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BILD – Building Industry and Land Development Association

The Lake Simcoe Phosphorus Loading Target: A Review of the Scientific Rationale

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Project Number:

111816

Date:

March 13, 2009

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March 13, 2009 Project No.: 111816

Danielle Chin, BURPl
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Dear Danielle Chin:

Re: Draft Report "The Lake Simcoe Phosphorus Loading Target: A Review of the Scientific Rationale"

I am pleased to submit this report to you that summarizes and evaluates the Lake Simcoe phosphorus loading target and recent Lake Simcoe phosphorus budgets. Our review concluded that the scientific rationale and approach behind the phosphorus target and budgets are sound and based on validated scientific evidence and methodologies. We noted, however, that due to an unsupported assumption the natural phosphorus loads were probably underestimated, challenging the feasibility of achieving a 44 tonne/yr remedial target that may not be much higher than the pre-settlement loading. We provide recommendations for further studies that can easily correct this and will help to more clearly articulate the challenge for remediation of Lake Simcoe. An evaluation of Lake Simcoe phosphorus loading sources and how the Lake Simcoe Protection Plan addresses them completes our analysis.

We have also compiled a brief summary of case studies that demonstrate the success of nutrient loading reductions to lakes and the measures that were required to restore water quality.

We trust that this review will be informative for BILD in its relevance to the present draft Lake Simcoe Protection Plan and future activities in the Lake Simcoe watershed. We thank you for the opportunity to assist BILD in their activities to restore Lake Simcoe.

Sincerely,
AECOM Canada Ltd.

Dörte Köster, Ph.D.

DK:jd

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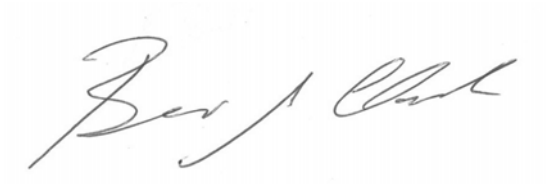

Bev Clark
Senior Aquatic Scientist

Executive Summary

In this report, we review the scientific studies that were used in setting the phosphorus loading target of 44 tonnes/yr established in the draft Lake Simcoe Protection Plan. Our review concluded that the scientific rationale and approach used for developing the target were sound and based on the best available science. This relates to both the rationale of the target as well as current phosphorus budgets for Lake Simcoe.

There was, however, one methodological problem in a source study (Johnson and Nicholls 1989) that may have led to an underestimation of natural phosphorus loads and thus natural phosphorus concentrations for Lake Simcoe. This implies that the figure of 32 tonnes / yr that was estimated as “natural” phosphorus is probably too low. This number does not affect the calculations that relate the oxygen target to the corresponding 44 tonne/yr phosphorus loading target to achieve 7 mg/L of oxygen for cold water fish recruitment. It may, however, put the present target into new perspective in that a better estimate of the pre-settlement load may not be very much below the remedial target of 44 tonnes. As such, the remedial target may be too ambitious – it may not be possible to reduce loadings to a level that is so close to the natural, pre-settlement load. In order to quantify the error of that study and assess the implications for the present phosphorus loading target, further study is needed, which could consist of a literature review and recalculation based on the available data or a field study that measures sediment characteristics properly. These are recommended in order to quantify the degree of error in the previous study and assess the implications for the present phosphorus loading target.

The loading estimates included in current phosphorus budgets appear to be based on sound approaches and data. There are some uncertainties, however, that relate to loads that are difficult to measure (i.e. septic systems) and we note the failure to estimate loadings from agricultural sources in the watershed.

The Lake Simcoe Protection Plan contains a series of policies that address phosphorus loads from the watershed to Lake Simcoe. The LSPP is not balanced in addressing phosphorus loadings as determined by phosphorus budgets, as loadings from sewage treatment plants and developments are thoroughly addressed, while no or little regulations are provided for addressing private urban, rural and shoreline sources as well as agricultural sources. We summarize recommendations on actions that can be taken by individual home owners to reduce their phosphorus contributions to Lake Simcoe.

In summary, the current phosphorus loading target and phosphorus budgets for Lake Simcoe are based on the best available science. There is potential for improvement, however, in properly addressing all phosphorus loading sources in the watershed, in which individual home owners can play a role. Further studies are warranted relating to background phosphorus loads to Lake Simcoe and to phosphorus loads that are currently only approximated.

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1. Background

An oxygen target for the remediation of Lake Simcoe was first developed in 1995 following the recognition that excessive nutrient loading to Lake Simcoe had led to water quality degradation and endangered the naturally occurring cold-water fish population. In the absence of a well-defined trophic state objective, an ecosystem objective was needed that would embody many of the desirable characteristics of the lake. It was agreed that an end-of-summer, volume weighted hypolimnetic (bottom-water) oxygen concentration would serve this purpose because it is the primary determinant of the suitability of Lake Simcoe for coldwater fish such as lake trout. Initially, an objective of 5 mg/L was set as a sub-optimal requirement for the survival of lake trout. This was lower than the optimal conditions (8 mg/L was felt to be optimal at that time), but represented a significant improvement over early 1990's conditions of ca. 3 mg/L. The 5 mg/L has almost been achieved (recent values are 4.6 to 4.7 mg/L, Winter et al 2007), but the fisheries have only begun to recover. In the interim, Evans (2006) has published a scientific rationale showing that 7 mg/L of end-of-summer, volume weighted hypolimnetic oxygen is required to support lake trout recruitment. The 7 mg/L has been adopted as a remedial target for Lake Simcoe (Ontario Ministry of the Environment (MOE) 2009).

The most important mitigation measure required to achieve the oxygen target is to reduce the load of phosphorus to Lake Simcoe. Phosphorus concentrations govern the rate of algae production in surface water and much of the algal production ultimately settles to the bottom of the lake where bacterial decomposition consumes oxygen that is locked into the hypolimnion (bottom waters) when thermal stratification of the lake sets up in early summer. Lake trout are confined to the cold water habitat at the bottom of the lake and hence are particularly vulnerable to depleted hypolimnetic oxygen. The phosphorus loading target that corresponds to the targeted remedial oxygen concentration of 7 mg/L, was originally estimated to be 44 tonnes/yr by Mr. Ken Nicholls, an MOE limnologist, in 1995 and has been adopted as the current phosphorus loading target for Lake Simcoe in the Draft Lake Simcoe Protection Plan (MOE 2009).

This report describes and evaluates the scientific rationale and studies that led to this target. Furthermore, we will discuss phosphorus sources to Lake Simcoe and how they are addressed in the draft version of the Lake Simcoe Protection Plan.

Snodgrass and Holubeshen (1993) established phosphorus loading targets using a probabilistic simulation model based on the response of dissolved organic carbon and particulate carbon production to phosphorus loading in Lake Simcoe, assuming 66 tonnes/yr of phosphorus loading at that time. This was later considered to be an underestimation (Beak Consultants Ltd. 1994), and so this target was also revisited using different methods.

2. The Scientific Rationale of a Phosphorus Loading Target for Lake Simcoe

The scientific rationale used to develop the phosphorus loading target is described in detail in a Ministry of the Environment and Energy report entitled "A Limnological Basis for a Lake Simcoe Phosphorus Loading Objective" (Nicholls 1995). In this study, phosphorus loadings to Lake Simcoe were linked to bottom-water oxygen concentrations through a series of established models and empirical relationships linking phosphorus loadings from the watershed to in-lake phosphorus concentrations, linking these to algae productivity (measured as the concentration of chlorophyll a) and linking this to deep-water oxygen conditions. The steps involved in this linkage are as follows.

1. Determine the volume-weighted oxygen depletion rate that produces the targeted end-of summer oxygen concentration in the hypolimnion after the lake stratifies in the early summer.
2. Use the Janus-Vollenweider (1981) Model to estimate the chlorophyll concentrations that yield the targeted oxygen depletion rate.
3. Use an empirical quantitative relationship between chlorophyll and phosphorus concentrations to determine the phosphorus concentration that corresponds to the targeted chlorophyll concentration.
4. Use the well established scientific relationship between phosphorus load and concentrations in the lake to determine the load associated with the phosphorus concentrations estimated in Step 3.

The results of this modeling exercise were compared to results from Snodgrass and Holubeshen (1993), and were found to be in excellent agreement. Therefore the results of both models were combined into a single equation that predicts the phosphorus load to Lake Simcoe based on a desired end-of- summer bottom-water oxygen concentration (see section 3.7).

This equation was used to derive a phosphorus loading target of 73 tonnes/yr to achieve the 5 mg/L oxygen target in 1995. The same equation was used to set the target of 44 tonnes/yr to achieve the objective of 7 mg/L oxygen for the Lake Simcoe Protection Plan.

3. Review of Scientific Studies that Form the Basis of the Phosphorus Loading Target

3.1 Estimates of Phosphorus Loadings to Lake Simcoe in the 1980s

In a sediment study pre-dating the Nicholls (1995) report, the phosphorus load of the 1980s to 1990s was estimated at 80 – 100 tonnes/yr (Johnson and Nicholls 1989). This range of phosphorus loads at the time was confirmed by a review of available information on phosphorus sources by Beak Consultants Ltd. (1994), who estimated a phosphorus load of ca. 90 t/yr. The range of 80-100 t/yr was taken as the basis for further calculations in the Nicholls (1995) report.

The same study (Johnson and Nicholls 1989) also estimated pre-settlement phosphorus loading rates (sometimes also referred to as "natural" or "background" loading rates) to Lake Simcoe, at a value of 32 tonnes/yr. This value represents the natural conditions at Lake Simcoe, and thus the conditions that could only be achieved if all modern human sources of phosphorus in the watershed were removed. The estimate of pre-settlement phosphorus load was not used in the development of a phosphorus loading target for Lake Simcoe, but commonly serves as a reference to which present and targeted loadings are compared. The Lake Simcoe Science Advisory Committee (2008), for example, stated the following: "…current (phosphorus loading) levels are still high relative to the estimated baseline (or background) loading rate of 32 t/yr prior to large-scale human activities in the watershed".

Our review of the study of Johnson and Nicholls (1989) concludes that their methodology to estimate pre-settlement phosphorus loads for Lake Simcoe was very sound and corresponded extremely well to independent estimates of phosphorus loadings in the Lake Simcoe watershed. We therefore confirm that the calculations described in the following sections (sections 3.2 to 3.6) are based on a reasonable estimate of phosphorus loadings in the 1980s and 1990. Their methodology to estimate pre-settlement phosphorus loads, however, involved an invalid assumption that may have resulted in the underestimation of pre-settlement phosphorus loads to Lake Simcoe, as detailed below.

Johnson and Nicholls (1989) measured the depth of sediments using sonar in the field and collected short sediment cores along the sonar transects. Four parameters that are necessary to calculate phosphorus loads were measured in the sediment cores and estimated for the entire sediment column (Table 1).

Table 1 Parameters and methods used in Johnson and Nicholls (1989) to estimate pre- and post-settlement phosphorus loadings to Lake Simcoe.

Parameter	Method for pre-settlement sediments	Method for post-settlement sediments
Sediment Depth	Sonar (7-29 m)	Measured core length (ca. 0.3 - 0.5 m)
Phosphorus concentrations	Values from the bottom of short sediment cores that have an approximate age of 180 years	Measured in sediment cores
Sediment density	**Values from the bottom of short sediment cores that have an approximate age of 180 years**	Measured in sediment cores
Sediment age	Time since last ice age	Measured radioisotopes in sediment cores

Note: Bold type indicates a method that involves invalid assumptions.

All estimates for post-settlement sediments are reliable, as they were measured. Also, they compared very well to estimated phosphorus loads that were calculated by adding up known sources, e.g., phosphorus budgets, as described in section 4.1. Therefore the estimation of post-settlement phosphorus loads by Johnson and Nicholls (1989) was sound and provided a good foundation for the subsequent calculations that led to the present Lake Simcoe loading target.

The phosphorus concentrations and sediment densities for the pre-settlement sediments, however, were taken from relatively young sediments (e.g. ca. 180 yrs old[1],) and were assumed to be constant over the entire period of 11,000 years of sediment deposition. This assumption may be correct for phosphorus concentrations, but it should still be verified with measured data. For sediment density, this assumption is likely false, as sediment density (expressed in weight per volume) usually increases with sediment depth and age due to compaction resulting from the weight of the overlying, younger sediments (Håkanson 2007). During the compaction process, pore water is pressed out of the sediments into areas of less pressure (i.e. younger sediments in upper layers of the sediment column) and the old sediments become denser, hence heavier. This process can result in sediment densities at least 3 times higher in pre-settlement sediments as compared to more recent sediments (Grimm 1983). An underestimation of sediment density leads to the underestimation of pre-settlement sedimentation rates and thus pre-settlement phosphorus loads.

On a different note about the usage of sediment phosphorus data for estimating phosphorus loads, it has been shown that such studies can yield erroneous records of the history of P loading to these lakes. The reason for that were that phosphorus can be mobile in the sediments (Carignan and Flett 1981) and that it can be recycled to the water column under low-oxygen conditions (Anderson *et al.* 1993, 1994). Although present-day phosphorus loads were well predicted from Lake Simcoe sediments by Johnson and Nicholls (1989), the results of this approach should be confirmed by an independent approach, such as a paleolimnological study, as described below.

In conclusion, our analysis suggests that the natural background (pre-settlement) phosphorus load to Lake Simcoe was higher than the 32 tonnes/yr estimated by Johnson and Nicholls (1989). This implies that the figure of 32 tonnes / yr that was estimated as “natural phosphorus is probably too low. This number does not affect the calculations that relate the oxygen target to the corresponding 44 tonne/yr phosphorus loading target to achieve 7 mg/L of oxygen for cold water fish recruitment. It may, however, put the present target into new perspective in that a better estimate of the pre-settlement load may not be very much below the remedial target of 44 tonnes. In order to correctly estimate pre-settlement phosphorus loadings, further study is required, as outlined below.

3.2 Oxygen Requirements of Coldwater Fish Species

The oxygen target of 7 mg/L was derived from research of Dr. David Evans (2006), of the Ontario Ministry of Natural Resources (MNR), from studies of juvenile lake trout survival under different oxygen and temperature

[1] *Note Johnson and Nicholls (1989) did neither provide the length nor the age of their cores in the publication. They did state, however, that the bottom sediments were older than 180 years. Therefore the oldest sediments in the short cores were probably ca. 200 years old.*

regimes and opinion evidence of MNR fisheries ecologists. The study concluded that lake trout life activities at temperatures typical for lake bottoms in summer require oxygen concentration between 6.6 and 7.5 mg/L. At oxygen levels below 7 mg/L, recruitment[2] and life activities of juvenile lake trout were impaired. Therefore, a dissolved oxygen criterion of 7 mg/L was recommended for the protection of juvenile lake trout habitat that would support a self-sustaining lake trout population.

3.3 Establishment of Volume-Weighted Oxygen Depletion Rate

The Nicholls (1995) report provides a reasonable rationale of establishing a volume-weighted oxygen depletion rate based on measured oxygen conditions. The scope of this report is not to describe the approach in detail, but it can be said that the specific characteristics of Lake Simcoe were taken into account to develop this relationship. It was also verified using measured chlorophyll data in the following step, and found to be in excellent agreement with measured data from around 1990 and from around 2000, as described below.

3.4 Relationship between Oxygen and Chlorophyll

In order to relate bottom-water oxygen depletion rates to algae production (measured as chlorophyll), a well established empirical[3] model was used (Vollenweider and Janus 1982). This model is based on chlorophyll and oxygen data obtained from a variety of lakes, including the Laurentian Great Lakes. The model was adapted to the local conditions encountered in Lake Simcoe and the results of the modelling exercise were compared with data measured in Lake Simcoe. The modelled data showed a high level of agreement with the measured data, showing that the model is appropriate for Lake Simcoe. This verification was repeated more recently using data from 1996-2004 showing that the original model described the relationship between chlorophyll concentrations and bottom-water oxygen conditions adequately (Winter 2006).

3.5 Relationship between Chlorophyll and Phosphorus

The relationship between chlorophyll and phosphorus in lakes is well established, as phosphorus is the nutrient that determines algae production in most freshwater systems. Chlorophyll and phosphorus data from 1990-1992 from twelve stations in Lake Simcoe as well as several other Ontario Lakes were used to derive a lake-specific equation for Lake Simcoe. This equation provides the link between the Vollenweider-Janus (1982) model described in section 3.4 and the phosphorus models described in the following section. The phosphorus-chlorophyll relationship was validated with more recent data from 1996 to 2004 and found to be in good agreement with the equation based on earlier data (Winter 2006).

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[2] *Recruitment is one process in the reproductive cycle of lake trout and describes the survival of newly hatched lake trout fry to the juvenile stages and eventually to reproducing adults.*

[3] *Developed from measured data and not exclusively based on theory*

3.6 Relationship of Phosphorus Loads to Phosphorus Concentration in Lakes

The next step was to develop a model to calculate the phosphorus load necessary to achieve the phosphorus concentrations required to achieve the target oxygen concentrations derived in the previous steps. This was achieved by applying a commonly used model that relates phosphorus loadings to phosphorus concentrations in lakes (Dillon and Rigler, 1975; Janus and Vollenweider 1981, OECD 1982) and that was further modified by Dillon (1994). These models are very well established with the scientific community and their results show good agreement. Both models were calibrated using current phosphorus loads, inflow phosphorus concentrations measured from 1989-1993, a coefficient related to the storage of phosphorus in the lake sediments, and water residence time. When applied to the assumed natural phosphorus load in Lake Simcoe, both models result in estimated natural phosphorus concentrations of 4-5 µg/L. In a recent study, the models were verified and found to be valid using more recent data from 1996 to 2004 (Winter 2006).

3.7 Summary Equations to Calculate Phosphorus Loadings from Oxygen Concentrations and Vice-versa

The results of the above modeling exercise and the previously cited modeling study by Snodgrass and Holubshen (1993) were used to establish and quantify a consensus curve to calculate any phosphorus load from a desired oxygen concentration. The final equation was used in the LSPP to establish the 44 t/yr target based on the 7 mg/L oxygen target. Our review found, however, disagreement between the published equations. The equation predicting the required phosphorus load from the oxygen target:

Phosphorus load (P_L) $=229 - 69.9 \times DO^{1/2}$ (Equation 1)

(DO = Dissolved Oxygen)
is correct and has been verified with more recent estimates of phosphorus loadings and oxygen conditions in Lake Simcoe (Winter 2006), but the inverse equation, predicting dissolved oxygen from phosphorus load

$DO = 10.73 - 0.94 * P_L + 0.0002 * P_L^2$ (Equation 2)

provided in the Nicholls (1995) study and the Winter (2006) verification appears to be incorrect. We were unable to duplicate the phosphorus load required to meet the 7 mg/L target using Equation 2.

Nonetheless, equation 1 is the relevant equation for the LSPP. All of the steps described in this section are based on sound scientific approaches and so the resulting summarizing equation is likely to be an appropriate guide to establish phosphorus loading targets for Lake Simcoe based on desired oxygen concentrations. The only weakness may be that there are no error estimates associated with the resulting equation, thus the level of confidence in estimates from these equations is unknown. We also note that these equations describe steady state and stable conditions under constant loading of water and phosphorus to Lake Simcoe. The lake takes several years to respond to changes in loading, and phosphorus, chlorophyll

and dissolved oxygen concentrations will vary from one year to the next. These fluctuations are not predicted from this type of model. Nevertheless, the models can be used to show a predictable response of dissolved oxygen to a decrease in phosphorus load.

The fact that the pre-settlement phosphorus load of 32 tonnes/yr may have been underestimated does not change the remedial target of 44 tonnes/yr, as the pre-settlement phosphorus loads were not used in any way to derive the relationships described above. It does, however, put the remedial phosphorus loading target of 44 tonnes/yr into perspective. The 44 tonne /yr target is likely closer to the natural background loads than previously thought. In other words, Lake Simcoe may never have had a load as low as 32 tonnes/yr before settlement. It may therefore be more difficult to achieve the 44 tonne/yr target given the permanent changes the landscape has undergone since settlement times.

3.8 Recommendations for Additional Study

In order to obtain more correct estimates for pre-settlement phosphorus loading rates, various approaches can be taken, as detailed below. Three of these approaches are focused on the fact that the sediment densities used to derive the pre-settlement estimate of 32 tonnes/yr were not correct and provide a means to obtain more accurate sediment densities by carefully sampling sediments in the lake with a coring device. The fourth approach is an alternative way of estimating pre-settlement phosphorus loads by analyzing fossil biota in lake sediments and is recommended as an independent study to address uncertainties associated with sediment phosphorus studies as discussed above.

1) We are aware that long sediment cores were taken in Lake Simcoe, along with sonar profiles, by researchers from the University of Rhode Island, working with the LSRCA. It would be useful to verify with the principal investigators, if the appropriate data (bulk sediment densities) were collected during their study. If so, these could be used to recalculate the pre-settlement phosphorus loading estimates using the approach of Johnson and Nicholls (1989). This would be the easiest and probably fastest, but still approximate way to obtain this information.

2) If this route is not possible, a second approach can be to collect compaction data from the scientific literature, as coring studies have been carried out in many systems, and likely some with similar sediment properties and depth as in Lake Simcoe. If compaction is known from several studies and are reasonably similar, a compaction factor could be applied to the data obtained by Johnson and Nicholls (1989) in order to recalculate pre-settlement sediment densities and thus phosphorus loadings. This would be a fast, but still approximate way to estimate phosphorus loadings.

3) A third possibility is to carry out a sediment study of Lake Simcoe by revisiting at least some or all of the sampling sites of Johnson and Nicholls (1989) and by taking long sediment cores that cover the entire time since the last deglaciation. Sediment density and phosphorus concentrations could then be directly measured on Lake Simcoe pre-settlement sediments and thus provide the most precise estimation of sedimentation rates and thus phosphorus loading. This study requires intensive field work for about a week using specialized equipment, some laboratory analyses and radiocarbon dating.

4) A fourth, independent way is to reconstruct the history of phosphorus and oxygen concentrations in Lake Simcoe from pre-settlement times to now, using the science of paleolimnology. Core samples of lake sediments are taken and the fossils of algae (diatoms) and midges (chironomids) that are preserved in the lake sediments can be used to reconstruct the lake history. Sediment cores such as those described above for study (3) can be used, thus both studies could be done on the same material. The simpler and cheaper technique of taking short surface sediment cores may be sufficient for this approach as well, in the case that pre-settlement sediments can be obtained with short cores. Quantitative models can be used to reconstruct phosphorus concentrations from fossil algae and oxygen concentrations from fossil chironomid (midge) remains. These reconstructions from biological indicators can serve as an independent assessment of the sediment studies described in 1) - 3). They would also provide the opportunity to study past conditions of phosphorus and oxygen together and to estimate the date at which oxygen concentrations dropped below 7 mg/L, and the corresponding phosphorus load. One core taken from each basin should be sufficient to properly describe historical phosphorus concentrations. This kind of study requires technical expertise in the specific fossils and the numerical techniques involved in quantitative reconstructions and is therefore more technical and labour-intensive. This expertise has historically been found only in academia but also resides in AECOM's Bracebridge office – with the author of this report and another scientist.

4. Lake Simcoe Phosphorus Budgets

Phosphorus budgets are estimates of the phosphorus loadings to a receiving water body, such as a lake or a river, subdivided into different sources. Phosphorus budgets can be developed by different approaches; the mass balance approach was used in Lake Simcoe. This is the most precise approach, as it uses measured phosphorus concentrations in all measurable inputs, such as inflowing tributaries, sewage treatment plant outflows and atmospheric deposition. Other, non-measurable inputs, such as the contribution of near-shore septic systems, were estimated using best available knowledge. In this section we evaluate the quantification of phosphorus sources for Lake Simcoe, discuss how these sources are presently addressed in the LSPP and what other measures may be considered to reduce phosphorus loadings.

4.1 Rationale of Lake Simcoe Phosphorus Budgets

The most recent phosphorus budgets for Lake Simcoe were prepared by Scott et *al*. 2006 and Winter *et al.* (2007) and were based on data from 1990-1998 and from 1998-2004, respectively. Total phosphorus loads (metric tonnes / yr) to Lake Simcoe were estimated from six source categories, including atmospheric deposition, tributary runoff, urban runoff (from point sources, e.g. sewage treatment plants, and from non-point sources, e.g. stormwater run-off), septic systems and vegetable polders from the Holland Marsh.

Atmospheric deposition was collected and phosphorus concentrations analysed. Where available, measurements of flow and phosphorus concentrations were used in tributaries to estimate tributary loads. Not all tributaries are monitored, however, and so for unmonitored sub-watersheds, loads were estimated

from the most similar monitored sub-watershed (in terms of land use) and prorated by watershed area. Urban non-point sources were estimated using phosphorus export coefficients (the amount of phosphorus that is exported per unit area from a certain land use type) that had been established previously in the area. Sewage treatment plant loads were calculated from plant outflow monitoring data. Septic system loads were estimated from the number of properties not connected to municipal wastewater services, usage terms distinguishing seasonal and permanent residences and the full per capita phosphorus load.

All of these methods are based on the most current available knowledge on phosphorus export from different land uses and through tributaries and are well described in the source documents. The highest level of uncertainty may be associated with the septic loading, as it was not measured directly. Based on most recent data on septic systems, the septic load to Lake Simcoe has increased by ca. 12% from 3.8 t/yr in 2002 to 4.4 t/yr in 2008 (LSRCA, unpublished data). Also, any septic systems near tributary shores are included in tributary loads and not in the explicit “septic systems” category. Therefore the relative importance of septic systems near the shores of Lake Simcoe and its tributaries for Lake Simcoe loads may be higher than currently evident in Lake Simcoe budgets. Given that the current septic load estimate is 6% of the total, compared to 7% for sewage treatment plants, this source certainly deserves more detailed attention.

It is also important to note that the published loading estimates do not attempt to assign loading to agricultural practices. Agricultural land uses make up 45% of the Lake Simcoe watershed (compared to urban land uses that make up 18%). It is therefore likely that portions of the measured tributary load, the unmonitored estimated load, and atmospheric deposition sources are related to agriculture. It is difficult to make accurate estimates from these sources, but it is certainly feasible, and such estimates are required to guide a sound remedial strategy.

Overall, the current loading estimates appear to be based on sound approaches and data. The estimated decrease in TP input to Lake Simcoe between 1990/91–1997/98 and 1998/99–2003/04 was comparable to the decrease in within-lake load estimated from spring TP concentrations, which gives additional confidence in loading estimates (Winter et al. 2007). Some uncertainties relate to loads that are difficult to measure (i.e. septic systems and agriculture) and these warrant further study.

4.2 Phosphorus Sources in the Lake Simcoe Protection Plan: Review and Recommendations

The Lake Simcoe Protection Plan contains a series of policies that address phosphorus loads from the watershed to Lake Simcoe. In the table below we summarize the different phosphorus sources that have been identified in Lake Simcoe phosphorus budgets, as discussed in the previous section, and evaluate how these sources are addressed in the Draft Lake Simcoe Protection Plan (Table 2). Where a source was insufficiently addressed, we provide recommendations on what additional measures could be encouraged in order to properly address all phosphorus sources and focus particularly on actions that can be taken by individual home owners to reduce their phosphorus contributions. Overall, loadings from sewage treatment plants and developments are thoroughly addressed in the LSPP, while no or little regulations are provided for addressing private urban, rural and shoreline sources or agricultural sources.

Table 2 List of phosphorus sources to Lake Simcoe, of how they are addressed in the Draft Lake Simcoe Protection Plan and recommendations where further measures could be encouraged.

Source of Nutrients	Source Category	Lake Simcoe Protection Plan Strategies	Recommended Actions
Urban	Storm water	Addressed in depth-requirements for management plans and MOE "enhanced level" treatment	
	Wastewater	Addressed in depth through restrictions on new and existing STPs and reductions in allowable phosphorus discharged.	
	Runoff from Private Properties	Not addressed	Reduce or eliminate lawn fertilizers, leave clippings on the lawn to help fertilize Encourage or enforce shoreline naturalization Introduce development permit system to link environmental remediation to building improvements for private landowners Wash vehicles on lawn or off property Remove animal wastes Respect stormwater drains no toxins or nutrients (only rain down the drain) Reduce impervious areas
Agriculture	Runoff	Addressed only through encouraging best management practices – no targets or means to measure success	Consider best management for non-agricultural rural home owners in areas adjacent to streams as with shoreline properties.
Shoreline Properties	Septic Systems	Only addressed for new, larger shoreline developments Not addressed for existing and new individual lots	Maintain septic systems, reduce phosphates entering the system. Encourage (require where feasible) extension of municipal service and decommission septic systems.
	Runoff	Only addressed for new, larger developments Not addressed for existing and new individual lots	No fertilizers on lawns, reduce lawn sizes, maintain riparian buffers to reduce runoff, discourage geese etc.
Atmospheric deposition	Agriculture, aggregates etc.	Sources from Aggregates and construction are addressed by strategic actions that may lead to policies	Encourage or require smaller farm fields and hedgerows to reduce wind erosion, and no till techniques to reduce soil disturbance.
Recreation	Watercraft	Not addressed	Pass legislation to outlaw gray water disposal and require holding tanks for gray water in all boats over a certain size.

4.3 Success Stories of Phosphorus Loading Management in Lakes

A review of lakes in North America and Europe which had undergone phosphorus load reductions, mostly through tributary control, examined the patterns in recovery of these lakes (Jeppesen *et al.* 2005). The reduction of external total phosphorus (TP) loading resulted in lower in-lake TP concentration, lower chlorophyll concentration and improved water clarity in almost all deep lakes. During the first 5–10 years, the measured annual mean lake TP concentration was typically higher than predicted from the Vollenweider (1976) equation (see section 3.6) likely due to enhanced internal loading[4]. As the bottom waters of Lake Simcoe are still oxygenated and thus phosphorus is considered to be "locked" into the sediments at this point (Lake Simcoe Science Advisory Committee 2008), it may be expected that phosphorus load reductions to Lake Simcoe can result in a relatively quick decline in phosphorus concentrations in the main lake. Other factors that are not presently quantified, such as climate change and the presence of invasive species (e.g. zebra mussels) however, may modulate the lake's response to nutrient loading reductions (Lake Simcoe Science Advisory Committee 2008).

A very well know success story of phosphorus loading reductions is the story of Lake Erie. Water quality degradation due to excessive cultural phosphorus inputs was recognized as a significant Great Lakes problem in the late 1960s. Phosphates from detergents, effluents from industries and as run-off from heavily-fertilized farmlands lead to increased phosphorus load to Lake Erie, more plant growth, more oxygen depletion and resulting fish kills. Public concern and various pro-active measures, which began with the 1972 signing of the Canada - United States Great Lakes Water Quality Agreement, began to work towards a solution to the phosphorus problem. The Agreement included municipal and industrial commitments to remove phosphorus from effluents and to eliminate phosphorus from detergents. Today, after years of hard work and cooperation, the phosphorus problem has essentially disappeared (Environment Canada 2009). The Lake Erie rehabilitation represented an unprecedented success in producing environmental results through international co-operation.

These case studies demonstrate that the scientific paradigm established ca. 30 years ago that predicted improvement of water quality following phosphorus loading reductions still holds today, even though each lake responds a little differently due to local watershed and lake-basin specifics.

[4] *Internal phosphorus loading is a process through which phosphorus contained in the sediments is returned to the water column. This mainly happens in highly eutrophic lakes, where the bottom waters become oxygen-depleted in the summer.*

5. Summary and Conclusions

The review of the scientific studies that were used to set the phosphorus loading target of 44 t/yr in the Lake Simcoe Protection Plan showed that the scientific rationale and approach were sound and based on the best available science. This relates to both the rationale of the target as well as current phosphorus budgets for Lake Simcoe.

There was, however, one methodological problem in a source study (Johnson and Nicholls 1989) that may have led to an underestimation of natural phosphorus loads and thus natural phosphorus concentrations for Lake Simcoe. This implies that the figure of 32 tonnes / yr that was estimated as “natural phosphorus load” is probably too low. This number does not affect the calculations that relate the oxygen target to the corresponding 44 tonnes/yr phosphorus loading target to achieve 7 mg/L of oxygen for cold water fish recruitment. It may, however, put the present target into new perspective in that a better estimate of the pre-settlement load may not be very much below the remedial target of 44 tonnes. As such, the remedial target may be too ambitious – it may not be possible to reduce loadings to a level that is so close to the natural, pre-settlement load. In order to quantify the error of that study and assess the implications for the present phosphorus loading target, further study is needed, which could consist of a literature review and recalculation based on the available data or a field study that measures sediment characteristics properly. These are recommended in order to quantify the degree of error in the previous study and assess the implications for the present phosphorus loading target.

The loading estimates included in current phosphorus budgets appear to be based on sound approaches and data. There are some uncertainties, however, that relate to loads that are difficult to measure (i.e. septic systems, agriculture) and that warrant further study.

The Lake Simcoe Protection Plan contains a series of policies that address phosphorus loads from the watershed to Lake Simcoe. The LSPP is not balanced in addressing phosphorus loadings as determined by phosphorus budgets, as loadings from sewage treatment plants and developments are thoroughly addressed, while no or little regulations are provided for addressing private urban, rural and shoreline sources as well as agricultural sources. We summarize recommendations on actions that can be taken by individual home owners to reduce their phosphorus contributions to Lake Simcoe.

A short discussion of cases where phosphorus loading reductions to lakes were put into place in response to water quality degradation showed the success of such measures. These case studies demonstrated that the scientific paradigm established ca. 30 years ago that predicted improvement of water quality following phosphorus loading reductions still holds today, even though each lake responds a little differently due to local watershed and lake-basin specifics.

In summary, the current phosphorus loading target and phosphorus budgets for Lake Simcoe are based on the best available science. There is potential for improvement, however, in properly addressing all phosphorus loading sources in the watershed, in which individual home owners can play a role. Further studies are warranted relating to background phosphorus loads to Lake Simcoe and to phosphorus loads that are currently only approximated.

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