

stem-and-leaf diagram for r-tdo

    1.60
    1.40
    1.20
    1.00
    0.80 - - - - - -  2x Accuracy
    0.60
    0.40
    0.20
   -0.00 Bom Car Hor Par St
   -0.20 Fai Har Iro
   -0.40 Mor
   -0.60 - - - - -
   -0.80
   -1.00
   -1.20
   -1.40
   -1.60
```

Table 1

Summary of Error Statistics

Statistic	Variable Spring P	Chl-a	Chl-max	Secchi	HOD	TDO
MODEL ERROR STATISTICS - excluding Shelburne						
Number of Lakes	14	13	11	13	9	9
Estimated MSE (a)	.12	.25	.26	.26	.18	.18
Observed MSE (b)	.11	.32	.51	.28	.02	.02
Var (Obs. Means) (c)	.016	.020	.036	.008	.009	.009
R-Squared	-.16	.16	.16	.06	.24	.96
ANOVA STATISTICS - excluding Shelburne						
Among-Lake Mean Sq.	.534	1.523	1.352	.986	.100	1.160
Within-Lake Mean Sq.(d)	.080	.072	.088	.028	.020	.020
F	6.7	21.0	15.3	35.1	5.0	57.8
ANOVA STATISTICS - all lakes (e)						
Among-Lake Mean Sq.	1.710	2.321	2.025	1.547	.100	1.160
Within-Lake Mean Sq.(d)	.080	.074	.083	.035	.020	.020
F	21.2	31.4	24.3	44.6	5.0	57.8

Note: all statistics on natural log scales

a error variance of estimated values calculated by LEAP
b observed error variance
c pooled estimate of error variance of observed mean values, based among-year variance and average number of sample years
d represents year-to-year variance within lakes
e details given in Appendix E

in development of LEAP. Observed variance is greater than estimated variance in the case of chlorophyll (.32 vs .25) and maximum chlorophyll (.51 vs .26).

R-squared values are appreciable only in the case of TDO (.96 vs -.16 to .24 for the other variables). The strength of the TDO prediction is attributed to the hypolimnetic depth effect discussed above. Thus, while it does explain variance in hypolimnetic oxygen status, the existing framework does not explain much variance in the observed productivities of this collection of lakes. This is attributed to the relatively low variance in lake productivities (most are mesotrophic), inherent "factor-of-two" accuracy limits of the empirical modelling approach, and to the effects of factors which are not considered in the models. The error analyses for predicted spring phosphorus in Appendix C indicate that the predominant sources of prediction error are in the phosphorus retention and export models. Further analyses discussed below indicate that there are good possibilities for improving these models and reducing prediction error.

A systematic residuals analysis has been undertaken to determine whether errors in the predictions are associated with any of the lake or watershed characteristics included in the data base. Any such associations may indicate need for re-calibration or re-structuring of the model framework. Shelburne is clearly an "outlier" in relation to the other lakes. It is the only lake outside of the factor-of-two error limits for spring phosphorus. Based upon review of the error histograms, bivariate residuals plots, review of soils data for each lake, and independent evidence from the literature, much of the error variance for Shelburne and other lakes can be attributed to the effects of two factors which are not currently considered in the LEAP framework: (1) the differences in phosphorus export between watersheds with sedimentary soils and those with non-sedimentary soils; and (2) the effects of internal loading (recycling) on the phosphorus balance and productivity. These effects are discussed in detail below.

The export functions used in the LEAP framework have been calibrated to data from over 100 watersheds in the Northeast, most of which have soils of glacial origin (Meta Systems, 1978). The analysis indicated that export coefficients for forested and agricultural lands uses are two to five times greater in the Midwest (western Ohio, Indiana, Illinois), which have soils of sedimentary origin. Greater phosphorus exports from sedimentary watersheds have been identified elsewhere. For example, Dillon and Kirchner (1975) found that mean export values from sedimentary watersheds were about 2.5 times greater than those from igneous watersheds of plutonic origin. This is primarily attributed to high phosphorus concentrations and often poor drainage characteristics of lake-plain soils, as compared with glacial till.

Of the 15 study lakes, three have watersheds with sedimentary soils: Shelburne (approx. 75%), Winona (approx. 40%), and Fairview (approx. 15%). The existing LEAP framework under-predicts spring phosphorus concentrations in each of these lakes, by factors of 6, 1.36, and 1.36, respectively. The bias for Shelburne is reduced to a factor of 4 if land use estimates from the planning map are used. Thus, it seems reasonable that these biases could be at least partially offset by using higher phosphorus export concentrations to represent the sedimentary portions of the watersheds. This will be investigated in future model refinements.

Another factor contributing to bias in the case of Shelburne, is that the watershed contains a high percentage of soils (approx. 75%) in Hydrologic Soil Group D. These high-clay, poorly-drained soils are highly subject to surface runoff, the predominant transport mechanism for total phosphorus. The watershed also contains a high percentage of tilled agricultural land use which, combined with the poorly-drained, lake-plain soil types, would tend to result in higher export coefficients than predicted by the LEAP framework. The location, watershed characteristics and water quality or Lake Shelburne suggest naturally eutrophic conditions which are not typical of other Vermont lakes.

Another curious aspect of Lake Shelburne is the apparent decreasing trend in spring total phosphorus, ranging from 147 mg/m3 in 1977 to 72 mg/m3 in 1981. Model bias reduces from a factor of 6 to a factor of 4 if 1981 measurements are used. This trend contrasts with many of the other lakes, which showed increasing trends over the same period. For example, Harveys increased from 10 to 22 mg/m3, Morey, from 17 to 48 mg/m3, Elmore, from 10 to 15 mg/m3, Parker from 14 to 21 mg/m3, St Catherines, from 10 to 17 mg/m3, and Star, from 10 to 23 mg/m3. These "trends" do not necessarily reflect significant variations in cultural impacts and are probably related to climatologic variations or to the timing of spring phosphorus sampling in relation to peak runoff and turnover.

Year-to-year variations in observed spring phosphorus levels are considerable and it would be useful to develop a better basis for interpreting them. One approach would be use watershed model relating direct runoff to precipitation sequences, similar to that developed in recent work for the New Haven Water Company (Walker, 1981), based upon the SCS Soil Cover Complex Method. The model simulates annual sequences of storm events and calculates direct runoff by event, as well as annual totals. By simulating multiple years, a feeling for year-to-year variations in loadings can be obtained. This provides some help in interpreting lake water quality measurements made during a given year in relation to the long-term-average and, thus, distinguishing naturally-induced from culturally-induced variations. Input data for this model are generally available from soils maps, land use maps, and weather stations which record daily total precipitation. Essentially, this framework is a second-order LEAP which attempts to simulate year-to-year variations, as opposed to the current version, which is focused on the long-term average.

Internal phosphorus recycling is another factor possibly contributing to errors in the spring phosphorus predictions from the existing framework. This effect is demonstrated most effectively using a modelling exercise. The current framework explicitly considers external phosphorus loading only. The effects of internal loading are implicitly included in the phosphorus retention function. If the nutrient balance equation is modified to account for internal loading directly, the equation for predicting lake phosphorus concentration becomes:

$$P = (WX + WI)\ (1 - RP)\ /\ (QS\ \ AS)$$

where,

P = lake phosphorus concentration (mg/m3)
WX = external phosphorus loading (kg/yr)
WI = internal phosphorus loading (kg/yr)
RP = phosphorus retention coefficient
QS = surface overflow rate (m/yr)
AS = lake surface area (km2)

The potential for internal loading is directly related to the oxygen status of the hypolimnion, since phosphorus release rates from anoxic sediments are generally orders of magnitude greater than release rates from oxic sediments. If we assume that the internal loading per unit of hypolimnetic area is proportional to the length of the anoxic period, the following expression results:

$$WI = FI\ TANOX\ AH\ \ = FI\ (200 - TDO)\ AH$$
$$TDO = 12\ ZH\ /\ HOD$$

where,

FI = effective P release rate from anoxic sediment (mg/m2-day)
TANOX = length of anoxic period (days/yr)
TDO = days of oxygen supply at spring turnover
AH = hypolimnetic surface area (km2)
ZH = mean hypolimnetic depth (m)
HOD = areal oxygen depletion rate (g/m2-day)

The above expression assumes an average stratified period of 200 days and spring oxygen concentration of 12 g/m3. Combining the above equations, the effect of internal loading on the predicted phosphorus concentration is given by:

$$P1 = (1-RP)\ WX\ /\ (AS\ QS)$$

$$P2 = (1-RP)\ [WX + FI\ (200 - TDO)\ AH]\ /\ (AS\ QS)$$

$$P2/P1 - 1 = FI\ (200 - TDO)\ AH\ /\ WX$$

where,

P1 = lake P calc. from external loading (mg/m3)
P2 = lake P calc. from external and internal loading (mg/m3)

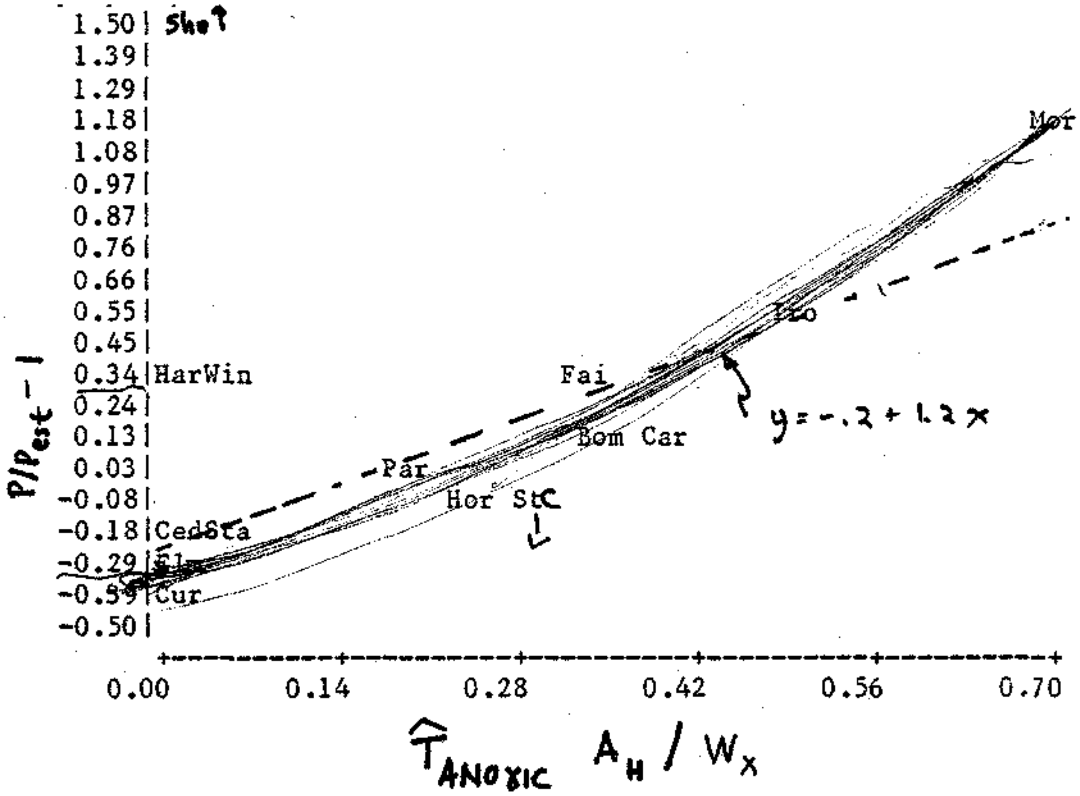
If the internal loading model is realistic, the expression on the right-hand side of the last equation reflects the potential significance of internal loading in relation to the external loading and should be related to the errors in the calculated phosphorus concentrations. Variables AH and WX are measured or calculated in the LEAP framework. TDO can be observed or calculated, based upon external phosphorus loadings, but is generally more sensitive to morphometry (mean hypolimnetic depth). If the model is to be useful, the remaining parameter, FI, should be reasonably constant across lakes and can be estimated from the slope of the line in Figure 4, which plots the error in the spring phosphorus prediction (expressed as P/PE - 1) as a function of the internal loading parameter derived from the right-hand side of the above equation. According to the model, internal loading should be of greater significance in lakes further to the right, including Morey, Iroquois, Fairview, and Carmi. Most of the lakes are close the line with the following equation:

$$P/PE - 1 = -.2 + 1.2\ (200 - TDO)\ AH\ /\ WX$$

The slope of the line indicates an average net release rate from of 1.2 mg/m2-day from anoxic hypolimnetic areas. The apparent negative intercept (-.2) may reflect a 20% bias in the phosphorus retention function for lakes which do not stratify or do not reach completely anoxic conditions. Since the retention function was developed on a

Figure 4

Error in Spring Phosphorus Estimate vs. Internal Loading Term



collection of oxic and anoxic lakes, it is possible that such a bias could exist.

The significance of the negative intercept needs further investigation with the refined data base, since some of the negative residuals may be attributed to problems with the input or observed values. As expected, the three lakes with partially sedimentary watersheds (Shelburne, Winona, and Fairview) still have positive biases when the effects of internal loading are considered. Modifications of the above model may be required to account for vertical variations in the volumetric oxygen depletion rate, as observed in Harvey's Lake (Vermont AEC,1981).

The above model provides a direct means of calculating internal loading which could be incorporated into the lake nutrient balances. The only additional input requirement would be the hypolimnetic surface area, which could be estimated from contour maps or from the mean depth, maximum depth, and thermocline depth using a scheme which is similar to that employed for estimating mean hypolimnetic depths. Modification of the existing LEAP to account for sedimentary soils and internal loading should reduce prediction error considerably and improve its usefulness as a planning tool for Vermont lakes. This work will proceed once the data base has been reviewed and, where possible, refined.

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APPENDIX A

Data Base

Observed Water Quality Data by Lake and Year
Observed Water Quality Data - Geometric Means
Lake Morphometry - I
Lake Morphometry - II
Land Use Fractions
Land Uses - Acres
Shoreline Septic Use Data
Other Model Input Variables
Soils Data - by Lake
Soils Data - by Name

Lake	yr	pspr	psum	chla	chlmax	secchi	hod
Bomoseen	77.00	14.00	-	-	-	-	-
Bomoseen	78.00	15.00	13.40	7.40	22.00	4.20	0.38
Bomoseen	79.00	19.00	11.00	4.40	10.00	5.00	0.38
Bomoseen	80.00	12.00	-	4.00	-	5.50	-
Bomoseen	81.00	15.00	-	6.40	-	4.00	-
Carmi	77.00	18.00	-	-	-	-	0.21
Carmi	78.00	25.00	-	19.80	64.00	2.20	-
Carmi	79.00	18.00	-	27.50	66.00	1.70	-
Carmi	80.00	17.00	-	23.00	-	1.70	-
Carmi	81.00	23.00	-	18.00	-	1.80	0.27
Cedar	77.00	21.00	-	-	-	-	-
Cedar	78.00	11.00	-	-	-	-	-
Cedar	79.00	19.00	-	-	-	-	-
Cedar	80.00	14.00	-	-	-	-	-
Cedar	81.00	24.00	-	-	-	-	-
Curtis	77.00	13.00	-	6.30	11.50	3.80	-
Curtis	78.00	17.00	-	-	-	-	-
Curtis	79.00	10.00	-	-	-	-	-
Curtis	80.00	8.00	-	-	-	-	-
Curtis	81.00	15.00	-	-	-	-	-
Elmore	77.00	10.00	-	3.87	8.40	3.30	-
Elmore	78.00	12.00	-	2.99	7.60	3.30	-
Elmore	79.00	12.00	10.00	4.14	8.00	3.20	-
Elmore	80.00	14.00	17.00	5.20	10.00	2.90	-
Elmore	81.00	15.00	-	5.40	-	3.50	-
Fairfield	78.00	17.00	-	6.70	14.20	4.30	-
Fairfield	79.00	17.00	-	14.90	33.00	2.23	-
Fairfield	80.00	25.00	-	13.00	-	3.00	-
Fairfield	81.00	22.00	-	9.20	-	2.30	0.45
Harveys	77.00	10.00	-	3.42	7.00	6.90	-
Harveys	78.00	11.00	-	2.68	5.20	6.80	-
Harveys	79.00	14.00	-	3.40	8.00	6.10	~~0.37~~ .39
Harveys	80.00	15.00 ← ?	8.3	5.30	9.00	7.00	~~0.37~~ .39
Harveys	81.00	22.00 –	-	3.50	-	6.50	~~-~~ .52
Hortonia	77.00	9.00	-	-	-	-	0.32
Hortonia	78.00	11.00	-	-	-	-	-
Hortonia	79.00	13.00	-	2.70	6.00	5.20	0.50
Hortonia	80.00	12.00	-	3.60	6.00	5.00	-
Hortonia	81.00	14.00	-	5.10	-	4.60	0.43
Iroquois	77.00	41.00	-	9.40	-	2.60	0.44 scratch
Iroquois	78.00	25.00	-	12.16	54.00	2.50	~~0.37~~ .51
Iroquois	79.00	26.00	-	9.90	25.00	2.60	~~0.51~~ .63
Iroquois	80.00	30.00	-	8.10	-	3.70	-
Iroquois	81.00	29.00	-	14.00	-	2.10	~~0.51~~ .63
Morey	75.00	26.00	9.00	-	-	6.00	-
Morey	77.00	17.00	-	-	-	-	-
Morey	78.00	29.00	-	6.15	21.40	5.50	-
Morey	79.00	32.00	-	9.26	20.00	5.00	0.53
Morey	80.00	20.00	14.30	12.00	20.00	3.30	0.46
Morey	81.00	48.00 – ?	-	12.00	-	4.30	0.53
Parker	77.00	14.00	-	4.73	12.30	3.70	-
Parker	78.00	10.00	-	-	-	-	-
Parker	79.00	18.00	-	6.75	20.00	4.47	-
Parker	80.00	16.00	-	7.90	-	3.80	-
Parker	81.00	21.00	-	5.90	-	3.30	0.40
St Cather	77.00	10.00	-	-	-	-	-
St Cather	78.00	10.00	-	2.33	4.40	7.90	-
St Cather	79.00	11.00	-	3.00	-	5.90	0.42

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St Cather	80.00	12.00	-	3.00	-	6.60	-
St Cather	81.00	17.00	-	4.90	-	5.40	0.39
Shelburne	77.00	147.00	-	-	-	-	-
Shelburne	78.00	128.00	-	59.30	132.00	0.70	-
Shelburne	79.00	135.00	-	96.80	150.00	0.34	-
Shelburne	80.00	99.00	-	-	-	-	-
Shelburne	81.00	72.00	-	-	-	-	-
Star	78.00	10.00	-	-	-	-	-
Star	79.00	7.00	-	17.00	33.00	0.90	-
Star	80.00	22.00	-	23.00	42.00	0.80	-
Star	81.00	23.00	-	-	-	-	-
Winona	77.00	40.00	-	-	-	-	-
Winona	78.00	22.00	-	-	-	-	-
Winona	79.00	20.00	-	-	-	-	-
Winona	80.00	29.00	-	-	-	-	-
Winona	81.00	23.00	-	-	-	-	-

Lake Water Quality Data - by Year

yr = year sampled
pspr = spring phosphorus concentration (mg/m3)
psum = summer epilimnetic phosphorus concentration (mg/m3)
chla = summer chlorophyll-a (mg/m3)
chlmax = maximum summer chlorophyll-s (mg/m3)
secchi = secchi depth (m)
hod = hypolimnetic oxygen depletion rate (g/m2-day)

Lake	pspr	psum	chla	chlmax	secchi	hod	tdo	zhyp
Bomoseen	14.83	12.14	5.37	14.83	4.64	0.38	113.68	3.60
Carmi	19.96	-	21.79	64.99	1.84	0.27	41.78	0.94
Cedar	17.13	-	-	-	-	-	-	0.00
Curtis	12.15	-	6.30	11.50	3.80	-	-	0.00
Elmore	12.48	13.04	4.22	8.45	3.23	-	-	0.00
Fairfield	19.97	-	10.45	21.65	2.85	0.45	75.70	2.84
Harveys	13.84	-	3.57	7.15	6.65	.43 ~~0.37~~	~~489.70~~ 458	~~15.10~~ 16.4
Hortonia	11.67	-	3.67	6.00	4.93	0.41	106.31	3.63
Iroquois	29.72	-	10.51	36.74	2.65	0.45	60.84	2.30
Morey	27.07	11.34	9.52	20.46	4.72	0.51	47.47	2.00
Parker	15.33	-	6.21	15.68	3.79	0.40	91.50	3.05
St Cather	11.75	-	3.18	4.40	6.38	0.40	162.60	5.42
Shelburne	112.61	-	75.76	140.71	0.49	-	-	0.00
Star	13.72	-	19.77	37.23	0.85	-	-	0.00
Winona	25.94	-	-	-	-	-	-	0.00

Lake Water Quality Data - Geometric Means

pspr = spring phosphorus concentration (mg/m3)
psum = summer epilimnetic phosphorus concentration (mg/m3)
chla = summer chlorophyll-a (mg/m3)
chlmax = maximum summer chlorophyll-a (mg/m3)
secchi = secchi depth (m)
hod = hypolimnetic oxygen depletion rate (g/m2-day)
tdo = days of oxygen supply at spring turnover = 12 zhyp / hod
zhyp = mean hypolimnetic depth (m)

lake	darea	sarea	zm	zm-hg	zx	t	ztherm	zhyp
Bomoseen	95.70	9.57	8.20	-	19.80	1.90	10.00	3.60
Carmi	30.87	5.57	6.20	5.44	10.10	1.80	8.00	0.94
Cedar	3.33	0.46	2.00	1.92	4.00	0.89	0.00	0.00
Curtis	3.73	0.31	3.30	3.32	9.80	0.46	0.00	0.00
Elmore	20.48	0.91	3.40	3.49	5.20	0.17	0.00	0.00
Fairfield	15.64	1.88	7.10	7.23	12.80	1.00	8.00	2.84
Harveys	20.68	1.66 1.40	17.70 20.	22.91	44.20	3.30	10.00	~~15.10~~ 16.4
Hortonia	17.86	1.82	5.50	5.59	18.30	1.30	11.00	3.63
Iroquois	8.92	0.83	5.90	5.78	11.30	1.60	7.50	2.30
Morey	20.68	2.18	7.60	8.30	13.10	1.80	9.00	2.00
Parker	21.49	0.97	7.70	7.61	14.70	0.52	8.00	3.05
St Cather	30.16	3.45	10.90	10.72	19.50	2.50	10.00	5.42
Shelburne	19.27	1.82	3.60	3.61	7.90	0.78	0.00	0.00
Star	2.87	0.23	1.50	1.48	2.40	0.18	0.00	0.00
Winona	11.30	0.95	1.20	1.02	2.70	0.32	0.00	0.00

Lake Morphometry - I

darea= total drainage area (km2)
sarea = lake surface area (km2)
zm = mean depth (from classification report) (m)
zm-hg = mean depth (calculated from hypsiographs) (m)
zx = maximum depth (m)
t = hydraulic residence time (yrs)
ztherm = thermocline depth (m)
zhyp = mean hypolimnion depth (m)

lake	elev	maxelev	shore	runoff	voldev	shordev	ulakfac
Bomoseen	411.00	2034.00	34610.00	0.43	1.24	3.15	15.95
Carmi	435.00	861.00	12816.00	0.62	1.84	1.53	0.61
Cedar	492.00	900.00	2665.00	0.31	1.50	1.11	0.00
Curtis	1219.00	1707.00	5122.00	0.60	1.01	2.59	0.00
Elmore	1139.00	2000.00	4218.00	0.89	1.96	1.25	0.77
Fairfield	550.00	1130.00	9048.00	0.85	1.66	1.86	0.00
Harveys	893.00	2379.00	6338.00	0.43	1.20	1.39	0.00
Hortonia	484.00	1125.00	12651.00	0.43	0.90	2.64	5.01
Iroquois	684.00	1250.00	5201.00	0.34	1.57	1.61	0.00
Morey	416.00	1776.00	7662.00	0.45	1.74	1.46	0.00
Parker	1299.00	2157.00	4830.00	0.67	1.57	1.38	0.26
St Cather	484.00	2100.00	15820.00	0.50	1.68	2.40	1.28
Shelburne	330.00	830.00	7423.00	0.44	1.37	1.55	0.00
Star	1851.00	2300.00	2150.00	0.67	1.88	1.26	0.00
Winona	467.00	1806.00	4152.00	0.32	1.33	1.20	0.00

Lake Morphometry - II

elev = surface elevation (ft, msl)
maxelev = maximum watershed elevation (ft, msl)
shore = shoreline length (m)
runoff = runoff rate from watershed (m/yr)
voldev = volume development ratio
shordev = shoreline development ratio
ulakfac = upstream lake P retention factor (km2)

lake	conif	hdwd	mxdf	untld	tild	urban	lake	ulake	wetln
Bomoseen LS	0.092	0.514	0.138	0.060	0.010	0.010	0.100	0.020	0.057
Bomoseen PM	0.081	0.453	0.122	0.069	0.030	0.069	0.100	0.020	0.057
Bomoseen XX	0.082	0.462	0.124	0.067	0.025	0.063	0.100	0.020	0.057
Carmi LS	0.018	0.278	0.102	0.222	0.121	0.000	0.180	0.002	0.076
Carmi PM	0.017	0.253	0.093	0.120	0.200	0.060	0.180	0.002	0.076
Carmi XX	0.016	0.248	0.091	0.207	0.120	0.060	0.180	0.002	0.076
Cedar LS	0.142	0.286	0.142	0.137	0.119	0.000	0.138	0.000	0.034
Cedar PM	0.094	0.189	0.094	0.030	0.360	0.060	0.138	0.000	0.034
Cedar XX	0.123	0.248	0.124	0.173	0.130	0.030	0.138	0.000	0.034
Curtis LS	0.248	0.468	0.091	0.090	0.010	0.000	0.083	0.000	0.010
Curtis PM	0.137	0.259	0.050	0.080	0.220	0.161	0.083	0.000	0.010
Curtis XX	0.162	0.305	0.059	0.229	0.072	0.080	0.083	0.000	0.010
Elmore LS	0.288	0.493	0.065	0.033	0.022	0.000	0.044	0.005	0.049
Elmore PM	0.222	0.379	0.050	0.090	0.120	0.040	0.044	0.005	0.049
Elmore XX	0.249	0.424	0.056	0.099	0.033	0.040	0.044	0.005	0.049
Fairfield LS	0.102	0.612	0.074	0.049	0.029	0.000	0.120	0.000	0.014
Fairfield PM	0.091	0.548	0.067	0.030	0.070	0.060	0.120	0.000	0.014
Fairfield XX	0.094	0.565	0.069	0.047	0.031	0.060	0.120	0.000	0.014
Harveys LS	0.427	0.291	0.073	0.063	0.011	0.000	0.080	0.000	0.055
Harveys PM	0.316	0.215	0.054	0.110	0.140	0.030	0.080	0.000	0.055
Harveys XX	0.345	0.235	0.059	0.178	0.029	0.019	0.080	0.000	0.055
Hortonia LS	0.104	0.501	0.161	0.040	0.010	0.000	0.102	0.033	0.048
Hortonia PM	0.084	0.404	0.130	0.110	0.030	0.060	0.102	0.033	0.048
Hortonia XX	0.090	0.433	0.139	0.076	0.019	0.060	0.102	0.033	0.048
Iroquois LS	0.095	0.364	0.069	0.231	0.088	0.000	0.093	0.000	0.061
Iroquois PM	0.085	0.326	0.062	0.000	0.272	0.101	0.093	0.000	0.061
Iroquois XX	0.077	0.294	0.056	0.231	0.088	0.101	0.093	0.000	0.061
Morey LS	0.188	0.613	0.069	0.010	0.010	0.000	0.105	0.000	0.004
Morey PM	0.166	0.543	0.061	0.100	0.010	0.010	0.105	0.000	0.004
Morey XX	0.166	0.543	0.061	0.085	0.010	0.025	0.105	0.000	0.004
Parker LS	0.438	0.331	0.097	0.061	0.010	0.000	0.045	0.002	0.015
Parker PM	0.201	0.152	0.045	0.130	0.380	0.030	0.045	0.002	0.015
Parker XX	0.234	0.177	0.052	0.317	0.136	0.023	0.045	0.002	0.015
St Cath LS	0.137	0.559	0.118	0.030	0.010	0.010	0.114	0.003	0.019
St Cath PM	0.106	0.429	0.090	0.060	0.129	0.050	0.114	0.003	0.019
St Cath XX	0.112	0.455	0.095	0.120	0.041	0.040	0.114	0.003	0.019
Shelburne LS	0.047	0.125	0.059	0.362	0.166	0.010	0.094	0.000	0.137
Shelburne PM	0.035	0.091	0.043	0.030	0.540	0.030	0.094	0.000	0.137
Shelburne XX	0.040	0.104	0.049	0.375	0.172	0.030	0.094	0.000	0.137
Star LS	0.318	0.366	0.155	0.020	0.010	0.020	0.080	0.000	0.031
Star PM	0.275	0.316	0.134	0.123	0.010	0.031	0.080	0.000	0.031
Star XX	0.277	0.318	0.135	0.118	0.010	0.031	0.080	0.000	0.031
Winona LS	0.118	0.428	0.082	0.119	0.028	0.009	0.084	0.000	0.131
Winona PM	0.091	0.330	0.063	0.187	0.092	0.020	0.084	0.000	0.131
Winona XX	0.099	0.357	0.069	0.160	0.080	0.020	0.084	0.000	0.131

Land Use Fractions

conif = conifer forest
hdwd = hardwood forest
untld = untilled agriculture
tild = tilled agriculture
urban = urban
lake = lake surfae area
ulake = upstream lakes
wetln = wetlands (exclusive of upstream lakes)

lake	tfor	untld	tild	urban	lake	ulake	wetln
Bomoseen LS	17573	1418	236	236	2364	468	1343
Bomoseen PM	15490	1636	701	1636	2364	468	1343
Bomoseen XX	15788	1584	591	1500	2364	468	1343
Carmi LS	3036	1696	925	0	1376	12	580
Carmi PM	2761	915	1524	457	1376	12	580
Carmi XX	2707	1578	915	457	1376	12	580
Cedar LS	470	113	98	0	114	0	28
Cedar PM	311	25	296	49	114	0	28
Cedar XX	407	142	107	25	114	0	28
Curtis LS	744	83	9	0	77	0	9
Curtis PM	411	74	203	148	77	0	9
Curtis XX	485	211	66	74	77	0	9
Elmore LS	4282	168	111	0	225	24	249
Elmore PM	3297	456	606	202	225	24	249
Elmore XX	3689	502	168	202	225	24	249
Fairfield LS	3044	188	113	0	464	0	54
Fairfield PM	2727	116	270	232	464	0	54
Fairfield XX	2812	181	120	232	464	0	54
Harveys LS	4042	321	54	0	410	0	281
Harveys PM	2987	562	715	153	410	0	281
Harveys XX	3266	907	148	96	410	0	281
Hortonia LS	3381	178	45	0	450	146	212
Hortonia PM	2722	485	132	265	450	146	212
Hortonia XX	2919	335	85	265	450	146	212
Iroquois LS	1163	508	193	0	205	0	134
Iroquois PM	1043	0	599	222	205	0	134
Iroquois XX	940	508	194	222	205	0	134
Morey LS	4445	51	51	0	538	0	22
Morey PM	3934	511	50	52	538	0	22
Morey XX	3935	434	50	128	538	0	22
Parker LS	4599	325	54	0	240	12	78
Parker PM	2113	690	2016	159	240	12	78
Parker XX	2458	1680	720	120	240	12	78
St Cath LS	6060	224	74	74	852	21	144
St Cath PM	4656	444	962	370	852	21	144
St Cath XX	4933	894	305	300	852	21	144
Shelburne LS	1101	1722	788	49	450	0	650
Shelburne PM	805	143	2569	143	450	0	650
Shelburne XX	917	1784	816	143	450	0	650
Star LS	595	14	7	14	57	0	22
Star PM	514	87	7	22	57	0	22
Star XX	518	83	7	22	57	0	22
Winona LS	1753	333	77	26	235	0	367
Winona PM	1352	523	258	56	235	0	367
Winona XX	1464	447	223	56	235	0	367

Land Uses - Acres

tfor = total forest
untld = untilled agriculture
tild = tilled agriculture
urban = urban
lake = lake surface area
ulake = upstream lakes
wetln = wetlands (exclusive of upstream lakes)

lake	seas-res	perm-res	day-use	nt-use	sload
Bomoseen	269.0	90.0	6929.0	12765.0	718.0
Carmi	225.0	75.0	18709.0	33322.0	679.4
Cedar	31.0	5.0	0.0	0.0	61.5
Curtis	30.0	5.0	0.0	0.0	60.0
Elmore	120.0	25.0	21371.0	10730.0	313.7
Fairfield	100.0	0.0	0.0	0.0	150.0
Harveys	85.0	17.0	0.0	0.0	178.5
Hortonia	50.0	17.0	0.0	0.0	126.0
Iroquois	30.0	10.0	0.0	0.0	75.0
Morey	75.0	25.0	0.0	68000.0	373.8
Parker	96.0	4.0	0.0	0.0	156.0
St Cather	280.0	90.0	40212.0	25304.0	814.4
Shelburne	0.0	0.0	0.0	0.0	0.0
Star	6.0	1.0	0.0	0.0	12.0
Winona	7.0	0.0	0.0	0.0	10.5

Shoreline Septic Use Data

seas-res = number of seasonal, shoreline residences
perm-res = number of permanent, shoreline residences
day-use = daytime use of state parks/resorts
night-use = overnight use of state parks/resorts
sload = computed shoreline septic use (capita/yr)

= 3 (perm-res + .5 seas-res) + (day-use/2 + night-use)/365

$\frac{3 \times 365}{20} = \frac{709}{20}$ 235

lake	ulakfac	sload	otherld	zbasin
Bomoseen	15.95	717.97	0.00	8.20
Carmi	0.61	679.43	0.00	5.44
Cedar	0.00	61.50	0.00	1.92
Curtis	0.00	60.00	0.00	3.32
Elmore	0.77	313.68	0.00	3.49
Fairfield	0.00	150.00	0.00	7.23
Harveys	0.00	178.50	0.00	17.70
Hortonia	5.01	126.00	0.00	8.90
Iroquois	0.00	75.00	0.00	5.78
Morey	0.00	373.82	0.00	8.30
Parker	0.26	156.00	0.00	7.61
St Cather	1.28	814.42	0.00	10.72
Shelburne	0.00	0.00	0.00	3.61
Star	0.00	12.00	0.00	1.48
Winona	0.00	10.50	0.00	1.02

Other Model Input Variables

ulakfac = upstream lake P retention factor (km2)
sload = shoreline septic use (capita/yr)
otherld = other direct P loading (kg/yr)
zbasin = mean depth of stratified part of lake (m)

Soils Data - by Lake

LAKE	%	SOIL ASSOCIATION	ORIGIN	HSG
Bomoseen	80	Nassau-Dutchess	T	C/D B
Bomoseen	10	Dutchess-Nassau	T	B C/D
Bomoseen	10	Bernardston-Pittston	T	C C
Carmi	45	Peru-Stowe	T	C C
Carmi	45	Cabot-Westbury	T	D C
Carmi	10	Carlisle-Terric	T	D D
Cedar	70	Nellis-Amenia	T	B B
Cedar	30	Berkshire-Marlo	T	B C
Curtis	90	Glover-Calais	T	C/D C
Curtis	10	Calais-Buckland	T	C C
Elmore	50	Peru-Marlo	T	C C
Elmore	30	Lyman-Marlo-Peru	T	C/D C C
Elmore	20	Cabot-Peru	T	D C
Fairfield	60	Woodstock-Tunbridge	T	C C
Fairfield	15	Peru-Stowe	T	C C
Fairfield	10	Carlise-Terric Med.	T	D D
Fairfield	10	Windsor-Missisquoi	S	A A
Fairfield	5	Scantic-Raynham-Bing.	S	C C B
Harveys	70	Paxton-Woodbridge	T	C C
Harveys	15	Woodstock-Colrain	T	C B
Harveys	15	Muck & Peat-Peacham	T	D
Hortonia	70	Dutchess-Nassau	T	B C/D
Hortonia	30	Bernardston-Pittston	T	C C
Iroquois	33	Peru-Cabot	T	C D
Iroquois	33	Lyman-Marlou	T	C/D C
Iroquois	33	Peru-Marlou	T	C C
Morey	80	Tunbridge-Woodstock-Colr	T	C C B
Morey	20	Tunbridge-Woodstock-Buckl	T	C C C
Parker	50	Cabot-Buckland	T	D C
Parker	40	Glover-Calais	T	C/D C
Parker	5	Buckland-Calais	T	C C
Parker	5	Muck & Peat Peacham	T	D
St Cather	70	Nassau-Dutchess	T	C/D B
St Cather	25	Bernardston-Pittstown	T	C C
St Cather	5	Stockbridge-Amenia	T	B B
Shelburne	50	Vergennes-Covington	S	D D
Shelburne	25	Muck & Peat	S	D D
Shelburne	25	Farmington-Nellis-Stockbr	T	B B
Star	60	Peru-Marlo-Lyman	T	C C C/D
Star	30	Marlo-Peru-Lyman	T	C C C/D
Star	10	Lyman-Marlo-Peru	T	C/D C C
Winona	40	Lyman-Berkshire-Marlow	T	C/D B C
Winona	20	Muck & Peat Assoc	S	D
Winona	20	Raynham-Amenia	S	C B
Winona	10	Berkshire-Marlow	T	B C
Winona	10	Colton-Stetson-Adams	S	A B A

% = approx. percent of drainage basin in given assoc.
ORIGIN = soil origin (S=sedimentary , T=Till)
HSG = hydrologic soil group

Soils Data

NAME	HSG	EROD	ORIGIN
Adams	B		S
Amenia	B		S
Berkshire	B		T
Bernardston	C		T
Binghamville	B	.49	S
Buckland	C		T
Cabot	D	.28	T
Calais	C		T
Carlisle	A/D		T
Colrain	B	.20	T
Colton	A		S
Covington	D		S
Dutchess	B		T
Farmington	C/D	.32	T
Glover	C/D	.20	T
Lyman	C/D		T
Marlo	C		T
Missisquoi	A	.17	S
Nassau	C/D		T
Nellis	B		T
Paxton	C		T
Peru	C	.24	T
Pittstown	C		T
Raynham	C		S
Scantic	C		S
Stetson	B		S
Stockbridge	B		T
Stowe	C	.24	T
Terric	B		T
Tunbridge	C	.20	T
Vergennes	D		S
Windsor	A	.17	S
Woodbridge	C		T
Woodstock	C	.20	T

HSG = hydrologic soil group
EROD = erodibility factor
ORIGIN = soil origin
(S=sedimentary,T=till)

APPENDIX B

LEAP Subroutine and Variables

Revised Lake Model Subroutine
Input Variable List (Lake Morey)
Output Variable List

```
3480 REM revised lake model subroutine
3490 A1=X(1)+X(2)+X(3)+X(4)+X(5)+X(6)+X(8)+X(9):'watershed
3500 Y(2)=X(1)*X(24)+X(2)*X(25)+X(3)*X(26)+X(8)*X(30)+X(9)*X(31)
3510 Y(2)=X(35)*X(15)*(Y(2)-X(20)*X(10))            :'natural p
3520 Y(3)=X(35)*X(15)*(X(4)*X(27)+X(5)*X(28))       :'agric p
3530 Y(4)=X(35)*X(15)*X(6)*X(29)                    :'urban p
3540 Y(5)=X(7)*X(32)                                :'atmos load
3550 Y(6)=X(16)*X(21)+X(17)                         :'septic
3560 Y(1)=Y(2)+Y(3)+Y(4)+Y(5)+Y(6)                  :'total load
3570 Y(7)=Y(1)/((A1+X(7))*X(15))                    :'inflow conc
3580 Y(8)=(A1+X(7))*X(15)/X(7)                      :'overflow rate
3590 Y(9)=X(11)/Y(8)                                :'residence time
3600 Y(10)=1!/(1!+.82*(Y(9)^.45)*X(36))             :'1-rp
3610 Y(11)=Y(10)*Y(7)                               :'p spring
3620 Y(12)=X(37)*EXP(-.69+.94*LOG(Y(11)))           :'chl-a
3630 Y(13)=X(38)*EXP(-.354+1.088*LOG(Y(11)))        :'chl-a max
3640 Y(14)=X(39)/(.025*Y(12)+X(23))                 :'secchi depth
3650 Z3=-15.6 + 46.1*LOG(Y(11))/2.303               :'tsi
3655 IF X(13)=0 AND X(14)=0 THEN Y(15)=0:Y(16)=0:Y(17)=0:GOTO 3720
3660 Z5=LOG(X(18))
3670 Y(15)= -3.58 + .0204*Z3 + 1.976*Z5-.3846*Z5*Z5
3680 Y(15)= X(40)*(10^Y(15))                         :'hod
3690 IF X(14)<>0 THEN Y(16)=X(14):GOTO 3710
3700 Y(16) = X(11)*(X(12)-X(13))/(X(12))             :'hypolimnetic depth
3710 Y(17) = X(22)*Y(16)/Y(15)                       :'days of oxygen supply
3720 Y(18) = Y(10)*Y(9)                              :'p residence time
3730 Z3=Y(1)/((1!+.82*(Y(9)^.45))*(X(7)*Y(8)))
3740 Y(19)= 1E-03*(Z3^.82)*(Y(1)/(X(7)))^.18        :'discriminant score
3750 Z3 = -(Y(19)^(-.25))
3760 Y(20)= EXP(-18.51-20.49*Z3)
3770 Y(21)= EXP(-36.77-29.33*Z3)
3780 Y(22)= EXP(-53.8-35.65*Z3)
3790 Z3 = Y(20)+Y(21)+Y(22)
3800 Y(20) = Y(20)/Z3                               :'prob(eutrophic)
3810 Y(21)= Y(21)/Z3                                 :'prob(mesotrophic)
3820 Y(22) = Y(22)/Z3                                :'prob(oligotrophic)
3830 RETURN
Ok
```

```
LIST INPUT VARIABLES

input file - run1

INPUT VARIABLES                          MEAN    STD DEV    CODE      Total

 1 Conifer For Area  km2                 3.44     0.00       4  Under
 2 Hardwood For Area  km2               11.23     0.00       4  Under
 3 Mixed For Area  km2                   1.26     0.00       4  Tilled
 4 Untilled Agric Area  km2              1.76     0.00       4  Tilled
 5 Tilled Agric Area  km2                0.20     0.00       4  Untill
 6 Urban  Area  km2                      0.52     0.00       4  Untill.
 7 Lake  Area  km2                       2.18     0.00       4
 8 Upstr Lake Area  km2                  0.00     0.00       4  urban -
 9 Wetland Area  km2                     0.09     0.00       4  lake
10 Upstr Lake Ret Fac  km2               0.00     0.00       4
11 Mean Depth  m                         8.10     0.00       4
12 Maximum Depth  m                     13.10     0.00       4
13 Thermocline Depth  m                  9.00     0.00       4
14 Hypolimnion Depth  m                  2.00     0.00       4
15 Runoff  m/yr                          0.56     0.13       4
16 Shoreline Septic Use  cap/yr        300.00     0.00       4
17 Extra P Load  kg/yr                   0.00     0.00       4
18 Basin Mean Depth  m                   8.10     0.00       4
19 Dummy                                 0.00     0.00       0— hypol surface area
20 Inflow Conc of Upst Lakes (mg        15.00     3.00       2
21 Septic P Factor (kg/cap-yr)           0.05     0.01       2
22 Spring,DO  g/m3                      12.00     0.50       1
23 Turbidity/Color (1/m)                 0.08     0.01       2
24 Conifer For P  mg/m3                 15.00     3.00       2
25 Hardwood For P mg/m3                 15.00     3.00       2
26 Mixed For P  mg/m3                   15.00     3.00       2
27 Untilled Agric P  mg/m3              15.00     3.00       2
28 Tilled Agric P  mg/m3                57.00     6.30       2
29 Urban P  mg/m3                      139.00    31.00       2
30 Upstream Lake P mg/m3                15.00     3.00       2
31 Wetland P mg/m3                      15.00     3.00       2
32 Atmos P Load kg/km2-yr               30.00    10.00       2
33 Dummy - Anoxic Pload mg/m2-day        0.00     0.00       0
34 Dummy                                 0.00     0.00       0
35 Error - Watshd                        1.00     0.30       2
36 Error - P Reten                       1.00     0.55       2
37 Error - Chl-a                         1.00     0.37       2
38 Error - Chl-max                       1.00     0.39       2
39 Error - Secchi                        1.00     0.39       2
40 Error - HOD                           1.00     0.23       2
```

LIST OUTPUT VARIABLES

input file - run1

DEPENDENT VARIABLES	CODE	
1 Total P Load kg/yr	4	
2 Undeveloped P Load kg/yr	2	
3 Agricultural P Load kg/yr	2	
4 Urban Runoff P Load kg/yr	2	
5 Atmospheric P Load kg/yr	2	
6 Septic P Load kg/yr	2	
7 Inflow P Conc mg/m3	~~2~~	Interne Load
8 Overflow Rate m/yr	~~2~~	Inflw P Conc.
9 Residence Time yr	2	
10 1 - P Retent Coef	2	
11 P Spring mg/m3	4	
12 Chlorophyll-a mg/m3	4	
13 Max Chl-a mg/m3	4	
14 Secchi Depth m	4	
15 Oxygen Depl Rate g/m2-day	4	
16 Hypol Depth m	2	
17 Days of O2 Supply	4	
18 P Residence Time yrs	2	
19 TS Discr Score	2	
20 Prob(Eutrophic)	1	
21 Prob(Mesotrophic)	1	
22 Prob(Oligotrophic)	1	
23 Dummy	0	
24 Dummy	0	
25 Dummy	0	

APPENDIX C

LEAP Output By Lake

Bomoseen

```
runl-sensitivity
PREDICTED VARIABLE                        MEAN   STD DEV        CV        5%       95%

 1 Total P Load  kg/yr                 1145.72    377.29      0.33    592.99   2213.64
 2 Undeveloped P Load  kg/yr            358.04    165.11      0.46    142.36    900.51
 3 Agricultural P Load  kg/yr           100.36     43.95      0.44     41.80    240.97
 4 Urban Runoff P Load  kg/yr           364.31    174.90      0.48    139.47    951.61
 5 Atmospheric P Load  kg/yr            287.10     95.70      0.33    147.40    559.19
 6 Septic P Load  kg/yr                  35.90      7.18      0.20     24.06     53.55
 7 Inflow P Conc  mg/m3                  27.74      7.27      0.26     16.42     46.86
 8 Overflow Rate  m/yr                    4.32      1.30      0.30      2.36      7.88
 9 Residence Time  yr                     1.90      0.57      0.30      1.05      3.45
10 1 - P Retent Coef                      0.48      0.14      0.29      0.26      0.86
11 P Spring  mg/m3                       13.24      5.02      0.38      6.21     28.26
12 Chlorophyll-a  mg/m3                   5.69      2.92      0.51      2.04     15.89
13 Max Chl-a  mg/m3                      11.67      6.62      0.57      3.75     36.30
14 Secchi Depth  m                        4.50      2.30      0.51      1.62     12.51
15 Oxygen Depl Rate  g/m2-day             0.41      0.17      0.42      0.18      0.96
16 Hypol Depth  m                         3.60      0.00      0.00      3.60      3.60
17 Days of O2 Supply                    105.62     44.89      0.43     45.14    247.12
18 P Residence Time  yrs                  0.91      0.33      0.37      0.44      1.89
19 TS Discr Score                         0.02      0.00      0.25      0.01      0.03
20 Prob(Eutrophic)                        0.00      0.01      1.99     -0.01      0.01
21 Prob(Mesotrophic)                      0.54      0.26      0.48      0.02      1.05
22 Prob(Oligotrophic)                     0.46      0.26      0.57     -0.06      0.98

runl-sensitivity

PREDICTED VARIABLE: 11  P Spring  mg/m3
MEAN = 13.2436           STD. DEV. = 5.01862      CV = .378948

INPUT VARIABLE                            MEAN        CV     DY/DX  DLY/DLX    % VAR.

 1 Conifer For Area  km2                  7.86     0.000    -0.031   -0.018     0.000
 2 Hardwood For Area  km2                44.17     0.000    -0.031   -0.103     0.000
 3 Mixed For Area  km2                   11.89     0.000    -0.031   -0.028     0.000
 4 Untilled Agric Area  km2               6.41     0.000    -0.031   -0.015     0.000
 5 Tilled Agric Area  km2                 2.39     0.000     0.178    0.032     0.000
 6 Urban  Area  km2                       6.07     0.000     0.587    0.269     0.000
 7 Lake  Area  km2                        9.57     0.000    -0.084   -0.060     0.000
 8 Upstr Lake Area  km2                   1.89     0.000    -0.031   -0.004     0.000
 9 Wetland Area  km2                      5.44     0.000    -0.031   -0.013     0.000
10 Upstr Lake Ret Fac  km2               15.95     0.000    -0.075   -0.090     0.000
11 Mean Depth  m                          8.20     0.000    -0.378   -0.234     0.000
15 Runoff  m/yr                           0.43     0.301    -1.405   -0.046     0.132
16 Shoreline Septic Use  cap/yr         717.97     0.000     0.001    0.031     0.000
20 Inflow Conc of Upst Lakes (mg         15.00     0.200    -0.080   -0.090     0.226
21 Septic P Factor (kg/cap-yr)            0.05     0.200     8.299    0.031     0.027
24 Conifer For P  mg/m3                  15.00     0.200     0.039    0.044     0.055
25 Hardwood For P mg/m3                  15.00     0.200     0.220    0.250     1.735
26 Mixed For P  mg/m3                    15.00     0.200     0.059    0.067     0.126
27 Untilled Agric P  mg/m3               15.00     0.200     0.032    0.036     0.037
28 Tilled Agric P  mg/m3                 57.00     0.111     0.012    0.051     0.022
29 Urban P  mg/m3                       139.00     0.223     0.030    0.318     3.502
30 Upstream Lake P mg/m3                 15.00     0.200     0.009    0.011     0.003
31 Wetland P mg/m3                       15.00     0.200     0.027    0.031     0.026
32 Atmos P Load kg/km2-yr                30.00     0.333     0.111    0.251     4.858
35 Error - Watshd                         1.00     0.300     9.510    0.718    32.317
36 Error - P Reten                        1.00     0.550    -6.885   -0.520    56.932

runl-sensitivity
```

Carmi

```
runl-sensitivity
PREDICTED VARIABLE                          MEAN   STD DEV       CV        5%       95%

 1 Total P Load  kg/yr                    670.51    185.74     0.28    385.30   1166.85
 2 Undeveloped P Load  kg/yr              118.82     46.26     0.39     54.54    258.88
 3 Agricultural P Load  kg/yr             190.79     72.26     0.38     89.45    406.92
 4 Urban Runoff P Load  kg/yr             159.83     68.47     0.43     67.86    376.48
 5 Atmospheric P Load  kg/yr              167.10     55.70     0.33     85.79    325.47
 6 Septic P Load  kg/yr                    33.97      6.79     0.20     22.77     50.68
 7 Inflow P Conc  mg/m3                    34.95      8.50     0.24     21.49     56.84
 8 Overflow Rate  m/yr                      3.44      0.72     0.21      2.27      5.23
 9 Residence Time  yr                       1.58      0.33     0.21      1.04      2.39
10 1 - P Retent Coef                        0.50      0.14     0.28      0.29      0.87
11 P Spring  mg/m3                         17.41      6.30     0.36      8.44     35.90
12 Chlorophyll-a  mg/m3                     7.36      3.70     0.50      2.69     20.10
13 Max Chl-a  mg/m3                        15.71      8.71     0.55      5.19     47.60
14 Secchi Depth  m                          3.79      1.99     0.52      1.33     10.82
15 Oxygen Depl Rate  g/m2-day               0.33      0.13     0.41      0.14      0.74
16 Hypol Depth  m                           0.94      0.00     0.00      0.94      0.94
17 Days of O2 Supply                       34.70     14.28     0.41     15.23     79.04
18 P Residence Time  yrs                    0.79      0.25     0.32      0.42      1.49
19 TS Discr Score                           0.02      0.01     0.24      0.02      0.04
20 Prob(Eutrophic)                          0.01      0.02     1.55     -0.03      0.05
21 Prob(Mesotrophic)                        0.74      0.16     0.22      0.42      1.05
22 Prob(Oligotrophic)                       0.25      0.18     0.71     -0.11      0.61

runl-sensitivity

REDICTED VARIABLE: 11  P Spring  mg/m3
MEAN = 17.4114          STD. DEV. = 6.30023       CV = .361845

INPUT VARIABLE                              MEAN        CV     DY/DX   DLY/DLX    % VAR.

 1 Conifer For Area  km2                    0.50     0.000    -0.195    -0.006     0.000
 2 Hardwood For Area  km2                   7.65     0.000    -0.194    -0.085     0.000
 3 Mixed For Area  km2                      2.81     0.000    -0.194    -0.031     0.000
 4 Untilled Agric Area  km2                 6.39     0.000    -0.194    -0.071     0.000
 5 Tilled Agric Area  km2                   3.70     0.000     0.483     0.103     0.000
 6 Urban  Area  km2                         1.85     0.000     1.806     0.192     0.000
 7 Lake  Area  km2                          5.57     0.000    -0.361    -0.115     0.000
 8 Upstr Lake Area  km2                     0.05     0.000    -0.198    -0.001     0.000
 9 Wetland Area  km2                        2.35     0.000    -0.194    -0.026     0.000
10 Upstr Lake Ret Fac  km2                  0.61     0.000    -0.242    -0.009     0.000
11 Mean Depth  m                            5.44     0.000    -0.719    -0.225     0.000
15 Runoff  m/yr                             0.62     0.209    -2.042    -0.073     0.178
16 Shoreline Septic Use  cap/yr           679.43     0.000     0.001     0.051     0.000
20 Inflow Conc of Upst Lakes (mg           15.00     0.200    -0.010    -0.009     0.002
21 Septic P Factor (kg/cap-yr)              0.05     0.200    17.643     0.051     0.078
24 Conifer For P  mg/m3                    15.00     0.200     0.008     0.007     0.002
25 Hardwood For P mg/m3                    15.00     0.200     0.123     0.106     0.346
26 Mixed For P  mg/m3                      15.00     0.200     0.045     0.039     0.046
27 Untilled Agric P  mg/m3                 15.00     0.200     0.103     0.089     0.241
28 Tilled Agric P  mg/m3                   57.00     0.111     0.060     0.196     0.357
29 Urban P  mg/m3                         139.00     0.223     0.030     0.238     2.159
 0 Upstream Lake P mg/m3                   15.00     0.200     0.001     0.001     0.000
 1 Wetland P mg/m3                         15.00     0.200     0.038     0.033     0.033
32 Atmos P Load kg/km2-yr                  30.00     0.333     0.145     0.249     5.271
35 Error - Watshd                           1.00     0.300    12.190     0.700    33.693
36 Error - P Reten                          1.00     0.550    -8.693    -0.499    57.595
```

Cedar

```
runl-sensitivity
PREDICTED VARIABLE                         MEAN  STD DEV        CV       5%       95%

 1 Total P Load  kg/yr                    39.73    12.77      0.32    20.89     75.54
 2 Undeveloped P Load  kg/yr               8.20     4.33      0.53     2.85     23.57
 3 Agricultural P Load  kg/yr             10.34     5.42      0.52     3.63     29.51
 4 Urban Runoff P Load  kg/yr              4.31     2.42      0.56     1.40     13.25
 5 Atmospheric P Load  kg/yr              13.80     4.60      0.33     7.09     26.88
 6 Septic P Load  kg/yr                    3.08     0.61      0.20     2.06      4.59
 7 Inflow P Conc  mg/m3                   38.43    10.61      0.28    22.12     66.76
 8 Overflow Rate  m/yr                     2.25     0.94      0.42     0.97      5.19
 9 Residence Time  yr                      0.86     0.36      0.41     0.37      1.96
10 1 - P Retent Coef                       0.57     0.14      0.25     0.34      0.94
11 P Spring  mg/m3                        21.78     7.24      0.33    11.20     42.35
12 Chlorophyll-a  mg/m3                    9.08     4.40      0.48     3.45     23.92
13 Max Chl-a  mg/m3                       20.04    10.66      0.53     6.92     58.09
14 Secchi Depth  m                         3.26     1.72      0.53     1.13      9.39
15 Oxygen Depl Rate  g/m2-day              0.00     0.00      0.00     0.00      0.00
16 Hypol Depth  m                          0.00     0.00      0.00     0.00      0.00
17 Days of O2 Supply                       0.00     0.00      0.00     0.00      0.00
18 P Residence Time  yrs                   0.49     0.20      0.41     0.21      1.10
19 TS Discr Score                          0.03     0.01      0.22     0.02      0.04
20 Prob(Eutrophic)                         0.03     0.04      1.29    -0.04      0.10
21 Prob(Mesotrophic)                       0.80     0.09      0.11     0.63      0.97
22 Prob(Oligotrophic)                      0.17     0.12      0.72    -0.07      0.41

runl-sensitivity

 REDICTED VARIABLE: 11   P Spring  mg/m3
 EAN = 21.7771             STD. DEV. = 7.24246       CV = .332572

INPUT VARIABLE                             MEAN        CV     DY/DX  DLY/DLX    % VAR.

 1 Conifer For Area  km2                   0.41     0.000    -2.708   -0.051     0.000
 2 Hardwood For Area  km2                  0.83     0.000    -2.706   -0.103     0.000
 3 Mixed For Area  km2                     0.41     0.000    -2.709   -0.051     0.000
 4 Untilled Agric Area  km2                0.58     0.000    -2.707   -0.072     0.000
 5 Tilled Agric Area  km2                  0.43     0.000     4.430    0.088     0.000
 6 Urban  Area  km2                        0.10     0.000    18.384    0.084     0.000
 7 Lake  Area  km2                         0.46     0.000     1.960    0.041     0.000
 9 Wetland Area  km2                       0.11     0.000    -2.711   -0.014     0.000
11 Mean Depth  m                           1.92     0.000    -2.196   -0.194     0.000
15 Runoff  m/yr                            0.31     0.419   -15.951   -0.227     8.198
16 Shoreline Septic Use  cap/yr           61.50     0.000     0.027    0.077     0.000
21 Septic P Factor (kg/cap-yr)             0.05     0.200    33.710    0.077     0.217
24 Conifer For P  mg/m3                   15.00     0.200     0.070    0.048     0.084
25 Hardwood For P mg/m3                   15.00     0.200     0.140    0.097     0.339
26 Mixed For P  mg/m3                     15.00     0.200     0.070    0.048     0.084
27 Untilled Agric P  mg/m3                15.00     0.200     0.098    0.068     0.165
28 Tilled Agric P  mg/m3                  57.00     0.111     0.074    0.193     0.411
29 Urban P  mg/m3                        139.00     0.223     0.017    0.108     0.529
31 Wetland P mg/m3                        15.00     0.200     0.019    0.013     0.006
32 Atmos P Load kg/km2-yr                 30.00     0.333     0.252    0.347    12.120
35 Error - Watshd                          1.00     0.300    12.527    0.575    26.925
 6 Error - P Reten                         1.00     0.550    -9.397   -0.431    50.922
```

Curtis

```
runl-sensitivity
PREDICTED VARIABLE                          MEAN  STD DEV        CV       5%       95%

 1 Total P Load  kg/yr                     71.69    23.11      0.32    37.62    136.62
 2 Undeveloped P Load  kg/yr               17.89     7.03      0.39     8.15     39.28
 3 Agricultural P Load  kg/yr              16.77     6.48      0.39     7.74     36.33
 4 Urban Runoff P Load  kg/yr              24.73    10.70      0.43    10.41     58.76
 5 Atmospheric P Load  kg/yr                9.30     3.10      0.33     4.77     18.11
 6 Septic P Load  kg/yr                     3.00     0.60      0.20     2.01      4.48
 7 Inflow P Conc  mg/m3                    32.23     8.69      0.27    18.80     55.28
 8 Overflow Rate  m/yr                      7.17     1.56      0.22     4.64     11.10
 9 Residence Time  yr                       0.46     0.10      0.22     0.30      0.71
10 1 - P Retent Coef                        0.63     0.13      0.20     0.42      0.95
11 P Spring  mg/m3                         20.40     6.82      0.33    10.45     39.82
12 Chlorophyll-a  mg/m3                     8.54     4.15      0.49     3.23     22.55
13 Max Chl-a  mg/m3                        18.67     9.96      0.53     6.42     54.25
14 Secchi Depth  m                          3.41     1.79      0.53     1.19      9.76
15 Oxygen Depl Rate  g/m2-day               0.00     0.00      0.00     0.00      0.00
16 Hypol Depth  m                           0.00     0.00      0.00     0.00      0.00
17 Days of O2 Supply                        0.00     0.00      0.00     0.00      0.00
18 P Residence Time  yrs                    0.29     0.08      0.27     0.17      0.50
19 TS Discr Score                           0.03     0.01      0.27     0.02      0.05
20 Prob(Eutrophic)                          0.06     0.08      1.46    -0.11      0.22
21 Prob(Mesotrophic)                        0.84     0.02      0.03     0.79      0.88
22 Prob(Oligotrophic)                       0.11     0.10      0.96    -0.10      0.32

runl-sensitivity

REDICTED VARIABLE: 11  P Spring  mg/m3
EAN = 20.4006          STD. DEV. = 6.82163        CV = .334384

INPUT VARIABLE                              MEAN       CV    DY/DX  DLY/DLX    % VAR.

 1 Conifer For Area  km2                    0.60    0.000   -2.018   -0.060     0.000
 2 Hardwood For Area  km2                   1.14    0.000   -2.015   -0.112     0.000
 3 Mixed For Area  km2                      0.22    0.000   -2.021   -0.022     0.000
 4 Untilled Agric Area  km2                 0.85    0.000   -2.017   -0.084     0.000
 5 Tilled Agric Area  km2                   0.27    0.000    5.101    0.067     0.000
 6 Urban  Area  km2                         0.30    0.000   19.003    0.278     0.000
 7 Lake  Area  km2                          0.31    0.000   -6.861   -0.104     0.000
 9 Wetland Area  km2                        0.04    0.000   -2.031   -0.004     0.000
11 Mean Depth  m                            3.32    0.000   -1.009   -0.164     0.000
15 Runoff  m/yr                             0.60    0.218   -0.202   -0.006     0.001
16 Shoreline Septic Use  cap/yr            60.00    0.000    0.014    0.042     0.000
21 Septic P Factor (kg/cap-yr)              0.05    0.200   17.071    0.042     0.063
24 Conifer For P  mg/m3                    15.00    0.200    0.102    0.075     0.202
25 Hardwood For P mg/m3                    15.00    0.200    0.193    0.142     0.722
26 Mixed For P  mg/m3                      15.00    0.200    0.038    0.028     0.027
27 Untilled Agric P  mg/m3                 15.00    0.200    0.145    0.106     0.404
28 Tilled Agric P  mg/m3                   57.00    0.111    0.046  [illegible]   0.178
29 Urban P  mg/m3                         139.00    0.223    0.051
31 Wetland P mg/m3                         15.00    0.200    0.006
32 Atmos P Load kg/km2-yr                  30.00    0.333    0.088
35 Error - Watshd                           1.00    0.300   16.900
 6 Error - P Reten                          1.00    0.550   -7.462
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Elmore

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run1-sensitivity
PREDICTED VARIABLE                          MEAN  STD DEV         CV        5%        95%

 1 Total P Load  kg/yr                    408.98   127.70       0.31    219.02     763.69
 2 Undeveloped P Load  kg/yr              203.50    73.18       0.36     99.13     417.76
 3 Agricultural P Load  kg/yr              61.47    21.56       0.35     30.48     123.96
 4 Urban Runoff P Load  kg/yr             101.02    40.55       0.40     45.26     225.46
 5 Atmospheric P Load  kg/yr               27.30     9.10       0.33     14.02      53.17
 6 Septic P Load  kg/yr                    15.68     3.14       0.20     10.51      23.40
 7 Inflow P Conc  mg/m3                    22.47     6.38       0.28     12.74      39.65
 8 Overflow Rate  m/yr                     20.00     2.93       0.15     14.93      26.80
 9 Residence Time  yr                       0.17     0.03       0.14      0.13       0.23
10 1 - P Retent Coef                        0.73     0.11       0.15      0.54       0.98
11 P Spring  mg/m3                         16.36     5.24       0.32      8.62      31.05
12 Chlorophyll-a  mg/m3                     6.94     3.31       0.48      2.67      18.01
13 Max Chl-a  mg/m3                        14.68     7.68       0.52      5.16      41.80
14 Secchi Depth  m                          3.95     2.01       0.51      1.43      10.92
15 Oxygen Depl Rate  g/m2-day               0.00     0.00       0.00      0.00       0.00
16 Hypol Depth  m                           0.00     0.00       0.00      0.00       0.00
17 Days of O2 Supply                        0.00     0.00       0.00      0.00       0.00
18 P Residence Time  yrs                    0.13     0.02       0.20      0.09       0.19
19 TS Discr Score                           0.03     0.01       0.28      0.02       0.05
20 Prob(Eutrophic)                          0.04     0.06       1.63     -0.09       0.17
21 Prob(Mesotrophic)                        0.82     0.07       0.08      0.69       0.96
22 Prob(Oligotrophic)                       0.14     0.13       0.98     -0.13       0.40

run1-sensitivity

 REDICTED VARIABLE: 11   P Spring  mg/m3
  EAN = 16.3591           STD. DEV. = 5.24078       CV = .320359

INPUT VARIABLE                              MEAN         CV     DY/DX   DLY/DLX     % VAR.

 1 Conifer For Area  km2                    5.09      0.000    -0.167    -0.052      0.000
 2 Hardwood For Area  km2                   8.69      0.000    -0.167    -0.089      0.000
 3 Mixed For Area  km2                      1.15      0.000    -0.168    -0.012      0.000
 4 Untilled Agric Area  km2                 2.03      0.000    -0.168    -0.021      0.000
 5 Tilled Agric Area  km2                   0.68      0.000     1.325     0.055      0.000
 6 Urban  Area  km2                         0.82      0.000     4.238     0.212      0.000
 7 Lake  Area  km2                          0.91      0.000    -1.693    -0.094      0.000
 8 Upstr Lake Area  km2                     0.10      0.000    -0.169    -0.001      0.000
 9 Wetland Area  km2                        1.01      0.000    -0.168    -0.010      0.000
10 Upstr Lake Ret Fac  km2                  0.77      0.000    -0.533    -0.025      0.000
11 Mean Depth  m                            3.49      0.000    -0.572    -0.122      0.000
15 Runoff  m/yr                             0.89      0.146     0.322     0.017      0.006
16 Shoreline Septic Use  cap/yr           313.68      0.000     0.002     0.038      0.000
20 Inflow Conc of Upst Lakes (mg           15.00      0.200    -0.027    -0.025      0.025
21 Septic P Factor (kg/cap-yr)              0.05      0.200    12.547     0.038      0.057
24 Conifer For P  mg/m3                    15.00      0.200     0.181     0.166      1.074
25 Hardwood For P mg/m3                    15.00      0.200     0.309     0.283      3.128
26 Mixed For P  mg/m3                      15.00      0.200     0.041     0.037      0.055
27 Untilled Agric P  mg/m3                 15.00      0.200     0.072     0.066      0.171
28 Tilled Agric P  mg/m3                   57.00      0.111     0.024     0.084      0.084
29 Urban P  mg/m3                         139.00      0.223     0.029     0.247      2.957
 0 Upstream Lake P mg/m3                   15.00      0.200     0.003     0.003      0.000
  Wetland P mg/m3                          15.00      0.200     0.036     0.033      0.042
32 Atmos P Load kg/km2-yr                  30.00      0.333     0.036     0.067      0.483
35 Error - Watshd                           1.00      0.300    14.640     0.895     70.229
36 Error - P Reten                          1.00      0.550    -4.438    -0.271     21.689
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Fairfield

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runl-sensitivity
PREDICTED VARIABLE                             MEAN   STD DEV       CV        5%       95%

 1 Total P Load  kg/yr                       356.93    106.01     0.30    197.07    646.47
 2 Undeveloped P Load  kg/yr                 148.53     55.05     0.37     70.77    311.72
 3 Agricultural P Load  kg/yr                 33.07     11.58     0.35     16.41     66.64
 4 Urban Runoff P Load  kg/yr                111.43     44.98     0.40     49.70    249.80
 5 Atmospheric P Load  kg/yr                  56.40     18.80     0.33     28.96    109.85
 6 Septic P Load  kg/yr                        7.50      1.50     0.20      5.03     11.19
 7 Inflow P Conc  mg/m3                       26.74      7.24     0.27     15.56     45.95
 8 Overflow Rate  m/yr                         7.10      1.08     0.15      5.24      9.63
 9 Residence Time  yr                          1.02      0.15     0.15      0.75      1.38
10 1 - P Retent Coef                           0.55      0.14     0.25      0.33      0.90
11 P Spring  mg/m3                            14.64      5.36     0.37      7.04     30.44
12 Chlorophyll-a  mg/m3                        6.25      3.16     0.51      2.28     17.17
13 Max Chl-a  mg/m3                           13.01      7.25     0.56      4.27     39.67
14 Secchi Depth  m                             4.23      2.18     0.51      1.51     11.84
15 Oxygen Depl Rate  g/m2-day                  0.40      0.17     0.41      0.17      0.91
16 Hypol Depth  m                              2.84      0.00     0.00      2.84      2.84
17 Days of O2 Supply                          85.27     35.33     0.41     37.24    195.28
18 P Residence Time  yrs                       0.56      0.15     0.28      0.32      0.97
19 TS Discr Score                              0.02      0.01     0.27      0.01      0.04
20 Prob(Eutrophic)                             0.01      0.02     1.88     -0.02      0.04
21 Prob(Mesotrophic)                           0.69      0.21     0.31      0.26      1.12
22 Prob(Oligotrophic)                          0.30      0.23     0.77     -0.16      0.76

runl-sensitivity

REDICTED VARIABLE: 11   P Spring  mg/m3
EAN = 14.637            STD. DEV. = 5.35797       CV = .366057

INPUT VARIABLE                                 MEAN        CV     DY/DX   DLY/DLX    % VAR.

 1 Conifer For Area  km2                       1.47     0.000    -0.220    -0.022     0.000
 2 Hardwood For Area  km2                      8.83     0.000    -0.219    -0.132     0.000
 3 Mixed For Area  km2                         1.08     0.000    -0.220    -0.016     0.000
 4 Untilled Agric Area  km2                    0.73     0.000    -0.220    -0.011     0.000
 5 Tilled Agric Area  km2                      0.49     0.000     1.250     0.042     0.000
 6 Urban  Area  km2                            0.94     0.000     4.118     0.264     0.000
 7 Lake  Area  km2                             1.88     0.000    -1.094    -0.141     0.000
 9 Wetland Area  km2                           0.22     0.000    -0.220    -0.003     0.000
11 Mean Depth  m                               7.23     0.000    -0.410    -0.203     0.000
15 Runoff  m/yr                                0.85     0.152     0.429     0.025     0.011
16 Shoreline Septic Use  cap/yr              150.00     0.000     0.002     0.021     0.000
21 Septic P Factor (kg/cap-yr)                 0.05     0.200     6.151     0.021     0.013
24 Conifer For P  mg/m3                       15.00     0.200     0.051     0.053     0.083
25 Hardwood For P mg/m3                       15.00     0.200     0.309     0.317     2.997
26 Mixed For P  mg/m3                         15.00     0.200     0.038     0.039     0.045
27 Untilled Agric P  mg/m3                    15.00     0.200     0.026     0.026     0.021
28 Tilled Agric P  mg/m3                      57.00     0.111     0.017     0.066     0.040
29 Urban P  mg/m3                            139.00     0.223     0.033     0.312     3.617
31 Wetland P mg/m3                            15.00     0.200     0.008     0.008     0.002
32 Atmos P Load kg/km2-yr                     30.00     0.333     0.077     0.158     2.070
35 Error - Watshd                              1.00     0.300    12.016     0.821    45.269
 6 Error - P Reten                             1.00     0.550    -6.595    -0.451    45.833
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Harveys

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runl-sensitivity
PREDICTED VARIABLE                          MEAN   STD DEV       CV       5%      95%

 1 Total P Load  kg/yr                    213.12     69.13     0.32   111.40   407.72
 2 Undeveloped P Load  kg/yr               92.74     41.08     0.44    38.24   224.90
 3 Agricultural P Load  kg/yr              38.40     17.10     0.45    15.76    93.54
 4 Urban Runoff P Load  kg/yr              23.26     11.18     0.48     8.90    60.81
 5 Atmospheric P Load  kg/yr               49.80     16.60     0.33    25.57    97.00
 6 Septic P Load  kg/yr                     8.93      1.79     0.20     5.98    13.31
 7 Inflow P Conc  mg/m3                    23.94      6.06     0.25    14.42    39.72
 8 Overflow Rate  m/yr                      5.36      1.62     0.30     2.93     9.81
 9 Residence Time  yr                       3.30      0.99     0.30     1.81     6.00
10 1 - P Retent Coef                        0.42      0.14     0.33     0.22     0.80
11 P Spring  mg/m3                          9.96      3.98     0.40     4.48    22.13
12 Chlorophyll-a  mg/m3                     4.35      2.29     0.53     1.52    12.49
13 Max Chl-a  mg/m3                         8.56      4.99     0.58     2.66    27.50
14 Secchi Depth  m                          5.30      2.63     0.50     1.96    14.30
15 Oxygen Depl Rate  g/m2-day               0.35      0.15     0.44     0.14     0.84
16 Hypol Depth  m                          15.10      0.00     0.00    15.10    15.10
17 Days of O2 Supply                      519.27    229.22     0.44   214.77  1255.46
18 P Residence Time  yrs                    1.37      0.53     0.39     0.63     2.98
19 TS Discr Score                           0.02      0.00     0.24     0.01     0.03
20 Prob(Eutrophic)                          0.00      0.00     2.31    -0.00     0.00
21 Prob(Mesotrophic)                        0.31      0.23     0.75    -0.15     0.77
22 Prob(Oligotrophic)                       0.69      0.23     0.34     0.23     1.15

runl-sensitivity

PREDICTED VARIABLE: 11   P Spring  mg/m3
MEAN = 9.95992            STD. DEV. = 3.97547       CV = .399146

INPUT VARIABLE                              MEAN        CV    DY/DX  DLY/DLX    % VAR.

 1 Conifer For Area  km2                    7.14     0.000   -0.053   -0.038     0.000
 2 Hardwood For Area  km2                   4.87     0.000   -0.053   -0.026     0.000
 3 Mixed For Area  km2                      1.22     0.000   -0.053   -0.006     0.000
 4 Untilled Agric Area  km2                 3.67     0.000   -0.053   -0.020     0.000
 5 Tilled Agric Area  km2                   0.60     0.000    0.792    0.048     0.000
 6 Urban  Area  km2                         0.39     0.000    2.441    0.095     0.000
 7 Lake  Area  km2                          1.66     0.000   -0.524   -0.087     0.000
 9 Wetland Area  km2                        1.14     0.000   -0.053   -0.006     0.000
11 Mean Depth  m                           17.70     0.000   -0.147   -0.261     0.000
15 Runoff  m/yr                             0.43     0.302   -0.278   -0.012     0.008
16 Shoreline Septic Use  cap/yr           178.50     0.000    0.002    0.042     0.000
21 Septic P Factor (kg/cap-yr)              0.05     0.200    8.343    0.042     0.044
24 Conifer For P  mg/m3                    15.00     0.200    0.144    0.216     1.175
25 Hardwood For P mg/m3                    15.00     0.200    0.098    0.147     0.546
26 Mixed For P  mg/m3                      15.00     0.200    0.024    0.037     0.034
27 Untilled Agric P  mg/m3                 15.00     0.200    0.074    0.111     0.311
28 Tilled Agric P  mg/m3                   57.00     0.111    0.012    0.069     0.036
29 Urban P  mg/m3                         139.00     0.223    0.008    0.109     0.372
31 Wetland P mg/m3                         15.00     0.200    0.023    0.034     0.030
32 Atmos P Load kg/km2-yr                  30.00     0.333    0.078    0.234     3.808
35 Error - Watshd                           1.00     0.300    7.215    0.724    29.648
[illegible]6 Error - P Reten                            1.00     0.550   -5.782   -0.581    63.988
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Hortonia

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runl-sensitivity
PREDICTED VARIABLE                        MEAN   STD DEV       CV       5%       95%

 1 Total P Load  kg/yr                   195.80    63.19      0.32   102.68    373.36
 2 Undeveloped P Load  kg/yr              53.39    25.96      0.49    20.19    141.20
 3 Agricultural P Load  kg/yr             17.22     7.59      0.44     7.13     41.57
 4 Urban Runoff P Load  kg/yr             64.29    30.88      0.48    24.60    168.01
 5 Atmospheric P Load  kg/yr              54.60    18.20      0.33    28.03    106.35
 6 Septic P Load  kg/yr                    6.30     1.26      0.20     4.22      9.40
 7 Inflow P Conc  mg/m3                   25.43     6.71      0.26    15.00     43.10
 8 Overflow Rate  m/yr                     4.23     1.28      0.30     2.31      7.73
 9 Residence Time  yr                      1.32     0.39      0.30     0.73      2.40
10 1 - P Retent Coef                       0.52     0.14      0.27     0.30      0.89
11 P Spring  mg/m3                        13.18     4.78      0.36     6.38     27.20
12 Chlorophyll-a  mg/m3                    5.66     2.85      0.50     2.07     15.48
13 Max Chl-a  mg/m3                       11.60     6.44      0.55     3.83     35.18
14 Secchi Depth  m                         4.51     2.29      0.51     1.64     12.43
15 Oxygen Depl Rate  g/m2-day              0.43     0.18      0.41     0.19      0.99
16 Hypol Depth  m                          3.63     0.00      0.00     3.63      3.63
17 Days of O2 Supply                     100.62    41.45      0.41    44.14    229.35
18 P Residence Time  yrs                   0.68     0.24      0.35     0.34      1.39
19 TS Discr Score                          0.02     0.00      0.25     0.01      0.03
20 Prob(Eutrophic)                         0.00     0.00      2.01    -0.01      0.01
21 Prob(Mesotrophic)                       0.51     0.26      0.50    -0.00      1.03
22 Prob(Oligotrophic)                      0.48     0.26      0.54    -0.04      1.01

runl-sensitivity

PREDICTED VARIABLE: 11  P Spring  mg/m3
 EAN = 13.1773            STD. DEV. = 4.77538       CV = .362393

INPUT VARIABLE                            MEAN        CV     DY/DX   DLY/DLX    % VAR.

 1 Conifer For Area  km2                   1.61     0.000    -0.142    -0.017     0.000
 2 Hardwood For Area  km2                  7.73     0.000    -0.142    -0.083     0.000
 3 Mixed For Area  km2                     2.48     0.000    -0.142    -0.027     0.000
 4 Untilled Agric Area  km2                1.36     0.000    -0.143    -0.015     0.000
 5 Tilled Agric Area  km2                  0.34     0.000     1.076     0.028     0.000
 6 Urban  Area  km2                        1.07     0.000     3.454     0.281     0.000
 7 Lake  Area  km2                         1.82     0.000    -0.125    -0.017     0.000
 8 Upstr Lake Area  km2                    0.59     0.000    -0.143    -0.006     0.000
 9 Wetland Area  km2                       0.86     0.000    -0.143    -0.009     0.000
10 Upstr Lake Ret Fac  km2                 5.01     0.000    -0.435    -0.166     0.000
11 Mean Depth  m                           5.59     0.000    -0.508    -0.216     0.000
15 Runoff  m/yr                            0.43     0.302    -2.840    -0.093     0.598
16 Shoreline Septic Use  cap/yr          126.00     0.000     0.003     0.032     0.000
20 Inflow Conc of Upst Lakes (mg          15.00     0.200    -0.145    -0.166     0.834
21 Septic P Factor (kg/cap-yr)             0.05     0.200     8.480     0.032     0.032
24 Conifer For P  mg/m3                   15.00     0.200     0.047     0.053     0.086
25 Hardwood For P mg/m3                   15.00     0.200     0.224     0.255     1.985
26 Mixed For P  mg/m3                     15.00     0.200     0.072     0.082     0.205
27 Untilled Agric P  mg/m3                15.00     0.200     0.039     0.045     0.061
28 Tilled Agric P  mg/m3                  57.00     0.111     0.010     0.043     0.017
29 Urban P  mg/m3                        139.00     0.223     0.031     0.328     4.084
30 Upstream Lake P mg/m3                  15.00     0.200     0.017     0.020     0.012
 1 Wetland P mg/m3                        15.00     0.200     0.025     0.028     0.024
 2 Atmos P Load kg/km2-yr                 30.00     0.333     0.122     0.279     6.579
35 Error - Watshd                          1.00     0.300     9.079     0.689    32.529
36 Error - P Reten                         1.00     0.550    -6.318    -0.479    52.955
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Iroquois

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runl-sensitivity
PREDICTED VARIABLE                        MEAN  STD DEV       CV       5%       95%

 1 Total P Load  kg/yr                  119.84    46.03     0.38    55.59    258.35
 2 Undeveloped P Load  kg/yr             22.38    11.20     0.50     8.23     60.87
 3 Agricultural P Load  kg/yr            25.94    12.83     0.49     9.65     69.74
 4 Urban Runoff P Load  kg/yr            42.87    22.82     0.53    14.78    124.28
 5 Atmospheric P Load  kg/yr             24.90     8.30     0.33    12.78     48.50
 6 Septic P Load  kg/yr                   3.75     0.75     0.20     2.51      5.59
 7 Inflow P Conc  mg/m3                  39.16    10.54     0.27    22.86     67.08
 8 Overflow Rate  m/yr                    3.69     1.40     0.38     1.73      7.87
 9 Residence Time  yr                     1.57     0.59     0.38     0.74      3.32
10 1 - P Retent Coef                      0.50     0.14     0.29     0.28      0.89
11 P Spring  mg/m3                       19.54     7.30     0.37     9.26     41.26
12 Chlorophyll-a  mg/m3                   8.20     4.18     0.51     2.96     22.75
13 Max Chl-a  mg/m3                      17.82    10.04     0.56     5.78     54.97
14 Secchi Depth  m                        3.51     1.88     0.54     1.20     10.24
15 Oxygen Depl Rate  g/m2-day             0.40     0.17     0.42     0.17      0.92
16 Hypol Depth  m                         2.30     0.00     0.00     2.30      2.30
17 Days of O2 Supply                     69.63    29.28     0.42    30.02    161.47
18 P Residence Time  yrs                  0.78     0.31     0.40     0.35      1.74
19 TS Discr Score                         0.03     0.01     0.26     0.02      0.05
20 Prob(Eutrophic)                        0.03     0.04     1.54    -0.06      0.12
21 Prob(Mesotrophic)                      0.81     0.10     0.12     0.61      1.00
22 Prob(Oligotrophic)                     0.17     0.14     0.86    -0.12      0.45

runl-sensitivity

PREDICTED VARIABLE: 11   P Spring  mg/m3
MEAN = 19.5437          STD. DEV. = 7.30121      CV = .373583

INPUT VARIABLE                            MEAN       CV    DY/DX  DLY/DLX    % VAR.

 1 Conifer For Area  km2                  0.69    0.000   -0.857   -0.030     0.000
 2 Hardwood For Area  km2                 2.62    0.000   -0.856   -0.115     0.000
 3 Mixed For Area  km2                    0.50    0.000   -0.857   -0.022     0.000
 4 Untilled Agric Area  km2               2.06    0.000   -0.856   -0.090     0.000
 5 Tilled Agric Area  km2                 0.78    0.000    1.491    0.060     0.000
 6 Urban  Area  km2                       0.90✓   0.000    6.076    0.279     0.000
 7 Lake  Area  km2                        0.83    0.000   -2.094   -0.089     0.000
 9 Wetland Area  km2                      0.54    0.000   -0.858   -0.024     0.000
11 Mean Depth  m                          5.78    0.000   -0.759   -0.224     0.000
15 Runoff  m/yr                           0.34    0.379   -0.738   -0.013     0.017
16 Shoreline Septic Use  cap/yr          75.00    0.000    0.008    0.031     0.000
21 Septic P Factor (kg/cap-yr)            0.05    0.200   12.230    0.031     0.028
24 Conifer For P  mg/m3                  15.00    0.200    0.038    0.029     0.025
25 Hardwood For P mg/m3                  15.00    0.200    0.147    0.113     0.364
26 Mixed For P  mg/m3                    15.00    0.200    0.028    0.021     0.013
27 Untilled Agric P  mg/m3               15.00    0.200    0.115    0.088     0.224
28 Tilled Agric P  mg/m3                 57.00    0.111    0.044    0.128     0.144
29 Urban P  mg/m3                       139.00    0.223    0.050    0.358     4.560
31 Wetland P mg/m3                       15.00    0.200    0.030    0.023     0.016
32 Atmos P Load kg/km2-yr                30.00    0.333    0.135    0.208     3.437
35 Error - Watshd                         1.00    0.300   14.871    0.761    37.339
36 Error - P Reten                        1.00    0.550   -9.740   -0.498    53.835
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runl-sensitivity
PREDICTED VARIABLE                        MEAN  STD DEV       CV         5%        95%

 1 Total P Load  kg/yr                  240.12    71.16     0.30     132.75     434.34
 2 Undeveloped P Load  kg/yr            106.95    47.48     0.44      44.01     259.87
 3 Agricultural P Load  kg/yr            16.91     7.48     0.44       6.98      40.97
 4 Urban Runoff P Load  kg/yr            32.17    15.26     0.47      12.46      83.08
 5 Atmospheric P Load  kg/yr             65.40    21.80     0.33      33.58     127.38
 6 Septic P Load  kg/yr                  18.69     3.74     0.20      12.53      27.88
 7 Inflow P Conc  mg/m3                  26.09     6.50     0.25      15.85      42.93
 8 Overflow Rate  m/yr                    4.22     1.23     0.29       2.35       7.57
 9 Residence Time  yr                     1.97     0.57     0.29       1.10       3.51
10 1 - P Retent Coef                      0.47     0.14     0.30       0.26       0.86
11 P Spring  mg/m3                       12.35     4.55     0.37       5.91      25.82
12 Chlorophyll-a  mg/m3                   5.33     2.70     0.51       1.93      14.69
13 Max Chl-a  mg/m3                      10.82     6.05     0.56       3.53      33.11
14 Secchi Depth  m                        4.69     2.36     0.50       1.71      12.85
15 Oxygen Depl Rate  g/m2-day             0.39     0.16     0.42       0.17       0.89
16 Hypol Depth  m                         2.00     0.00     0.00       2.00       2.00
17 Days of O2 Supply                     62.02    25.87     0.42      26.93     142.82
18 P Residence Time  yrs                  0.93     0.34     0.36       0.45       1.92
19 TS Discr Score                         0.02     0.00     0.23       0.01       0.03
20 Prob(Eutrophic)                        0.00     0.00     1.92      -0.00       0.01
21 Prob(Mesotrophic)                      0.46     0.24     0.52      -0.02       0.94
22 Prob(Oligotrophic)                     0.54     0.24     0.45       0.05       1.02

runl-sensitivity

REDICTED VARIABLE: 11  P Spring  mg/m3
EAN = 12.355            STD. DEV. = 4.55314       CV = .368526

INPUT VARIABLE                            MEAN       CV     DY/DX   DLY/DLX     % VAR.

 1 Conifer For Area  km2                  3.44    0.000    -0.112    -0.031      0.000
 2 Hardwood For Area  km2                11.23    0.000    -0.112    -0.102      0.000
 3 Mixed For Area  km2                    1.26    0.000    -0.112    -0.011      0.000
 4 Untilled Agric Area  km2               1.76    0.000    -0.112    -0.016      0.000
 5 Tilled Agric Area  km2                 0.20    0.000     0.849     0.014      0.000
 6 Urban  Area  km2                       0.52    0.000     2.727     0.115      0.000
 7 Lake  Area  km2                        2.18    0.000    -0.251    -0.044      0.000
 9 Wetland Area  km2                      0.09    0.000    -0.113    -0.001      0.000
11 Mean Depth  m                          8.30    0.000    -0.351    -0.236      0.000
15 Runoff  m/yr                           0.45    0.292    -3.104    -0.112      0.785
16 Shoreline Septic Use  cap/yr         373.82    0.000     0.003     0.078      0.000
21 Septic P Factor (kg/cap-yr)            0.05    0.200    19.236     0.078      0.178
24 Conifer For P  mg/m3                  15.00    0.200     0.079     0.096      0.270
25 Hardwood For P mg/m3                  15.00    0.200     0.257     0.312      2.872
26 Mixed For P  mg/m3                    15.00    0.200     0.029     0.035      0.036
27 Untilled Agric P  mg/m3               15.00    0.200     0.040     0.049      0.070
28 Tilled Agric P  mg/m3                 57.00    0.111     0.005     0.022      0.004
29 Urban P  mg/m3                       139.00    0.223     0.012     0.134      0.657
31 Wetland P mg/m3                       15.00    0.200     0.002     0.002      0.000
32 Atmos P Load kg/km2-yr                30.00    0.333     0.112     0.272      6.069
35 Error - Watshd                         1.00    0.300     8.028     0.650     27.981
 6 Error - P Reten                        1.00    0.550    -6.470    -0.524     61.077
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Parker

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runl-sensitivity
PREDICTED VARIABLE                     MEAN  STD DEV      CV      5%       95%

[illegible] Total P Load  kg/yr                 362.16   119.27     0.33   187.44    699.75
 2 Undeveloped P Load  kg/yr          100.88    38.30     0.38    47.21    215.56
 3 Agricultural P Load  kg/yr         179.25    66.66     0.37    85.20    377.11
 4 Urban Runoff P Load  kg/yr          45.14    19.02     0.42    19.43    104.84
 5 Atmospheric P Load  kg/yr           29.10     9.70     0.33    14.94     56.68
 6 Septic P Load  kg/yr                 7.80     1.56     0.20     5.23     11.64
 7 Inflow P Conc  mg/m3                25.21     7.06     0.28    14.41     44.13
 8 Overflow Rate  m/yr                 14.81     2.88     0.19    10.04     21.85
 9 Residence Time  yr                   0.51     0.10     0.19     0.35      0.76
10 1 - P Retent Coef                    0.62     0.13     0.21     0.41      0.95
11 P Spring  mg/m3                     15.68     5.46     0.35     7.82     31.45
12 Chlorophyll-a  mg/m3                 6.67     3.29     0.49     2.48     17.90
13 Max Chl-a  mg/m3                    14.02     7.62     0.54     4.73     41.59
14 Secchi Depth  m                      4.05     2.08     0.51     1.45     11.33
15 Oxygen Depl Rate  g/m2-day           0.45     0.18     0.40     0.20      1.00
16 Hypol Depth  m                       3.05     0.00     0.00     3.05      3.05
17 Days of O2 Supply                   81.57    32.60     0.40    36.67    181.40
18 P Residence Time  yrs                0.32     0.08     0.26     0.19      0.54
19 TS Discr Score                       0.03     0.01     0.28     0.02      0.05
20 Prob(Eutrophic)                      0.03     0.05     1.70    -0.06      0.12
21 Prob(Mesotrophic)                    0.80     0.11     0.14     0.57      1.03
22 Prob(Oligotrophic)                   0.17     0.16     0.93    -0.15      0.49

runl-sensitivity

PREDICTED VARIABLE: 11   P Spring  mg/m3
MEAN = 15.6829            STD. DEV. = 5.45552      CV = .347865

INPUT VARIABLE                         MEAN       CV    DY/DX  DLY/DLX    % VAR.

 1 Conifer For Area  km2               5.04    0.000   -0.171   -0.055     0.000
 2 Hardwood For Area  km2              3.80    0.000   -0.171   -0.041     0.000
 3 Mixed For Area  km2                 1.11    0.000   -0.172   -0.012     0.000
 4 Untilled Agric Area  km2            6.80    0.000   -0.171   -0.074     0.000
 5 Tilled Agric Area  km2              2.91    0.000    1.043    0.194     0.000
 6 Urban  Area  km2                    0.49    0.000    3.417    0.106     0.000
 7 Lake  Area  km2                     0.97    0.000   -2.046   -0.127     0.000
 8 Upstr Lake Area  km2                0.05    0.000   -0.169   -0.001     0.000
 9 Wetland Area  km2                   0.32    0.000   -0.172   -0.003     0.000
10 Upstr Lake Ret Fac  km2             0.26    0.000   -0.434   -0.007     0.000
11 Mean Depth  m                       7.61    0.000   -0.349   -0.169     0.000
15 Runoff  m/yr                        0.67    0.195    1.598    0.068     0.145
16 Shoreline Septic Use  cap/yr      156.00    0.000    0.002    0.022     0.000
20 Inflow Conc of Upst Lakes (mg      15.00    0.200   -0.007   -0.007     0.002
21 Septic P Factor (kg/cap-yr)         0.05    0.200    6.754    0.022     0.015
24 Conifer For P  mg/m3               15.00    0.200    0.146    0.139     0.642
25 Hardwood For P mg/m3               15.00    0.200    0.110    0.105     0.366
26 Mixed For P  mg/m3                 15.00    0.200    0.032    0.031     0.031
27 Untilled Agric P  mg/m3            15.00    0.200    0.197    0.188     1.172
28 Tilled Agric P  mg/m3              57.00    0.111    0.084    0.307     0.949
29 Urban P  mg/m3                    139.00    0.223    0.014    0.125     0.638
30 Upstream Lake P mg/m3              15.00    0.200    0.001    0.001     0.000
[illegible] Wetland P mg/m3                    15.00    0.200    0.009    0.009     0.003
32 Atmos P Load kg/km2-yr             30.00    0.333    0.042    0.080     0.593
35 Error - Watshd                      1.00    0.300   14.085    0.898    59.990
36 Error - P Reten                     1.00    0.550   -5.906   -0.377    35.453
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St Catherine

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runl-sensitivity
PREDICTED VARIABLE                        MEAN   STD DEV        CV        5%       95%

 1 Total P Load  kg/yr                  435.46    124.58      0.29    245.73    771.69
 2 Undeveloped P Load  kg/yr            144.81     61.50      0.42     61.93    338.58
 3 Agricultural P Load  kg/yr            62.23     25.61      0.41     27.32    141.74
 4 Urban Runoff P Load  kg/yr            84.20     38.37      0.46     33.84    209.48
 5 Atmospheric P Load  kg/yr            103.50     34.50      0.33     53.14    201.59
 6 Septic P Load  kg/yr                  40.72      8.14      0.20     27.30     60.75
 7 Inflow P Conc  mg/m3                  28.95      7.02      0.24     17.83     47.01
 8 Overflow Rate  m/yr                    4.36      1.14      0.26      2.59      7.34
 9 Residence Time  yr                     2.46      0.63      0.26      1.47      4.12
10 1 - P Retent Coef                      0.45      0.14      0.31      0.24      0.83
11 P Spring  mg/m3                       12.99      4.91      0.38      6.10     27.66
12 Chlorophyll-a  mg/m3                   5.58      2.86      0.51      2.00     15.58
13 Max Chl-a  mg/m3                      11.42      6.47      0.57      3.68     35.48
14 Secchi Depth  m                        4.55      2.32      0.51      1.64     12.62
15 Oxygen Depl Rate  g/m2-day             0.47      0.20      0.42      0.20      1.10
16 Hypol Depth  m                         5.42      0.00      0.00      5.42      5.42
17 Days of O2 Supply                    138.44     58.78      0.42     59.21    323.64
18 P Residence Time  yrs                  1.10      0.40      0.36      0.54      2.26
19 TS Discr Score                         0.02      0.00      0.23      0.01      0.03
20 Prob(Eutrophic)                        0.00      0.00      1.82     -0.01      0.01
21 Prob(Mesotrophic)                      0.53      0.24      0.44      0.06      1.00
22 Prob(Oligotrophic)                     0.47      0.24      0.51     -0.01      0.95

runl-sensitivity

PREDICTED VARIABLE: 11  P Spring  mg/m3
 EAN = 12.9854          STD. DEV. = 4.9086       CV = .378009

INPUT VARIABLE                            MEAN        CV     DY/DX   DLY/DLX    % VAR.

 1 Conifer For Area  km2                  3.38     0.000    -0.101    -0.026     0.000
 2 Hardwood For Area  km2                13.72     0.000    -0.100    -0.106     0.000
 3 Mixed For Area  km2                    2.88     0.000    -0.101    -0.022     0.000
 4 Untilled Agric Area  km2               3.62     0.000    -0.101    -0.028     0.000
 5 Tilled Agric Area  km2                 1.24     0.000     0.524     0.050     0.000
 6 Urban  Area  km2                       1.21     0.000     1.743     0.163     0.000
 7 Lake  Area  km2                        3.45     0.000    -0.360    -0.096     0.000
 8 Upstr Lake Area  km2                   0.09     0.000    -0.100    -0.001     0.000
 9 Wetland Area  km2                      0.58     0.000    -0.100    -0.005     0.000
10 Upstr Lake Ret Fac  km2                1.28     0.000    -0.223    -0.022     0.000
11 Mean Depth  m                         10.72     0.000    -0.299    -0.247     0.000
15 Runoff  m/yr                           0.50     0.261    -2.128    -0.082     0.318
16 Shoreline Septic Use  cap/yr         814.42     0.000     0.001     0.094     0.000
20 Inflow Conc of Upst Lakes (mg         15.00     0.200    -0.019    -0.022     0.014
21 Septic P Factor (kg/cap-yr)            0.05     0.200    24.286     0.094     0.245
24 Conifer For P  mg/m3                  15.00     0.200     0.050     0.058     0.094
25 Hardwood For P mg/m3                  15.00     0.200     0.204     0.236     1.556
26 Mixed For P  mg/m3                    15.00     0.200     0.043     0.049     0.068
27 Untilled Agric P  mg/m3               15.00     0.200     0.054     0.062     0.108
28 Tilled Agric P  mg/m3                 57.00     0.111     0.018     0.081     0.056
29 Urban P  mg/m3                       139.00     0.223     0.018     0.193     1.302
30 Upstream Lake P mg/m3                 15.00     0.200     0.001     0.001     0.000
 1 Wetland P mg/m3                       15.00     0.200     0.009     0.010     0.003
 2 Atmos P Load kg/km2-yr                30.00     0.333     0.103     0.238     4.393
35 Error - Watshd                         1.00     0.300     8.685     0.669    28.174
36 Error - P Reten                        1.00     0.550    -7.121    -0.548    63.671
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Shelburne

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runl-sensitivity
PREDICTED VARIABLE                     MEAN   STD DEV      CV       5%       95%

   Total P Load  kg/yr               260.51    90.40     0.35   130.14   521.47
 2 Undeveloped P Load  kg/yr          41.49    18.14     0.44    17.30    99.49
 3 Agricultural P Load  kg/yr        129.34    56.26     0.43    54.19   308.70
 4 Urban Runoff P Load  kg/yr         35.08    16.77     0.48    13.48    91.29
 5 Atmospheric P Load  kg/yr          54.60    18.20     0.33    28.03   106.35
 6 Septic P Load  kg/yr                0.00     0.00     0.00     0.00     0.00
 7 Inflow P Conc  mg/m3               31.01     8.13     0.26    18.36    52.38
 8 Overflow Rate  m/yr                 4.62     1.38     0.30     2.54     8.38
 9 Residence Time  yr                  0.78     0.23     0.30     0.43     1.41
10 1 - P Retent Coef                   0.58     0.14     0.24     0.36     0.93
11 P Spring  mg/m3                    17.89     6.16     0.34     8.98    35.62
12 Chlorophyll-a  mg/m3                7.55     3.71     0.49     2.82    20.17
13 Max Chl-a  mg/m3                   16.18     8.75     0.54     5.49    47.73
14 Secchi Depth  m                     3.72     1.94     0.52     1.31    10.56
15 Oxygen Depl Rate  g/m2-day          0.00     0.00     0.00     0.00     0.00
16 Hypol Depth  m                      0.00     0.00     0.00     0.00     0.00
17 Days of O2 Supply                   0.00     0.00     0.00     0.00     0.00
18 P Residence Time  yrs               0.45     0.15     0.33     0.23     0.88
19 TS Discr Score                      0.03     0.01     0.26     0.02     0.04
20 Prob(Eutrophic)                     0.02     0.03     1.63    -0.04     0.08
21 Prob(Mesotrophic)                   0.77     0.14     0.19     0.48     1.06
22 Prob(Oligotrophic)                  0.21     0.17     0.81    -0.13     0.56

runl-sensitivity

PREDICTED VARIABLE: 11   P Spring  mg/m3
 EAN = 17.8859           STD. DEV. = 6.1602        CV = .344416

INPUT VARIABLE                         MEAN       CV     DY/DX  DLY/DLX    % VAR.

 1 Conifer For Area  km2               0.76    0.000    -0.302   -0.013    0.000
 2 Hardwood For Area  km2              2.00    0.000    -0.302   -0.034    0.000
 3 Mixed For Area  km2                 0.95    0.000    -0.302   -0.016    0.000
 4 Untilled Agric Area  km2            7.22    0.000    -0.301   -0.122    0.000
 5 Tilled Agric Area  km2              3.31    0.000     0.953    0.176    0.000
 6 Urban  Area  km2                    0.58    0.000     3.408    0.110    0.000
 7 Lake  Area  km2                     1.82    0.000    -0.558   -0.057    0.000
 9 Wetland Area  km2                   2.63    0.000    -0.302   -0.044    0.000
11 Mean Depth  m                       3.61    0.000    -0.940   -0.190    0.000
15 Runoff  m/yr                        0.44    0.298    -0.757   -0.018    0.026
24 Conifer For P  mg/m3               15.00    0.200     0.023    0.019    0.012
25 Hardwood For P mg/m3               15.00    0.200     0.060    0.050    0.085
26 Mixed For P  mg/m3                 15.00    0.200     0.028    0.024    0.019
27 Untilled Agric P  mg/m3            15.00    0.200     0.216    0.181    1.108
28 Tilled Agric P  mg/m3              57.00    0.111     0.099    0.315    1.024
29 Urban P  mg/m3                    139.00    0.223     0.017    0.135    0.760
31 Wetland P mg/m3                    15.00    0.200     0.079    0.066    0.147
32 Atmos P Load kg/km2-yr             30.00    0.333     0.125    0.210    4.115
35 Error - Watshd                      1.00    0.300    14.137    0.790   47.399
36 Error - P Reten                     1.00    0.550    -7.539   -0.421   45.304
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Star

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runl-sensitivity
PREDICTED VARIABLE                          MEAN  STD DEV        CV       5%       95%

 1 Total P Load  kg/yr                      42.13    13.00      0.31    22.72    78.10
 2 Undeveloped P Load  kg/yr                21.89     8.23      0.38    10.32    46.45
 3 Agricultural P Load  kg/yr                4.47     1.74      0.39     2.05     9.74
 4 Urban Runoff P Load  kg/yr                8.27     3.48      0.42     3.56    19.21
 5 Atmospheric P Load  kg/yr                 6.90     2.30      0.33     3.54    13.44
 6 Septic P Load  kg/yr                      0.60     0.12      0.20     0.40     0.90
 7 Inflow P Conc  mg/m3                     21.98     5.85      0.27    12.91    37.43
 8 Overflow Rate  m/yr                       8.33     1.62      0.19     5.65    12.30
 9 Residence Time  yr                        0.18     0.03      0.19     0.12     0.26
10 1 - P Retent Coef                         0.73     0.11      0.15     0.54     0.98
11 P Spring  mg/m3                          15.97     4.85      0.30     8.70    29.31
12 Chlorophyll-a  mg/m3                      6.78     3.17      0.47     2.66    17.27
13 Max Chl-a  mg/m3                         14.30     7.31      0.51     5.14    39.76
14 Secchi Depth  m                           4.01     2.02      0.50     1.46    10.97
15 Oxygen Depl Rate  g/m2-day                0.00     0.00      0.00     0.00     0.00
16 Hypol Depth  m                            0.00     0.00      0.00     0.00     0.00
17 Days of O2 Supply                         0.00     0.00      0.00     0.00     0.00
18 P Residence Time  yrs                     0.13     0.03      0.23     0.08     0.20
19 TS Discr Score                            0.02     0.01      0.26     0.01     0.04
20 Prob(Eutrophic)                           0.01     0.02      1.74    -0.03     0.06
21 Prob(Mesotrophic)                         0.74     0.18      0.24     0.39     1.09
22 Prob(Oligotrophic)                        0.25     0.20      0.80    -0.15     0.64
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runl-sensitivity

PREDICTED VARIABLE: 11  P Spring  mg/m3
EAN = 15.9679          STD. DEV. = 4.85027      CV = .303751

INPUT VARIABLE                              MEAN        CV     DY/DX  DLY/DLX    % VAR.

 1 Conifer For Area  km2                    0.79     0.000    -1.079   -0.054     0.000
 2 Hardwood For Area  km2                   0.91     0.000    -1.078   -0.062     0.000
 3 Mixed For Area  km2                      0.39     0.000    -1.081   -0.026     0.000
 4 Untilled Agric Area  km2                 0.34     0.000    -1.081   -0.023     0.000
 5 Tilled Agric Area  km2                   0.03     0.000     9.550    0.017     0.000
 6 Urban  Area  km2                         0.09     0.000    30.298    0.169     0.000
 7 Lake  Area  km2                          0.23     0.000    -2.029   -0.029     0.000
 9 Wetland Area  km2                        0.09     0.000    -1.082   -0.006     0.000
11 Mean Depth  m                            1.48     0.000    -1.325   -0.123     0.000
15 Runoff  m/yr                             0.67     0.195    -1.295   -0.054     0.120
16 Shoreline Septic Use  cap/yr            12.00     0.000     0.019    0.014     0.000
21 Septic P Factor (kg/cap-yr)              0.05     0.200     4.547    0.014     0.009
24 Conifer For P  mg/m3                    15.00     0.200     0.201    0.189     1.547
25 Hardwood For P mg/m3                    15.00     0.200     0.231    0.217     2.047
26 Mixed For P  mg/m3                      15.00     0.200     0.098    0.092     0.368
27 Untilled Agric P  mg/m3                 15.00     0.200     0.085    0.080     0.279
28 Tilled Agric P  mg/m3                   57.00     0.111     0.007    0.026     0.009
29 Urban P  mg/m3                         139.00     0.223     0.023    0.196     2.076
31 Wetland P mg/m3                         15.00     0.200     0.023    0.021     0.019
32 Atmos P Load kg/km2-yr                  30.00     0.333     0.087    0.164     3.230
35 Error - Watshd                           1.00     0.300    13.125    0.822    65.903
36 Error - P Reten                          1.00     0.550    -4.355   -0.273    24.391
```

Winona

```
runl-sensitivity
PREDICTED VARIABLE                          MEAN   STD DEV       CV        5%       95%

 1 Total P Load  kg/yr                     98.80    37.22      0.38     46.51    209.90
 2 Undeveloped P Load  kg/yr               35.05    18.37      0.52     12.28    100.00
 3 Agricultural P Load  kg/yr              24.80    12.88      0.52      8.77     70.10
 4 Urban Runoff P Load  kg/yr               9.94     5.53      0.56      3.26     30.24
 5 Atmospheric P Load  kg/yr               28.50     9.50      0.33     14.63     55.51
 6 Septic P Load  kg/yr                     0.53     0.10      0.20      0.35      0.78
 7 Inflow P Conc  mg/m3                    27.73     7.42      0.27     16.25     47.35
 8 Overflow Rate  m/yr                      3.75     1.55      0.41      1.64      8.55
 9 Residence Time  yr                       0.27     0.11      0.41      0.12      0.61
10 1 - P Retent Coef                        0.69     0.12      0.18      0.48      0.99
11 P Spring  mg/m3                         19.05     5.73      0.30     10.43     34.76
12 Chlorophyll-a  mg/m3                     8.00     3.73      0.47      3.15     20.32
13 Max Chl-a  mg/m3                        17.32     8.82      0.51      6.26     47.97
14 Secchi Depth  m                          3.57     1.83      0.51      1.28      9.95
15 Oxygen Depl Rate  g/m2-day               0.00     0.00      0.00      0.00      0.00
16 Hypol Depth  m                           0.00     0.00      0.00      0.00      0.00
17 Days of O2 Supply                        0.00     0.00      0.00      0.00      0.00
18 P Residence Time  yrs                    0.19     0.07      0.39      0.09      0.41
19 TS Discr Score                           0.03     0.01      0.24      0.02      0.04
20 Prob(Eutrophic)                          0.02     0.03      1.52     -0.04      0.07
21 Prob(Mesotrophic)                        0.77     0.14      0.18      0.49      1.04
22 Prob(Oligotrophic)                       0.22     0.16      0.75     -0.11      0.54

runl-sensitivity

PREDICTED VARIABLE: 11  P Spring  mg/m3
MEAN = 19.045           STD. DEV. = 5.72999       CV = .300865

INPUT VARIABLE                              MEAN       CV     DY/DX   DLY/DLX    % VAR.

 1 Conifer For Area  km2                    1.11    0.000    -0.536    -0.031     0.000
 2 Hardwood For Area  km2                   4.04    0.000    -0.534    -0.113     0.000
 3 Mixed For Area  km2                      0.78    0.000    -0.536    -0.022     0.000
 4 Untilled Agric Area  km2                 1.81    0.000    -0.535    -0.051     0.000
 5 Tilled Agric Area  km2                   0.90    0.000     2.015     0.096     0.000
 6 Urban  Area  km2                         0.23    0.000     6.999     0.083     0.000
 7 Lake  Area  km2                          0.95    0.000     1.512     0.075     0.000
 9 Wetland Area  km2                        1.49    0.000    -0.535    -0.042     0.000
11 Mean Depth  m                            1.02    0.000    -2.624    -0.140     0.000
15 Runoff  m/yr                             0.32    0.412    -9.128    -0.151     4.288
16 Shoreline Septic Use  cap/yr            10.50    0.000     0.010     0.005     0.000
21 Septic P Factor (kg/cap-yr)              0.05    0.200     2.026     0.005     0.001
24 Conifer For P  mg/m3                    15.00    0.200     0.068     0.053     0.126
25 Hardwood For P mg/m3                    15.00    0.200     0.245     0.193     1.648
26 Mixed For P  mg/m3                      15.00    0.200     0.047     0.037     0.061
27 Untilled Agric P  mg/m3                 15.00    0.200     0.110     0.087     0.331
28 Tilled Agric P  mg/m3                   57.00    0.111     0.055     0.164     0.365
29 Urban P  mg/m3                         139.00    0.223     0.014     0.101     0.556
31 Wetland P mg/m3                         15.00    0.200     0.090     0.071     0.223
32 Atmos P Load kg/km2-yr                  30.00    0.333     0.183     0.288    10.214
35 Error - Watshd                           1.00    0.300    13.450     0.706    49.590
36 Error - P Reten                          1.00    0.550    -5.948    -0.312    32.596
```

APPENDIX D

Charts of Observed and Predicted Lake Responses by Lake and Year

obs: = observed values, symbol = last digit of year
est: = estimated values, symbols L = landsat land use
P = planning map land use
X = "best" land use

* = overlay of two or more symbols

minimum scale values = 0 in each case

```
case:Bomo
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                   0   7*      9                            |
est:|               L     XP                                     |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|        09    1 8                                           |
est:|         L  XP                                              |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|           9             8                                  |
est:|         L   *                                              |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                             18     9   0                   |
est:|                                *      L                    |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                             *                              |
est:|                       L       XP                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Bomoseen

good agreement for all variables
PM closer than LS

```
case:Carm
    +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                 scale max = 35
obs:|                           0*        1  8                  |
est:|                     L     X  P                            |
    +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                             scale max = 25
obs:|                                         1   8       0    9|
est:|            L  X P                                         |
    +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                scale max = 50
obs:|                                                          *|
est:|            L   X P                                        |
    +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                   scale max = 8
obs:|          *1  8                                            |
est:|                        P X    L                           |
    +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                scale max = .75
obs:|              7    1                                       |
est:|                  L     X P                                |
    +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Carmi

model under-predicts lake productivity, as measured by chlorophyll-a and transparency
PM closer than LS
chlorophyll increases dramatically in summer
strong positive bias in observed chlorophyll vs obs. spring P plot
observed summer chl-a/spring P = 1.1
internal and/or seasonal point-source loading indicated
summer phosphorus measurements would be useful and likely to be considerably greater than spring values

```
case:Ceda
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                 8     0       9   7    1                   |
est:|                                L   X                 P     |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|                                                            |
est:|                  L X      P                                |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|                                                            |
est:|                    L  X        P                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                                                            |
est:|                  P    X L                                  |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                                                            |
est:|*                                                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Cedar

model over-predicts spring P
wide variance between LS and PM, LS closer
need better land use definition
atmospheric loading component greatest
assumed runoff value (.31 m/yr) seems low compared with typical (.6 m/yr) and may be partially responsible for error, based upon sensitivity analysis

```
case:Curt
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|            0   9    7  1   8                               |
est:|                    L            X                 P        |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|              7                                             |
est:|           L       X         P                              |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|            7                                               |
est:|            L        X           P                          |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                           7                                |
est:|                  P     X        L                          |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                                                            |
est:|*                                                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Curtis

large variance between LS and PM, LS closer to observed data
LS/PM variance due to differences in urban land use
need better definition of urban land use

```
case:Elmo
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                7  *   01                                   |
est:|                    L      X   P                            |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|      8 *  *                                                |
est:|           L   X  P                                         |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|        *7 0                                                |
est:|            L   X  P                                        |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                    0  * 1                                  |
est:|                         P  X     L                         |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                                                            |
est:|*                                                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Elmore

model over-predicts productivity, as measured by P and Chl-a

LS closer than PM

Over-prediction of transparency due to higher non-algal turbidity/color than other lakes, as indicated by observed secchi vs. chl-a plot

```
case:Fair
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                            *       1    0                  |
est:|                 L   .  XP                                  |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|               8     1        0   9                         |
est:|         L   XP                                             |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|                8                     9                     |
est:|         L    XP                                            |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|               91    0         8                            |
est:|                             PX      L                      |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                                   1                        |
est:|                      L       X P                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Fairfield

productivity under-predicted by all land use estimates

PM closer than LS

phosphorus export probably underestimated for approx. 15% of watershed which is sedimentary

internal loading may also be important, as indicated by internal loading model

```
case:Harv
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                78     90           1                       |
est:|             L  X   P                                       |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|     8 *   0                                                |
est:|        LX P                                                |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|     8 790                                                  |
est:|       L X  P                                               |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                                            9  1  *0        |
est:|                                 P    X  L                  |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                            *                               |
est:|                       L  X      P                          |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Harveys

slight under-prediction of spring P estimates, exaggerated by high 1981 spring P value, which may be an outlier (check)

bias in P may be due to effect of S. Peacham Brook, as described in 1981 report

agreement reasonable for chlorophyll, hod

observed chl estimates variable because of hypolimnetic populations

under-prediction of transparency due to low turbidity and hypolimnetic algal populations, which have no impact on secchi

check morphometry (mean depth)

```
case:Hort
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|              7  8 0 9 1                                    |
est:|              L      *                                      |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|     9 0   1                                                |
est:|        L   *                                               |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|      *                                                     |
est:|        L   XP                                              |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                                 1  0 9                     |
est:|                                *       L                   |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                        7        1     9                    |
est:|                       L         XP                         |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Hortonia

reasonable agreement for all variables
PM closer than PS
meta/hypolimnetic algal populations

```
case:Iroq
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                                         8 9    1 0        7|
est:|                     L          X      P                    |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|                  0  79     8   1                           |
est:|            L     X   P                                     |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|                             9                             8|
est:|             L      X    P                                  |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|              1  8*       0                                 |
est:|                      P  X      L                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                            8     7    *                    |
est:|                     L        X     P                       |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Iroquois

substantial under-prediction of P and productivity
PM closer than LS
errors explained by internal loading model

```
case:More
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                            7    0         5    8    9     1|
est:|                 LP X                                       |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|             8       9     *                                |
est:|          *X                                                |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|                       *8                                   |
est:|          *X                                                |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                       0       1    9   8   5               |
est:|                                  XPL                       |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                                   0     *                  |
est:|                          LP X                              |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Morey

substantial under-prediction of P, productivity, and hod
aside from Shelburne, only lake outside of predicted P
confidence range (6 - 26 vs. obs. mean 27)
septic loadings may be higher than estimated
internal loading model explains most of the deviation
transparency agreement OK because of meta/hypol. algal pops.
(offsetting biases)

```
case:Park
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                8      7  0  9     1                        |
est:|                 L       X           P                      |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|          7  1 9 0                                          |
est:|          L    X     P                                      |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|             7         9                                    |
est:|          L    X        P                                   |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                       1  70    9                           |
est:|                      P      X       L                      |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                               1                            |
est:|                       L          X              P          |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Parker

good agreement between best land use estimates and data
large variance been LS and PM
land use needs better definition

```
case:St C
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                *9 0        1                               |
est:|                 L   X   P                                  |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|    8 *   1                                                 |
est:|          L X P                                             |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|    8                                                       |
est:|          L X  P                                            |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                                       1   9    0         8 |
est:|                              P  X   L                      |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                              1 9                           |
est:|                              L     X     P                 |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

St Catherine

obs P and productivity slightly lower than best land use estimates
LS closer than PM
meta/hypolimnetic algal populations

```
case:Shel
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                                                           *|
est:|                          L  X              P               |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|                                                           *|
est:|               L X       P                                  |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|                                                           *|
est:|                L X          P                              |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:| 9  8                                                       |
est:|                    P     X L                               |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                                                            |
est:|*                                                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Shelburne

. P and productivity under-predicticted by about 6x
wide variance between PM and LS, PM closer
need better estimate of tilled agric land
most (at least 75%) is sedimentary and poorly drained (hsg D)
export coefficients substantially higher than those used

```
case:Star
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                 scale max = 35
obs: |          9    8                   0 1                     |
est: |                       L *                                 |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                             scale max = 25
obs: |                                      9              0     |
est: |             L*                                            |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                scale max = 50
obs: |                                     9          0          |
est: |             L *                                           |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                   scale max = 8
obs: |    *                                                      |
est: |                            *L                             |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                scale max = .75
obs: |                                                           |
est: |*                                                          |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Star

agreement with average spring P ok, but large variance in
observed values (check)
chlorophyll substantially under-predicted
outlier on observed chl-a vs obs. spring P plot
observed Chl-a/Spring P = 1.44
substantial increases in chl-a in early summer may be due
to seasonal loading component
are you sure there are no shoreline resorts/public facilities
summer P measurements would be useful
observed chlorophyll vs. secchi suggests high non-algal
turdibity/color

```
case:Wino
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 1  spring p                                  scale max = 35
obs:|                                  9  8 1         0          7|
est:|                            L  XP                            |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 2  summer chl-a                              scale max = 25
obs:|                                                             |
est:|                L  *                                         |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 3  max chl-a                                 scale max = 50
obs:|                                                             |
est:|                 L XP                                        |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 4  secchi                                    scale max = 8
obs:|                                                             |
est:|                          *  L                               |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
variable: 5  areal hod                                 scale max = .75
obs:|                                                             |
est:|*                                                            |
     +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

Winona

model under-predicts spring P values
PM closer than LS
about 40% sedimentary - export coef. under-estimated

APPENDIX E

Analyses of Variance
Observed Lake Quality

```
anova for variable 2 pspr

Lake            n             mean         std dev       variance
Bomoseen        5             2.6969       .165688       .0274525
Carmi           5             2.99367      .171697       .02948
Cedar           5             2.84079      .317351       .100712
Curtis          5             2.49765      .30592        .0935869
Elmore          5             2.5239       .157471       .024797
Fairfield       4             2.99409      .192948       .0372289
Harveys         5             2.62773      .308131       .094945
Hortonia        5             2.45681      .170699       .0291381
Iroquois        5             3.39181      .194939       .0380011
Morey           6             3.29855      .366193       .134097
Parker          5             2.72983      .281696       .0793524
St Cather       5             2.46424      .219791       .0483079
Shelburne       5             4.72391      .290235       .0842362
Star            4             2.61876      .589563       .347585
Winona          5             3.25569      .278044       .0773087

source          dof           sum sq       mean sq
among groups    14            23.8306      1.70218
within groups   59            4.73419      .0802406
total           73            28.5648      F= 21.2135       median:
h
```

```
anova for variable 4 chla

Lake            n             mean         std dev       variance
Bomoseen        4             1.68142      .294419       .0866827
Carmi           4             3.08143      .185077       .0342534
Curtis          1             1.84055      0             0
Elmore          5             1.44086      .240302       .0577452
Fairfield       4             2.34691      .359321       .129112
Harveys         5             1.27194      .246462       .0607436
Hortonia        3             1.30114      .318475       .101427
Iroquois        5             2.35246      .216424       .0468392
Morey           4             2.25299      .315637       .0996266
Parker          4             1.82632      .217274       .0472082
St Cather       4             1.15808      .31115        .0968145
Shelburne       2             4.32763      .346513       .120071
Star            2             2.98435      .213745       .0456867

source          dof           sum sq       mean sq
among groups    12            27.8513      2.32094
within groups   34            2.51102      .0738534
total           46            30.3623      F= 31.4263
h
```

```
anova for variable 5 chlmax

Lake          n           mean        std dev      variance
Bomoseen       2           2.69681     .557524      .310833
Carmi          2           4.17427     .0217491     4.73022E-04
Curtis         1           2.44235     0            0
Elmore         4           2.1346      .119213      .0142117
Fairfield      2           3.07488     .596278      .355547
Harveys        4           1.96781     .236242      .0558103
Hortonia       2           1.79176     0            0
Iroquois       2           3.60393     .544547      .296532
Morey          3           3.01829     .0390259     1.52302E-03
Parker         2           2.75267     .343747      .118162
St Cather      1           1.4816      0            0
Shelburne      2           4.94672     .090394      8.17108E-03
Star           2           3.61709     .170527      .0290794

source        dof          sum sq      mean sq
among groups   12          24.304       2.02534
within groups  16          1.33194      .0832462
total          28          25.636      F= 24.3295
h
```

```
anova for variable 6 secchi

Lake          n           mean        std dev      variance
Bomoseen       4           1.53389     .148826      .0221491
Carmi          4           .609375     .122391      .0149795
Curtis         1           1.335       0            0
Elmore         5           1.17369     .0690249     4.76444E-03
Fairfield      4           1.04803     .304382      .0926485
Harveys        5           1.89489     .0558181     3.11566E-03
Hortonia       3           1.59472     .0626105     3.92008E-03
Iroquois       5           .975517     .205933      .0424086
Morey          5           1.5517      .235082      .0552638
Parker         4           1.33366     .125137      .0156592
St Cather      4           1.85382     .164057      .0269146
Shelburne      2          -.717742     .510626      .260739
Star           2          -.164252     .0832851     6.93641E-03

source        dof          sum sq      mean sq
among groups   12          18.5655      1.54712
within groups  35          1.21478      .0347081
total          47          19.7802     F= 44.5752
h
```

```
anova for variable 7 hod

Lake            n            mean          std dev       variance
Bomoseen         2           -.967584       0             0
Carmi            2           -1.43499       .177706       .0315795
Fairfield        1           -.798508       0             0
Harveys          2           -.994252       0             0
Hortonia         3           -.892184       .227016       .0515365
Iroquois         4           -.790481       .152638       .0232983
Morey            3           -.682095       .0817813      6.68818E-03
Parker           1           -.916291       0             0
St Cather        2           -.904555       .0524022      2.74599E-03

source          dof          sum sq        mean sq
among groups     8            .798504       .099813
within groups    11           .220669       .0200608
total            19           1.01917      F= 4.97552
h
```

```
anova for variable 3 tdo

Lake            n            mean          std dev       variance
Bomoseen         2            4.73342       0             0
Carmi            2            3.85802       .177708       .03158
Fairfield        1            4.32722       0             0
Harveys          2            6.19385       0             0
Hortonia         3            4.66632       .227008       .0515328
Iroquois         4            4.1083        .152644       .0233002
Morey            3            3.86015       .0817751      6.68716E-03
Parker           1            4.51634       0             0
St Cather        2            5.07956       .0524078      2.74658E-03

source          dof          sum sq        mean sq
among groups     8            9.28119       1.16015
within groups    11           .220673       .0200611
total            19           9.50186      F= 57.8306
h
```