SELECTION OF PHOSPHORUS LOADING MODEL FOR NOVA SCOTIA
Phase I

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EXECUTIVE SUMMARY

This report has been prepared at the request of the Nova Scotia Department of Environment and Labour (NSDEL) in an effort to summarise the Nova Scotia experience with phosphorus loading models that can predict the effects of human activities on phosphorus movement through lake systems. The authors collaborated with three other modelling groups (Acadia Centre for Estuarine Research (ACER), the Soil & Water Conservation Society of the Municipality of Halifax (SWCSMH), and Loucks Oceanography Ltd. (LOL)) in compiling the information

Phosphorus loading models have been used to predict the eventual impact of human activities on lakes. Since the 1970s, a number of researchers have developed modelling tools that utilise physical aspects of the surrounding environment, properties of the land itself, human and natural land uses, and human behaviours as inputs to these models. The original work on this subject was carried out under the sponsorship of the Organisation for Economic Co-operation and Development (OECD) and set the scientific "stage" for the predictive models discussed in this report. Examples of data that are used in these models include information such as size of watershed, surface area of lake(s), amount of precipitation, land uses (forestry, farming, wetlands, etc.) in the watershed, and the number of households or institutions that discharge sewage into the soils and water of the watershed. Other variables are used and are described in the report. It is important to note that some human activities such as lawn or crop fertilisation can have important impacts on the phosphorus loading of any lake, and that these activities can be changed over time. One benefit of having models of this kind is that planners and decision makers can use them to predict the eventual water quality condition of lakes by changing those parameters that are under human control. In this way housing density, fertilisation practices, or other land use policies can be modified to, hopefully, ensure ongoing water quality of a given level.

The report concludes that the four groups that have been carrying out phosphorus loading modelling activity in Nova Scotia have been using essentially the same methodology and (with a few exceptions) the same numerical values for most of the environmental parameters that are applied within the model. The report also concludes that there has been reasonably good agreement among the results when the same lakes have been examined by different groups. Differences in results are usually related to interpretation of data from maps (e.g. determining watershed areas or the extent of various land use types) or assumptions about the extent of phosphorus retention by local soils. The report recommends that communication among the various modelling groups can be improved; that a central repository of information be established within the NSDEL library; and that efforts be made to encourage all of the modellers to use similar numerical values.

TABLE OF CONTENTS

EXECUTIVE SUMMARY ..... **i**

1.0 INTRODUCTION **1**

2.0 PHOSPHORUS LOADING MODELS USED IN NOVA SCOTIA **1**

3.0 LIMITATIONS OF THE MODELS **1**

4.0 MODEL ASSESSMENTS **2**

5.0 INPUT VARIABLES **2**

6.0 EXPORT COEFFICIENTS AND LOADING FIGURES **3**

7.0 MODEL OUTPUTS **5**

8.0 INTERPRETATION OF AVAILABLE INFORMATION FOR THE ESTIMATION OF INPUT VARIABLES **5**

9.0 DIFFERENCES BETWEEN OBSERVED AND PREDICTED TOTAL PHOSPHORUS **6**

10.0 MODELLING WORK COMPLETED TO DATE **6**

11.0 CONCLUSIONS AND RECOMMENDATIONS **9**

12.0 REFERENCES **11**

APPENDIX I – PHOSPHORUS LOADING MODEL USED BY CWRS **15**

AI.1.0 MODEL DESCRIPTION **15**

AI.2.0 MODELLING ASSUMPTIONS **15**

AI.3.0 MODEL INPUT VARIABLES **16**

AI.3.1 LAND USE EXPORT COEFFICIENTS 16
AI.3.2 PRECIPITATION 21
AI.3.3 ON-SITE SEPTIC SYSTEMS 21
AI.3.4 SEWAGE TREATMENT PLANT (STP) EFFLUENT PHOSPHORUS 21
AI.3.5 HOUSEHOLD OCCUPANCY 21
AI.3.6 URBAN/DEVELOPED 21

AI.4.0 LOUCKS OCEANOGRAPHY LTD. MODELLING WORK **22**

AI.5.0 REFERENCES **23**

APPENDIX II - SOIL & WATER CONSERVATION SOCIETY OF METRO HALIFAX MODELLING WORK 28

1. INTRODUCTION 28

2. OUR MODELS IN MS EXCEL SPREADSHEET FORMAT 28

2.1. CORRESPONDENCE BETWEEN MODELLED AND FIELD VALUES, AND CAUTION FOR DYSTROPHIC LAKES (CF. APPENDIX B) 29
2.2. EXPORT COEFFICIENTS APPLICABLE TO ALL SCENARIOS 30

3. DETAILS ON VARIOUS SPREADSHEETS WITHIN OUR MODELS BASED ON MS EXCEL 32

3.01. Flow-spreadsheet: 32
3.02. Master Spreadsheet (Master SS): 32
3.03. Control Spreadsheet (Control SS): 32
3.04. Background –plus- aerial deposition (B+A): 33
3.05. Recent development scenario: 33
3.06. Future development scenario: 33
3.07. Runoff spreadsheet: 34
3.08. Predictive graphical models utilized: 34
3.09. OECD (1982) Model (Vollenweider and Kerekes, 1982): 35
3.10. Vollenweider (1976) Model (Vollenweider, 1976): 36
3.1. PRIMARY REGRESSIONS USED IN PREDICTIVE TP MODELLING 37
3.1.01. Lakeshore Capacity Study (Dillon et al.*, 1986, 1994; Hutchinson* et al.*, 1991): 37*
3.1.02. OECD (1982) regressions (Vollenweider and Kerekes, 1982): 38
3.1.03. Additional regressions (Rast and Lee, 1978): 38

4. REFERENCES UTILIZED IN THE MODELLING 39

APPENDIX A: LISTING OF THE MODELLED LAKES/PONDS 43

APPENDIX B: NARRATIVE- SELECT LISTING OF THE MODELLED AND FIELD DATA FOR 72 SIGNIFICANT LAKES IN HRM 51

APPENDIX III – ACADIA CENTRE FOR ESTUARINE RESEARCH MODELLING WORK 63

AIII.1.0 INTRODUCTION 64

AIII.2.0 MODEL STRUCTURE AND FORMULATIONS 64

AIII.3.0 MODEL VALIDATION 71

AIII.4.0 CONCLUSIONS 73

AIII.5.0 REFERENCES 75

1.0 Introduction

The Centre for Water Resources Studies (CWRS) was contracted by the Nova Scotia Water Quality Objective and Model Development Steering Committee to work with the Soil & Water Conservation Society of Metro Halifax (SWCSMH), and the Acadia Centre for Estuarine Research (ACER) to carry out a review of the phosphorus loading models that are currently being applied to lake systems in Nova Scotia. Work being carried out by these groups, as well as Loucks Oceanography Ltd. (LOL), forms the basis of this report.

Detailed descriptions of the models used by each group are reviewed in Appendices I – III.

2.0 Phosphorus Loading Models Used in Nova Scotia

Phosphorus loading models have become an important component of environmental management and land use planning during the past thirty years. Much of the work related to these models is based on the groundbreaking work of Richard Vollenweider and others who analyzed data from around the world in order to determine relationships among physical, biological and limnological parameters that have led to our present ability to predict the effects of human activities on lake water quality. Based on Vollenweider's work (the OCED model), researchers in Ontario developed the first reliable and easily applicable phosphorus loading model in the early 1970's (Dillon and Rigler, 1975). The Dillon and Rigler gives the researcher or decision maker the ability to easily change a variety of parameters related to actual or possible human activities in a watershed and predict the eventual efect on water quality. While the OECD model has been used in Nova Scotia (Kerekes)it does not have the flexibility of the Dillon and Rigler refinements and has not been widely used to predict the potential impacts of residential development on Nova Scotia surface waters. For this reason the OECD model has not been discussed further in this report.

Work undertaken in Nova Scotia by the four groups identified above utilized models described in Dillon and Rigler (1975) (D-R) and Dillon et al. (1986), the latter also referred to as the Trophic Status Model (TSM), a model developed under Ontario's Lakeshore Capacity Study. This model is a refinement of the Dillon and Rigler (1975) version. In their work, the SWCSMH also considers the OCED Management Model (Vollenweider and Kerekes 1982) for illustrative purposes only. This group has, to a very limited extent, used regressions as reported in Rast and Lee (1978). Other work using the OECD model is described in Schwartz and Underwood (1986), in which selected lakes in the Shubenacadie River watershed were examined. Although these models are capable of predicting other trophic status indicators (chlorophyll$_a$, Secchi Disk), the report has focused on phosphorus.

3.0 Limitations of the Models

1. These models are used to predict average lake phosphorus concentration and are not able to address observed variation both temporally and/or spatially.
2. For maximum predictive efficiency, the models should only be applied to those lakes that fall within the range of conditions under which the models were developed.
3. For watersheds that contain on-site wastewater disposal systems, measured lake phosphorus concentrations may not reflect the total potential load from this source. The

time frame surrounding the movement of phosphorus from a disposal trench to a receiving water could be many decades.
4. The models were not intended for application to shallow lakes.
5. Coloured or dystrophic lakes do not respond to nutrient loading as might a clear water lake.

4.0 Model Assessments

Both the D-R and TSM models are mass-balance, steady state models, the later being a slight refinement of the former. The only significant difference between the two is the equation used to estimate in-lake phosphorus retention.

The Dillon and Rigler version uses the relationship adopted from Kirchner and Dillon (1975):

$$\mathbf{R = (0.426e^{-0.271(\text{“Water Load”})}) + (0.574e^{-0.00949(\text{“Water Load”})})}$$

where “Water Load” = $Q/ A_o = q_s$ (Q = annual lake outflow volume, m^3, A_o = lake area, m^2)

while that used by Dillon et al. (1986) is:

$$\mathbf{R_p = v/(v+q_s)}$$

where v = settling velocity (12.4 for lakes with an anoxic hypolimnion, and 7.2 for those with an oxic hypolimnion

$q_s = Q/A_o$, where Q = annual lake outflow volume, and A_o = lake area

5.0 Input Variables

Both the D-R and TSM models contain input variables common to both. The units used will depend on how the respective spreadsheets have been set up. These variables are provided in the following list:

- lake area, ha or m^2
- subwatershed area, ha or m^2
- lake volume, ha.m or m^3
- annual moisture surplus or land runoff, m/yr or mm/yr
- phosphorus load contributed by precipitation, as kg ha^{-1} yr^{-1} or mg m^{-2} yr^{-1}
- breakdown of land use within the watershed into specific categories, ha or m^2
- number of dwelling or approved lots

The bulk of this information can be obtained from provincial and federal government sources. The contribution of phosphorus loads via precipitation have been documented by

field research (Hart 1977; Underwood 1984; Dillon and Molot 1996). Although limited information exists describing the bathymetry of lakes in Nova Scotia, and in turn lake volume figures, the elimination of this variable from the model has no bearing on its ability to estimate the total phosphorus load. The implications are such that calculated values for mean depth, flushing rate and turnover time will not be available. Also, without knowing maximum depth, and in the absence of hypolimnetic dissolved oxygen data, it is necessary to assign an arbitrary sedimentation velocity factor in the calculation of the in-lake phosphorus retention coefficient when using the Dillon et al. (1986) model.

6.0 Export Coefficients and Loading Figures

The estimated total phosphorus load to a lake equals the sum of loads contributed by specific land use categories, precipitation to the lake surface, and on-site septic systems and sewage treatment facilities. If the lake is not a headwater lake, the amount of phosphorus exported from the upstream lake is added to this total. The procedure followed to acquire the total load value starts with the delineation of a watershed into its component parts as defined by categories presented in Table 1. The next step is to apply an export coefficient, the amount of phosphorus exported from a particular land type or activity per unit area per year, to individual categories to determine a load. The individual export coefficients have been established through field research.

The export coefficients and loading figures applied to the models by researchers in Nova Scotia have been drawn from a similar working list of values. Table 1 presents that list. Two sets of coefficients were used by CWRS and SWCSMH for the “forested”, and “forested + .15% cleared + wetland” categories as a result of a study conducted by Scott et al. published in 2000. The first set of values listed, as well as those identified for Loucks, came from Hart et al. (1978). Lowe (2002) developed those used by ACER for the Gaspereau River watershed. The “Urban/Developed/Serviced” values were taken from research carried out in both Ontario and Nova Scotia.

Landuse export coefficients are mean values developed from a series of data sets representing a specific category. For example, Scott et al. (2000) used 4 sites for igneous and 11 sites for sedimentary forested categories to estimate mean values of 6.9 and 8.8 mg m^{-2} yr^{-1}, respectively. Individual values for these two categories ranged from 4.2 – 15.3 and 5.6-15.9 mg m^{-2} yr^{-1}, respectively. It is evident that a total phosphorus budget can be significantly affected by the use of mean values.

From Table 1, it can be seen that for the most part, the values used are the same among researchers. In the case of the “golf course” numbers used by CWRS and SWCSMH, numbers quoted were obtained from different sources. Given the recent study by Scott et al. (2000), the lower value of 0.104 kg ha^{-1} yr^{-1} may no longer be appropriate. Work could be done to investigate and if necessary, update this value. It also appears that the exchange of information among groups, either directly or through a central registry, does not occur in a timely fashion. Work produced by Dillon and Loucks Oceanography Ltd. (2003) used export coefficients generated in 1978, and not from the more recent 2000 study.

Research conducted by the Ontario Ministry of the Environment resulted in a per capita phosphorus contribution of 0.6 kg yr^{-1} (France, 2002). The figure currently in use for Nova Scotia is 0.8 kg yr^{-1}. This new information should be reviewed for use in this province.

During this review, an export figure for agricultural land use was uncovered and should also be reviewed. Winter and Duthie (2000) published an export figure of 45 mg m^{-2} yr^{-1} (0.450 kg ha^{-1} yr^{-1}). Export values for land use categories described in Table 1 that have an agricultural component ranged from 0.304 – 0.625 kg ha^{-1} yr^{-1} (Lowe 2002).

Table 1. Summary of export coefficients and loading values used in Nova Scotia.

	CWRS		**SWCSMH**		**ACER[1]**	**Loucks**
	Prior to Aug/00	Since Aug/00	664 Lakes Prior to 2001	271 Lakes 2001		
	kg ha^{-1} yr^{-1}					
Igneous Bedrock/Forested	0.054	0.069	0.054	0.069	0.163	0.054
Igneous Bedrock/Forest + (>15% Cleared + Wetland)	0.078	0.083	0.078	0.083		0.078
Igneous Bedrock/>15% Clear-cut					0.634	
Igneous Bedrock/>15% Agriculture					0.625	
Igneous Bedrock/>15% Agriculture + Clear-cut					0.304	
Metamorphic/Forested					0.191	
Metamorphic/>15% Agriculture					0.333	
Metamorphic/>15% Agriculture + Clear-cut					0.321	
Sedimentary Bedrock/Forested	0.054	0.088	0.054	0.088		0.054
Sedimentary Bedrock/Forest + (>15% Cleared + Wetland)	0.078	0.115	0.078	0.115		0.078
Agriculture or recreational	0.104[2]		0.104[2]			
Golf Courses	0.104[2]		0.60[3]			
Urban/Developed/Serviced	0.22[4], 0.52[5]		0.52, 1.1[6]			0.30[7]
Light Commercial, No Vegetation, Low Traffic[8]						0.40
Heavy Commercial, No Vegetation, High Traffic[8]	2.02		2.02			2.00
Institutional[8]			0.42			
Precipitation	0.250[9]		0.173[10]		0.250	0.250
On-Site Septic System Loading, kg P $capita^{-1}$ yr^{-1}[11]	0.8		0.8		0.8	0.8
Soil Phosphorus Retention, On-Site Systems	0.5		0.5		0	0

[1] Landuse export coefficients were estimated by Lowe (2002). The bedrock geology of study sites was determined to be igneous or metamorphic and land-use characteristics ranged from agricultural and clear-cut to forested and bog. Phosphorus export ranged from 0.163 to 0.634 kg ha^{-1} yr^{-1} (Appendix III).
[2] Hart et al. (1978)
[3] USEPA (1976).
[4] Griffiths Muecke Asociates, Gordon Ratcliffe Landscape Architects, CWRS, and Derek Davis (1998)
[5] Waller (1977)
[6] Waller and Novak (1981)
[7] Adapted from Waller and Hart (1985) and Shuyler (1993)
[8] Waller and Hart (1985)
[9] Hart (1977)
[10] Underwood (1984); Dillon and Molot (1996)
[11] Dillon and Rigler (1975)

7.0 Model Outputs

Model "output" variables calculated in similar fashion for both versions include:

- total area, ha or m^2 (sum of lake and watershed areas)
- mean depth, m, V/ A_o, where V = Lake Volume, m^3, and A_o = Lake Area, m^2
- areal water load, m/yr, $=Q/A_o$, where Q = runoff, m^3, and A_o = lake area m^2
- total annual runoff, ha.m/yr or m^3/yr
- flushing rate, times/yr, = Q/V, where Q = runoff, m^3/yr, and V = lake volume m^3
- turnover time, yr, = V/Q, where Q = runoff, m^3/yr, and V = lake volume m^3
- lake phosphorus retention coefficient, equal to either R or $Rp = (0.426e^{-0.271(\text{"Water Load"})}) + (0.574e^{-0.00949(\text{"Water Load"})})$, where "Water Load" = $Q/ A_o = q_s$ (Q = annual lake outflow volume, m^3, A_o = lake surface area, m^2), or, $R_p = v/(v+q_s)$, where v = settling velocity (12.4 for lakes with an anoxic hypolimnion, and 7.2 for those with an oxic hypolimnion) and $q_s = Q/A_o$, where Q = annual lake outflow volume, and A_o = lake surface area
- response time, yr, = 0.69/(FR + 10/z), where FR = Q/V and z = mean depth or
- $RT = 2.07 / (1/\tau_w + v/z)$, where τ_w is the water replenishment time, and z is the lake mean depth
- total phosphorus load, kg/yr
- phosphorus concentration, ice-free period, ug/L, $= L(1-Rp)/0.956q_s$, where L = total phosphorus load, Rp = lake phosphorus retention coefficient, and q_s = areal water load $= Q/A_o$, where Q = runoff, m^3, and A_o = lake surface area m^2

8.0 Interpretation of Available Information for the Estimation of Input Variables

In some cases, lakes have been modelled by more than one researcher and the total annual phosphorus load predicted different. In addition to the effects of using different equations to estimate in-lake phosphorus retention (D-R vs TSM), other factors that can contribute to that difference are described below. In-lake phosphorus retention refers to the amount of the phosphorus load that is lost to lake sediments.

One of the potential contributing factors to variation in model output between modellers is different input data. The use of different source information (i.e. mapping, occupancy rate) is the main cause. Add to this the subjective nature of map interpretation, and the potential for variation increases. Watershed areas are typically determined using 1:50,000 NTS topographic maps, although at times 1:10,000 scale mapping is used. Establishing watershed boundaries is a somewhat subjective procedure, which can lead to differences in results between investigators depending on the user and map scale.

An area that affects the modelling process in general is the relevance of best available mapping to current conditions. The Nova Scotia Department of Natural Resources are continuously updating forest cover maps which are the main source of land use information. Aerial photography used to generate these maps is produced such that the entire province is covered approximately every 10 years, which means some of the data could be up to 10 years old. The use of out-of-date mapping will definitely contribute to modelling error.

9.0 Differences Between Observed and Predicted Total Phosphorus

There are several potential factors that may contribute to the separation between observed (measured) and predicted phosphorus figures. Some of these include:

1. sampling and analytical error
2. duration and intensity of record
3. lag between installation of on-site septic system and contribution of phosphorus to a lake
4. presence of aquatic plants (Dillon et al. (1986) model equations based on lake systems with <30% of littoral zone affected)
5. phosphorus contributed to system by waterfowl
6. application of fertilizers to shorefront properties
7. an effect of using mean export coefficients
8. applying a phosphorus load contributed by precipitation from one area of the province to other areas. The contribution of phosphorus from precipitation for the Halifax area has been based on work by Hart (1977). Although data exists for other areas of the province (Underwood 1984), the Hart figure has been used in Kings County modelling.
9. inaccurate figures for landuse categories
10. contribution of internal phosphorus load. Work by Dillon et al, (1993) demonstrated that internal inputs of phosphorus averaged about 8 percent of the total annual phosphorus load (range 0 – 22%). The highest loads were seen to occur in lakes with periods of extended summer anoxia.
11. lake morphometry (the models were developed using a data set generated from a group of lakes within a specific range of physical characteristics. The models should not be applied to lakes outside this range without additional testing)

Minor influences may include:

1. losses to fish harvesting (angling and fish-eating birds) through bio-accumulation of phosphorus in fish tissue
2. contribution of forest litterfall

10.0 Modelling Work Completed To Date

The four groups identified in this report have investigated approximately 1000 lakes in the province. The SWCSMH alone has considered 935 lakes, a number of which are among those investigated by CWRS and Loucks Oceanography Ltd.. ACER have concentrated on lakes in the Gaspereau River system, Kings County. The results of this work have been recorded in several referenced documents (Table 2), the majority of which are included in the reference sections. Copies of the reports that have been released to the public form part of this submission.

Contributors to this report indicated that modelled phosphorus values are within 20% of measured values for the majority of lakes investigated. It is especially important to remember that when comparing predicted versus measured phosphorus concentrations for lakes with on-site wastewater disposal systems, the total contribution of phosphorus from this source may or may not have been expressed in measured values. The modelled

phosphorus value is based on an assumed percentage of phosphorus from this source actually making its way to a lake at some point in time and not necessarily at the time lake phosphorus is measured. Other reasons given to explain why some lakes were outside this range were:

1. that the lakes were shallow and phosphorus levels may be influenced by resuspension of lake sediments and/or the presence of aquatic plants
2. insufficient numbers of measured phosphorus readings
3. estimation of overland export phosphorus load using mean values may not be appropriate
4. over- or under-estimation of in-lake phosphorus retention

Table 2. Application of phosphorus loading models to lakes in Nova Scotia. Reports submitted with this report are marked with an "*".

Dillon and Rigler (1978) Model

1978*	Headwater Lakes of the Shubenacadie River Watershed (CWRS)
1980	Headwater Lakes of the Gaspereau River Watershed (CWRS)
1991*	Headwater Lakes of the Shubenacadie River Watershed (CWRS)
1995, 2001	Headwaters of the Woodens River Watershed (CWRS)
1998*	Morris Lake (CWRS)

Trophic Status Model (Dillon et al. 1986)

On-going	Lakes in the Halifax Regional Municipality (SWCSMH)
1995*, 2002*	Gaspereau River Watershed, Kings County (ACER)
1996	Lumsden Pond, Kings County (CWRS)
1996	Birch Cove Lakes, Halifax County (LOL)
2003	Nine Mile River Watershed (LOL)

OECD

1980	Lakes in Atlantic Canada National Parks (Kerekes)
1983	Freshwater Lake, Cape Breton Highlands National Park (Kerekes)
1986*	Selected Lakes in the Headwaters of the Shubenacadie River Watershed Schwartz and Underwood (1986)

11.0 Conclusions and Recommendations

1. The four modelling groups identified in this report are using either a slightly modified Dillon and Rigler (1975) or Dillon et al. (1986) phosphorus loading model. With the exception of the equation used to estimate in-lake phosphorus retention, all remaining input variables and equations are the same for both models.

2. Values used for certain input variables can vary among modellers using the same model. The main contributing factor for this is the use of different baseline information required to generate these values, specifically, the mapping. Unless the mapping used to determine land use areas is identical, and the final delineation of boundaries the same, there will not be agreement between input data sets. These differences can be used to explain some of the variation in model predictions that may exist between two modellers. It is also not always the case that two researchers looking at the same watershed will apply the same assumptions to their modelling. Consistency in the application of export coefficients to land use among researchers may also differ. As a result of this review, it was revealed that up-dated land use coefficients were used by 2 of 3 modellers, while the third continued to use those that were produced 15 years earlier. This fact may have to do with access to information. It was also revealed that when modelling the same watershed, storm drainage information privy to only one of two modellers led to the use of an export coefficient different than that used by the modeller who was unaware of the phosphorus retention measures planned for the watershed in question. This would have contributed to any discrepancy in model output.

3. All modellers in this report assume that any on-site system within 300m of a lake or tributary stream will eventually contribute some fraction of its effluent phosphorus load. There is, however, no scientific basis for the 300m boundary. The distance should be reviewed.

4. Two of the groups have routinely considered a 50% retention of phosphorus released from on-site septic system by soils, while 2 have assumed 0% removal. Based on the analysis of the Third Lake watershed, Hart et al. (1978) determined that the local soils (Halifax (medium texture) and Wolfville (fine texture)) appeared to retain 50% of the phosphorus from septic drainage. These researchers assumed that soils in other watersheds were capable of removing the same percentage of phosphorus, hence the 50% value was similarly applied. It may be that a watershed with a greater percentage of fine soils may retain more, while those with coarser or sandy soils retain less. More attention could be directed to gaining a better understanding the role of soils in the attenuation of phosphorus from on-site septic systems in Nova Scotia. Debate on this issue continues. Hutchinson (France, 2002) suggests that assuming up to 74% retention of phosphorus by soils is not unrealistic. He bases this figure on research of Dillon et al. (1994), supported by the work of Stumm and Morgan (1970); Jenkins et al. (1971); and Isenbeck-Schroter et al. (1993). Based on direct on-site system observations made by Robertson et al.(1998) and Wood (1993), in which up to 90% of the phosphorus was removed, he goes on to suggest that the 74% figure may be conservative.

5. Most of the phosphorus modelling work in Nova Scotia has been directed at lakes in the Halifax area. The 25 mg m^{-2} yr^{-1} figure used to represent the phosphorus load contributed by precipitation was based on a 1977 study that focused on the Halifax area. Although loading rates were produced in 1984 for other regions of the province, the 1977 Halifax rate continued to be used in modelling work outside the Halifax area.

6. Two export values have been used to estimate the phosphorus load contributed by golf courses. Both values were produced prior to 1980. The appropriateness of the coefficients is in question and therefore should be reviewed.

7. At the present time, reference material related to phosphorus loading models and their application to lakes in Nova Scotia is largely confined to the modellers themselves and clients for whom to work was done. Some, not all, of this information is held by local libraries. To reduce the time necessary to identify, locate and access this information, it would be beneficial to have as much of this material as possible located in a central registry. One obvious choice would be the library operated by NSDEL. For the sake of convenience and speedy access, a reference list of the compiled reports available should be posted to a web site. It would also be beneficial to have the contents of the more important materials copied to that site.

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APPENDIX I – Phosphorus Loading Model Used by CWRS

This section describes the model that has been used by CWRS and its staff since 1978. It also includes a brief description of the model utilized by Ron Loucks Oceanography Ltd..

AI.1.0 Model Description

The modified Dillon and Rigler (1975) phosphorus loading model utilized by CWRS has been set up in an Excel spreadsheet format. The model, which incorporates and expands on the work of Vollenweider and others (Vollenweider, 1968, 1969; Dillon and Kirchner, 1975; Dillon and Rigler, 1974) was first applied to Nova Scotia lakes by Hart et al. (1978). Since then, it has been used extensively within the province (Scott, R.S.. 2001; Griffiths Muecke Asociates, Gordon Ratcliffe Landscape Architects, CWRS, and Derek Davis. 1998; Porter Dillon Ltd. et al. 1996; Hart, W.C. and R.S. Scott. 1995; Scott, R.S., W.C. Hart, and D.H. Waller. 1991; Geolimnos Consulting. 1980a; Geolimnos Consulting. 1980b).

The model utilizes empirical and semi-empirical relationships to estimate natural and anthropogenic phosphorus sources, and hydrologic and morphometric information in a mass-balance budget, to predict the total phosphorus load of a lake.

AI.2.0 Modelling Assumptions

Assumptions of the modelling process include:

1. That all anthropogenic phosphorus sources within 300m of a lake or tributary stream will contribute to and are included in the total phosphorus load of a lake system (Dillon and Rigler, 1975; Dillon et al., 1986). There is, however, no scientific basis for the 300m boundary (France, 2002).

2. Many have assumed that 100% of the phosphorus exported from septic systems will eventually make its way to a lake and should be considered in the total phosphorus load (Dillon et al., 1986, 1994). Modelling by CWRS assumes a 50% figure, which was based on retention estimates for Halifax (medium texture) and Wolfville (fine texture) soils (Hart et al., 1978). It is assumed that the soils for those watersheds modelled are capable of removing the same percentage. It may be that a watershed with a greater percentage of fine soils may retain more, while those with coarser or sandy soils retain less.

3. The annual per capita export for on-site systems is 0.8 kg (Dillon and Rigler, 1975).

4. Landuse export coefficients (Scott et al. 2000) for igneous and sedimentary forested and forest + >15% cleared + wetlands categories are mean values (6.9 and 8.3, and 8.8 and 11.5 mg m^{-2} yr^{-1}, respectively) based on a range of values (4.2 – 15.3 and 2.5 – 11.1, and 5.6-15.9 and 6.6-20.4 mg m^{-2} yr^{-1}, respectively) for each category. The total phosphorus budget can therefore be significantly affected by the use of mean values.

5. Most of the modelling by CWRS has focused on the Halifax region of the province. The value used to represent phosphorus loading by precipitation has been 25 mg m^{-2} yr^{-1}. It is understood that the use of a single value for phosphorus loading by precipitation to a water body may not be realistic for all areas of Nova Scotia.

6. The number of occupants per household has varied for modelling purposes for the watersheds studied. Statistics Canada census data has been the basis for values used. (Woodens – 3.15; Shubenacadie – 4.3; Aylesford – 4.2; etc.). Although the figures applied typically represented an average household occupancy for a geographical area much larger than that being modelled, it was assumed that any difference between the two areas was negligible.

A description of input/output variables used in the model is presented in Table 1.

AI.3.0 Model Input Variables

AI.3.1 Land Use Export Coefficients

Prior to the 1978 Shubenacadie study, no published information for Nova Scotia landscapes existed that described phosphorus export for the non-urban landuse categories. Two Nova Scotia based studies, that by Hart et. al. (1978) and a more extensive study performed by Scott et. al..(2000), developed coefficients for the forested and forested + (>15% Cleared + Wetland) categories. Those from Hart et. al. have been applied in modelling efforts up until August 2000, after which the Scott et. al. values have been used.

	Prior to August 2000[a]	Since August 2000[b]
	mg m^{-2} yr^{-1}	
Igneous Bedrock/Forested	5.4[1]	6.9
Igneous Bedrock/Forest + (>15% Cleared + Wetland)	7.8[2]	8.3
Sedimentary Bedrock/Forested		8.8
Sedimentary Bedrock/Forest + (>15% Cleared + Wetland)		11.5
		Since 1978
Agriculture or recreational (golf course)[3]		10.4

[a] Hart et. al. 1978.
[1] Value was calculated using data for 2 undisturbed lakes.
[2] Calculated using 7-months phosphorus data from Uniacke Brook. Runoff estimates were extrapolated from records obtained over a 7-month period from a neighbouring watershed using a simple proportional relationship between drainage areas. The total load was then determined using phosphorus values for

specific periods of time multiplied by the amount of corresponding runoff. The sum of individual periods equaled the total load. This figure was then divided by the watershed area to determine the unit area export value.

[3] Calculated in the same manner as 2, using phosphorus data from an area draining a golf course.

[b] Scott et. al. 2000. This study was an extensive investigation documenting phosphorus export from 29 watersheds in Nova Scotia. The study was conducted over a period of 12 months.

Table 1. Description of the Input and Output variables in the modified Dillon and Rigler (1975) phosphorus loading model.

VARIABLE	TYPE	DESCRIPTION
LAKE AREA-m^2	Input	Water surface area of the water body
Subwatershed area- m^2	Input	Watershed area, not including lake area
Total area to outlet m^2	Output	Sum of water surface and subwatershed areas
LAKE VOL.- m^3	Input	Lake volume
MEAN DEPTH- M	Output	Equals "Lake Volume m^3"/"Lake Area m^2"
MEAN Q- M/YR	Input	Longterm average height of water runoff per unit area. Typically obtained using Environment Canada hydrometric records for similar watershed. Equals mean annual discharge/watershed area
PERSONS- STP	Input	The number of persons serviced by a sewage treatment plant
DWELLINGS- ON-SITE	Input	The number of cottages and dwellings located within 300 metres of a lakeshore or tributary stream
AREAS IN m^2		A breakdown of a watershed into its various landuse categories using best available mapping
-FOREST	Input	Where Forested area of watershed is >85% of total area
-FOREST+>15% CLEAR + WETLAND	Input	Where sum of cleared area plus wetland is >15% of the total watershed area. Cleared Includes barren, clearcut and "other" NSDNR designated areas. 'Other' refers to miscellaneous non-forested land e.g. roads, open water)
-AGRIC/RECREATION	Input	The area designated as agriculture or recreational, such as golf courses
-URBAN	Input	The area designated as urban

VARIABLE	TYPE	DESCRIPTION
RUNOFF VOL.- m^3/YR	Output	The total volume of runoff passing through the outlet of a lake. 1. If the "Sub-watershed Area" is more than 10 times the "Lake Area", the outflow volume is equal to "Total Area m^2" times "Mean Q m^3" 2. If the "Sub-watershed Area" is less than 10 times the "Lake Area", the outflow volume is equal to to "Total Area m^2" times "Mean Q m^3" + "Lake Area m^2" times Precipitation minus Evaporation.
FLUSH.RATE- TIMES/YR	Output	The number of times per year a lake's volume is exchanged. Equals "Runoff m^3/yr"/"Lake Volume m^3"
WATER LOAD- M/YR	Output	Areal water load, or the depth of water applied to the surface of a lake in 1 year Equals "Runoff m^3/yr"/"Lake Area m^2"
RETENTION COEFF.	Output	The phosphorus retention coefficient is that proportion of the phosphorus entering the lake which will remain in the basin. $R = (0.426e^{-0.271(\text{"Water Load"})}) + (0.574e^{-0.00949(\text{"Water Load"})})$ Equation from Kirchner and Dillon 1975 in which R was found to be highly correlated with to areal water loading, Q/A or q_s
RESPONSE TIME- YR.	Output	The time required for a lake's phosphorus concentration to respond to a change in loading and is described in Dillon and Rigler (1975) as the time required for a lake's phosphorus concentration to move half-way (50%) from the original steady-state concentration to the final steady-state concentration. Response time is expressed as 0.69/(flushing rate + 10/mean depth). Dillon and Rigler (1975) suggested that a more realistic response time for a lake would be 3-5 times the calculated time, the time necessary to reach 87.5-96.9% of the final steady-state concentration

VARIABLE	TYPE	DESCRIPTION
P IN RUNOFF- KG/YR	Output	Equals the total phosphorus load contributed by the various landuse categories.
P UPSTREAM- KG/YR	Output	Equals phosphorus load contributed to a lake from all tributary lake sources, expressed as the sum of (1-retention coefficient) times "Total P Load" for each upstream lake/10^6
P FROM PRECIP- KG/YR	Output	The contribution of phosphorus directly to a lake by precipitation, expressed as precipitation load, mg/m^2/yr times "Lake Area, $m^2/10^6$
P PERSONS-STP- KG/YR	Output	Phosphorus load attributable to sewage treatment plants
P DWELL-O.S.- KG/YR	Output	Phosphorus load attributable to on-site systems
P POINT SOURCES	Input	Additional phosphorus point sources
TOTAL P LOAD- KG/YR	Output	Total phosphorus load. Equals the sum of all sources.
WANTED TROPHIC STATUS - 1 to 3 (see table) - Max. SPRING P	 Input Output	 Desired trophic status for lake The maximum spring phosphorus concentration, ug/L, associated with trophic status identified.
PERMISSABLE P- KG/YR	Output	The maximum phosphorus load possible to maintain the desired trophic level. Equals "Maximum Spring P" concentration, ug/L X "Lake Volume m^3" X "Flushing Rate"/(1-retention coefficient) X 10^6
Avg. Lake Conc ug/L	Output	An estimate of the mean annual lake concentration. Equals "Total Load, kg/yr" X (1 - "Retention Coefficient") X 10^2/("Lake Area, $m^2/10^4$) X 0.956 X ("Total Area, m^2"X $0.98/10^6$) X 10^6/"Lake Area, m^2")

AI.3.2 Precipitation

The contribution of phosphorus from precipitation has been based on work by Hart (1977). The figure used, 25 mg m^{-2} yr^{-1}, represents deposition for the Halifax area. In the absence of representative phosphorus figures for other areas of the province, it is acknowledged that the application of this figure throughout the province may be unrealistic.

AI.3.3 On-Site Septic Systems

A 50% reduction of total load based on 0.8 kg P $capita^{-1}$ yr^{-1} has been adopted. The 50% soil retention figure was based on an analysis of the Third Lake watershed as part of the Hart et al. (1978) study. The Third Lake watershed contains medium to fine texture soils (Halifax and Wolfville sseries).

AI.3.4 Sewage Treatment Plant (STP) Effluent Phosphorus

The study of the Woodens River Watershed by CWRS (2001) for Three Brooks Development Corporation identified a sewage treatment facility for the Sir John A. MacDonald High School. A figure of 5 mg/L was used as an average effluent phosphorus concentration (P. Klaamas, pers. comm.) Total flow was calculated using data from the metered plant and the number of school days. An estimate of the total load equalled the product of the three variables. A second study (Scott et al. 1991) estimated the contribution of a proposed STP using design figures provided. Effluent phosphorus concentration in this case was 6 mg/L.

AI.3.5 Household Occupancy

The occupancy rates used for individual studies have varied over the 25 years of modelling experience. All figures have been based on Statistics Canada census data.

AI.3.6 Urban/Developed

The export coefficient used for urban stormwater varies depending on setting. For residential, the figure used is 0.52 kg ha^{-1} yr^{-1} (Waller, 1977). For high-traffic commercial with no vegetation, 2.02 kg ha^{-1} yr^{-1} is used (Waller and Hart, 1986).

AI.4.0 Loucks Oceanography Ltd. Modelling Work

The application of the Ontario Lakeshore Capacity Trophic Status Model (Dillon et al. 1986) to lake systems in Nova Scotia has been carried out by Loucks Oceanography Ltd. (Porter Dillon Ltd., 1996: Dillon Consulting Ltd., 2003). This model is a refinement of the Dillon Rigler (1975) model. Loading figures (Table 2) used in the model by this group are the same as those used by both CWRS and SWCS.

Table 2. Phosphorus export for various landuse categories and on-site wastewater systems.

Source	kg ha^{-1} yr^{-1}	Reference
Precipitation	0.25	Hart et al., 1978
Forest	0.054	Hart et al., 1978
Marsh or >15% cleared	0.078	Hart et al., 1978
Residential, serviced	0.30	Adapted from Waller and Hart, 1986; Shuyler, 1993
Persons On-Site	0.8 kg/c/yr	Dillon et al., 1986
Light Commercial - no vegetation, low traffic	0.40	Waller and Hart, 1986
Heavy Commercial - no vegetation, high traffic	2.00	Waller and Hart, 1986

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Chairman and Scientific Director
Date: March 12, 2003
Subject: An overview of our Predictive Modelling

Thank you for inviting us in partnering with the CWRS in the initial survey of Predictive Models in Nova Scotia for the Nova Scotia Department of the Environment and Labour (NSDEL).

Table of Contents

1. INTRODUCTION 28

2. OUR MODELS IN MS EXCEL SPREADSHEET FORMAT 28

2.1. CORRESPONDENCE BETWEEN MODELLED AND FIELD VALUES, AND CAUTION FOR DYSTROPHIC LAKES (CF. APPENDIX B) 29
2.2. EXPORT COEFFICIENTS APPLICABLE TO ALL SCENARIOS 30

3. DETAILS ON VARIOUS SPREADSHEETS WITHIN OUR MODELS BASED ON MS EXCEL 32

3.01. Flow-spreadsheet: 32
3.02. Master Spreadsheet (Master SS): 32
3.03. Control Spreadsheet (Control SS): 32
3.04. Background –plus- aerial deposition (B+A): 33
3.05. Recent development scenario: 33
3.06. Future development scenario: 33
3.07. Runoff spreadsheet: 34
3.08. Predictive graphical models utilized: 34
3.09. OECD (1982) Model (Vollenweider and Kerekes, 1982): 35
3.10. Vollenweider (1976) Model (Vollenweider, 1976): 36
3.1. PRIMARY REGRESSIONS USED IN PREDICTIVE TP MODELLING 37
3.1.01. Lakeshore Capacity Study (Dillon et al., *1986, 1994; Hutchinson* et al., *1991): 37*
3.1.02. OECD (1982) regressions (Vollenweider and Kerekes, 1982): 38
3.1.03. Additional regressions (Rast and Lee, 1978): 38

4. REFERENCES UTILIZED IN THE MODELLING 39

APPENDIX A: LISTING OF THE MODELLED LAKES/PONDS 43

APPENDIX B: NARRATIVE- SELECT LISTING OF THE MODELLED AND FIELD DATA FOR 72 SIGNIFICANT LAKES IN HRM 51

1. Introduction

We have carried out Predictive Phosphorus modelling of nine hundred and thirty five (935) lakes and ponds over 1 hectare in size within the watersheds of HRM, and in those watersheds which overlap the adjoining areas of East Hants, and Chester. A list is provided in Appendix A.

The bulk of the modelling was carried out by just two professionals, by Applied Limnologist, Shalom Mandaville (664 lakes/ponds) and by Environmental Engineer from Bremen, Germany, Heike Pfletschinger (271 lakes/ponds).

There were three other professionals who assisted greatly with the assembly of the land use data during the early 1990s. They were Geotechnical Engineer, David Wismath, Biologist, Julie Sircom, and Agricultural Engineer, Tom Campbell.

In addition, we have also carried out related models incorporating other indicators, namely nitrogen and select persistent pesticides. This aspect of our work is only at a preliminary stage and we are not yet comfortable in enunciating details at the present time.

2. Our models in MS Excel spreadsheet format

Our Predictive TP modelling was based primarily on the following three sources: the leading research of Peter Dillon and collaborators in Ontario; the research spearheaded by international peers in limnology under the chairmanship of Richard Vollenweider which culminated with the Organisation for Economic Co-Operation and Development report (OECD, 1982); and the Vollenweider (1976) model. We have also applied other peer reviewed models developed by various researchers and mostly narrated in the Rast and Lee OECD report (1978). But the latter were an exception to the rule.

The value of our spreadsheet modelling is that inputs can be varied with ease over time and results can be obtained in literally minutes. This facilitates altering land use, various regression relationships, export coefficients, and inlake retention factors at ease. They also allow incorporation of automated macros for calibration of the model where extensive field data is extant, and for other benefits. In addition, there is an utilitarian `Goal Seek' function built into the Excel spreadsheets, and we were also able to enlarge the `Goal Seek' macro to include more variables when needed!

The user needs to use only the Control Spreadsheet (Control SS) to alter any land use data and obtain the results in the same sheet instantaneously.

Once a user understands the various aspects, it becomes quite routine in using our spreadsheet models. Only rarely is there any need to use various importable macros except for example in dystrophic lakes and in some shallow lakes that are macrophyte-driven as opposed to the algal-driven scenario.

A "shallow lake" or "pond" is usually defined as a permanent standing body of water that is sufficiently shallow to allow light penetration to the bottom sediments adequate to potentially support photosynthesis of higher aquatic plants over the entire bottom (Wetzel, 2001).

2.1. Correspondence between modelled and field values, and caution for dystrophic lakes (cf. Appendix B)

With exceptions, this modelling may not account for the higher phosphorus values normally found in dystrophic lakes especially as regards the natural background inlake concentration. But it is expected that the modelled future scenarios may indeed reflect the increased phosphorus loading from anthropogenic sources, though the trophic status based on phosphorus alone may not predict the actual state.

As an example of a highly dystrophic lake where our modelling appears to accurately predict the TP value was Sheldrake Lake of the Woodens River watershed. Our predicted TP value based on the 1988 land use data was 23.7 µg/l in comparison with our measured 1991-92 volume-weighted mean of 13 discrete-depth monthly events of 22 µg/l resulting in a correspondence of 7.7%. This correspondence was wholly unexpected.

We did obtain excellent correspondence, in the range of 0-20%, in most lakes where extensive field data was extant, for both clearwater as well as for several dystrophic lakes in the Recent development scenarios. For further examples, *cf.,* Appendix B.

Where we had only seasonal field data, the correspondence was not as satisfactory in all cases. In such instances we surmise that may have been as a result of the field data not being sufficiently reliable due to poor sampling frequency or other causes, and not the modelled TP data.

2.2. Export coefficients applicable to all scenarios

In most scenarios, phosphorus export coefficients have been applied primarily from Hart *et al*., (1978), Underwood (1984), USEPA (1976), Vokey (1998), Waller (1977), Waller and Novak (1981), and Waller and Hart (1985).

After receipt of the latest report on background TP export coefficients from the Nova Scotia Dept. of Environment (Scott *et al.,* 2000), we experimented by inputting these latest export coefficients into our select models, and we arrived at the conclusion that there were no statistical differences in the resulting mean yearly TP inlake concentrations.

Though we did apply the latest export coefficients from Scott *et al* (2000) in some recent eastern shore models (HRM Dt.# 1) for 271 lakes/ponds which were modelled by Heike Pfletschinger during 2001.

Assuming properly functioning septic systems, onsite TP retention coefficient=0.5 w/in 300m of watercourses (Hart *et al*., 1978), 0.8 kg/cap.yr (Dillon *et al.*, 1986), 3.5 cap.yrs/residence.

The worst case onsite retention coefficient=0 (Dillon and Molot, 1996) was not applied in this modelling but can be easily edited into the Master SS.

Urban/serviced area TP export computed @ 0.52 kg/ha.yr (Cambridge Street [Waller, 1977]; and Settle and Bissett Lakes subwatersheds [Vokey, 1998]), and @ 1.1 kg/ha.yr (mean Ontario urban coeff. [Waller and Novak, 1981]).

An interesting note here is that the mean value for urban watersheds from an extensive national data base in the USA as reported by the USEPA (1976) is a value of 0.8 kg/ha.yr which coincidentally works out to be the mean of the 0.52 and 1.1 kg/ha.yr utilized as above!

Crown and park lands assumed to stay undeveloped in all cases.

Forested @ 0.054 kg/ha.yr (Hart *et al.,* 1978),
and Forested greater than 15% cleared + wetlands @ 0.078 kg/ha.yr (Hart *et al.,* 1978);
Golf Courses & Agricultural @ 0.104 kg/ha.yr (Hart *et al.,* 1978);
Direct aerial deposition over watercourses @ 0.173 kg/ha.yr (Underwood, 1984; Dillon and Molot, 1996);
Institutional @ 0.42 kg/ha.yr impervious area (Waller and Hart, 1985); and
Industrial/Commercial @ 2.02 kg/ha.yr impervious area (Waller and Hart, 1985).

For our modelling conducted in year 2001 for 271 lakes/ponds in the eastern part of HRM (Dt. # 1), export coefficients utilized were:
Igneous Forested @ 0.069 kg/ha.yr (Scott *et al.,* 2000),
Igneous Forested greater than 15% cleared + wetlands @ 0.083 kg/ha.yr (Scott *et al.,* 2000);
Sedimentary Forested @ 0.088 kg/ha.yr (Scott *et al.,* 2000),
Sedimentary Forested and greater than 15% cleared + wetlands @ 0.115 kg/ha.yr (Scott *et al.,* 2000).

Note re golf courses: In some watersheds, especially where new golf courses were being planned, we established that the aforementioned 0.104 kg/ha.yr (Hart *et al.,* 1978) was too low; in such cases, we applied a mean value of 0.6 kg/ha.yr extrapolated from the from the USEPA (1976)

Re Sewage Treatment Plants (STP), assuming a base value of 0.8 kg/cap.yr contribution (Dillon *et al.,* 1986), we calculated the export from this source based on the following treatment efficiencies as reported by Myers and Harding (1983):
0-20% removal with primary treatment,
10-30% removal with secondary treatment, and
80-95% removal with tertiary treatment.

This methodology was only applied in cases where the actual export from STPs was not available. No scientifically based allowance was made to take into account the highly biological nature of the effluent from STPs although the lower removal efficiencies from Myers and Harding (1983) were applied.

For greater confidence, it is recommended that the methodology employed by Joe Kerekes in his assessment of an STP's impacts on the Freshwater Lake in Cape Breton be employed (Kerekes, 1983).

3. Details on various spreadsheets within our models based on MS Excel

TP diagnostics spreadsheet summarizes the leading and relevant phosphorus predictive methodologies.

3.01. Flow-spreadsheet:

This spreadsheet depicts the watershed in a flow chart.

3.02. Master Spreadsheet (Master SS):

The Master SS is essentially the workhorse, and contains the various land use stats as well as the development scenarios inclusive of the aerial deposition, and background values.

3.03. Control Spreadsheet (Control SS):

The Control SS summarizes the modelling results as well as incorporates an innovative "what if" analysis feature. The results of the various scenarios in the Master SS have been inserted into the Control SS. The Control SS has a section titled `Experimental theoretical analysis' (shaded grey), and this is the section where the principal variables could be varied to obtain the new TP loading (yellow), the OECD trophic status (blue) as well as the Carlson TSI (green). The aforementioned altered inputs from the Control SS are incorporated into the Master SS (into the relevant columns of the `Recent' scenario) resulting in new values for the TP conc, and the associated trophic parameters. `Recent Theoretical TP conc' section of the Control SS has the modelled values per the date noted. `Recent Field value & reference' section of the Control SS contains pertinent historic field data. The two sections can be utilized for comparison of the `Recent' scenario (per the date noted).

Note: The OECD Management Model was used to predict the trophic states in the `Experimental theoretical analysis' and the `Recent Theoretical TP conc' sections, whereas the OECD Diagnostic Model was used to determine the trophic states in the `Recent Field value & Reference' section. The trophic state categories (based on TP) for both of the OECD models have been included towards the end of this Control SS. The TP values may not be indicators of the trophic states for dystrophic lakes (dystrophic lakes have been so denoted).

The Carlson TSIs smooth out minor variations in the TP concentrations.

The `Basic Morphometric and Hydrologic data' section of the Control SS summarizes relevant and available features of the lakes some of which were obtained from the GIS mapping available at the HRM.

3.04. Background –plus- aerial deposition (B+A):

The theoretical background loading –plus- direct aerial deposition have been noted as “Th B+A”, and in clearwater lakes it is expected that these were the natural background values including direct aerial deposition.

3.05. Recent development scenario:

Onsites- those existing within 300 m of all watercourses inclusive of upstream areas (Dillon and Rigler, 1975).

Urban/Serviced- existing developed areas in the watersheds with sanitary sewerage exported out of the watershed.

Sewage Treatment Plant (STP) contributions taken into account.

3.06. Future development scenario:

Onsite disposal systems:

F-P (Future Probable)= lands within 300m of all lakes developed with onsite systems @ 2.5 lots/ha density.

F-U (Future Ultimate)= F-P scenario + lands within 300m of all streams developed with onsite systems @ 2.5 lots/ha.

Future Sewage Treatment Plant (STP) contributions taken into account.

Urban/Serviced (watersheds developed as residential- sanitary sewerage exported out of the watershed):

F-P (Future Probable)= Urban/serviced area export coeff. @ 0.52 kg/ha.yr (Waller, 1977; and Vokey, 1998).

F-U (Future Ultimate)= Urban/serviced area export coeff. @ 1.1 kg/ha.yr (Waller and Novak, 1981).

3.07. Runoff spreadsheet:

The runoff spreadsheet contains the ten year (1982-92) runoff stats supplied by Environment Canada from their various guaging stations within the Metro Halifax area. By comparison with long term records of Environment Canada, it was found during Dec-1994 that this period was reasonably depictive of an average year.

3.08. Predictive graphical models utilized:

Predictive Model spreadsheets are comprised of graphical models constructed with the EasyPlot software (http://www.spiralsw.com/EasyPlot) and transferred onto Excel spreadsheets. The world renowned base models are the OECD (Vollenweider and Kerekes, 1982) Management Model and the Vollenweider (1976) Model. These spreadsheets visually depict the modelled theoretical as well as any relevant `recent' field values.

OECD (1982) Management Model (Vollenweider and Kerekes, 1982): This model synthesizes the standard OECD equations for the relationships between average inflow phosphorus concentration (Pj), expected average lake concentration P_{λ}, and expected average chlorophyll concentration (Cha) as a function of the average water residence time T(w). The model also gives approximate indications of the expected trophic category. As these categories are management oriented, they are slightly more stringently defined (i.e., approximately at the class midpoints) than are the categories used for diagnostic purposes. This provides a certain safety margin for the design of the loading objectives. Since the model requires the hydraulic residence time as one of the axes, it is not possible to plot most lakes due to insufficient bathymetric data. **(*cf.* §3.09.)**

Vollenweider (1976) Model: Although this model pre-dates the above OECD (1982) Model, in most cases this model is more appropriate since one of the axes-variables, q_s (areal water load) is available for all lakes. In order to incorporate the probabilistic scenario, the management categories from the OECD (1982) model have been incorporated into this model. **(*cf.* §3.10.)**

When possible and relevant, lakes with sufficient bathymetric data were plotted on both of the above models.

3.09. OECD (1982) Model (Vollenweider and Kerekes, 1982):

The OECD Management Model as inserted below. This model synthesizes the standard OECD equations for the relationships between average inflow phosphorus concentration $[\overline{P}]_j$, expected average lake concentration $[\overline{P}]_\lambda$ and expected average chlorophyll $[\overline{Chl}]$ concentration as a function of the average water residence time T(w). This diagram also gives approximate indications of the expected trophic category. As these categories are management oriented, they are slightly more stringently defined (i.e. approximately at the class midpoints) than are the categories used for diagnostic purposes. This provides a certain safety margin for the design of the loading objectives. The long term correlation equations are:

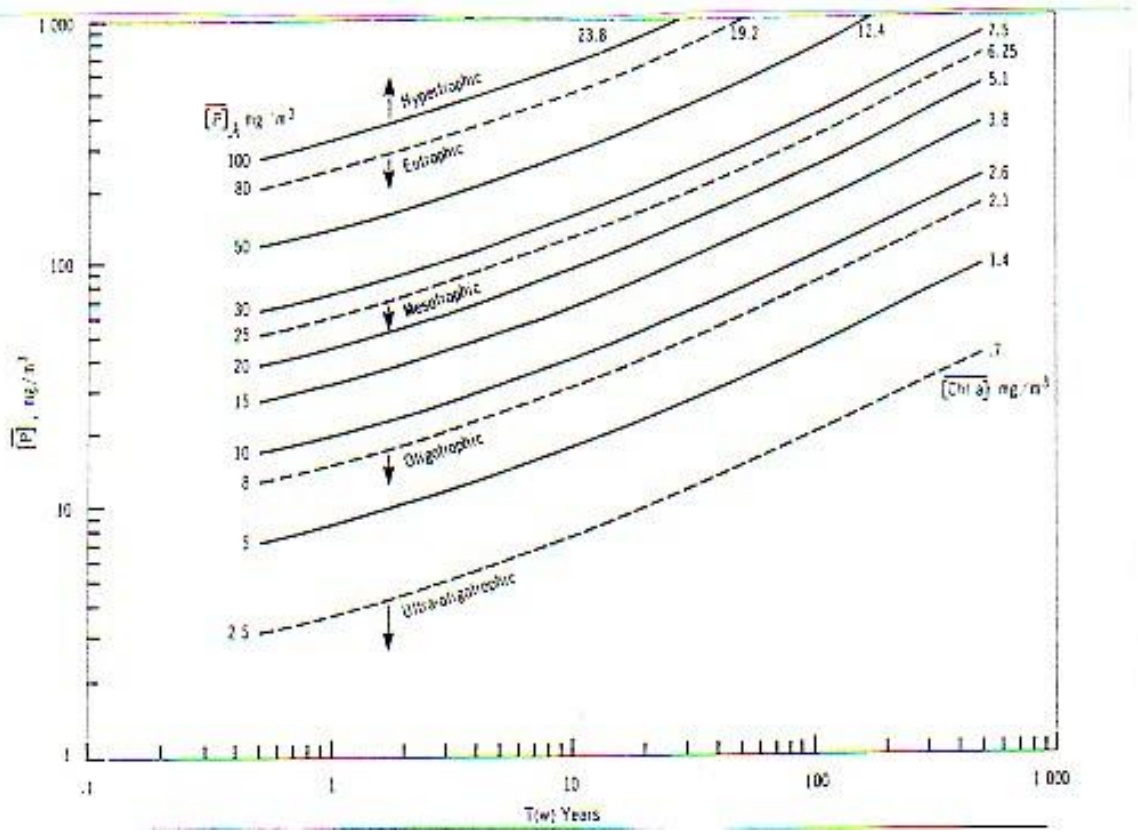
$$[\overline{P}]_\lambda = 1.55\left[[\overline{P}]_j \Big/ \left(1+\sqrt{T(w)}\right)\right]^{.82}, \quad [\overline{Chl}] = 0.28\,[\overline{P}]_\lambda^{.96}, \quad \left[\begin{matrix}\max\\ Chl\end{matrix}\right] = 0.64\,[\overline{P}]_\lambda^{1.05}, \text{ and}$$

$$[\overline{N}]_\lambda = 5.34\left[[\overline{N}]_j \Big/ \left(1+\sqrt{T(w)}\right)\right]^{.78}$$

The corresponding approximate long term orthogonal regression equations are:

$$[\overline{P}]_\lambda = 1.22\left[[\overline{P}]_j \Big/ \left(1+\sqrt{T(w)}\right)\right]^{.87}, \quad [\overline{Chl}] = 0.18\,[\overline{P}]_\lambda^{1.09}, \quad \left[\begin{matrix}\max\\ Chl\end{matrix}\right] = 0.42\,[\overline{P}]_\lambda^{1.17}, \text{ and}$$

$$[\overline{N}]_\lambda = 3.25\left[[\overline{N}]_j \Big/ \left(1+\sqrt{T(w)}\right)\right]^{.85}$$



3.10. Vollenweider (1976) Model (Vollenweider, 1976):

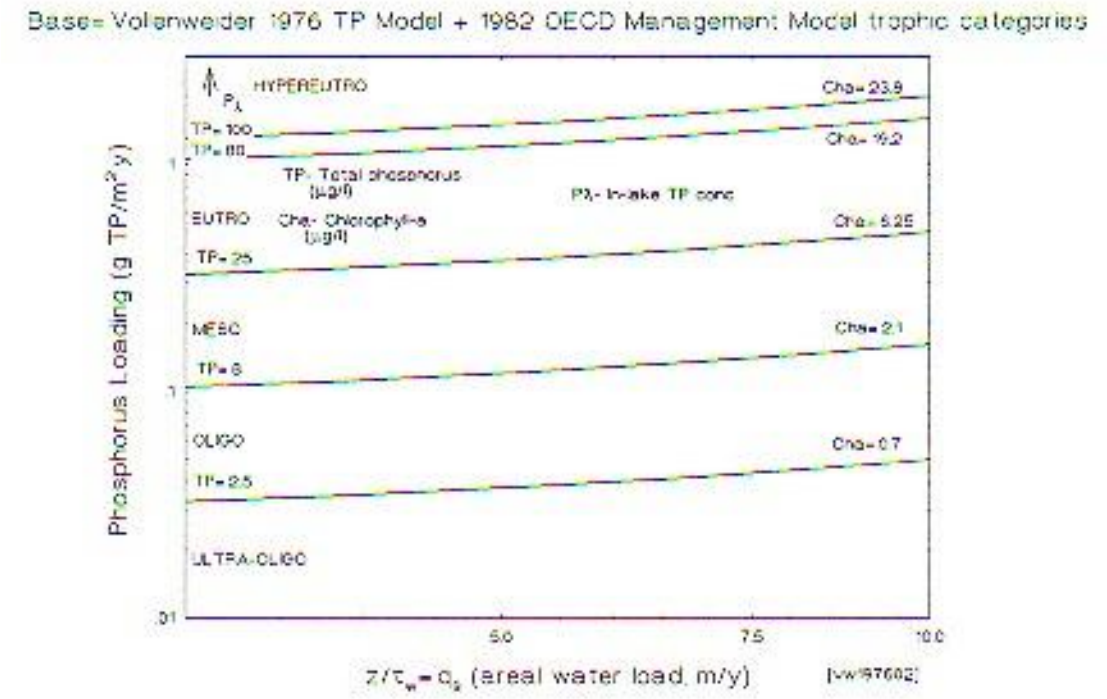
The OECD (1982) regressions alluded to earlier need the water residence time, τ_w, which in turn would imply mean depth. In many cases, mean depths of lakes are not available. In such cases, this older model, which was also a part of the OECD programme, may be used with the appropriate trophic categories, preferably the OECD (1982) Management Model, plotted on the graphs.

The model is:

L_c (mg/m^2.y) = P_c^{sp} (z/τ_w + 10), where

L_c is the critical loading of phosphorus,
P_c^{sp} is the critical concentration of total phosphorus (mg/m^3) for simplicity taken at spring overturn,
z is the mean depth, and
τ_w is the water residence time

In this model, $z/\tau_w = q_s$ represents the hydraulic load which is independant of mean depth. It can be argued however that the model ignores, or at least underestimates, the effect of mean depth, i.e., the dilution function.



3.1. Primary regressions used in Predictive TP modelling

3.1.01. Lakeshore Capacity Study (Dillon et al., *1986, 1994; Hutchinson* et al., *1991):*

Mean ice-free conc. of TP, $TP_{IF} = J * (1-R_p) / (0.956 * Ao * q_s)$, where
- J = total phosphorus input from all sources,
- R_p = TP retention factor,
  - $R_p = v / (v + q_s)$
    - (v is the sedimentation velocity, and is 12.4 for lakes with oxic hypolimnia, and 7.2 for lakes with anoxic hypolimnia)
- A_o = lake surface area, and
- q_s = areal water load
  - $q_s = Q / A_o$
    - Q is the annual lake outflow volume

Response time, $RT = 2.07 / (1/\tau_w + v/z)$, where
- τ_w is the water replenishment time, and
- z is the lake mean depth

Long term predicted Chlorophyll*a* concentrations can be calculated from:
- $Chl_{IF} = 0.83TP_{EP} + 0.12(N/P)_{EP} - 0.018TIN_{EP} - 0.0076TON_{IC} - 5.56$, or
- $Chl_{IF} = 0.48\ TP_{EP} + 0.060(N/P)_{EP} - 3.14$, where
  - N/P ratios in the epilimnion, if not available, can be predicted from
    - $(N/P)_{EP} = 0.43(N/P)_{FO} + 19.4$, where
      - TIN and TON= total inorganic and organic nitrogen respectively, and subscripts
      - IF= ice free
      - EP= epilimnion,
      - IC= ice covered, and
      - FO= fall overturn

Calibration range of the Ontario Trophic Status Model (Hutchinson *et al.,* 1991):

TP= 5.6-19.3 μg/l; Ch*a*= 1.1-5.9 μg/l; Colour= 5-23 Hazen units; A_o= 10-124 ha; Emergent macrophytes covered <30% of the littoral zone; pH= 5.6-7.4; Z (mean depth)= 4.8-16.7 m; Z_{max} (maximum depth)= 12-40 m; SD (Secchi disk) depth= 2.2-8.4 m; DO (Dissolved oxygen) deficit= 161-501 mg O_2/m^2.day.

$TP_{IF} = (0.8 * TP_{so}) + 2.04$, where TP_{so}= spring overturn value, 5m depth composite

If the hypolimnium dissolved oxygen conc. is not known, then assume anoxic hypolimnia if Z_{max}= 10-25 m for clear water lakes, and Zmax= 8-25 m for coloured water lakes with TCU>30.

Other Ontario regression relationships utilized when needed:

Long term, annual average C*ha* conc. for the ice-free period can be predicted without nitrogen measurements as,

$Chl_{IF} = 0.329TP_{epi} + 0.606$ (Molot and Dillon, 1991)

Additionally, the following relationships were applied as well when needed during the model calibrations:

$R_p = 0.426e^{-0.271q_s} + 0.574e^{-0.00949q_s}$ (Kirchner and Dillon, 1975)

For long term Chl_s, $LogChl_s = 1.45LogP_{sp} - 1.14$ with spring N/P>12, where Chl_s is the average summer chlorophyll*a* conc., and P_{sp} is the average spring total phosphorus conc. (Dillon and Rigler, 1975).

3.1.02. OECD (1982) regressions (Vollenweider and Kerekes, 1982):

These were presented in §3.09.

3.1.03. Additional regressions (Rast and Lee, 1978):

In rare cases, other regressions developed in the USA were employed from another OECD report (Rast and Lee, 1978). These lakes were only a handful among the 935 lakes/ponds modelled by us and do not have major relevance at the present time.

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Appendix A: Listing of the modelled lakes/ponds

(Names have been capitalized to denote the lakes for bathymetric maps are available)

[blindbay.xls]= **Blind Bay headwaters** (15 lakes & ponds); updated: April 05, 1998

Upper Trout, Lower Trout, Slough, Oak Hill, Porcupine Pd., Canaan, Powers, Mosers Hill, Hoop Pole, Otter, Barnframe, Murphys, Deep Cove, Lily, and Welsh.

[chezzetc.xls]= **Chezzetcook Inlet headwaters** (33 lakes & ponds); updated: April 05, 1998

Fox, Knowlan, Triplet, Pine, Otter, Gazette, Burnt, Lily Pad, Chezzetcook, R+pds., Gulf, Camp+North, Thompson, Elbow, Sole, Pine, Canoe, Thief, Conrod-1, Long Bridge, Grassy, PETPESWICK, Granite, Lac aux Pattes, CHEZZETCOOK, Roast, Miseners, Bell, Unnamed, Fiddle, Little, Petit Lac, Conrod-2, and Gaetz.

[clambay.xls]= **Clam Bay headwaters** (6 lakes); updated: April 05, 1998

Unnamed-1, Unnamed-2, Muskrat, Rabbit Hill, Grassy, and Abbiecombec.

[colehrbr.xls]= **Cole Harbour headwaters (part)** (4 lakes); updated: April 10, 2000

Bottle, Nelson, Robinson, and Gammon.

[cowbayr.xls]= **Cow Bay River headwater lakes** (8 lakes); updated: April 05, 1998- extensive urban development has taken place here:

SETTLE, BISSETT, PENHORN, RUSSELL, Topsail, Lamont, BELL, and MORRIS.

[dartmisc.xls]= **Dartmouth Miscellaneous** (3 lakes); updated: April 05, 1998- totally developed urban area:

Martin, ALBRO, and OATHILL.

[eastrhx.xls]= **East River (St Margarets) watershed** (10 lakes); updated: April 05, 1998- extensive development pressures, all on onsite septic systems:

Lizard, TAYLOR, Patient Ross, STILLWATER, Flat, LAND OF LAZINESS, ELBOW, LEWIS, ROUND, and HUBLEY MILL.

[halibutb.xls]= **Halibut Bay headwaters**, Halifax Harbour (7 ponds); updated: April 05, 1998

Cranberry Pd., Little Latter Pd., Big Latter Pd., Davidsons Third Pd., Davidsons Second Pd., Davidsons First Pd., and Charley Pd.

[hubbards.xls]= **Hubbards Cove headwaters** (21 lakes & ponds); updated: April 05, 1998

Mountain, Camp, Rocky, Quacks, Brigley, Vinegar, Otter Pds., Marsh, Birch, Shoal Mountain, Deep Mountain, Centre, Little Kip Hill, Kip Hill, Caribou, Skinner, Pitch Pine, Duck Pd., Dauphinees Mill (Chester), Sawler (Chester), and Dorey.

[jeddoreh.xls]= **Jeddore Harbour headwaters** (17 lakes & ponds); updated: April 05, 1998
Oyster Point, Ned, Leader, Little-2, Fish, Black Duck, Clearwater, Unnamed, Big Duck, Southeast Cove, Little-1, Oyster Pd., Newcombes, Porcupine, Bull, Gossard, and Abrahams.

[ketchhrb.xls]= **Ketch Harbour headwaters** (11 lakes & ponds); updated: April 05, 1998

Clarks Pd., PORTUGUESE COVE, Little, Cranberry Pd., Fourth Pd., Unnamed Pd., Semmidinger Pd., Cocked Hat Pd., Third Pd., Second Pd., and First Pd.

[lawrence.xls]= **Lawrencetown Lake headwaters** (62 lakes & ponds); updated: April 05, 1998

O'Brien, Bell, Miller Brook, Little No Good, BECKWOOD, Little Camp, Camp, Cranberry, McKAY, Camphill + bogs, Nest River, WILLIAMS, Eureka, East, Wisdom Mill, Egg, Beckwith, New Found, Lamprey, Little Sixmile, Byron, Narrow, Tittle, Loon, Salmon R Long, Porcupine, Woody, Crowbar, Barren, OTTER, Blue, Sparks, Moose, Camp, West, Granite, Little Browns, McKay Pd., Browns, Jack Weeks, LEWIS, MARTIN, McCoys Pd., Duck, Griswold, Mountain, ECHO, No Good, Bear, Turtle, Little, Winder, EAGLE, Rodgers Duck, Decoy, Preston Long, Carter, Samson Carter Pd., Trimbel, Frog, and Little Gammon.

[moosecove.xls]= **Moose Cove headwaters** (6 lakes & ponds) … being finalised …

Skull, Rocky, Billys Pd, Oak, Moose Cove L, and Bear Cove L.

[mushaboo.xls]= **Mushaboom headwaters** (4 lakes); updated: April 05, 1998
Big Eastern, Grass, Mud, and East Mushaboom.

[musqr-lakes.xls]= **Musquodoboit River headwaters** (134 lakes & ponds); … being finalised …

River-1, Unnamed-1, Crooked-1, Martin-1, Martin-2, Martin-3, Duke, Mc Grattans Pd, Devils Elbow, Lemmon, Little Teakettle, Cox Flowage, Upper Mill, Pot, Farnell, Mill-1, Pug, Hartshore, Moore, Sherlock, Dedication, Unnamed-2, 1st Pratt, 2nd Pratt, Jennings, Fraser-1, Fraser-2, Fraser-3, Dry, Mill-2, Mill-3, Unnamed-3, Unnamed-4, Watson, Unnamed-5, Unnamed-6, Lindsay, Brown-1, Brookvale, Mc Keen, Brown-2, Unnamed-7, Unnamed-8, Cooks, Unnamed-9, Unnamed-10, Crooked-2, Crocket, Cranberry, Little River, Grassy, Rocky-1, Shaw Big, Higgins, Reid, Unnamed-11, McMullin, Tully, Murphys, Milnes, Rocky-2, Otter, Eastern Run Waters, McCullough, Dollar, Mud Pd, John Brayden, Mystery, Little Rocky, Rocky-3, Bruce, Trout, Grant, Beaver, Clearwater, Big Pilgrim, Stillwater, Unnamed-12, Mitt, Red, Unnamed-13, Fuller, Eastern Run, Grand, Pot, Grassy, Lay, Unnamed-14, Unnamed-15, Christopher, Robinson, Hurley, Flat Iron, Roberts Little, River-2, Unnamed-16, Murphy, Unnamed-17, Drummer, Graham, George, Crow, Saddleback, Gillespie, Moose, Donkin, Loon, Blair, Gibraltar, Lawrence, Sherriff, Cove, Johnson, East, West, Centre, Water Lily, Mountain, Duck, Old Hrb Rd, White, Collins, Campbells Pd, Caribou, Sparrow, Granite, Turtle, Bayer, Unnamed-18, Eunice, Little, Unnamed-19, Unnamed-20, and Faulkner.

[musquodh.xls]= **Musquodoboit Harbour headwaters (part)** (10 lakes & ponds); updated: April 05, 1998

Williams, Oyster Pd., Paddys Duck Pd., Duck, Long, Frostfish Br., Dooks, Goose, Little, and Narrows.

[newcombe.xls]= **Newcombe Brook (Ship Harbour) watershed** (19 lakes & ponds); updated: April 05, 1998

Green, Hatchet, Niagara, Unnamed, Otter, Trout, Phillips Boot, Black Duck, Spectacle, Otter-1, Otter-2, Long, Bare Rock, Brandy, Little, Lily Pd., Muskrat Pd., Pats Camp, and Newcombe.

[ninemrhx.xls]= **Nine Mile River (St Margarets) headwaters** (32 lakes & ponds); updated: April 05, 1998- considerable development pressures, serviced by urban systems as well as by onsite septic systems:

Thompsons Pd., Perrys Pd., COXS, Bartlett, Masons Mill Pd., Flat, SCHMIDT, BAPTIZING, Duck Pd., Second, Cranberry, Long-1, Maple, FRASER (urban), Morton, Long-2, Ash, Lewis, Ragged, Black Duck Pds. (Urban), Lovett (urban), GOVERNOR (urban), Six Mile, Half Mile (urban), Upper Marsh, Lower Marsh, Grassy, Upper Five Bridge, Middle Five Bridge, Big Five Bridge, Moores, and Gingerbread.

[northeas.xls]= **Northeast River watershed** (23 lakes & ponds); updated: April 05, 1998- part of this system comprises the Pockwock watersupply, and downstream, significant developments based on onsite services are planned in the local watersheds of Wrights, Cooper and Anderson lakes:

Little Indian (East Hants), Deep (East Hants), Fifteen Minute (East Hants), Unnamed (East Hants), Sandford (East Hants), Fales (East Hants), West (East Hants), Island (East Hants), Bottle (East Hants), Lacey (East Hants), Peggys Pond (East Hants), POCKWOCK, Little Pockwock, Beaver Pd., Clay, Green, Thompson Pd., Thompson, Cooper, Anderson, WRIGHTS, Bull Pd., and Coon Pd.

[papermil.xls]= **Paper Mill Lake watershed** (22 lakes & Ponds); updated: April 05, 1998- with extensive serviced urban development downstream, the headwaters will be opened for urban development in the next decade or two:

Little Horseshoe, Three Finger, Big Horseshoe, Flat, Little Cranberry, Big Cranberry, Crane, Ash, SUSIES, Fox, QUARRY, Charlies, Charlies Pd., Belchers Pd., WASHMILL, Little Kearney, McQuade, Hobsons Pd., Hobsons, KEARNEY, Jack, and PAPER MILL.

[pennantr.xls]= **Pennant River watershed** (46 lakes & ponds); updated: April 05, 1998

Narrow, Sheas, Silver, Doyles, RUN, Round, Cranberry, French, Bayer, Lizard, Bennett, Snowshoe, BLUFF, MOODY, Harry, First, Second, Dryhill, Little Cranberry, Secret, Halfmoon, Frederick, Weaver Hole, Sandy, Ragged, Fourth Pd., Third Pd., Little Burnthill, Little Trout, Burnthill, Fish Br. Pd., SPRUCE HILL, Weavers North, Weavers South, HENRY, Donovan Pd., Governors (or Parr), Grovers, Mud, Rocky Pd., Unnamed Pd-1, Grover, Unnamed Pd-2, Sheehan, Little Pd., and Grand.

[petpeswi.xls]= **Petpeswick Inlet headwaters** (24 lakes & ponds); updated: April 05, 1998

Grassy, Howe, Bottle, Quaver, Drews Trout Pd., Little Moose, Crawford, Sugar Camp, Church-1, Roy, Farquhars, Bear, Julien Pd., Duck, Church-2, PACES, Scots, Scots Pd., Mill Pd., Dark, Catcha, Goose, Round, and Young.

[porters.xls]= **Porters Lakes watershed** (39 lakes & ponds); updated: April 05, 1998- varying amounts of development downstream, all on onsite septic systems:

North, Meadow Bk., Dark Pd., Horseshoe, No Good, Round, Grassy, West Bk., Deadman, Hilltop, Deadman Is. Bk., Cousins, Ledwidge, Dark, Rocky, Y, Clump, Griswold, East Bk., Robert, Rocky, Trout, Trout Bk., PORTERS-UPPER, Little, Forked Pd., Long Pd., Rocky, Grassy, Round, Grand, Mill, Teal Pd., Figure Eight, Caribou, Goose, Snow, Smelt Bk., and PORTERS-LOWER.

[powerspd.xls]= **Powers Pd. Watershed** (17 lakes & ponds), Herring Cove; updated: April 05, 1998- urban services upstream (w/in former Halifax City) and onsite systems downstream:

Bayers, Cranberry Pd., Witherod, Hail Pd., LONG, KIDSTON, Unnamed Pd., Roachs Pd., Flat, Duck Pd., Sheehan Pd., LONG Pd., West Pine Island Pd., Upper Mud Pd., East Pine Island Pd., Lower Mud Pd., and Powers Pd.

[prospecr.xls]= **Prospect River watershed** (11 lakes); updated: April 05, 1998

Ragged, Blueberry, OTTER, Dick, BIG INDIAN, Little Indian, Nichols, McDonald, Fiddle, Pantaloon, and WHITES.

[sackvilr.xls]= **Sackville River watershed** (17 lakes & ponds); updated: April 05, 1998-significant impact from privately operated STPs, considerable development pressures especially with onsite systems, future diversion of 7MIGD from Tomahawk to the Pockwock WTP:

PENTZ (East Hants), Yellow Lily, Duck Pd., LEWIS, Beaver-1, TOMAHAWK, HALFWAY, Beaver Pd., Bottle, Beaver-2, Sandy-1 (Hammonds Plains), LITTLE SPRINGFIELD, Drain, McCabe, WEBBER, SANDY-2 (Bedford), and Marsh.

[salmon-jeddore.xls]= **Salmon River Lake watershed, Jeddore** (57 lakes & ponds) … being finalised …

Spider, Red, Big Tom, Scrabble, Hard Scrabble, North West, McCaffrey, Unnamed-1, Pine, McCaffrey Long, Dilman, Rocky-1, Piney, Duck Pd, Catamaran-1, Catamaran-2, Rocky-2, Fuller, Officer's Camp, Brooks-1, Byron, Brooks-2, Little Tom, Wildcat, ADMIRAL, Pine Grove, Otter Pd, Poplar, Spoon, Unnamed-2, Hartman, Bell, Portapique, Fishing, Horseshoe, Moose Pd, Rabbits, Lily Pd, Unnamed-3, Little Rock, Unnamed-4, Moose, Round, Mud, Skull Pd, East, Western R. Pd, Richardson, Eastern R. Pd, Dooks Pd, Rocky-3, Logging, Logging Pd, Tomson, Round Pd, Maskell Pd, and SALMON RIVER LAKE.

[sheethrb.xls]= **Sheet Harbour headwaters** (7 lakes); updated: April 05, 1998

Caps, Keefe, Lindsay, Fraser, Gaspereaux, GRAND, and West.

[westarm-sheethrb.xls]= **Sheet Harbour- Northwest Arm headwaters** (74 lakes & ponds) … being finalised …

Sand, Burke, Cope Flowage, Kent-1, Upper Fisher, Fisher, Pat, Grassy-1, Rocky Brook, Unnamed-1, Unnamed-2, Upper Beaver, Middle Beaver, Lower Beaver, Kent-2, River, McGregor, Cope Pd, Brandon, Tent, Lawlor, Upper-1, Upper-2, Unnamed-3, West, Crusher, Unnamed-4, Mud-1, Tait, Unnamed-5, Jakes, Mud-2, Lake Dan, Unnamed-6, Unnamed-7, Black Brook, Unnamed-8, Unnamed-9, Unnamed-10, Yellow, Butler, First Essen, Second Essen, Grassy-2, Rocky-1, Lucifer, Otter, Upper Kidney, Lower Kidney, Atlanta, Unnamed-11, Unnamed-12, Southwest, Grassy-3, Unnamed-13, Unnamed-14, Blackie, Lake Alma, Unnamed-15, Unnamed-16, Union Dam, Nowlan, Unnamed-17, Unnamed-18, Sam Northwest, Long, Sam Northeast, Sam Grassy, Sam, Rocky-2, Unnamed-19, Falls West Hill, Sheet Harbour Lake, and Coon.

[shiphrbr.xls]= **Ship Harbour River watershed** (67 lakes, ponds & rivers); updated: April 05, 1998

Mud, Burkner, Black Duck, Long, McLeod, Dollar, Keith (Ryder), Butcher, Grassy, Fairbank, Grassy, Long, Moose R., Square, Cope, Rocky, Philip, Boot, Loon Pd., Scraggy, South Twin, North Twin, Dreadnought, Melvin, Sucker, Shea L. Br., Maple Hill, Ash Hill, (Upper) Fish R., Big Ass, Gold, Stillwater, Faulkner, (Lower) Fish R., Trout, Big, Loon, Shaw, Little, Cranberry, Ship Harbour Long, Little Hartman, Mitchells Hill, South, Dry, Island, Flat, Mill Br., Porcupine Pd., Little Lily Pd., Sal Pd., Webber, Hook, Level Spot, CHARLOTTE, Second, Little Mud, Grassy-1, Cranberry, Spider, Dam, Duck, Grassy-2, Unnamed-1, Unnamed-2, Mikes Flowage, Bait, Cowan Mill Pd., and Weeks.

[shubier.xls]= **Shubenacadie River headwaters** (61 lakes & ponds); updated: January 01, 2000-the w/shed with varied development pressures in Nova Scotia as it spans several bustling urban and suburban areas. Present developments span a variety of scenarios, urban (with no sanitary outfalls into the lakes), suburban (onsite septic systems), a handful of large municipally operated STPs discharging into lakes (mostly secondary treatment, minimal P-removal), a few privately operated package STPs (with poor treatment), and perhaps the system with the most significant development pressures in the upcoming decades:

Preeper Big, King/Queen, Juniper, Rocky, L. Red Trout, Granite, L. Soldier, SOLDIER, MILLER, CRANBERRY, LOON, CHARLES, Spriggs, Skerry Pd., FIRST, ROCKY, SECOND, THIRD, THREE MILE, POWDER MILL, WILLIAM, Willis, Perry, Muddy Pd., THOMAS, A, Lizard-1, FLETCHER, SPRINGFIELD, Lisle, Wilson, Horseshoe, FENERTY, LEWIS, SAVAGE, Nicholson, Square, Hamilton, TUCKER, Hawkin Hall, Rasley, Duck, Cranberry, Sandy, Crotched, BEAVERBANK, BARRETT, Duck Pd., Beaver Pd., KINSAC, FISH, Kelly Long, Kelly, Golden, Haunted, Lizard-2, Oak, Ash, Whites, Rocky-1, and GRAND.

[stmargmi.xls]= **St Margarets Miscellaneous lakes** (25 lakes & ponds); updated: April 05, 1998

Brine, Fraser, Unnamed Pd., Little, Boutiliers, Nowlan, Unnamed-2, Forth, Unnamed-1, Selena Pd., Third, Peggys Cove Long, Second, First, Long Canal, Canal, Little Chain, Big Chain, Grassy, Powers, Long, Corneys, Corneys Little, St Margarets Bay Long, and Big.

[terencbr.xls]= **Terence Bay River watershed** (25 lakes & ponds); updated: April 05, 1998

Peters, Flat, Back, HATCHET, McGRATH, Loon, Duck, Moosehorn, Third, Fourth, Muskrat Pd., Porcupine Pd., Shellbird, Dadies, Little, Little Brophy, Brophys Back, Long Pd., Brophys Front, Quarry, Unnamed-1, Unnamed-2, Unnamed-3, Whale Cove, and Round Pd.

[williamh.xls]= **Williams Lake watershed** (2 lakes), Halifax Mainland; updated: April 05, 1998- w/in the urban area with sanitary exported out of the watershed and the area will see further development pressures in the future:

COLPITT, and WILLIAMS.

[woodensr.xls]= **Woodens (Hosier) River headwaters** (16 lakes); updated: February 11, 2001- considerable development pressures, all serviced by onsite septic systems:
Upper Sheldrake, Camp Hill, SHELDRAKE, Pot, CRANBERRY, Black Point, Frederick, LIZARD, FIVE ISLAND, Birch Hill, HUBLEY BIG, Long, Croucher, Gates, Millyard, and Albert Bridge.

Appendix B: Narrative- Select listing of the modelled and field data for 72 significant lakes in HRM

Following are examples of correspondence as well as non-correspondence extracted from our Predictive TP Modelling of 664 lakes/ponds conducted during the 1990s. No examples are shown from the modelling of 2001 since the 271 lakes/ponds modelled then were primarily within the Crown Land areas of District #1 of HRM and no reliable field data was available for comparison purposes.

Legend:

w/shed= watershed
HWL= Headwater lake
Modelled TP= Theoretical modelled value
#s= number of discrete sampling dates
surf= arms depth sampling
vw= volume weighted depth sampling (depths vary)
colour= Hazen or TCU
swcs= Soil & Water Conservation Society of Metro Halifax (SWCSMH)

Note:

The years shown in the field data column are the years when the actual field sampling was carried out. The sampling years could be compared with the relevant years for which reliable land use data was available.

Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
Chezzetcook Inlet headwaters-PETPESWICK LAKE	**1988**	**4.3**	**5 (SWCS, 7#s, vw, 1995-96)**	
Chezzetcook Inlet headwaters-CHEZZETCOOK LAKE	**1988**	**6.2**	**8.3 (SWCS, 7 #s, vw, 1995-96)**	
Cow Bay River w/shed-SETTLE LAKE (HWL)	**1993**	**11.5 @ 0.52 kg/ha; 22.1 @ 1.1 kg/ha**	**22 (SWCS, 10 #s, vw, 1991-92)**	**Urban services- a single TP-export coefficient not recommended**
Cow Bay River w/shed-BISSETT LAKE	**1993**	**25.0 @ 0.52 kg/ha; 45.0 @ 1.1 kg/ha**	**21 (SWCS, 11 #s, vw, 1992-93)**	**Urban services- a single TP-export coefficient not recommended**
Cow Bay River w/shed PENHORN LAKE (HWL)	**1993**	**7.7 @ 0.52 kg/ha; 10.4 @ 1.1 kg/ha**	**10 (SWCS, 5#s, vw, 1991-92)**	**Urban services- a single TP-export coefficient not recommended**
Cow Bay River w/shed-RUSSELL LAKE	**1993**	**24.3 @ 0.52 kg/ha; 31.1 @ 1.1 kg/ha**	**25 (SWCS, 15#s, vw, 1991-92)**	**Urban services- a single TP-export coefficient not recommended**
Cow Bay River w/shed-BELL LAKE (HWL)	**1993**	**4.2 @ 0.52 kg/ha; 7.1 @ 1.1 kg/ha**	**6.0 (SWCS, 3 #s, surf, 1990)**	**Urban services- a single TP-export coefficient not recommended**
Cow Bay River w/shed-MORRIS LAKE	**1993**	**16.3 @ 0.52 kg/ha; 29.1 @ 1.1 kg/ha**	**12 (SWCS, 12 #s, vw, 1991-92)**	**Urban services- a single TP-export coefficient not recommended**
ALBRO LAKE, Dartmouth	**1993**	**12.9**	**11.5 (SWCS, 3 #s, surf, 1990)**	**Urban services- guesstimate made on the TP-export coefficient; field sampling not sufficient**
OATHILL LAKE (HWL), Dartmouth	**1993**	**19.1**	**13.8 (SWCS, 3 #s, surf, 1990)**	**Urban services- guesstimate made on the TP-export coefficient; field sampling not sufficient**

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(Table continued)

Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
East River, St. Mgts. w/shed- HUBLEY MILL LAKE (dystrophic)	**1988**	**8.9**	**15.8 (SWCS, 7 #s, vw, 1995-96)**	**Dystrophic lake (mean colour=45)**
Ketch Harbour headwaters- PORTUGUESE COVE LAKE (dystrophic)	**1991**	**5.8**	**13.8 (SWCS, 3 #s, surf, 1990)**	**Highly dystrophic (mean colour=67); field sampling not sufficient**
Lawrencetown Lake headwaters- LAKE ECHO	**1980**	**6.9**	**6.4 (Hinch & Underwood, 5 #s, vw, 1984)**	
Nine Mile River w/shed, St. Margaret's- COXS LAKE	**1988**	**14.0**	**11.8 (SWCS, 7 #s, vw, 1995-96)**	
Nine Mile River w/shed, St. Margaret's- GOVERNOR LAKE	**1988**	**9.5 @ 0.52 kg/ha; 16.2 @ 1.1 kg/ha**	**8 (Mandell, 4 #s, surf, 1991-92)**	**Urban services- a single TP-export coefficient not recommended; Field sampling not sufficient**
Northeast River w/shed- POCKWOCK LAKE	**1988**	**2.5**	**4 (Mandell, 4 #s, surf, 1991-92)**	**Field sampling not sufficient**

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(Table continued)

Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
Paper Mill Lake w/shed- SUSIES LAKE	**1988**	**2.9 @ 0.52 kg/ha; 3.1 @ 1.1 kg/ha**	**3 (Staicer, 4 #s, 1989-90)**	**Urban services- a single TP-export coefficient not recommended; Not known if surface or outlet samples**
Paper Mill Lake w/shed- QUARRY LAKE	**1988**	**3.3 @ 0.52 kg/ha; 3.5 @ 1.1 kg/ha**	**4 (Porter Dillon, 4 #s, surf & vw, 1994-95)**	**Urban services- a single TP-export coefficient not recommended**
Paper Mill Lake w/shed- WASHMILL LAKE	**1988**	**4.3 @ 0.52 kg/ha; 4.4 @ 1.1 kg/ha**	**5 (Porter Dillon, 4 #s, surf & vw, 1994-95)**	**Urban services- a single TP-export coefficient not recommended**
Paper Mill Lake w/shed- KEARNEY LAKE	**1988**	**7.3 @ 0.52 kg/ha; 7.7 @ 1.1 kg/ha**	**7.2 (SWCS, 3 #s, surf, 1990)**	**Urban services- a single TP-export coefficient not recommended; Field sampling not sufficient**
Paper Mill Lake w/shed- PAPER MILL LAKE	**1988**	**7.6 @ 0.52 kg/ha; 9.0 @ 1.1 kg/ha**	**7.6 (SWCS, 3 #s, surf, 1990)**	**Urban services- a single TP-export coefficient not recommended; Field sampling not sufficient**
Pennant River w/shed- MOODY LAKE (dystrophic)	**1988**	**8.7**	**10.1 (Bishop, 3 #s, vw, 1997-98)**	**Dystrophic lake; Field sampling not sufficient**
Pennant River w/shed- SPRUCE HILL LAKE (HWL)	**1991**	**3.3**	**5 (Mandell, 4 #s, surf, 1991-92)**	**Field sampling not sufficient**
Porters Lake w/shed- PORTERS LAKE (Lower)	**1988**	**7.5**	**10.2 (SWCS, 7 #s, vw, 1995-96)**	

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(Table continued)

Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
Powers Pond w/shed- LONG LAKE (dystrophic)	**1991**	**6.9 @ 0.52 kg/ha; 7.8 @ 1.1 kg/ha**	**8.4 (Scott, 4 #s, Jan-April 1991)**	**Urban services- a single TP-export coefficient not recommended; Dystrophic lake (mean colour=49); field sampling not whole year**
Powers Pond w/shed- EAST PINE ISLAND POND (dystrophic)	**1991**	**4.5 @ 0.52 kg/ha; 4.5 @ 1.1 kg/ha**	**9 (Staicer, 3 #s, 1990)**	**Urban services- a single TP-export coefficient not recommended; Dystrophic (mean colour=37); field sampling not sufficient**
Powers Pond w/shed- POWERS POND (dystrophic)	**1991**	**9.0 @ 0.52 kg/ha; 13.0 @ 1.1 kg/ha**	**8 (Staicer, 4 #s, 1989-90)**	**Urban services- a single TP-export coefficient not recommended; Dystrophic (mean colour=40); field sampling not sufficient**
Prospect River w/shed- RAGGED LAKE (HWL)	**1988**	**2.6**	**4 (Staicer, 4 #s, 1989-90)**	**Field sampling not sufficient**
Prospect River w/shed- WHITES (dystrophic)	**1988**	**4.6**	**12.2 (SWCS, 7 #s, vw, 1995-96)**	**Highly dystrophic (mean colour=70)**

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(Table continued)

Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
Sackville River w/shed-LEWIS LAKE (HWL)	**1991**	**10.0**	**15 (Staicer, 4 #s, 1989-90)**	**Field sampling not sufficient**
Sackville River w/shed-HALFWAY LAKE (HWL, dystrophic)	**1991**	**20.7**	**17.0 (CWRS, 2 #s, vw, Sept-Dec, 1996)**	**Field sampling not sufficient**
Sackville River w/shed-BOTTLE LAKE (HWL)	**1991**	**2.8**	**6.2 (CWRS, 2 #s, vw, Sept-Dec, 1996)**	**Field sampling not sufficient**
Sackville River w/shed-BEAVER-2 LAKE (dystrophic)	**1991**	**8.5**	**16.4 (CWRS, 2 #s, vw, Sept-Dec, 1996)**	**Field sampling not sufficient**
Sackville River w/shed-SANDY LAKE (HWL), Hammonds Plains	**1991**	**2.4**	**4.3 (CWRS, 2 #s, vw, Sept-Dec, 1996)**	**Field sampling not sufficient**
Sackville River w/shed-LITTLE SPRINGFIELD LAKE (HWL)	**1988**	**9.8**	**7 (Staicer, 5 #s, 1989-90)**	
Sackville River w/shed-DRAIN LAKE	**1991**	**36.1**	**33 (Mandell, 4 #s, surf, 1991-92)**	
Sackville River w/shed-SANDY LAKE, Bedford	**1991**	**11.2**	**10.9 (SWCS, 3 #s, surf, 1990)**	

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(Table continued)

Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
Ship Harbour River w/shed-LAKE CHARLOTTE	**1988**	**3.5**	**5.2 (Bishop, deep stn. across outlet, vw, Aug. 20/97)**	**Field sampling not sufficient**
Shubie River headwaters-MILLER LAKE	**1988**	**7.0**	**7.5 (SWCS, 3 #s, surf, 1990)**	
Shubie River headwaters-CRANBERRY LAKE (HWL), Dartmouth	**1988**	**16.0**	**15 (Mandell, 4 #s, surf, 1991-92)**	
Shubie River headwaters-LOON LAKE	**1988**	**8.0**	**7.4 (SWCS, 3 #s, surf, 1990)**	
Shubie River headwaters-LAKE CHARLES	**1988**	**10.5**	**12.78 (Scott *et al*, 9 #s, vw, 1990)**	
Shubie River headwaters-FIRST LAKE (HWL)	**1988**	**13.1**	**13.2 (SWCS, 3 #s, surf, 1990)**	**Urban services- a single TP-export coefficient not recommended**
Shubie River headwaters-ROCKY LAKE	**1988**	**8.7**	**7.7 (SWCS, 3 #s, surf, 1990)**	
Shubie River headwaters-SECOND LAKE (HWL)	**1988**	**8.1**	**8.0 (SWCS, 11 #s, vw, 1991-92)**	
Shubie River headwaters-THIRD LAKE	**1988**	**8.2**	**5.5 (SWCS, 2 #s, surf, 1990)**	**Field sampling not sufficient**
Shubie River headwaters-THREE MILE LAKE	**1988**	**7.6**	**7.0 (Schwartz & Underwood, 4 #s, vw, 1983)**	
Shubie River headwaters-POWDER MILL LAKE	**1988**	**6.7**	**7.0 (Mandell, 4 #s, surf, 1991-92)**	

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(Table continued)

Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
Shubie River headwaters-LAKE WILLIAM	**1988**	**8.7**	**8.27 (Scott *et al*, 9 #s, vw, 1990)**	
Shubie River headwaters-PERRY LAKE (HWL)	**1988**	**3.2**	**4.5 (Schwartz & Underwood, 4 #s, vw, 1983)**	
Shubie River headwaters-LAKE THOMAS	**1988**	**10.7**	**10.49 (Scott *et al*, 9 #s, vw, 1990)**	
Shubie River headwaters-LAKE FLETCHER	**1988**	**12.3**	**12.06 (Scott *et al*, 9 #s, vw, 1990)**	
Shubie River headwaters-SPRINGFIELD LAKE (HWL)	**1988**	**10.4**	**11.1 (SWCS, 2 #s, surf, 1990)**	
Shubie River headwaters-FENERTY	**1988**	**12.0**	**10.0 (Environment Canada, biwkly, surf, June-Sept, 1974)**	**Mean colour=27**
Shubie River headwaters-LEWIS LAKE (HWL), East Hants	**1988**	**8.8**	**9.9 (Geolimnos, 18 #s, vw, 1980-81)**	
Shubie River headwaters-TUCKER LAKE (HWL)	**1988**	**9.0**	**9.9 (SWCS, 3 #s, surf, 1990)**	
Shubie River headwaters-BEAVERBANK LAKE (HWL)	**1988**	**14.6**	**16.7 (SWCS, 3 #s, surf, 1990)**	
Shubie River headwaters-BARRETT LAKE (HWL)	**1988**	**16.1**	**15.0 (SWCS, 2 #s, surf, 1990)**	

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Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
Shubie River headwaters-KINSAC LAKE	**1988**	**11.9**	**13.3 (SWCS, 3 #s, surf, 1990)**	
Shubie River headwaters-FISH LAKE (HWL)	**1988**	**11.5**	**16.1 (Hart *et al*, 9#s, vw, 1977)**	
Shubie River headwaters-GRAND LAKE	**1988**	**6.3**	**6.44 (Scott *et al*, 9 #s, vw, 1990)**	
Terence Bay River w/shed-BACK LAKE (dystrophic)	**1977**	**7.2**	**13 (Staicer, 3 #s, outflow, 1990)**	**Highly dystrophic (mean colour=113); Land use stats from 1977 only**
Terence Bay River w/shed-HATCHET (HWL)	**1980**	**15.0**	**7.3 (SWCS, 6 #s, vw, 1995-96)**	**Land use stats only from 1980**
Terence Bay River w/shed-MCGRATH LAKE (dystrophic)	**1980**	**11.1**	**10.9 (Geolimnos, 18 #s, vw, 1980-81)**	**Highly dystrophic (mean colour=82.5)**
Terence Bay River w/shed-LOON LAKE (HWL, dystrophic)	**1991**	**20.4**	**22 (Staicer, 3 #s, surf, 1989-90)**	**Highly dystrophic (mean colour=180)**
WILLIAMS LAKE, Jollymore	**1988**	**7.7 @ 0.52 kg/ha; 13.8 @ 1.1 kg/ha**	**7.8 (SWCS, 3 #s, surf, 1990)**	**Urban services- a single TP-export coefficient not recommended**

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(Table continued)

Lake and watershed	Year of land use stats	Modelled TP (µg/l)	Mean field TP in µg/l (# of samples, weighting & years)	Comments
Woodens River w/shed-SHELDRAKE LAKE (dystrophic)	**1988**	**23.7**	**22.0 (SWCS, 13 #s, vw, 1991-92)**	**Dystrophic lake (mean colour=69)**
Woodens River w/shed-BLAKPOINT LAKE (dystrophic)	**1988**	**11.2**	**18.7 (SWCS, 8 #s, 1-m depth, 1995-96)**	**Dystrophic lake (mean colour=65)**
Woodens River w/shed-FREDERICK LAKE (dystrophic)	**1988**	**5.8**	**11 (CWRS, 1 #, Aug. 1995)**	**Dystrophic lake (colour=50); insufficient field samples**
Woodens River w/shed-FIVE ISLAND LAKE (dystrophic)	**1988**	**15.0**	**12.1 (SWCS, 2 #s, surf, 1991)**	**Dystrophic lake (mean colour=36); insufficient field samples**
Woodens River w/shed-HUBLEY BIG LAKE (dystrophic)	**1988**	**8.7**	**12.2 (SWCS, 3 #s, surf, 1990)**	**Dystrophic lake (mean colour=32); insufficient field samples**
Woodens River w/shed-LONG LAKE (dystrophic)	**1991**	**7.6**	**11.5 (CWRS, 1 #, Nov. 2000)**	**Dystrophic lake (colour=65); insufficient field samples**

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APPENDIX III – Acadia Centre for Estuarine Research Modelling Work

Overview of the Kings County Lake Capacity Model

Re: Selection of a Predictive Phosphorus Loading Model for Nova Scotia

Prepared for

Nova Scotia Department of
Environment and Labour
and
Water Quality Objectives and
Model Development Steering Committee

By

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AIII.1.0 Introduction

In 1992, the Municipality of Kings County initiated a program to study phosphorus loading and trophic status in lakes of the South Mountain watersheds. This program was in response to long-standing concerns of cottage owners about the adequacy of development standards to prevent degradation of water quality and the lake environment in general (MacIntyre 2000). In 1993, Horner Associates Ltd. was commissioned to develop and apply a lake capacity model, as an effective and defensible means of determining sustainable levels of development in the Gaspereau River watershed (Horner Associates 1995).

The Kings County model is based on a series of equations that quantify how a lake's phosphorus balance is determined by atmospheric deposition, hydrologic regime and land use and development, as they affect not only that lake directly but also all upstream lakes that drain into it. Once a lake's net supply of phosphorus has been estimated, the model predicts Secchi disk depths, phosphorus concentrations and chlorophyll *a* levels, which are the three parameters most commonly used to determine the trophic status of lakes.

Phosphorus loading models may be divided broadly into two classes: those which consider the lake as a blackbox and deal with inputs, outputs and the total phosphorus mass in the lake; and those in which differential equations represent rates of change of phosphorus at different spatial locations and of different fractional forms (e.g. mechanistic phosphorus loading models). The Kings County model is of the former type, and its basis is the assumption of continuity (or mass balance), calculated from both allochthonous and autochthonous nutrient inputs and outputs from the system (Henderson-Sellers 1987).

The Kings County model and many other common empirical models are the result of extensive research undertaken in Ontario in the 1970s and 1980s (Vollenweider 1968, 1975, Vollenweider and Kerekes 1982, Dillon 1974, Dillon and Rigler 1975, Ontario Ministry of Muncipal Affairs 1986). Most are directly based on the original work of Richard Vollenweider, including his zero-D model developed in 1968, as it relates to annual areal phosphorus loading and mean lake depth relationships (Henderson-Sellers 1987). The only substantial differences among these models are the equations used to estimate phosphorus losses to the sediments (Hutchinson et al. 1991).

Various versions of these phosphorus loading models have been successfully applied in Ontario by the Ministry of Environment and Energy, the Municipality of Muskoka, townships surrounding Lower and Upper Rideau Lakes and the Township of Chandos (Horner Associates 1995). The Kings County model was, at the time of application, the most recent (1986) steady-state phosphorus loading model used by the Ontario Ministry of Municipal Affairs.

AIII.2.0 Model Structure and Formulations

To predict a lake's total phosphorus concentration using this model, the following information is required:

- lake surface area;
- lake drainage basin area;
- depth per year of precipitation, lake evaporation, and runoff;
- rate (mass per unit of area per year) of phosphorus deposition from the atmosphere;
- rate (mass per unit of area per year) of overland phosphorus export in the lake drainage basin;
- number of shoreline residences on private sewage services;
- number of shoreline commercial and institutional accommodation units on private sewage services;
- human use per privately serviced shoreline residence and shoreline accommodation unit per year;
    - the extent to which phosphorus discharged into private services is likely to be retained in shorelands rather than ultimately discharged into the lake;
    - rate (mass per unit of use) of phosphorus discharge from shoreline development on private services;
    - rate (mass per year) of phosphorus discharge in effluent from communal (e.g. municipal) sewage treatment; and
    - volume of water discharged downstream from upstream lakes

From the following information the model predicts:

- the volume of water outflow per year;
- the mass of phosphorus supplied to the lake each year from each of atmospheric deposition, overland export, and on-lake development;
- the mass of phosphorus discharged from the lake annually;
- the lake's mean ice-free chlorophyll *a* concentration;
- the lake's total phosphorus concentration; and
- the lake's summertime Secchi disk depth.

Variable land-use or development characteristics in the watershed necessitate the use of representative input coefficients so that predicted trophic state indicators can be determined with accuracy (Horner Associates 1995). The model's variables, symbols, units and roundings used for each variable, and the model equations are outlined in Tables 1-3.

Table 1. Kings County trophic state model protocol as applied by Horner Associates (1995).

Input variables	**Symbol**	**Unit or Value**	**Rounding (to nearest)**
Lake surface area	Ao	ha	1
Lake volume	V	ha.m	1
Lakeshed area excluding lake	Ad	ha	1
Precipitation	Pr	1200 mm/yr	100
Lake evaporation	Ev	542 mm/yr	1
Runoff	Ru	889 mm/yr	1
P load from atmosphere	D	25.0 mg/m²/yr	0.1
P load from overland export	E	mg/m²/yr	0.1
Residential property use	Ur	user d/unit/yr	1
Commercial accommodation use	Uc	user d/unit/yr	1
Developed residential properties	Nr	#	n.a.
Commercial accommodation units	Nc	#	n.a.
Approved, vacant residential lots	Nv	#	n.a.
P load, residential/commercial accommodation use	Sr	0.8 kg/user yr	0.1
Septic retention coefficient present	Rsp	0	0.01
Septic retention coefficient expected	Rse	0	0.01
P load, present communal system	Scp	0 kg/yr	1
P load, approved communal system	Sce	0 kg/yr	1
Chlorophyll ª, maximum acceptable	[chl.ª]p	µg/L	0.1
Chlorophyll ª, measured	[chl.ª]m	µg/L	0.1
Dissolved organic C, measured	[DOC]m	mg/L	0.1
Secchi disc, measured	[SD]m	m	0.1
Model coefficients/constants			
P retention constant	Kr_1	7.2	n.a.
Chlorophyll ª coefficient	Cc	1.45	n.a.
Chlorophyll ª constant	Kc	1.14	n.a.
Secchi disc constant	Ksd	10.27	n.a.
Secchi disc coefficient a (DOC)	Csda	-1.26	n.a.
Secchi disc coefficient b (P)	Csdb	-0.065	n.a.
Secchi disc coefficient c (chl. ª)	Csdc	-0.39	n.a.

[1] Kr is represented by "v" in the equation presented in Dillon et al (1986)

Table 2. Kings County trophic state model protocol as applied by Horner Associates (1995).

Model products	Symbol	Unit or Value	Rounding
Mean depth	z	m	0.1
Outflow volume	Q	ha.m	1
Flushing rate	r	/yr	0.01
Turnover time	t	yr	0.01
Areal water load	Qs	m/yr	0.01
Lake P retention coefficient	Rp		0.01
P supply from atmosphere	Jd	kg/yr	0.1
P supply from overland export	Je	kg/yr	0.1
P supply from upstream	Ju	kg/yr	0.1
P supply, on lake development	Jr	kg/yr	0.1
P supply, total present	Jt	kg/yr	0.1
P, springtime, predicted	[P]	µg/L	0.1
Chlorophyll ^{a}, predicted	[chl.^{a}]	µg/L	0.1
Chlorophyll ^{a}, predicted-measured	[chl.^{a}]a	µg/L	0.1
Secchi disc, predicted	[SD]	m	0.1
Secchi disc, predicted-measured	[SD]a	m	0.1
P supply, approved lots on lake	Jv	kg/yr	0.1
P supply, approved lots upstream	Juv	kg/yr	0.1
P supply, total with approved	Jtv	kg/yr	0.1
P outflow, total present	Jto	kg/yr	0.1
P outflow, approved development	Jvo	kg/yr	0.1

*All input variables are rounded as indicated before being entered. With the exception of phosphorus concentration, all predicted variables are rounded as indicated when calculated, and where one predicted variable is used to calculate another, the rounded version is used. As phosphorus concentration serves only an intermediate purpose in the model, this variable is displayed in a rounded form, but is not rounded when used to calculate other variables.

Where values for V, [chl.^{a}]p, [chl.^{a}]m, [DOC]m, or [SD]m are not available, the label “n.a.” should be entered.

Table 3. Kings County trophic state model equations as applied by Horner Associates (1995).

(1) z = V/Ao

(2) Q = (Ad*Ru/1000) + (Ao * (Pr-Ev)/1000) + Q of lakes immediately upstream

(3) r = Q/V

(4) t = V/Q

(5) Qs = Q/Ao

(6) Rp = Kr/(Kr + Qs)

(7) Jd = D * Ao/100

(8) Je = Ad * E/100

(9) Ju = Jto of lake(s) immediately upstream

(10) Jr = (Sr/365.24 * ((Ur * Nr) + (Uc * Nc)) * (1-Rsp)) + Scp

(11) Jt = Jd + Je + Ju +Jr

(12) [P] = Jt * (1-Rp) * 100/0.956Q

(13) $[\text{chl.}^{a}] = 10^{((Cc*\log_{10}((0.8*[P]) + 2.04))-Kc)}$

(14) [SD] = Csda * [DOC]m + Csdb * [P] + Csdc * $[\text{chl.}^{a}]$ + Ksd

(15) $[\text{chl.}^{a}]a = [\text{chl.}^{a}] - [\text{chl.}^{a}]m$

(15A) [SD]a = [SD]-[SD]m

(16) Jv = Sr/365.24 * Ur * (1-Rse) * Nv

(17) Juv = Jvo of lake(s) immediately upstream

(18) Jvt = Jt + Jv + Juv + Sce

(19) Jto = Jt * (1-Rp)

(20) Jvo = (Jv + Juv + Sce) * (1-Rp)

A. Morphometric and meteorological data must be first identified for the watershed.

Specifically, it necessary to determine the following input variables:

1) Lake surface area, Ao (ha)
2) Subwatershed area excluding the lake, Ad (ha)
3) Precipitation on lake, Pr (m/yr)
4) Lake evaporation, Ev (m/yr)
5) Runoff, Ru (m/yr)

B. The following hydrologic characteristics must be calculated for all lakes in the watershed using the equations as presented in Table 3:

1) Total annual outflow, Q (m^3/yr)

Areal water load, Qs (m/yr)

2) Lake phosphorus retention coefficient, Rp

Note: The above-noted model for phosphorus retention is used for lakes which tend to show a build-up of phosphorus in their deep layers. These increases result either from the release of phosphorus from sediments or from its inefficient removal from the water column (Horner Associates 1995).

C. Prediction of current total phosphorus supply to lakes is a function of the following parameters: (Appendices 13-21)

1) Phosphorus contribution
    a. atmosphere, Jd (kg/yr)
    b. overland export, Je (kg/yr)
    c. upstream sources, Ju (kg/yr)
    d. natural sources, Jn (kg/yr) – (i.e. Jd, Ju, and Je)
    e. artificial sources, Ja (kg/yr) – (i.e Sr and Nc)
    f. current total phosphorus, Jt (kg/yr)

Many of the values incorporated as input coefficients in the Kings County model are based on studies of Ontario watersheds. The lake phosphorus retention coefficient (Rp) employed in the Horner Associates model was obtained from the work of Chapra (1975) and Dillon and Kirchner (1975), and is based on a relationship between the apparent phosphorus settling velocity (7.2 m/yr) and the areal water load of a lake.

Larsen and Mercier (1976) examined the relationships between phosphorus retention and areal water load as they apply to this formula. They found that considerable variation was evident between lakes, and that the equation was only accurate for oligotrophic and mesotrophic systems that had not undergone recent changes in phosphorus loadings. Larsen and Mercier (1976) also reported that their best-fit linear regression equation for retention versus areal water load did not apply to certain shallow lakes.

Many of the Kings County lakes exhibit high flushing rates, do not strongly stratify and contain much of their phosphorus is in a dissolved form. As a result, little of the phosphorus

is retained. This has recently been addressed in the model by basing the retention coefficient on phosphorus fractionation rather than the areal water load.

Similarly, overland phosphorus export coefficients (Je) for Nova Scotia watersheds were not available at the time of model application. The consultants incorporated values from the work of Dillon and Kirchner (1974), and they were simply doubled to reflect the higher precipitation observed in Eastern Canada.

In 2001, overland phosphorus export was measured in a variety of geological and land-use settings in the Gaspereau River watershed. In total, ten streams were designated as experimental sites and each was monitored for discharge, pH, conductivity, apparent color and various forms and speciation of phosphorus for one year. The bedrock geology of study sites was determined to be igneous or metamorphic and land-use characteristics ranged from agricultural and clear-cut to forested and bog. The highest phosphorus export of 63.4 $mg\,m^{-2}\,yr^{-1}$ was measured at an igneous clear-cut site and the lowest export values were observed at metamorphic and igneous forested sites. The results of this analysis have since been incorporated into the model (Lowe 2002; 2003).

A value of 0.8 kg/user year was applied to all lakes in the model to represent the amount of phosphorus contributed by residential development per capita year of use (Sr), and is based on information obtained from the Ontario Ministry of Municipal Affairs. A septic retention coefficient of zero was used in the model to represent a “worse case scenario”, where no retention of phosphorus by shoreline soils is assumed. Although this may be reasonable as a conservative approach, recent investigations of septic system geochemistry in the Precambrian Shield indicate that 100% migration of phosphorus is unlikely where soils are present between a septic system and water body. With this type of lot design, a septic retention coefficient of 0.75 may be more appropriate, as phosphorus is immobilized by charged soil surfaces and complexion with Al and Fe in the soil (Hutchinson 2002).

The equation used to predict springtime total phosphorus concentrations [P] was developed by the Ontario Ministry of Municipal Affairs, and is directly dependent on lake phosphorus retention. As with the formulation for phosphorus settling velocity, it was intended for use in lakes having increased concentrations of phosphorus in the hypolimnion, either from sediment release or inefficient removal from the water column.

A sensitivity analysis was carried out (Brylinsky 1999) to determine which parameters of the Kings County model were the most important in determining predicted total phosphorus concentrations. Significantly, overland phosphorus export and lake phosphorus retention were identified as the parameters that exerted the most influence on model outputs.

AIII.3.0 Model Validation

In 1997, a volunteer based water-quality monitoring program was initiated to collect monthly water samples from a number of the lakes within the Gaspereau River watershed, in order to obtain data that could be used to validate the model.
Predicted total phosphorus concentrations were recorded and compared against the mean of all measured total phosphorus data collected by the Kings County Volunteer Lake Monitoring Program. Results of this analysis are presented in Table 4.

Table 4. Mean measured and predicted total phosphorus concentrations for 1997-2002, percentage agreement between modeled and measured total phosphorus, and details of the overland phosphorus export and lake phosphorus retention coefficients recently incorporated into the model.

	Mean Measured [TP] ug l^{-1}	Predicted [TP] ug l^{-1}	% Difference 1997-2002	Export Coefficients mg m^{-2} yr^{-1}	P-Retention Coefficients
Lake George	11.7	15.3	30.8	16.3	0.29
Loon Lake	12.1	14.9	23.1	16.3	0.29
Aylesford	11.2	13.0	16.1	16.3	0.29
Crooked	-	14.6	-	16.3	0.29
Four Mile	-	20.4	-	30.4	0.40
Two Mile	-	14.6	-	16.3	0.29
Blue Mountain	-	21.9	-	30.4	0.40
Gaspereau	13.1	12.3	-6.1	16.3	0.29
Salmontail	-	16.0	-	16.3	0.29
Murphy	12.9	14.0	8.5	30.4	0.40
Trout River	-	14.5	-	63.4	0.33
Moosehorn	-	13.1	-	19.1	0.45
Little River	12.8	13.8	7.8	63.4	0.33
Methals	-	10.0	-	16.3	0.29
Dean Chapter	-	15.0	-	16.3	0.29
Black River	12.3	13.6	10.6	63.4	0.33
Lumsden	13.8	11.8	-14.5	40.8	0.30

AIII.4.0 Conclusions

The Kings County lake capacity model is not a separate entity from other input-output models, such as those developed by Vollenweider (1968) and Dillon (1974) for lakes in Ontario watersheds. Rather, like most phosphorus loadings model currently used in Canada and the United States, it is an adaptation of this earlier work.

Empirical models such as these assume a well-mixed layer with either no phosphorus release from the sediments or have a net sedimentation term included, and calculate phosphorus concentrations on a mean annual scale. They are not capable of predicting on shorter temporal scales and thus, cannot foresee the timing or extent of algal blooms, seasonal variation in water quality etc. (Henderson-Sellers 1987).

It is important to calibrate these models if they are to be applied to lakes outside the climatic and geological range in which they were developed. Overland phosphorus export and lake phosphorus retention were determined to be the most sensitive parameters in the Kings County model, and original model inputs were replaced with measured data accordingly.

Hutchinson (2002) recommends that a model criterion of 40% be chosen as the mean coefficient of variation in measured phosphorus concentrations, as this degree of error reflects the range of the natural variation of water quality. The modified Kings County model predicts total phosphorus within this range for all monitored lakes in the Gaspereau River watershed. In most instances, predicted total phosphorus concentrations are within $\pm$ 20% of measured values, and therefore valid based on the data collected to date.

AIII.5.0 References

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Appendix III - Table 1. Kings County model application – Lake George and Loon Lake

Scenario A- Existing usage -Seasonal all lakes water quality objective 2.5 ug/L chl a

		LAKE GEORGE	LOON LAKE
Input variables			
Lake surface area	Ao	141 ha	108 ha
Lake volume	V	n.a. ha.m	n.a. ha.m
Lakeshed area excl. lake	Ad	775 ha	852 ha
Precipitation	Pr	1200 mm/yr	1200 mm/yr
Lake evaporation	Ev	542 mm/yr	542 mm/yr
Runoff	Ru	889 mm/yr	889 mm/yr
P load from atmosphere	D	25.0 mg/m²/yr	25.0 mg/m²/yr
P load from overland export	E	16.3 mg/m²/yr	16.3 mg/m²/yr
Residential property use	Ur	348 user d/unit/yr	552 user d/unit/yr
Commercial accommodation use	Uc	5036 user d/unit/yr	0 user d/unit/yr
Developed residential properties	Nr	100	15
Commercial accommodation units	Nc	1	0
Approved, vacant res. lots	Nv	0	0
P load, res./comm. accom. use	Sr	0.8 kg/user yr	0.8 kg/user yr
Septic retention coeff., present	Rsp	0	0
Septic retention coeff., expected	Rse	0	0
P load, present communal sys.	Scp	0 kg/yr	0 kg/yr
P load, approved communal sys.	Sce	0 kg/yr	0 kg/yr
Chlor. [a], maximum acceptable	[chl.a]p	n.a. µg/L	n.a. µg/L
Chlor. [a], measured	[chl.a]m	1.9 µg/L	2.2 µg/L
Dissolved organic C, measured	[DOC]m	3.5 mg/L	4.3 mg/L
Secchi disc, measured	[SD]m	3.8 m	2.9 m
Model coefficients/constants			
P retention constant	Kr	7.2	7.2
Chlor. [a] coefficient	Cc	1.45	1.45
Chlor. [a] constant	Kc	1.14	1.14
Secchi disc constant	Ksd	10.27	10.27
Secchi disc coefficient a (DOC)	Csda	-1.26	-1.26
Secchi disc coefficient b (P)	Csdb	-0.065	-0.065
Secchi disc coefficient c (chl. [a])	Csdc	-0.39	-0.39
Model products			
Mean depth	z	n.a. m	n.a. m
Outflow volume	Q	782 ha.m	828 ha.m
Flushing rate	r	n.a. /yr	n.a. /yr
Turnover time	t	n.a. yr	n.a. yr
Areal water load	Qs	5.55 m/yr	7.67 m/yr
Lake P retention coefficient	Rp	0.29	0.29
P supply from atmosphere	Jd	35.3 kg/yr	27.0 kg/yr
P supply from overland export	Je	126.3 kg/yr	138.9 kg/yr
P supply from upstream	Ju	0.0 kg/yr	0.0 kg/yr
P supply, on lake development	Jr	87.3 kg/yr	18.1 kg/yr
P supply, total present	Jt	248.9 kg/yr	184.0 kg/yr
P, springtime, predicted	[P]	23.6 µg/L	16.5 µg/L
Chlor. [a], predicted	[chl.a]	6.0 µg/L	3.8 µg/L
Chlor. [a], predicted-measured	[chl.a]a	4.1 µg/L	1.6 µg/L
Secchi disc, predicted	[SD]	2.0 m	2.3 m
Sec. disc, predicted-measured	[SD]a	-1.8 m	-0.6 m
P supply, approved lots on lake	Jv	0.0 kg/yr	0.0 kg/yr
P supply, approved lots upstream	Juv	0.0 kg/yr	0.0 kg/yr
P supply, total with approved	Jtv	248.9 kg/yr	184.0 kg/yr
P outflow, total present	Jto	176.7 kg/yr	130.6 kg/yr
P outflow, approved development	Jvo	0.0 kg/yr	0.0 kg/yr

Appendix III – Table 2. Kings County model application – Aylesford and Crooked Lake

		AYLESFORD LAKE			CROOKED LAKE		
Input variables							
Lake surface area	Ao		582	ha		58	ha
Lake volume	V	n.a.		ha.m	n.a.		ha.m
Lakeshed area excl. lake	Ad		3264	ha		605	ha
Precipitation	Pr		1200	mm/yr		1200	mm/yr
Lake evaporation	Ev		542	mm/yr		542	mm/yr
Runoff	Ru		889	mm/yr		889	mm/yr
P load from atmosphere	D		25	mg/m²/yr		25	mg/m²/yr
P load from overland export	E		16.3	mg/m²/yr		16.3	mg/m²/yr
Residential property use	Ur		407	user d/unit/yr		182.5	user d/unit/yr
Commercial accommodation use	Uc		0	user d/unit/yr		0	user d/unit/yr
Developed residential properties	Nr		169			1	
Commercial accom. units	Nc		0			0	
Approved, vacant res. lots	Nv		0			0	
P load, res./comm. accom. use	Sr		0.8	kg/user yr		0.8	kg/user yr
Septic retention coeff., present	Rsp		0			0	
Septic retention coeff., expected	Rse		0			0	
P load, present communal sys.	Scp		0	kg/yr		0	kg/yr
P load, approved communal sys.	Sce		0	kg/yr		0	kg/yr
Chlor. ª, maximum acceptable	[chl.ª]p	n.a.		µg/L	n.a.		µg/L
Chlor. ª, measured	[chl.ª]m		2.9	µg/L		0	µg/L
Dissolved organic C, measured	[DOC]m		5	mg/L		0	mg/L
Secchi disc, measured	[SD]m		3	m		0	m
Model coefficients/constants							
P retention constant	Kr		7.2			7.2	
Chlor. ª coefficient	Cc		1.45			1.45	
Chlor. ª constant	Kc		1.14			1.14	
Secchi disc constant	Ksd		10.27			10.27	
Secchi disc coefficient a (DOC)	Csda		-1.26			-1.26	
Secchi disc coefficient b (P)	Csdb		-0.065			-0.065	
Secchi disc coefficient c (chl. ª)	Csdc		-0.39			-0.39	
Model products							
Mean depth	z		n.a.	m		n.a.	m
Outflow volume	Q		5527	ha.m		576	ha.m
Flushing rate	r		n.a.	/yr		n.a.	/yr
Turnover time	t		n.a.	yr		n.a.	yr
Areal water load	Qs		9.5	m/yr		9.93	m/yr
Lake P retention coefficient	Rp		0.29			0.29	
P supply from atmosphere	Jd		151	kg/yr		14.5	kg/yr
P supply from overland export	Je		532	kg/yr		98.6	kg/yr
P supply from upstream	Ju		360.8	kg/yr		0	kg/yr
P supply, on lake development	Jr		150.7	kg/yr		0.4	kg/yr
P supply, total present	Jt		1194.5	kg/yr		113.5	kg/yr
P, springtime, predicted	[P]		16.1	µg/L		14.6	µg/L
Chlor. ª, predicted	[chl.ª]		3.6	µg/L		3.2	µg/L
Chlor. ª, predicted-measured	[chl.ª]a		0.7	µg/L		3.2	µg/L
Secchi disc, predicted	[SD]		1.5	m		8.1	m
Sec. disc, predicted-measured	[SD]a		-1.5	m		8.1	m
P supply, approved lots on lake	Jv		0	kg/yr		0	kg/yr
P supply, approved lots upstream	Juv		0	kg/yr		0	kg/yr
P supply, total with approved	Jtv		1194.5	kg/yr		113.5	kg/yr
P outflow, total present	Jto		848.1	kg/yr		80.6	kg/yr
P outflow, approved development	Jvo		0	kg/yr		0	kg/yr

Appendix III - Table 3. Kings County model application – Four Mile and Two Mile Lake

		FOUR MILE LAKE		TWO MILE LAKE	
Input variables					
Lake surface area	Ao	265	ha	125	ha
Lake volume	V	n.a.	ha.m	n.a.	ha.m
Lakeshed area excl. lake	Ad	5685	ha	322	ha
Precipitation	Pr	1200	mm/yr	1200	mm/yr
Lake evaporation	Ev	542	mm/yr	542	mm/yr
Runoff	Ru	889	mm/yr	889	mm/yr
P load from atmosphere	D	25	mg/m²/yr	25	mg/m²/yr
P load from overland export	E	30.4	mg/m²/yr	16.3	mg/m²/yr
Residential property use	Ur	433	user d/unit/yr	433	user d/unit/yr
Commercial accommodation use	Uc	0	user d/unit/yr	0	user d/unit/yr
Developed residential properties	Nr	0		0	
Commercial accom. units	Nc	0		0	
Approved, vacant res. lots	Nv	0		0	
P load, res./comm. accom. use	Sr	0.8	kg/user yr	0.8	kg/user yr
Septic retention coeff., present	Rsp	0		0	
Septic retention coeff., expected	Rse	0		0	
P load, present communal sys.	Scp	0	kg/yr	0	kg/yr
P load, approved communal sys.	Sce	0	kg/yr	0	kg/yr
Chlor. ª, maximum acceptable	[chl.ª]p	n.a.	µg/L	n.a.	µg/L
Chlor. ª, measured	[chl.ª]m	0	µg/L	0	µg/L
Dissolved organic C, measured	[DOC]m	0	mg/L	0	mg/L
Secchi disc, measured	[SD]m	0	m	0	m
Model coefficients/constants					
P retention constant	Kr	7.2		7.2	
Chlor. ª coefficient	Cc	1.45		1.45	
Chlor. ª constant	Kc	1.14		1.14	
Secchi disc constant	Ksd	10.27		10.27	
Secchi disc coefficient a (DOC)	Csda	-1.26		-1.26	
Secchi disc coefficient b (P)	Csdb	-0.065		-0.065	
Secchi disc coefficient c (chl. ª)	Csdc	-0.39		-0.39	
Model products					
Mean depth	z	n.a.	m	n.a.	m
Outflow volume	Q	5804	ha.m	6173	ha.m
Flushing rate	r	n.a.	/yr	n.a.	/yr
Turnover time	t	n.a.	yr	n.a.	yr
Areal water load	Qs	21.9	m/yr	49.38	m/yr
Lake P retention coefficient	Rp	0.4		0.29	
P supply from atmosphere	Jd	66.3	kg/yr	31.3	kg/yr
P supply from overland export	Je	1728.2	kg/yr	52.5	kg/yr
P supply from upstream	Ju	80.6	kg/yr	1125.1	kg/yr
P supply, on lake development	Jr	0	kg/yr	0	kg/yr
P supply, total present	Jt	1875.1	kg/yr	1208.9	kg/yr
P, springtime, predicted	[P]	20.3	µg/L	14.5	µg/L
Chlor. ª, predicted	[chl.ª]	4.9	µg/L	3.2	µg/L
Chlor. ª, predicted-measured	[chl.ª]a	4.9	µg/L	3.2	µg/L
Secchi disc, predicted	[SD]	7	m	8.1	m
Sec. disc, predicted-measured	[SD]a	7	m	8.1	m
P supply, approved lots on lake	Jv	0	kg/yr	0	kg/yr
P supply, approved lots upstream	Juv	0	kg/yr	0	kg/yr
P supply, total with approved	Jtv	1875.1	kg/yr	1208.9	kg/yr
P outflow, total present	Jto	1125.1	kg/yr	858.3	kg/yr
P outflow, approved development	Jvo	0	kg/yr	0	kg/yr

Appendix III - Table 4. Kings County model application – Blue Mountain and Gaspereau Lake

		BLUE MOUNTAIN		GASPEREAU LAKE	
Input variables					
Lake surface area	Ao	35	ha	1900	ha
Lake volume	V	n.a.	ha.m	n.a.	ha.m
Lakeshed area excl. lake	Ad	201	ha	6532	ha
Precipitation	Pr	1200	mm/yr	1200	mm/yr
Lake evaporation	Ev	542	mm/yr	542	mm/yr
Runoff	Ru	889	mm/yr	889	mm/yr
P load from atmosphere	D	25	mg/m²/yr	25	mg/m²/yr
P load from overland export	E	30.4	mg/m²/yr	16.3	mg/m²/yr
Residential property use	Ur	182.5	user d/unit/yr	297	user d/unit/yr
Commercial accommodation use	Uc	0	user d/unit/yr	0	user d/unit/yr
Developed residential properties	Nr	0		26	
Commercial accom. units	Nc	0		0	
Approved, vacant res. lots	Nv	0		0	
P load, res./comm. accom. use	Sr	0.8	kg/user yr	0.8	kg/user yr
Septic retention coeff., present	Rsp	0		0	
Septic retention coeff., expected	Rse	0		0	
P load, present communal sys.	Scp	0	kg/yr	0	kg/yr
P load, approved communal sys.	Sce	0	kg/yr	0	kg/yr
Chlor. ^{a}, maximum acceptable	[chl.^{a}]p	n.a.	µg/L	n.a.	µg/L
Chlor. ^{a}, measured	[chl.^{a}]m	0	µg/L	0	µg/L
Dissolved organic C, measured	[DOC]m	0	mg/L	0	mg/L
Secchi disc, measured	[SD]m	0	m	0	m
Model coefficients/constants					
P retention constant	Kr	7.2		7.2	
Chlor. ^{a} coefficient	Cc	1.45		1.45	
Chlor. ^{a} constant	Kc	1.14		1.14	
Secchi disc constant	Ksd	10.27		10.27	
Secchi disc coefficient a (DOC)	Csda	-1.26		-1.26	
Secchi disc coefficient b (P)	Csdb	-0.065		-0.065	
Secchi disc coefficient c (chl. ^{a})	Csdc	-0.39		-0.39	
Model products					
Mean depth	z	n.a.	m	n.a.	m
Outflow volume	Q	202	ha.m	18959	ha.m
Flushing rate	r	n.a.	/yr	n.a.	/yr
Turnover time	t	n.a.	yr	n.a.	yr
Areal water load	Qs	5.77	m/yr	9.98	m/yr
Lake P retention coefficient	Rp	0.4		0.29	
P supply from atmosphere	Jd	8.8	kg/yr	475	kg/yr
P supply from overland export	Je	61.1	kg/yr	1064.7	kg/yr
P supply from upstream	Ju	0	kg/yr	1748.3	kg/yr
P supply, on lake development	Jr	0	kg/yr	16.9	kg/yr
P supply, total present	Jt	69.9	kg/yr	3304.9	kg/yr
P, springtime, predicted	[P]	21.7	µg/L	12.9	µg/L
Chlor. ^{a}, predicted	[chl.^{a}]	5.3	µg/L	2.8	µg/L
Chlor. ^{a}, predicted-measured	[chl.^{a}]a	5.3	µg/L	2.8	µg/L
Secchi disc, predicted	[SD]	6.8	m	8.3	m
Sec. disc, predicted-measured	[SD]a	6.8	m	8.3	m
P supply, approved lots on lake	Jv	0	kg/yr	0	kg/yr
P supply, approved lots upstream	Juv	0	kg/yr	0	kg/yr
P supply, total with approved	Jtv	69.9	kg/yr	3304.9	kg/yr
P outflow, total present	Jto	41.9	kg/yr	2346.5	kg/yr
P outflow, approved development	Jvo	0	kg/yr	0	kg/yr

Appendix III – Table 5. Kings County model application – Salmontail and Murphy Lake

		SALMONTAIL			MURPHY LAKE		
Input variables							
Lake surface area	Ao		405	ha		115	ha
Lake volume	V	n.a.		ha.m	n.a.		ha.m
Lakeshed area excl. lake	Ad		1532	ha		927	ha
Precipitation	Pr		1200	mm/yr		1200	mm/yr
Lake evaporation	Ev		542	mm/yr		542	mm/yr
Runoff	Ru		889	mm/yr		889	mm/yr
P load from atmosphere	D		25	mg/m²/yr		25	mg/m²/yr
P load from overland export	E		16.3	mg/m²/yr		30.4	mg/m²/yr
Residential property use	Ur		182.5	user d/unit/yr		391	user d/unit/yr
Commercial accommodation use	Uc		0	user d/unit/yr		0	user d/unit/yr
Developed residential properties	Nr		0			84	
Commercial accom. units	Nc		0			0	
Approved, vacant res. lots	Nv		0			0	
P load, res./comm. accom. use	Sr		0.8	kg/user yr		0.8	kg/user yr
Septic retention coeff., present	Rsp		0			0	
Septic retention coeff., expected	Rse		0			0	
P load, present communal sys.	Scp		0	kg/yr		0	kg/yr
P load, approved communal sys.	Sce		0	kg/yr		0	kg/yr
Chlor. ª, maximum acceptable	[chl.ª]p	n.a.		µg/L	n.a.		µg/L
Chlor. ª, measured	[chl.ª]m	n.a.		µg/L	n.a.		µg/L
Dissolved organic C, measured	[DOC]m	n.a.		mg/L	n.a.		mg/L
Secchi disc, measured	[SD]m	n.a.		m	n.a.		m
Model coefficients/constants							
P retention constant	Kr		7.2			7.2	
Chlor. ª coefficient	Cc		1.45			1.45	
Chlor. ª constant	Kc		1.14			1.14	
Secchi disc constant	Ksd		10.27			10.27	
Secchi disc coefficient a (DOC)	Csda		-1.26			-1.26	
Secchi disc coefficient b (P)	Csdb		-0.065			-0.065	
Secchi disc coefficient c (chl. ª)	Csdc		-0.39			-0.39	
Model products							
Mean depth	z		n.a.	m		n.a.	m
Outflow volume	Q		1628	ha.m		2528	ha.m
Flushing rate	r		n.a.	/yr		n.a.	/yr
Turnover time	t		n.a.	yr		n.a.	yr
Areal water load	Qs		4.02	m/yr		21.98	m/yr
Lake P retention coefficient	Rp		0.29			0.4	
P supply from atmosphere	Jd		101.3	kg/yr		28.8	kg/yr
P supply from overland export	Je		249.7	kg/yr		281.8	kg/yr
P supply from upstream	Ju		0	kg/yr		249.2	kg/yr
P supply, on lake development	Jr		0	kg/yr		71.9	kg/yr
P supply, total present	Jt		351	kg/yr		631.7	kg/yr
P, springtime, predicted	[P]		16.0	µg/L		15.6	µg/L
Chlor. ª, predicted	[chl.ª]		3.6	µg/L		3.5	µg/L
Chlor. ª, predicted-measured	[chl.ª]a		n.a.	µg/L		n.a.	µg/L
Secchi disc, predicted	[SD]		n.a.	m		n.a.	m
Sec. disc, predicted-measured	[SD]a		n.a.	m		n.a.	m
P supply, approved lots on lake	Jv		0	kg/yr		0	kg/yr
P supply, approved lots upstream	Juv		0	kg/yr		0	kg/yr
P supply, total with approved	Jtv		351	kg/yr		631.7	kg/yr
P outflow, total present	Jto		249.2	kg/yr		379	kg/yr
P outflow, approved development	Jvo		0	kg/yr		0	kg/yr

Appendix III – Table 6. Kings County model application – Trout River Pond and Moosehorn Lake

		TROUT RIVER POND		MOOSEHORN LAKE	
Input variables					
Lake surface area	Ao	85	ha	22	ha
Lake volume	V	n.a.	ha.m	n.a.	ha.m
Lakeshed area excl. lake	Ad	4113	ha	161	ha
Precipitation	Pr	1200	mm/yr	1200	mm/yr
Lake evaporation	Ev	542	mm/yr	542	mm/yr
Runoff	Ru	889	mm/yr	889	mm/yr
P load from atmosphere	D	25	mg/m²/yr	25	mg/m²/yr
P load from overland export	E	63.4	mg/m²/yr	19.1	mg/m²/yr
Residential property use	Ur	182.5	user d/unit/yr	182.5	user d/unit/yr
Commercial accommodation use	Uc	0	user d/unit/yr	0	user d/unit/yr
Developed residential properties	Nr	1		5	
Commercial accom. units	Nc	0		0	
Approved, vacant res. lots	Nv	0		0	
P load, res./comm. accom. use	Sr	0.8	kg/user yr	0.8	kg/user yr
Septic retention coeff., present	Rsp	0		0	
Septic retention coeff., expected	Rse	0		0	
P load, present communal sys.	Scp	0	kg/yr	0	kg/yr
P load, approved communal sys.	Sce	0	kg/yr	0	kg/yr
Chlor. ^{a}, maximum acceptable	[chl.^{a}]p	n.a.	µg/L	n.a.	µg/L
Chlor. ^{a}, measured	[chl.^{a}]m	1.7	µg/L	0	µg/L
Dissolved organic C, measured	[DOC]m	6.3	mg/L	0	mg/L
Secchi disc, measured	[SD]m	2.8	m	0	m
Model coefficients/constants					
P retention constant	Kr	7.2		7.2	
Chlor. ^{a} coefficient	Cc	1.45		1.45	
Chlor. ^{a} constant	Kc	1.14		1.14	
Secchi disc constant	Ksd	10.27		10.27	
Secchi disc coefficient a (DOC)	Csda	-1.26		-1.26	
Secchi disc coefficient b (P)	Csdb	-0.065		-0.065	
Secchi disc coefficient c (chl. ^{a})	Csdc	-0.39		-0.39	
Model products					
Mean depth	z	n.a.	m	n.a.	m
Outflow volume	Q	25199	ha.m	158	ha.m
Flushing rate	r	n.a.	/yr	n.a.	/yr
Turnover time	t	n.a.	yr	n.a.	yr
Areal water load	Qs	296.46	m/yr	7.18	m/yr
Lake P retention coefficient	Rp	0.33		0.45	
P supply from atmosphere	Jd	21.3	kg/yr	5.5	kg/yr
P supply from overland export	Je	2607.6	kg/yr	30.8	kg/yr
P supply from upstream	Ju	2725.5	kg/yr	0	kg/yr
P supply, on lake development	Jr	0.4	kg/yr	2	kg/yr
P supply, total present	Jt	5354.8	kg/yr	38.3	kg/yr
P, springtime, predicted	[P]	14.9	µg/L	13.9	µg/L
Chlor. ^{a}, predicted	[chl.^{a}]	3.3	µg/L	3.1	µg/L
Chlor. ^{a}, predicted-measured	[chl.^{a}]a	1.6	µg/L	3.1	µg/L
Secchi disc, predicted	[SD]	0.1	m	8.2	m
Sec. disc, predicted-measured	[SD]a	-2.7	m	8.2	m
P supply, approved lots on lake	Jv	0	kg/yr	0	kg/yr
P supply, approved lots upstream	Juv	0	kg/yr	0	kg/yr
P supply, total with approved	Jtv	5354.8	kg/yr	38.3	kg/yr
P outflow, total present	Jto	3587.7	kg/yr	21.1	kg/yr
P outflow, approved development	Jvo	0	kg/yr	0	kg/yr

Appendix III – Table 7. Kings County model application – Little River and Methal's Lake

		LITTLE RIVER LAKE		METHALS LAKE	
Input variables					
Lake surface area	Ao	340	ha	110	ha
Lake volume	V	n.a.	ha.m	n.a.	ha.m
Lakeshed area excl. lake	Ad	2903	ha	1048	ha
Precipitation	Pr	1200	mm/yr	1200	mm/yr
Lake evaporation	Ev	542	mm/yr	542	mm/yr
Runoff	Ru	889	mm/yr	889	mm/yr
P load from atmosphere	D	25	mg/m²/yr	25	mg/m²/yr
P load from overland export	E	63.4	mg/m²/yr	16.3	mg/m²/yr
Residential property use	Ur	405	user d/unit/yr	433	user d/unit/yr
Commercial accommodation use	Uc	0	user d/unit/yr	0	user d/unit/yr
Developed residential properties	Nr	14		1	
Commercial accom. units	Nc	0		0	
Approved, vacant res. lots	Nv	0		0	
P load, res./comm. accom. use	Sr	0.8	kg/user yr	0.8	kg/user yr
Septic retention coeff., present	Rsp	0		0	
Septic retention coeff., expected	Rse	0		0	
P load, present communal sys.	Scp	0	kg/yr	0	kg/yr
P load, approved communal sys.	Sce	0	kg/yr	0	kg/yr
Chlor. ª, maximum acceptable	[chl.ª]p	n.a.	µg/L	n.a.	µg/L
Chlor. ª, measured	[chl.ª]m	0	µg/L	0	µg/L
Dissolved organic C, measured	[DOC]m	0	mg/L	0	mg/L
Secchi disc, measured	[SD]m	0	m	0	m
Model coefficients/constants					
P retention constant	Kr	7.2		7.2	
Chlor. ª coefficient	Cc	1.45		1.45	
Chlor. ª constant	Kc	1.14		1.14	
Secchi disc constant	Ksd	10.27		10.27	
Secchi disc coefficient a (DOC)	Csda	-1.26		-1.26	
Secchi disc coefficient b (P)	Csdb	-0.065		-0.065	
Secchi disc coefficient c (chl. ª)	Csdc	-0.39		-0.39	
Model products					
Mean depth	z	n.a.	m	n.a.	m
Outflow volume	Q	26901.1	ha.m	27905.1	ha.m
Flushing rate	r	n.a.	/yr	n.a.	/yr
Turnover time	t	n.a.	yr	n.a.	yr
Areal water load	Qs	79.12	m/yr	253.68	m/yr
Lake P retention coefficient	Rp	0.33		0.29	
P supply from atmosphere	Jd	85.0	kg/yr	27.5	kg/yr
P supply from overland export	Je	1840.5	kg/yr	170.8	kg/yr
P supply from upstream	Ju	3429.42	kg/yr	3596.1	kg/yr
P supply, on lake development	Jr	12.4	kg/yr	0.9	kg/yr
P supply, total present	Jt	5367.32	kg/yr	3795.3	kg/yr
P, springtime, predicted	[P]	14.0	µg/L	10.1	µg/L
Chlor. ª, predicted	[chl.ª]	3.1	µg/L	2.1	µg/L
Chlor. ª, predicted-measured	[chl.ª]a	3.1	µg/L	2.1	µg/L
Secchi disc, predicted	[SD]	8.2	m	8.8	m
Sec. disc, predicted-measured	[SD]a	8.2	m	8.8	m
P supply, approved lots on lake	Jv	0	kg/yr	0	kg/yr
P supply, approved lots upstream	Juv	0	kg/yr	0	kg/yr
P supply, total with approved	Jtv	5367.32	kg/yr	3795.3	kg/yr
P outflow, total present	Jto	3596.1	kg/yr	2694.7	kg/yr
P outflow, approved development	Jvo	0	kg/yr	0	kg/yr

Appendix III – Table 8. Kings County model application – Dean Chapter and Black River Lake

		DEAN CHAPTER LAKE		BLACK RIVER LAKE	
Input variables					
Lake surface area	Ao	305	ha	735	ha
Lake volume	V	n.a.	ha.m	n.a.	ha.m
Lakeshed area excl. lake	Ad	2137	ha	5927	ha
Precipitation	Pr	1200	mm/yr	1200	mm/yr
Lake evaporation	Ev	542	mm/yr	542	mm/yr
Runoff	Ru	889	mm/yr	889	mm/yr
P load from atmosphere	D	25	mg/m²/yr	25	mg/m²/yr
P load from overland export	E	16.3	mg/m²/yr	63.4	mg/m²/yr
Residential property use	Ur	433	user d/unit/yr	389	user d/unit/yr
Commercial accommodation use	Uc	0	user d/unit/yr	0	user d/unit/yr
Developed residential properties	Nr	0		32	
Commercial accom. units	Nc	0		0	
Approved, vacant res. lots	Nv	0		0	
P load, res./comm. accom. use	Sr	0.8	kg/user yr	0.8	kg/user yr
Septic retention coeff., present	Rsp	0		0	
Septic retention coeff., expected	Rse	0		0	
P load, present communal sys.	Scp	0	kg/yr	0	kg/yr
P load, approved communal sys.	Sce	0	kg/yr	0	kg/yr
Chlor. ^{a}, maximum acceptable	[chl.^{a}]p	n.a.	µg/L	n.a.	µg/L
Chlor. ^{a}, measured	[chl.^{a}]m	0	µg/L	0	µg/L
Dissolved organic C, measured	[DOC]m	0	mg/L	0	mg/L
Secchi disc, measured	[SD]m	0	m	0	m
Model coefficients/constants					
P retention constant	Kr	7.2		7.2	
Chlor. ^{a} coefficient	Cc	1.45		1.45	
Chlor. ^{a} constant	Kc	1.14		1.14	
Secchi disc constant	Ksd	10.27		10.27	
Secchi disc coefficient a (DOC)	Csda	-1.26		-1.26	
Secchi disc coefficient b (P)	Csdb	-0.065		-0.065	
Secchi disc coefficient c (chl. ^{a})	Csdc	-0.39		-0.39	
Model products					
Mean depth	z	n.a.	m	n.a.	m
Outflow volume	Q	2100	ha.m	35758.1	ha.m
Flushing rate	r	n.a.	/yr	n.a.	/yr
Turnover time	t	n.a.	yr	n.a.	yr
Areal water load	Qs	6.89	m/yr	48.65	m/yr
Lake P retention coefficient	Rp	0.29		0.33	
P supply from atmosphere	Jd	76.3	kg/yr	183.8	kg/yr
P supply from overland export	Je	348.3	kg/yr	3757.7	kg/yr
P supply from upstream	Ju	0	kg/yr	2996.2	kg/yr
P supply, on lake development	Jr	0	kg/yr	27.3	kg/yr
P supply, total present	Jt	424.6	kg/yr	6965	kg/yr
P, springtime, predicted	[P]	15.0	µg/L	13.7	µg/L
Chlor. ^{a}, predicted	[chl.^{a}]	3.3	µg/L	3	µg/L
Chlor. ^{a}, predicted-measured	[chl.^{a}]a	3.3	µg/L	3	µg/L
Secchi disc, predicted	[SD]	8	m	8.2	m
Sec. disc, predicted-measured	[SD]a	8	m	8.2	m
P supply, approved lots on lake	Jv	0	kg/yr	0	kg/yr
P supply, approved lots upstream	Juv	0	kg/yr	0	kg/yr
P supply, total with approved	Jtv	424.6	kg/yr	6965	kg/yr
P outflow, total present	Jto	301.5	kg/yr	4666.6	kg/yr
P outflow, approved development	Jvo	0	kg/yr	0	kg/yr

Appendix III – Table 9. Kings County model application – Lumsden Pond Reservoir

		LUMSDEN POND	
Input variables			
Lake surface area	Ao	65	ha
Lake volume	V	n.a.	ha.m
Lakeshed area excl. lake	Ad	4172	ha
Precipitation	Pr	1200	mm/yr
Lake evaporation	Ev	542	mm/yr
Runoff	Ru	889	mm/yr
P load from atmosphere	D	25	mg/m²/yr
P load from overland export	E	40.8	mg/m²/yr
Residential property use	Ur	533	user d/unit/yr
Commercial accommodation use	Uc	949	user d/unit/yr
Developed residential properties	Nr	33	
Commercial accom. units	Nc	101	
Approved, vacant res. lots	Nv	0	
P load, res./comm. accom. use	Sr	0.8	kg/user yr
Septic retention coeff., present	Rsp	0	
Septic retention coeff., expected	Rse	0	
P load, present communal sys.	Scp	0	kg/yr
P load, approved communal sys.	Sce	0	kg/yr
Chlor. ª, maximum acceptable	[chl.ª]p	n.a.	µg/L
Chlor. ª, measured	[chl.ª]m	0	µg/L
Dissolved organic C, measured	[DOC]m	0	mg/L
Secchi disc, measured	[SD]m	0	m
Model coefficients/constants			
P retention constant	Kr	7.2	
Chlor. ª coefficient	Cc	1.45	
Chlor. ª constant	Kc	1.14	
Secchi disc constant	Ksd	10.27	
Secchi disc coefficient a (DOC)	Csda	-1.26	
Secchi disc coefficient b (P)	Csdb	-0.065	
Secchi disc coefficient c (chl. ª)	Csdc	-0.39	
Model products			
Mean depth	z	n.a.	m
Outflow volume	Q	39510.1	ha.m
Flushing rate	r	n.a.	/yr
Turnover time	t	n.a.	yr
Areal water load	Qs	607.85	m/yr
Lake P retention coefficient	Rp	0.3	
P supply from atmosphere	Jd	16.3	kg/yr
P supply from overland export	Je	1702.2	kg/yr
P supply from upstream	Ju	4666.6	kg/yr
P supply, on lake development	Jr	248.5	kg/yr
P supply, total present	Jt	6633.6	kg/yr
P, springtime, predicted	[P]	12.3	µg/L
Chlor. ª, predicted	[chl.ª]	2.6	µg/L
Chlor. ª, predicted-measured	[chl.ª]a	2.6	µg/L
Secchi disc, predicted	[SD]	8.5	m
Sec. disc, predicted-measured	[SD]a	8.5	m
P supply, approved lots on lake	Jv	0	kg/yr
P supply, approved lots upstream	Juv	0	kg/yr
P supply, total with approved	Jtv	6633.6	kg/yr
P outflow, total present	Jto	4643.5	kg/yr
P outflow, approved development	Jvo	0	kg/yr