OXYGENATION OF SHELDRAKE LAKE

FINAL REPORT TO WOODENS RIVER WATERSHED ENVIRONMENTAL ORGANIZATION

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INTRODUCTION

In 1991, the Soil and Water Conservation Society of Halifax (SWCS) carried an extensive study of the water quality in several lakes in the Woddens River Watershed. Among other things, they found that Sheldrake Lake became anoxic in the summer and had a phosphate level of 27 μg P/l (0.87 μM)[1]. This was much higher that than found in the other lakes.

While anoxia is common in the lakes in the watershed, the high phosphate level was cause for concern. Phosphate levels are widely used to evaluate the water quality of a lake. For example, 0.16 –0.32 μM = epitrophic (good); 0.32-0.97 μM = mesotrophic (average); 0.97-3.23 μM = eutrophic (bad). High levels of phosphate >1 μM can lead to algae blooms that compromise the recreationsal use of the lake.

The 1991 data placed Sheldrake as "late mesotrophic". In 1994, SWCS issued the following statement: "The theoretical phosphorus loading model predicts a future mean TP conc. of 41.7 μg/l" [1.35 μM]. This, if true, would place Sheldrake as "early eutrophic", which is undesirable[2].

Based on their study, SWCS issued the following reccomendation for Sheldrake: "NSDOE should consider the installation of hypolimnetic aeration in order to provide a suitable refuge for salmonoids, herbivores and other food-web organisms".

In November of 2000, we confirmed that the phosphate concentration in Sheldrake was much higher than several other lakes in the watereshed. Fig. 1 shows those results:

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[1] Phosphate concentration is usually reported as μg P/l. While that is a convenient unit, it can be misleading. There is no phosphorus (P) in our lakes. Phosphorus bursts into flame on contact air. It combines with four oxygen atoms to form a phosphate ion (PO_4^{-3}). Secondly, phosphate is not measured by weight (μg). It is converted to "molybdenum blue" and measured in a specrophotometer. It is just as convenient to use μM (micromols/liter) as the unit and there is a big advantage. Molar concentration counts molecules and is independent of the nature of the molecule. Thus, a 1 M solution contains 6.02×10^{23} molecules/liter. A 1μM solution contains 6.02×10^{17} molecules/liter. We will use μM; to convert to μg/l, multiply by 31.

[2] Phosphate concentration is a useful tool for predicting the "trophic status" of a lake, However, the real evaluation of a lake is more complicated than this and depends, to a large degree, on subjective judgement. Furthermore, the predictions a model makes are no better than the data and assumptions that are used to run the model. It should be noted that the current concentration (spring, 2010) is 0.45 μM, not the 1.35 μM predicted.

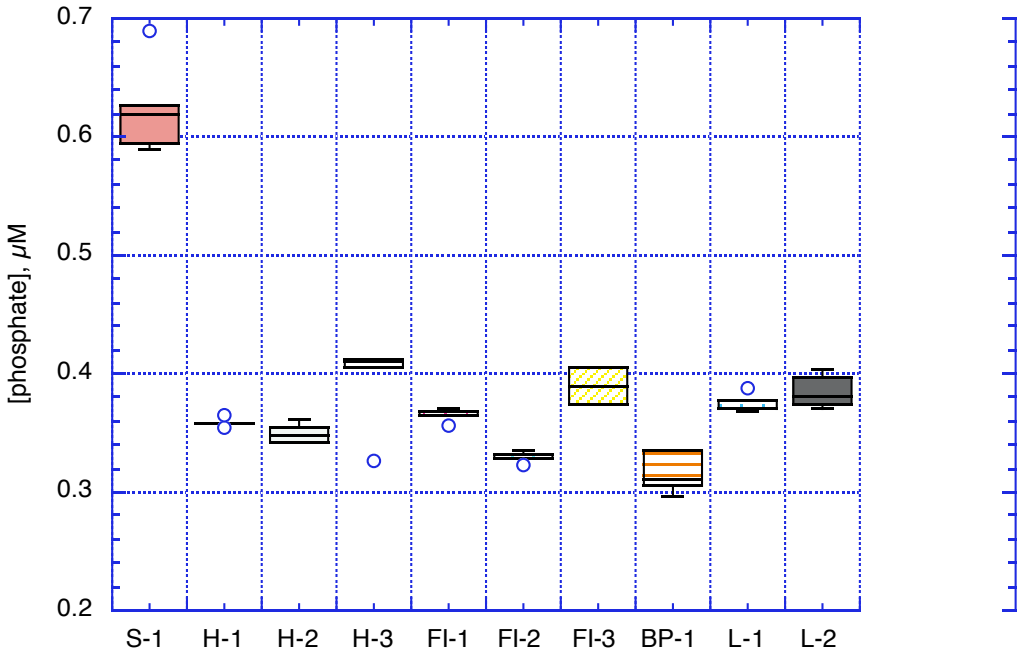

Fig. 1. Comparison of the Phosphate Concentrations in Eight Lakes in the Woodens River Watershed on November 22, 2000. Five samples were taken were taken at 1 m at each station. The Box Plots were calculated from the data with Kleidagraph. The circles represent "outliers". If the boxes overlap, there is no significant difference between the means. This was confirmed by Student's t-tests. S=Sheldrake, H=Hubley, FI = Five Island, BP = Black Point, L = Long.

Based on the recommendation by SWCS, WRWEO, under the leadership of Tim McGee, a consideable sum of money was raised to purchase the necessary equipment and fund an oxygenation project. Through the efforts of Frank Hope, WRWEO obtained the specifications for an aeration devise from Ken Ashley Associates, an engineering and limnology consulting firm in British Columbia. Through the effort of Rich Campbell, Tim MeGee, Frank Hope, Hanna Jenner and several other members of WRWEO and the Sheldrake Homeowners Association, the aeration project was initiated in the spring of 2009. This report describes the results of the project in 2009.

Rationale:

Phosphate is an essential nutrient. All living cells require significant amounts, which must be furnished from the envirenment[3]. Very often, phosphate is the limiting nutrient for algae growth. However, the phosphate concentration is related, amoung other things, to oxygen levels, and oxyen levels are dependent upon temperature and pressure.

[3] For Sheldrake, there are several sources. Streams that feed the lake (from Upper Sheldrake Lake and from the small stream that runs under the playground) ; run-off from the surrounding land; aerosols; sediment at the bottom of the lake; dead algae in the anoxic zone.

In the summer, the lake stratifies. Three distinct temperature layers develop:

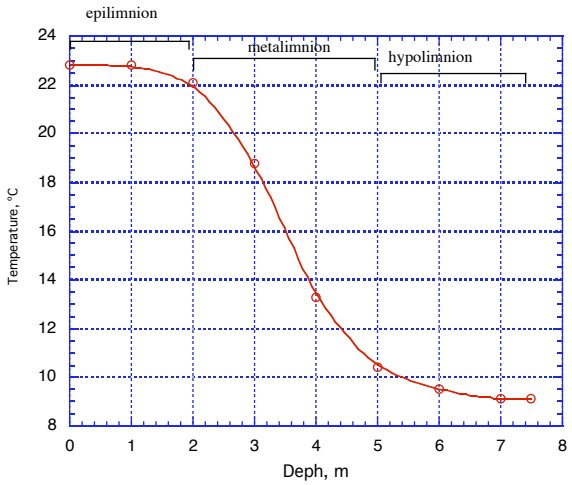

Fig. 2. Stratification of Sheldrake Lake on August 22, 1995.

These layers are given the essoteric names epilimnion (upper layer), mesolimnion (middle layer and hypolimnion (lower layer). Temperature gradients (thermoclines) similar to that shown in Fig. 2 develop in lakes in the watershed where the sampling station is more that 5 m. deep. We have observed this on five of the eight lakes studied[4].

As the lake stratifies, it becomes anoxic and the phosphate level increase dramatically. Fig. 3 shows the inverse relationship between the dissolved oxygen levels and the phosphate concentration:

[4] Birch Hill, Cranberry, Five Island, Hubley and Sheldrake.

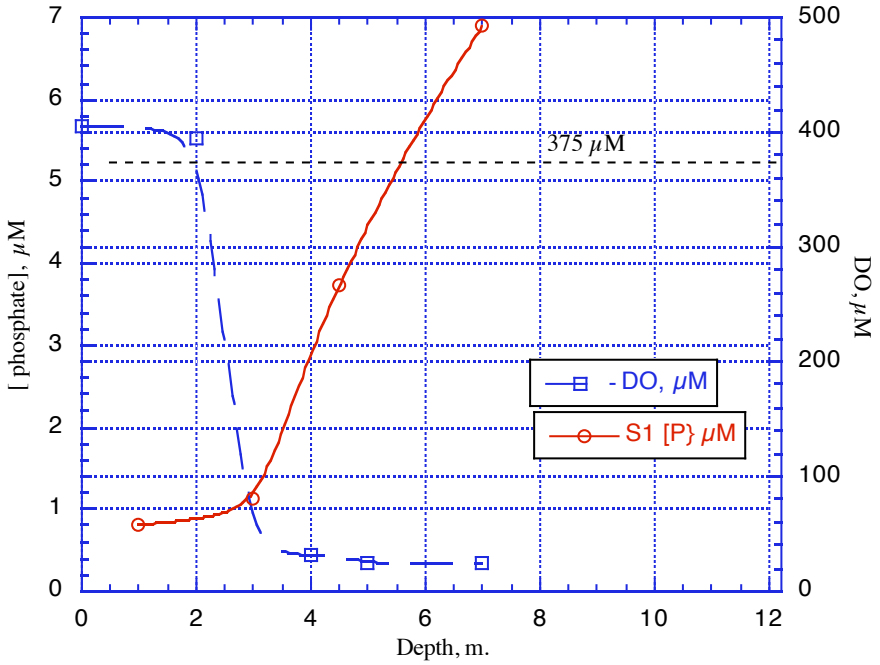

Fig. 3. The Reciprocal Relationship Between Dissolved Oxygen and Phosphate Concentration on Sheldrake Lake on August 22, 1995. The arrow indicates the level of oxygen required to sustain trout (right axis).

The lake becomes anoxic at 3 m. Trout require at least 375 μM dissolved oxygen. This occurs ar about 2 m. as shown in Fig. 3. The DO drops rapidly, and the lower layer (hypolimnion) becomes anoxic. As the DO decreases, phosphate increases. Therefore, if anoxia could be prevented by aeration of the lake, the increase in phosphate should also be reduced. There is precident for this. However, it not clear what would happen in a relatively shallow, highly colored lake (110 Hazen units) such as Sheldrake. Thus, the aeration project represented a particularly interesting experiment.

Based on these considerations the following objectives were set up:

Objectives

1. Slow down eutrophication by reducing the phosphate.
2. Improve the fish habitat.

Questions to Answer

1. Does the aerator prevent anoxia?
2. Does the aerator work without disturbing the thermocline?
3. How far does the oxygenation extend?
4. Does oxygenation reduce the phosphate levels?

Base line studies were initiated on April 28. The aerator was activated on May 9. This report provides a background for the project and describes the results of the experiment.

EXPERIMENTAL PROCEDURES[5]

Sampling Stations were established as shown in Fig. 4. S1 is at the deepest part of the lake (7-8 m). The aeration distribution box is located here. S4 is located close to houses. S2 is far removed fomr any houses. These two statons were extablished to see if we coluld detect any difference in the samples taken close to houses and those far removed from houses. No differences were found.

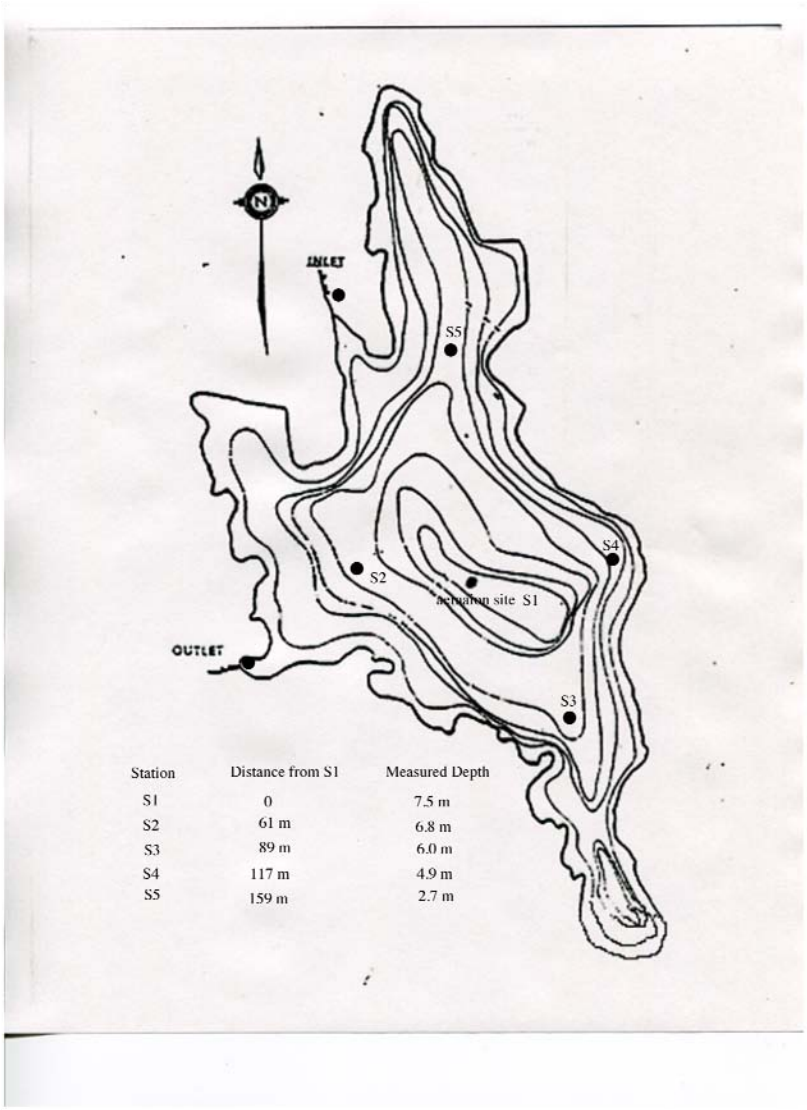

Fig. 4. Sampling Stations on Sheldrake Lake.

Temperature, dissolved oxygen and pH were measured on site with a YSI 556 multiprobe meter[6]. Often, when submersed with the metal guard in place, the probe gave abnormally low pH readings. The reasons for this are not clear. Therefore, pH was measured both on

[5] We are indebted to Mr. David Bryson for funds to carry out these analyses.

[6] The oxygen probe was standardized against air saturated with water vapor using the current barometric pressure at sea level furnished by the Halifax Weather Service. Sheldrake Lake is at about 243 m above sea level. The correction for this is negligible.

site with the YSI 556 probe and in the laboratory with a Radiometer pH meter and Beckman electrodes. When a discrepancy was found, the laboratory results are reported.

Samples were taken for phosphate analysis at various depths using a grab sampler for surface samples and Kemmerer Sampler for other depths. The samples were collected in 200 ml, high density polyethelene bottles that were rinsed rinsed three times with lake water before collecting the sample.

Samples for chlorophyll and phaeophatin analysis were delivered to the laboratory on the same day. For other measurements, samples were frozen as soon as possible and stored for subsequent transport to the laboratory. On arrival at the laboratory, the samples were thawed. The pH of the samples was measured. An an aliquot was frozen for later phosphate analysis. The remaining sample was refrigerated until it could be analyzed further. Color, and total phosphate were measured within five days of collection[7].

Phosphate analysis was performed by the method of Murphy and Riley[8] This method measures total phosphate. Briefly, each sample was digested with persulfuric acid to lyse cells and convert organic phospahte to inorganic. The "molybdenum blue" color was developed by reduction with ascorbic acid and measured spectrophotometrically at 880 nm. Each sample was analyzed in duplicate and the absorbance values averaged. Absorbance was converted to μg P/l using a standard curve prepared with known amounts of KH_2PO_4. These data were converted to μM by dividing by the atomic weight of phosphorus (31).

Color. Unfiltered samples were examined spetrophotometrically for color at 400 nm[9] .A standard curve was prepared with a stock solution containing 2.492 g. K_2PtCl_6 + 2 g. $CoCl_2{\cdot}6H_2O$ + 200 ml conc. HCl made up to 1 liter with distilled water. This solution contains 1 mg/ml Pt and is 0.005M in Pt. A "total color unit" (TCU) has been defined as 1 mg Pt.

Statistical Analyses: Means and standard deviations were calculated. Plots of the data were made with the computer program, Kleidagraph. Curve fitting was done with Kleidagraph, which uses the least squares method.

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[7] Phosphate, color, chlorophyll a and phaeophytin analyses were done at the Centre for Water Resource Studies at Dalhousie University. We are indebted to Mr. Richard Scott for these analyses

[8] Murphy, J. and Riley, J (1962). *Anal. Chim. Acta*, **27**, 31

[9] Hongave, D. and Akesson, G. (1996). *Wat. Res.*, **30**, 2771-2775. The authors show that 410 nm is a more appropriate than 400 nm if one wishes to compare the results with older data obtained with a visual color comparator. Our spectrophotometric data, however, are internally consistent.

RESULTS AND DISCUSSION

Thermocline: In the Spring, Sheldrake is fairly well mixed as judged by the temperature profile at five sampling stations. Fig. 5 shows the results for S1[10]. The results at the other stations were similar.

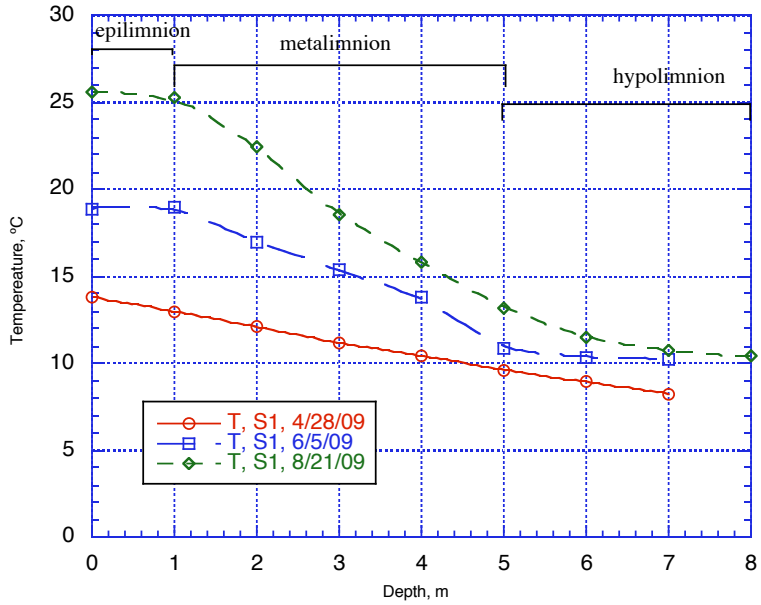

Fig. 5. Stratification of Sheldrake Lake as Measured by Temperature (2009).

On April 28, before the aerator was started, there is a small, linear thermocline (8-14° C). This is normal. There are no well defined layers at this time. A week later (June 5) stratification had begun. As sown in Fig. 5, three layers were evident. Stratification continued as the lake warmed up. The process is usually complete in July (data not shown). The top curve (August 21) shows a typical themocline when the lake is fully statified. Throughout the stratification process, the temperature in the upper layer (epilimnion) continues to increase, but the temperature in the lower layer (hypolimnion) remains within a narrow range (8-11 ° C). These results are similar to those obtained in earlier studies. These data are important. The oxygenation equipment must deliver oxygen to the hypolimnion without disturbing the thermocline in order to preserve the cool water that trout need.

Dissolved Oxygen: Fig. 6 shows the dissolved oxygen concentrations that correspond to the temperature changes shown in Fig. 5. This figure shows the progress of the oxygenation project[10].

[10] We took weekly readings. Some of the data has been omitted because it clutters up the figure and does note add any new information.

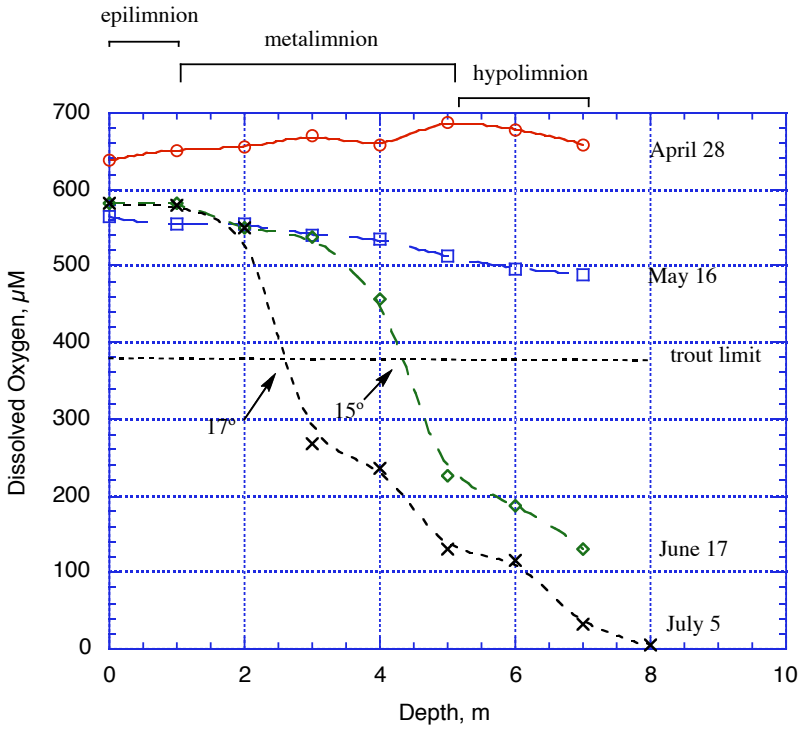

Fig 6. Dissolved Oxygen at S1 of Sheldrake in 2009. The horizontal, dashed line indicates the oxygen cut-of for trout(6 mg/l = 375 μM).

In general, the amount of oxygen that can dissolve in the lake depends on the barometric pressure and the temperature. The meter is standardized against the current barometric so the DO is a function of temperture. Cold water holds more oxygen than warm water. Therefore, we should see more oxygen in the lower layer (hypolimnion) than in the upper layer (epilimnion). The top curve (April 28) agrees with this. As the epilimnion warms up, we should see a decrease in DO. Fig. 6 shows this (compare the values at the surface; far left of graph). However, as the lake stratifies, the temperature decreases with depth. therefore, the DO should increase with depth. As shown in Fig. 6, we see the reverse. Clearly, oxygen is being used up faster than it can be delivered.

The aerator was turned on May 9. Vigourus bubbling was oberved in the distribution box at S1. The equipments seemed to be working as expected. However, on May 16, there was an indication that the DO in the hypolimnion was decreasing. A month later (June 17), it was clear that the aeaation was not proceeding as hoped. Oxygen became limiting for trout at about 4.5 m. The temperature was 15° at this depth. On June 26, a sample taken at 5m inside the discharge tube gave DO = 425 μM (62% saturation) compared to 175 μM (26% saturation) at 5 m outside the discharge tube in the lake about 2 m from the dischage tube. This low value was confirmed by a Winkler titration. While the aearator was delivering some oxygen to the hypolimnion, it was insufficient to prevent anoxia.

On July 5, as shown in Fig. 6, oxygen became limiting at abouty 2.5 m. where the temperature was 17°. The lake was anoxic near the bottom. Based on these results, the aerator was turned off and the project was terminated for the year. However, we took samples on August 21.The dissolved oxygen profile shown in Fig. 7:

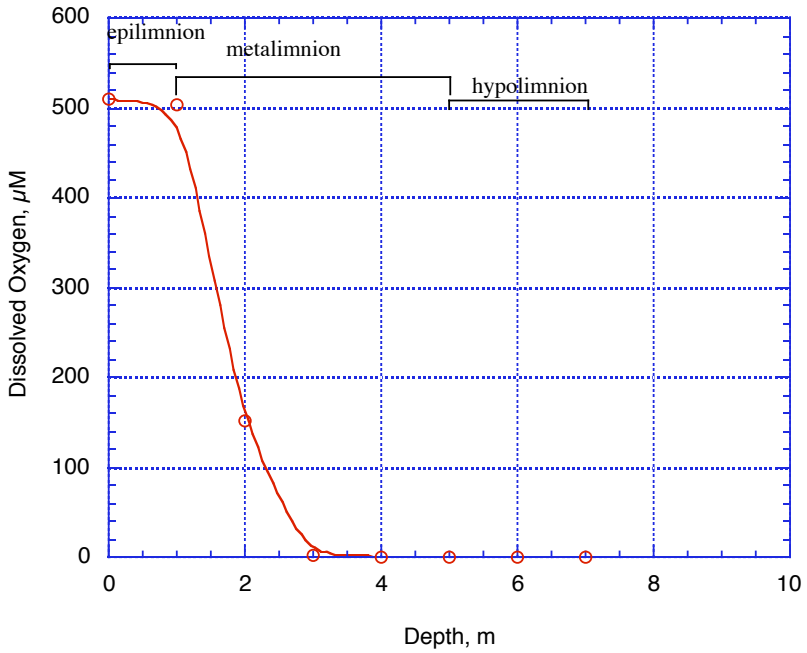

Fig. 7. Dissolved Oxygen in Sheldrake Lake at S1 on August 21, 2009. The layers are based on temperture data.

Why Does the Lake Become Anoxic? There is plenty of oxygen in the air, and the air is in contact with the surface of the lake. However, oxygen must difuse from the surface to the bottom. Difussion is slow, but given time, oxygen from the air should get down to the hypolimnion. When oxygen is used up faster than it can be delivered, the lake becomes anoxic.

A lake is a dynamic ecosystem. In addition to fish and aquatic plants that we can see, there are a variety of organisms that we cannot see with the naked eye. The sediment on the bottom is full of bacteria. Some of these are quite versitle; they can live either with or without oxygen. They prey on dead organisms such as algae. Microscopic animals (zooplanckton) are also present. They require oxygen. Algae, which are plants, are important components of most bodies of water. Some forms of algae are visable; they form filimentous, green mats on the suface. Other forms are microscopic. Nomally, we cannot see them. However, under the proper conditions, they can form a bloom that turns a lake green. All forms of algae produce oxygen by photosynthesis. In fact, they are responsible for much of the oxygen in our lakes. However, they too are versitle. If there is insufficient

sunlight to carry out photosynthesis, their metabolism changes to respiration, and they use up oxygen just like animal cells. There is a delicate balance between the metabolism of organisms that use oxygen and those that produce it.

At depths greater than 5 m., anoxia is a normal process in our lakes. We have observed it in Birch Hill, Five Island, Hubley, Cranberry and Frederick and Sheldrake Lakes.

Phosphate Concentration. There was very little diffenence in the values obtained at different depths in the spring indicating that the lake is fairly well mixed at this time of year. The available data are shown in Table 1:

Table 1. Phosphate Concentration in Sheldrake Lake, 1991-2010.

Date	collected by	depth, m	inlet[PO_4], µM	S1 [PO_4], µM	outlet. µM
May 23, 1991	SWCS	0	n.a.	0.87	n.a.
May 3, 1992	SWCS	2	n.a.	0.35	n.a
May 15, 1995	CWRS	2	n.a.	0.40	n.a.
May 31, 2001	RWC	1	n.a.	0.63	0.52
June 11, 2002	RWC	1	n.a.	0.61	n.a.
April 28, 2009	RWC	1	0.33	0.44	0.425
April 24, 2010	CWRS	1	0.18	0.45	0.37

Fig. 8 shows a plot of the S1 data in Table 1:

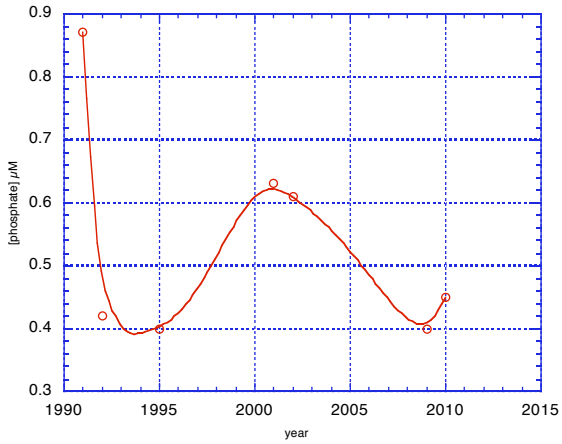

Fig. 8. Spring Phosphate Concentrations in Sheldrake Lake, 1991-2010.
The data are from Table 1.

The 2009 value shown in Fig. 8 was obtained just before the aerator was turned on. It represents a baseline for the aeration project. Some caution is required in interpreting the results shown in Fig. 8 because the samples were taken at different depths (see Table 1). Even in the spring, when the lake is faily well mixed, there are sometimes significant differences between samples taken at different depths. Fig. 9 illustrates this:

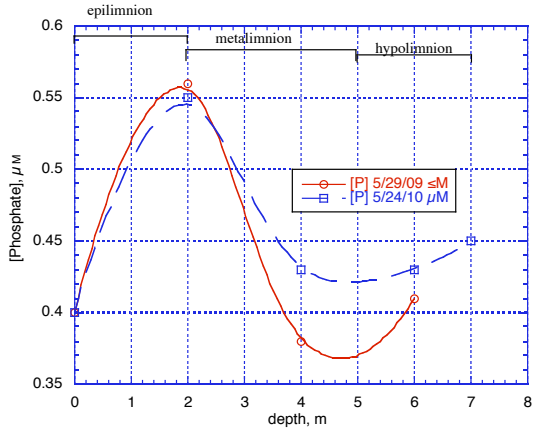

Fig. 9. Phosphate Concentration as a Function of Sample Depth in the Spring of 2009 and 2010.

The results for 2009, before the start of aeration, and for the following year are very similar. The maximum concentration occurs at about 2 m. The position of this peak is close to the Secchi depth (1.5 m in 2009, 2.4 m. in 2010). Thus, the maximum phosphate concentration occurs near the limit of the photic zone. It may be due to lysis of algae cells that no longer have sufficient light to carry out photosynthesis.

The phosphate concentrations are higher at 1 and 2 m than at the surface. The difference between the 1 and 2 m. samples is fairly small (6%). However, the difference between 0 and 2 m. is significant (37%). Thus, if anything, the 1992-2010 data shown in Table 1 tend to overestimate the concentration compared to the surface value obtained in 1991. It is very important that future samples be taken from the surface and 2 m. in order to compare with earlier data.

In spite of these uncertainties, three important points emerge from these data. First, the phosphate concentrations vary from year to year. It is not clear whether the concentration has leveled off or has started a new cycle. It is even possible that the flutuation is random and depends on a number of factors such as rainfall.

Second, the values at S1 for 2009 and 2010 (0.44 and 0.45 μM) are much lower than the value (0.87 μM) that lead to the SWCS recommendation that the lake be aerated. Furthermore, the observed value (0.45 μM) is considerably less than the value predicted by the SWCS model (1.35 μM). In fact, the 2009 and 2010 levels are similar to those found in other lakes in the watershed (0.32-0.45 μM). It is of considerable interest to see how the levels change in the next few years.

Third, the data in Table 1 show that the concentrations at the outlet is higher that at the inlet. Therefore, the phosphate should decrease unless there is another source. As pointed out previously, there are several potential sources. Phosphate from these sources tends collect in the sediment on the bottom of the lake.

The spring and fall phosphate concentrations are impotant, but the values obtained when the lake becomes anoxic are the most interesting. Fig. 10 shows the results obtained in 2001 and 2002.

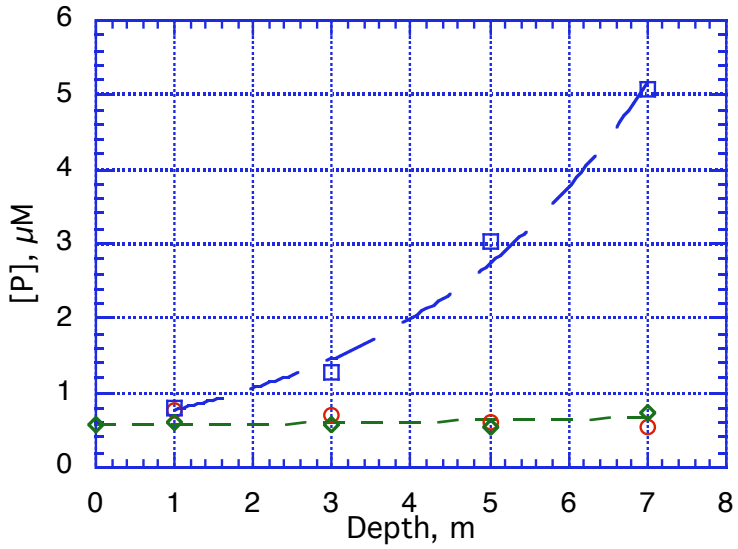

Fig. 10. Phosphate Concentration at Station 1 of Sheldrake Lake in the Summer of 2002. ○ November 11, 2001; ◇ June 6, 2002; □ July 31, 2002. The July 31 data fit the equation: [P] (in μM) = 0.56182 e $^{0.31715\ d}$, R =0.99, where d = depth in meters.

In the spring and fall, the concentrations were low (≈ 0.6 μM). In the late summer, when the lake was fully stratified and anoxic, the phosphate concentation increased almost 10-fold at 7 m. There is a clear concentration gradient from the surface to the bottom.

Table 2 shows the data for color, phosphate, chlorpphyll a and phaeophytin in the fall of 1995 and 2009:

Table 2.[11] Color, Phosphate, Clorophyll and Phaeophytin at S1 of Sheldrake Lake on August 22, 1995 and August 21, 2009

Date	Depth, m	color, Hz	[P], μM	Chl a, nM	Phaeophytin,nM	Chl+ Pha
8/22/95	0	110	0.81	9.1	n.a	n.a
8/22/95	3	140	1.13	9.75	n.a	n.a
8/21/09	0	80	0.77	7.5	0.1	6.4
8/21/09	3	233	1.56	2.7	6.6	8.7

[11] We are indebted to Mr. Richard Scott of CWRS for these data. Chlorophyll a and phaeophyin were reported in μg/l. The values were converted to nanamolar (nM) using MW chlorophyll a = 893.5 and MW phaeophytin = 869.5.

The [P] data are consistent with that shown in Fig. 10. However, because the fall values are so sensitive to depth, comparing years may be deceptive.

Chlorophyll is often used as a measure of algal mass. Table 3 compares the chlorophyll level in Sheldake with the levels in several close by lakes in the watershed.:

Table 3. Comparison of Chlorophyll a Concentrations in Several Lakes on August 22,1995.

Lake	Chlorophyll a, μM
Sheldrake (S-1), 1m	9.1
Black Point (BP-1), surface	4.8
Frederick (F-1), surface	7.9
Hubley (H-1), 2 m.	3.7
Hubley (H-2), 2 m.	2.3
Hubley (H-3), 2 m.	3.4
Hubley (H-4), 2m	2.3
Hubley (H-5), surface	1.7
Five Island (FI-1), 1 m.	4.5
Five island (FI-2), 1m.	1.8
Five Islan (FI-3), 1 m.	2.2

Although there is some uncertainty because samples were taken at different depths, it is clear that in 1995 Sheldrake and Frederick lakes had levels significantly higher than the other lakes. However, as shown in Table 2, the concentrations at S1 of Sheldrake have decreased since 1995.

Phaeophyin is usually considered a degredation product of chlorophyll a. Table 2 shows a large increase in phaeophytin at 3 m. compared to 1 m. Fig. 7 shows the lake is anoxic at 3 m. The Secchi depth was 1.75 m. so there insuficient light at 3 m. to support photosynthesis. Thus, the increase in phaeophytin may indicate acculation of dead cells at 3 m.

Acidity:

Acidity is usually expressed as pH, which is defined as $pH = 1/\log [H^+]$[12]. This is a convenient scale for expressing large changes in acidity, but the actual $[H^+]$ is more important for our purposes. A pH of 6.0 corresponds to 1 μM $[H^+]$. Acidity greater than 1 μM may have an adverse effect on the biodiversity of the lake. Base line measurements taken on April 28, 2009 gave an average $[H^+] = 20$ μM, which was essentially constant at different depths. That value is consistent with those found in our earlier studies. Clearly, our lakes are quite acidic. This is cause for concern.

Fig. 11 shows the acidities observed on August 29, 2001, July 23, 2002 and August 24, 2009:

[12] Glass electrodes measure hydrogen ion activity in terms of mV. The meter converts these data to pH. The probe is standardized against pH 7 ($[H^+] = 10^{-7}$ M) and pH 4 ($[H^+] = 10^{-4}$ M) buffers.

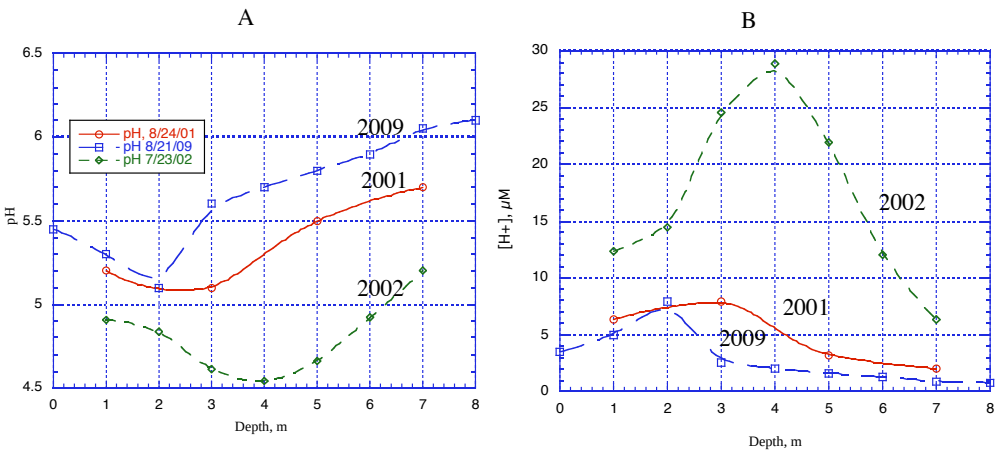

Fig.11. Variation of pH with Depth in Summer 2001, 2002 and 2009. The pH measurements were taken at S1 of Sheldrake. The data in 9A are plotted as pH vs. depth. The same data are plotted in 9B as acidity (H^+) vs. depth.

The acidity in Sheldrake is depth-dependent and varies from year to year. The increase in acidity between the surface and 4 m. is reproducible. The position of the peak varies from year to year, but it always occurs in the region where dissolved oxygen is decreasing rapidly. There was a large increase in acidity in 2002. The source of the acid is not clear.

When the lake is anoxic, the acidity decreases as the phosphate concentration increases. Fig. 12 shows the data for S1:

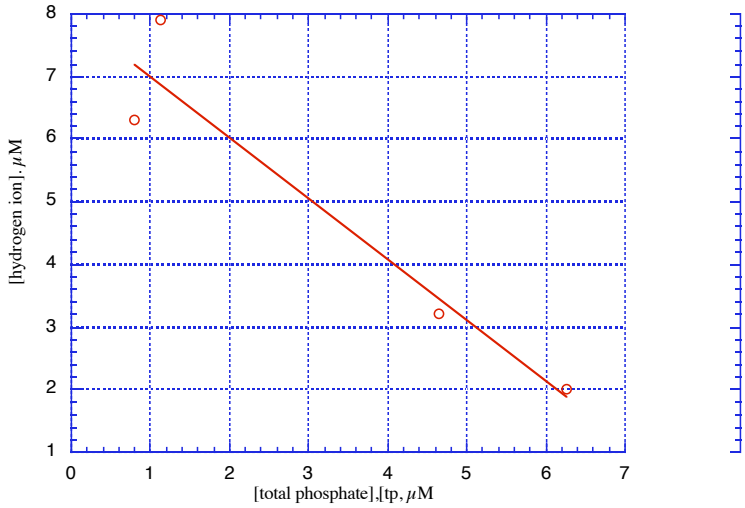

Fig. 12. Correlation Between [P] and Acidity on August 23, 2001. The samples wee taken at 1, 3 , 5 and 7 m. The curve fits the equation: [μM H^+] = 7.96 –0.97 [μM P], R = 0.96. The data from S2 (not shown) also fits this curve.

This suggests that dibasic phosphate[13] is neutralizing some of the acidity.

Iron phosphate residing in the sediment can also contribute to the total phosphate. Ferrus (reduced) phosphate is more soluble than ferric (oxidized) phosphate so ferrus phosphate should prevail when the lake is anoxic[14]. However, at the pH of the sediment, ferrus phosphate will be in its monobasic form [$Fe(H_2 PO_4)_2$], which is unable to buffer H^+ in the pH range of the lake. In order to act as a buffer, the phosphate must come from inside a cell where the pH ≈ 7.

SUMMARY AND CONCLUSIONS

Sheldrake Lake undergoes cyclic changes every year. In the spring, the lake is fairly well mixed. The temperature, dissolve oxygen concentration and phosphate concentration are fairly constant from the surface to the bottom. As the water warms up, a temperature gradient develops and stratification begins. Eventually, three layers are evident. The top layer (epilimnion) extends from the surface to 1 m. Depending on the time of year, the temperature ranges from about 19° in late spring to 26° in late summer. The bottom layer (hypolimnion) starts at about 5 m. and extends to the bottom (about 7 m.). The temperature in this layer is 10-14°. The middle layer (metalimnion) connects the upper and lower layer, and the temperature varies with depth. Once established, these layers are quire sable.

As stratification develops, the dissolved oxygen concentration decreases with depth.. Cold water holds more oxygen than warm water so we should see an increase in DO with depth, but we see the reverse. Clearly, oxygen is being used up faster than it can be delivered. Trout need about 375 μM dissolved oxygen. In early spring (June 17 in 2009) the cut-off occurs at about 4.5 m. In early summer (July 6 in 2009) the cut-off occurs at 2.5-3 m. When stratification is complete, the cut-off occurs at 1.5-2 m and the lake is anoxic (no oxygen) at 3 m.

In the spring, the phosphate concentration increases from about 0.4 μM at the surface to 0.55 μm at 2 m. Then it falls back to 0.4 μM in the hypolimnion. Although a peak is clearly visible, the concentrations are fairly low. However, as stratification develops, the phosphate concentration increases dramatically. When stratification is complete, the phosphate concentration is 5 μM at 7 m. This is more than 10 times the spring value at this depth.

In the fall, as the lake cools down, convection as well as wind and waves, start mixing the lake and the process reverses. This cycle occurs every year.

In 1991, the Soil and Water Conservation Society of Halifax reported that the phosphate concentration at the surface on May 23 was much higher than in other lakes in the watershed (27 μg/l = 0.87 μM). They predicted the total phosphate in the lake would go much higher (41.7 μg/l =1.35 μM) and the lake would become "eutrophic"

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[13] Assuming an average $pK_2 = 6.2$ and an intracellular pH = 7.4, more than 90% of the phosphate will be in its dibasic form.

[14] The solubility data indicate that ferrus phosphate is soluble enough the account for the values we see. However, the solubility studies were done with anhydrous ferrus phosphate. Ferrus phosphate combines with 8 molecules of water. $Fe_3(PO_4)_2 \cdot 8\ H_2O$ crystallizes to form the insoluble mineral, Vivianite [Handbook of Chemistry and Pyysics, 45th Edition,The Chemical Rubber Co.1964,p. B-183]. Analysis of sediment samples is needed to resolve this issue.

(unacceptable for recreational purposes). They recommended that an aeration program be initiated to interrupt this projected process.

On May 9, 2009 WRWEO initiated an aeration program intended improve the fish habitat by preventing anoxia from developing. It was hoped that this would decrease the phosphate concentration and prevent deterioration of the water quality. Initially, the aeration equipment appeared to be delivering oxygen as hoped, but it soon became apparent at this was not the case. On June 26, the DO at 5 m inside the delivery tube was 425 μM (62% saturation) compared to 175 μM (27% saturation) at 5 m outside the tube. Clearly, the aeration equipment was not preventing anoxia. The project was terminated on July 5, 2009.

In spite of the disappointment, we did obtain some valuable data. Comparison of equivalent data from 1991, 1992, 1995, 2001, 2002 2009 and 2010 indicated that phosphate concentration at approximately the same time of year and at the same depth is about half the value observed 1991. The current level (0.45. μM) is at the upper end of the range found in the seven other lakes in the watershed that we have studied.

The acidity appears to be improving. This parameter, like phosphate and dissolved oxygen, is depth dependent. The current value of the hypolimnion, which is particularly important, is about 2 μM. This is down from considerably from values obtained in 2001 (6 μM) and 2002 (24 μM). It is approaching the value that is conducive to healthy reproduction (1 μM).

During weekly studies on the lake, there was no evidence of algae booms or any other undesirable characteristics. Residents are using the lake for swimming and boating. Even if the oxygenation had been successful, it is unlikely that the habitat would have been satisfactory for trout. The early Mayfly hatch (first week in May) disappeared from all the lakes in 1989-90. The reasons for this are not clear, but without this important food source, trout are unlikely to survive. There are some indications that the lakes maybe recovering on the lower watershed, but the data are entirely anecdotal.

Should the Aeration Study be Continued? Anoxia is common in the lakes of the Woodens River Watershed. Table 4 shows the results of our 2002 and 2003 study.

Table 4. Stratification and Anoxia in Selected Lakes of the Woodens River Watershed

The data are from late summer samples. BP= Black Point Lake, BH = Birch Hill Lake, C = Cranberry Lake, 5I = Five Island lake, F = Frederick lake, H = Hubley ig lake, L = Long lake, S = Sheldrake lake. The numbers following the lake designations refer to different sampling stations. The Secchi Depth can be used to estimate the depth to which sunlight penetrates.

Lake	Depth, m	Secchi Depth	Stratifies 2001	Anoxic 2001	Stratifies 2002	Anoxic 2002
BH-2	4.0	2.1	-	-	no	no
BH-3	5.3	1.8	-	-	yes	yes (4.5 m)
BH-4	9.1	2.8	-	-	yes	no
BP-1	2.0	bottom	no	no	no	no
BP-2	2.0	bottom	no	no	no	no
C-1	7.4	4.6	-	-	yes	yes (6.0 m)
C-4	2.5	bottom	-	-	no-	no
5I-1	2.5	bottom	no	no	no	no
5I-2	10.6	3.2	yes	yes (7.0 m)	yes	yes 9.5 m)
5I-3	8.0	4.2	yes	yes (8.0 m)	no	no
F-0	2.6	bottom	no	no	no	no
F-1	2.6	bottom	no	no	no	no
F-2	6.7	0.4	no	no	no	no
F-3	4.7	3.9	no	no	no	no
F-5	9.6	3.7	no	no	no	no
H-1	8.0	3.4	yes	yes (7.0 m)	no	no
H-2	7.2	3.7	no	no	no	no
H-3	13.7	2.6	yes	no	yes	no
L-2	2.1	bottom	no	no	no	no
L-3	4.5	2.9	no	no	no	no
S-1	8.2	1.2	yes	yes (4 m)	yes	yes (3 m)
S-2	5.5	2.0	yes	yes (4 m)	yes	yes (4 m)
S-3	5.5	2.0	yes	yes (4 m)	yes	yes (4 m)

Stratification occurred at sampling stations five or more meters deep. Usually, this is accompanied by anoxia. Paradise Cove of Hubley Big Lake (H-3) is a notable exception. This is the deepest sampling station of those examined. It stratifies each summer. As shown in Fig. 13, oxygen depletion occurs, but a significant amount of oxygen (1.7.mg/l = 103 μM) remains at the bottom[15]. Station 4 of Birch Hill Lake showed similar behavior in 2002.

[15] This is too low to support trout.

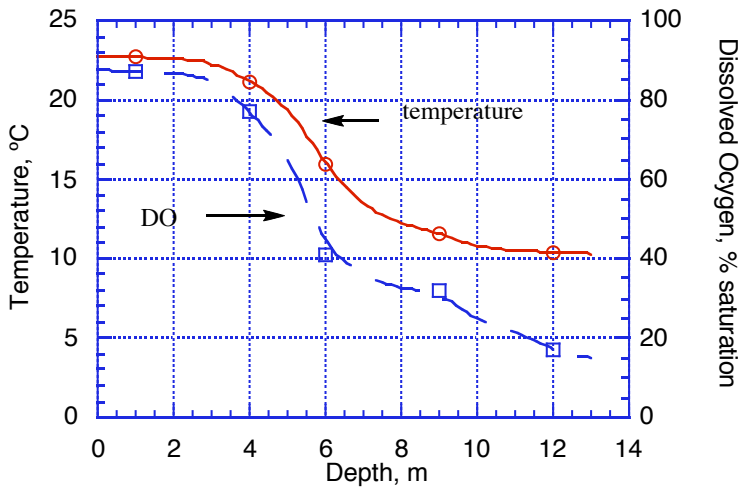

Fig. 13. Thermocline and DO for Paradise Cove in Hubley Big Lake . August 11. 2002.

Sheldrake Lake is unique among the lakes studied. Stratification and anoxia has been observed at all the sampling stations each year. For this reason, the oxygenation study has particular scientific merit. There is little doubt that the aeration equipment can be modified to prevent anoxia from occurring at the aeration site. It is not clear, however, whether this would extend to the rest of the lake. Nor is it clear what effect this would have on the phosphate levels and the acidity. While successful oxygenation would not, by itself, provide suitable habitat for trout, it would certainly be a step in the right direction. Although the process is too expensive and too labor intensive to warrant use as a general procedure, it is certainly worthy of further investigation.