LAKE SIMCOE HYPOLIMNION AERATION

An Assessment of the Potential for Direct Treatment of Oxygen Depleted Hypolimnetic Waters in Lake Simcoe

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for

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Technical Committee, August, 1990


Liaison: K.H. Nicholls
Water Resources Branch
Ontario Ministry of the Environment
FOREWORD

The following quotation from MacCrimmon and Skobe (1970) eloquently expresses the feelings of the many scientists and users who have come to know this most precious resource:

'It is hoped that, through a better understanding of the lake and its past and present fishery, users of the lake may better appreciate the legacy which they have inherited and may recognize more clearly the need for research, management, and wise public use if the unique qualities of Lake Simcoe are to be preserved and enhanced for the benefit of future generations.'

The Fisheries of Lake Simcoe (1970)
Hugh R. MacCrimmon
Elmars Skobe
Department of Lands and Forests
EXECUTIVE SUMMARY

Lake Simcoe is probably the most valuable lake in Canada It supports a productive year-round fishery of both cold and cool water species. The water is generally free from serious pollutants and subject to only infrequent aquatic nuisance problems. Its desirable quality and proximity to a major metropolitan area has resulted in a heavy and growing demand on the recreational resources it provides.

The status of the Lake is mesotrophic but the typical signs of advancing eutrophy are evidenced by loss of reproduction in cold water fish species, increased frequency of algae blooms, shoreline aquatic plant, accumulations, oxygen deficits in hypolimnetic waters and sediment oxygen demand greater than can be satisfied during periods of spring and fall turnover. These signs of increasing eutrophy are interrelated in that phosphorus plays a key role in increasing productivity and feedback of this element is enhanced when sufficient oxygen is not available at the sediment water interface to maintain a state of oxidation sufficient to fix this nutrient as a permanent sink.

In the past fifteen years, the Lake has been the subject of both comprehensive studies and the implementation of remedial measures. Most significantly, important reductions have been made through the control of phosphorus from sewage effluents. None the less, little measurable benefit has been achieved in terms of salmonid reproduction, reduced algae populations or improved hypolimnetic oxygen conditions.

The essential purpose of this report is to assess the feasibility of resolving the depleted oxygen problem by supplementation of the natural oxygen resources of the Lake. This has been done through responding to five objectives which include a compilation of background information, a calculation of the quantity of oxygen supplementation required, an evaluation of two systems having the capability of delivering the required tonnage, estimating the cost of such a treatment and responding to questions posed on potential environmental affects.

A good time series of oxygen data is available upon which to base calculations of apparent oxygen demand. To this must be added the demand which will be induced by improvements to hypolimnetic condition as the accumulated oxygen debt is repaid. The induced demand was estimated using the maximum slope of seasonal demand
which resulted in the recommended addition being 1.6 times the apparent quantity of oxygen required to maintain the 5mg/L objective of the Ministry of the Environment. A separate calculation was made for Kempen-felt Bay and the Open Water basins of the Lake. As these bodies of water are somewhat separated, it is recommended that Kempenfelt Bay which requires about one fourth of the oxygen tonnage be selected for initial treatment to establish efficacy and cost.

Two systems having the potential to add and distribute the required oxygen resources are evaluated. The Locher "Mountain Creek" system is of Swiss design and has been used very effectively in a number of smaller lakes in Europe. The principles of operation are simple, incorporating one pump with two-thirds of the oxygen requirement being supplied by air and one-third by pure oxygen. The system is designed to supply a massive flow of oxygen-enriched water along the sediment water interface to provide the oxygen resources necessary to oxidize the sediment and enrich the most severely depleted waters at the lake bottom both in summer and winter. While scale-up would be required, the technology of construction and operation is known and the efficacy demonstrated.

The second option evaluated is a purpose-built vessel-mounted system, designed to pump water highly enriched with oxygen to the specific areas of need within the Lake. The model used is based on a vessel constructed to inject approximately the same tonnage into the Thames River in the City of London, England. The "Thames Bubbler" is designed for surface aeration rather than hypolimnion injection. The design proposed for Lake Simcoe treatment incorporates a dual-pump system to inject a large volume of highly enriched water through two down legs at a depth several meters above the bottom. Further engineering will be required to complete and test the distribution system proposed. The vessel would not operate in winter so that depleted conditions may recur until the time when summer treatment reduces the oxygen demand to a rate where natural resources no longer require supplementation.

A total of 4,800 tonnes of oxygen is estimated to be required to achieve the Ministry objective of 5mg/L in the hypolimnion of Lake Simcoe during the summer. Of this total, 1,200 tonnes would be required for Kempenfelt Bay and 3,600 tonnes to serve the need in the open water basin. As the initial treatment systems have been designed for Kempenfelt Bay, the equipment proposed is designed to inject 12t/day
during a 100-day summer/fall period.

The budget cost supplied by Locher & Cie which would include the supply of the equipment (Dorr-Oliver Canada Ltd., Orillia), installation, oxygen storage and services is $4,000,000. The capital cost estimated by our consultants for the vessel system is $1,023,000. The annual operating cost for the Locher system including power, oxygen and maintenance is $140,000. The operating cost of the vessel including oxygen, fuel, crew and maintenance is $300,000. The annual operating cost for the Locher system covers both summer and winter operation (240 days) while costs for the vessel represent summer operation only (100 days). Over a twenty-year life expectancy of both units, the annual cost (without interest) of treating Kempenfelt Bay is estimated to be about the same for both systems at $350,000.

While these costs exceed those we are accustomed to expend on environmental solutions, they must be evaluated in the context of other options, including collection and treatment of municipal storm waters, technically difficult reductions in sewage treatment, neither of which may show short term benefits or a resolution to the accumulated oxygen demand resident in the Lake. The second alternative of doing nothing to preserve this most valuable resource is unthinkable. We see no alternative to an early full-scale treatment in Kempenfelt Bay with future treatment of the main lake basin when the efficacy has been demonstrated and experience gained from treatment of the smaller basin.
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LAKE SIMCOE HYPOLIMNION AERATION

INTRODUCTION

Lake Simcoe is the largest lake in southern Ontario apart from the Great Lakes and is located within easy driving distance of Metropolitan Toronto. Due to its proximity, and because of relatively good quality water, it is a highly important recreational resource.

The cities of Barrie and Orillia are located on the Lake and the remaining shoreline is generally encircled by permanent and summer dwellings and a number of villages and hamlets. Its productive fishery provides an important summer and winter fishery supplying 15% of the angler recreation of the Province and a cash flow of 20 million dollars per year (LSEMS, 1985).

A trend toward increased eutrophication of the Lake has been recognized and considerable research work has been devoted to obtaining background information on the physical, chemical and biological characteristics of the water body, measuring trends, making recommendations for and implementing remedial actions, and measuring lake response (LSEMS, 1995).

Of the options available to upgrade the present quality of Lake Simcoe, several important initiatives have already been implemented. Probably the most significant has been phosphorus reductions that have been achieved through improved chemical precipitation in the sewage treatment practice for Barrie and Orillia and the diversion
of effluents from Newmarket and Aurora to the Lake Ontario watershed. Ongoing improvements to home septic tank facilities and farm drainage contributions have undoubtedly reduced nutrient inputs from these sources.

There is, however, a practical limit to the extent to which enrichment can be controlled. Atmospheric contributions are significant (MOE, 1975). Storm water flow and land drainage are difficult and costly to control effectively and the memory system within the Lake reflects an ongoing degradation and circulation of accumulated organic matter.

While a net reduction in phosphorus input has occurred over the past fifteen years there appears to be no measurable improvement in oxygen conditions in the hypolimnetic waters. Populations of the most important cold water fish species, Lake Whitefish, *Coregonus clupeaformis*, and Lake Trout, *Salvelinus namaycush*, can no longer maintain their populations by natural reproduction and must be supplemented by stocking programs. Whether this is a direct effect of reduced oxygen levels may be questioned, nonetheless these species do not have free access to major areas of hypolimnetic water during the summer and early fall which must impact on both the species in question and the sensitive invertebrate and forage fish species they are dependant upon for food.

The best nutrient management practice, including total control of additional inputs, may at best prevent further degradation of lake water quality. It is unlikely however that controls alone can establish a trend that will reduce the level of eutrophication and return the lake to its previous capability of supporting a naturally reproducing cold
water fish population and the ecosystem upon which it is dependent. To achieve this objective direct action to provide the necessary oxygen resource would appear to be the only practical and positive means of reclamation in the near term.

Research has indicated that water quality and the ecology of oxygen impaired hypolimnetic waters can be improved through supplementation of this resource (McQueen and Lean, 1986). The means to do this have been largely based on individual studies accomplished by means of systems devised by the researcher to suit the need of the project. Some larger scale commercial systems have been proposed for Canadian and North American use but they have not been widely applied nor have the results been well documented.

Recently, two oxygen injection systems have been developed in Europe that would appear to offer both the scale of oxygen delivery required and a demonstrated stage of technical development that suggest their feasibility as a means of resolving some or all of the deficiency in Lake Simcoe. The purpose of this study is to determine the technical feasibility and the order of cost for use of these two systems as a means to resolve the ongoing problem of oxygen deficiency in Lake Simcoe.
Objectives

The following specific objectives have been developed as the terms of reference for this study.

1. Review and document available information on the Lake volume of seasonably depleted oxygen concentrations below the 5 ppm MOE water quality objective and data on depletion rates.

2. From information assembled, calculate the input of oxygen required to meet this objective in the major sub basins of the lake during each month of impaired quality.

3. Evaluate the technical feasibility of oxygen supplementation by:
   a) The Locher Hypolimnetic Oxygenator;
   b) A vessel-mounted liquid oxygen injection system.

4. Based on Oxygen requirements calculated in Objective 2 and cost data developed for the two systems, prepare cost estimates to upgrade the oxygen resources of the sub-basins to achieve Ministry objectives.

5. To provide comment on:
   a) the relationship between improved oxygen conditions and reduced phosphorus feedback.
   b) the potential for hypolimnion aeration to cause reduced oxygen in the metalimnion.
   c) the potential for summer aeration reducing winter oxygen concentrations.
   d) the potential for an undesirable concentration and buildup of dissolved nitrogen.
Objective 1:
BACKGROUND INFORMATION

Physiography and Eutrophic Status

Lake Simcoe lies entirely within the Trenton limestone formation of Southern Ontario. The lake has a shoreline of 732 km and an area of 725 km which is comprised of a single basin and two well-defined bays (Kempenfelt Bay and Cook Bay, Fig. 1). The basin slopes from east to west and has a mean and maximum depth of 17.1 m and 40 m, respectively (Waring, 1986). The bathymetry of the lake creates a large hypolimnetic body of water occupying the west central portion of the Lake and Kempenfelt Bay. During the summer stratification, the hypolimnion underlies approximately 230 km² of the 725 km area of the Lake and contains about 20% of the total volume.

There is a striking relationship between a series of chemical, physical and biological conditions that occur within the boundaries demarked by the hypolimnetic zone (MOE, 1975). This deep area of the Lake is believed to be a sink where fine inorganic materials and biological production drop to a quiescent area not significantly disturbed by external forces. The sediment composition is mud rather than a sand, gravel, rock substrate found in shallower waters. The area of the lake bottom composed of soft organic sediments has been defined by sonar mapping (Johnson and Nicholls, 1989). The organic content of the soft sediments is about three times the level of surrounding hydrosols (MOE, 1975).
Figure 2: LAKE SIMCOE, Depth Contours - Sample Stations.
Bottom fauna in the profundal areas are typical of soft sediment species being composed almost entirely of tubificid worms and midge larvae (MOB, 1975). The common genera present include *Tubifex*, *Limnodrilus*, *Procladius* and *Chironomus*, all faunal types capable of enduring low oxygen conditions. The densities of 2,000 to 3,000 organisms/m² suggest a moderately enriched sediment. Values for sediment oxygen demand of 0.65 g of oxygen/day are about twice that of shallower waters. The organic content of sediments in profundal water varies between 8% to 12% (MOE. 1975).

The foregoing condition of the sediments underlying the hypolimnetic waters of the Lake, together with oxygen profiles which show a gradual loss of oxygen as the summer progresses, place the lake in a mesotrophic condition. At this stage in its evolution, a delicate balance exists where decomposition and respiration depletes the hypolimnetic oxygen to a level that is suboptimal to coldwater fish species and some species of bottom fauna upon which the food chain is built.

**Effect of Depleted Oxygen on Coldwater Species**

Adequate oxygen resources are fundamental to life in water. All animal species require oxygen for respiration although some are better adapted than others to live in conditions of reduced oxygen. Coldwater species such as Lake Trout *Salvelinus namacush*, Lake Whitefish, *Coregonus clupeaformis* and Freshwater Herring *Leucichthys artedi*, are important angler species in the Lake Simcoe fishery and all require favourable oxygen conditions.
Evans (1978), classified the oxygen regimes of Lake Simcoe into zones with respect to the potential influence of oxygen depletion on Lake Simcoe coldwater fish species. He describes the incipient limiting zone (5 mg/L) as corresponds to the level of oxygen tension at which respiratory functions such as heart rate, or volume and oxygen saturation of the blood are initially affected. The lower boundary equates to the incipient lethal zone (less than 3 mg/L) and he indicates this to be the region of dissolved oxygen within which direct lethal effects would begin to occur.

It will be noted (Figure 3) that by midsummer the important coldwater species of the Lake are precluded from utilizing the full body of the hypolimnion and between mid-August and early October, the pool of optimum temperature encompassing 20% of the lake volume is within the incipient lethal range.

Surveys conducted by Evans in 1978 and by Ministry of Natural Resources 1981, have also found a declining winter oxygen condition. While the data is sparse, a condition of 1-3 mg/L was noted in the bottom five meters by Evans and a declining concentration projected from February 24, 1981, to ice-off indicates a 5m band of 1-3 mg/L would have developed by early March. While further work is required to confirm the extent of a winter oxygen depletion, it is an observation of which Lake management personnel have not been fully cognizant.

The following report of findings has been organized to respond to each of the five objectives identified for this contract.
Figure 3: Area Of Oxygen Depletion.
Review and Compilation of Relevant Information

Prior to the determination of supplementary oxygen requirements, available literature was reviewed to compile information on seasonal oxygen depletion and hypolimnion volume in Lake Simcoe. Contact was made with appropriate personnel of the Ontario Ministries of Environment and Natural Resources and the Lake Simcoe Conservation Authority to obtain unpublished records.

A report on Lake Simcoe water quality and use (MOE, 1975) summarized the problems of hypolimnnetic oxygen depletion. An examination of the bottom substrates indicated that shallow and exposed substrates were dominated by sand and rock. In deeper and sheltered areas, the Lake bottom was mud with coverage of this substrate corresponding closely to the hypolimnetic zone. Hypolimnetic waters were generally described as greater than 18m deep.

Monitoring of dissolved oxygen concentration in the hypolimnion yielded periods of near saturation levels following spring and fall turnover. Depletion occurred from midsummer to early fall with a measured minimum of 2-3 mg/L prior to fall turnover. Well oxygenated conditions were reported to continue during the ice covered period (MOE, 1975).

A subsequent report (MOE, 1979) supported the deleterious effect of eutrophication on hypolimnetic oxygen conditions. Minimum concentrations reported were 1-3 mg/L. It was estimated that oxygen depletion was occurring under 33% of the Lake surface area, and totalling 20% of the Lake volume (MOE, 1979).
The final report of the Lake Simcoe Environmental Management Strategy (LSEMS) Steering Committee (1985) provided further information on oxygen depletion in lake Simcoe hypolimnetic waters. Improvement of these conditions was strongly recommended for the reclamation of coldwater fish habitat and reduction of phosphorous release from the bottom sediments.

A series of reports published by the Ontario Ministry of Natural Resources' Lake Simcoe Fisheries Assessment Unit were obtained which documented open water temperature and dissolved oxygen concentrations for the years 1980-1986 (Willcox 1982, Waring 1986, Butterwick 1987). Unpublished oxygen data from the 1987 open water season was obtained from Ken Nicholls (MOE, Limnology Section). As the project progressed, questions concerning winter oxygen depletion arose. Unpublished data was gratefully forwarded by J.F. Humber (MOE, Central Region) and R. Allen (OMNR, Lake Simcoe Fisheries Assessment Unit). The data contained in these reports were critical to the calculation of hypolimnetic oxygen concentration and depletion for Lake Simcoe.

Beak Consultants' report (Snodgrass and Holubeshen 1987), prepared for the Ministry of the Environment and the Lake Simcoe Conservation Authority, provided valuable information on Lake Simcoe temperature, dissolved oxygen and hypolimnetic depletion rates.

Finally, primary literature was reviewed (eg. McQueen and Lean 1986, Partook Lorenzen & Ginn, 1982, Taggart & McQueen 1981) for more general information related to hypolimnetic oxygen depletion and aeration.
Objective 2:  CALCULATION OF BASIN OXYGEN SUPPLEMENTATION REQUIREMENTS

Requirement to Achieve 5mg/L Minimum Concentration Basin Approach

For purposes of this study, the hypolimnetic conditions for Kempenfelt Bay as represented by Sta. 42 and the Open Water as represented by Sta. 45 were used. A sub-basin approach was selected because each had different oxygen regimes, depth and basin profiles. From a practical sense, future treatment would initially be experimental as an induced demand has been found by other researchers to occur when oxygen resources are supplemented. This induced demand is not well understood so that the factor used for the total oxygen requirement is a best estimate based on available information. This would suggest that a program of oxygen supplementation might be best phased perhaps by selecting the basin with the lesser total oxygen requirement (Kempenfelt Bay) to evaluate the true demand and test the mechanics of equipment selected.

Information does not appear to be available on the exchange of hypolimnetic water between two basins. Nonetheless, Kempenfelt Bay appears to be a somewhat discrete body of water as the basin is deeper and the mean summer temperature is statistically cooler. (8.69°C vs 9.34°C, \( P < 0.0005 \) Willcox 1982).

Hypolimnion Volume

The depth of the hypolimnion may vary during the season and from year to year. Likewise, the thickness of the Metalimnion is generally rather broad as the Lake is large and subject to wind-induced mixing forces. Nonetheless, once the thermal stratification
has been established in June, little mixing occurs (MOE 1975). A mean summer hypolimnion depth from the Lake bottom to the thermocline of 20m was determined from the eight years of data evaluated for this study.

**Estimation of Oxygen Depletion Quantity and Rate**

As each basin has a different bathymetric profile and differing oxygen regimes, a separate calculation of oxygen demand and supplemental requirements were made. For this purpose, the volume of each 3.05m (10 ft) depth was calculated from data provided by the Ministry of Natural Resources (R. Allen, personal communication). Table 1, Figure 4). Using the mean measured oxygen concentration from depth series reported by investigators during the years 1980 to 1987, inclusive, it was then possible to calculate the depletion in each 3.05m (10 ft) layer of hypolimnion (Table 2) and from this derive a weighted depletion curve that is cognizant of the oxygen consumed for that volume of water contained within the hypolimnion.

**Estimate of Induced Demand**

As noted by McQueen and Lean (1986), a number of lake treatments have failed when treatments were based on oxygen supplementation equating to the calculated apparent demand of the hypolimnion. This is believed to be the result of enhanced metabolism of unoxidized organic substances and increased chemical oxygen demand of reduced sediments accumulated on the Lake bottom.
Table 1: Hypolimnion Volumes (m$^3$).

<table>
<thead>
<tr>
<th>Depth m</th>
<th>Depth feet</th>
<th>Open water Station</th>
<th>Kempenfelt Station</th>
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<tr>
<td>19.7</td>
<td>60</td>
<td>611,194,000</td>
<td>134,164,000</td>
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<td>23.0</td>
<td>70</td>
<td>427,861,000</td>
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<td>26.2</td>
<td>80</td>
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<td>2,947,000</td>
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<tr>
<td>44.6</td>
<td>136</td>
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<td></td>
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1,470,000,000  501,919,000
(74.5%) of Hypo. vol. - (25.5%)

Ontario Ministry of Natural Resources Data
Figure 4: Volume of Hypolimnion by Basin and Depth.
Under changed conditions of oxygen availability, the metabolic chemical demand of the sediment is increased, thereby nullifying the expected oxygen benefit in the overlying waters. The memory system in a lake reflects an oxygen debt that has been incurred. This debt of accumulated demand must be repaid before a new balance can be struck so that the budget must include both current operating oxygen requirements and repayment of the debt.

In planning the oxygen input, consideration should be given to retaining some flexibility with respect to the total capacity of the equipment in order that initial high demands can be adequately met and then reduced as the sediment debt is satisfied. Locher suggests this should occur in ten to fifteen years (Schmid pers Comm).

Based on the advice of Dr. McQueen and the published work of Hall et al. (1989), it was decided that the calculation of the total oxygen requirement to provide for both the apparent depletion rate and the induced sediment demand would best be calculated from the curve depicting the maximum seasonal rate of oxygen depletion. Figure 5 illustrates the oxygen demand approximating the mean value over the eight years of data evaluated for Kempenfelt Bay. The oxygen demand is highest in early summer, somewhat reduced in midsummer and lowest in the fall prior to turnover. The slope for early summer in Kempenfelt indicated the maximum demand and this value was used in subsequent calculations of the oxygen supplementation requirements.
Figure 5: Oxygen - Seasonal Demand Curve.

Kempenfelt Bay
Mean Value 1980-1987
**Oxygen Requirement Calculations**

Calculations of hypolimnion depth, weighted hypolimnetic oxygen concentration, and supplementary oxygen requirements were made using the published and unpublished data compiled between 1980 and 1987.

**STEP 1.** assembled D.O. and temperature profiles for the years 1980 to 1987 from sources at the Ministries of Environment and Natural Resources.

**STEP 2.** using the temperature isopleths available for each of the eight years reported, the depth of the hypolimnion was recorded at four weekly intervals for each month that a thermocline was established.

**STEP 3.** the hypolimnion profile was then superimposed on depth-time diagrams of isopleths of dissolved oxygen concentrations.

**STEP 4.** depths of oxygen concentrations falling within the hypolimnion were determined at the same weekly intervals per month for each year's data.

**STEP 5.** average depths of oxygen concentrations falling within the hypolimnion from the eight years of data were determined.

**STEP 6.** average depths-at-oxygen concentrations were converted to imperial measurements (ft.) and hypolimnion volumes calculated from Ministry of Natural Resources estimates of hypolimnion volumes.

**STEP 7.** weighted oxygen concentration of the hypolimnion was calculated.

\[ \text{e.g.: } ((\text{vol. at } 12\text{ ppm}) \cdot 12) + ((\text{vol at } 11\text{ ppm}) \cdot 11) + \ldots + ((\text{vol at } x \text{ ppm}) \cdot x) \text{ Volume/100} \]

\[ x \text{ ppm oxygen in hypolimnion volume} \]
STEP 8. depletion rate calculated between weighted oxygen concentrations of consecutive dates.

STEP 9. the results of these calculations are presented in Table 2.

**KEMPENFELT BAY CALCULATIONS**

Calculation of hypolimnion volume indicated that the mean volume over eight years was $404 \times 10^6 m^3$ and the mean annual depletion rate was 0.070 mg/L/d.

*As mg/L and g/m$^3$ are equivalent subsequent calculations are based on g/m$^3$ values.*

For purposes of estimating the quantity of oxygen that must be introduced to the hypolimnion to maintain a level of 5 mg/L, three Calculations were made based on depletion rates as calculated by Limnos (0.07 g/m$^3$/d), the rate by Beak (0.077 g/m$^3$/d) and by a mass balance calculation based on the oxygen values at the beginning and the end of the Lake's hypolimnion regime. The calculation and the results determined are as follows:

**Summer/Fall Oxygen Loss**

(a) **Limnos Depletion Rate Calculation**

\[
\text{Depletion Rate} \times \text{Volume} = \text{t/day oxygen loss} \\
0.07 \text{ g/m}^3/\text{d} \times 404 \times 10^6 \text{ m}^3 = \text{Daily Loss - 28.28 t/d} \\
\text{tonnes/day} \times 115\text{-day season} = \text{Total summer depletion} \\
28.2 \text{ t/d} \times 115 \text{ days} = \text{Total season 3252t}
\]
## Table 2. Average Oxygen Depletion Rates For Lake Simcoe Hypolimnion, (1980 - 1987).

### Kempenfelt Bay

<table>
<thead>
<tr>
<th>Date</th>
<th>Hypolimnion Depth (m)</th>
<th>Weighted Mean O₂ Concentration (mg/L)</th>
<th>Depletion Rate (mg/L/d)</th>
<th>Hypolimnion Volume x10⁶ (m³ x 10⁶)</th>
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### Open Water Station

<table>
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<tr>
<th>Date</th>
<th>Hypolimnion Depth (m)</th>
<th>Weighted Mean O₂ Concentration (mg/L)</th>
<th>Depletion Rate (mg/L/d)</th>
<th>Hypolimnion Volume x10⁶ (m³ x 10⁶)</th>
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<td><strong>1,044</strong></td>
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</table>
(b) **Beak Depletion Rate Calculation**

\[
0.077 \, \text{g/m}^3/\text{d} \times 404 \times 10^4 \, \text{m}^3 = \text{Daily loss 31.11t/d}
\]

\[
31.1 \, \text{t/d} \times 15 \, \text{days} = \text{Total season 3578t}
\]

(c) **Mass Balance Calculation**

\[
(\text{Oxygen Content at beginning of season} - \text{oxygen content before turnover}) \times \text{volume} = \text{Total seasonal loss}
\]

\[
(11.8 \, \text{g/m}^3 - 3.2 \, \text{g/m}^3) \times 404 \times 10^4 \, \text{m}^3 = \text{Total season 3474t}
\]

\[
3474 \, \text{t} / 115 \, \text{days} = \text{Daily Loss: 30.21t/d}
\]

**Induced Demand (McQueen Factor)**

The results of the oxygen demand calculations are provided in Table P and plotted on Figure 5. To determine the induced demand, McQueen and Lean (1984), proposed that the maximum seasonal depletion rate should be used to calculate the total input requirement.

To do this the seasonal averages as determined from Table 2 have been used:

- Early Summer June 22 - August 1 = 0.118 g/m\(^3\)/d.
- Summer August 1 - September 1 = 0.82 g/m\(^3\)/d.
- Fall September 1 - Turnover = 0.029 g/m\(^3\)/d.

The mean summer depletion rate is 0.07 g/m\(^3\)/day. Table 2

Therefore

\[
\frac{\text{Mean Seasonal Rate}}{\text{Maximum Rate}} = \text{Induced Demand}
\]

\[
\frac{0.070 \, \text{g/m}^3/\text{d}}{0.118 \, \text{g/m}^3/\text{d}} = 0.59
\]

For purposes of subsequent calculations, the induced demand factor used is 0.60.
Calculation of Oxygen Replacement required to maintain 5 mg/L (i.e. 5 g/m³) in Hypolimnion Calculation

(1) Calculation based on Limnos Depletion Rate (0.070 g/m³/d)

\[
\text{Spring O}_2 \text{ conc. - Min. objective} = \text{Acceptable Depletion Rate} \\
\text{No. of days} \\
\frac{11.8 \text{ g/m}^3 - 5.0 \text{ g/m}^3}{115 \text{ days}} = 0.0591 \text{ g/m}^3/\text{d}
\]

Apparent O₂ demand 6.070 g/m³/d
Therefore current depletion rate - Acceptable depletion rate = Oxygen Replacement Value for apparent demand.

\[
0.070 \text{ g/m}^3/\text{d} - 0.0591 \text{ g/m}^3/\text{d} = 0.0109 \text{ g/m}^3/\text{d}
\]

Therefore, replacement demand x hypo. Vol. x days
Replacement quantity for apparent demand.

\[
0.0190 \text{ g/m}^3/\text{d} \times 404 \text{ m}^3 \times 115 \text{ days} = 506.4 \text{t}
\]

Apparent replacement requirement: 506.4t
Induced replacement @ 0.6 of Apparent: 303.8t
Total seasonal oxygen required 801.2t

(2) Calculation based on Beak Depletion Rate (0.077 g/m³/d)

Logic the same as Limnos depletion rate estimate.

\[
\frac{11.8 \text{ g/m}^3 - 5.0 \text{ g/m}^3}{115 \text{ days}} = 0.1591 \text{ g/m}^3/\text{d}
\]

Apparent Oxygen demand 0.077 g/m³/d
(Beak Value Replacement value for apparent demand:
\[
0.077 \text{ g/m}^3/\text{d} - 0.0591 \text{ g/m}^3/\text{d} = 0.0179 \text{ g/m}^3/\text{d}
\]

Replacement Oxygen quantity to meet apparent demand:
\[
0.0179 \text{ g/m}^3/\text{d} \times 404 \text{ m}^3 \times 115 \text{ days} = 831.6 \text{t}
\]

Apparent replacement requirement: 831.6t
Induced demand @ 0.6 of apparent: 498.9t
Total Seasonal Oxygen Required: 1,330.5t
Calculation based on difference between observed oxygen concentration and objective.

Total Oxygen resource in hypolimnion at 5 g/m³
404 x 10⁶ m³ x 5 g/m³ = 2020t

Minimum observed resource a 3.2 mg/L
404 x 10⁶ m³ x 3.2 g/m³ = 1293t

Apparent replacement requirement:
Induced demand @ 0.6 of apparent:

Total Seasonal Oxygen Required: 1,163t

OPEN WATER CALCULATIONS

Calculation of hypolimnion volume indicated that the mean volume over the eight years was 1044 x 10⁶ m³ and the mean annual depletion rate was 0.0525 g/m³/d (Table 2).

For the purposes of estimating the quantity of oxygen that must be introduced to the hypolimnion to maintain a level of 5 mg/L, three calculations are made based on the depletion rates determined from Table 2, the Beak value of 0.077 and a mass balance calculation based on the oxygen values at the beginning of the season of 9.6 mg/L (June 22) and the minimum value measured 2.9 mg/L (October 8).
(a) **Summer/Fall Oxygen Loss**

**Limnos Depletion Rate Calculation**

Depletion Rate x Volume = t/day O\(_2\) loss

0.0525 g/m\(^3\)/d x 1044 = Daily loss = 54.8t/d

Tonnes/day x 115-day season = Total summer depletion

54.8t x 115 days = Total Season = 6302t

(b) **Beak Depletion Rate Calculation**

Depletion rate x volume = t/day O\(_2\) loss

0.077 g/m\(^3\)/d x 1044 = 80.4t/d

Tonnes/day x 115 day season = Total summer Depletion

80.4t/d x 15 days = Total season - 9246t

(c) **Mass Balance Calculation**

Oxygen content at beginning of season - oxygen content before turnover

x volume = Total seasonal loss

9.6 g/m\(^3\) - 2.9 g/m\(^3\) x 1044 x 10\(^6\) g/m\(^3\) = Total season 6995t

**Calculation of Oxygen Replacement required to maintain 5 mg/L in Hypolimnion**

1) Calculation based on **Limnos Depletion Rate** (0.0525 g/m\(^3\)/d)

Spring \(O_2\) conc. - Min. objective = Acceptable Depletion Rate

No. of days

\[
9.6 \text{ g/m}^3 - 5.0 \text{ g/m}^3 = 0.040 \text{ g/m}^3/d
\]

= 0.040 g/m\(^3\)/d

115 days

Apparent Oxygen Demand = 0.0525 g/m\(^3\)/d

Therefore current depletion rate - Acceptable depletion rate

= Oxygen Replacement required to meet objective

\[
0.0525 \text{ g/m}^3/d - 0.040 \text{ g/m}^3/d = 0.0125 \text{ g/m}^3/d
\]
Therefore, replacement demand x Hypo. Vol. x days Replacement quantity for apparent demand

\[ 0.0125 \, \text{g/m}^3/\text{d} \times 1044 \times 10^6 \, \text{m}^3 \times 115 \, \text{d} = 1500 \, \text{t} \]

Apparent replacement requirement: 1500t

Induced replacement @ 0.6 of apparent: 900t

Total Seasonal O\(_2\) required: 2400t

(2) Calculation based on Beak Depletion Rate (0.077 g/m\(^3\)/d)

\[ \text{spring O}_2 \text{ concentration - minimum objective} = \text{Acceptable depletion rate} \]

\[ 9.6 \, \text{g/m}^3 - 2.9 \, \text{g/m}^3 = 0.058 \, \text{g/m}^3/\text{d} \]

115 days

Apparent demand 0.077 g/m\(^3\)/d

Apparent rate - acceptable rate = O\(_2\) replacement required

\[ 0.077 \, \text{g/m}^3/\text{d} - 0.058 \, \text{g/m}^3/\text{d} = 0.019 \, \text{g/m}^3/\text{d} \]

Replacement demand x Hypo Vol x days = Replacement quantity

\[ 0.019 \, \text{g/m}^3/\text{d} \times 1044 \times 10^6 \, \text{m}^3 \times 115 \, \text{d} = 2281 \, \text{t} \]

Apparent replacement requirement: 2281t

Induced replacement @ 0.6 of apparent: 1369t

Tote Seasonal O\(_2\) required: 3650t

(3) Calculation based on difference between observed Oxygen concentration and objective.

Total Oxygen resource in hypolimnion at 5 g/m\(^3\)

\[ 1044 \times 10^6 \, \text{m}^3 \times 5 \, \text{g/m}^3 = 5220 \]

Minimum observed resource

\[ 1044 \times 10^6 \, \text{m}^3 \times 2.9 \, \text{g/m}^3 = 3028 \]

Apparent replacement requirement 2192

Induced demand a 0.6: 1315

Total Seasonal O\(_2\) requirement: 3507t
**Induced Oxygen Factor**

It should be noted that data to determine the maximum seasonal depletion rate do not show an early summer maxima for the open water station.

For this reason the 0.6 x apparent demand calculated for Kempenfelt Bay was used as this is in the order of anticipated induced demand (McQueen - personal communication).
<table>
<thead>
<tr>
<th></th>
<th>Kempenfelt Bay Replacement (t)</th>
<th>Open Water Replacement (t)</th>
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</tr>
<tr>
<td>Limnos Depletion Est</td>
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</tr>
<tr>
<td>(0.07 g/m²/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beak Depletion Est</td>
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<td>831</td>
</tr>
<tr>
<td>(0.077 g/m³/d)</td>
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<td></td>
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<tr>
<td>Mass Balance</td>
<td>3474</td>
<td>727</td>
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</table>

**Table 3.** Summary of Loss O₂, and Replacement Requirements.
**Figure 6.** Estimates of Summer/Fall Oxygen Loss and Replacement Requirements.

* A - Limnos Depletion Rate
B - Beak Depletion Rate
C - Observed & Objective Calculation
OBJECTIVE 3: EVALUATION OF THE TECHNICAL FEASIBILITY OF OXYGEN SUPPLEMENTATION

Background

State of the Art
The scale of oxygen injection required to meet 5 mg/L objective in the Lake Simcoe would appear to be the greatest that has been attempted as a remedial action in a natural lake system. McQueen and Lean (1986) reviewed published information on methods used for lake studies that have been conducted to that time. More recently Dr. E. Prepas of the University of Alberta has implemented an ongoing whole lake experiment in Lake Amisk, Alberta using pure oxygen dissolution through mat aerators designed to resolve a depletion problem. Locher have also installed smaller full scale lake treatment equipment in a number or European lakes and monitored the results over the past ten years. They have also designed and bid a major treatment systems approximating Lake Simcoe requirements that is at an approval stage in Switzerland.

The Thames barge system, while designed as a shallow water aerator, is capable of delivery 30 tonnes of pure oxygen per day and thus is of the order of magnitude required in Lake Simcoe.

Principles of Oxygen Injection

The principles of oxygen solubility in water and the design of systems to solubilize the gas are well understood. A direct relationship exists between solubility and pressure, a principle which is used for the oxygen injection systems evaluated for Lake Simcoe. Figure 7 illustrates the solubility of oxygen at the approximate depth of injection that would be used in Lake Simcoe. The advantages of pressure-driven
solubilization may be utilized either by taking advantage of the water depth of the lake (as with U tube practice) or by pressurization in a pumping system (side stream injection) or both. The quantity of oxygen that may be dissolved in pressure systems follows Boyles Law and is a function of the water volume, pumped pressure and temperature.

Much of the current technology and propriety equipment available on the market today has been developed for sewage treatment processes and aquaculture applications. Both Locher and Linde hold patents in this regard for equipment that is incorporated in the designs of the proposed Lake Simcoe equipment.

Lake Simcoe Considerations

Lake Simcoe being large and mesotrophic in nature differs from many other waters where replacement oxygen in the hypolimnion has been attempted. In most small eutrophic lakes, a sharp drop in hypolimnetic oxygen concentrations occurs shortly after thermal stratification with concentrations remaining at or near zero until fall turnover. In Lake Simcoe, a slow decline occurs throughout the summer reaching minimum concentrations shortly before turnover. As the hypolimnion is relatively deep, the effect of the sediment demand is apparent as the oxygen concentration decreases with depth. As depletion exceeding 5 mg/L exists most frequently in the bottom 10 m to 15 m zone, it is important that any treatment procedure inject and/or direct dispersion to the deepest possible strata.

An additional factor that must be considered in selecting treatment options is the forces of diffusion driving oxygen equilibrations in are relatively weak.
Figure 7. Solubility of Oxygen with Depth at 10°C.

Calculations based on principle that solubility doubles at hydrostatic pressure of 34ft.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Oxygen Saturation - mg/L</th>
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<td>0 ft</td>
<td>0 m</td>
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<td>102</td>
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</table>

CONCLUSION - Oxygen solubility 5x surface at bottom of Kempenfelt Bay.
The observed oxygen gradient in the hypolimnion during summer and fall is from about 6 mg/L below the metalimnion to 2 mg/L above the sediment-water interface with most of the loss occurring in the bottom four meters. Oxygen systems such as mat aerators which provide only vertical mixing may improve the upper waters of the hypolimnion but because of the low diffusion characteristics of oxygen it will leave a chemocline in place and contribute little to the concentration of oxygen in waters overlying the lake bottom or to the oxidation of sediments.

The systems to be subsequently discussed are intended to assist the dispersion of oxygen-enriched water along the sediment interface either by introduction of a directional flow of a very large volume of water (Locher), or by using a mobile system to inject water of high oxygen concentration at the required depth to specific areas of need.

As noted previously, a late winter condition of oxygen depletion has been documented at stations K42 (Kempenfelt Bay) and 45 (Open Water). While limited data is available, the chemocline appears quite similar to the summer depletion curves, with the break occurring about 20 m from the bottom and oxygen concentrations decreasing with depth at a fairly constant rate to a level about 5 m above the bottom where a uniform condition of 2 ppm has been recorded (Evans 1978). The zone of depleted winter oxygen corresponds closely to the sink areas of the lake where organic sediments contain the principal "memory system".

If improvement is to be made in winter oxygen conditions, either a mixing force is required to circulate oxygenated water to the profundal region or summer treatment to reduce winter sediment demands, or both.
LOCHER "MOUNTAIN CREEK" HYPOLIMNITIC AERATOR

Background

Locher & Cie AG is a Swiss design-build contracting company located in Zurich. The company has been in continuous business for the past 135 years. The function of design and construction of civil works in Switzerland, unlike Canadian practice, it normally combined. Their design and construction activities have included extensive road, bridge and tunneling, water and sewage treatment and building construction. They were also contractors for a major university project in Saudi Arabia.

As a component of previously constructed waste water treatment facilities, they designed and patented a deep shaft aeration system presently utilized for the treatment of municipal and industrial wastes in Switzerland. The success of the system and the apparent need for renovation of many lakes in Switzerland and Europe led to a recognition that the basic design used for waste treatment could be applied to the aeration of the profundal water of lakes.

Initial experiments started in 1976 and were followed by a series of installations as noted below:

1976 Initial experiments in Attisholz Industrial deep shaft application).

1978-1979 Basic findings about oxygen input with the deep shaft are utilized for the development of lake aeration equipment. The first pilot plants patented world wide.

1980-1981 Development of the LOCHER-EQUIPMENT according to the "Mountain Creek System". Full-size tests at Aurichsee (Obersee). Participation in project design-competition for restoration of the Swiss Lakes of Baldeggersee, Hallwilecsee, Sempachersee and award with first prizes.
Successful installation of the first LOCHER-EQUIPMENT in the Wilersee (Switzerland).

1982 Large-scale test in Riedholz (Industrial deep shaft application).


1984-1986 Development of large-size equipment and establishing international activities.

1987-1988 Implementation of a DEEP-SHAFT-AERATION project in Evionnaz (Switzerland) with oxygen-input of 2.5 tons per day.

1988 Installation of equipment in private lake (Switzerland).

1990 Second contract award in Evionnaz.

In addition to the above installations, detailed design and costing for bid purposes have been completed on several tendeced projects including Lake Zug, a body of water having a very deep profile and about the same hypolimnetic volume as Lake Simcoe.

**Principles of Design and Operation**

The "Mountain Creek" system utilizes pressure as a means of dissolution of oxygen from air. Normal practice involves the use of conventional pumps to draw water from the profundal zone of a lake. Air is aspirated into the pump stream and the mixture of water and finely divided bubbles is pumped down to a depth of approximately 30m where it is discharged to a much larger draft tube. The release of the pressurized air/water mixture in the draft tube serves as an air lift pump. Oxygen is dissolved under pressure both in the pump stream and as the bubbles rise in the
draft tube, so that the water rising to the surface is essentially saturated. The remaining air bubbles are released at the surface together with any dissolved gasses (i.e. ammonia, hydrogen sulphide, methane) that may have been produced in anaerobic profundal waters. The degassed and oxygenated water is then returned to the desired depth strata of the lake where it imparts a momentum to establish a circulation pattern within the hypolimnion (Figure 8). If additional oxygen is required, it may be injected to the down leg of the discharge pipe where the increasing pressure with depth maximizes solubilization.

The advantage of this system is that the total pumping and air injection system is accomplished by one water pump. The result is that the two essential features of the hypolimnion treatment are achieved:

- to bring a large volume of oxygen-saturated water to the depleted environment,
- to impart a directional flow to distribute the enriched water along the sediment-water interface to provide for oxidation of reduced sediments.

**Applications in Europe**

The Locher "Mountain Creek" equipment has been installed in a number of lakes in Switzerland and Germany, and the changes in water quality have been monitored and reported by the Swiss agency responsible for water resources management. The results determined from several years of measurement have been highly satisfactory having demonstrated the return of aerobic conditions, reduced phosphorus and ammonia concentrations and essentially no change in temperature (Appendix A).
1. A pump draws a small amount of lake bottom waters.
2. These lake bottom waters will be exposed to a downflow air injection system whilst being saturated with highly diffused air bubbles. In the sparkling water-air-mixture the dissolution of the oxygen is commencing when these bottom waters are pressed downwards.
3. In a rising shaft the water-air-mixture diffuses into a large amount of bottom waters. The dissolving process continues and an uplift of substantial quantities is initiated.
4. In the degasification zone waste gases are vented to the atmosphere.
5. During summer the oxygen-enriched lake bottom waters will be returned to the Hypolimnion at adjustable levels.
6. During winter the oxygen-enriched lake bottom waters can be guided into the Epilimnion in order to support the natural circulation.

In case your lake requires any remedy the LOCHER-Equipment will be very helpful.

**Provide us with information on:**
- local conditions (situation, size, sea-level. depth. maps)
- nature of impurities (legal requirements, test results, expert reports)
- measures so far executed (results)

**You shall receive proposals on:**
- usage of the LOCHER-Equipment
- local licensed manufacturer
- possible cooperation with your Engineer
- investment and operation cost
- performance guarantees
European work has evaluated the comparative effort of Locher treatment and matt aerators on the oxidation of sediments where these treatments have been implemented in separate lakes. Bubbler systems show little of no benefit to the sediment whereas the circulation induced by the Locher flow has demonstrated an initial oxidation at the sediment surface that increased in depth with time (Zullig 1988. Brandl 1987).

It should be noted that most of the data providing a time series of results on water quality and sediment improvements have been drawn from studies of relatively small lakes and remain to be proven in basins the size of Lake Simcoe.

**Proposed Locher Installation for Lake Simcoe**

Information on the physical conformation of Lake Simcoe, limnological characteristics and relevant data from water quality studies were provided to Locher for their consideration in the design of equipment. The Locher system can be either floating or shore-mounted and initially there seemed some potential to position the draft tube(s) on the north shore of Kempenfelt Bay as a very steep drop to hypolimnion depths occurs close to shore.

Subsequent Ministry of the Environment information of soil conditions in this area however indicated that the artesian flow of ground water is very strong in this area (Yakutchik, T. pers. comm.). The difficulties of constructing major civil works under these conditions led to the selection of a floating structure.
A second consideration of concern was that the floating structures must be capable of withstanding strong storm conditions and spring conditions of ice flow. To meet these requirements, the equipment has to be designed with submersible pumps and the degassing chamber constructed sub surface. The only component extending above the water surface is the vent for gases and the air intake. The vent is mounted on a goose-neck so that it may be laid over in the event of heavy ice flow (Figure 9).

Details with respect to dimensions, structural design, anchoring and the selection of pumps and controls have not yet been developed specifically for a Lake Simcoe installation. These specifications have however been developed for the anticipated Lake Zug treatment, so that the design features and costs were adapted to the Simcoe requirements and transposed to Canadian dollars.

Power draw for the pump for each installation would be 160kw or 120 H.P. of energy. The rising tube and discharge will be in the order of 4m diameter and the flow generated approximately 15 m$^3$/sec. The return flow will be through a pipe that may be adjusted to discharge to any level and in the direction selected to compliment the established flow vector within the hypolimnion. The 15 m$^3$/sec. flow from the system induces a jet-effected circulation equivalent to fifty times the flow generated by the introduction of 120 H.P. of directional energy.
Figure 9. Swiss Lake System.
The system proposed to resolve the problem in the whole lake would be made up of multiple units strategically placed to satisfy the basin demands and compliment natural patterns of circulation. The concept to be subsequently discussed would be to make the first installation in Kempenfelt Bay in order that the environmental benefits could be monitored and measured. For this reason, further discussion on the specifics of the unit and its installation, servicing requirements and cost will be directed to Kempenfelt Bay.

The oxygen requirement to resolve the deficiency in Kempenfelt Bay and satisfy the induced demand has been estimated to be 12 tons/day during the summer. The Locher design proposes that 8 tons/day of this requirement be provided by aspirated air and 4 tons/day by supplementation with pure oxygen delivered from a shoreline storage facility and piped to service the unit. It is intended that the aeration equipment would be used in this mode from the onset of stratification in June to lake turnover about mid-October and without supplemental oxygen from the formation of ice cover in December to breakup in April for a total operating period of about eight months.

The purpose in operation under ice is to add oxygen, induce circulation and prevent winter oxygen depletion. By creating improved oxygen conditions at the sediment water interface, it is anticipated that enhanced chemical and biological oxidation. Of the sediments will continue during the winter and prevent the development of an anoxic period critical to the survival of oxygen-sensitive bottom fauna.
Background

The potential for using a vessel to transport and inject oxygen to depleted zones has been considered by the author to offer a number of practical advantages and certain disadvantages for oxygen treatment in lakes. A self-propelled unit would be capable of injecting oxygen-enriched water to the specific areas and depth of need and is not dependent on induced flow or natural circulation for dispersion. It would create no permanent obstruction in waterways and if designed with sufficient capacity to accomplish treatment in a one-shift operation, it would offer, a degree of flexibility in total input capability if operating hours ace extended. Using this flexibility, it would be possible to respond to specific areas of the lake developing a low oxygen condition extending the area of treatment if oxygen requirements in a particular basin were found to be overestimated, after input, if year to year variations were found to be significant or if treatment requirements were reduced with time as the memory debt was repaid.

The development of the "Thames Bubbler" (Figure 10) by the Thames Water Authority provided an interesting model for this purpose and the author had the opportunity to visit the Authority to obtain technical information from their staff and to go aboard the vessel during a period when it was undergoing commissioning trials.
Figure 10. Thames Bubbler.
The Thames River abatement program which includes direct oxygen injection to the River during critical periods, has proven to be a successful remedial action. For many years prior to 1970, the section of the Thames River flowing through the City of London was devoid of oxygen. Major improvements to the sewage works were carried out in the mid-seventies at a cost of approximately 700 million dollars. Improved oxygen conditions resulted, followed by a substantial improvement of biological conditions, fish returned to the river including salmon after an absence of 100 years.

Nonetheless, five or six critical periods of oxygen sag reoccurred each year during heavy storm events when jump weirs released storm water overflow to the River. The cost of providing hydraulic detention or other options designed to prevent this condition was estimated at several hundred million pounds sterling, so that the construction of a purpose-built vessel which provided a solution at 3 million pounds was considered to be a viable alternative.

The initial phase in the development of their mobile oxygen injection system was the modification of a Thames River barge by constructing a 10-ton-per-day Pressure Swing Absorption Plant (PSA aboard the vessel to generate oxygen on a continuous basis for 24 hour treatment during the five or six day duration of depleted oxygen conditions. During this time, the barge moved up and down the River following the "plug" of oxygen-poor water as it moved with the tide until it recovered and was flushed out to sea. Based on the experience gained with the original barge, the purpose-built vessel has been constructed. It was undergoing final commissioning in the spring of 1989 and was expected to be fully operational shortly thereafter.
Aeration Vessel Design

While the general concept of a vessel-mounted aeration unit considered by the author for Lake Simcoe and the principal of injection are similar to the "Thames Bubbler", a much less complex and less expensive option is required. The basic concept proposed in the following has been developed around a vessel of sufficient size to carry a storage tank equivalent to one truckload of delivered oxygen, together with the diesel-driven pumps and piping systems required for oxygen dissolution and injection to the required strata of the hypolimnion.

In developing this concept, the author enlisted the following technical support people to provide specific information in each area of their expertise:

1. **Linde Products - Union Carbide of Canada**
   Mr. Mike Fullam and Mr. Steve Greg provided the data on the oxygen storage and delivery system including cost information.

2. **Tadco Engineering Limited**
   Mr. Fred Tadros provided the information on pump specifications and costs to deliver the flow and pressures specified by the Linde design.

3. **Mr. John E. Maytham - Naval Architect & Marine Engineer**
   Mr. Maytham prepared the specifications and the cost estimates for the vessel according to the weights and dimensions of the oxygen storage and delivery systems and the operating requirements as specified by the author.
The basic criteria established by the author covering the general vessel design and delivery system included the following:

1. The total oxygen delivery system should be capable of delivering 12 t of oxygen to the hypolimnion in an eight-hour period.
2. The oxygen storage capacity on the vessel should provide for two shifts between truck delivery and recharging (26 t).
3. The vessel should be capable of speeds to 10 knots and be of a size and draft that would allow transit through the Trent Canal System.

**Oxygen Delivery System**

Linde personnel used the following criteria for the design of the oxygen delivery system:

- Water temperature 20°C (through hull intake)
- Instantaneous oxygen dissolution rate of 1500 kg/hr
- Intake D.O. concentration 10 mg/L
- Oxygenated water discharge depth 30 m (100 ft.)
- Estimated dissolution efficiency required 75% at discharge nozzle (Note - additional solubilization of the 25% gaseous oxygen to take place in the hypolimnion)

A schematic of the system proposed is illustrated by Figure 11.

The calculation to achieve the delivery system proposed resulted in the following information:

The "side stream" process of oxygen dissolution selected utilizes pressurized water delivered to a series of fourteen 15 cm (6 in.) I.D. pipes, (contactors) each 59 m (180 ft.) in length.
Figure 11: Linde - Oxygenation.
Oxygen is injected to each contactor by means of a proprietary venturi and each is independently valved. The purpose of the tubing network is to provide contact time in the pressurized stream for oxygen dissolution. Discharge from the tube bundles is collected in a manifold for delivery to the down-legs.

For purposes of this design, two identical systems are used comprised of two diesel driven pumps each connected to an independent through hull suction source and discharging to a manifold feeding a seven-pipe contactor bundle for subsequent collection and discharge through two retractable down-legs.

The oxygen storage proposed for the vessel is a baffled horizontal tank having a nominal capacity of 25 t of liquid oxygen. A vaporizer is required to gasify liquid oxygen prior to injection through the venturi system and is specified as a component of the oxygen delivery system.

**Pumps**

Using the specified pumping requirement of 6800 USGPM at 125 psi for each of two identical pump systems, Tadco Engineering Limited established the following service requirements:

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>6800 US GPM</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.0</td>
</tr>
<tr>
<td>Discharge Pressure</td>
<td>125 PSI</td>
</tr>
<tr>
<td>Total Dynamic Head</td>
<td>290 ft.</td>
</tr>
<tr>
<td>Bowl Efficiency Design</td>
<td>86%</td>
</tr>
<tr>
<td>Brake H.P. required</td>
<td>577 H.P.</td>
</tr>
<tr>
<td>Maximum Brake H.P. required</td>
<td>660 H.P.</td>
</tr>
<tr>
<td>Minimal Submergence over Bell</td>
<td>3 ft.</td>
</tr>
<tr>
<td>NPSH required</td>
<td>21 ft.</td>
</tr>
<tr>
<td>Pump Speed</td>
<td>1160 RPM</td>
</tr>
<tr>
<td>Down Thrust</td>
<td>6100 lb.</td>
</tr>
</tbody>
</table>
Based on this specification, a Byron Jackson 3-stage vertical turbine pump, Model VCT was selected. The pump drive proposed is a G.M. Detroit diesel engine, Model 12V71T developing 760 H.P. at 2100 RPM (See appendix for detailed specification of engine, drive and pump).

Vessel

With the system design, the component dimensions and weight specification completed, the data was provided to John Maytham for the design of a suitable vessel capable of carrying the designed load at a practical travel speed and able to traverse the lock systems providing access to the Lake. Because of significant loading created by a loaded oxygen tank, the additional weight added by 770 m (2520 ft.) of 15 cm (6 in.) pressure tubing filled with water, weight, positioning and distribution is an important consideration.

The most difficult engineering component is the down-leg delivery system required to deliver the pressurized oxygen enriched water to a depth of 30 m (100 ft.). Several concepts were considered. The one selected utilizes a telescoping pipe in a pipe design which is swivelled at the deck to enable the pipes to be raised in the telescoped configuration and secured at deck height along side the vessel during transport. When performing lake treatment, the down-legs would be lowered to a vertical position and extended to the operating depth by means of deck-mounted winches.

The technology for significant components in the gooseneck flexible sections at the deck to enable the 90° change in direction for the down-legs (travel to injection modes) has been developed and is used in suction dredge design. The design of the
discharge ports at the terminal end of the down-legs would be supplied by Linde technical staff at the time of final design. The discharge ports will be directed horizontally to the Lake bottom in 360 degree radius. The design of the ports includes proprietary hardware as they are critical to the efficiency of operation in that the final 25% of oxygen which remains to be dissolved following discharge must be in a fine bubble form.

An important consideration in the arrangements of ports at the distal end of the down-leg will be their even distribution in the 360 degree radial configuration. This is required as each leg will deliver the forces generated by water pumped by 570 H.P. of energy and the forces must be balanced evenly in all directions.

The vessel *per se* has been generally specified in the correspondence and two drawings of a "Draft General Arrangement" which are appended (Appendix C). The design requires a vessel with an overall length of 27.7 m (84.5 ft.), a beam width of 8 m (24.5 ft.) and a draft of 1.6 m (5.0 ft.). Hull displacement is 162 tons. (L.) Power selected is a GM12V-71T1 engine, the same as specified for the pumps so that all three power units will be the same. As the drive is single screw, a bow thruster is used to provide additions manoeuvrability for turning and docking. The estimated speed of the vessel is 9 knots (10.3 mph).

**Potential Effect of Pumped Surface Water on Hypolimnion**

One criteria for oxygen enhancement of the hypolimnion is that any procedure used will not significantly affect the natural summer temperature regime.

As it is proposed that the vessel system utilize pressurized surface water, a
calculation has been made of the anticipated temperature change resulting from a 100 day oxygen treatment.

Total Volume of surface water discharge to hypolimnion
(2 pumps @ 6800 USgpm, 8 hours/day, 100 days = 27.4 x 10^6 m^3

Total volume of hypolimnion Kempenfelt Bay - 404 x 10^6 m^3
Temperature of surface water - 22°C
Temperature of Hypolimnion - 10°C
Difference 12°C

Based on this data, the increase in hypolimnion temperature over one season in Kempenfelt Bay would be 0.69°C.

This change in temperature is within the year to year temperature range of 1.34 °C that presently exists in the hypolimnion (Waring, 986) and should therefore be acceptable.
Objective 4. Estimates of Costs for Delivery System

LOCHER SYSTEM COST

Capital Cost
Locher equipment installed: $4,000,000
The capital cost to include:
fabrication, delivery to site, setup, anchoring,
installation of power cable, pad and fencing for oxygen
storage tanks, piping for pure oxygen supply,
commissioning. (Site presumed to be on public land).

Operating Costs
(A) Power
Kilowatt charge @ 160kw/day
160 kwh usage: $572/mo.
Energy charge: 115,200kwh: $5,678/mo.
Power Cost/month: $6,250/mo.
8-month operating period ($6,250x 8mo.)
Total Power Cost: $50,000

(B) Commercial Oxygen
Lease equipment-shore storage
$600/mo. x 12mo.: $7,200
Delivered oxygen supply
4 tons/day x $110/t x 100d: $44,000
Total: $52,000

(C) Labour
1 inspection/wk. x 32 wks.
Salary $200 + boat & travel $80,
32 days x $280: $9,000

(D) Maintenance
0.05% of capital cost of $4,000,000: $20,000
Total Operating Cost: $131,000

(E) Contingencies @ 0.75% of operating costs: $9,000

Total Annual Operating Costs: $140,000
Arrangements for Construction, Installation and Guarantees

Locher have established a general arrangement with Dorr-Oliver Canada Limited of Orillia, Ontario for the construction and installation of the Locher "Mountain Creek" aeration systems. The final cost of equipment installed in Lake Simcoe would be based on the sum of the costs for Locher design, Dorr-Oliver cost of fabrication and installation and related overheads.

Equipment designed and installed by Locher carries a performance guarantee warranting that the tonnes of oxygen specified by the contract would be delivered to the hypolimnion.
VESSEL SYSTEM CAPITAL COST

Oxygen Delivery System

Oxygen storage vessel would be supplied by Linde on an annual lease basis. The tank proposed for the vessel would be of standard horizontal design and fitted to be mounted in the vessel at the time of construction. The vaporizer unit is likewise supplied as a component of the lease.

For this reason, costs associated with oxygen storage are considered to be operating rather than capital cost items.

Additional components specific to this application including pipes, valves, and venturis would be at owner cost and are estimated at: $10,000.

Pumps for Pressurized Side-Stream Delivery

Tadco Engineering estimate for budget purposes:

- 2 units required at $114,000 each: $229,000

Price includes pump, diesel engine, flanged couplings, Randolf right-angle gears, air vacuum release valve, and discharge pressure gage. Diesel engine equipment includes residential type exhaust mufflers and 500 gal. fuel tank.

Vessel Cost:

- Vessel - Basic Hull and drives: $635,000
- Pressure bundles: 58,000
- Telescoping down-legs and winches: 82,000

Total Estimated Capital Cost: $775,000

Summary of Capital Costs:

- Oxygen Deliver: $10,000
- Pumps and Drives: $228,000
- Vessel: $775,000
- Total Cost: $1,013,000
OPERATING COSTS

The following calculation has been made for the annual operating costs for 100 operating days based on the following assumptions:

Cost Elements
Cost for oxygen delivered to vessel: $110/ton
Annual rental for oxygen storage tank and vaporizer on vessel at $600 per month.
Fuel consumption - diesel drives at operating load 45.5 liters/hr. (10 MPH)
Vessel propulsion during injection, 23 liters/hr. (5 IGPH)
Labour - Two operators a $15 and $10/hr., 100 injection days plus 30-day downtime and mobilization.

Maintenance: 15% of capital cost (i.e. $300,000) for pumps and diesel engines.
% of capital cost ($700,000), hull and accessories.

Other - dockage, lay up and miscellaneous.

Estimate of Operating Costs
Oxygen - ___ days @ 12t/day x $10/t: $132,000
Lease Charge - annual - oxygen tank and vaporizer: $12,000
Fuel - Side-stream pumps
45.5 L/hr. x $0.35/L x 8 hrs.: $128/day/pump
2 pumps operating 100 days: $25,600

- Vessel Propulsion
2 hrs./d a 45.5 L/hr. and 8 hrs./d @ $23/hr.
   = 275 L/day x $0.35/L = $96/day
Cost for 100 days: $9,600

Estimated Total Fuel cost: $35,000
Labour - Vessel captain @ $15/hr.
  10 hr./day x 135 day: $20,000
- Vessel Assistant @ $10/hr.
  10hr./day x 130 days: $13,000

Estimated Total Labour Cost: $33,000

Vessel Maintenance - 15% of capital cost ($300,000)
  of pumps and diesel engines: $45,000
  5% of hull and accessories cost
  @ $700,000: $35,000

Estimated maintenance: $80,000

Dockage Layup and Miscellaneous: $8,000

Estimated total Annual Operating Cost: $300,000

The operating cost elements indicate that:

- The cost per operating day is: $3,000
- The cost per ton of oxygen injected is: $230
- The ratio of oxygen cost to injected cost is: 1:1.3
- Effective working days assigned is: 75%
Summary of Comparative Costs of Locher and Vessel

Table 4 summarizes the costs determined for the delivery of 12t of oxygen a day during the period of summer thermal stratification in Kempenfelt Bay. The cost of the Locher equipment also includes the cost of operating during the period of ice cover to provide circulation and an additional input of 8t of oxygen per day over the four winter months.

While the capital cost of the Locher equipment is four times the vessel cost, the annual operating expenditure for the vessel is twice the stationary unit. Based on a 20-year life expectancy, the annual cost of treatment would be approximately $350,000 for both systems.
Table 4.  Comparison of Treatment Costs.

**Capital and Operating Costs**

<table>
<thead>
<tr>
<th></th>
<th>Locher</th>
<th>Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost:</td>
<td>$4,000,000</td>
<td>$1,013,000</td>
</tr>
<tr>
<td>Annual Operating Cost:</td>
<td>140,000</td>
<td>300,000</td>
</tr>
</tbody>
</table>

Based on 20-year Life of Equipment

<table>
<thead>
<tr>
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<th>Locher</th>
<th>Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-year Capital Cost:</td>
<td>200,000/yr</td>
<td>50,650/yr</td>
</tr>
<tr>
<td>Annual Operating Cost:</td>
<td>$140,000/yr</td>
<td>$300,000/yr</td>
</tr>
<tr>
<td>Total Cost Per Year:</td>
<td>$340,000</td>
<td>$350,650</td>
</tr>
</tbody>
</table>

**Operating Cost Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Locher</th>
<th>Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Operating Days</td>
<td>240</td>
<td>100</td>
</tr>
<tr>
<td>Cost per Operating Day</td>
<td>$530</td>
<td>$3,000</td>
</tr>
<tr>
<td>Total Oxygen Injected(t):</td>
<td>2,000</td>
<td>1,200</td>
</tr>
<tr>
<td>Cost per Ton Of Oxygen Injected:</td>
<td>$70</td>
<td>$ 230</td>
</tr>
</tbody>
</table>
Objective 5: Comment on Environmental Effects

The following comments are provided to a series of questions as requested by the contract document:

5.1 Effect of Improved Oxygen Conditions on Phosphorus Cycling

In a review of the effects of hypolimnetic aeration on phosphorus concentrations, for a number of studies reported in the literature, McQueen and Lean (1986) noted that variable results were found. They conclude that "while early experiments suggest that phosphorus sedimentation was unpredictable, recent work has demonstrated that when a ratio of total iron to soluble reactive phosphorus exceeds 10:1 and pH is greater than 7.5 (Lake Simcoe 8.3) phosphorus sedimentation is assured and internal loading greatly reduced". Beaver (personal communication) noted that Fe:SRP-P ratios in Lake Simcoe were 2:7.1 and for this reason aeration of the hypolimnion may not reduce the internal phosphorus loading. McQueen and Lean (1986) concluded that hypolimnetic aeration could have a major impact on phosphorus sedimentation and regeneration, but that when available iron was not present, hypolimnetic aeration could not substantially reduce hypolimnetic phosphorus concentrations (Murphy et al, 1983).

Iron availability occurs when hydrogen sulphide produced in the muds react with iron producing insoluble iron sulphides. This is a common feature in eutrophic lakes sediments and may explain the lack of universal success in lake rehabilitation through hypolimnetic aeration.
Data supplied by Locher on whole lake hypolimnion aeration for Lake Huttnersee between 1983 before aeration and 1989 after five years of circulation are included in Appendix A. It will be noted that before aeration oxygen in the bottom waters was lost by May and remained at zero until fall turnover, The equipment was installed in December, 1983 and thereafter oxygen remained in the hypolimnion each summer. It did not continuously exceed the Ministry of the Environment 5ppm objective until 1986 suggesting that oxidation of the lake sediments were occurring during the first three years of treatment.

The effect on soluble phosphorus in the hypolimnion was dramatic with an order of magnitude reduction the first year and remaining at this level thereafter. Total phosphorus reduction in profundal waters reflects the loss of the SRP fraction which remained at low levels after treatment. There appears to be little change in the total phosphorus levels in the epilimnion following treatment.

The observation of variable results noted by McQueen and Lean (3986) may well have been the result of incomplete oxidation of sediment where bubble treatment did not result in adequate oxygen being absorbed at the interface, Under these conditions available iron would be tied up in sulphides and therefore not available to retain phosphorus. Once surplus iron becomes continuously available under oxidized conditions, phosphorus would be permanently stored in the sediment. The success of the Huttnersee treatment supports this thesis (Appendix A).

5.2 Potential for Hypolimnion Aeration to Cause Reduced Oxygen in the Metalimnion

*not determined*
5.3 Potential for Summer Aeration to Reduce Winter Oxygen Concentrations

McQueen and Lean (1984, 1986) noted one instance where winter oxygen depletion was accelerated in an enclosure where hypolimnion aeration had occurred during the previous summer. This finding was not repeated and has not been observed in whole lake systems, so whether it remains as a valid concern is questionable. In discussing this concern with Dr. McQueen, he suggested that it may have occurred because an increased rate of biological activity in organic sediments that resulted from improved summer oxygen conditions extended into the winter period.

Whether this phenomenon would occur in Lake Simcoe is not known. We would suggest, however, that the sediments of Lake Simcoe are less organic in nature and that the sediment oxygen demand will be less. The essential purpose in hypolimnion aeration is to repay the debt of organic demand and if successful, the potential for winter oxygen depletion should be reduced.

It is proposed that a Locher installation would be operated during periods of ice cover to improve circulation at the sediment interface and add oxygen to the water. This practice may be expected to provide the oxygen requirements for an enhanced rate of organic degradation and prevent the occurrence of oxygen depletion resulting from summer aeration, should it occur.

5.4 Potential for an Undesirable Concentration of Dissolved Nitrogen

Fish living in an environment of supersaturated nitrogen are affected by a phenomenon known as "gas bubble disease". This occurs when a supersaturated
concentration of nitrogen in the blood releases gas bubbles to the blood stream and the minute bubbles cause blockage in the capillary systems. It is the same phenomenon as the "bends" occurring in divers. In hatchery practice, this problem is most serious to small fish because of the small size of blood vessels in critical systems of the body. For this reason, concentrations of dissolved nitrogen should be maintained below 103% saturation.

In considering the potential for creating a problem to fish using the two solutions proposed for Lake Simcoe, there is no possibility from vessel oxygen injection as only pure oxygen is released to the hypolimnion. The Locher equipment uses air to supply two-thirds of the total oxygen injection. Both the pressurization in the pump-leg release and further dissolution in the updraft pipe will increase the concentration of dissolved nitrogen. The upwelling water is depressurized at the surface, at which time the water may be expected to return to a normal surface-saturated concentration before being returned to the hypolimnion.

This is quite different than an air bubble system discharging and dissolving nitrogen at a depth where increased pressure enhances and retains the solubilized gases. Under these conditions the nitrogen concentration will be several times that found at the surface. It should be noted that the problem relates a condition of supersaturation irrespective of concentration, so that no problem will occur under elevated concentrations providing a condition of supersaturating is not induced. This will not occur using the Locher system as the water returned to the hypolimnion contains only a fraction of the saturation level at that depth, Trout and whitefish, reintroduced following treatment of Huttnernsee using Locher equipment have prospered, which would appear to confirm this conclusion.
DISCUSSION

The essential purpose of this report has been to assess feasibility of resolving the depleted oxygen conditions in Lake Simcoe by supplementing natural oxygen resources in the hypolimnion during critical periods. The estimates of requirements for oxygen input must be considered preliminary, particularly with respect to the need calculated to supply the "induced demand" anticipated to result from enhanced conditions of biological and chemical oxidation. None the less, the range of values estimated is sufficient to establish the magnitude of supplementation required.

Likewise, the mechanics of introducing the volume of oxygen required are on a scale not previously attempted in natural lake systems. The Locher equipment proposed to do this has been demonstrated to be effective on a smaller scale and as such may be considered as pilot scale to Lake Simcoe in scope. The vessel system evaluated has not been used previously in hypolimnetic application. A model of the essential size required is available in the Thames bubbler.

Superimposed on the question of specific benefits to result from oxygen deployment to the hypolimnion is a series of limnological questions on conditions that may be expected to result from changes to the chemical and physical environment. These changes are expected to upgrade the environment through improved dissolved oxygen content of the total hypolimnion, but perhaps most importantly to repay the oxygen sediment debt that has been incurred through induced eutrophy. If repayment of the debt by oxidation of sediments results, the natural process of semiannual replenishment of the lake's total oxygen requirement may he restored and the self-destructive cycle of phosphorus feedback from reduced sediments broken.
The best solution to any health problem is prevention. Lake Simcoe through time, changes to the watershed and municipal discharges has become the repository of fertilizing elements which supports a level of biological productivity whose demand for oxygen in the hypolimnetic recycling process presently exceeds the seasonal oxygen supply. The demand is composed of that required to support the combined requirements of the unoxidized organic substances that have accumulated and an increasing quantity of annual production that must be degraded. To prevent a worsening of the problem, the important steps of removing phosphorus from sewage effluents and diversion of others from the watershed have become accomplished. No measurable improvement has resulted to this time which is not entirely unexpected as the surrounding population continues to grow and the memory system within the lake continues to feed the nutrient cycle.

The City of London, England was faced with a similar dilemma. Those preventative actions which could practically be taken had been achieved and appropriate oxygen conditions in the Thames River restored except during five or six heavy rain events per year. These oxygen deficiencies, while infrequent, would be catastrophic to the newly re-established fish populations and to the pride of accomplishment following a hundred years of neglect. The best environmental solution would probably have been to prevent any storm water runoff but this would have required the expenditure of impractical amounts of money and for this reason might never have been implemented.

A parallel exists for Lake Simcoe, The most important and economically achievable preventative measure has been implemented. Other diffuse controls such as storm water treatment, changed practices in agriculture and ongoing vigilance of
septic tank systems are the options that remain. Atmospheric contributions are unlikely

to be reduced and superimposed on these is the feedback system from the sediments

that will not be curtailed until the oxygen debt of past neglect has been repaid.

Perhaps the only practical option is the one selected for the Thames and Lake

Huttnersee to help nature to pay down the debt until such time as other controls can

balance the oxygen budget. To do this according to the estimates calculated by the

foregoing will require expenditure of a much larger sum of money than is the custom

of society to direct to environmental solutions. The downside of not acting to ensure

an early and positive solution to the Lake Simcoe problem will be increasing stress and

ultimate loss of the valuable coldwater fishery, more frequent and excessive blooms

of algae and the deterioration of the aesthetics of probably the most valuable inland

lake in Canada.

While the cost is high, it should be considered in relation to the cost of other

options to bring it into better focus. For example, the ongoing cost resulting from

modification to the Barrie and Orillia sewage treatment plants to improve phosphorus

removal has been estimated at $24 to $55/kg of phosphorus removed (Limnos 1984).

Considerations for storm water management are best done and should be implemented

for any new construction. The retrofit of old systems require studies by consultants,

engineering plans, renovation and changes in built-up areas and possibly the purchase

of land for retention ponds. Costs in the order of millions of dollars would soon be

dispensed which may not result in any short term benefit.

Perhaps the most compelling reason relates to the value attached to the

property specifically because of its location along the shore, Already an ordinary
property on a fifty-foot lot may be worth a quarter of a million dollars and these values will continue to escalate as the population of the Metropolitan area grows and the demand for a unique home location escalates prices.

Technical aspects in the foregoing report may be the subject of debate and other options for the addition of oxygen to the hypolimnion proposed. We believe the key element in the solution to the oxygen problem and the constraint it imposes on the biological systems lies at the sediment water interface. To correct this will require the continuous availability of oxygen in the surficial micro-environment. This will not be achieved by a less expensive bubble system as the solution of enriched oxygen is directed upwards. Lateral movement of oxygenated water along the sediment surface is required to satisfy the demand and to enhance the forces of diffusion, as they are presently insufficient at reduced oxygen levels, to satisfy the requirements of oxidation.

To do this, we have evaluated two systems. The Locher equipment described is in an advanced state of engineering and ready for trial in a major body of water. Their terminology of "Mountain Creek" envisages a flow of 1.3 million m³/day of highly oxygenated water driven in this instance by 120 hp of energy and carrying with it approximately fifty times that quantity in a jet-assisted flow. The oxygen to be delivered to the hypolimnion is our best estimate of the oxygen required by Kempenfelt Bay to meet the 5mg/L Ministry of the Environment objective. The unit must be positioned in the Bay and the flow directed to take advantage of the existing flow vector and where the effect would not be lost into the open water of the main lake. The Locher system has the advantage of circulation and oxygen enrichment during the quiescent winter period when wind-induced circulation cannot assist the natural
processes of diffusion and dispersion.

The vessel option brings certain advantages and disadvantages. The transport and dissolution of oxygen into the pressurized water stream is based on existing knowledge. The delivery system to dissipate the enriched flow into the hypolimnion is not and further, careful study of the mechanics of the most suitable means to do this is required. Likewise, the distribution of the flow and the oxygen it carries over the bottom should be the subject of further study, perhaps by modeling to evaluate the concentrations left in the vessel path and the anticipated rate of utilization. It has the advantage of directing flow to the strata of specific need and being mobile ran respond to critical areas in the lake. The design is based on an injection time of eight hours per day, so that inputs could be adjusted up or down by increasing or decreasing operating hours. It will not be useful in solving winter depletion other than by contributing to a more effective oxidation during the summer which would be expected in time to reduce sediment oxygen consumption in the winter period.

We see no means whereby small-scale experimental work may be used to measure the anticipated benefits. An initial full-scale installation of Locher equipment in Kempenfelt Bay or vessel treatment would, however, carry the expectation of a solution to the problem in this segment of Lake Simcoe and enable the effectiveness of treatment to be evaluated before further units were designed and installed as a solution for the open water basin.

With respect to cost, both systems, have the capability of supplying the oxygen required to upgrade the level to meet the Ministry of the Environment objective. To do this, the estimated capital costs of the Locher equipment is four times the vessel cost.
($4,000,000 versus $1,000,000). Operating costs, however, are expected to be less for the Locher system and it has been estimated that over the twenty-year life expectancy of both units, the cost (without interest would be about equal at $350,000 per annum.
RECOMMENDATIONS

The following recommendations are made in order that further more specific action may be taken to implement hypolimnetic aeration in Lake Simcoe. It is therefore recommended that:

1) A study be commended as soon as possible to determine the direction and rate of water flow at the bottom of Lake Simcoe during each season in the areas encompassed by the hypolimnion.

2) A careful evaluation of the late winter oxygen deficiencies be made in those areas of the lake containing organic sediments.

3) A comprehensive study be undertaken of the organic sediment areas of Lake Simcoe to determine both the total demand and the oxygen uptake rate so that the rate required for oxygen supplementation to satisfy both the oxygen debt and current demand can he determined. From this information it should be possible to predict when and if the program of supplementation will be completed.

4) As part of the sediment oxidation study, determine the benefits in reduced phosphorus return that may be expected. This information should be expressed in cost/kg of phosphorus retained, based on the cost of the hypolimnion treatment. This value may then be compared to the other options (i.e. storm water control or enhanced sewage treatment) for purposes of cost/benefit determinations.

5) A physical limnologist should be directed to develop a model to predict the effect of:
   a) the circulation of water and the utilization of the total oxygen resources (nature plus 12 t/day input) within Kempenfelt Bay under the regime established by the Locher aeration unit.
   
   b) the anticipated oxygen regime that would be established by the injection of oxygen at selected levels within the hypolimnion with special reference to the theoretical rates of diffusion and natural water movement as determined from the flow and vector studies.
6) A contract designed to cover out-of-pocket cost should be issued to Locher to provide a detailed design and cost estimate of the equipment they would propose. A second contract should be issued to an appropriate marine consultant to develop the conceptual information provided herein for the design and costing of a purpose-built vessel, including specification for the down-leg design.

7) An early objective should be established to select the most suitable means to supplement oxygen to increase the oxidation state of organic sediments within the lake and an early full-scale trial/treatment implemented in Kempenfelt Bay.
ACKNOWLEDGMENTS

The author is indebted to a large number of people who have contributed to the content of this report.

Provincial Government agencies including the Ministries of Environment and Natural Resources and The Lake Simcoe Conservation Authority have been the principal agencies that developed the basic water resource information. My special thanks are extended to Dr. H. Vandermeulen and Mr. K. Nicholls who have provided data and supervised the contract and Mr. R. Allen, Ministry of Natural Resources who provided essential data.

Mr. Walter Schmid and Mr. Walter Buhl of Locher & Cie, AG have contributed an essential component to the study, both from the information provided on the specifics of their equipment and also through their ongoing interest in and knowledge of lake reclamation. Studies in Europe of comparative systems and limnological results reported by the Swiss Government and academic organizations were made available to us through the Company.

Staff of the Thames Water Authority graciously provided a tour of the London Bubbler and background information on the vessel design and Thames River Treatment.

Mr. Steven Gregg and Mr. Michael Fullam of Linde Air provided the basic design of the oxygen dissolution processes and Mr. John Maytham the vessel design and delivery systems.

The published reports and personal advice of Dr. Don McQueen York University has been used throughout the report and has been invaluable in the assessment of the reclamation procedures evaluated herein.

Mr. Paul Schaap and Mr. Jeff Graham, Limnos staff members contributed in the data gathering phases and assessment of oxygen requirements.
REFERENCES


APPENDIX A

Hypolimnion Improvements Hattnersee 1983-1988
APPENDIX B

Pump and Drive Specifications - Tadco Engineering Ltd.
June 19, 1989

Cool Water Farms Limited
Aquaculture Centre:
591 Liverpool Road
Pickering, Ontario
L1W 1R1

Attn: Mr. John Neil, Vice President
Re: Byron Jackson Diesel Driven Vertical Turbine Pump

Dear Mr. Neil:

Further to our telephone conversation related to the above subject, we are pleased to provide the following proposal for budget purposes only:

Diesel Engine Driven Pump:

SERVICE:

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>6800 USGPM</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.0</td>
</tr>
<tr>
<td>Discharge Pressure</td>
<td>125 PSI</td>
</tr>
<tr>
<td>Total Dynamic Head</td>
<td>290 Ft</td>
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<tr>
<td>Bowl Efficiency (design)</td>
<td>86 %</td>
</tr>
<tr>
<td>Brake Horsepower Required (design)</td>
<td>577 HP</td>
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<tr>
<td>Max. Brake Horsepower Require</td>
<td>660 HP</td>
</tr>
<tr>
<td>Minimum Submergence Over Bell</td>
<td>3 Ft</td>
</tr>
<tr>
<td>NPSH Required (design)</td>
<td>21 Ft</td>
</tr>
<tr>
<td>Pump Speed</td>
<td>1160 RPM</td>
</tr>
<tr>
<td>Down Thrust</td>
<td>6100 Lb</td>
</tr>
</tbody>
</table>

Recommendation:

One (1) Only Byron Jackson heavy duty Vertical Turbine Fire Pump Model VCT and Diesel engine units, each including the following:

3 stage 28 RXM cast iron bowl assembly with cast bronze impellers, 416 stainless steel bowl shaft 2 11/16” diameter, dual rubber - bronze bearings, and cast iron suction bell.
16" Diameter flanged column assembly with 2 7/16" diameter 416 stainless steel line shafting and couplings, rubber bearings in integral L.C.S. spiders, shafting to be product lubricated type construction. Total pump length from bottom of discharge head to bottom of suction strainer will be 7'- 6" approx.

16 x 24 1/2 type DE fabricated steel surface discharge head with 16" diameter 150 lb. discharge ASA flange, high pressure bleed - off packed type stuffing box, and two piece head shaft which require less overhead room for easier gear installation and removal, and c/w fabricated steel sole plate.

Randolph right angle gear drive model 590 F vertical hollow shaft standard thrust fig. '1 rotation, 6:5 gear ratio, water cooled and complete with non reverse ratchet.

Val-Matic Model 102 automatic air and vacuum release valve 2". Aschcroft discharge pressure gauge with valve.

Hayes Dana type 1 coupling model GWB 587.50, c/w 2 companion flanges and coupling guard.

GM Detroit diesel engine model 12V71T developing 760 HP at 2100 RPM, complete with heat exchanger water cooled, raw water system and manual by-pass, one set of lead acid batteries with battery racks and cables, 24 volt, and engine block heater, flexible exhaust pipe, residential type exhaust muffler, and engine sub base.
Diesel fuel tank 500 gal. complete with accessories.

Price complete unit as above $ 114,400.00

Alternate Pump

Byron Jackson model 20 HQ-H, 5 stages, all other items remain the same, except total pump length will be 12’- 0" approx.

Price complete unit as above $ 93,000.00

The above prices are in Canadian Dollars, FOB Pickering, Ontario, with all taxes extra. Duty and brokerage where applicable are included.

Delivery: 16 to 18 Weeks.

Terms: Net 30 days, from shipment and date of invoice, provide partial shipment and invoicing allowed.

We trust the above will meet with your approval, and should additional information be required, please contact this office.

Yours very truly,

TADCO ENGINEERING LIMITED

Fred Tadros, P. Eng.
APPENDIX C

Hypolimnion Aeration Vessel Design - J. Maytham
Aug. 21, 1989

Mr. John H. Neil
Limnos Ltd.
591 Liverpool Rd.
Pickering, Ont.
L1W 1R1

Dear John,

Enclosed are 2 copies of a Draft General Arrangement of the proposed vessel for the Lake Simcoe Aeration Program.

**Vessel**

Although the Trent Severn Waterways is listed as having a draft of 6 ft. I was advised by the Peterborough Office not to exceed 5' 6". I am therefor showing the minimum size of vessel for the required loading of 89.3 tons(L).

The vessel will have transverse & longitudinal bottom framing and transverse side framing, with 5/16 bottom plating and sides and deck.

I am proposing a GM 12V 71T, single screw as this means three engines of similar servicing and spare parts requirements. This power will give a speed of 10+ MPH.

This vessel will be such that it could be converted to other uses if the proposed program should be phased out.

**Pressure Piping**

My estimates of weight and price are based on using 6" dia. sch. 40 pipe. This will handle the working pressure of 125 p.s.i.

The headers will be 16" dia. sch. 40 pipe and the overboard discharges to the legs will be 16" dia. sch. 80 pipe as the legs will pivot about this axis.

**Telescoping Legs**

The leg proposed is a 55' length of 32" pipe with 1/2" wall and fitted with a 50' length of 30" pipe. The bottom 5' of the upper pipe will have a gasket seal that will be effective once the leg is extended to 100'.

If you do not think that this will give large enough flow, we could use 34" & 32" pipe. However the 32" size is more readily available than 34".

The telescoping can be handled by a 5 ton hydraulic winch mounted on the top end of the 32" pipe upper leg. This will be used to raise the 30" lower leg which will be lowered by gravity under the control of the 5-ton winch.
Telescoping Legs. (cont'd)

Once the lower pipe has been raised to the position in the larger pipe, as shown on the drawing, the entire assembly will be raised by the 10 ton hydraulic winch mounted on the structurally reinforced bridge of the Pilot house.

The four hydraulic winches shown are to be self braking, and require to be powered in both directions.

Conclusion

Although there remains a great deal of detail engineering before construction could begin, I do not foresee any problems that cannot be handled, and I feel that this basic concept can be successfully developed.

Sincerely

John E. Maytham
Hypolimnion Aeration Vessel

Vessel Specification
- Length 84.5'
- Width 24.5'
- Draught 5' - 6" with oxygen load
  5' - 0" without "
- Engine 510'HP

Speed 10± (± 10 mph required)

Elements of design loading

<table>
<thead>
<tr>
<th></th>
<th>Wt.</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen(25)storage tank(17t) Vaporizer(1t)</td>
<td>43t</td>
<td>Tank 25' x 8'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vaporizer deck pad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6' x 8'</td>
</tr>
<tr>
<td>Pressure piping 2500 ft. 6&quot; steel pipe</td>
<td>27t</td>
<td>Maytham calculation</td>
</tr>
<tr>
<td>Filled with water -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - HP Diesel pumps each 6800 gpm</td>
<td></td>
<td>See pump Diesel specs.</td>
</tr>
<tr>
<td>@ 125 psi.</td>
<td>10t</td>
<td></td>
</tr>
<tr>
<td>2 - 32&quot; telescoping down legs to 100'</td>
<td>20t</td>
<td>Maytham concept</td>
</tr>
<tr>
<td></td>
<td>100 ton</td>
<td>(89.3 tons. L)</td>
</tr>
</tbody>
</table>

Estimated Cost.

Vessel - Basic Hull 6 Drives $635,000
Oxygen Delivery System (John Neil to add) $58,000
Pressure Piping bundles (John Maytham est.) $228,800
Diesel pump systems (2) as specified $82,000
Telescoping down legs (John Maytham est.) $82,000
MEMBERSHIP ON THE STEERING COMMITTEE FOR THE LAKE SIMCOE ENVIRONMENTAL MANAGEMENT STRATEGY IMPLEMENTATION PROGRAM

A. Morton, Lake Simcoe Region Conservation Authority (Chairman)
J. Barker, Maple District, Ministry of Natural Resources
E. Cavanagh, York County, Ministry of Agriculture and Food
R. DesJardine, Central Region, Ministry of Natural Resources
J. Kinkead, Watershed Management Branch, Ministry of the Environment
J. Merritt, Director - Central Region, Ministry of the Environment
B. Noels, Lake Simcoe Region Conservation Authority (Secretary)
APPENDIX
MEMBERSHIP ON THE TECHNICAL COMMITTEE FOR THE
LAKE SIMCOE ENVIRONMENTAL MANAGEMENT STRATEGY
IMPLEMENTATION PROGRAM

B. Noels, Lake Simcoe Region Conservation Authority (Chairman)
J. Beaver, Central Region, Ministry of the Environment
R. DesJardine, Central Region, Ministry of Natural Resources (past member)
J. Dobell, Huronia District, Ministry of Natural Resources
D. Green, Resources Management Branch, Ministry of Agriculture and Food
   (past member)
B. Kemp, Lake Simcoe Region Conservation Authority
J. Kinkead, Watershed Management Section, Ministry of the Environment
   (past member)
R. MacGregor, Central Region, Ministry of Natural Resources
N. Moore, Victoria-Haliburton County, Ministry of Agriculture and Food
K. Nicholls, Water Resources Branch, Ministry of the Environment
B. Peterkin, Central Region, Ministry of Natural Resources
T. Rance, Maple District, Ministry of Natural Resources
B. Stone, Northumberland County, Ministry of Agriculture and Food
M. Walters, Lake Simcoe Region Conservation Authority
C Willox, Lake Simcoe Fisheries Assessment Unit, Ministry of Natural Resources
K. Willson, Watershed Management Section, Ministry of the Environment
LAKE SIMCOE ENVIRONMENTAL MANAGEMENT STRATEGY

REPORTS


REPORTS


Imp. B.5 Duckweed Harvest from Holland River. 1988. Limnos Ltd.


