Auckland
Regional Council
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Summer oxygen depletion in Lake Pupuke during 2004-05 with summary of historic data

September 2005 TP276

Auckland Regional Council
Technical Publication No. 276, 2005
ISSN 1175-205X, ISBN 1-877353-96-5
www.arc.govt.nz

Summer oxygen depletion in Lake Pupuke during 2004-05 with summary of historic data

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Prepared for
Auckland Regional Council

NIWA Client Report: HAM2005-107
September 2005

NIWA Project: ARC06202

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1 Executive Summary

At the request of the Auckland Regional Council, NIWA have analysed a series of depth profiles of temperature and dissolved oxygen concentration from Lake Pupuke taken over the summer of 2004-05 and to compare these with similar data collected for 2002-03 and 2003-04, as well as historic data collected between 1967 and 1996.

During 2004-05, the temperature regime in Lake Pupuke followed a similar pattern to all previous years and the lake became thermally stratified by the middle of October 2004. Stratification remained steady and strong at approximately 20 m all summer. The hypolimnion remained at just above 12.5 °C while, after a cooler than usual December (2004), the epilimnion increased to over 23 °C. Oxygen depletion occurred in the bottom waters (hypolimnion) only, and was most rapid close to the lake bed, as expected, where it fell to zero by November. This is attributable to oxygen consumption due to the decomposition of organic material accumulating in the hypolimnion.

Lake Pupuke is well suited to calculation of the VHOD rate (volumetric hypolimnetic oxygen depletion rate), as the hypolimnion becomes well defined and isolated. The VHOD rate calculated for the 20-30 m depth interval was 0.054 g m^{-3} d^{-1} for 2004-05, which is substantially higher than the VHOD rates estimated in 2002-03 and 2003-04 at 0.038 and 0.024 g m^{-3} d^{-1}, respectively.

VHOD rates were estimated for the same depth stratum for each year in the period 1993-1996, inclusive, from unpublished data held by NIWA and the complete data set from 1967 to present was evaluated. With the exception of 3 years (1967, 1995, and 2005), all VHOD rates were within the range 0.023 – 0.038 g m^{-3} d^{-1} and there was no significant trend within these data, suggesting that the processes that lead to accumulation of organic material in the hypolimnion have not changed greatly since at least 1984.This range of VHOD rates places Lake Pupuke in the mesotrophic category.

Of the 3 high VHOD years, 1967 [VHOD rate = 0.073 g m^{-3} d^{-1}] may be attributed to a residual effect of historical sewage discharge into the lake and farm run-off, and the subsequent improvement in water quality to a VHOD rate of 0.031 g m^{-3} d^{-1} in 1985 is evidence of the recovery of the lake once those inputs had been removed.

The other 2 high VHOD years may be attributed to "climate events". However, while the expectation would be for events which added organic material to the lake (e.g., high sediment run-off or significant algal blooms), relational evaluations indicated that the opposite was more likely as 76% of the variability in the data could be explained by low rainfall in winter-spring [total rainfall between June and December]. Algal biomass was low also preceeding and during the event summers.

The unusual mid water peak of oxygen depletion at 20-30 m noted in previous reports was present in the 2004-05 data and also in all the historic data. While the previous report suggested that this depletion was likely to be related to a zone of midwater decomposition or to a concentration of respiring organisms in or just below the metalimnion, an alternative suggestion, which might account for the high VHOD – low algal biomass years, is that the band of higher oxygen was associated with a relatively well oxygenated cold-water spring inflow below the depletion zone. Such an inflow would cause local re-oxygenation in the otherwise oxygen depleted hypolimnion. During low rainfall winters, the spring flow might reduce thus reducing the re-oxygenation effect and allowing a naturally higher VHOD rate to prevail despite the lack of an increase in algal biomass to drive the VHOD rate by decompositional processes. Such springs are known to occur in the volcanic rock beneath Auckland City, the most obvious being the spring rising at Onehunga, which is used as part of the city water supply.

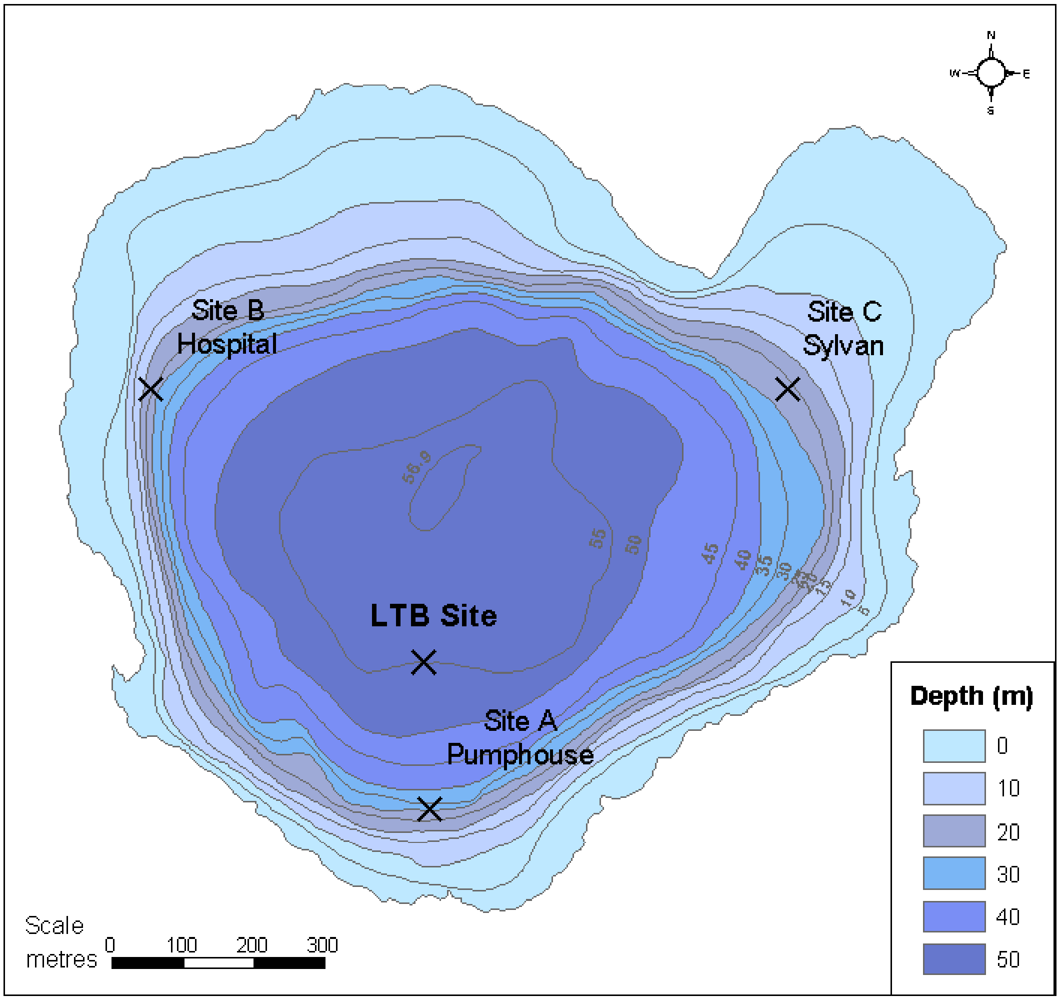
If the spring scenario is correct then this has implications for the management of Lake Pupuke water quality. Further study is required to resolve this issue.

2 Glossary

AHOD	Areal hypolimnetic oxygen depletion: the rate of oxygen loss from the hypolimnion of a lake normalised to the maximum area of the hypolimnion.
VHOD	Volumetric hypolimnetic oxygen depletion: the rate of oxygen loss from the hypolimnion of a lake normalised to the maximum area of the hypolimnion.
Epilimnion	The upper layer of water in a thermally stratified water body.
Hypolimnion	The lower layer of water in a thermally stratified water body.
Metalimnion	The zone occupied by the density gradient between the Epilimnion and Hypolimnion.
Thermocline	The plane within the metalimnion of maximum rate of temperature change with depth.

Figure 1

Bathymetry of Lake Pupuke, with the four sampling locations used. Contours are at 5 m intervals. VHOD rates are estimated from the deep site LTB, which has been used for all recent and historic data.



3 Introduction

At the request of the Auckland Regional Council, NIWA have analysed a series of depth profiles of temperature and dissolved oxygen concentration from Lake Pupuke taken over the summer of 2004-05 and compared these with similar data collected for 2002-03 and 2003-04 (Hawes & Haskew 2003 & 2004), as part of a monitoring study of this lake. Auckland Regional Council also requested that the report produced should include a brief comparison with earlier estimates by Vant et al., (1990) and the data collected by Dr Noel Burns during the period 1992-1996.

Additional data from a Datasonde moored at a depth of 34 m in Lake Pupuke during the 2004-05 VHOD monitoring period is included in the data evaluation. A second Datasonde moored at 25 m was deployed from 29 September 2004 and removed on 29 October 2004, produced suspect data which has not been used.

This report presents a summary of these data and provides a brief interpretation of variability within the data. These findings provide a new perspective on the hydraulic regime within Lake Pupuke which may have further implications for the management of this lake.

3.1 Background

From time series dissolved oxygen profiles taken from the deep site in Lake Pupuke (Fig. 1) during spring, after the lake has thermally stratified, an estimate can be made of the volumetric hypolimnetic oxygen depletion (VHOD) rate. The VHOD rate integrates all biological processes and carbon production within the lake as well as external inputs and provides an indication of the overall water quality of the lake which can be related to previous years to detect changes in the water quality of the lake.

The VHOD rate can be influenced by a number of factors (Vant 1987; Burns 1995) including temperature, which affects the solubility of oxygen in freshwater. Consequently, both temperature and dissolved oxygen are measured in each profile. Ideally, temperature in the hypolimnion should not change during the period of VHOD determination, or any change should be minimal. A second important consideration is the effect of chemical oxygen demand at low oxygen concentrations. Such effects can alter the VHOD rate when oxygen concentrations fall below about 2 g m^{-3} and minerals such as iron become reducing. Consequently, oxygen profiles can be used reliably for VHOD estimation only when oxygen concentrations are at or above 2 g m^{-3}. A third important consideration is that the hypolimnion must remain isolated from the epilimnion and thus not be re-oxygenated during the period of VHOD determination.

These constraints have been applied to the data used in estimating VHOD rates from the 2004-05 data and the data collected by Dr Noel Burns during the period 1992-1996.

Methods used for estimating VHOD rates are as per previous reports (Hawes & Haskew 2003 & 2004) i.e., by summation of the volume-weighted mass of dissolved oxygen lost per unit time from the 20-30 m depth interval calculated from 1-m increments within this layer.

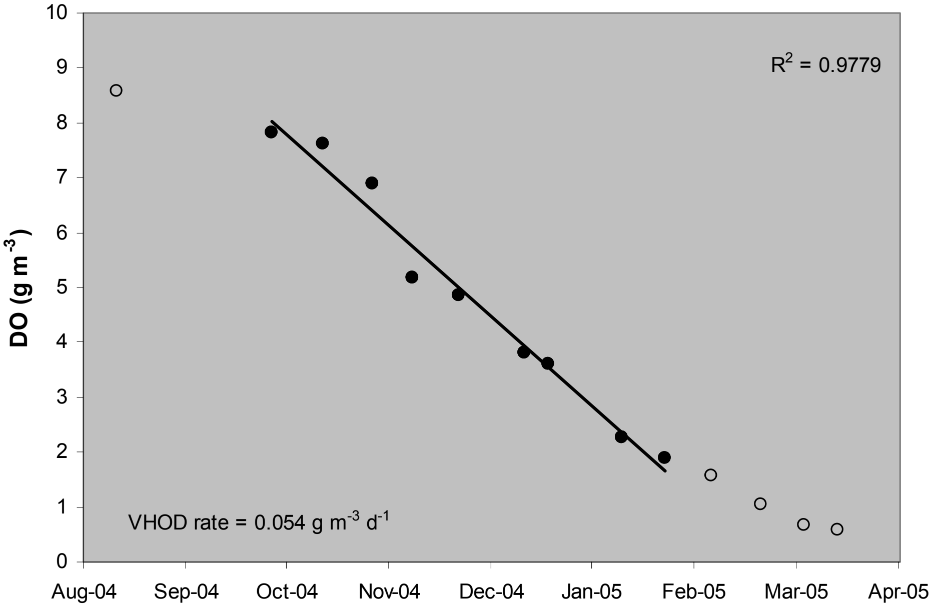
4 Results

4.1 2004-05 VHOD rate

The VHOD rate for 2004-05 was estimated for the 20-30 m depth interval as 0.054 g m^{-3} d^{-1} (Fig. 2). This VHOD rate is substantially higher than those estimated in 2002-03 and 2003-04 at 0.038 and 0.024 g m^{-3} d^{-1}, respectively (Hawes & Haskew 2003 & 2004). The decline in the volume-weighted-mean oxygen concentrations was essentially linear (r^2 = 0.9779) indicating that there was no downward mixing of oxygen through the thermocline during the period of VHOD determination.

Figure 2

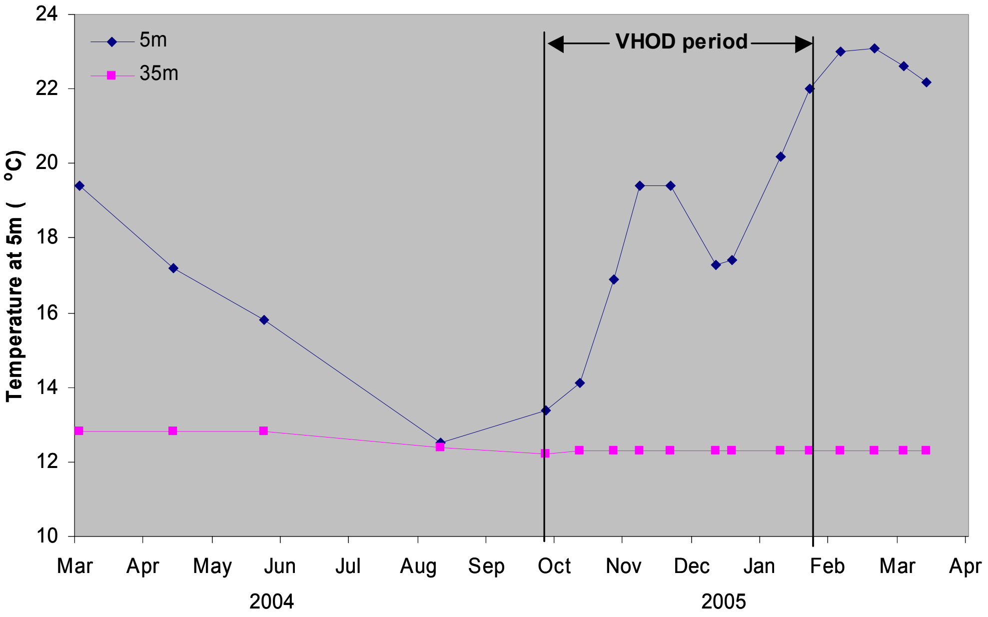
VHOD rate for 2004-05 was estimated from the slope of the linear regression through the volume-weighted-mean dissolved oxygen concentrations in the 20-30 m depth layer from after the lake had thermally stratified and before the average dissolved oxygen concentrations fell substantially below 2 g m^{-3} (r^2 = 0.9779, n = 9). Solid circles indicate data used in the regression. Open circles indicate the rest of the dataset available but not used in the regression.



Examination of the time-series temperature data for the 2004-05 period (Fig. 3) shows that the hypolimnion did not warm during the period of the VHOD calculation and thus the estimate requires no temperature correction. The temperature data also show that the epilimnion experienced significant cooling during December 2004, consistent with the weather conditions at that time.

Figure 3

Time-series temperature data in Lake Pupuke from the epilimnion at 5 m and the hypolimnion at 35 m during 2004-05. These data show that the hypolimnion did not warm during the period of the VHOD calculation.



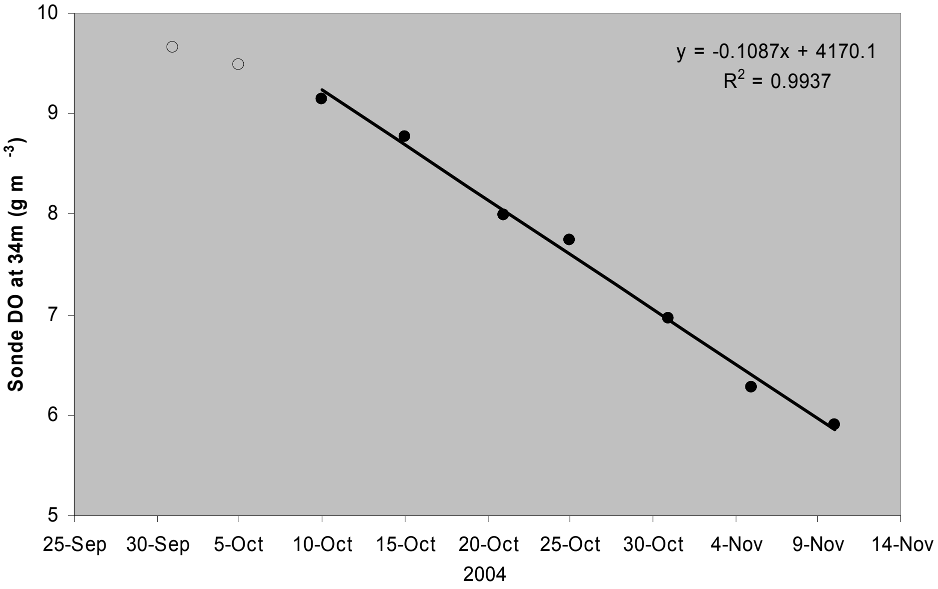
Hypolimnetic oxygen depletion was also demonstrated in the Datasonde probe records from a depth of 34 m in Lake Pupuke (Fig. 4). These data, extracted at 5-day intervals with individual plotted-points being averaged concentrations over 12 hours, show a consistent decrease in hypolimnetic oxygen concentrations through October 2004 with a depletion rate, estimated by regression, of 0.109 g m^{-3} d^{-1}. This rate is considerably higher than the VHOD rate estimated for the full VHOD period from October 2004 to February 2005 (Fig. 2). As the period used for estimation is different, these rates cannot be directly compared. However, using time series profile data for the same period as the Datasonde collection provides a VHOD rate estimate of 0.089 g m^{-3} d^{-1}, which is much closer to the Datasonde value.

Unfortunately the maintenance of the 34 m Datasonde introduced several problems in the data including some discontinuity in the precision of the data recorded following early cleaning. Consequently, dissolved oxygen data were unusable after 10 November 2004. Data (12 hour daily means) from the 25 m Datasonde showed an unexplained sudden rise in oxygen concentrations of more than 2 g m^{-3} at this depth a few days after deployment and before falling at a rate of 0.065 g m^{-3} d^{-1} (r^2 = 0.97) for the next 20 days. While it is tempting to use this depletion rate, the unexplained initial response from the probe means that this data is suspect and thus unusable, even though the apparent oxygen depletion rate was consistent with the estimate from the oxygen profile data for the 20-30 m depth layer (Fig. 2).

Notwithstanding this, from the usable oxygen record from the 34 m Datasonde, it is apparent that the use of Datasondes could improve the resolution and precision of the data used for the VHOD estimate i.e., Datasonde r^2 = 0.994 versus depth profiling r^2 = 0.978. However, as the VHOD estimate is a volume-weighted-mean over a 10-m depth range, the single depth value may not match the volume-weighted-mean value, and a more complete Datasonde record over the same period as used for the depth profiling VHOD estimate is required to validate its use and calibrate the results with historic data.

Figure 4

Extracted oxygen concentration data from the Datasonde deployed at 34 m in Lake Pupuke. Regression analysis through the solid points gives a depletion rate of 0.109 g m^{-3} d^{-1} (r^2 = 0.9937, n = 7). Open circles indicate the rest of the dataset available but not used in the regression.



4.2 Historical data VHOD rates

The VHOD rates for data collected between 1992 and 1996 (Dr Noel Burns, NIWA, unpublished data) are presented in Table 1 together with earlier VHOD rates estimated and reported by Vant et al.(1990), and the current VHOD data from 2002-2005.

Table No. 1

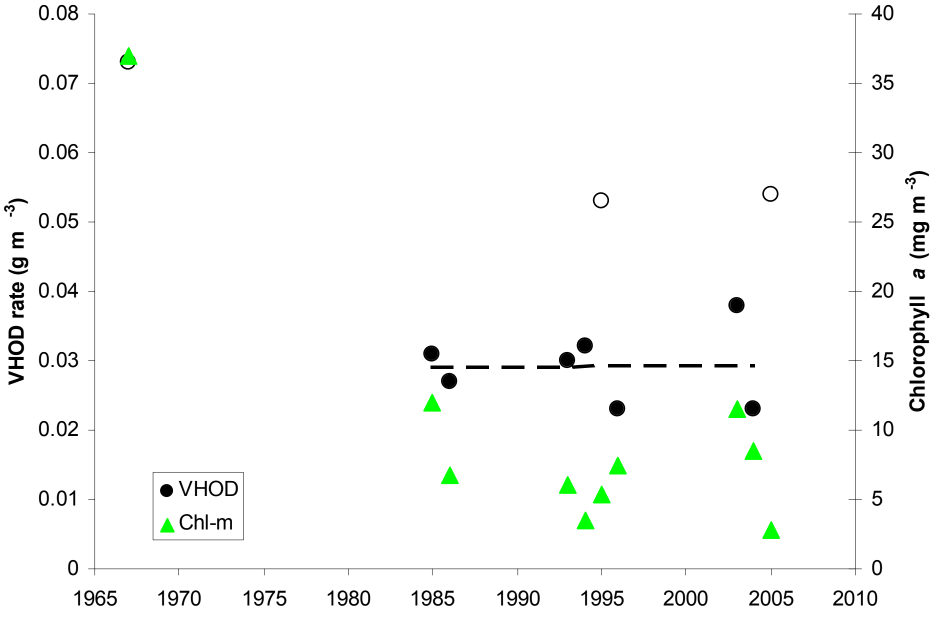
Summary of VHOD rates (g m^{-3} d^{-1}) in Lake Pupuke for the 20-30 m depth layer. (* regression value estimated from data in report Vant et al. 1990). Data , are also provided on average and peak chlorophyll *a* concentrations (mg m^{-3}) in spring, Chl_{avg} and Chl_{peak}, respectively.

Period	1966-67	1984-85	1985-86	1992-93	1993-94	1994-95	1995-96	2002-03	2003-04	2004-05
VHOD	73	31	27	30	32	53	23	38	23	54
R^2	>0.80*	>0.95*	>0.90*	0.967	0.992	0.994	0.911	0.998	0.959	0.978
n	8	7	6	7	9	6	8	5	6	9
Chl_{avg}	37	12	6.7	6.1	3.5	5.4	7.5	11.5	8.5	2.8
Chl_{eak}	61	26	13	8.8	3.6	9.8	10.0	11.5	9.2	4.4

Although Vant et al. (1990) caution that the "1966-67 results may be unreliable: mean values are close to the detection limits of the methods employed at the time", the plot of the data provided in their report shows a substantially steeper slope across the 8 mean oxygen values for 1966-67 than the slope across the 7 and 6 mean oxygen values for 1984-85 and 1985-86 plotted on the same graph. This gives some credibility to the VHOD rate being much higher in 1966-67 than in 1984-85 and 1985-86. Furthermore, the associated mean chlorophyll *a* concentration in spring 1966 at 37 mg m^{-3} (peak 61 mg m^{-3}) is also substantially higher than the mean values for spring 1984 and 1985 at 12 and 6.7 mg m^{-3} (peak 26 and 13 mg m^{-3}), respectively (Table 1). These data complement the VHOD data, implying that the water quality of Lake Pupuke had recovered to some degree during that period. Subsequent to that improvement, with the exception of 1994-95 and 2004-05, the VHOD data have remained essentially unchanged (Fig.5) suggesting that the processes that lead to accumulation of organic material in the hypolimnion have not changed greatly since at least 1984.This range of VHOD rates places Lake Pupuke in the mesotrophic category.

Figure 5

Summary of all VHOD rates and mean spring chlorophyll *a* concentrations in Lake Pupuke. The regression line through the VHOD data excludes the open circles. Open circles are apparently anomalously high values which would alter the regression line to show decreasing VHODs since 1965 or increasing VHOD since 1985. Their exclusion from the solid circle regression is to demonstrate that the bulk of the data show no significant trend since 1985 (r2 = 0.0006, n = 7) There is little correlation between the VHOD rates and spring chlorophyll *a* concentrations since 1985 and the high (open circle) VHOD data in 1994-5 and 2004-5 were not accompanied by high chlorophyll *a* as would be expected (see text).



4.3 Anomalies

As VHOD is an integration of all biological processes ocurring in the lake, a sudden increase as occurred in 1994-95 and in 2004-05 would be expected to be associated with a corresponding sudden increase in the carbon load on the lake in those years. With sewage no longer entering the lake, the most likely sources of additional carbon to the lake in spring would be an algal bloom or sediment in surface run-off following heavy rain.

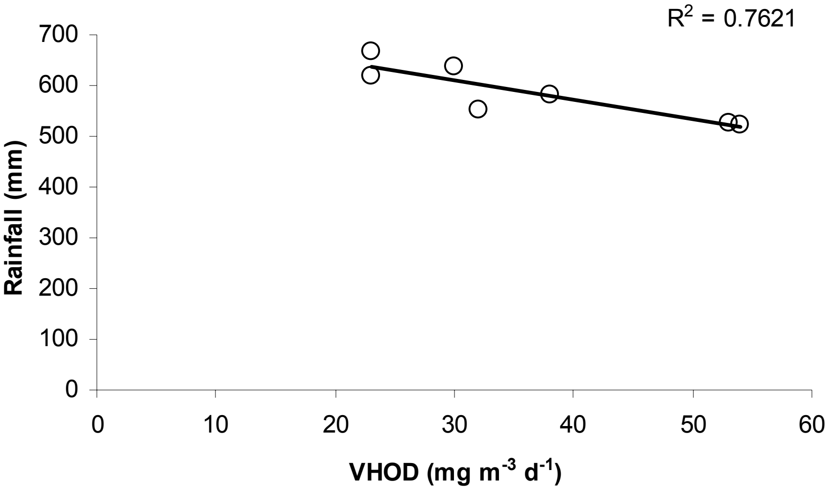
Apart from the 1967 VHOD rate, which is clearly influenced by decomposition of the spring algal bloom, the annual VHOD rates, especially the 2 high rates, do not appear to be related to the mean spring algal biomass as indicated by chlorophyll *a* (Fig. 5). In 2004-05 the mean spring chlorophyll *a* concentration was actually less than the previous two years when the annual VHOD rates were lower.

This leaves rainfall and increased run-off as the most likely source. As there was no rainfall data collected at Lake Pupuke, daily rainfall data from the meteorological station at Whangaparoa was used as a likely indicator of rainfall on the lake. Data from this meteorological station were available from 1990 on and hence regression analyses were made using the VHOD rates from 1992-93 to 2004-05 only.

While the expectation was for a positive correlation between VHOD and rainfall (i.e., a surface run-off effect), regression analyses showed a consistent inverse relationship between annual VHOD rates and spring rainfall by month. The best relationship obtained with the annual VHOD rate was with the total rainfall between June and December ($r^2 = 0.76$) which explained 76% of the variability in the VHOD data (Fig. 6). Further investigation using just the early oxygen depletion rates through October and November in each year showed an even stronger relationship ($r^2 = 0.85$) with the total rainfall between June and August in the same year, explaining 85% of the variability in those oxygen depletion rates.

Figure 6

Correlation between mean annual VHOD rate and the total rainfall in the preceding winter-spring period between June and December, inclusive. VHOD data for 1993 to 2005 using rainfall from the Whangaparoa meteorological station.



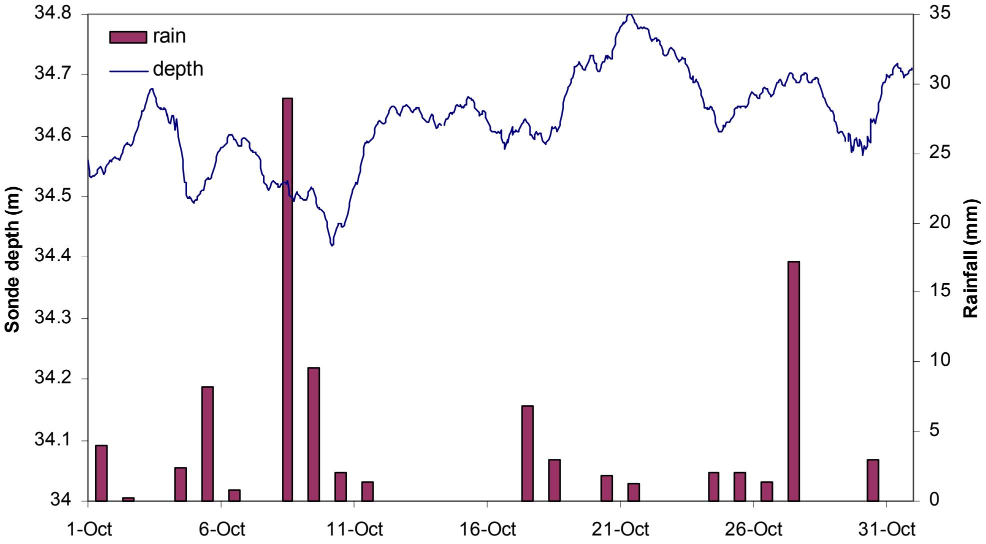
The inverse relationship shows that as the amount of spring rainfall decreases the annual VHOD rate increases. This implies that the increased removal of oxygen in the lake is somehow related to a reduced water input to the lake. As Lake Pupuke has no surface inflows, this implies a change in the groundwater input to the lake.

When the Datasonde was first installed in Lake Pupuke, the deployment was stable enough to allow the depth sensor to record changes in the lake level. Correlating the relative depth changes of the Datasonde with rainfall data (Fig. 7) shows that the lake level rises following heavy rainfall, but not immediately. The heavy rainfall on 8 October 2004 was followed by a rise in lake level starting 2 days later, on 10 October showing that there was a lag in the recharge of the lake through the groundwater. However, there was a further rise in lake level around 18 October which was far greater than would be expected from the small rain showers preceding it, based on the rise associated with the heavy rainfall. This raises the possibility of an increase in the groundwater further back in the catchment taking about 8 days to reach the lake, which is reasonable.

A recent investigation of the groundwater nutrients in the Lake Pupuke catchment (Salter 2005) found that, although the lake is situated in a basalt basin, there are areas of higher permeability below the water table in the Sylvan Park area (landwards side of the lake) extending back at least 100 m and laterally about half the catchment width. Based on observed hydraulic gradients and measured and estimated hydraulic conductivity values, Salter (2005) estimated the total groundwater inflow to be 36.8 m^3 d^{-1}. This translates to a groundwater inflow of around 0.4 l s^{-1} which is considerably less than the earlier estimate of around 22 l s^{-1} by Hoare (1990) from hydrological data (reported in Coffey 1990). However, the Salter estimate is based on the surface aquifer and does not preclude a sublacustrine groundwater inflow from a deeper aquifer.

Figure 7

Relative lake level from a bottom-referenced depth sensor on the Datasonde and daily rainfall in the catchment during 2004.

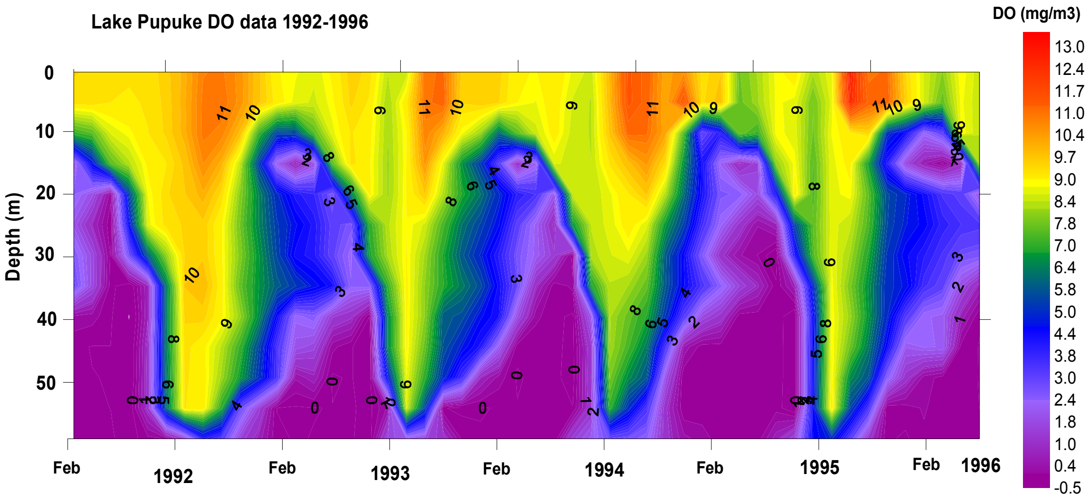


The water level response times to rainfall are relatively rapid. If a deep groundwater aquifer exists, given that the soil structure in the higher permeability zone is largely gravely and fractured basalt, it is likely that the groundwater will be well oxygenated as it reaches the lake and may be reoxygenating the hypolimnion. Consequently, we hypothesise that when the rainfall is low in a dry winter-spring, there would be less re-oxygenation by this groundwater and thus the annual VHOD rate would appear to rise.

The 'anomalous' oxygen depletion just below the thermocline referred to in previous reports (Hawes & Haskew 2003 & 2004) may actually be the natural oxygen depletion rate due to water column decomposition of sedimenting algal biomass and other detritus from the epilimnion while the higher oxygen zone below may indicate the depth of the groundwater inflow that is reoxygenating the hypolimnion (Fig. 8).

Figure 8

Contoured profile data in Lake Pupuke between 1992 and 1996 showing the peak oxygen depletion in the 15 – 20 depth layer and the oxygen bulge in the 20 – 40 m depth layer, which may be due to re-oxygenation by deep groundwater intrusion.



Hawes and Haskew (2004) identified that "*most of the difference in VHOD between years could be ascribed to differences in the depletion within the 15-30 m depth band.*" They concluded that "*the exact relationship between the peak of depletion of oxygen in this band in Lake Pupuke and lake production is not absolutely clear, though the most likely explanations are decomposition of sedimenting lake production and/or a concentration of organisms within the metalimnion. Because of this uncertainty, the conclusion that the trophic status of Lake Pupuke has not changed since previous observations must be a cautious one until the nature of the oxygen consumption at 20-30 m, which has been noted in previous files, is fully characterised.*"

From the 1992 – 1996 oxygen profile data (Fig. 8) it can be seen that the extent of the 15-30 m depletion zone appears to be greatest in the summer of 1994-5 even though this was a year when lake production, as indicated by mean spring chlorophyll *a* concentrations, was average but less than in the following year (Table 1). Similarly, the lake production in spring 2004-05 was the lowest on record (Table 1) and yet the VHOD rate was high. These data indicate that the VHOD rate in those years was not primarily influenced by sedimenting lake production and, without that lake production, it is unlikely that there would be a concentration of organisms within the metalimnion.

Considering the oxygen bulge in the depth layer 20 – 40 m (Fig. 8), it can be seen that this is minimum in the summer of 1994-5 and maximum in the following summer, 1995-6. The weather pattern for this period saw a dry winter in 1994 with the Auckland City reservoirs drying to their lowest levels by summer 1994-5. With the possibility that it would take several years for the reservoirs to refill, the concept of a water pipeline from the Waikato River was put forward as an alternative water supply. This dry period coincided with the minimal oxygen bulge in the 20 – 40 m depth layer in summer 1994-5 and the higher VHOD rate.

The drought broke in February 1995. The very wet winter and spring 1995 saw the reservoirs completely refill. This wet period coincided with the maximum oxygen bulge in the 20 – 40 m depth layer in summer 1995-6, and a much lower VHOD rate.

The correlation between winter and spring rainfall and the subsequent annual VHOD rate (Fig. 6) is indicative rather than conclusive. It is very unlikely that this relationship is the only influence on the water quality in the lake. The traditional lake production influence is still present along with sediment oxygen demand associated with the annual cycle of stratification and mixing. It is more likely that the annual VHOD rate reflects the net oxygen consumption of all in-lake processes including the possibility of some level of re-oxygenation through a deep groundwater inflow.

4.4 Implications and further work

The scenario of a sublacustrine spring feeding oxygenated water into Lake Pupuke has a number of implications for management of the lake.

Assuming that this inflow exists, it will be contributing nutrients to the lake and these may have a significant effect on the water quality of the lake. Contamination of the source of that groundwater could cause or contribute to the long-term deterioration of the water quality in Lake Pupuke despite management strategies focused on the lake and within the topographic catchment.

The volume of water associated with the deep inflow may be large, as indicated by the difference between the recent surface groundwater study (Salter 2005) and the earlier hydrological study (Coffey 1990), and sufficient to alter the hydraulic flushing rate of the lake and thus alter the expectations of responses attributable to purely biological or biogeochemical considerations.

The natural level of Lake Pupuke appears to be self regulating at about 5 m above MSL, with a range of about 1 m. However, from a time-line of Lake Pupuke water quality and water level data (Salter 2005), there are reports that over-pumping in the 1920's lowered the lake level about 5 m. When pumping stopped in 1943, there was a "rapid rise" in water level followed by a slower rise continuing from 1955 – 1965. This may be interpreted to indicate a groundwater source rapidly refilling the lake until it reached some natural outflow level through the bed of the lake which then slowed the filling process.

Of prime importance will be the confirmation of the existance of this deep groundwater inflow into the lake and estimating the inflow volume.

It will also be important to find the recharge zone in order to manage land use in that area to reduce the incidence of contamination. Because the inflow is likely to be 20 – 40 m below the lake surface, the recharge zone may be a considerable distance from the lake to achieve the hydraulic head required to move the groundwater that deep. It will almost certainly be outside the topographic catchment of the lake.

How likely is a deep groundwater inflow or spring?

As a 'rule-of-thumb', in the salt wedge at the coast, for every meter that the water table is above sea level, fresh water will extend below sea level for 40 m before salt water occurs (Bouwer 1978). With an average level of 5 m above sea level, the freshwater layer may be as deep as 200 m below Lake Pupuke, more than enough to accommodate a deep water spring. Springs are not uncommon in Auckland and even form part of the water supply to the city (e.g., Onehunga abstraction rate[1] 16,000 m^3 d^{-1}). The chemistry of the Onehunga spring water may give a clue as to the likely chemistry of a deep spring in Lake Pupuke and thus the potential effect of such a spring on the water quality of the lake.

In terms of the size any possible spring, a simple water balance such as used by Hoare (1990) shows that, based on average meteorological conditions (i.e., rainfall = 1240 mm, lake evaporation = 870 mm, land evaporation mean = 600 mm), the mean outflow from Lake Pupuke should be about 29 $l\ s^{-1}$. If the mean outflow is at 57 $l\ s^{-1}$, as suggested by Hoare (1990), then the deep spring would need to supply the additional 28 $l\ s^{-1}$ or 2500 $m^3\ d^{-1}$, which is entirely feasible.

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[1] Data from Watercare Services Ltd.

5 Recommendations

- Deployment of dissolved oxygen and temperature sensors should be made from a more substantial mooring system where the suspension line is held taut between a 20-30 kg iron disk bottom weight (e.g., old gear wheel) and a sub-surface hard 20 cm buoy at a depth of at least 3 m below the lake surface. A slack rope to a small surface float will enable retrieval. Close to this instrument mooring, and marked with a large surface float, should be a separate permanent mooring substantial enough to tether a boat to in a light wind while working on the instument mooring.
- The oxygen sensors need to be more reliable than the Datasondes used in this experiment. The D-opto or similar sensors fitted with anti-fouling rings would be ideal. Preferred depths would be 25 m and 35 m to augment oxygen profiles taken to the full depth of the lake.
- The hypothesis that a large deep groundwater inflow may exist should be investigated further. The recent URS study (Salter 2005) investigated the surface groundwater aquifer to a depth of < 5 m below lake level and thus would miss any deeper confined aquifers. It is hypothesised that the deep groundwater could be entering the lake at a depth of up to 40 m below lake level. This may require a deep bore hole (< 30 m below lake level) being drilled in the vecinity of Sylvan Park.

6 Conclusions

The long term VHOD data suggest that the water quality of Lake Pupuke improved markedly between 1967 and 1985 and this can be attributed to the removal of the sewage effluent and farm discharges into the lake. Since 1984-5, the VHOD data show no significant trend of improvement or decline. However, within this time period there were 2 high outliers at about twice the average VHOD rate [1994-5, 2004-5] which cannot be explained by water quality parameters but appear to be correlated with low winter rainfall. This correlation may indicate a possible groundwater flow into the hypolimnion 20 – 40 m below the lake level.

7 References

Bouwer, H (1978). Groundwater hydrology. McGraw Hill, New York. 480 p.

Burns, N.M. (1995). Using hypolimnetic dissolved oxygen depletion rates for monitoring lakes. New Zealand Journal or Marine and Freshwater Research. 29: 1-11.

Coffey B.T. 1990: An assessment of the hydrology and trophic status of Lake Pupuke and their implications for weed control. Report TR / NSCC / 03 / September 1990 prepared for North Shore City Council by Brian T. Coffey and Associates Limited.

Hoare, R.A. (1990). The hydrology of Lake Pupuke. A report to B.T. Coffee and Associates for the North Shore City Council. R.A. Hoare and Associates, August 1990.

Salter (2005). Lake Pupuke catchment groundwater nutrient investigation. URS draft report to North Shore City Council

Vant, W.N. (1987). Hypolimnetic dissolved oxygen: survey and interpretation. In Vant, W.N. (ed) Lake Managers Handbook. Water and Soils Miscellaneous Publication 103. DSIR, Wellington. Pp 59-65.

Vant, W.N.; Pridmore, R.D.; Challis, D.A. (1990). Changes in the water quality of Lake Pupuke 1966-1990. Auckland Regional Water Board Technical Publication 93.