Forests and surface waters of Sandy Lake & Environs (Bedford, Nova Scotia)

A Natural History Perspective

Critique of Predictions/No Followup Monitoring

More details on Sandy Lake re: section 4.2 Critique of the AECOM (2014) Predictions/No Followup Monitoring:

(i) *As cited by AECOM (2014), modelled phosphorus concentrations differed by far more than 20% of the measured concentrations (it was 67% higher), indicating the model is not valid, but they did not follow recommended procedures to revise the model.*

From AECOM (2014) Appendix E, p.13:

> The predicted phosphorus concentration in Sandy Lake under current conditions is 20 µg/L. This predicted value is significantly greater than the median measured phosphorus concentration of 12 µg/L. Brylinsky (2004) and MOE (2010) indicate that a model is not valid if the modeled phosphorus concentrations differ by more than 20% of the measured concentrations, as is the case with the Sandy Lake results.
>
> As discussed in Section 3, the model assumptions may over-predict phosphorus concentrations by not factoring in phosphorus retention as water travels within the watershed before it reaches the lakes. Predicted phosphorus inputs to the lakes can be reduced by adjusting the lake phosphorus retention coefficient, which in turn reduces the predicted lake phosphorus concentration.
>
> In this study, the phosphorus retention coefficient was adjusted from 0.33 to 0.6 in the LCM to reduce the predicted phosphorus concentration to match the measured phosphorus.

Brylinski 2004, p. 38ff, provides a detailed example of how model re-evaluation was conducted for a case – Lake George in Kings Co. – in which "The model under predicts the lake's phosphorus concentration by 21.9 % which is above the 20% difference generally considered acceptable for model validation." None of the steps for re-evaluation advised by Brylinski 2004 were conducted by AECOM 2014 even though the predicted value exceeded the observed value by a much larger factor (67%); rather AECOM 2014 made the model work by "adjusting the lake phosphorus retention coefficient… from 0.33 to 0.6 in the LCM to reduce the predicted phosphorus concentration to match the measured phosphorus." This is not a procedure cited by Brylinski 2004.

The MOE 2010 document cited by AECOM likewise adopts a maximum of 20% difference between observed and predicted P values as acceptable. As in Brylinski (2004), the MOE (2010) document makes no mention of a one-stop book-keeping fix for the model as applied by AECOM 2014. So the predicted impacts of development and of mitigative measures on lake Total P are highly hypothetical.

(ii) *Setting the Water Quality Objective (WQO) for Total P in Sandy Lake at 50% above the current value is not justified.*

AECOM (2014) provides the following ratioanle for setting the WQO for Total P at 50% above the current value:

> 7.1 Development of Total Phosphorus Water Quality Objectives (WQO)
>
> For the Sandy Lake watershed AECOM recommends the use of Environment Canada's trophic status classification to set WQOs for total phosphorus.
>
> **Table B1. Trophic Status Based Trigger Ranges for Canadian Waters (CCME, 2004)**

Trophic Status	Trigger Ranges for Total Phosphorus (µg/L)	
	Lakes	Rivers and Streams
Ultra-oligotrophic	<4	-
Oligotrophic	4-10	<25
Mesotrophic	10-20	25-75
Meso-eutrophic	20-35	-
Eutrophic	35-100	>75
Hypereutrophic	>100	-

> As noted in section 1.2.1, an objective of the 2006 HRM Regional Plan is to "maintain the existing trophic status of our lakes and waterways". This suggests that both Sandy and Marsh Lakes should be maintained in their current mesotrophic state and so the WQO (water Quality Objective) for total phosphorus should be the upper limit of the mesotrophic range, or 20 g/L. However, since both lakes are currently at the lower end of the mesotrophic range, considerable water quality degradation could occur before the lakes were at risk of exceeding such a WQO.

If the objective is to "maintain the existing trophic status of our lakes and waterways", how can the WQO be set at 50% higher than the current (circa 2012) value? According to this interpretation of the statement "maintain the existing trophic status of our lakes and waterways", no efforts would be made to reduce phosphorus levels in lakes that currently have phosphorus levels highly elevated above recorded historic levels such as Banook Lake. All that is being maintained is the classification of the lake as mesotrophic.

AECOM 2014 cites evidence showing that in its *current* state (at 12 ug P/L), Sandy Lake is already seriously degraded. In 1979, Total P was 7 ug/L or less, well under the upper limit (10 ug/L) for oligotrophy (the 'clean' state of a lake); the transition to mesotrophic status occurred circa 2001 (re AECOM Fig 9). AECOM (2014) cites data showing that by 2008-2011 deep water Total P on some samplings was much higher than surface water P, which they attributed to oxygen deprivation. From AECOM 2014:

Table 5. Sandy Lake Shallow and Deep Total Phosphorus

Sample Name	Sample Date	Total Phosphorus (1 m depth)	Total Phosphorus (deep)
		µg/L	µg/L
Sandy Lake	Sept 3, 2008	11.0	15.0
	May 24, 2010	10.0	26.0
	August 19, 2011	6.0	5.0

> Table 5 compares the phosphorus concentrations of shallow (epilimnion) to deep (hypolimnion)

> samples from three sampling events. Total phosphorus concentrations in the shallow surface (epilimnion) samples are less than in the deep (hypolimnion) samples in two of the three examples. Although the data are limited, this suggests that the deeper portions of Sandy Lake may be fully or partially oxygen- deprived during certain times of the year, a situation that may arise when decomposing organic matter consumes available oxygen at depth. This in turn promotes the release of phosphorus from lake sediments, which is recorded in the water samples.

In commenting that "that both Sandy and Marsh Lakes should be maintained in their current mesotrophic state and so the WQO for total phosphorus should be the upper limit of the mesotrophic range, or 20 g/L", AECOM (2014) seems to have taken a cue from the MOE (Ontario Minister of Environment) 2010 document in which it is suggested that "*If the model fails*….a total phosphorus concentration of 20 µg/L will be used as the upper limit to protect against nuisance algal blooms."

Total P is a well validated and widely accepted predictor of the general condition of temperate lakes, but it is also well recognized it does not predict the precise condition of a particular lake. For a set of Ontario lakes, Malot et al., 1992 observed that "lake morphometry exerts a large influence on profiles and this influence is particularly evident in shallow (<20 m maximum depth) oligotrophic lakes" and that "Predictions of O2 profiles are sensitive to changes in TP concentrations, with all study lakes predicted to have severely O2-depleted hypolimnions by the end of summer at an epilimnetic TP of only 15 ug.L^{-1}." At 21 m maximum depth, Sandy Lake could likewise be expected to very sensitive to Total P concentrations and indeed the evidence cited by AECOM 2014 suggests significant deterioration in hypolimetic oxygen at Total P of 12 ug.L^{-1}.

(iii) Varying the phosphorus export coefficient, rather than increasing the lake retention coefficient would be a more realistic "fix" to make the model work and would likely increase the predicted impacts of development on Total P

The failure of the Phosphorus Model to meet the criterion of Brylinski (2004) and MOE (2010) that the predicted Total P values for existing conditions be within 20% of actual values and by a large factor means that the model as applied by AECOM 2014 cannot be regarded as a good description of how the system is working.

The model overestimated Total P under existing conditions (when the report was written) by 67%, yet it is making predictions of changes of Total P under different management scenarios of 1-4 ug/l, i.e of 8-33%. The model was made to work by increasing the lake P Retention Coefficient from 0.33 to 0.6, i.e. by assuming that more P is being trapped in sediments than initially assumed. However, as cited above there is actually evidence that lake phosphorus retention has probably been *reduced* because of lowered oxygen in the hypolimnion in some years.

AECOM (2014) does not mention that evidence in relation to the lake P Retention coefficient, but it does cite two possible sources of error (p 10 of Appendix E) that could have resulted in the overestimation of Total P under existing conditions: (i) removal of phosphorous en route from the sources to the lake in the ground for systems on septic, and in watercourses or overland flow; and (ii) dilution by groundwater; these factors are not included in the standard LCM model as presented by Brylinski (2004).

The extent of dilution by groundwater would depend on the concentration of phosphorus in the ground water (likely to be less and possibly zero or much less than in surface waters), and the flow of groundwater relative to surface waters. They estimated the flow of groundwater to be 11% of total flow, so the error associated with this factor is likely to be low in comparison to the difference between predicted Total P values for existing conditions and actual values.

The absorption of septic P en route to the lake is also likely to be small compared to the overestimate of Total P under existing conditions, as diverting both the Uplands Park Waste Water Treatment Facility effluent (or the input to the Facility) reduces lake total P by only 1 ug/L according to the AECOM 2014 model.

Removal of phosphorus as water flows through watercourses however could be very significant. From Brylinski (2004):

> The model makes no allowance for the assimilation of phosphorus within upstream rivers or streams entering a lake, or for tributaries contained within a lake's drainage basin. This is a potentially serious limitation if the model is used to determine the permissible level of development within the watershed of a lake that has effluents entering lakes located downstream. If a downstream lake exceeds a phosphorus objective, no upstream development would be allowed.
>
> The retention of phosphorus in streams and rivers can result from settling of particulate phosphorus, sorption of dissolved phosphorus to stream sediments, chemical precipitation of phosphorus, and uptake of phosphorus by benthic algae and macrophytes (Wagner et al. 1996). Behrendt and Opitz (2000) carried out a number of studies in which it was found that as much as 20 to 40 % of the phosphorus load was retained within streams before reaching the receiving water body.

This limitation is acknowledged in Appendix E of the AECOM 2014 Report, p. 10 and it is commented that "The retention of phosphorus from water as it travels through the watershed can be approximated in the LCM by varying the phosphorus export coefficient as needed". However, that was not done, rather "the lake phosphorus retention factor (a variable that approximates the amount of phosphorus removed through sedimentation within a lake) can be used to approximate both phosphorus retention during transport and dilution by groundwater."

There could be a large difference between the effects of development on lake Total P so estimated, and the effects if they were estimated with consideration of P removal in watercourses. Currently, phosphorus from settled areas goes into watercourses fairly high up in the watercourses; much of the proposed development would be closer to the lake and thus bypass a lot of the watercourse, including the large wetland NIA1. This could result in a much higher proportion of the phosphorus from settled areas going into the lake than currently assumed.

(iv) *Further monitoring, as strongly advised by AECOM 2014, has not been conducted.*

One route Brylinski (2004) and MOE (2010) advised to revising an invalid model is to conduct more monitoring; AECOM 2014 was explicit on the need for more monitoring. From page iii of the Executive Summary:

> "The predictions from the phosphorus load model are consistent with observations of urbanization in other watersheds. However, the degree of influence of urbanization on water quality in Sandy Lake can only be approximated using the phosphorus load model because of limitations arising from assumptions and uncertainty in the application of the model. Therefore a robust water quality monitoring plan is proposed for the Sandy Lake watershed to provide a further assessment of current conditions and to evaluate the impacts of development on the water quality."

Section 9 (p 42) in AECOM (2014) provides specific recommendations for robust Water Quality Monitoring.

The AECOM Report was submitted in 2014. In 2020, such monitoring has still not been initiated, and, I am told, a request for Secondary Planning in the study area of the AECOM report was submitted to HRM in the summer of 2020.

So we could be proceeding to secondary planning without any validation of the AECOM model as advised by AECOM 2014, or revision of the model as advised by Brylinksi (2004).

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Mirror Lake – Sandy Lake comparison

There is a well documented example of spring turnover being impaired at chloride levels below 120 mg/L* and when summer profiles of temperature, oxygen and EC are similar to profiles for Sandy Lake; it is for Mirror Lake, (50 ha, 18 m maximum depth) at Lake Placid, N.Y. in the Adirondack Mountains:

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*The CCME guideline for chloride ion for the protection of aquatic life for long term exposure; 120 mg/L is equivalent to EC of 470 uS/cm using the AECOM (2020) conversion equation.

> **A reduction in spring mixing due to road salt runoff entering Mirror Lake (Lake Placid, NY)** by B. Wiltse et al., 2020, *Lake and Reservoir Management* 36:109–121.

Improved monitoring in this oligotrophic lake, initiated in 2014, revealed that the deepest area of the lake was sometimes anoxic during the summer, also observers had noted that chloride and EC had increased substantially over historic levels. They were concerned that salts could be causing some impairment of the seasonal turnover expected for this typically dimictic lake. Biweekly sampling was conducted though all of 2016 and 2017, allowing detailed charts to be drawn up showing the changes in temperature, chloride (calculated from EC values), oxygen and calculated density over the entire water column through those two years.

The lake exhibited normal spring turnover in 2016, but in 2017, when the difference between surface and deep water chloride in the January to April period increased by approx. 1.75 fold compared to 2016, there was no spring turnover.

From the paper (literature citations and references to tables and figures are omitted):

> The hypolimnion was anoxic during summer stratification in both years The duration and spatial extent of the anoxic conditions were greater in 2017. Anoxic conditions were present at the lake bottom during the winter in 2017, but not in 2016…Lake trout habitat was restricted in both 2016 and 2017 by warm surface water and anoxic conditions in the hypolimnion…
>
> The incomplete mixing in the spring of 2017 resulted in a longer duration and spatial extent of anoxic conditions in the hypolimnion, which have consequences for both the chemistry and biology of the lake. The lack of oxygen in the hypolimnion shifts the redox chemistry, causing mobility of phosphorus, manganese, iron, and other ions from the sediments and particulates in the water column. This has the potential to lead to toxic concentrations of trace metals, sulfide, and ammonia in the hypolimnion, combined with anoxia, which can result in declines in biodiversity as well as fish kills. Prolonged periods of anoxia also may lead to increased internal phosphorus loading in the lake…Precambrian shield lakes, such as Mirror Lake, typically have low rates of internal phosphorus loading, but also tend to be phosphorus limited.. Therefore, increases in internal phosphorus loading of these lakes can be ecologically significant.

> Lake trout are the only native cold-water lake- dwelling top predatory fish in the Adirondack Park… Narrow habitat requirements (cold, well-oxygenated water), slow growth, and late sexual maturity make lake trout particularly vulnerable to climate change, eutrophication, and other stressors. In small upland lakes, like Mirror Lake, lake trout habitat is likely to decline with increasing temperatures. Mirror Lake has demonstrated a significant increase in the ice-free period over the past 114years, with the lake currently experiencing an average of 24 more days being ice-free than in the early 1900s… Climate-driven effects on the lake trout population in Mirror Lake will be further exacerbated by the lack of complete mixing in the spring.
>
> The small amount of historical data for Mirror Lake suggests that incomplete mixing is not a natural occurrence for the lake… Other historical data suggest that incomplete mixing is a more recent phenomenon for the lake. Surveys of the lake in August 1971 and August 1974 generally found hypolimnetic dissolved oxygen concentrations and specific conductance consistent with greater mixing… Despite the low dissolved oxygen in 1974, specific conductance measurements from that day show a 16 uS/cm difference from the surface to the bottom, indicating that there was little or no chemical stratification. A survey on 10 August 2001 found 0 mg/L of dissolved oxygen at 15 m and a difference in specific conductance from surface to bottom of 150.5 uS/cm, consistent with a lack of spring mixing.
>
> We believe that restoration of the lake to dimictic conditions would occur during the spring following a substantial reduction in salt load. The lake has demonstrated an ability to overcome the salt-induced density gradient during fall mixing, and without the establishment of a new gradient the following winter, the lake would mix in the spring. The winter of 2015–2016 offers a glimpse at the restoration potential for the lake. Following a winter with less snowfall and a lower salt load, the lake completely mixed in the spring. Substantial reductions in the application of road salt within the watershed, coupled with stormwater improvements to retain stormwater runoff before entering the lake, would provide marked improvements in the water quality of Mirror Lake.

To facilitate some comparison with the more limited data we have on Sandy Lake, the following stats on chloride were extracted from the Mirror Lake paper; values are approximate as they were interpolated from charts; chloride values were converted to EC values using the conversion formula for Halifax area lakes given in AECOM (2020).

Top: Chloride concentration and equivalent EC values at the surface and near the bottom of Mirror Lake
when the differences between top and bottom were at their peak for the winter and summer periods of lake

stratification respectively. **Bottom: EC values at the surface and near the bottom of Sandy Lake** during or close to the end of the summer stratification period for 4 years over the interval 1971 to 2019.

The recent (2017 and 2019) EC values for Sandy Lake in summer are similar to those for Mirror Lake in 2016; while the maximum deep water value for Mirror Lake in 2017 is only 23% higher than the highest deep water value for the two Sandy lake profiles in 2017 and 2019. (That particular profile was obtained when the stratification was breaking down and it's possible that an earlier sampling would have revealed higher EC in the hypolimnion.)

If seasonal stratification and turnover at Sandy Lake behave similarly to Mirror Lake, it seems possible that spring turnover in Sandy Lake is likewise being impaired in some years. Clearly, we should monitor the lake profile in the spring when the lake would be expected to be fully mixed, and in the late summer/early fall to get some assessment of whether spring turnover is being impaired, and of the effects on hypolimnion oxygen during the summer/fall stratification.

Even if such impairment has not occurred to date, it seems clear that that Sandy Lake is on track for some impairment of spring turnover, and very possibly even before salt levels exceed 120 mg/L Chloride/EC 470 uS/cm (the CCME guideline for chloride ion for the protection of aquatic life for long term exposure).

The 2019 report for Mirror Lake provides some detail on Total P status of Mirror Lake:

From Mirror Lake 2019 Water Quality Report

> In 2019, total phosphorus concentrations at the surface were generally low and consistent with an oligotrophic lake. Hypolimnion total phosphorus concentrations increased through the summer stratified period. When phosphorus rich organic sediments are exposed to anoxic conditions for prolonged periods of time, phosphorus is released from sediments and moves back into the water column (Wetzel 2001). This results in internal phosphorus loading in the lake. As long as this phosphorus remains trapped in the cold, dark hypolimnion it will not result in increased primary production. However, if the lake were to partially mix during a period when hypolimnion phosphorus concentrations are high, this could trigger an algal bloom. The small surface area and orientation of the long axis of the lake perpendicular to the predominant wind direction, reduces the

likelihood of mixing during the summer stratified period. If a strong southerly wind were to create a seiche in the lake it is possible that a portion of the phosphorus rich bottom water could be mixed to the surface and trigger an algal bloom.

How comparable are the two lakes?

Mirror Lake area and depth (50 ha, 18 m maximum depth) are similar to Sandy Lake (78.5 ha, 21 m maximum depth; also similar is the percent forested (51% Mirror Lake 48% Sandy lake), and the percent developed (27% and 29%), however Mirror lake is a much smaller watershed (301 ha versus) 2420 ha for Sandy Lake, and correspondingly it has a much lower flushing rate (0.59 T/Y – 2014 Lake Assessment Report) than Sandy Lake (3.4 times per year, AECOM 2014). Twenty-two stormwater outfalls discharge directly in Mirror Lake; at Sandy Lake such discharge is into streams that drain into Sandy Lake. The volume of Mirror Lake is 4,250,000 m^3, Sandy Lake 6,080,000 m^3.

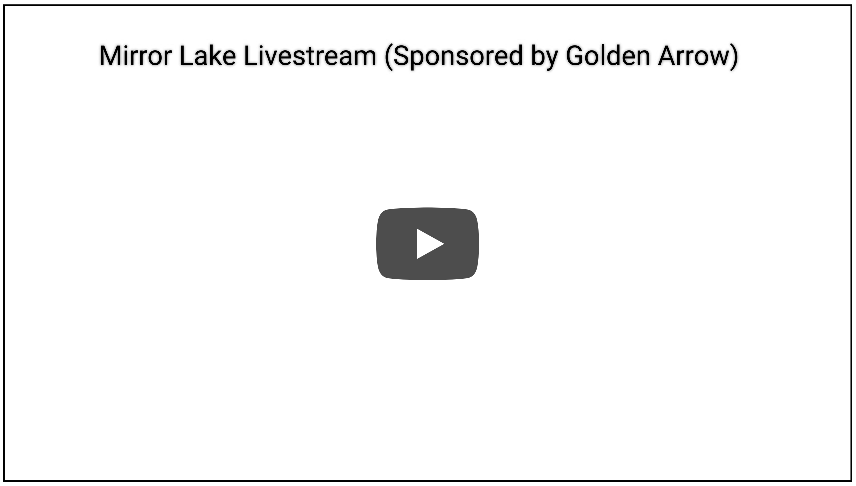
Mirror lake is the most developed lake within the Adirondak Park. There is a small lake upstream. The headwaters are forested and the development is concentrated around the lake. To date at Sandy Lake, most of the development within the watershed is not close to the lake, however, if development proposed above Hammonds Plains Road goes ahead there would be a lot more development within 1000 m of the lake.

Like Sandy Lake historically, Mirror Lake is still oligotrophic by the Total P criterion. Nevertheless, in recent years, deep waters in Mirror Lake had elevated levels of Total P due to hypoxia or anoxia during summer stratification. Wiltse et al. (2020) commented that "that incomplete mixing is not a natural occurrence for the lake" and attributed the incomplete mixing to salt stratification during the period of the normal spring turnover.

We have very limited data on deep water Total P in Sandy Lake, but what is available is suggestive of similar patterns in Sandy Lake: for two out of three years in the interval 2008 to 2011 when water samples were taken during the summer from the surface and near the bottom, Total P was highly elevated in the deep water samples (AECOM 2014).

On the other hand, it is equally plausible that the reduced hypolimnion oxygen in late summer/early fall is associated with increased input of organic and nutrients to the lake with increasing urbanization in the watershed; in this context, the "salt signal" is an "urbanization signal" more broadly. Both phenomena could have been involved in the past. A program of spring and late summer monitoring as suggested by AECOM (2020) should help to sort it all out.

More on Mirror Lake



(View From the Air for equivalent views of Sandy Lake.)

Ausable River Association: Mirror Lake

Website, with subpages on Mirror Lake. Includes detailed annual reports 2014 to 2019.

Road salt pollutes lake in one of the largest US protected areas, new study shows

www.eurekalert.org NEWS RELEASE 9-DEC-2019 "Mirror Lake is the first in the Adirondack Park to show an interruption in lake turnover due to road salt", says Dr. Brendan Wiltse from Ausable River Association, who led the study. Mirror Lake, located in the Village of Lake Placid, is the most developed lake within the Adirondack Park – a publicly protected area greater than Yellowstone, Yosemite, Glacier, and Grand Canyon National Parks combined. Like many northern temperate lakes, Mirror Lake experiences 'dimictic' turnover – a natural process where wind and less stratified water conditions (layers of different temperature and density) of spring and fall allows mixing of the water column that redistributes oxygen and nutrients throughout the lake. High levels of surface-water chloride were first noticed in Mirror Lake in 2014 when it was surveyed as part of the Adirondack Lake Assessment Program, and so the following year, Wiltse and colleagues began monitoring Mirror Lake more intensely…."