CHAPTER X TROPHIC STATUS AND PERMISSIBLE LOADINGS

A. INTRODUCTION

The trophic status of a waterbody is a hybrid concept. It refers to the nutritive state (especially phosphorus) of a lake or pond, but is often described in terms of the biological activity that occurs as a result of nutrient levels. Trophic state indices have been developed using a single parameter or several parameters.

Table X-1, reproduced in part from the EPA Clean Lakes Program Guidance Manual (1980), describes the lake water characteristics of the oligotrophic and eutrophic states. Mesotrophic conditions exist between the limits for eutrophy and oligotrophy. This chapter will examine several trophic classification and permissible loading schemes.

Table X-1
Summary of Quantitative Definitions of Lake Trophic Status

Characteristics	Oligotrophic	Eutrophic
Total phosphorus (µg/L, summer)	≤ 10	≥ 20
Chlorophyll-a (µg/L, summer)	≤ 4	≥ 10
Secchi disk depth (m, summer)	≥ (3 to 5)	≤ (1.5 to 2)

B. TROPHIC CLASSIFICATION SCHEMES

1. State of New Hampshire Trophic Classification System

The classification system developed by the DES Biology Bureau (Table X-2) utilizes four parameters (NHWSPCC, 1981). Table X-3 presents the calculated value of each classified parameter for the 1976 and 1985 surveys as well as the 1994/1995 study year along with the trophic points received and the trophic status.

In 1976, Great Pond received a total of eleven trophic points and was classified as eutrophic. The parameter most responsible for that rating, bottom dissolved oxygen concentration was 0.1 mg/L at a depth of 12.8 meters, earning the maximum score of 6 trophic points. Vascular plants were rated as being abundant, falling in the eutrophic range as well. Transparancy was in the mesotrophic range measured at 3.3M, and the chlorophyl-a of 4.85 mg/L fell within the oligotrophic range. Great Pond was surveyed again in 1985, and received an identical trophic score, with the same number of points in each catagory.

The system used to trophically classify New Hampshire lakes and ponds was revised in 1989 (Table X-4). The purpose of the revision was to provide for equal points under each attribute and to reduce the impact of the bottom dissolved oxygen criterion. Unlike the previous system, the extent of oxygen depletion is evaluated in the new system.

The revised trophic classification system was applied to data collected at both the North and South Stations during the 1994/1995 study year at Great Pond. Morphologically the North and South Stations are very similar, so it is not surprising that the trophic rating is the same whether the stations are considered individually or collectively. Under the current DES trophic rating system Great Pond falls in the mesotrophic range, with a total of 10 trophic points.

Table X-2
Trophic Classification System For New Hampshire Lakes and Ponds

1. Summer Bottom Dissolved Oxygen:	Trophic Points
a. D.O. ≥ 5 mg/L	0
b. 2 mg/L ≤ D.O. < 5mg/L & < 30 foot depth	1
c. 2 mg/L ≤ D.O. < 5mg/L & ≥ 30 foot depth	2
d. .5 mg/L ≤ D.O. <2 mg/L & < 30 foot depth	3
e. .5 mg/L ≤ D.O. <2 mg/L & ≥ 30 foot depth	4

f. D.O. < .5 mg/L & <30 foot depth	5
g. D.O. < .5 mg/L & ≥ 30 foot depth	6
2. Summer Secchi Disk Transparency:	Trophic Points
a. > 24 feet	0
b. > 12 feet to 24 feet	1
c. > 6 feet to 12 feet	2
d. > 3 feet to 6 feet	3
e. > 1 foot to 3 feet	4
f. > .5 foot to 1 foot	5
g. ≤ .5 foot	6
3. Aquatic Vascular Plant Abundance:	Trophic Points
a. Sparse	0
b. Scattered	1
c. Common	2
d. Abundant	3
e. Very Abundant	4
4. Summer Epilimnetic Chlorophyll-a (mg/M^3):	Trophic Points
a. Chl a < 5	0
b. 5 ≤ Chl a < 10	1
c. 10 ≤ Chl a < 20	3
d. Chl a ≥ 20	5

	Trophic Points	
Trophic Classification	Stratified	*Unstratified
Oligotrophic	0-5	0-3
Mesotrophic	6-10	4-6
Eutrophic	11-21	7-15

*Unstratified lakes are not evaluated by the bottom dissolved oxygen criterion.

Table X-3
Trophic Classification of Great Pond

Trophic Classification - 1976 Survey		
Parameter	Value	Trophic Points
Dissolved Oxygen	0.1 mg/L	6

Secchi Disk	3.3 m	2
Plant Abundance	Abundant	3
Chlorophyll-a	4.85 µg/L	0
Classification : Eutrophic		Total = 11
Trophic Classification - 1985 Survey		
Parameter	Value	Trophic Points
Dissolved Oxygen	0.3 mg/L	6
Secchi Disk	3.4 m	2
Plant Abundance	Abundant	3
Chlorophyll-a	4.73 µg/L	0
Classification : Eutrophic		Total = 11
North Station Trophic Classification - 1994/1995 Study Year		
Parameter	Value	Trophic Points
Dissolved Oxygen	0.2 mg/L - 6M to bottom	4
Secchi Disk	3.73 m	2
Plant Abundance	Common	3
Chlorophyll-a	4.95 µg/L	1
Classification : Mesotrophic		Total = 10
South Station Trophic Classification - 1994/1995 Study Year		
Parameter	Value	Trophic Points
Dissolved Oxygen*	0.2 mg/L - 6M to bottom	4
Secchi Disk	3.80 m	2
Plant Abundance	Common	3
Chlorophyll-a	4.91 µg/L	1
Classification : Mesotrophic		Total = 10

Table X-4
Trophic Classification Systems for New Hampshire Lakes and Ponds
Revised 1989

1. Summer Bottom Dissolved Oxygen:

a. D.O. > 4 mg/L	0
b. D.O. = 1 to 4 mg/L & hypolimnion volume ≤ 10% of lake volume	1
c. D.O. = 1 to 4 mg/L & hypolimnion volume > 10% of lake volume	2
d. D.O. < 1 mg/L in < 1/3 hypo. volume & hypo. volume < 10% lake volume	3
e. D.O. < 1 mg/L in ≥ 1/3 hypo. volume & hypo. volume ≤ 10% lake volume	4
f. D.O. < 1 mg/L in < 1/3 hypo. volume & hypo. volume > 10% lake volume	5
g. D.O. < 1 mg/L in ≥ 1/3 hypo. volume & hypo. volume > 10% lake volume	6
2. Summer Secchi Disk Transparency:	Trophic Points
a. > 7 m	0
b. > 5 m - 7 m	1
c. > 3 m - 5 m	2
d. > 2 m - 3 m	3
e. > 1 m - 2 m	4
f. > 0.5 m - 1 m	5
g. ≤ 0.5 m	6
3. Aquatic Vascular Plant Abundance:	Trophic Points
a. Sparse	0
b. Scattered	1
c. Scattered/Common	2
d. Common	3
e. Common/Abundant	4
f. Abundant	5
g. Very Abundant	6
4. Summer Epilimnetic Chlorophyll-a (mg/M^3):	Trophic Points
a. < 4	0
b. 4 - < 8	1
c. 8 - < 12	2
d. 12 - < 18	3
e. 18 - < 24	4

f. 24 - < 32	5
g. ≥ 32	6

Trophic Classification	Trophic Points Stratified	*Unstratified
Oligotrophic	0-6	0-4
Mesotrophic	7-12	5-9
Eutrophic	13-24	10-18

*Lakes without hypolimnions are not evaluated by the bottom dissolved oxygen criterion.

2. Carlson's Trophic Index

Carlson's (1977) TSI system is based on Secchi depth as a means of characterizing algal biomass. This parameter, in the absence of turbidity and colored materials in water, is a direct measure of "plankton-algal manifested eutrophication processes" in natural waters. Its range of values can easily be transformed into a convenient scale. Further, by using empirically derived relationships between Secchi depth and both phosphorus and chlorophyll-a concentrations, Carlson derived equations to estimate the same index value from these two parameters as well as from Secchi

depth. Carlson's trophic index is basically a linear transformation of Secchi depth, such that each 10 unit increase in his TSI scale represents a halfing of the Secchi visibility. Conversely, for total phosphorus each 10 unit increase represents a doubling in phosphorus concentrations. The computational form of the equations for his trophic scheme is as follows:

here:

SD = Secchi depth

TP = Total phosphorus concentration

Chl = chlorophyll-a concentration

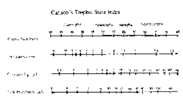
JNC { TSI ~ (SD) ~ = ~ 10 ~ LEFT (6- ~{ ln SD} OVER { ln ~ 2 } RIGHT) } #~# ~ # JNC { TSI ~ (Chl) ~ = ` 10 ~ LEFT (6- ~ .04 ~ - ~ 0.68~ ln ~ Chl}OVER { ln ~ 2} GHT) } #~# ~ # FUNC { TSI ~(TP) ~= ~ 10 ,EFT(6- ~{ ln ~ {48} OVER { Tp }} OVER { ~ 2 } RIGHT) }

According to Carlson (1977), this index system has the advantages of easily obtained data, simplicity, absolute TSI values, valid relationships, retrieval of data from the index, and can be grasped by the layman in much the same manner as the Richter earthquake scale. The TSI incorporates most lakes in a scale of 0 to 100 as Figure X-1 demonstrates. Each major division (10, 20, 30, etc.) represent a doubling of phosphorus and about a 2.8 increase in algal biomass.

Results of the Carlson TSI were obtained by substituting summer mean Secchi depth, chlorophyll-a, and phosphorus values from the North and South stations of Great Pond into the equations to compute the TSI. Table X-5 shows the mean summer values, the TSI number and the classification for each measured parameter. The chlorophyll-a values observed at the North and South Stations of Great Pond reflected intermediate concentrations that are typical of mesotrophic waterbodies. Mean Secchi disk depths were also indicative of mesotrophic conditions at both lake stations. Mean summer phosphorus concentrations from the epilimnion of the North Station reflected mesotrophic conditions and, due to internal loading, hypolimnion concentrations reflected eutrophic conditions. The mean phosphorus of the South Station during the summer of 1995 were indicative of oligotrophic conditions in the epilimnion, and mesotrophic conditions in the hypolimnion.

Table X-5
Carlson Trophic Classification for the North and South Stations at Great Pond

NORTH STATION			
Parameter	Mean Summer Value	Trophic Points	Classification
Chlorophyll-a (µg/L)	4.95	46	Mesotrophic
Secchi Disk (m)	3.73	41	Mesotrophic
Epilimnetic Phosphorus (µg/L)	10.20	38	Mesotrophic
Hypolimnetic Phosphorus (µg/L)	26.50	51	Eutrophic
SOUTH STATION			
Parameter	Mean Summer Value	Trophic Points	Classification
Chlorophyll-a (µg/L)	4.91	46	Mesotrophic
Secchi Disk (m)	3.80	41	Mesotrophic
Epilimnetic Phosphorus (µg/L)	8.00	34	Oligotrophic
Hypolimnetic Phosphorus (µg/L)	18.60	46	Mesotrophic



3. Dillon/Rigler Permissible Loading Model

Mathematical models can also be useful both in diagnosing lake problems and evaluating potential solutions. They represent in quantitative terms the cause-effect relationships that determine lake quality. In some cases, the determination of the trophic state of a lake involves a comparison of actual phosphorus loading to the lake with a maximum permissible loading that the lake can tolerate before excessive weed and algae growth occurs and transparency diminishes. The trophic model developed by Dillon/Rigler (1974) has been widely utilized and well documented by researchers. Its application classifies a lake as oligotrophic, mesotrophic or eutrophic by comparing calculated annual loadings with permissible annual loadings. The tolerance of the lake to phosphorus loading is predicted as a function of two morphological parameters, mean depth (z) and water retention time (T), which have been proven by several researchers to be the primary determinants of loading permissibility. Additionally, the model considers the phosphorus retention in the lake sediments. The retention coefficient (R) may be empirically calculated from morphological data or may be derived from a definitive phosphorus budget.

Table X-6 shows the qualitative relationship between the model input parameters and phosphorus loading tolerance.

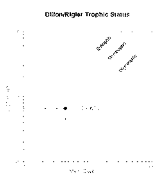
Table X-6
Dillon/Rigler Permissible Loading Tolerance

High Phosphorus Loading Tolerance	Low Phosphorus Loading Tolerance
Large mean water depth	Small mean water depth
Rapid flushing rate	Slow flushing rate
High sediment retention	Low sediment retention

Thus, existing trophic status is set by existing values for these parameters and annual phosphorus loading. Similarly, historical trophic status can be determined from estimates of previous phosphorus loading. The degree of trophic state improvement, which would result from the implementation of watershed and in-lake management strategies, can be gauged from predicted changes of loading and morphology. Table X-7 presents the Dillon/Rigler trophic status calculations for Great Pond. Figure X-2 is a graphical representation of the Dillon/Rigler model showing trophic zones, plotted on axes of mean depth and areal loading (Table X-7) with the data point for the Great Pond study year.

Table X-7
Dillon/Rigler Trophic Status Calculations

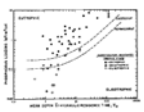
Parameter	Calculation
Lake area (m^2)	826000.0
Mean z (m)	4.5
Total loading (kg)	397.1
Flushing rate (yr^{-1})	3.74
Water retention time (yr) T	0.27
P coefficient R	0.49
Total areal loading ($g/m^2/yr$) Lp	0.48
LT (1-R) (g/m^2)	0.66



The Dillon/Rigler model also predicts in-lake phosphorus concentration. Utilizing the Dillon/Rigler equation P=Lp(1-R)/qs, the calculated predicted in-lake phosphorus concentration for Great Pond was 0.007 mg/L. This predicted value is lower than actual study year mean hypolimnetic phosphorus concentration of 0.022 mg/L and much closer to than the study year mean epilimnetic phosphorus concentration of 0.009 mg/L. The actual mean epilimnetic phosphorus concentration was calculated from the summer phosphorus data collected by the Biology Bureau during the 1995 sample year.

4. Vollenweider Phosphorus Loading and Surface Overflow Rate Relationship

The Vollenweider model is based on a five year study involving the examination of phosphorus load and response characteristics for about 200 waterbodies in 22 countries in Western Europe, North America, Japan and Australia. Vollenweider, working on the Organization for Economic Cooperation and Development (OECD) Eutrophication Study, developed a model describing the relationship of phosphorus load and the relative general acceptability of the water for recreational use (Vollenweider, 1975). Vollenweider found that when the annual phosphorus load to a lake is plotted as a function of the quotient of the mean depth and hydraulic residence time, lakes which were eutrophic tended to cluster in one area and oligotrophic lakes in another (Figure X-3, from Flanders, 1986 and Connor, et al. 1994).



Vollenweider developed a statistical relationship between areal annual phosphorus loading (Lp) to a lake normalized by mean depth (Z) and hydraulic residence time (T), to predict phosphorus lake concentration (P). Table X-8 summarizes the Vollenweider model parameters for the Great Pond sample year.

Table X-8

Vollenweider Phosphorus Concentration Prediction

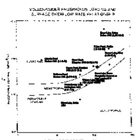
Parameter	**Equation**	**Great Pond**
1. Hydraulic residence time (T**)**	T= V OVER Q	0.27 yr
2. Surface overflow rate (qs)	qs=z OVER T	16.76 (m/y)
3. Areal phosphorus load (Lp**)**	Lp={P~load} OVER{ lake~surface~area}	0.48 (g/m^2/y)
4. Mean depth (Z**)**	measured	4.5 (m**)**
5. Phosphorus concentration prediction (P)	P~=~{Lp} OVER {qs}~ LEFT [1 OVER {1+ SQRT {z OVER {qs}}} RIGHT]	0.019 (mg/L**)**

Thus, based on the physical constraints that control water volume, the hydraulic residence time in the lake, and mean lake depth, combined with phosphorus loading, the Vollenweider model predicts the existing in-lake phosphorus concentration to be 0.019 mg/L in Great Pond. An examination of actual mean epilimnetic in-lake phosphorus concentrations during the 1995 summer study period, revealed that the mean measured epilimnetic phosphorus concentration of 0.009 mg/L was lower than the predicted value of 0.019 mg/L. However, the predicted phosphorus value compared more favorable with the mean summer hypolimnetic phosphorus value of 0.022 mg/L.

Figure X-4 graphically portrays the measured loading rates for Great Pond and compares the lake with other studied lakes in New Hampshire. Based on the permissible and excessive loading curves, it can be seen that Great Pond lies in the mesotrophic/eutrophic border line, in the vicinity of the moderate loading range.

C. TROPHIC CLASSIFICATION SUMMARY

A summary of the four classification schemes utilized in this study (Table X-9) shows



that the New Hampshire Lake classification system classifies Great Pond as mesotrophic. The Vollenweider Phosphorus Loading model classifies Great Pond as borderline mesotrophic/eutrophic while the Dillon/Rigler model classifies the lake as a mesotrophic lake.

The Carlson Trophic Status Index defines a trophic class for several parameters. Epilimnetic phosphorus measurements in Great Pond fell into the upper mesotrophic range while chlorophyll-a and secchi disk transparency concentration fell into the mesotrophic range. Epilimnetic phosphorus varied with the station, the North Station was mesotrophic while the South Station was in the borderline eutrophic range.

Table X-9
Great Pond Trophic Classification Summary

Classification Model	Trophic Classification
1. New Hampshire Lake Classification	Mesotrophic
2. Carlson's TSI	
Chlorophyll-a	Mesotrophic
Secchi Disk	Mesotrophic
Phosphorus (Epilimnion)	Oligotrophic/Mesotrophic
Phosphorus (Hypolimnion)	Mesotrophic/Eutrophic
3. Dillon/Rigler	Mesotrophic
4. Vollenweider	Mesotrophic/Eutrophic

D. PREDICTING THE CAPACITY OF A LAKE FOR DEVELOPMENT

New Hampshire has experienced significant growth and development in the last two decades and is likely to continue to see such growth into the new century. This growth has greatly increased pressures on one of the very features that has attracted people to the state -- the lakes. While new development, both year-round and seasonal, and conversion/expansion of existing development allow more people to enjoy these resources, it also can threaten the quality of a lake environment.

A predictive computer model has been utilized to aid in quantifying the environmental impacts of development on a lake. This model, which measures the phosphorus loading to a lake resulting from the surrounding development, predicts the capacity of the lake for seasonal and/or permanent development that will not threaten existing lake quality. Utilizing available data on the particular lake of interest and relying on several conservative assumptions about phosphorus impacts from certain kinds of development, the model presents the results in the form of a maximum number of allowable units of development around the lake. This number is intended as a guide for local officials in evaluating the impacts of proposed development on lakes.

Phosphorus (P) is the nutrient most frequently controlling lake productivity and, therefore, trophic status in New Hampshire lakes. Therefore, predictions concerning the impact of development on the phosphorus concentration of a lake, and subsequently on parameters describing the trophic state, are central to a predictive management scheme. From the geology and land use considerations of a lake's drainage basin, it is possible to estimate the total phosphorus exported or washed out per unit area of watershed. When combined with the drainage area, this provides an estimate of the total phosphorus supplied to the lake from the land. The addition of phosphorus input from direct lake precipitation determines the natural phosphorus load to the lake. Existing development -- both year-round and seasonal -- is then measured (tax maps or field counts with the assistance of local officials), and the phosphorus loading from artificial sources is calculated with the assistance of certain coefficients and conservative assumptions. The total P loading, natural plus artificial, may then be combined with the lake morphometry (general physical characteristics -- size, depth, etc.) and water budget to predict a phosphorus concentration that is subsequently related to the average summer chlorophyll-a concentration. Chlorophyll-a is an indication of the planktonic algal biomass in the lake and is directly proportional to the phosphorus inputs. From the chlorophyll calculation one can calculate the lake clarity or Secchi disk transparency. Finally, the maximum permissible artificial loading that will not lower lake quality in terms of chlorophyll-a or water clarity can be estimated. This maximum is expressed as the maximum of allowable development units (i.e., number of cottages).

This model is designed to predict the capacity of a lake for development without utilizing actual water quality data. In the case of Great Pond, actual watershed phosphorus loading has been calculated and input into the capacity model.

Table X-10 designates the capacity model data inputs. The model takes under consideration just those dwellings around the first tier of the lake. The model also considers loadings from Greenwood Pond, Halfmoon Pond and Long Pond which are all within the Great Pond watershed.

Table X-11 presents the model results using two different chlorophyll-a criteria. A chlorophyll-a criterion of 5 mg/m^3 was chosen for the first model because it is slightly above the mean productivity levels that presently occur in Great Pond. The lake productivity at this level of chlorophyll is considered by lake managers and New Hampshire recreationists to be acceptable for any water related activities. Transparency is often above four meters and algae blooms are usually not a problem. The other level chosen was 4 mg/m^3, this level is slightly below the study average of 4.85 mg/L and would reflect an improvement in water quality.

At the 5 mg/L level of chlorophyll the model would allow the development of 48 year-round homes around the lake. This sounds like good news until you take into account that 1995 data was used to run the model, in the ensuing four years much of this allowable development may have already taken place. At the 4 mg/L of chlorophyll the model says that Great Pond is over-developed, that total supply of Phosphorus exceeds the allowable supply for the lake. Taking all modeling data into account it is clear that Great Pond is very close to the balancing point as far as development goes. Any further development may drive the lake toward eutrophication, and result in degradation of water quality.

The ultimate goal of a lake manager is to balance the lake productivity to meet the needs of the lake user. This is a difficult job because different user groups have different goals and user conflicts often arise. The lakeshore property owner may enjoy a clear umproductive lake while the fishermen knows that high productivity means larger fish. However, decreasing nonpoint

Table X-10

Predicting the Capacity of Great Pond for Development

MORPHOLOGY	Lake 1	Lake 2	Lake 3	Lake 4
	Great Pond	Greenwood	Halfmoon	Long
Surface area (m2):	826000.	200300.	62700.	361800.
Mean Depth (m):	4.5	2.6	2.3	1.6
Volume (m3):	3700500.	524500.	142000.	566000.
Drainage Area (m2):	21756000.	1316000.	737000.	10360000.
Direct Drainage A:	9343000.	1316000.	737000.	10360000.
Flushing Rate:	3.74	1.10	2.30	8.30
Phosphorus retention coefficient	0.49	0.75	0.65	0.52
Present Development (dwellings)				
Year-round Homes:	95	6	12	32
Seasonal Homes:	20	0	4	10
Weekend Camps:	10	0	0	0
Campgrounds:	340	0	0	0
Present Development (capita-yrs/yr)				
Year-round Homes:	380	24	12	32
Seasonal Homes:	20	0	4	10

Weekend Camps:	3	0	0	6
Campgrounds:	84	0	0	0
TOTAL CAPITA YEARS/YR	487	24	52	140
Selected Export Coefficients				
Natural:	1.50	1.50	1.50	0.40
Residential:	0.60	0.60	0.75	0.60
Sub-Watershed Supply (kg/yr)				
Natural:	76.0	17.0	5.8	31.3
Residential:	292.0	14.4	39.0	83.8
Total:	367.9	31.4	44.8	115.1
Downstream:	187.7	7.8	15.7	55.2

sources of phosphorus to the lake is the key issue in lake protection. Managers must balance human activities, such as logging, construction and land-use conversions, through watershed management techniques. These techniques offer best management practices that reduce phosphorus, runoff and the movement of unstabilized soils to the lake or its tributaries. We all have to realize that towns usually don't favor moratoriums on developments even around a sensitive lake. Therefore, all stakeholders must work together to manage the surrounding watershed with the goal of protecting the waterbody that lies below.

Table X-11
Great Pond Predicted Development Capacity Summary

Supply (kg/yr)	Chlorophyll-a criteria=4.0	Chlorophyll-a criteria=5.0
Natural	97.3	958.3
Artificial	349.5	527.3
Total	446.7	1485.6
Permissible	433.4	1657.1
Development (capita-yrs/yr)	Total Supply>Permissible	Total Supply<Permissible
Present		486.6
Permissible	433.4	680.5
Additional	Allow no further development	193.8
Homes	0	48