Hydrol. Earth Syst. Sci. Discuss., 12, C4492–C4501, 2015
www.hydrol-earth-syst-sci-discuss.net/12/C4492/2015/

Hydrology and Earth System Sciences
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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Received and published: 28 October 2015

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 Abell et al. (2015)

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Correspondence to: Val H. Smith (vsmith@ku.edu) âĂČ Abstract This Comment amplifies upon key conclusions presented by Abell et al. (2015) in their Comment on the paper by Morgenstern et al. (2015) entitled "Using groundwater age and hydrochemistry to understand sources and dynamics of nutrient contamination through the catchment into Lake Rotorua, New Zealand". Abell et al. (2015) strongly disagreed with the statement by Morgenstern et al. (2015) that "the only effective way to limit algae blooms and improve lake water quality in such environments is by limiting the nitrate load", a strategy that contradicts a current multi-million dollar programme to restrict both phosphorus and nitrogen loading to the lake. I strongly concur with the four primary reasons identified by Abell et al. (2015) as to why recommendations for N-only loading control are invalid, and I present additional empirical evidence in support of dual (N and P) nutrient control in the eutrophication management of Lake Rotorua. My Comment does not touch upon the methodology or results presented by Morgenstern et al. (2015), and I acknowledge that their paper is valuable contribution to the understanding of hydrochemical processes and nitrogen dynamics in the Lake Rotorua catchment.

1 Comment The Comment by Abell et al. (2015) challenges a key assertion made in a recent study of the hydrochemistry of Lake Rotorua, New Zealand. Morgenstern et al. (2015) concluded that to manage the symptoms of eutrophication, lake managers should not control P inputs and should focus only upon restricting nitrogen (N) loads to the lake, stating multiple times in their paper that "the only effective way to limit algae blooms and improve lake water quality in such environments is by limiting the nitrate load". After carefully considering the basis for this conclusion, Abell et al. (2015) identified four main reasons why they believe that a recommendation of N-only control is invalid. Each of the four concerns raised in the Comment by Abell et al (2015) is completely valid. Morgenstern et al.'s (2015) recommendation for nitrogen-only management is at variance with current approaches to managing water quality in

Lake Rotorua, which are founded upon on a strategy of dual nitrogen and phosphorus loading control. Morgenstern et al.'s (2015) single-nutrient control proposal also is inconsistent with published studies worldwide which have concluded that eutrophication control is best achieved by restricting the inputs of both N and P (Conley et al. 2009; Lewis et al. 2011; Paerl and Otten 2013; Smith and Schindler 2009). Moreover, Morgenstern et al. (2015) regrettably appear to have ignored unambiguous experimental evidence that the eutrophication of freshwater lakes cannot be controlled by reducing nitrogen inputs alone (Schindler et al. 2008). It has been known since the publication of White et al. (1983) that New Zealand lakes are highly sensitive to variations in phosphorus availability, as reflected by mean annual concentrations of total phosphorus (TP, mg P m-3) measured in the water column. Rutherford et al. (1989) concluded that water quality in Lake Rotorua deteriorated after the 1960s because of excessive phytoplankton growth driven by increased nutrient inputs to the lake from the City of Rotorua's wastewater treatment plant. Rutherford et al. (1989) further concluded that "Removal of phosphorus alone may produce no measurable improvement in lake condition unless it can be made the limiting nutrient. Even then, this may take a number of years, because of recycling of phosphorus already in the lake system. Removal of nitrogen alone may reduce phytoplankton growth, in the short term (say 5–10 yr) but is not recommended because the algal community may become dominated by heterocystous blueâĂŘgreen algae, which can meet their nitrogen requirements by fixing dissolved molecular nitrogen and form dense unsightly assemblages. Thus, removal of both nitrogen and phosphorus is recommended." As documented by Mueller et al. (2015), the first steps towards regulating nutrient inputs to restore water quality in Lake Rotorua to its pre-1960s levels were taken in 2002 by proposing a nutrient loss limit for the entire catchment. Alum dosing to flocculate phosphorus (P) in the inflowing streams to reduce P loading and thereby limit algal growth in the lake began in 2006; subsequent to the stream alum dosing, water quality improved and in 2012 met the target consistent with 1960s water quality levels for the first time (Mueller et al. 2015). It is very important to understand why it is critical to manage P loading to Lake Rotorua.

Rutherford (1984) observed that water quality in Lake Rotorua (e.g., concentrations of the photosynthetic pigment chlorophyll a) correlated almost equally well with water column concentrations of total phosphorus (TP) and total nitrogen (TN). Rutherford et al. (1996) later concluded that that that improvements in water quality should occur at the same rate as reductions in TP concentrations; nonetheless, it was not clear at the time of this publication whether the close correlations between water quality and concentrations of TP and TN that had been observed in the past would continue after the imposition of nutrient loading management efforts in the Lake Rotorua catchment. I tested the hypothesis of continued equal sensitivity of Lake Rotorua water quality to N and P by analyzing data presented in Table 2.1 of Abell et al. (2012). As can be seen in Fig. 1, a very strong power relationship (r2 = 0.75) was evident between the mean annual concentrations of chlorophyll a (Chla, mg m-3) and the mean annual concentrations of total P (TP, mg m-3) in Lake Rotorua during 2002-2012. In contrast, however, total phytoplankton biomass was much more poorly correlated with mean annual concentrations of total N (TN, mg m-3) during the same period (r2 = 0.47; see Fig. 2). I thus conclude that present-day biomass production by the phytoplankton community in Lake Rotorua is now currently far more sensitive to changes in total phosphorus inputs than to variations in nitrogen loading. The results shown in Fig. 1 and 2 are therefore inconsistent with an N loading-only nutrient management policy, and very strongly support the admonition for continued dual N and P control made by Abell et al. (2015). Moreover, it is exceptionally important to note that the public do not respond to changes in TN and TP per se. Instead, the public are sensitive to the nutrient-driven formation of surface scums by bloom-forming cyanobacteria, and they very strongly disapprove of associated water quality events such as the occurrence of nuisance taste and odor problems in their drinking water, or the presence of high cyanobacterial toxin concentrations in the lakewater. As has been stressed by Paerl and Otten (2013), P enrichment (especially relative to enrichment with N) can stimulate the development of harmful cyanobacterial blooms (CyanoHABs), particularly blooms of N2-fixing cyanobacterial taxa such as Anabaena and Aphanizomenon that can meet their cellular nitrogen requirements by enzymatically converting atmospheric N2 gas into biologically available ammonia (NH3). Although I was unable to find corresponding data from New Zealand lakes to include in this analysis, a very strong sensitivity of mean annual cyanobacterial biovolume (BG, 103 mm3 m-3) to concentrations of total phosphorus in 71 lakes located worldwide is clearly evident in Fig. 3. Moreover, peak summer bloom concentrations of the nuisance cyanobacteria Anabaena, Aphanizomenon, Microcystis, and Oscillatoria are all highly correlated with water column TP concentrations (Smith et al. 1987). The results of Smith et al. (1987) and the data shown in Fig. 3 thus very clearly indicate that a failure to restrict external P inputs to Lake Rotorua would result in an undesirable increase in the intensity and frequency of nuisance cyanobacterial blooms. In closing, I am in complete agreement with Abell et al. (2015) that the current eutrophication control strategy of managing both N and P inputs to Lake Rotorua is both desirable and completely warranted, and should without question be maintained. Furthermore, I concur with Abell et al. (2011) that mitigating eutrophication in New Zealand lakes in general will require action to reduce nutrient exports from intensive pasture, and that quantifying P exports from plantation forestry should be considered as well. In contrast, I conclude that changing to a policy of N-only control is ill-advised in the extreme, because it would ultimately result in a rapid and highly undesirable deterioration in the lake's water quality.

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1. Relationship between annual mean concentrations of chlorophyll a and total phosphorus in Lake Rotorua, 2002-2012. Data from Abell et al. (2012). Figure 2. Relationship between annual mean concentrations of chlorophyll a and total nitrogen in Lake Rotorua, 2002-2012. Data from Abell et al. (2012). Figure 3. Relationship between summer mean concentrations of cyanobacterial biovolume and total phosphorus in 71 lakes located worldwide. Data from Smith (1985) and V.H. Smith (unpubl.).

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/12/C4492/2015/hessd-12-C4492-2015-supplement.pdf

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 10379, 2015.

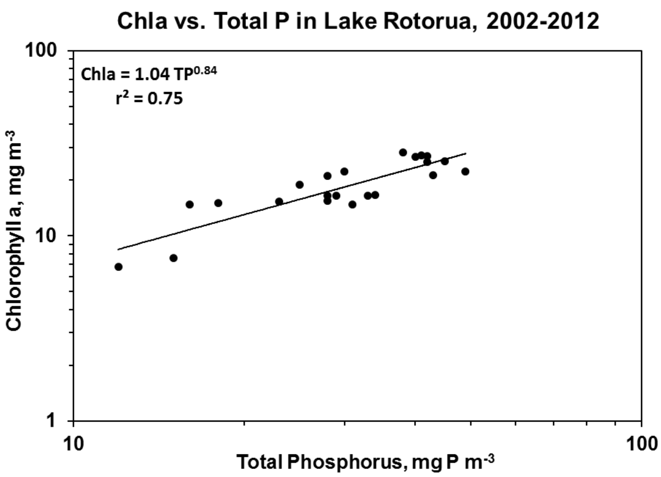

Fig. 1.

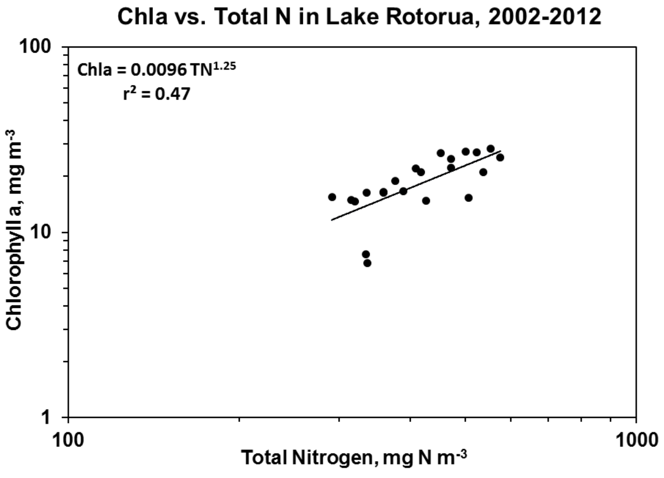
Chla vs. Total N in Lake Rotorua, 2002-2012
Chla = 0.0096 TN^1.25
r² = 0.47
Chlorophyll a, mg m⁻³
100
10
1
100
1000
Total Nitrogen, mg N m⁻³

Fig. 2.

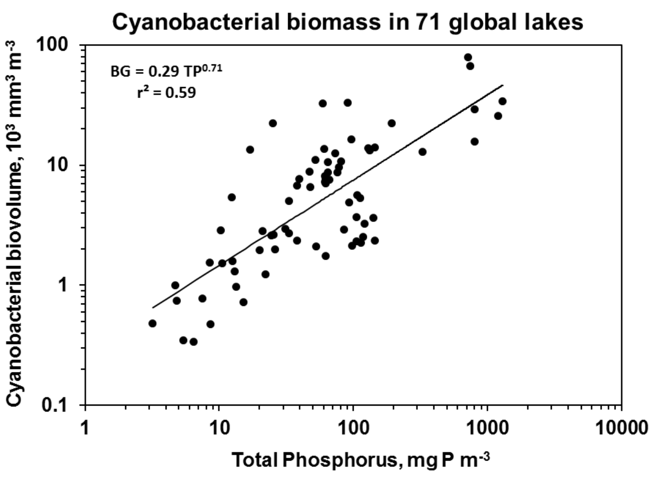
Cyanobacterial biomass in 71 global lakes
BG = 0.29 TP^0.71
r² = 0.59
Cyanobacterial biovolume, 10³ mm³ m⁻³
100
10
1
0.1
1
10
100
1000
10000
Total Phosphorus, mg P m⁻³

Fig. 3.