Sandy Lake Conservation Association
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Response of Sandy Lake Conservation Association (SLCA) to: Sandy Lake Watershed Study - Final Report (AECOM 2014)

The Sandy Lake Conservation Association (SLCA) has serious concerns and questions about the Sandy Lake Watershed Study - Final Report (AECOM 2014) that we believe must be addressed before the document is accepted by HRM and before any form of development can be allowed in the Sandy Lake (Bedford) watershed.

In addition, we have related concerns about the general development process relevant to lakes. **We would like to see improvements to the system piloted at Sandy Lake and other lakes to benefit all lakes in HRM.** A new watershed policy and superior yet cost-effective practices can better avoid potential problems and can ensure healthy lakes in HRM for citizens to enjoy over the long term.

Re: Sandy Lake Watershed Study – Final Report (AECOM 2014)

We lack confidence in the total phosphorus (TP) data set and in how it was used to draw the conclusions in the report. The coefficient of variation[1] in the TP concentration is very high, indicating that the inherent variability in the data is 70% as large as the mean value of the TP concentration (Figure 8). The data set is very small (17 samples) for the time period under consideration (about 10 years for Figure 8), with no consistency as to the time of year or the depth of sampling, as far as sampling strategy was concerned[2]. The results span all three trophic states (categories or levels of nutrient-richness), from eutrophic (far too rich), to mesotrophic, to oligotrophic (very nutrient poor). Just over[3] one-quarter of the total phosphorus data collected since early in 2005 puts the lake in the eutrophic category (Figure 8). **Such a data-set is hardly a sound scientific basis on which to base the broad conclusions that the lake "is" mesotrophic, nor is the data of sufficient quality or consistency to make reliable predictions.**

[1] standard deviation divided by the mean.

[2] it is significant that a detailed sampling program, one which includes temperature, is recommended by AECOM (page 43).

[3] if the threshold data point of 20 μg/L is counted, 5/17 or 29.4 % of the data indicates eutrophic conditions.

Note: Assistance in the preparation of this report was provided by David Hansen, Ph.D., P.Eng.

The AECOM report omits quantitative statements of the level of uncertainty in their predictions, such as confidence intervals[4]. The early-warning TP value of 15 mg/L would be easily enveloped by the bounds of a common confidence interval (such as the 95% C.I.). The report seems to be lacking with respect to quantifying such uncertainty, in both the backward and forward senses. Given such uncertainty (both evident and unstated), to have a water quality objective for this lake that is the "upper limit of the mesotrophic range" (page 31) is not at all comforting to SLCA, especially given that: **(i)** eutrophic urban lakes (the next trophic level) are not amenities but are liabilities, **(ii)** eutrophic lakes have a short life-span as lakes, and that **(iii) it is admitted in the WQM (water quality management) plan that Sandy Lake is "highly vulnerable" (page 42).**

It is general knowledge that phosphorus and nitrates can worsen the trophic state of a water body. However, the warming of bodies like Sandy Lake and Marsh Lake[5]:

1. increases the rate at which nutrients such as TP are eventually used by algae, increasing their abundance,
2. decreases O_2 levels, altering the ecology of a water body, by affecting what flora and fauna are favoured and what species are even fundamentally viable[6],
3. as a side-effect of the joint action of #1 and #2 above, the nutrient level a water body can be altered (worsened). Page 14 of AECOM report admits this by saying that "Additionally, the increase in impervious surfaces, such as asphalt roads, and heat retention of these surfaces may increase water temperature, which can also adversely affect the lake's aquatic health." (bottom of paragraph 4). In connection with possible changes to the water quality of Florence Lake on Vancouver Island (due to urbanization), the BC Dept of Environment has stated (by way of background information) that:
   "Challenges to water quality management on Florence Lake include phosphorus loading from non-point sources, shallow depths, warm temperatures and low oxygen levels, primarily during the summer months. Excess phosphorus can cause spring and summer algal blooms as well as the spread of aquatic vegetation. When the vegetation and blooms die off and settle to the bottom, this can lead to oxygen depletion in the lake which provides favourable temperatures and photic opportunities for algae growth throughout the water column. Furthermore, as O_2 levels decrease near the bottom, internal nutrient loading occurs, whereby phosphorus is released from the sediment and enters the water column, exacerbating an already nutrient rich environment. With the lack of flushing of the lake in the fall and winter months, these nutrients are not removed and the process begins again."

If the Terms of Reference prepared by HRM precluded consideration of temperature, they were fundamentally flawed. If they did not, the modelling approach used by AECOM was flawed.

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[4] we note the vague admission of the presence of "inherent uncertainty" in the LCM model (page 42).

[5] Marsh Lake is surrounded by a wetland that is quite large compared to its own surface area.

[6] *e.g.* catfish and suckers are quite happy in warm eutrophic waters. Page 22 of the AECOM report admits the possibility of oxygen deprivation in the case of Sandy Lake, and that it would promote TP release from sediments in the bed of the lake.

It is admitted in the report that the model used to develop the conclusions in this report is a steady-state model (pg 32). That is, it inherently reaches some new equilibrium state with respect to its nutrient level or balance, as an outcome for a given set of imposed hypothetical conditions. By contrast, the TP data (though very scattered) has a clearly upward trend, showing increasing TP levels over time, and this with no significant historic increase in the amount of actual urbanisation. **We are concerned that the Lake Capacity Model (LCM) results are accepted and believed even though they do not account for this temporal trend; they are used to suggest that TP will simply plateau in the mesotrophic range (we note again that the LCM does not consider temperature, nor associated micticity[7] changes, nor temperature-change-driven TP release from lake-bed sediments[8]).** Page 5 of the report states that the "retention time" of Sandy Lake is only about four months (paragraph 5 – White *et al.* 1984). **This means that the time scale of the replacement of the 6 million m^3 in the lake is routinely encompassable by a single summer season, indicating a clear potential for higher summer lake temperatures, given that urban runoff has persistently higher summer temperatures.**

The LCM, now 39 years old (Dillon & Rigler 1975. Appendix A), was developed for, and first applied to, various lakes/watersheds (and therefore soils and bedrock geologies) in southern Ontario. It does not take into account microbiological contamination (Dillon & Rigler 1975), as is commonly caused by pets in urban areas (especially cats), nor does it account for phosphorus release from bed sediments, as can be caused by low oxygen in the hypolimnion (Dillon & Rigler 1975, page 1522, column 1)[9]. **Its application to small temperature-sensitive lakes is questionable. There is an abundance of more recent research that describes how urbanisation changes the quality of urban receiving waters, including temperature and ecological changes (Jones *et al.* 2012).**

Firstly, the Sandy Lake Conservation Association is concerned that this well-known warming phenomenon was not considered. Secondly, an important aspect of the LC model that must drastically affect results coming from it is the TP generation rates ("export coefficients"). We are told that "large-lot residential" developments have export coefficients of 0.2 kg/ha per year, whereas "commercial" land uses have export coefficients of 0.6 kg/ha per year. We are also told that good stormwater management practices would have the effect of reducing this phosphorus export rate by "50%" (page 40-41). **Clearly, such phosphorus 'export' rates (and hoped-for reductions in such rates) are educated guesses; changing them would completely change the conclusions of this report.** This is admitted by the progenitors of the LCM: "Uncertainty in the phosphorus export figures and in the loading from

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[7] *i.e.* mixing regime, most Canadian lakes being dimictic – 'turning over' twice a year. The AECOM report contains recognition of the fact that this actually occurs in Sandy Lake (top of page 18) but takes the matter no further. The twice-a-year turnover prevents stagnation of the deepest water layers of a lake, and is temperature-driven.

[8] a significant fraction of sediment will probably accumulate in a lake, not simply flush through. AECOM assumed a phosphorus sequestration rate by sediment in Sandy Lake of 33% based on an oxygenated hypolimnion. Oxygen content decreases exponentially with increasing temperature, and increased lake temperatures are a normal expectation. Sediment accumulation, over time, together with a warmer lake (lower O_2) could have a significant effect on the actual TP sequestration/desequestration rates, but no modelling was done in this regard.

[9] More capable models exist, such as the EQuIS LakeWatch Limnology Decision Support System, and the GLM-FABM (http://aed.see.uwa.edu.au/research/models/GLM/) model.

precipitation alone could result in a 100% error in the calculation of the natural phosphorus while factors such as the soil retention factor are still only approximations". **We are concerned that no analysis of the amount of inherent uncertainty in the assumed export coefficients is presented in the AECOM report, nor are supporting references given for the values that were used (no authorities are cited beside the stated values of the coefficients).** Are these export coefficients well-supported by virtue of NS experience (post-development data)?

Page 1 mentions municipal services, and Figure 2 shows "water and sewer services". **The frequently used word "sewer" in the report does not differentiate between the sanitary sewerage systems and the storm-sewer system (real or hypothetical), but it should have.** The bottom of page 1 apparently indicates that storm sewerage is not part of future development, in some cases. **Since TP does indeed come from stormwater, the SLCA would like to see where all future storm sewers will probably be located, especially the outfalls from same, and whether or not any stormwater will be directed into the lake (and/or its tributaries), and if so, how it will end up in the lake. The sanitary sewerage system should have been portrayed in a figure, noting in addition whether a given area will instead remain on septic systems, under a given scenario.**
The future area to be serviced by storm sewerage system(s) should have been portrayed in a separate figure, noting the most probable locations of any outfalls and stormwater retention facilities.

The report appears to advocate development Scenario 2 (page 45, chapter on satisfying HRM's E-17 policy), but it is hard to find an explicit recommendation to this effect.

The amount of hydrologic detail in the report is also disappointing. **No pre-development and post-development hydrographs or other graphics are presented. To get some sense of volumes involved, one should compare the volume associated with the expected amount of urban development to the lake volume.** If the volume of 6 million m^3 (page 5) of Sandy Lake is spread over the expected newly-developed area of 361 hectares, a depth of 1662 mm results. This means that an annual runoff figure of 850 mm (for example[10]) represents about half of this depth. This means that if the annual runoff from the 361 hectares becomes both greater and warmer, this volume of warm water will represent a relatively large percentage of the volume of Sandy Lake. **We would like to see a description and discussion of studies on lakes of comparable relative size.**

HRM's Regional Plan's E-17 (Appendix B) **requires that <u>specific</u> recommendations be made from studies such as this one. Contrary to the fact that changes to the stormwater runoff behaviour is the very reason that studies such as this one are done, we find the following vague statement on page 42: "The meaning of the term Advanced Stormwater Management does not reflect any specific methods of stormwater management...." (second paragraph).**

Also contrary to the need for specific recommendations plural, page 45 of the report merely mentions undifferentiated "best forestry practices" (other than a simple buffer zone recommendation).

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[10] approximately the value found from the runoff map for NS, in the Hydrologic Atlas of Canada, AECOM estimates 755 mm. The mean annual precipitation is about 1350 mm, with higher variability in recent years.

This report does recommend (i) that the effluent from the two wastewater treatment (WWT) plants in the watershed be 'sent' elsewhere. In connection with the WWT plant overflows (due to an 'overflowing' sanitary sewerage system, or 'SSO'), page 47 of the report states "Overflows typically occur during extreme weather events. The timing, frequency, and severity of these events are not possible to predict and so the water quality impacts from overflows cannot be quantified or modelled." **This statement is true if one is limited to the LCM model, but completely false in general. Halifax Water and HRM have paid for extensive studies to quantitatively address just such SSO problems, and these studies are on their shelves. (These have been done because the CCME has asked that municipalities put an end to all SSO's, as per the statement at the bottom of page 51).**

Related Questions and Concerns

Note: The watershed study is required to address E-17 of the Regional Plan.

1. It is acknowledged in the report that urban development is currently increasing phosphorus concentrations in Sandy and Marsh Lake. As stated in item E-17, the purpose of the watershed study is to determine the carrying capacity of the watershed and determine the amount of development. All three development scenarios are full development scenarios for the areas targeted for development. **Given the current negative water quality trend and the low-flush rate of the lake, a development scenario that takes a precautionary approach and is not full-build out would be advisable. Why was this type of scenario not considered?**

2. All the scenarios contain a constraint of 20 metres around watercourses, wetlands, and waterbodies. **Given the objective in item E-17-i states to "identify and recommend measures to protect and manage natural corridors and critical habitats for terrestrial and aquatic species, including species at risk", why was research conducted by Rideout (2012) stating "a wider buffer of >50m is required to provide terrestrial habitat services" not taken into consideration? Our Sandy Lake advisors recommend a 60m <u>minimum</u>, given the vulnerability of the lake, and that more would be preferable.**

3. Also, item E-17-j states to "identify appropriate riparian buffers for the watershed". **Given the intensity of the proposed development and the rising levels of nutrients, again, why is only the minimum distance of riparian buffers (i.e. 20m) recommended?**

4. It is acknowledged in the report that there was no comprehensive study of wildlife undertaken in the Sandy Lake area. Within the Birch Cove Lakes watershed study, sensitive areas were listed as development constraints. In the **Sandy Lake report, merely stating that an analysis for Sandy Lake was not completed therefore there are no constraints does not satisfy the requirement of E-17-i. Why was there not an ecological study and/or GIS analysis conducted to identify sensitive areas to satisfy the E-17-i requirement?**

5. Within the Birch Cove Lakes watershed study old growth forest was considered a constraint. The Sandy Lake report mentions a mature hemlock forest on the southern peninsula of Sandy Lake. Mature hemlock represents a late-successional stage forest which is indicative of old-growth forest. Data was collected on October 3, 2014 by a Department of Natural Resources (DNR) employee to quantify the mature hemlock (See Edward Glover's submission on old-growth forest). Bruce Stewart, manager of research and planning at DNR, states that this forest stand ranks high as old growth. **Item E-17-k states "identify areas that are suitable and not suitable for development". Omission of old growth forests from the report implies that old-growth forest is suitable for development. Why was this old growth forest, or any other for that matter, not considered a constraint for the Sandy Lake watershed study?**

6. We are resubmitting our March 22, 2014 (Appendix C) letter because the final report did not include a table of concordance documenting how those issues from our letter were addressed.

"How Lakes Work" as applied to Sandy Lake:

"No Swim" advisories are often associated with high water temperatures, because bacteria multiply much more quickly when it is warm (the same reason why we refrigerate our food). Protozoans eat bacteria and bigger 'microscopic' life-forms eat protozoans, and on up the food chain. The types of benthic invertebrates present (spineless bottom dwellers that live in sediment) are important indicators of water quality; persistently warmer water will alter the type and diversity of the limnic fauna (lake creatures) broadly speaking. High water temperatures inherently limit the saturation level (upper limit) of Oxygen (O2) in the water, altering what kinds of fish will be happy in a given lake or stream. All salmonidae (this family includes trout) like cold high-O2 water, whereas carp and suckers and perch are much more tolerant of poor O2 levels (but are considered less desirable as fish). Salmonidae want gormet benthic invertebrates like dragonfly nymphs, but carp will eat garbage.

Warmth also tends to change the flora (botanic ecology); some aquatic weeds do well in warmer water, so when water warms one can get post-development 'blooms' of plants that you previously did not see much of, or any of, before. These weeds increase the rate at which a lake traps sediment, matter that would normally just pass through the lake. This trapping of sediment and the way that lakes become marshes and then bogs and then land is called 'natural succession'.

There are more factors. At many Canadian beaches (such as Mooney's Bay on the Ottawa River) there are regular closures right after it rains, in the summer. This is because cat faeces have accumulated in the watershed and get washed into the river.

Dark south-facing surfaces should be avoided in new developments. One can intelligently use trees and orient the streets appropriately to minimize the warming of runoff. One can orient roofs so that most of their surfaces are not south-facing surfaces (even though this increases people's heating bills). Rain barrels should be on all properties. A golf course should be limited as to what it can apply (like farmers, golf courses tend to waste fertilizer by putting on too much fertilizer at a time).

If the two wastewater treatment plants within the Sandy Lake watershed cannot do their job from time to time due to "I and I" (inflow & infiltration = surface water and groundwater leaking into the sanitary sewerage system) occurring every time it rains, methods exist for relining the pipes in the existing system (trenchless technologies).

New sanitary sewerage systems should be tested every 5 years and leaks fixed.

Another factor is Sandy Lake's dimicity (It turns over twice a year), a function that can also be altered by watershed urbanisation.

We understand that the annual precipitation in the Sackville area is about 1200 mm per year (this number varies from year to year, of course). This published annual precipitation value includes the water equivalent of the annual snowfall - itself a highly variable number. If one has a watershed area which 'suddenly' has 30% more impermeable surfaces, one's surface runoff proportion from that area goes up by 360 mm (and the groundwater system receives that much less of the annual precipitation). As an example, if the amount of newly developed area is 1 km2, that represents an additional volume of water of 360,000 cubic meters (water likely with cat faeces etc. in it). Whether or not a given lake is going to be strongly affected or not depends on ITS own volume. A small-volume lake could be 'killed' by such a change.

Overall, we would have thought we would see some clearer work on the relative volumes involved (by AECOM); i.e. basic hydrologic budgets as compared to Sandy Lake's own typical volume (Note: Bachiu's "hydraulic" budgets, hydraulic is the wrong word). There are many useful studies out there on this kind of thing. **To just study total phosphorus and use it as one's sole criteria is too narrow.** HRM would be wise to catch up to the times on data collection. Use of equipment now available for continuous monitoring of surrogate parameters is quite cost-effective and very informative, compared to having a guy fill a bottle from the lake. AECOM had very little data to work with. One does not get a picture of what is going on from a couple-of-dozen grab samples. The scatter would have been due to when in the year the sample was taken and how long since it had rained. **Drawing conclusions of this importance, that is, when development of this magnitude is being considered near a lake, from so little data is very questionable.**

<u>Recommendations</u>

SLCA recommends putting a halt to all further development, subject to (i) implementation of the data collection program recommended by AECOM in Section 9 of this report plus an associated follow-up modelling effort of a more complete type, and (ii) the full and formal assessment of the state of health and abundance of the four species-at-risk, already identified as being at risk on page 50 of the report itself (salmon and turtles, asters and stitchworts).

If development is to eventually go ahead, HRM and Halifax Water should:

1. **switch households who are on septic systems (especially those that fail a timely inspection[11]) to a new sanitary sewerage collection system before allowing further development,**
2. **move both sources of WWT plant effluent before allowing further development (see on page 47).**

   The above would lessen two major existing nutrient sources before the addition of any new nutrient sources,
3. **increase the minimum buffer size to 60 m (given the stated vulnerability of the lake),**
4. **pass a by-law requiring use of rain barrels on every residential lot in the Sandy Lake watershed,**
5. **require the implementation of state-of-the-art stormwater management measures for any proposed sub-division developments, such as the use of permeable pavements (Ferguson 1994), and underground detention systems (Poornima and Davis 2010),**
6. **expect the use of tree canopies (Jones *et al.* 2012) and the adjust orientation of developments at the sub-division-layout stage so as to lessen the warming of runoff (adjustment of azimuths of roofs and roads),**
7. **disallow uncontrolled tree removal,**
8. **ban the use of road salt in the watershed,**
9. **disallow the bulldozing of drumlins, so as to preserve groundwater recharge sites (see last paragraph on page 9),**
10. **limit the use of lawn fertilizers (amount applied, time of year),**
11. **ban herbicides and limit the use fertilizer by the golf course (alluded to on page 47),**
12. **specify a minimum lot size for all new lots[12], to a size that will clearly lessen adverse hydrologic changes.**

The above might be ensured by passing by-laws before any further watershed change, thus communicating to potential developers what they are 'getting themselves into', before they begin construction.

[11] as per item 9 page 52. We also note the statement on pg 32 of the report that: "Unfortunately, mitigation (*sic*) measures to reduce total phosphorus concentrations are seldom instantaneous or completely effective so …early warning values are often used to manage lake quality, rather than waiting for the … water quality objective to be met."

[12] one that is relatively large. We note the following statement on page 40 "In Scenario 2 the contribution from small lot residential increases by a factor of three and is the dominant source of phosphorus, at 25% of the total load, in this scenario."

In Closing

We trust that readers will see that we deeply care about the welfare of this lake that has been in existence for a very long time and that is being put at risk by human activity. Thorough evaluation along with careful application of current science and knowledge can retain its health as a continuing natural habitat as well as provide an enduring beautiful resource for recreation and enjoyment for citizens.

There is a need for better monitoring, better data, better analysis, better modelling, and better literature reviews. There is modern equipment for monitoring multiple parameters continuously (rainfall, lake depth, specific conductivity, temperature,...) and it is far more clever and affordable than it used to be.

As was noted in the second watershed meeting (Appendix D), the absence of policies that might be applied to HRM watersheds is part of the problem. **This absence of policy is a political problem that HRM councillors, now aware of it, can rectify.**

Sandy Lake is already at significant risk from the uncontrolled clear cut that occurred in 2013. Putting into place policies and controls to prevent such events in other areas of HRM would logically be a part of watershed protective policies. We ask that such protective policies for trees and wooded lands be created and implemented across HRM.

Regarding the protection of trees and lakes:

1. Florence Lake (1980-2009) Water Quality Monitoring Program (Appendix E)

2. Ottawa Tree By-law:
http://search.ottawa.ca/search?q=Tree+Bylaws&btnG=Search&client=ottawa_en&proxystylesheet=ottawa_en&lr=lang_en&sort=date%3AD%3AL%3Ad1&entqr=3&entqrm=0&entsp=a&oe=UTF-8&ie=UTF-8&ud=1&site=ottawa_en&filter=0

3. Saskatchewan Lakeshore Development:
http://www.municipal.gov.sk.ca/dedicated-land/lakeshore-development

We respectfully request that HRM decision makers follow our lead to protect Sandy Lake and will develop policies that will benefit and protect lakes throughout HRM from this time on. We believe that our document provides much information that can be used to develop these improvements to policy and practice.

We in the SLCA would like to be part of the solutions and we offer our ongoing efforts and input to this end.

In the meantime, **we request that this watershed report not be accepted by HRM, and that no development be allowed in the Sandy Lake watershed until our questions and**

concerns outlined in the bolded parts of this document are addressed satisfactorily, and until up to date lake protection policies and practices are put into place.

We also request a meeting with appropriate HRM staff and our local councillors to chart the way forward.

Submitted by the Sandy Lake Conservation Association (SLCA)
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October 13, 2014

References

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E, Rideout (2012), Setbacks and Vegetated Buffers in Nova Scotia,

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Poornima N. and Davis A.P. 2010. Thermal reduction by underground storm-water retention system. ASCE J. of Environmental Eng., 136(5):520-526.

List of Appendices

Appendix A: Dillon P.J. and Rigler F.H. 1975. A simple method for predicting the capacity of lake for development based on lake trophic status. Journal of the Fisheries Research Board of Canada, 32(9):1519-1531.

Appendix B: E-17 From The Regional Plan

Appendix C: Sandy Lake Conservation Association response to the February preliminary report

Appendix D: Sackville River's Association, 2014 Sep Big Sandy Lake Watershed Water Quality Study

Appendix E: Florence Lake (1980-2009) Water Quality Monitoring Program

Appendix F: Additional Resources

Appendix A (Dillon)

Journal of the Fisheries Research Board of Canada

Journal de l'office des recherches sur les pêcheries du Canada

Volume 32, No. 9, September 1975 Volume 32, n° 9, septembre 1975

A Simple Method for Predicting the Capacity of a Lake for Development Based on Lake Trophic Status

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DILLON, P. J., AND F. H. RIGLER. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Board Can. 32: 1519–1531.

A general technique is presented for calculating the capacity of a lake for development based on quantifiable relationships between nutrient inputs and water quality parameters reflecting lake trophic status. Use of the technique for southern Ontario lakes is described. From the land use and geological formations prevalent in a lake's drainage basin, the phosphorus exported to the lake in runoff water can be calculated, which, when combined with the input directly to the lake's surface in precipitation and dry fallout, gives a measure of the natural total phosphorus load. From the population around the lake, the maximum artificial phosphorus load to the lake can be calculated and, if necessary, modified according to sewage disposal facilities used. The sum of the natural and artificial loads can be combined with a measure of the lake's morphometry expressed as the mean depth, the lake's water budget expressed as the lake's flushing rate, and the phosphorus retention coefficient of the lake, a parameter dependent on both the lake's morphometry and water budget, to predict springtime total phosphorus concentration in the lake. Long-term average runoff per unit of land area, precipitation, and lake evaporation data for Ontario provide a means of calculating the necessary water budget parameters without expensive and time-consuming field measurements. The predicted spring total phosphorus concentration can be used to predict the average chlorophyll *a* concentration in the lake in the summer, and this, in turn, can be used to estimate the Secchi disc transparency. Thus, the effects of an increase in development on a lake's water quality can be predicted. Conversely, by setting limits for the "permissible" summer average chlorophyll *a* concentration or Secchi disc transparency, the "permissible" total phosphorus concentration at spring overturn can be calculated. This can be translated into "permissible" artificial load, which can then be expressed as total allowable development. This figure can be compared to the current quantity of development and recommendations made concerning the desirability of further development on the lake.

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DILLON, P. J., AND F. H. RIGLER. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Board Can. 32: 1519–1531.

Les auteurs décrivent une méthode générale permettant de calculer la capacité de développement d'un lac. Cette méthode est fondée sur les relations quantifiables entre l'apport d'éléments nutritifs et les paramètres de qualité de l'eau reflétant la statut trophique de lac. Ils expliquent comment la méthode peut être appliquée à des lacs du sud de l'Ontario. A partir de l'utilisation des terres et des formations géologiques qui prévalent dans le bassin hydrographique d'un lac, on peut calculer le phosphore qui pénètre dans le lac avec l'eau de ruissellement, lequel, combiné à l'apport qui tombe directement à la surface du lac par précipitation ou retombée sèche, donne une mesure de la charge naturelle totale de phosphore. En se basant sur la population qui vit autour du lac, on peut calculer la charge artificielle maximale que peut recevoir le lac et, si nécessaire, la modifier en fonction des systèmes d'égoûts existants. La somme des charges naturelles et artificielles peut être combinée à la morphométrie du lac, exprimée en profondeur moyenne, au budget hydrologique du lac, exprimé en terme de vitesse de vidange du lac, et au coefficient de rétention du phosphore du lac, paramètre dépendant à la fois de la morphométrie et du budget hydrologique du lac, pour prédire la concentration printannière totale de phosphore dans le lac. Le ruissellement moyen à long terme, par unité de superficie de terre, la précipitation et l'évaporation dans l'Ontario sont des données qui permettent de calculer les paramètres de budget hydrologique sans avoir recours à des mesures longues et dispendieuses sur le terrain. La concentration printannière totale prédite de phosphore peut servir à prédir la concentration moyenne de chlorophylle *a* du lac en été et celle-ci, à son tour, peut être utilisée pour estimer la transparence au disque de Secchi. On peut, de cette façon, prédire les effets d'un développement accru sur la qualité de l'eau du lac. Inversement, en établissant des limites à la concentration estivale moyenne de la chlorophylle *a* ou de la transparence au disque de Secchi « permissibles », on peut calculer la concentration totale « permissible » de phosphore au moment du brassage général de printemps. Ceci peut être traduit en terme de charge artificielle « permissible », pour enfin être exprimé sous forme de développement total permissible. Ce chiffre peut être comparé au degré de développement présent et servir de base à des recommandations quant aux avantages de développements plus poussés sur le lac.

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THE demand for summer cottages and other recreational facilities in Ontario is increasing rapidly, with about 10,000 new cottages under construction in each year (Department of Tourism and Information 1971). Governmental planners, biologists, and engineers must evaluate and subsequently approve or reject proposed developments without guidelines that quantitatively determine the environmental impact of such development. Suitable guidelines must be based on predictive ecological and social theories that, to date, have not been formulated in terms of practical management tools. It is the aim of this paper to provide a means of determining the capacity of a lake for cottage or permanent home development, assuming that specific acceptable limits can be established for some parameters that reflect the quality of the aquatic environment. Translation of these limits to permissible cottage numbers or other development schemes can be achieved through application of techniques described in this report. Conversely, if a decision is made to allow the development of a given number of cottages or large-scale condominiums, then the governmental agency responsible will be completely cognizant of the environmental ramifications of its decision.

At this time, only the problem of lake trophic status is considered, with the equally important concerns of the effects of development on fisheries, wildlife, and on human health not taken into account (there is, of course considerable relationship between trophic state and fisheries potential, as well as health hazards). It should be stressed that the approach described herein is limited by its inability to consider these alternate parameters.

In understanding lake conditions, it is important to realize that the entire watershed and not just the lake or the lake and its shoreline, is the basic ecosystem unit. The terrestrial and aquatic portions of any watershed are inherently linked with the gravitational movements of minerals in drainage waters flowing from the land to the water (i.e. lakes, oceans), as the major terrestrial–aquatic linkage (Likens and Bormann 1974). It is important to note that the aquatic portion of a watershed is "downhill" from the terrestrial portion; that is, dissolved and particulate materials from the land are transported by geological process to the water and eventually to the less accessible sites of the sediments in the aquatic portions of the ecosystem. There is, of course, some "uphill" movement of material by meteorological and biological transport, e.g. release of N_2

from a lake through denitrification and gas diffusion, followed by precipitation of the same to the land for the former process and movement of material through the food chain for the latter. However, the net movement is always "downhill" to the aquatic system, with the deficit made up by geological weathering of rocks. The implication of this in terms of a lake's capacity for development is that any alteration in a watershed ultimately affects the lake. Thus, any management approach based solely on the lake and its shoreline is both simplistic and inaccurate.

Although a number of attempts to manage lake fisheries by the empirical approach have been tried (Moyle 1946; Rawson 1952, 1955; Ryder 1965), very little has been accomplished in terms of managing lakes for development with regard to trophic status by a similar method. An exception was Seppanen's proposal (1972) to determine a lake's summer cottaging capacity. The author suggested that a suitable formula for the recommended number of shoreline cottages was

$$\frac{A\sqrt{D_L}}{10}$$

where A is the lake area in hectares, D_L is the development of shoreline equal to the shorelength divided by the circumference of a circle of the same area, and 10 is a figure representing the minimum area of lake surface (in hectares) needed per cottage for a round lake with no islands. While providing a formula that takes into account both lake area and shoreline length, many other important factors are neglected limiting the technique. An entirely different, although somewhat indirect, approach has recently been used in a lake management sense. In 1968, Vollenweider published a plot of total annual phosphorus loading L (the amount of material added per unit surface area of lake per annum) vs. mean depth ($\bar{z}$). He found that bands could arbitrarily be drawn separating the lakes into the three standard lake types in terms of degree of eutrophy: oligotrophic, mesotrophic, and eutrophic. In 1973, Vollenweider modified his relationship to take hydraulic flushing rate into account. This was accomplished by incorporating the mean residence time of the water in the lake (τ_w). By plotting L vs. $\bar{z}/\tau_w$, a more realistic representation was achieved. The parameter $\bar{z}/\tau_w$ is equivalent to the areal water loading (i.e. the height of the water load over the lake's area that is supplied in 1 yr). The L vs. $\bar{z}/\tau_w$ model has been used for predicting changes in trophic status of several Muskoka Lakes (Michalski et al. 1973) that would result from changes brought about by the reduction of phosphorus in sewage effluent. As effected by Michalski et al. (1973), the model can be employed by environmental managers in the same manner as the L vs. $\bar{z}$ plot: the maximum additional loading to a lake that will not surpass the "permissible" loading can be calculated and interpreted in terms of cottage development. Although a significant improvement over the L vs. $\bar{z}$ plot, this method still lacks quantitative predictibility in terms of water quality parameters.

Basis for a New Approach

It has been demonstrated on numerous occasions (Schindler et al. 1971; Schindler 1974; Fuhs et al. 1972) that phosphorus is the nutrient most frequently controlling production and therefore trophic status in north temperate lakes. Therefore, any approach to predict water quality from a trophic status point of view must take into account the importance of phosphorus. As early as 1947, Sawyer (1947) recognized that phosphorus concentration in the lake water was the factor controlling eutrophication. Although Vollenweider's L vs. $\bar{z}$ plot relates loading rather than concentration to trophic state, his improved second relationship, L vs. $\bar{z}/\tau_w$, relates phosphorus concentration, and not loading, to trophic state. This may seem at first to be a contradiction but the rationale is as follows: the lines separating lakes into distinct trophic types have the dimensions of $L/\bar{z}/\tau_w$ or g m^{-2} yr^{-1}/m yr^{-1}, i.e. g m^{-3}. Thus, the lines are independent of time and have units of concentration (the lines of the L vs. $\bar{z}$ plot have units of g m^{-3} yr^{-1}, i.e. of volumetric rather than areal loading). Since the parameters with which one subjectively evaluates a lake (chlorophyll *a*, oxygen in the hypolimnion) are also expressed in terms of concentration, the above interpretation is most reasonable. Consequently, predictions relating the impact of development on the phosphorus concentration of a lake and subsequently on parameters describing the trophic state are central to a predictive management scheme.

The overall approach employed here is shown in Fig. 1. From consideration of the geology and land use of a lake's drainage basin, it is possible to estimate the total phosphorus exported or washed out per unit of watershed, which, combined with the drainage area, provides an estimate of the total phosphorus supplied to the lake from the land. Addition of the input of phosphorus in precipitation directly falling on the lake allows calculation of the natural phosphorus load to the lake. Development existing on the lake is then measured (aerial survey or field counts) and

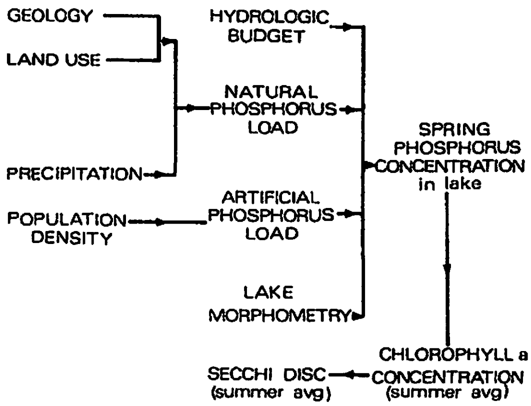

FIG. 1. Scheme of simple empirical models used to assess effects of development on trophic status of lakes.

the phosphorus loading from artificial sources calculated. The total loading, natural plus artificial, may then be combined with the lake's morphometry and water budget to predict a phosphorus concentration that is subsequently related to the average summer chlorophyll *a* concentration. From this latter calculation, one may determine the mean Secchi disc visibility. This method will most often be used in the opposite sense. For example, maximum acceptable average summer chlorophyll *a* concentration (or minimum Secchi disc reading) will be established by the appropriate governmental agency. From these limits, decision-making personnel will be able to calculate a maximum permissible phosphorus concentration, which can be interpreted in terms of a maximum "permissible" total phosphorus load, because the lake morphometry and water budget are essentially fixed. That is, although there are year-to-year variations in the lake's water budget, the long-term average budget is used. Finally, the maximum permissible artificial phosphorus loading can be estimated and expressed as the maximum allowable development (i.e. numbers of cottages, etc.). Although hypolimnetic oxygen deficits have been related to phosphorus loading for the Great Lakes (Gilbertson et al. 1972), a direct relationship applicable to a wide variety of lakes and especially to lakes of the Precambrian Shield is not yet available. Mortimer (1941–42) suggested a limit of 0.25 mg O_2 cm^{-2} day^{-1} for oligotrophic lakes, but the quantitative link to nutrients is, as yet, unformulated.

In the following section the theory and method for each step of the scheme are described and subsequently a stepwise procedure for calculating the lake's capacity is outlined for use by planners, managers, etc. Although the research work that the specific models are based on was largely carried out in southern Ontario and the particular values suggested for different parameters apply to southern Ontario lakes, the overall approach is general enough that with the appropriate data available, a similar sequence of predictions could be made for lakes of other regions.

Theory for Each Step of the Management Scheme for Southern Ontario Lakes

CALCULATION OF THE PHOSPHORUS LOADING TO THE LAKE

1. *Natural phosphorus load from land* (L_e) — The geological formations of southern Ontario can, as a first approximation, be classified as Precambrian igneous rock of plutonic origin (Canadian Shield) or sedimentary rock. The former is typically composed of granites, gneisses, pegmatites, syemite, migmatites, diorite, gabbro, hornblendite, amphibolite, and pyroxenites, the latter of limestone, dolomite, shale and basal clastics. A very large proportion of Ontario's recreational lakes are situated on the Shield, with only the southern portion of the Kawartha–Trent system, Lake Simcoe, and a few smaller lakes on sedimentary material. In addition, the watersheds of most of the Shield lakes are entirely or almost entirely forested, with the remainder being either marshland or pastureland that, although used for agricultural purposes, is not chemically fertilized. Even south of the Shield on the sedimentary bedrock, there are few areas where intensive agriculture (i.e. chemical fertilization) is practiced in prime recreational land; some areas around Lake Simcoe are a notable exception. Dillon and Kirchner (1975) have developed a phosphorus export scheme (Table 1) that is based on classification of geology as either "igneous" or "sedimentary" and land use as "forest" or "forest plus

TABLE 1. Ranges and mean values for export of total phosphorus (E) from 43 watersheds. Results in mg m^{-2} yr^{-1} (from Dillon and Kirchner 1975).

Land use	Geological classification: Igneous	Sedimentary
Forest		
Range	0.7–8.8	6.7–18.3
Mean	4.7	11.7
Forest + Pasture		
Range	5.9–16.0	11.1–37.0
Mean	10.2	23.3

pasture"; the latter category implies that 15% or more of the watershed is cleared but unfertilized land. This export scheme is applicable to almost the entire recreational lake area of Ontario. The results of Dillon and Kirchner are based on a combination of a study of the phosphorus export (E) of 34 watersheds in southern Ontario and all additional phosphorus export studies reported in the literature where watersheds fall into the above-mentioned categories. It is important to note that the natural export from sedimentary materials (off the Shield) is almost exactly double that from igneous bedrock (on the Shield); therefore, lakes such as the Kawarthas have a higher natural loading than Precambrian lakes. In addition, a change from a land use of forest to forest plus pasture doubles the export within a geological classification; for example, from 4.7 to 10.2 mg m^{-2} yr^{-1} for igneous watersheds and from 11.7 and 23.3 mg m^{-2} yr^{-1} in sedimentary watersheds. If a development significantly alters the amount of cleared land in a watershed, then an appropriate change in the export value used must be made.

It is also important to note that a range of values was measured for each category. Forested igneous watersheds, for example, exported 2.5–7.7 mg P m^{-2} yr^{-1} in the southern Ontario region alone, while Schindler et al. (1974) measured a range of 3–7 mg m^{-2} yr^{-1} in the Experimental Lakes Area. The total nutrient budget can obviously be significantly affected by the choice of export figure.

To calculate the natural phosphorus loading to a lake from its drainage area, one must know the area of the watershed (A_d) of each tributary to the lake, and be able to classify each as to geology and land use so that the export coefficient can be determined. Should the location be one of the few where intensive farming is undertaken, the reader should consult Vollenweider (1968), Dillon and Kirchner (1975), and Loehr (1974). The total amount of phosphorus supplied to the lake from the land is therefore calculated as the sum of the area of each drainage basin times its phosphorus export coefficient:

$$J_E(\text{mg}) = \sum (A_d \cdot E_i) \text{ with } A_d \text{ in m}^2. \qquad (1)$$

The areal loading of phosphorus supplied to the lake from the land L_E, is equal to $(\sum A_d E_i)/A_o$ and is equivalent to the supply divided by the lake area (A_o).

A complicating factor arises if any tributary or watershed of the lake in question has an additional lake or lakes in its course. These lakes undoubtedly act as traps for phosphorus and other nutrients, decreasing the actual amount of material transported from the drainage area to the lake in question. A means of accounting for this is described in a later section.

2. *Natural phosphorus load from precipitation* (L_{PR}) — Phosphorus input via precipitation (wet and dry fallout) has been virtually ignored until recent years. Studies by Schindler and Nighswander (1970), Armstrong and Schindler (1971), Barica and Armstrong (1971), Dillon and Rigler (1974a), Lee and Kluesener (1971) and Shannon and Brezonik (1972) have demonstrated that, for many lakes, precipitation can be a major source of nutrients. From consideration of the above-mentioned studies, which found loadings ranging from 24 to 102 mg m^{-2} of lake surface yr^{-1}, a value of 75 mg m^{-2} yr^{-1} is recommended as applicable to southern Ontario lakes. Some of the lower values did not include a measure of phosphorus in dry fallout, while others were measured in more remote areas far from urban and agricultural centres (Schindler et al. 1974) and the highest value, 102 mg m^{-2} yr^{-1}, was measured in an area where much of the land was used for agriculture. Furthermore, the figure of 77 mg m^{-2} yr^{-1} found by Dillon (1974a) was measured in the Haliburton Highlands area of the province, an area of prime concern for recreational development, although one close to much of the province's agricultural and industrial development. Thus, a figure of 75 mg m^{-2} yr^{-1}, for southern Ontario, although reasonable may be in error by as much as 100%. The year to year variation alone was greater than 100% in certain areas (Schindler et al. 1974). Additional research on this topic is obviously needed. A review has been provided by Chapin and Uttormark (1973).

With L_{PR} = 75 mg m^{-2} yr^{-1}, the natural phosphorus supply to a lake (J_N) is given as:

$$J_N = J_E + J_{PR}$$
$$= \sum (A_d \cdot E_i) + 75 \cdot A_o \quad (\text{mg yr}^{-1}) \qquad (2)$$

or the loading (L_N)

$$L_N = \frac{\sum (A_d \cdot E_i)}{A_o} + 75 \qquad (\text{mg m}^{-2}\ \text{yr}^{-1})$$

3. *Artificial phosphorus load* (L_A) — The calculation of the phosphorus supplied to a lake by the population in its drainage basin is a difficult task and must necessarily be based on a supply per capita-year figure with several assumptions inherent in this method. Although numerous figures are quoted in the literature (e.g. see Vollenweider 1968 or Vollenweider and Dillon 1974, summary) great care must be taken in selecting

the appropriate value. The following points must be remembered:

a) Values measured in studies such as that of Johnson and Owen in 1971 (1.5 kg capita^{-1} y^{-1}) are no longer applicable because of legislation to reduce the phosphorus content of laundry detergents. High phosphorus content dishwashing detergents, however, remain legal and a survey of the Muskoka Lakes found that 30% of the cottages in the area employed automatic dishwashers.

b) The waste disposal technique for most developments that are already established or will be established in the near future is the conventional septic tank–tile field system. The efficiency of this treatment as far as phosphorus removal is concerned is dependent on the type and depth of soil surrounding the tile bed and between the tile bed and the lake. In Precambrian areas typically having very shallow, coarse-textured sandy or muck soils there is no satisfactory evidence which indicates that phosphorus is retained in the soils. Therefore, it must be assumed that all phosphorus discharged to soils of a tile bed area eventually gains access to the lake. In sedimentary areas, septic tank–tile field systems located in sand, gravel, or muck areas are likely to be as ineffective as far as phosphorus retention is concerned as those systems located on the Shield. Lakes surrounded by silt, clay, or clay–loam soil, however, will be provided with some measure of protection. Representative values for the fraction of phosphorus retained in some soils are given in Table 2.

c) Additional sources of phosphorus, (e.g. fertilizer applied to lawns in cottage areas), are

TABLE 2. The retention coefficients of total phosphorus for septic tile filter beds of different characteristics. Results are based on 4 yr of data (after Brandes *et al.* 1974).

Filter bed	R_s
1. 22 in. sand (D_{10} = 0.24 mm) 8 in. mixture 4% red mud, 96% sand	0.76
2. 30 in. sand (D_{10} = 0.30 mm)	0.34
3. 30 in. sand (D_{10} = 0.60 mm)	0.22
4. 30 in. sand (D_{10} = 0.24 mm)	0.48
5. 30 in. sand (D_{10} = 1.0 mm)	0.01
6. 30 in. sand (D_{10} = 2.5 mm)	0.04
7. 15 in. sand (D_{10} = 0.24 mm) 15 in. mixture 10% red mud, 90% sand	0.88
8. 15 in. sand (D_{10} = 0.24 mm) 15 in. mixture 50% limestone, 50% sand	0.73
9. 30 in. silty sand	0.63
10. 15 in. sand (D_{10} = 0.24 mm) 15 in. mixture 50% clay–silt, 50% sand	0.74

impossible to evaluate quantitatively without a lake by lake survey.

With the above factors in mind, a reasonable phosphorus supply per capita-year can be calculated. According to the data of Bucksteeg (described in Vollenweider 1968), the annual per capita amount of phosphorus uptake in food in Germany in 1960 was 0.55 kg.; a similar amount is assumed to be excreted. In addition, the yearly per capita phosphorus supplied as domestic sewage (excrement plus household wastes) in 13 studies in North America and Europe averaged 0.80 kg. year^{-1}, the studies having been carried out before use of high phosphate detergents was common. Thus, the two results are in basic agreement, and with food consumption in North America being greater than that in Europe and there being continued usage of high phosphate dishwashing detergents in North America, the figure of 0.80 kg phosphorus capita^{-1} year^{-1} is a good estimate of the phosphorus supplied from domestic sources.

For all lakes situated on the Precambrian Shield the artificial supply of phosphorus can therefore be calculated as:

$$J_A = 0.8\ (\text{kg capita}^{-1}\ \text{yr}^{-1}) \times N\ (\text{cottages}) \times T\ (\text{capita-yr cottage}^{-1}\ \text{yr}^{-1}) \quad (3)$$

where N = the number of cottages or dwelling unit equivalents

T = the average number of capita years spent at each cottage in each year.

The same formula can be used for areas south of the Shield that consist of sand, gravel, or muck soils. In cases where holding tanks are employed and all wastes are removed to a treatment plant outside the lake's watershed, the supply of phosphorus from such dwellings should not be included in the calculations. Recent investigations (Brandes et al. 1974) involving the use of a red mud (aluminum mill waste) fill around the tile bed have demonstrated a potential phosphorus removal mechanism. In cases where such modifications to conventional tile bed systems are used and known to be in working order, a per capita phosphorus supply figure of 0.10 kg is suggested (88% removal). A factor $(1 - R_s)$, can be included in the model to allow for alterations in the phosphorus removal capacity of the system, with some values for R_s given in Table 2. The number of cottages or permanent dwellings (N) situated on a lake can be obtained by aerial photography or by field count. The time (in capita-years) spent at each dwelling per year (T) can be calculated using data gathered by the Department of Tourism and Information (1971). For cottages in southern Ontario, 253 capita days per year (or 0.69 capita-years per year) are spent at each cottage (based on a survey figure of 4.3 people per cottage). For permanent dwellings, the appropriate value for T is 1570 capita-days per year (or 4.3 capita-years per year). An actual field survey for a particular lake would undoubtedly improve these figures; nevertheless, they will serve as adequate, generally applicable estimates.

The total supply to the lake can be calculated as the sum of the natural and artificial supplies;

$$J_T = J_N + J_A$$
$$= \Sigma(A_d \cdot E_i) + L_{PR} \cdot A_o + 0.8\, N \cdot T\,(1 - R_s) \qquad (4)$$

where R_s is the retention capacity of the disposal system and will be equal to 0 for most Shield areas. The loading is, of course, equal to the supply per unit of lake area,

$$L_T = J_T / A_o.$$

Prediction of the Phosphorus Concentration in a Lake

A review of the theory and derivation of nutrient budget models published to the end of 1972 has been prepared by Dillon (1974b). Additional work by R. A. Vollenweider (unpublished data), Imboden (1973, 1974), Lerman (1974), Fleming (1974), W. J. Snodgrass and C. R. O'Melia (unpublished data), and Dillon (1975) is also highly pertinent to the topic. The model used here derived from Vollenweider (1969) is employed because a) it is simply derived and can be used with a minimum of field measurements and b) it alone has been tested for lakes in southern Ontario and has been found to have good predictive capabilities.

Vollenweider assumed that the change in the concentration of phosphorus in a lake with time is equal to the supply added per unit volume minus the loss through sedimentation and the loss by outflow:

$$\frac{d[P]}{dt} = \frac{J}{V} - \sigma[P] - \rho[P] \qquad (5)$$

where [P] represents the phosphorus concentration, J is the amount of phosphorus supplied per annum, V is the lake volume, σ is the sedimentation rate (yr^{-1}), and ρ is the flushing rate (yr^{-1}) which is equal to the total volume of water outflowing per year (Q) divided by the lake volume (V).

The solution to this differential equation describing the concentration at a time t is:

$$[P] = \frac{L}{\bar{z}(\sigma + \rho)} 1 - \left(1 - \frac{\bar{z}(\sigma + \rho)[P]_o}{L}\right) e^{-(\sigma+\rho)t} \qquad (6)$$

where $[P]_0$ is the initial concentration. The steady-state solution to this differential equation is:

$$[P] = \frac{L}{\bar{z}(\sigma + \rho)} \qquad (7)$$

Equation (7) can be used to predict the phosphorus concentration in a lake if the parameters required for this, the loading (L), mean depth ($\bar{z}$), sedimentation rate (σ), and flushing rate (ρ), can be predicted or easily measured. While the loading is calculated as described in the preceding section and the mean depth is measured or obtained from previous lake surveys, the flushing rate (ρ) is approximated from the total outflow volume per year (Q) and the lake volume (V). Since the method outlined here is intended for use without field work if possible, a method of calculation of Q is required. The long-term average annual areal runoff (r, in m yr^{-1}) has been mapped for Ontario south of the Shield by Coulson (1967) and for the entire Great Lakes Basin by Pentland (1968). Thus, virtually the entire area of recreational lakes in Ontario is mapped in terms of r, where r represents the differences between precipitation and evapotranspiration. The total long-term average inflow via surface runoff to a lake can therefore be calculated as $A_d \cdot r$. The total water balance can now be described by the equation:

$$Q = A_d \cdot r + A_o\,(Pr - Ev) \qquad (8)$$

where $A_o \cdot Pr$ represents the direct input of water to the lake by precipitation and $-A_o \cdot Ev$ represents loss from the lakes by evaporation. The average value for Pr for a given area can be obtained from isohyet maps (e.g. Canada Land Inventory 1966) of Canada or for particular areas, e.g. Ontario (Brown et al. 1968). Maps of Ev (evaporation from lake surface) are given for Canada by Bruce and Weisman (1966). If A_d is large compared to A_o, then Q can be simply approximated as $A_d \cdot r$. In the few studies undertaken in Ontario (e.g. Schultz 1950), groundwater has made a negligible contribution to the overall budget. The flushing rate, ρ, is then calculated as $Q(m^3\,yr^{-1})/V(m^3)$.

It must be cautioned that water budgets predicted in this manner may be very inaccurate, especially for small lakes and small drainage areas. Thus, Schindler et al. (1974) found measured water budgets for Rawson Lake to provide 3–5 times more water to the lake than predicted from precipitation, evaporation, and evapotranspiration figures. Dillon (1974a), however, found that measured values were generally within 25% of those predicted using long-term runoff maps, although these watersheds were much larger and might be expected to integrate out localized hydrologic variations. Measurement of the water budget rather than estimation would undoubtedly provide much more accurate results, and should be undertaken where possible.

Measurement of σ, the sedimentation rate coefficient, for phosphorus in a lake is, at best, extremely difficult. Fortunately, an alternate parameter, the retention coefficient, R, can be shown to have a functional relationship to σ. R is much more easily measured than σ; (R is equal to the fraction of the loading that is not lost via the outflow) as well, the retention coefficient has been shown to be predictable (Kirchner and Dillon 1975). Equation (7) used to predict the steady-state phosphorus concentration was rewritten by Dillon and Rigler (1974a) as:

$$[P] = \frac{L(1 - R)}{\bar{z}\rho} \qquad (9)$$

Kirchner and Dillon (1975) determined by multiple regresion analysis that R was highly correlated with Q/A, the areal water loading, usually written as q_s. Their equation for prediction of R is:

$$R = 0.426 \exp(-0.271\, q_s) + 0.574 \exp \times (-0.00949\, q_s) \qquad (10)$$

This basic formulation is almost identical to that predicted on theoretical grounds (Snodgrass 1974).

In some cases, the lake in question will have one or more lakes upstream that are sufficiently large to retain a significant amount of the total phosphorus exported from their respective portion of the watershed. This is taken into account by calculating the supply to the upstream lake, the lake's retention coefficient and multiplying the supply by $(1 - R_A)$ to give the fraction transfer to Lake B.

The Concept of Response Time of a Lake

As pointed out earlier, change in the phosphorus loading to a lake results in a change in the phosphorus concentration and a subsequent change in water quality. The change is, of course, not instantaneous but rather is described in equation (6) and shown in Fig. 2. The time required for

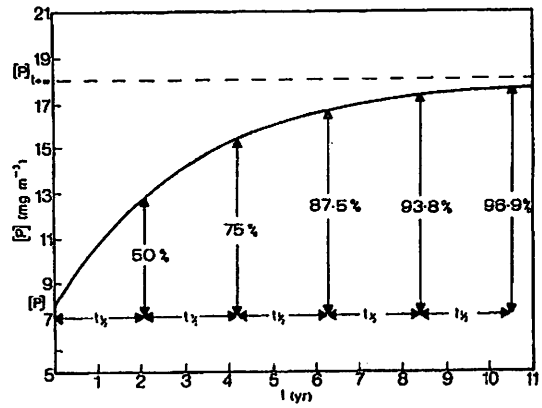

FIG. 2. Phosphorus concentration as a function of time for a lake with an increase in loading. The initial concentration was 8 mg m^{-3}, the final steady-state concentration is 18 mg m^{-3}, the half-life is 2.1 yr.

a lake having an initial loading of L_1 to respond to a change in loading to a new level L_2, (L_2 can be greater or less than L_1) can be described by the half-life of the change in concentration, $t_{\frac{1}{2}}$ (i.e. by the time required for the lake's phosphorus concentration to move half-way from the original steady-state concentration to the final steady-state concentration. Because equation (6) is exponential, two half-lives ($2t_{\frac{1}{2}}$) are required for the lake to reach 75% of its final concentration, $3t_{\frac{1}{2}}$ for 87½%, etc. The half-life, $t_{\frac{1}{2}}$, depends only on the rate coefficients σ and ρ, representing the losses of phosphorus by sedimentation and outflow; it is independent of the loading level or the initial phosphorus concentration in the lake. It can be easily shown that

$$t_{\frac{1}{2}} = \ln 2/(\sigma + \rho)$$

and using the approximation that $\sigma = 10/\bar{z}$ (R. A. Vollenweider unpublished data), the half-life can be estimated as:

$$t_{\frac{1}{2}} = 0.69/(\rho + 10/\bar{z}). \qquad (11)$$

Therefore, one must consider the response time of a lake when predicting the effects of an increased loading (e.g. resulting from development) or a decreased loading (e.g. from improved sewage treatment facilities). It is suggested that 3–5 times the $t_{\frac{1}{2}}$ (i.e. 87.5–96.9% of the way to the final steady-state concentration) can be used as an indicator of the lake's response time. Characteristically, lakes with a rapid flushing rate will have short half-lives and therefore response times, while lakes that are very slowly flushed may take a long time to respond to a change in loading. For example, a lake with flushing rate of $\rho = 1.0$ yr^{-1}

(i.e. the lake's volume is replaced once per year by flushing) and a mean depth of 10 m has a $t_{\frac{1}{2}}$ of $0.69/(1 + 10/10) = 0.35$ yr. Therefore, between 1.1 and 1.8 yr are required for the lake to approach a new steady-state following a change in loading.

Relationship of the Spring Phosphorus Concentration to the Summer Chlorophyll *a* Concentration and Water Transparency (Secchi Disc)

Based on the work of Sakamoto (1966), Dillon and Rigler (1974b) developed a predictive relationship suitable for estimating the average summer chlorophyll *a* concentration in lakes with spring N:P ratios >12, a conservative estimate of the lower limit for proportionate uptake. The data comprising this relationship were based on a combination of information presented by Sakamoto for 30 Japanese lakes, results for a wide variety of North American and European lakes reported by various authors, and information for 19 lakes in southern Ontario studied by Dillon and Rigler. The equation for the prediction of the summer average chlorophyll *a* concentration from the spring phosphorus concentration is:

$$\log_{10}[\text{chl } a] = 1.45 \log_{10}[\text{P}] - 1.14$$

with [chl *a*] and [P] in mg m^{-3}.

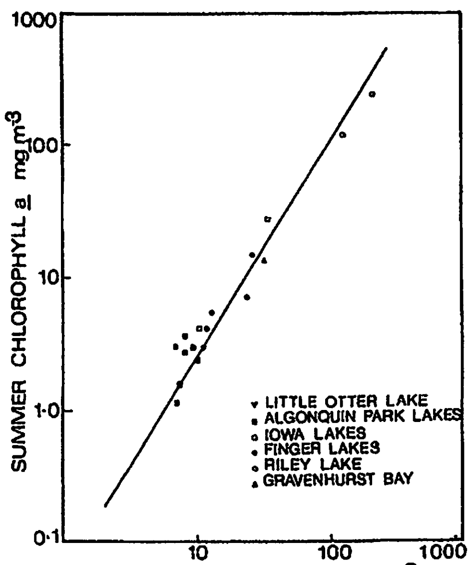

FIG. 3. Total phosphorus concentration at spring overturn vs. summer average chlorophyll *a* concentration for lakes not included by Dillon and Rigler (1974b).

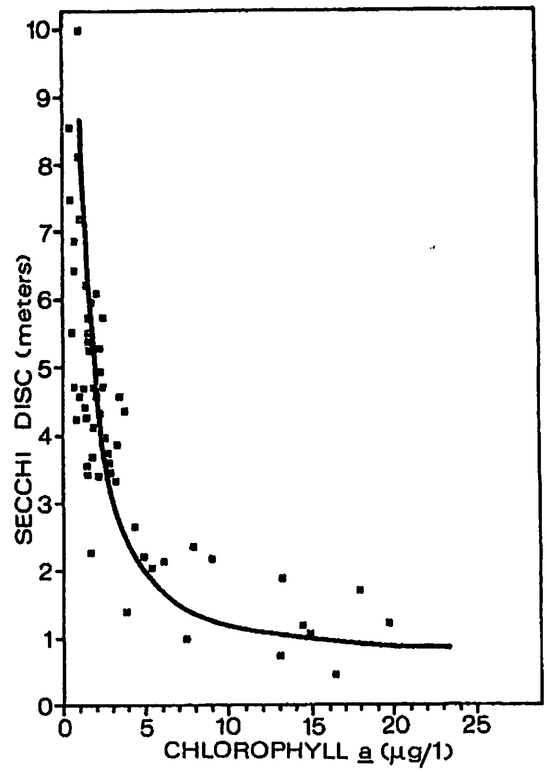

FIG. 4. The relationship between Secchi disc depth and chlorophyll *a* concentration for a number of lakes in southern Ontario. Values for each lake are based on means of values collected over the period of stratification (June–September).

Additional phosphorus–chlorophyll *a* data have been supplied by Scheider and Rigler (unpublished studies) for six lakes in Algonquin Park, by Oglesby and Shaffner for some of the Finger Lakes in New York State, and by Bachman and Jones (1974) for some Iowa lakes. These data are also shown in Fig. 3 and it is apparent that in all cases the fit to the model is very good.

It is expected that chlorophyll *a* concentration will be inversely related to the Secchi disc reading, a measure of the water's transparency. Collection of data for a large number of lakes is shown in Fig. 4. From the predicted chlorophyll *a* concentration, a prediction of the likely average Secchi disc reading is possible. Care must be taken in interpreting this relationship in the case of dystrophic (brown water) lakes, whose Secchi disc readings are lower than would be expected on the basis of chlorophyll *a* concentration alone.

Stepwise Procedure for Calculating the Development Capacity of a Southern Ontario Lake

Step 1. Based on long-range plans for the lake, decide what the maximum permissible average summer chlorophyll *a* concentration will be:

Level 1: 2 mg m^{-3}; for lakes to be used primarily for body contact water recreation, and where it is desirable to maintain hypolimnetic concentrations of oxygen in excess of 5 mg $liter^{-1}$ to preserve cold water fisheries. The lake will be extremely clear with a mean Secchi disc visibility of 5 m and will be very unproductive. (Note — the Secchi disc visibility may be lower in brown water [dystrophic] lakes).

Level 2: 5 mg m^{-3}; for lakes to be used for water recreation but where the preservation of cold water fisheries is not imperative. The lake will be moderately productive and correspondingly less clear, with a mean Secchi disc visibility of 2–5 m.

Level 3: 10 mg m^{-3}; for lakes where body-contact recreation is of little importance, but emphasis is placed on fisheries (bass, walleye, pickerel, pike, maskinonge, bluegill, yellow perch). Hypolimnetic oxygen depletion will be common. Secchi disc depths will be low (1–2 m), and there is a danger of winterkill of fish in shallow lakes.

Level 4: 25 mg m^{-3}; suitable only for warmwater fisheries. Secchi disc depth <1.5 m, hypolimnetic oxygen depletion beginning early in summer, considerable danger of winterkill of fish except in deep lakes. The planning agency may pick any intermediate level should it so desire.

Step 2: From the chosen summer average chlorophyll *a* concentration, calculate the permissible spring phosphorus concentration, [P] from:

$$\log_{10} [\text{chl } a] = 1.45 \log_{10} [\text{P}] - 1.14$$

$$\text{i.e. } \log_{10} [\text{P}] = \frac{\log_{10} [\text{chl } a] + 1.14}{1.45}$$

e.g.

[chl *a*]	[P]
2 mg m^{-3}	9.9 mg m^{-3}
5	18.5
10	29.9
25	56.3

Step 3: Determine the lake surface area (A_o in m^2), mean depth ($\bar{z}$ in m), and volume (V in m^3) from available information if possible. If such data are not available, the lake must be sounded and a contour map drawn. The area (A_o) is obtained by planimetry from an aerial photograph of known scale.

Step 4: Outline the lake's drainage area on a 1:50,000 scale topographic map or on aerial photographs and calculate the area (A_d in m^2) by planimetry.

Step 5: From Plate 13 in Pentland (1968) determine the total annual unit runoff (*r*) in cfs mi^{-2} and convert to $m^3\ yr^{-1}\ m^{-2}$ or m yr^{-1} by multiplying by 0.345.

Step 6: If $A_d > 10\ A_o$ calculate Q, the total outflow volume as:

$$A_d \cdot r \ (m^3\ yr^{-1})$$

and calculate the flushing rate (ρ) as Q/V or

$$(A_d \cdot r)V \ (yr^{-1})$$

If A_d is $<10\ A_o$, determine the mean annual precipitation (Pr) from figure 32 in Brown et al. (1968), and the mean annual lake evaporation (Ev) from figure 9 in Bruce and Weisman (1966), convert to m yr^{-1} by multiplying by 0.0254 and calculate Q:

$$Q = A_d \cdot r + A \quad (\text{Pr} - \text{Ev})$$

$$\therefore \quad \rho = (A_d \cdot r + A_o (\text{Pr} - \text{Ev}))/V \qquad (yr^{-1})$$

Step 7: Calculate the areal water load as (q_s) as

$$Q/A_o \qquad (m\ yr^{-1})$$

Step 8: Calculate retention coefficient (R) as

$$R = 0.426 \exp(-0.271\ q_s) + 0.574 \exp(-0.00949\ q_s)$$

Step 9: Calculate the response time of the lake to a change in phosphorus loading:

$$\text{Response time} = (3 \rightarrow 5)\ t_{\frac{1}{2}}$$
$$= (3 \rightarrow 5)\ 0.69/(\rho + 10/\bar{z}) \quad (yr)$$

This will provide an indication of the time required for a lake to "respond" to development and will give an idea of when follow-up studies (if any) should be carried out. Conversely, the response time can assist in the interpretation of present water quality. For example, a lake with 250 new cottages may appear to be in good condition, but if one can calculate that it has a response time of 6–10 yr, then caution is necessary before additional development is allowed.

Step 10: Calculate the permissible phosphorus load (L_{perm}) to the lake:

$$L_{perm} = \frac{[P] \cdot \bar{z} \cdot \rho}{(1 - R)} \quad (\text{mg m}^{-2}\,\text{yr}^{-1})$$

and the permissible supply (J_{perm})

$$J_{perm} = \frac{L_{perm} \cdot A_o}{10^6} \quad (\text{kg yr}^{-1})$$

Step 11: Divide the watershed of the lake (on the topographic map) into subunits for all inflows and determine the area for each one (A_{di}). From the most recent aerial photographs available determine if >15% of the area of each watershed is either cleared land or marsh. Determine whether the watershed (not just the lake) is on Precambrian igneous rock or on sedimentary rock, and estimate the export (E mg m^{-2} yr^{-1}) for each subwatershed from Table 1. Calculate the total supply of phosphorus from the land to the lake:

$$J_E = (\Sigma_i A_{di} \cdot E)$$

and the load

$$L_E = (\Sigma_i A_{di} \cdot E)/A_o \quad (\text{mg m}^{-2}\,\text{yr}^{-1})$$

Take into consideration an upstream lake by reducing the supply to the downstream lake from the watershed containing the upstream lake by multiplying by $(1 - R^1)$ where R^1 is the phosphorus retention coefficient of the upstream lake. R^1 is calculated as in Step 8, using q_s for the upstream lake. R^1 is calculated as in Step 8, using q_s for the upstream lake.

Step 12: The phosphorus load from precipitation, L_{PR}, is 75 mg–^{2} yr^{-1}.

Calculate the supply from precipitation as:

$$J_{PR} = \frac{75 \cdot A_o}{10^6} \quad (\text{kg yr}^{-1})$$

Step 13: The natural supply and natural loading are:

$$J_N = J_E + J_{PR}$$
$$L_N = L_E + L_{PR}$$

If $J_N \geqslant J_{perm}$, i.e. if the natural supply is greater than the permissible supply, allow no (further) development.

Step 14: Determine the present number of cottages (N_C) and permanent dwellings (N_D) within 300 m (1000 ft) of the lake or any of the inflowing streams or rivers from recent aerial photographs or field surveys. For cottages, assume 253 capita-days per year (0.69 capita-years yr^{-1}). Assume 4.3 people per dwelling, and calculate N_{CY}, the number of capita-years yr^{-1} spent at the lake:

$$N_{CY} = 0.69 \times N_C + 4.3 \times N_D$$

i.e. one permanent unit = 6.2 cottage units.

Step 15: calculate the phosphorus supplied to the lake from the cottage units (artificial supply) as:

$$J_A = 0.8 \times N_{CY}\,(1 - R_s) \quad (\text{kg yr}^{-1})$$

where $R_s = 0$ for conventional septic tank–tile field systems on the Precambrian Shield. If there is firm evidence that holding tanks are used for all household wastes and the systems are pumped and removed to a treatment plant outside of the watershed, neglect such cottage(s) in the calculations. If the septic tile filter beds are situated off of the Shield on soils that correspond to those of Table 2, use the appropriate values for R_s.

Step 16: Calculate the present total of phosphorus to the lake:

$$J_T = J_N + J_A \quad (\text{kg yr}^{-1})$$

If $J_T \geqslant J_{perm}$, allow no further development.

Step 17: If $J_T < J_{perm}$, calculate the total permissible number of cottage units:

$$N_{perm} = \frac{J_{perm} - J_N}{0.69 \times 0.8\,(1 - R_s)}$$

Step 18: The additional number of cottage units permitted is:

$$N_{add} = N_{perm} - N_{CY}$$

Discussion

The methodology outlined in the previous section provides a simple means of calculating the capacity for development of southern Ontario lakes based on lake trophic status. A number of previously tested empirical models are linked in a logical sequence relating watershed characteristics and utilization to water quality. Although the specific figures used are applicable only to southern Ontario, the approach is general enough to be applied to any lake, provided suitable data are available for parameters such as the phosphorus export coefficient, E, the loading from precipitation, L_{PR}, the phosphorus soil retention coefficient, R_s, etc. The advantages of this method are that quantitative predictions of the effects of development on important water quality parameters, chlorophyll *a* concentration and Secchi disc depth, are possible, and that these predictions can be made with no field work, provided the lake's morphometry is available. The disadvantages are that other important considerations, e.g. location of fish spawning grounds and wildlife habitat, microbiological contamination etc., are not taken into account, and that, although the individual models or relationships have been tested and found to make reasonably accurate predictions, for lakes in southern Ontario, overall predictions provided by the modeling sequence must be considerably less accurate. The uncertainty in the phosphorus export figures and in the loading from precipitation alone could result in a 100% error in the calculation of the natural phosphorus budget, while factors such as the soil retention factor are still only approximations. Nevertheless, these predictions should be valuable to those involved in lake management because of both their simplicity and their quantitative nature, provided proper caution is taken in interpretation of the results.

Acknowledgments

We thank all those involved in the various field studies from which were drawn the individual components of this study; W. Scheider, W. Coombs, P. Cross, D. Andrews, C. Fehr, H. Banks, and J. McNight. We also thank Mr M. F. P. Michalski, Mr M. Fielding, and Mr W. Scheider for helpful comments on the manuscript.

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Appendix B

From The Regional Plan:

"E-17 Watershed or sub-watershed studies concerning natural watercourses shall be carried out as part of comprehensive secondary planning processes. These studies shall determine the carrying capacity of the watersheds to meet the water quality objectives which shall be adopted following the completion of the studies. The studies, where appropriate, shall be designed to:

(a) recommend measures to protect and manage quantity and quality of groundwater resources;
(b) recommend water quality objectives for key receiving watercourses in the study area;
(c) determine the amount of development and maximum inputs that receiving lakes and rivers can assimilate without exceeding the water quality objectives recommended for the lakes and rivers within the watershed;
(d) determine the parameters to be attained or retained to achieve marine water quality objectives;
(e) identify sources of contamination within the watershed;
(f) identify remedial measures to improve fresh and marine water quality;
(g) recommend strategies to adapt HRM's stormwater management guidelines to achieve the water quality objectives set out under the watershed study;
(h) recommend methods to reduce and mitigate loss of permeable surfaces, native plants and native soils, groundwater recharge areas, and other important environmental functions within the watershed and create methods to reduce cut and fill and overall grading of development sites;
(i) identify and recommend measures to protect and manage natural corridors and critical habitats for terrestrial and aquatic species, including species at risk;
(j) identify appropriate riparian buffers for the watershed;
(k) identify areas that are suitable and not suitable for development within the watershed;
(l) recommend potential regulatory controls and management strategies to achieve the desired objectives; and
(m) recommend a monitoring plan to assess if the specific water quality objectives for the watershed are being met."

Appendix C (SLCA response to preliminary study)

Sandy Lake Conservation Association
115 Farmer's Dairy Lane • Bedford • Nova Scotia • B4B 2C9 sandylake.org info@sandylake.org

March 22, 2014

Cameron Deacoff
Environmental Performance Officer
HRM Energy & Environment

Sandy Lake Watershed Study—Recommendations

Watershed Monitoring and Preservation of Watershed Recreational Potential

While SLCA agrees with the concept of watershed studies being carried out prior to development and is pleased with the effort put into the Sandy Lake watershed study to date, we are deeply concerned for the long-term health of the watershed and the water quality of Sandy Lake itself. Given the potential negative impact on Sandy Lake water quality, this high-density urban development and the clear-cutting preceeding development couldn t be situated in a worse location. We fear that water quality data will become a trailing indicator once extensive development beings, and that there will be no practical recourse to alleviate contamination once land is sold and construction commences. Considering it to be in the best long-term interest of the health of Sandy Lake proper and it's surrounding community to alleviate contaminants from entering the lake, how does a watershed plan take the precautionary approach and mitigate potential contamination?

We believe that the potential recreational value to the growing regional community of a pristine Sandy Lake and surrounding watershed is beyond measure. We have one chance to get this right. Your committment to maintaining the water quality will play an integral part in the long-term preservation ofthe future of the Sandy Lake area as a prime community recreational resource. We hope you will make every effort to preserve and protect the value of this community resource.

Suggested Protocols for Insuring Water Quality

Typically ground water fed lakes like Sandy Lake have high retention rates meaning contaminants will reside for longer periods. As stated in section 5.1.9 of the following report (http://www.halifax.ca/regionalplanning/publications/SubwatershedPlan.pdf), Sandy Lake is potentially more susceptible to contaminants, exacerbating the increase in poor water quality.

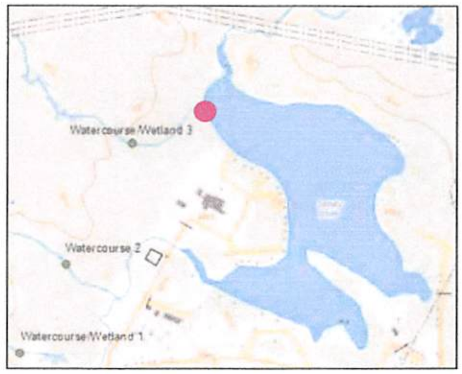
5.1.9 Sandy Lake
Sandy Lake lies within the watershed of the Sackville River. It has a catchment area of 1,676 ha and a lake area of 67 ha. It has a very low flushing rate of once every six months; thereforethere is the potential to accumulate urban contaminants.

As a significant proportion of the urban settlement designated lands on the Sandy Lake watershed are upslope and in close proximity to the lake where watercourse tributaries flow directly into the lake, it would seem that ambitious strategies well beyond simply establishing buffer zones along watercourses are required to guarantee water quality long-term.

We urge the planners carrying out the watershed study to immediately gain a detailed and accurate understanding of the flush rate of Sandy Lake and, given the contamination potential of a large scale development, to propose a plan for the preemptive prevention of pollution and the longterm protection of the water quality. Accordingly, we urge that an ongoing program of routine and repeated water sampling takes place, as well as upstream and point-of-entry sampling be initiated to continually monitor water quality. We also urge that, once a baseline for current water quality has been established, protocols be in place to quickly determine when and where contamination occurs and what action(s) will be taken to arrest the threat to water quality.

Suggested Protocols

To underline the importance of water quality monitoring, we have already noticed negative effects from the massive clear-cutting on the watershed heights. SLCA has detected a significant sediment increase since the clear cut. *(Note the red dot indicating the feeder stream lake entrance on the attached chart.)* Without sampling and addressing this occurrence during the watershed study phase, eventually anthropogenic contaminants will accompany sediments flowing into the lake and add to poor water quality. We suggest, adding 2 sampling locations to your study: 1) upstream from clearcut; and, 2) lake point-of-entry *(red dot)*. These sites would enhance the ability to quantify how the development impacts water quality.

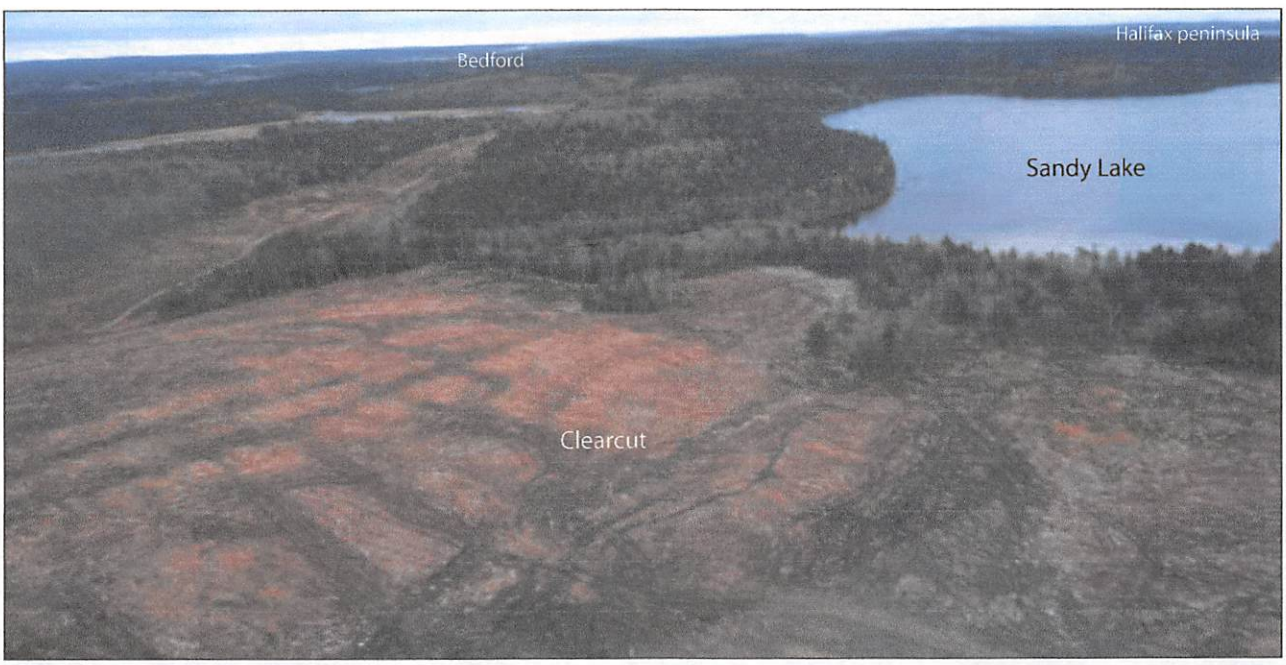


Committments

SLCA is committed to doing everything possible to preserve the water quality of the Sandy Lake watershed. We believe that as the Hammonds Plains region of Bedford continues to be developed, the Sandy Lake park and waters will prove an invaluable recreational resource and everything that can be done to guarantee the water quality should be done. Thus, before the commencement of actual construction (sewers, roadways, buildings etc.) we expect HRM, sharing our view of the potential of this area, will committ to any and all monitoring, investigative and ameliorative protocols required to protect the watershed. Working together we can establish a system that will preserve the area such that a generation from now people will be able to enjoy a pristine Sandy Lake recreational resourse and give thanks to the foresight of the planners and citizens whose vision and work made it possible.

Questions

1) The Sandy Lake Watershed Study Preliminary Report cited White et al. 1984 as the source for the retention rate. Will the retention rate be measured as part of the watershed study.
2) Will water sampling take place upstream from clearcut and at lake point-of-entry following a rain event to quantify water quality?
3) Will the lake capacity model incorporate the already negatively trending water quality measures?
4) Will storm water management be addressed in the final report?
5) Will environmentally unique sites like old growth forest be identifed and protected from development?



Appendix D (Sackville Rivers Association minutes of final watershed meeting)

From: "Sackville Rivers Association" <sackvillerivers@ns.sympatico.ca>
Date: 23 September, 2014 12:55:53 PM ADT

Subject: 2014 Sep Big Sandy Lake Watershed Water Quality Study

Geoscientist Timothy Bachiu said "there is a trend of increasing phosphorus in Sandy Lake over time," at a public meeting discussing the Sandy Lake Watershed final report, as directed in Policy E-17 of the 2006 Regional Municipal Planning Strategy. (Cyndi Sweeney)

Coined as the Point Pleasant Park of Hammonds Plains, local residents concerned for Sandy Lake Watershed had an opportunity to hear the final study report and summary of development scenarios for Sandy Lake and Marsh Lake on Sept. 11 at Bedford Hammonds Plains Community Centre.

"There is a trend of increasing phosphorus in Sandy Lake over time," said Timothy Bachiu, geoscientist with AECOM Consulting. The study examined areas serviced by water and waste water; measuring water quality objectives based on increasing phosphorus levels due to factors like stormwater runoff, aging septic systems, waste water facilities and urban development.

Baschiu presented four scenarios, from Sandy Lake's current condition of 12 micrograms-per-litre (ug/L) of phosphorus, to a maximum recommended water quality objective of 18 ug/L, or up to a maximum capacity increase of 50 per cent. The study concluded a "robust water quality monitoring plan be proposed for the Sandy Lake watershed."

About 17 people turned out to ask questions and understand the findings, including local residents, developers, river protectionists and two HRM councillors.

"What brought me out was concern for the lake," said Ed Giles, a local resident who uses the lake almost daily. "My take on it is, they'll do what they want to do … but we'll wait and see."

A key point raised during the presentation was at what point are mitigation measures, like waste water and advanced stormwater measurement, implemented and if it's to be after the lake reaches 18 ug/L and inundated with phosphorus.

"It's communities and people who decide what is acceptable and what is not acceptable. We are using science here to help describe what is and what can change … it's up to you as residents, who are concerned for the lake, to decide what do you want the lake quality to be," said Cameron Deacoff, an environment officer with HRM and project director on the watershed study. Once parameters are set, Deacoff said it's municipality's responsibility to set standards and policy to achieve these societal objectives.

"We're also working on a study in the Preston area, including Lake Major … It's an urban lake but it's a protected urban lake and they're looking at between a four and eight (ug/L), or four and ten micrograms per litre per phosphorus … it's quite low," said Deacoff. As Sandy Lake is an area designated for development, the objectives were based on existing conditions, plus 50 per cent.

While two more approval steps are required before HRM can schedule community planning for the area, Deacoff says it's important the community sets guidelines now and consider mitigation measures to control phosphorus level increases.

Based on a large development scale, Baschiu said key mitigation measures include: bringing waste water treatment facilities online with municipal services; looking at other opportunities for clean sources to be directed to municipal waste water; and advanced storm management.

In terms of the 20 metre distance bylaw of any urban development from lakes, Walter Regan, says "bigger is better." The president of Sackville Rivers Association says he thinks the minimum should be 30 metres. "I'm ecstatic they're going to 300 metres in Fall River," says Regan, a former civil servant. "It means HRM is serious about water quality protection in Fall River, not the rest of the municipality."

"There's an area in Bedford West that is already 30 metres minimum," says Counc. Tim Outhit (Bedford). He says overall it's been a good process with engaged public involvement. "A lot of the questions now are policy-related which will be determined if and when we move to the next stage."

Outhit emphasized he's in no rush to see this area developed. "When it does happen, we're going to have to get very creative on the protection of the lake … and before we let anymore development in this area at all, we're going to have to have significant improvements to traffic and public transportation," said Outhit.

Regan stressed importance for water quality management and baseline testing to be implemented on the more than 1,000 lakes in the area. "On average it takes $300 to pump out your septic tank. If everyone paid $100 a year, the county would come around and pump your tank every three years and the general tax payer would save millions … by doing that, 80 per cent of the failing tanks are caught and repaired," said Regan.

Runoff from impermeable surfaces like roads and parking lots are all factors producing greater amounts of nutrients, increasing phosphorus levels in lakes.

In response to Regan suggesting stormwater runoff be directed into the ground, Baschiu agreed it could decrease phosphorus concentrations.

"Don't forget about temperature and don't forget about the warming of the water caused by urban development in laying out your streets … it's just part of good stormwater management," urged David Hansen, associate professor of civil engineering at Dalhousie University. Hansen says water temperature increases caused by water hitting pavements and roofs can be "lessened on purpose," if considered during the planning process.

The study provides a starting point to begin creating policy, said Maureen Ryan, from HRM planning and infrastructure. "Once we know the baselines and impacts … then we can work from there." She said planning programs for the area are not currently a priority.

"Generally speaking, the big picture answer to all of your questions are, it's a matter of policy that's not yet been determined," said Deacoff.

Ryan says there are many policy mechanisms pertaining to watershed management and advanced stormwater controls that can be applied in various land use development models in future. "Right now, we're just looking theoretically."

Have your say

Have a say in policy development and an input in the future of Sandy Lake Watershed: Residents are invited to send their opinions and comments on the draft final study report to HMR or AECOM until 11:59 p.m. on Mon. Oct. 13, to be taken into consideration for the final study report for HRM. The final study report will then be submitted to North West Community Council for approval as background for future community planning around Dec. 15. Cameron Deacoff, Halifax Regional Municipality cameron.deacoff@halifax.ca, 902.490.1926 Timothy Bachiu, AECOM timothy.bachiu@aecom.com, 902.428.2048 A copy of the report can be found on www.halifax.ca.

Appendix E (Florence Lake)

BRITISH COLUMBIA | Ministry of Environment

Florence Lake (1980-2009)

Water Quality Monitoring Program

(September 2011)

The Importance of Florence Lake and its Watershed

British Columbians want lakes to provide good water quality, aesthetics and recreational opportunity. When we do not see these features in our lakes, we want to know why. Through regular monitoring programs the Ministry of Environment (MoE) can come to understand a lake's current water quality, identify the designated uses for a given lake, and monitor changes resulting from land development within the lake's watershed. The MoE can work in partnership with local government, land owners, and the BC Lake Stewardship Society (BCLSS) to develop lake specific monitoring programs and provide educational materials on general lake protection issues. This useful information can help communities play a more active role in the protection of the lake resources.

Monitoring data for Florence Lake has been collected since 1980. This status report provides the results from all data collected up to 2009 and outlines long term and seasonal changes in the physical, chemical and biological makeup of the lake. The main focus of this study is to determine the overall health of the lake, its suitability as fish habitat and to identify potential threats that may compromise the integrity of the lake and its watershed. Recommendations for future monitoring are also provided.

Watersheds are a crucial component in the hydrological cycle and, when intact, support proper maintenance of ecosystem functions. Water is continuously cleansed and recycled as it moves through watersheds and other hydrological compartments. The quality of the water resource is largely determined by a watershed's capacity to buffer impacts and absorb pollution.

According to the Freshwater Atlas (GeoBC, 2011), Florence Lake's watershed (defined as the entire area of land that moves the water it receives to a common water body) drains an area of 1.48 km^2 (Figure 1).

Florence Lake lies within the Coastal Douglas-fir biogeoclimatic zone and is located on Vancouver Island, in the southeast region of the City of Langford, at an altitude of 81 m. The lake's surface area is approximately 8.4 hectares, its perimeter 1500 m (FIDQ, 2011a), and it is relatively shallow with a mean and maximum depth of 1.92 m, and 4.27 m, respectively (FIDQ, 2011b).

Every component of a watershed (vegetation, soil, wildlife, etc.) has an important function in maintaining good water quality and a healthy aquatic environment. It is a common misconception that detrimental land use practices will not impact water quality if they are kept away from the area immediately surrounding a water body. Poor land-use practices anywhere in a watershed can eventually impact the water quality of the downstream environment.

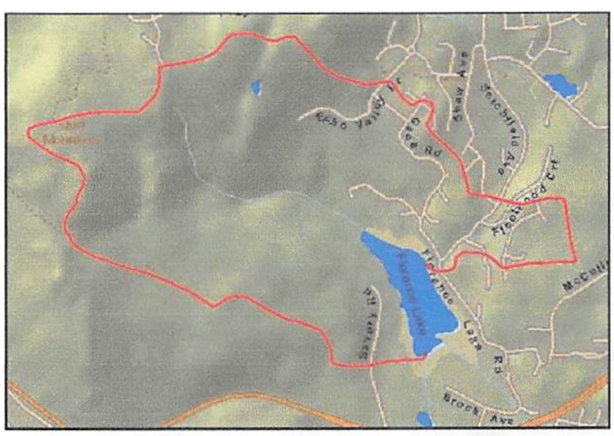


Figure 1: Florence Lake with its watershed outlined in red (iMapBC, 2011).

Florence Lake is largely surrounded by rocky hills to the east, west and north of the drainage basin. Of these, Skirt Mountain has the highest peak at 316 meters. The mountains to the west of the lake, including the southern Vancouver Island range and the Olympic Mountains, provide the lake a rain shadow, which effectively reduces precipitation at the site, resulting in relatively dry summers (McCullough, 1980). Figure 2 shows a bathymetric map of Florence Lake, including the boat launch, water monitoring location, inflow and outflow points, and a small seasonal water body located just south of the permanent lake. The Florence Lake watershed is a tributary to Millstream Creek which drains into Price Bay.

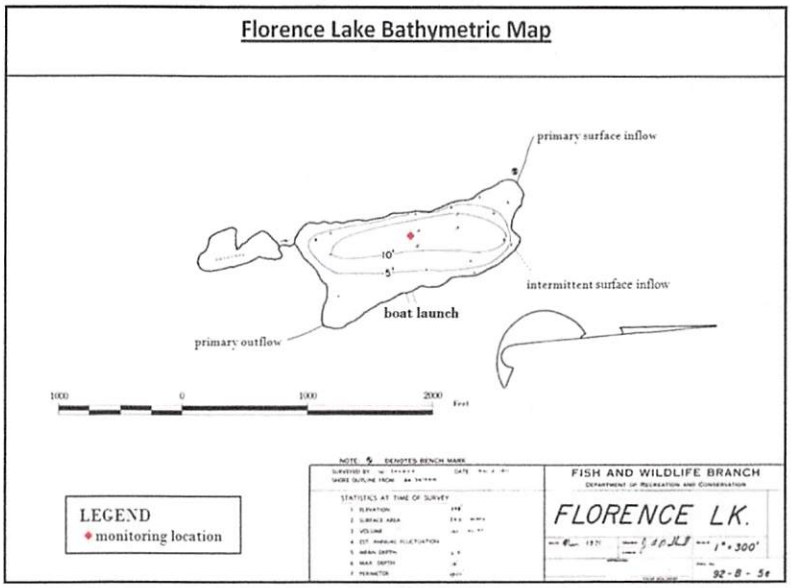


Figure 2: Florence Lake bathymetric map (FIDQ, 2011), modified by Scott Skagford June 20, 2011.

Historically, cutthroat trout, rainbow trout, sunfish, prickly sculpin and smallmouth bass have been observed in Florence Lake. From 1977 to 1985, the lake was stocked exclusively with cutthroat trout, and from 1986 to 1997 it was stocked with both cutthroat and rainbow trout. All stocking up to this point released yearling, diploid trout (fertile fish each having two complete sets of chromosomes). However, with concerns regarding water quality during the summer and its affect on trout growth mechanisms, the lake was solely stocked with catchable-sized, triploid rainbow trout (infertile fish, each having three sets of chromosomes) (FIDQ, 2011c), in an effort to create an instant fishery. The stocking program ended in 2007 due to inadequate public access, which essentially resulted in a private fishery for local residents, water quality issues that contributed to constantly waning fish populations, more opportune lakes on Vancouver Island to receive stocking efforts, and a general lack of interest from the angling community to fish Florence Lake (Silvestri, pers. comm., 2011). Florence Lake is also habitat to freshwater jellyfish. There are 20 known species of freshwater jellyfish; however, only *Craspedacusta sowerbii* has been observed in North America (Smith & Alexander, 2008). These creatures remain relatively enigmatic and have only been observed in eight other freshwater lakes in BC.

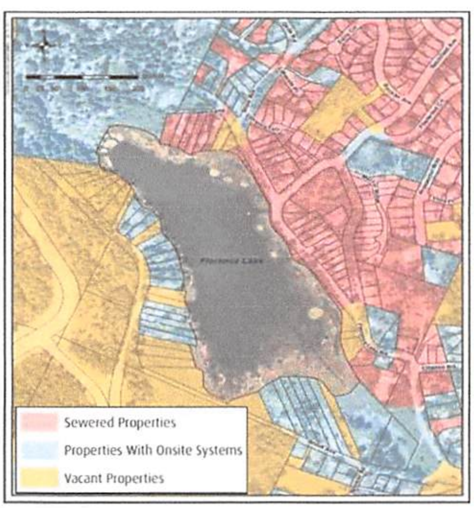


Figure 3. Septic (blue), sewage (red), and vacant (yellow) properties surrounding Florence Lake (CRD, 2011).

Urban residential development borders approximately 75% of the lake perimeter with the remainder privately owned but undeveloped thus far (Figure 3). Most of the properties on the east side of Florence Lake are connected to the municipal sewer system; however, there are many residences within the watershed that utilize septic tanks. The majority of onsite systems are located on the west and north of the lake in a steep and rocky area conducive to surface runoff directly into the lake (McCullough, 1980). Approximately 100 mobile homes, located to the north of the lake, rely entirely upon a septic system which is regularly pumped to remove effluents. While there are no current cases citing failing septic tanks around the lake (Mills, pers. comm., 2011), some of these systems are older and may not be functioning properly. Langford Bylaw 1066 stipulates that all homes within the watershed are to be connected to municipal sewage. Corix Utilities Division has connected 177 residencies within the Florence Lake watershed to the municipal sewage system from February, 2007 to June, 2011. While there are still remaining properties that are not hooked up to the sewage system, the City of Langford is satisfied with the number of homes that have been connected to date (Manson, pers. comm., 2011). Future plans to connect homes off of Savory Road and Brock Avenue (southwest of the lake) to the municipal sewage system are contingent on the completion of the Spencer Highway Interchange which is to be constructed on the southwest side of the lake (Parkinson, pers. comm., 2011).

Challenges to water quality management on Florence Lake include phosphorous loading from non-point sources, shallow depths, warm temperatures and low oxygen levels, primarily during the summer months. Excess phosphorous can cause spring and summer algal blooms as well as the spread of aquatic vegetation. When the vegetation and blooms die off and settle to the bottom, this can lead to oxygen depletion in the lake which can affect aquatic life, such as fish. Nutrient loading is compounded by the lake's shallow depth, which provides favourable temperatures and photic opportunities for algae growth throughout the water column. Furthermore, as oxygen levels decrease near the bottom, internal nutrient loading occurs, whereby phosphorous is released from the sediment and enters the water column, exacerbating an already nutrient rich environment. With the lack of flushing of the lake in the fall and winter months, these nutrients are not removed and the process begins all over again.

Another foreseeable challenge to the health of the lake and its watershed depends upon possible future developments on Skirt Mountain. Currently, Skirt Mountain is the site of the Bear Mountain Resort, golf course and community. To date, development has been focused on the east and north facing slopes, which lie outside of the lakes drainage basin (Figure 4). However, developers own portions of the south and west facing slopes that are inside the watershed (Blackwood, pers. comm., 2011). Although developers are managing runoff to limit their effect on the watershed, expansion into this area could still impact the watershed and lake. Similarly, construction of the Spencer Interchange, located just southwest of the watershed (Figure 4), could also affect lake quality as prevailing winds flow across the lake from south to north and could deposit sediments and other pollutants from the construction site, and eventual roadway, into the watershed or directly into the lake itself.

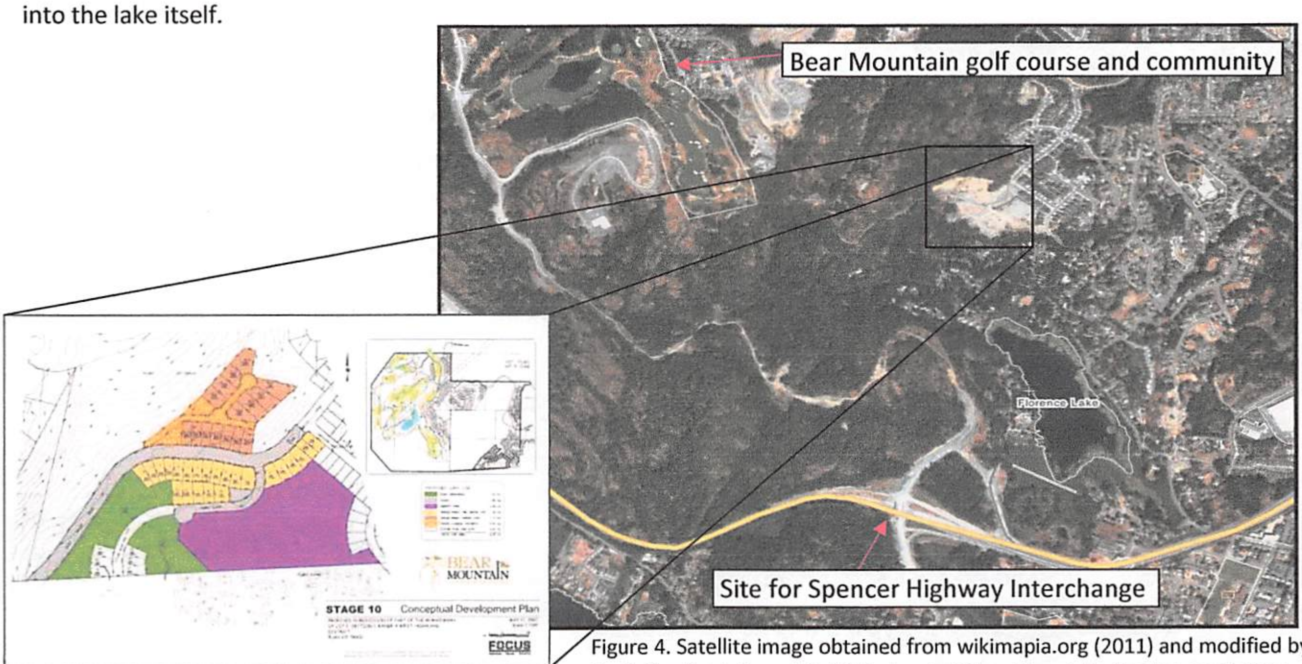


Figure 4. Satellite image obtained from wikimapia.org (2011) and modified by Scott Skagford, August 2, 2011. Inset of Bear Mountain development plans obtained from the City of Langford, 2011.

Non-Point Source Pollution and Florence Lake

Point source pollution originates from municipal or industrial effluent outfalls. Other pollution sources exist over broader areas and may be hard to isolate as distinct effluents. These are referred to as non-point sources (NPS) of pollution (Figure 5). Shoreline modification, urban stormwater runoff, onsite septic systems, agriculture and forestry are common contributors to NPS pollution. One of the most detrimental effects of NPS pollution is phosphorous loading to water bodies. The amount of total phosphorous (TP) in a lake can be greatly influenced by human activities. If local soils and vegetation do not retain this phosphorous, it will enter water courses where it will become available for algal production. Watersheds have the ability to buffer against pollution in time but the ability is impeded with landscape modification and/or significant increases in pollution.

Photo 1: Picture of Florence Lake with Skirt Mountain in background. (2011).

Land Use

Lakeshore property owner's rights and increasing land values can promote high land use expectations at the expense of lake-shore riparian areas. Residential development generally includes clear-cutting and other vegetation removal for placement of structures. This can be limited to just the building site requirements or can include removal of riparian vegetation, land clearing for lawns or agricultural activities, shoreline protection structures, and docks. All of these land disturbance activities can alter water flow, and potentially increase sediment and phosphorous inputs to water bodies.

Agriculture

Agriculture, including livestock, the production of grains, and mixed farming can alter water flow and increase sediment, chemical, bacterial, and parasitic input into water bodies. Agricultural runoff is a potential source of freshwater eutrophication – a process where organic and inorganic compounds such as nitrogen and phosphorous, not normally present in such abundance, are introduced to a lake. The usual result of eutrophication is an overabundance of algae growth on the lake surface.

Onsite Septic Systems and Greywater

As long as onsite septic systems are properly located, designed, installed and maintained, they can effectively treat human wastewater and wash water (grey water). Failure of onsite septic systems can cause significant nutrient and pathogenic waste to enter the water body and can be dangerous to human and animal health.

Storm Water Runoff

Lawn and garden fertilizer, sediment eroded from modified shorelines or infill projects, lawn chemicals, oil and fuel leaks from vehicles and boats, road salt, and litter can all be washed by rain and snowmelt from properties and streets into water courses. Phosphorous and sediment are of greatest concern, providing nutrients, and/or rooting medium for aquatic plants and algae. Paved structures prevent infiltration of water to soils, collect hydrocarbon contaminants during dry weather, and increase direct runoff of these contaminants to lakes during heavy rain events. Severe stormwater runoff can cause soils to erode and can result in property loss. As a common resource, it is the responsibility of everyone to ensure that the freshwater resources remain clean. The control of runoff pollution, at the source, is vital to the protection of this precious resource.

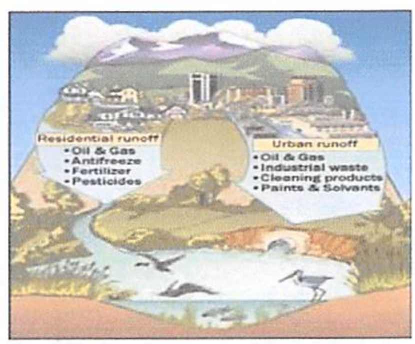


Figure 5. Non-point sources of pollution in a watershed.

What's Going on Inside Florence Lake?

Temperature

Temperature can affect the solubility of many chemicals and can therefore influence the effect of pollutants on aquatic life. If lake temperature drops more than 1°C over an increase in depth of 1 m, a thermocline develops, effectively layering (stratifying) the water body and preventing overturning (mixing from top to bottom). Colder water is denser and heavier and lies on the bottom overlain by subsequent warmer, less dense layers. Temperature stratification patterns are important to lake water quality because they determine much of the seasonal oxygen, phosphorous, and algal conditions. Most Vancouver Island lakes stratify in the summer and, like coastal lakes, are typically monomictic, overturning once during late winter or spring as wind energy overcomes the differences in temperature and density between layers within the water column. Without adequate wind agitation, shallow lakes may exhibit heightened temperatures, which in turn, elevate the metabolic oxygen demand of aquatic organisms while reducing the solubility of oxygen in the water.

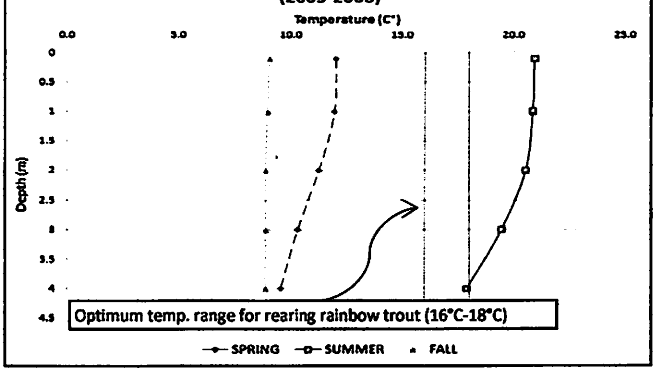
Table 1 shows the optimum temperature ranges for both rainbow and cutthroat trout during various life history stages. Understanding the temperature trends of water bodies can help identify suitable habitat and forecast species distribution. Furthermore, long-term monitoring of lake temperatures can help to determine the potential effects of climate change and how it might affect water quality over time.

Table 1: Optimum temp. (°C) ranges for cutthroat and rainbow trout during life stages.

Species	Incubation	Rearing	Spawning
cutthroat	9.0-12.0	7.0-16.0	9.0-12.0
rainbow	10.0-12.0	16.0-18.0	10.0-15.5

Florence Lake temperature data were collected at the deep mid-lake station (Figure 1) 15 times from 2003 to 2009. A seasonal depth profile for temperature was created by summarizing data into seasonal classes (Figure 6). The seasons are classified to represent temperature trends for Vancouver Island and have been divided into spring (Feb 21–June 20), summer (June 21 – Sept 20), and fall (Sept 21 –Dec 19). No data were collected during the winter season (Dec 20–Feb 20). A maximum temperature measurement of 22.33°C was recorded on July 22, 2008 and a minimum value of 5.40°C was recorded on March 16, 2003.

Figure 6. Florence Lake Seasonal Temperature Profile (2003-2008)

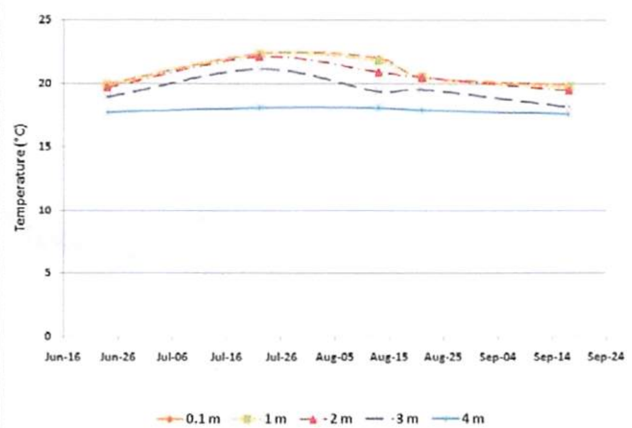


Nearly all seasonal temperature averages, from surface to bottom waters, are outside the optimum temperature range for rearing rainbow trout, making Florence Lake poor habitat for natural recruitment. Although fall and spring temperatures are tolerable for most fish species, during the summer, water temperature becomes elevated and may negatively impact fish survival rates. The elevated temperatures also reduce the availability of oxygen, making fish species even more vulnerable in the summer.

The absorption of solar radiaton and its conversion into heat have profound effects on the thermal structure, stratification and circulation pattern of lakes (Wetzel, 2001). Based on the seasonal temperature profile, Florence Lake tends to be isothermic (its temperature is relatively uniform from top to bottom) in the fall, with average surface and bottom temperatures of 9.1 °C and 8.9 °C, respectively. The lake began to stratify during the spring with an average temperature of 11.3 °C at 4 m; 1 degree colder than the average temperature at 3 m. In the summer, the lake tends to form a weak thermocline, with average temperatures of 20.5, 19.4 and 17.9 °C at 2, 3 and 4 m deep, respectively, during the sample period. -5-

Temperature data, recorded by depth during the summer of 2008 (Figure 7 (n=25)), showed that summer temperatures in Florence Lake are high throughout the water column, and ranged from 22.33 °C, on July 22nd at 0.1 m, to 17.59 °C on September 17th at 4 m. Surface and bottom water temperatures had the greatest separation on July 22nd, with surface temperature measuring 22.33 °C and bottom temperature measuring 18.11 °C.

Figure 7. Florence Lake Summer Temperature Profile (2008)



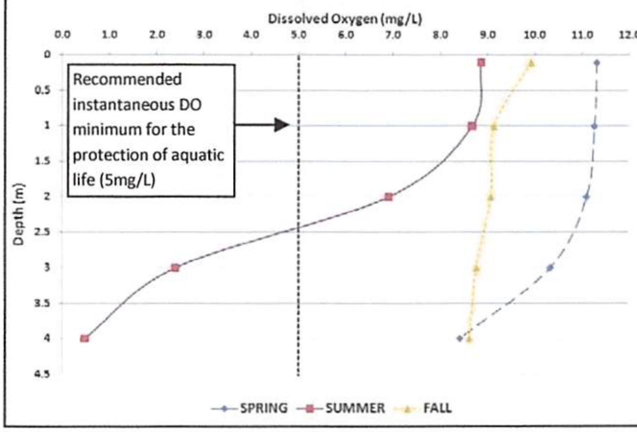
Dissolved Oxygen

The availability of oxygen in water is critical to the maintenance of aquatic life. Oxygen enters the water as dissolved oxygen (DO) from many sources including air, wind action, and through plant photosynthesis. Oxygen is consumed by the respiration of plants and animals and through the decomposition of dead organic material by bacteria (Carter & Roumiew, 2008).

Lakes that are low in productivity (oligotrophic) typically have sufficient levels of oxygen to support life at all depths. As lakes become more productive (eutrophic) and more organisms consume oxygen, its availability becomes increasingly limited and sufficient quantities to accommodate new life may only be found at certain depths. Fish, for example, can become stressed when oxygen levels fall below 5 mg/L, the instantaneous minimum level recommended for the protection of aquatic life (MoE, 2001). However, sufficient amounts of oxygen may not be at depths that correspond with the optimum temperature ranges that support certain species.

From 2003 to 2009, dissolved oxygen data for Florence Lake was collected 15 times at the deep station. Figure 8 shows the seasonal averages for dissolved oxygen by depth. Dissolved oxygen ranged from a maximum of 14.6 mg/L in March, 2005 to a minimum of 0.25 mg/L in July, 2008 at depths of 0.1 and 4 m, respectively.

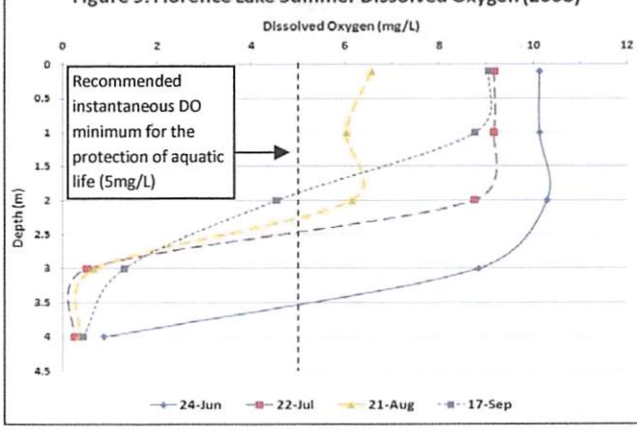
Figure 8. Florence Lake - Seasonal Dissolved Oxygen Profile (2003 - 2009)



Dissolved oxygen levels in Florence Lake tend to stratify during the summer months and, during this time, the instantaneous DO minimum for the protection of aquatic life was not met at depths greater than 2.5 m.

During the summer of 2008, data for DO was collected four times, once in each month, from June to September (Figure 9).

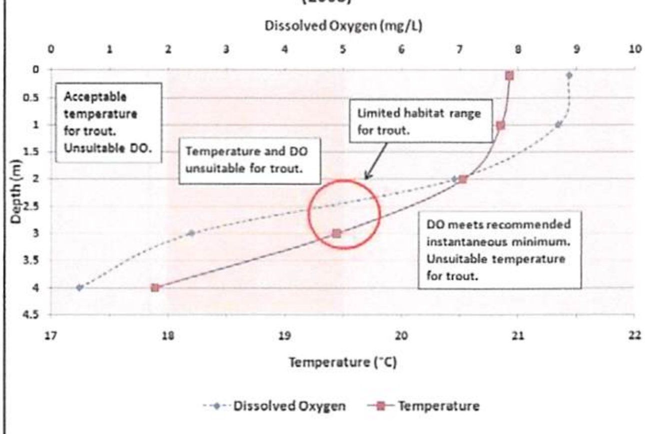
Figure 9. Florence Lake Summer Dissolved Oxygen (2008)



A maximum oxygen level of 10.29 mg/L was observed at a depth of 2 meters on June 24th and a minimum oxygen level of 0.25 mg/L was measured at a depth of 4 meters on July 22nd. The average DO concentration for surface depths (the epilimnion, 0-1 m) was 8.15 mg/L (n=15), and for bottom depths (the hypolimnion, ≥ 3 m), the average DO concentration was just 1.44 mg/L (n=10). The insufficient amount of DO in deeper waters during the summer can restrict productivity in the hypolimnion and confine habitat suitability to depths no deeper than 2.5 m.

However, because shallower water can be exposed to greater amounts of solar radiation, the temperature of such depths may not be fitting for certain organisms or particular life stages of many species. For example, during the summer of 2008 Florence Lake did not exhibit adequate DO concentrations at depths that correspond to the optimum temperatures for rearing rainbow trout (Figure 10). These fish would be physically stressed with a limited habitat range in the lake, represented by the red circle in Figure 10. The capacity for water to carry DO is inversely related to temperature, and so, the shallow nature of Florence Lake is a challenge to many aquatic species both in terms of elevated temperatures and limited DO.

Figure 10. Florence Lake Average Summer DO and Temperature (2008)



Trophic Status and Phosphorous

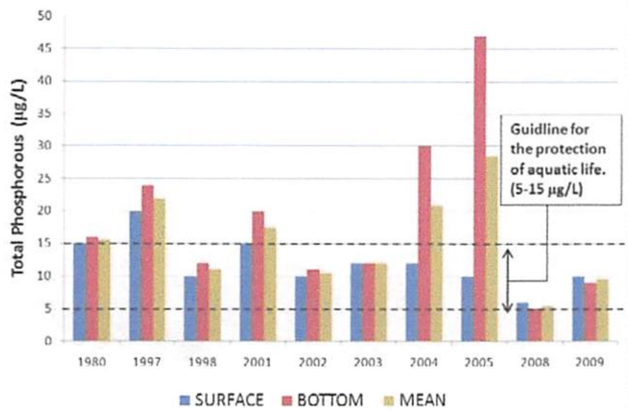
The term trophic status is used to describe a lake's level of productivity and depends upon the amount of nutrients available for plant growth, including tiny floating algae called phytoplankton. Algae are important to the overall ecology of the lake because they are food for zooplankton, which in turn are food for other organisms, including fish. In many lakes phosphorous is the nutrient in shortest supply, acting as the nutrient limiting aquatic life production. When in excess, phosphorous accelerates growth and can artificially advance a lake towards a higher trophic status. As mentioned on Page 4, TP in a lake can be greatly influenced by human activities.

The trophic status of a lake can be determined by measuring productivity. Productivity is determined by measuring nutrient levels and chlorophyll (the green photosynthetic pigment in plants). The more productive a lake is the higher the algal growth and the less clear the water. Phosphorous concentrations measured during spring overturn are often used to assess current productivity and predict summer algal productivity. Lakes of low productivity, referred to as oligotrophic, are typically clear water lakes with low nutrient levels (1-10 µg/L TP), sparse plant life (0-2 µg/L chl. *a*), and low fish production. Lakes of high productivity are called eutrophic. They have abundant plant life (> 7 µg/L chl. *a*), including algae, due to higher nutrient levels (> 30 µg/L TP). Lakes with an intermediate productivity are called mesotrophic (10-30 µg/L TP and 2-7 µg/L chl. *a*) (Nordin, 1985). Mesotrophic lakes tend to encompass some characteristics of oligotrophic and eutrophic lakes.

Lake sediments can themselves be a major source of phosphorus. If deep-water oxygen becomes depleted, a chemical shift occurs in bottom sediments. This shift causes sediment to release phosphorus to overlying waters. The release of TP from sediments can cause algal blooms and lead to further oxygen depletion when algae die. This internal loading of phosphorus can be natural but is often the result of phosphorus pollution. Lakes displaying internal loading usually have elevated algal levels and typically lack recreational appeal. The phosphorus guideline recommended for the protection of aquatic life is 5-15 µg/L TP and for recreational utility, phosphorous should not exceed 10 µg/L (MoE, 2001).

Total phosphorous data were collected at Florence Lake from 1980-2009. Figure 11 shows surface and bottom phosphorous concentrations during the spring overturn months of February and March. Surface and bottom phosphorous readings were also averaged to display an overall lake mean value for TP. At spring overturn, the water column is isothermal, providing a good representation of the supply of phosphorous to the lake over the following summer growing period (Nordin, 1985). Generally, biomass (as chlorophyll *a*) at this time is low (less than 0.5 µg/L) as biological activity has not begun.

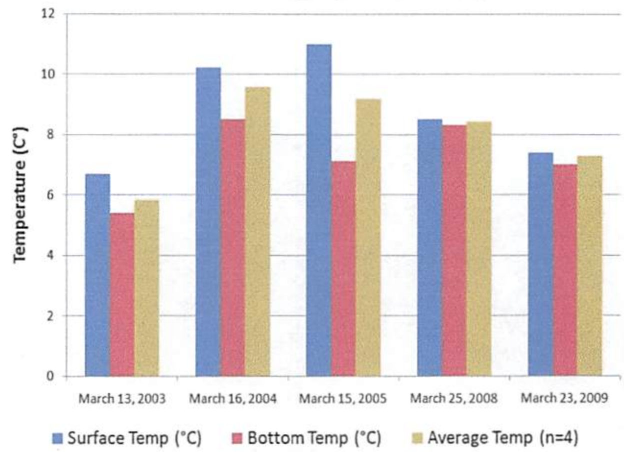
Figure 11. Florence Lake Surface Spring Overturn Bottom and Mean Phosphorous (1980-2009)



In Florence Lake, total phosphorous concentrations vary from year to year with mean spring overturn levels ranging from 5.5 µg/L in 2008 to a maximum of 28.5 µg/L in 2005. Based only on spring overturn TP data, Florence Lake nutrient levels have varied in recent years, exhibiting moderate to high levels of phosphorous.

Comparing phosphorous levels during spring overturn with corresponding water temperatures (Figure 12) shows that temperature likely has an effect on the amount and distribution of phosphorous in Florence Lake. When colder water settles towards the bottom, it takes phosphorous with it, concentrating TP in the hypolimnion. In Florence Lake, stratification had already begun during March in 2004 and 2005 which prevented mixing between the epilimnion and hypolimnion while surface temperatures supported biological uptake of surface TP. When algae died off and sank to the bottom, they contributed to an environment already rich in phosphorous. Consequently, there is greater separation between surface and bottom TP values in 2004 and 2005. Conversely, the lake was still isothermic and overturning in March of 2008 and 2009, resulting in similar surface and bottom TP readings, and with decreasing surface temperatures (2005: 11 °C, 2008: 8.5 °C, 2009: 7.4 °C), biological activity was relatively limited. The relatively large drop in TP from 2005 to 2008 may also be attributed to the number of homes that were connected to sewage in 2007. In total, 32 residencies were connected to sewage, and of these, nine are considered lakeside properties, located less than 100 m from the water. As well, at least six other properties connected in 2007 are no more than 250 m from the shoreline. Wastewater can contain large amounts of nutrients such as nitrogen and phosphorous, and as such, the removal of potentially compromised or failing septic systems from the Florence Lake watershed would decrease the amount of external nutrient loading to the lake.

Figure 12. Florence Lake Spring Overturn Temperature



Seasonal fluxes of phosphorous levels in Florence Lake are shown in Figure 13, which charts the changes in surface and bottom phosphorous concentrations from spring to early fall of 2008. Surface and bottom phosphorous levels remained similar from late March to mid-June and indicate that the lake was relatively isothermal, while in June, bottom TP levels began to increase due to temperature stratification and algal die off. TP levels in the hypolimnion continue to increase throughout most of the summer as low oxygen levels chemically activate the release of phosphorous from the lake substrate. While bottom TP levels rose steadily, surface values concurrently dropped for approximately two months, primarily due to biological uptake. Bottom concentrations reached a maximum value of 34 µg/L, on August 13th, 2008, when surface values were relatively low at 9 µg/L. In mid August, TP trends briefly reverse as surface values rose sharply; a simultaneous and equally sharp decrease was seen in levels of bottom TP. This is likely due to wind storm events that can occur in the summer, a fairly common occurrence in shallow lakes. From late summer to fall, both bottom TP, and to a lesser extent, surface TP levels decreased until similar levels were found in the hypolimnion and epilimnion of Florence Lake, indicating that thorough water column mixing had occurred.

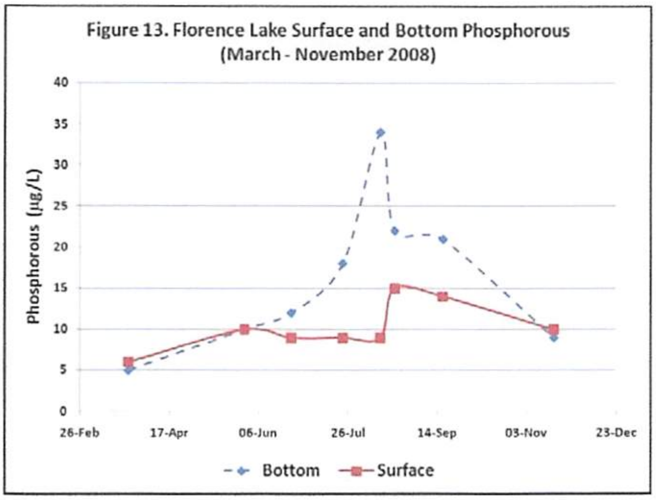


Figure 13. Florence Lake Surface and Bottom Phosphorous (March - November 2008)

Summer plant life samples, as measured by chlorophyll *a*, were collected in 2008 from March to December in the epilimnion. Chlorophyll *a* concentrations are displayed with Secchi depth readings in Figure 14. Secchi depth is an indicator of water clarity and is measured by submerging a 20 cm diameter black and white disc into the lake and recording the depth at which the disc is no longer visible.

In 2008, chlorophyll *a* concentrations were relatively low in spring to early summer with March, May and June readings of 1.5, 4.8 and 4.6 µg/L, respectively. However, by July 22nd, concentrations had increased significantly to 7.9 µg/L and this trend continued into late summer with high readings on August 21st (10.7 µg/L) and September 17th (17.2 µg/L). This increase in chlorophyll *a* was caused by warming temperatures that not only supported algae growth directly but led to a decrease in DO (as more organisms grew, more oxygen was consumed and higher temperatures increase an organism's metabolic rate). In turn, anoxic conditions in the benthic environment triggered the remobilization of phosphorous into the water column, which further supported algae. Generally, Secchi depth displays a negative correlation to concentrations of chlorophyll *a* because algal blooms reduce water clarity. In March, May and June, when chlorophyll *a* concentrations were relatively low, Secchi depth averaged 3.83 meters.

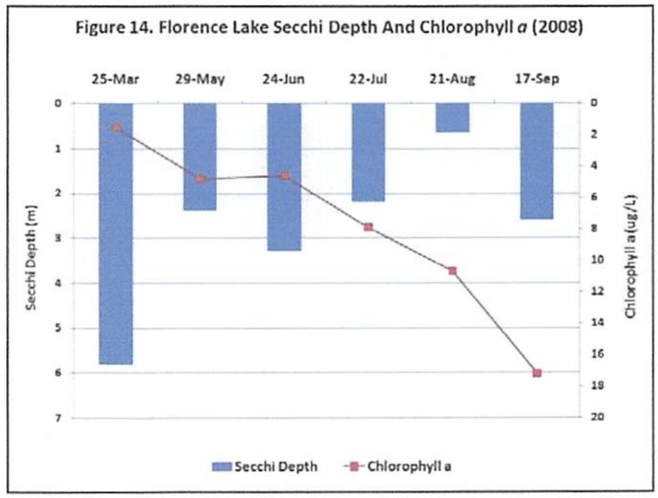


Figure 14. Florence Lake Secchi Depth And Chlorophyll *a* (2008)

When concentrations were relatively high in July, August and September, Secchi depth averaged 1.82 meters. Using 2008 chlorophyll *a* data as a basis for plant abundance and trophic status, Florence Lake becomes eutrophic in late spring to early July.

Recommendations for Water Quality Management at Florence Lake

Florence Lake weakly stratifies during the summertime due to its shallow nature, which demands less wind energy to disrupt the layers (i.e., lake water temperatures can become uniform during the summer) (McCullough, 1980). Within the hypolimnion, DO levels during the summer are depleted below the recommended instantaneous minimum of 5 mg/L. Conversely, at this same time, while DO levels in the epilimnion are sufficient for the protection of aquatic life, the water temperatures are elevated (above 18°C). Due to this, Florence Lake is not considered suitable habitat for cold water fish species for natural recruitment, nor as a site for stocking programs.

Lake monitoring results suggest that Florence Lake generally has moderate water quality conditions, with water quality greatly compromised during the summer due to algal blooms. It is a eutrophic lake; however, due to its relatively small size and shallow depth, there is the potential for Florence Lake to become hyper eutrophic if nutrient inputs to the lake are not monitored and properly managed. Hyper eutrophic episodes would alter the lakes consistency and change its color to green, widespread throughout the lake; degrading its aesthetic appeal, reducing its recreational utility and potentially lowering property values surrounding the water body. Therefore, all residencies within the watershed should be connected to the municipal sewage system in a timely fashion to reduce the potential for external nutrient loading. Water quality monitoring at Florence Lake should resume and include a nutrient budget to assess if the lake is trending towards hyper eutrophication.

Bacteriological data has not been collected in Florence Lake. Considering the number of homes within the watershed that still utilize onsite septic systems, it is recommended that monitoring be implemented to assess fecal coliform content of the lake and ensure that values do not exceed the BC Water Quality Guidelines for primary contact recreation. This data would also support the need to ensure all homes in the area are connected to the sewer system.

Construction projects within a watershed can increase the amount of pollution and sediment discharge into a lake. Current construction plans for the Spencer Interchange, to be located to the southwest of the lake, and residential development to the north on Skirt Mountain could both impact the health of the lake. Water quality monitoring at Florence Lake should include monitoring of turbidity, which would help determine how these projects may impact the water body and the effectiveness of the management of runoff from development. As well, BC Lake Stewardship Society lake monitoring could be conducted and Florence Lake is a potential site to study the freshwater jellyfish, *Craspedacusta sowerbii.*

All lakeside residents and those living in or developing in the watershed are advised to practice good land management such that pollution, nutrient or sediment input into Florence Lake or its tributary is minimized.

Tips to Keeping Florence Lake Healthy

Yard Maintenance, Landscaping & Gardening

- Minimize the disturbance of shoreline areas by maintaining natural vegetation cover
- Minimize high-maintenance grassed areas
- Replant lake-side grassed areas with native vegetation
- Do not import fine fill
- Use paving stones instead of pavement
- Stop or limit the use of fertilizers and pesticides
- Do not apply fertilizers or pesticides before or during rain due to the likelihood of runoff
- Compost yard and food waste and use it to boost your garden's health as an alternative to chemical fertilizers
- Use natural insecticides such as diatomaceous earth
- Prune infested vegetation and use natural predators to keep pests in check. Pesticides can kill beneficial and desirable insects such as ladybugs

Agriculture

- Locate confined animal facilities away from water bodies and divert incoming water and treat outgoing effluent from these facilities
- Limit the use of fertilizers and pesticides
- Construct adequate manure storage facilities
- Do not spread manure during wet weather, on frozen ground, in low-lying areas prone to flooding, within 3 m of ditches, 5 m of streams, 30 m of wells, or on land where runoff is likely to occur
- Install barrier fencing to prevent livestock from grazing on stream banks and lake-shores
- If livestock cross streams, provide gravelled or hardened access points
- Provide alternate watering systems, such as troughs, dugouts, or nose pumps for livestock
- Maintain or create a buffer zone of vegetation along a stream bank, river or lake-shore and avoid planting crops right up to the edge of a water body

Onsite Sewage Systems

- Inspect your system yearly, and have the septic tank pumped every 2 to 5 years by a septic service company. Regular pumping is cheaper than having to rebuild a drain-field
- Use phosphate-free soaps and detergents
- Conserve water: run the washing machine and dishwasher only when full and use only low-flow showerheads, faucets, and toilets.
- Do not put toxic chemicals (paints, varnishes, thinners, waste oils, photographic solutions, or pesticides) down the drain. They can kill the bacteria at work in your on-site sewage system and can contaminate water bodies

Auto Maintenance

- Use a drop cloth if you fix problems yourself
- Recycle used motor oil, antifreeze, and batteries
- Use phosphate-free biodegradable products to clean your car and wash your car over gravel or grassy areas, but not over sewage systems

Boating

- Do not throw trash overboard or use lakes or other water bodies as toilet
- Use biodegradable, phosphate-free cleaners instead of harmful chemicals
- Use absorbent bilge pads to soak up minor leaks or spills
- Check for and remove all aquatic plant fragments from boats and trailers before entering or leaving a lake. Eurasian milfoil is an aggressive invasive aquatic weed. Be sure to familiarize yourself with this plant and remove and discard any fragments
- Do not use metal drums in dock construction. They rust, sink and become unwanted debris. Use blue or pink closed-cell extruded polystyrene billets or washed plastic barrel floats and label them with owner's name and phone number in case they wash away.

----------------------------------Who to Contact for More Information--------------------------------

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City of Langford, Parks and Recreation
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Appendix F

Additional Resources

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