Memo

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To	Trevor James Tasman District Council
CC	
Date	21 February 2018
Subject	Lake Killarney

Summary findings concerning Lake Killarney's recent eutrophication

The issue

Lake Killarney (Tasman District; maximum depth about 12 m) experienced algal blooms recently, urging an investigation of potential causes. In 2013-2014 Lake Killarney had its first algal bloom turning the lake from a clear blue colour to a very turbid brown. Such blooms have occurred every summer since. As is understandable, the locals are concerned and want the lake restored.

The lake is within a sinkhole 0.8 ha in size and within Takaka township. Residential land lies to the west of the lake and dairy farmland to the east. There are no waterways flowing into or out of the lake. Very limited storm water volumes appear to enter the lake from urban and dairy farm land use. No obvious source of nutrients had been found before this study commenced. Groundwater quality in the area is generally high with low concentrations of dissolved minerals and nutrients and extensively used for private domestic supplies.

The aim of this work, funded by an Envirolink advice grant, was to suggest investigations and lake sampling, to obtain the information needed to be able to provide advice regarding the work required for restoration of the lake. NIWA provided advice regarding the collection of limnological data, of water column nutrient concentrations (total and dissolved phosphorus and nitrogen, both in surface water and in the hypolimnion), oxygen and temperature depth profiles, and to carry out sediment analysis of the phosphorus (P) content in the sediment and its proportions, ranging from easily released to strongly bound, to provide a basis for the diagnosis of the problem and potential sources of nutrient enrichment. The discussion of the results and the further advice based on the results are summarized here.

Water column nutrient concentrations

Nutrient concentrations in the surface water, collected at 2 m depth, was determined on 12 October 2017 and presented in Table 1. Organic fractions of TP and TN were calculated as total nutrients minus their inorganic fractions. TN was calculated at TKN + NNN.

The surface nutrient concentrations are high but not excessively high. Out of 119 lakes monitored (Verburg et al. 2010), 31 lakes (26%) had higher average TN concentrations and 21 lakes (18%) had higher average TP concentrations. TN was 82% higher compared with the median of the monitored lakes and TP was 276% higher than the median. Suspended solids were higher in 35% of monitored lakes (Verburg et al. 2010) compared with Lake Killarney. In view of the high organic proportion of nutrients (below) this is likely to be mostly organic matter.

In contrast to the high TP concentration, which was high not only as an absolute value but also relative to TN as indicated by the somewhat low TN : TP ratio (10.5; the median of 119 lakes in Verburg et al., 2010, was 22), the DRP concentration was low, both as absolute value and relative to dissolved inorganic nitrogen (DIN). DRP was below detection (detection limit = 4 mg m^{-3}), but the ratio DIN : DRP was >30, and possibly much higher. This indicates strong P limitation, a strong demand for P resulting in a drawdown of the dissolved phosphorus that is easily available to algae. As a result of algal growth limitation by P there was excess inorganic nitrogen, 14% of TN, whereas inorganic P (DRP) was only 2.5% of TP (assuming DRP concentration to be half of the detection limit, see Table 1). The organic N : organic P ratio was 9 (on weight basis and 20 as a molar ratio), close to the Redfield ratio for balanced algal growth (N:P = 16 molar ratio). Both N and P were present mainly in organic matter and not as free nutrients: 97% of P was organic and 86% of N was organic, proportions that are uncommonly high. The organic fraction of nutrients is present both in particulates and in dissolved organic matter.

Table 1.

Variables	Acronym	Unit	Value
Total suspended solids	TSS	g m^{-3}	5
Total nitrogen	TN	g m^{-3}	0.83
Total Phosphorus	TP	g m^{-3}	0.079
Nitrite-N	NO2	g m^{-3}	0.004
Nitrate-N	NO3	g m^{-3}	0.084
Nitrate-N + Nitrite-N	NNN	g m^{-3}	0.087
Total Ammoniacal-N	NH4	g m^{-3}	0.032
Total Kjeldahl Nitrogen	TKN	g m^{-3}	0.74
Dissolved Reactive Phosphorus	DRP	g m^{-3}	<0.004
Organic P	TOP	g m^{-3}	0.077
Organic N	TON	g m^{-3}	0.711
Organic P:TP	TOP:TP	%	97
Organic N:TN	TON:TN	%	86
TN:TP			10.5

Algal chlorophyll *a* was not measured but would be of interest to have a better idea of the severity of algal blooms in the lake. Bottom water nutrient concentrations were not determined because no van Dorn water sampler was available, but are likely higher than at the surface, in view of the strong thermal stratification, combined with the anoxia in the bottom water resulting in release from the sediments. In particular, dissolved reactive phosphorus (DRP) is likely to be much higher in the bottom water, than it was in the surface water where it was below detection. During vertical mixing, such as will occur in autumn, this DRP will be mixed up to the surface and may enhance algal growth and result in more extensive algal blooms.

Oxygen and temperature depth profiles

Oxygen and temperature depth profiles were collected on 1 August 2017, and on 12 October 2017. Those in August showed a gradual decrease in oxygen down the water column with complete anoxia from about 8 m (northern site) to 10 m (southern site) depth down to the bottom. Temperature showed little stratification, less than 1 °C surface to bottom difference, as expected in winter, and surprisingly showed a slight increase of 0.5 °C from 8m depth down to the bottom. Because warmer water is normally lighter than cooler water, this suggests the deeper water may have been denser as a result of high concentrations of soluble material. The increase in temperature in bottom water occurred at both sites in the lake.

In October there was a strong thermocline from near the surface down to about 6 m depth, with a difference of about 10 °C. At this time the increase in depth near the bottom was not seen. There was a sharp oxycline at around 3 m depth, and the water was anoxic from 4 m down to the bottom. The anoxia must be driven by high oxygen consumption, most likely driven by high inputs of organic matter. This organic matter may in part be derived from algal growth within the lake, but more likely from the catchment, in view of the high concentration in the sediment (see below). Also the rapid deoxygenation of the water column points to external source of organic matter. In only two months roughly half of the lake volume (there is no bathymetry for the lake) lost its oxygen. This is too fast to be likely to be mostly driven by algal growth in the lake. The bottom water anoxia will result in release of mobile P from the sediment which in turn will result in algal blooms. In view of the high concentrations of P in the sediment and the substantial proportion of mobile P in the sediment (see below) the release would be expected to be massive. When the release of P from the sediment results in a low TN:TP ratio in the surface waters, this will enhance the growth of N fixing cyanobacteria. The TN:TP ratio of 10.5 in October was fairly low (Table 1) and may decrease further through summer, as P release continues while nitrogen is removed by denitrification.

Sediment analysis

Two sediment samples were collected and here the averages of the results are reported (Fig. 1). Total recoverable phosphorus in the sediment, as a proportion of total phosphorus, was very high - higher than known from other lakes. Total P (TP) was 5.8 gram per kg dry weight, more than 4x higher for instance in Lake Horowhenua (Horizons Region), where the sediment legacy of P is considered a problem as a result of the present intensive land use, and in the past the loading with untreated sewage. Total nitrogen (TN) was also very high, 28 gram per kg dry weight. It must also be noted that the sediment samples were collected while the water column was anoxic, which is likely to result in P release from the sediment. Therefore, under oxic conditions the amount of P bound in the sediment might be expected to be even higher. As Fig. 1 shows, the “easily exchangeable P” in the sediment, which is the fraction that is the first to be released under anoxic conditions, was nearly zero.

Pore water was an average 95% of the weight of the near surface sediment, suggesting quite fluid mud. Total organic matter was also very high, 59% of the sediment dry weight, suggesting recent large inputs of organic matter that has not yet been broken down and mineralized. Also visually the sediment was described as fluid organic mud (James, personal communication).

The fractions of P in the sediment are shown in Fig. 1, by weight and by proportion. The following is a legend for the different fractions of P in the sediment:

Ex-P = easily exchangeable P (extracted with NH_4Cl)
Red-P = redox sensitive P fraction (extracted with BD solution)
pH-P = high pH sensitive P fraction (reactive P extracted by NaOH)
Org-P = organic P fraction (Total P minus reactive P in the NaOH extract)
Ca-P = Ca associated P (extracted by HCl)
Res-P = Recoverable P in sediment after first 4 extraction steps = thought to be mainly refractory organics.

The fractions Ex-P, Red-P, pH-P, and Org-P, are potentially mobile, that is, can potentially be released under certain conditions of low oxygen and/or high pH. About 52% of the phosphorus in the sediment was potentially mobile. As a proportion this is moderate to high, however in terms of the absolute amount it was extremely high (6.9 gram P per kg dry weight sediment).

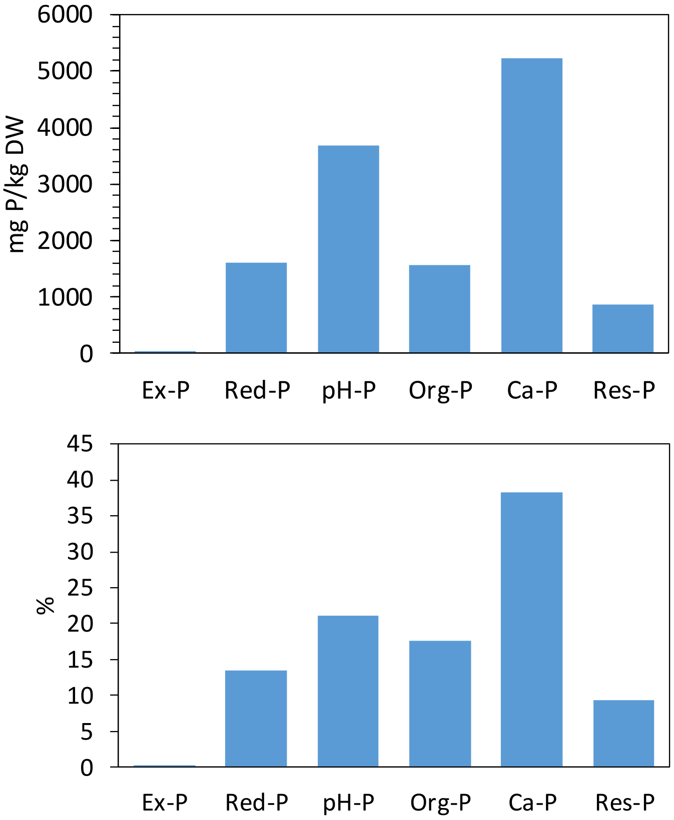

Fig. 1. Proportions of total phosphorus in the sediment, ranked from easily releasable (on the left) to strongly bound (right), in mg per kg sediment dry weight (top), and as a proportion (bottom). See text for legend.

Source of nutrients

Initially it was unknown from where nutrients might be entering the lake, especially since no streams enter the lake and surface runoff was thought to be minimal. However, it seemed likely, in view of the high nutrient concentrations in the lake, that there was an external source of nutrients, and therefore likely entering the lake via the surface, and a closer look was recommended. Eventually this probable source was located and identified as springing from intermittent overflow discharge from a storm water drain. The source and nature of the material exiting the drain is not known to us at this point but it may include agricultural runoff. It is certain to be of high organic matter content. The report by James (2017) mentions a pipe installed in 1970 which leads into the lake, coming off the storm water drain in the paddock near the back of the houses on Meihana street. The discharge presumably occurs from this pipe, although surface overflow into the lake from the storm water drain may occur as well (James 2017). The nutrient concentrations in the discharge, measured twice in August 2017, were extremely high, on average 2.7x the concentration in the lake for TN and 13.0x for TP. The proportion of the DRP concentration was relatively high in the discharge (41% of TP), in contrast to the lake (in the order of 2%), where the DRP is assimilated quickly by algal growth. In contrast, the proportion of inorganic nitrogen in the discharge (17% of TN), was similar to the lake (14%), a further indication of the P limitation of the algae in the lake and the therefore greater demand for P. Of the nitrogen in the discharge 83% was organic. Suspended solids were also very high, 30x the concentration the lake. This clearly indicates the discharge as the source of the organic matter in the lake which causes the deoxygenation of the bottom water.

Based on rainfall frequency it is estimated that discharge from the storm water drain to the lake may occur 10 times per year which is likely the cause of the strong deterioration in the lake. It would be interesting to find out what may have changed about the drainage in recent years that could have caused increased inputs to the lake, since no algal blooms have been reported in the lake before 2014. The sump in the paddock behind Meihana street was installed in 2004 and a possibility is that discharge into the lake by overland flow, following overflow from this sump, has been substantial only since then. This could perhaps cause additional transport of organic material and nutrients from the paddock which could have accumulated in the lake sediment over the past decade, resulting in deoxygenation of the bottom water. However, it seems that the pipe leading from the sump, which was already installed in 1970, would be better not to lead into the lake either. The lake is relatively vulnerable to external inputs in view of the absence of an outflow and therefore long residence time.

Recommendations

The loss of oxygen from the bottom water is likely mostly driven by high inputs of organic matter from the catchment. This likely results in release of phosphorus from the sediment as the concentration of mobile P in the sediment is extremely high. Algal blooms have occurred as a result. It would be useful to have information available of algal chlorophyll *a* concentrations in the surface water, and of nutrient concentrations in the bottom water. Regular oxygen and temperature profiles would also be a useful and relatively cheap way of monitoring the condition and hopefully the progress of the lake. However, more information is at this point not crucial for restoration planning of the lake as the road to recovery appears pretty straightforward. The source of nutrients, and especially of organic matter, to the lake has been identified, and must be stopped. The storm water discharge should be diverted away from the lake. Time will tell how fast the lake will then recover. With the absence of an outflow, and therefore little flushing of the lake, this may take a long time because the high organic content of the sediment and the high nutrient concentrations will decrease only slowly. However, more involved methods to speed up the recovery of the lake (sediment P locking with alum, aeration) are costly and would need careful management. P locking of the sediment would not alleviate the problem of deoxygenation by the high organic matter content of the material discharged into the lake, but would stop P release from the sediment. However, continued discharge of phosphorus into the lake would ultimately cancel the beneficial effect of P locking.

References

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Verburg, P., K. Hamill, M. Unwin, and J. Abell, 2010. Lake water quality in New Zealand 2010: Status and trends. NIWA report HAM2010-107. Prepared for the Ministry for the Environment. 54p. http://www.mfe.govt.nz/publications/fresh-water-environmental-reporting/lake-water-quality-new-zealand-2010-status-and-2