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Discussions

Interactive comment on "Comment on "Using groundwater age and hydrochemistry to understand sources and dynamics of nutrient contamination through the catchment into Lake Rotorua, New Zealand" by Morgenstern et al. (2015)" *by* J. M. Abell et al.

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Interactive comment on "Comment on "Using groundwater age and hydrochemistry to understand sources and dynamics of nutrient contamination through the catchment into Lake Rotorua, New Zealand" by Morgenstern et al. (2015)" by J. M. Abell et al. U. Morgenstern u.morgenstern@gns.cri.nz

This comment is in response to comments by Abell et al. (2015) on our paper Mor-

genstern et.al. (2015). In their comment, Abell et al. (2015) content that one of our conclusions, "the only effective way to limit algae blooms and improve lake water quality in such environments is by limiting the nitrate load", is invalid. They outline four reasons to support this. I show below that the first two reasons are based on interpretations of our paper implying statements that we never made, the third reason presents a biased view of P removal strategies, and the fourth reason does not contradict our conclusion. Given the seemingly doubtful argumentation in Abell et al. (2015), I suggest that a fresh look into long-term strategies for lake water improvement may be warranted.

Abell et al. (2015) add very valuable information about in-lake processes in respect to primary productivity - which was not the aim of our paper. Their comments raise interesting questions and show that more clarification is needed, both of which I address below.

Our paper Morgenstern et al. (2015) had as its aim an understanding of the nutrient fluxes on a broad level. We analysed hydrochemistry and age tracer data across the catchment to provide an understanding of groundwater processes and the relative importance of anthropogenic and geological sources of nutrients that travel with the groundwater to this lake, which is dominated by groundwater-fed streams rather than near-surface runoff. As stated, we evaluated only the groundwater components of the N and P fluxes to the lake, not other fluxes such as particulate forms or discharges from wastewater treatment plants. We concluded that the phosphate load that reaches the lake from the catchment via the groundwater system is natural (i.e. geogenic), whereas the nitrate load that reaches the lake via the groundwater system is anthropogenic. The former cannot be managed because it is a result of natural processes that will occur regardless of what happens on land, whereas the latter can be managed. As all major streams have naturally high PO4 loads, we concluded: 'The high phosphate load to the lake via groundwater is natural. As the turn-over time of the lake water is only 2.2 years via the high PO4-bearing streams, there is a constantly high PO4 load reaching the lake via all streams. Therefore, the only effective way to limit algae blooms and improve lake water quality in such environments is by limiting the nitrate load'.

We consider this a sensible conclusion, as any effort and investment into managed in-lake phosphorus (P) removal will have no lasting effect and is only a temporary fix. As soon as the P removal is discontinued, P will return to its naturally high concentration in the lake - the benefits of in-lake P removal don't continue over time, beyond approximately a year after application. The money spent on P removal thus results in no long-term improvement. On the other hand, any effort towards removal of nitrogen (N) in the catchment will be a step towards a permanent solution for a healthier lake. Another key conclusion in our paper is that no significant nitrate attenuation can be expected in the groundwater system and therefore N needs to be removed at its source, which is more difficult than P removal within the lake, as it may require land-use changes. Any benefits of removing N at its source on land will, however, accumulate over time, while past efforts of P removal within the lake will not contribute to a healthier lake in the future. Therefore we consider our conclusion correct - the only effective way to limit algae blooms and improve lake water quality over the long term, in an environment in which the P load entering the lake is naturally high and above the limit for primary productivity, is by limiting the nitrate load.

Abell et al. (2015) use the following four reasons to support their assessment of invalidity of our statement.

1. Abell et al. (2015) describe that natural and artificial in-lake processes can contribute to P removal and limit phytoplankton growth at times. They disagree that 'P does not have potential to limit primary productivity', and that 'P control is redundant'. This was, however, never implied in Morgenstern et al. (2015). We do not question that P removal processes (in-lake or at source) can limit phytoplankton growth at times, this is not the point of our paper. However, artificial in-lake P removal in such environments with constantly very high natural P influxes has only a very short-term effect and is therefore not effective over the long term. Investments into short-term benefits via complementary P removal strategies reduce potential investments in the long-term

solutions of reducing N at its source and therefore both strategies need to be carefully weighted against each other.

2. Abell et al. (2015) describe natural and anthropogenic nutrient loads, and state that we concluded 'N-only control should be adopted', and that we implied that 'anthropogenic sources of P to the lake are negligible'. This was, however, again never stated or implied in Morgenstern et al. (2015) and was not the point of our paper. We agree that management of anthropogenic P sources can improve lake water quality at times, and this has been demonstrated by Abell et al. (2015). The point of our paper is that the natural P load entering the lake via the old groundwater is sufficient on its own to cause eutrophication when nitrogen is available. Additional anthropogenic P sources will only make it worse. And we agree that anthropogenic sources of P and N should be reduced wherever possible, for example through good farming practice.

3. Abell et al. (2015) refer to the time lag of the nitrate fluxes via the groundwater that 'inhibit the timelines over which lake water quality objectives could be achieved'. Unfortunately, they used a rather unrealistic example of 300 years and suggested that this 'would prevent community aspirations of lake water quality from being achieved for multiple generations'. This is, however, not true. It will clearly not take several generations to see the improvements in the lake water, as it also took only less than 10 years for the algal blooms to start after land-use intensification.

In the following I show three reasons why community aspirations of significant lake water quality improvement via N source removal through land-use change can be achieved within a decade: (1) Hamurana Stream discharges the highest fraction of old water to the lake. But even in this stream there are significant fractions of young water (Fig. 10 in Morgenstern et al. (2015)). Approximately 20% of this discharging water is younger than 10 years and will respond to land-use changes within 10 years. (2) The majority of the streams discharge significantly younger water, with a mean residence time of about 50 years, and over 30% of the water discharges are younger than 10 years. Thus, over 30% of the total discharges to the lake will respond to land-use changes within the first decade. (3) By targeted selection of land areas closer to the lake with shorter flowpaths and travel times, more than 50% of the discharges into the lake would respond to land-use changes within a decade. Consequently, we conclude that the statement by Abell et al. (2015) ‘of focussing on only reducing nitrate loads to the lake would prevent community aspirations of lake water quality from being achieved for multiple generations’ is groundless.

4. Abell et al. (2015) describe a complex relation between the N:P ratio and the occurrence of undesirable cyanobacteria in the lake, and state that lowering the N:P ratio ‘has the potential to promote greater relative abundance of undesirable cyanobacteria in the lake’. We fully acknowledge this complex relationship, that P removal strategies may be required as temporary measures for lake water improvement, and that algae communities are different now compared to 50 years ago. However, the point we make is that with the high P and low N loads entering the lake prior to catchment development, the N:P ratio was naturally very low and any lowering of the current N:P ratio by removing N sources will shift the N:P ratio back towards the low natural ratio of the time before algal blooms began to occur. This should be considered in the development of long-term strategies for lake water improvement under the special conditions that prevail in Lake Rotorua.

Considering the above facts, the arguments in Abell et al. (2015) to support in-lake P-removal strategies seem biased. While in-lake P removal is a well-established technique to improve lake water quality over the short-term, and may be applicable in lakes that do not have a natural high P load such as Lake Rotorua, this strategy will be compromised and unlikely to result in long-term benefits in Lake Rotorua. Due to the constantly large natural P load entering this lake via the groundwater, combined with the short lake water turn-over time, P concentrations would revert back to above the limit for primary productivity within a year after P removal ceased. Therefore, P removal efforts would have to continue at a high rate over the long term, with no lasting effect. In addition, the managed in-lake P removal is under current conditions still strongly

supported by biological uptake and subsequent sedimentation of particulate organic matter. The aim of the lake action plan is, however, to reduce such biological processes (including phytoplankton growth), and with reduced biological processes the rate of managed P removal would have to even increase considerably in the future, without any lasting effect.

Efforts toward long-term solutions need to be well balanced against efforts that do not contribute to a long-term solution. Considering that such in-lake P removal strategies reduce potential investments into long-term benefits via N source reduction, it may be time now, 10 years into the program, to revise strategies to managing water quality in this nationally-important lake.

Our study was not aimed at the behaviour of algae to N or P or a full evaluation of the various N and P management options for Lake Rotorua. We also have not included the economics or sustainability of in-lake treatment options. We only provided basic information about the nutrient fluxes into the lake via the groundwater-dominated streams and their implications for informed decision-making on long-term strategies for lake water improvement. We consider all of our conclusions to be relevant and needing to be considered in lake action plans.

The discussion in Abell et al. (2015) shows that a much better dialog between lake ecologists, and surface water and groundwater hydrologists is required if long term lake water quality improvement targets are to be achieved. We hope this discussion will facilitate such a process and ultimately usher in a more holistic view of water and nutrient cycling in catchments and lakes beyond a largely in-lake-centric view.

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