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Nutrients and phytoplankton (chlorophyll a) in the Waikato River

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Subject:	Nutrient and phytoplankton in the Waikato River – synthesis statement

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Nutrients and phytoplankton (chlorophyll a) in the Waikato River

A summary prepared by the TLG for the CSG – Updated 18th September 2015

Background

In its deliberations to date the CSG have considered which Attributes to use as measures of core values. Included in that Attribute set are total nitrogen (TN), total phosphorus (TP) and chlorophyll *a* (as a measure of algal levels in the water) in the main stem of the Waikato River. The rationale for inclusion of those attributes and its application to the main stem of the Waikato River has been given at previous CSG meetings and will not be repeated here.

The purpose of this synthesis report is to summarise the studies that address relationships between N, P and algae in the Waikato River system. This is important because if algal levels are to meet the desired attribute bands (as per the CSG-developed scenarios) we need to understand how algal growth responds to, and might be controlled by, N and P. This understanding also underpinned the development of the HRWO scenario model (Doole et al 2015).

This synthesis report draws upon studies commissioned by the TLG as well as those previously commissioned and undertaken by others. We also draw on our experience of the river so as to provide context to the reader. All TLG commissioned reports are either on the CSG portal or will be in the next couple of days.

The issue of phytoplankton in the river

Phytoplankton (floating/planktonic algae) are a natural part of lake and lake-fed river food webs, providing energy to the food chain and cycling nutrients. However, phytoplankton also contribute to degradation of water clarity, taste and smell and alter water colour and blooms of certain algal species can cause skin irritation and may be toxic. Phytoplankton only become problematic in the main stem of the Waikato, and are monitored there as Chlorophyll a (Chla). The Waipa is too turbid and lacks the residence time for phytoplankton to develop. Phytoplankton is a diverse community of species belonging to broader groups (e.g., greens, dinoflagellates, diatoms, cyanobacteria) that range widely in size, mobility and physiology (e.g., the N and P concentrations at which growth becomes limited). Consequently, phytoplankton management is complicated because these species respond differently to environmental influences.

Phytoplankton biomass in the Waikato main stem may be expected to be influenced by a number of factors including:

- residence time that is influenced strongly by the presence of the hydro-dams and secondarily by river flow rate/discharge;
- solar input (influenced by day length, sun angle, greatest in summer) and its effect on temperature (increases algal growth rates);
- light penetration into the water column, influenced by fine suspended sediment and dissolved colour;
- hydro lake stratification (influenced by residence time, insolation and possibly hydropower drawdown position); this increases the light exposure of phytoplankton in the surface (epilimnetic) layer;
- nutrients, particularly N and P, either of which can limit growth if in short supply. If P is in short supply, this will limit growth regardless of the amount of N available. If N is in short supply, but P supply is sufficient, phytoplankton growth may be limited or, if the conditions are right, N-fixing cyanobacteria may grow within the limits of available P (e.g., *Anabaena planktonica* that bloomed in parts of Lake Taupo and along the river in early 2003);
- zooplankton grazing of algal cells;
- inputs of phytoplankton to the river from the lowland riverine lakes, particularly when they are experiencing blooms.

Of these influences, the only one that is within the scope of Healthy Rivers is nutrient management.

This paper summarises lines of evidence relating to nutrient limitation of phytoplankton biomass within the Waikato River main stem, including spatial and temporal patterns and trends in Chlorophyll a and nutrients and the results of 3 sets of bioassays. The work builds on an earlier review by a caucusing of experts who reviewed the patterns and trends in water quality in Vant (2013) and two bioassay reports (Gibbs et al. 2014a and 2014b). It also incorporates key findings of further bioassay work (Gibbs and Croker 2015) and research on patterns and trends in water quality at the Waikato main stem sites from the later report of Verburg (2016).

Broad patterns in phytoplankton biomass and nutrients along the Waikato Main stem

Spatial and annual temporal patterns

- Chl.a generally increases with distance down the river from very low levels at Taupo Gates and Ohaaki (Fig. 1, 2).

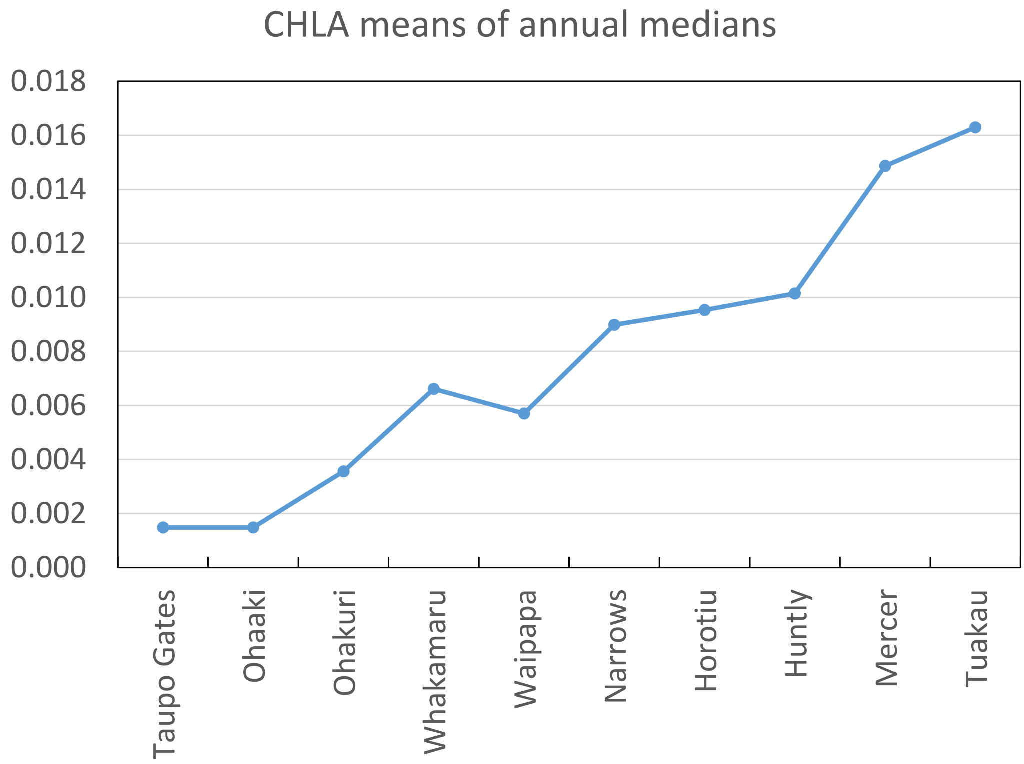

Figure 1: Spatial variation in median chlorophyll a (g/m^3) along the Waikato main stem (1990-2014).

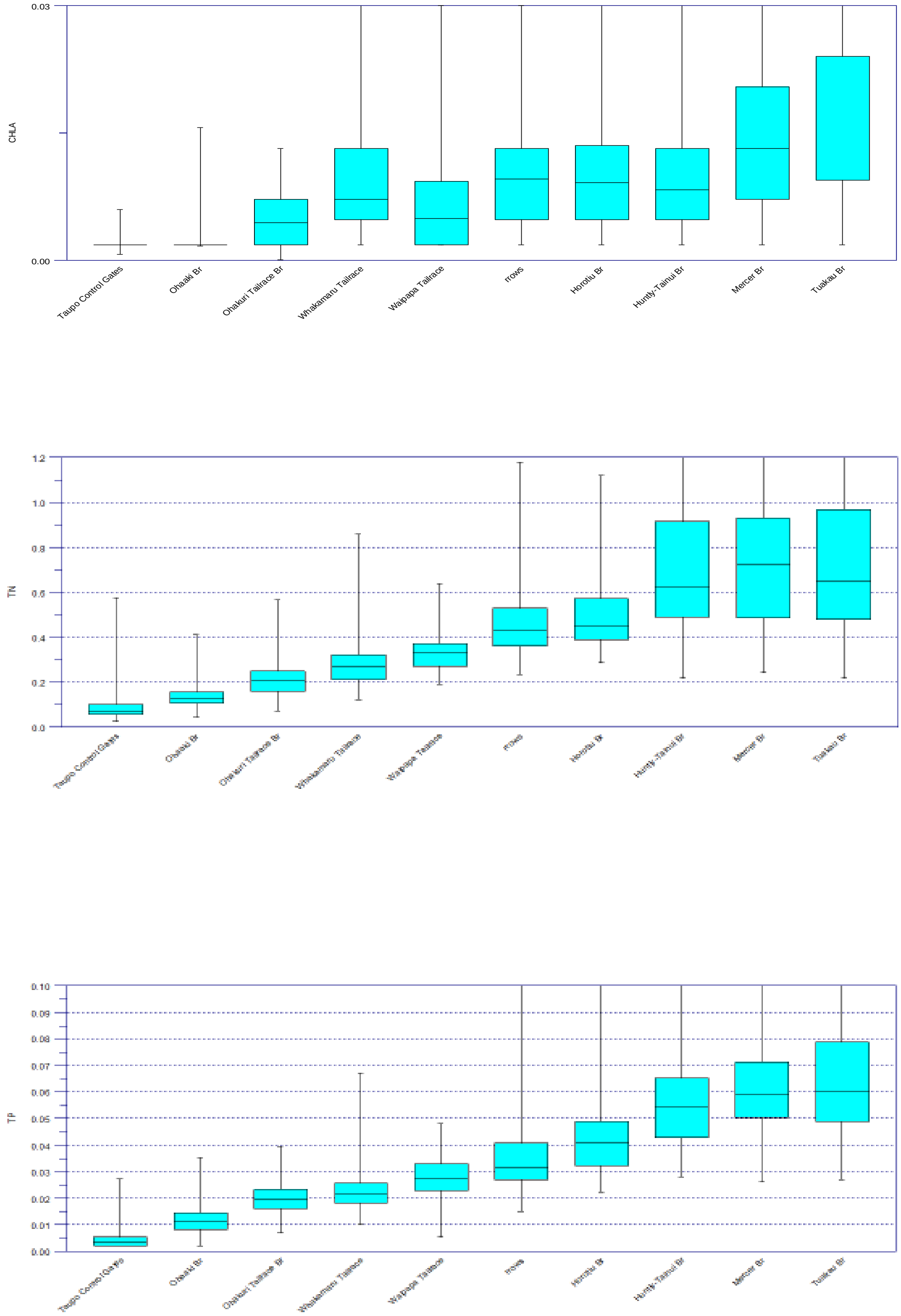

Figure 2: Boxplots of Chlorophyll a, total nitrogen and total phosphorus at main stem Waikato River sites (2006-2016). The box represents the 25th-75th percentile range of the data, the line within the box is the median (50th percentile) and the whiskers shown the data extremes.

- Annual median TN and TP concentrations also increase downstream in a similar pattern to Chl.a (Figures 1 and 2) and at annual scale there are strong correlations between annual median Chl.a and annual medians of both TN and TP across all sites (Fig. 3).

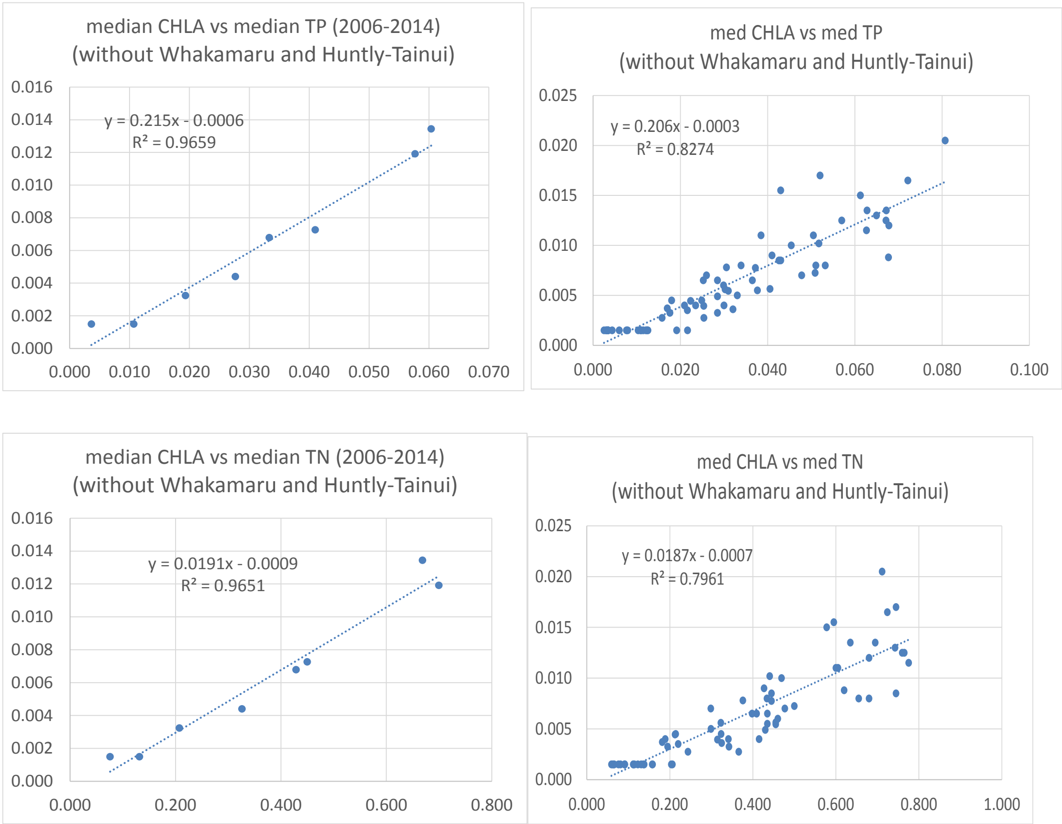

Fig 3: Relationships between Chlorophyll a vs TP and TN at sites along the Waikato mainstem (annual medians 1990-2014, units all g/m³) showing overall medians and annual median data. Graphs exclude Whakamaru (because periphyton entrainment causes a high Chl. a artefact) and Huntly (Chl. a diluted by Waipa inflow leads to lower than expected Chl. a).

- Annual Max Chl. a also shows a strong relationship with median TN and TP across the Waikato River sites (Fig 4).

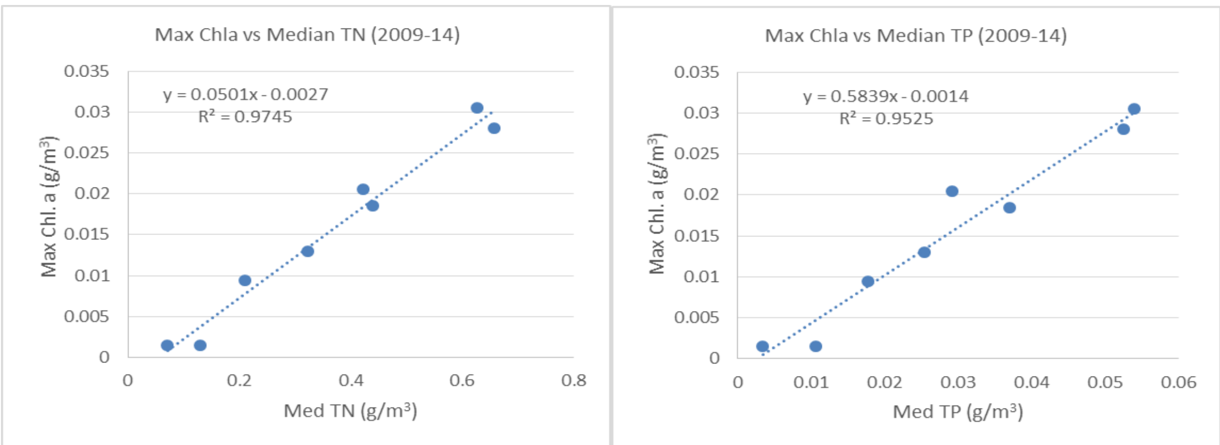

Fig 4: Relationships between Annual Max Chl. a and TN and TP across Waikato Mainstem sites (excluding Whakamaru and Huntly) 2010-2014.

- TN and TP are strongly correlated (Fig. 5), so that separation of their effects on Chl. a is not straightforward from these results alone (correlation is different from causation).

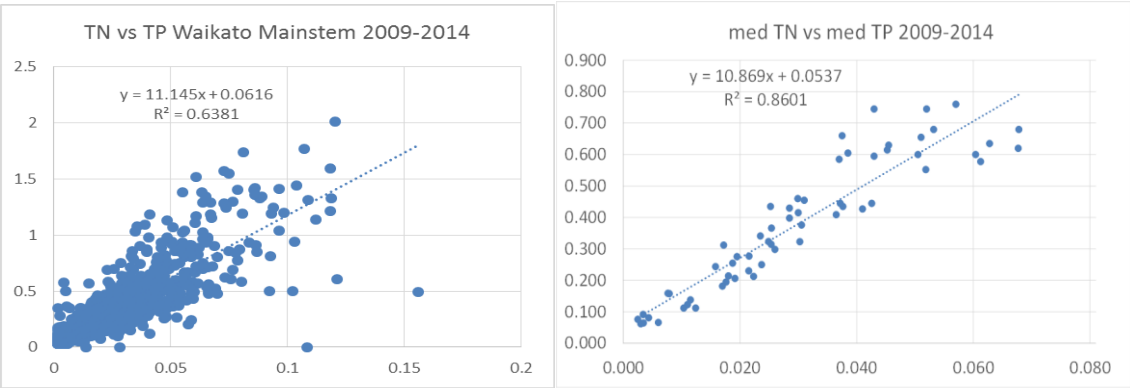

Figure 5: Relationships TN and TP across Waikato Mainstem sites below Arapuni 2009-2014 for all data and annual medians.

- However, analysis of relationships between annual median Chl. a and annual median TP and TN at individual sites over the last 20 years generally show positive relationships with TP but weak or negative relationships with TN (Fig. 6). **This is evidence that chlorophyll a is mainly responding to TP not TN in the Waikato River main stem under current conditions**.

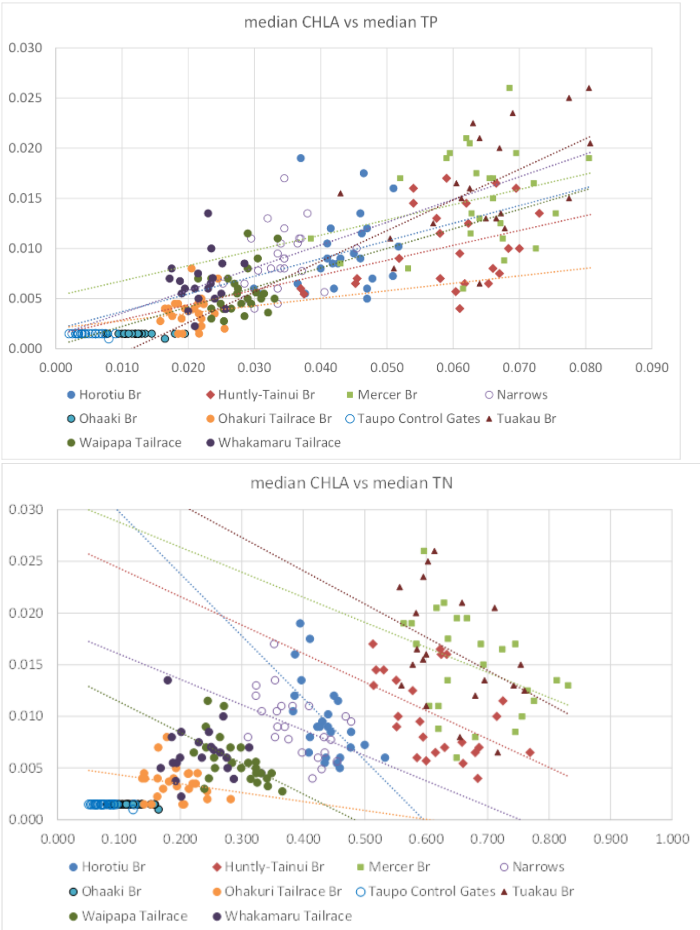

Figure 6: Relationships at each site between annual median Chl. a and TN and TP (all g/m^3) at Waikato main stem sites 1990-2014 (from 1995 for Tuakau and Whakamaru) showing regression lines for individual sites (excluding Whakamaru, Ohaaki, Taupo Gates).

- Long term trends (since 1990) at Waikato main stem sites show decreasing Chl. a (all sites downstream of Ohakuri, Fig. 7) and TP (Fig. 8), but increasing TN (particularly between Waipapa and the Narrows, Fig. 9) and therefore increasing TN/TP (indicating greater likelihood of P limitation) at all sites (Fig. 10). Note that patterns were similar when the analysis was repeated for summer (January- March) data only (data not shown). This is reconfirmation of the analysis performed by Vant (2013).

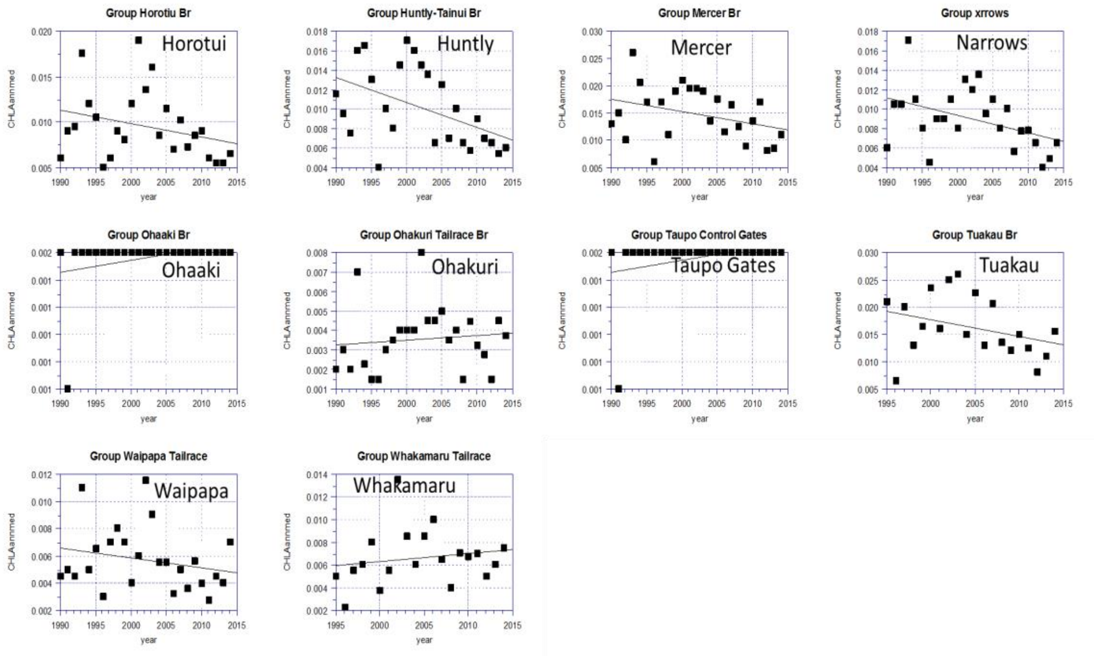

Figure 7: Trends in annual median chlorophyll a (g/m^3) over 1990-2014 at Waikato main stem sites. NB Whakamaru data are unreliable.

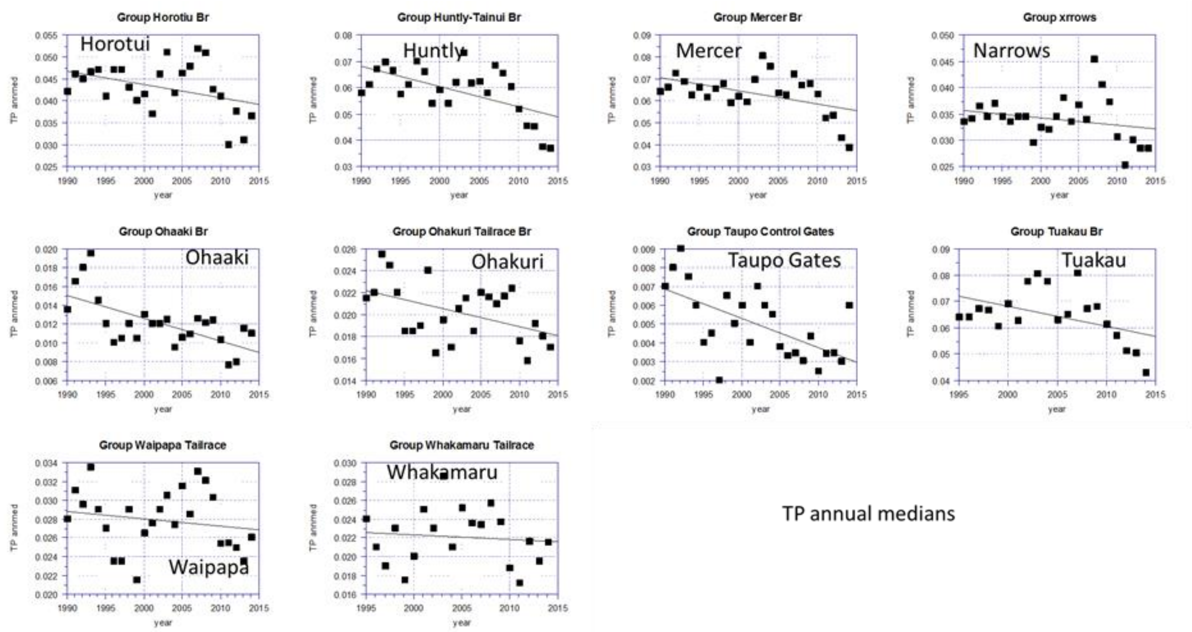

Figure 8: Trends in annual median total phosphorus (g/m^3) over 1990-2014 at Waikato mainstem sites.

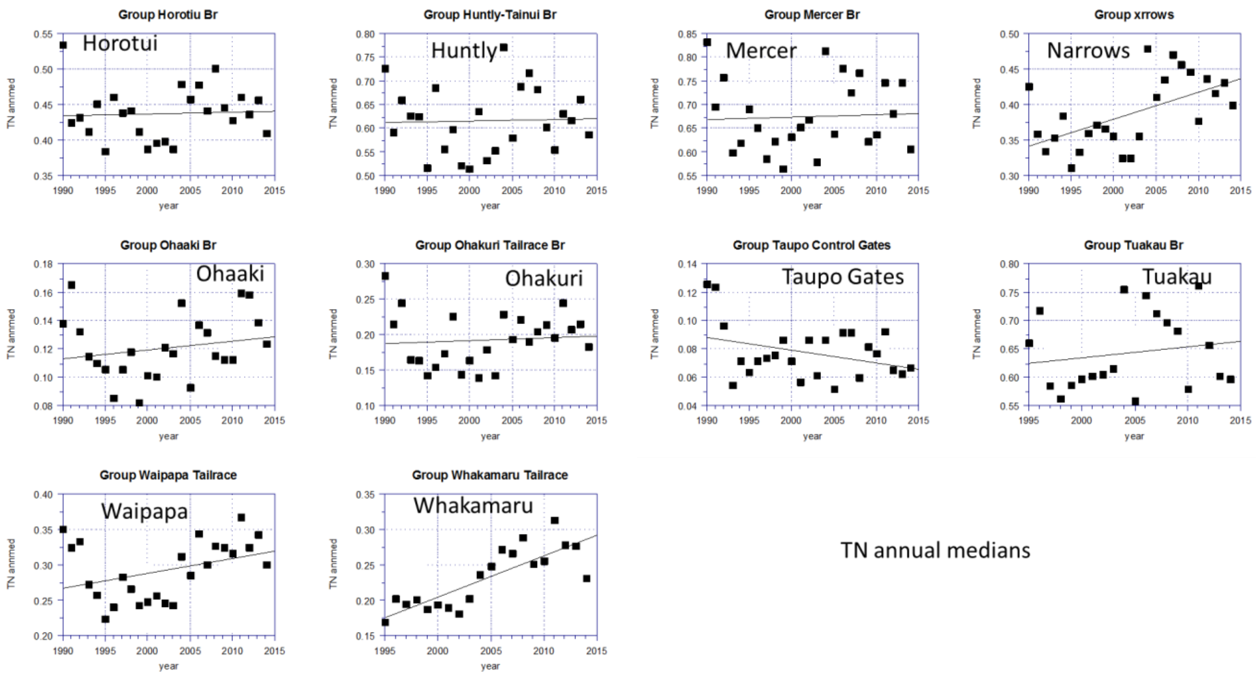

Figure 9: Trends in annual median total nitrogen (g/m^3) over 1990-2014 at Waikato main stem sites.

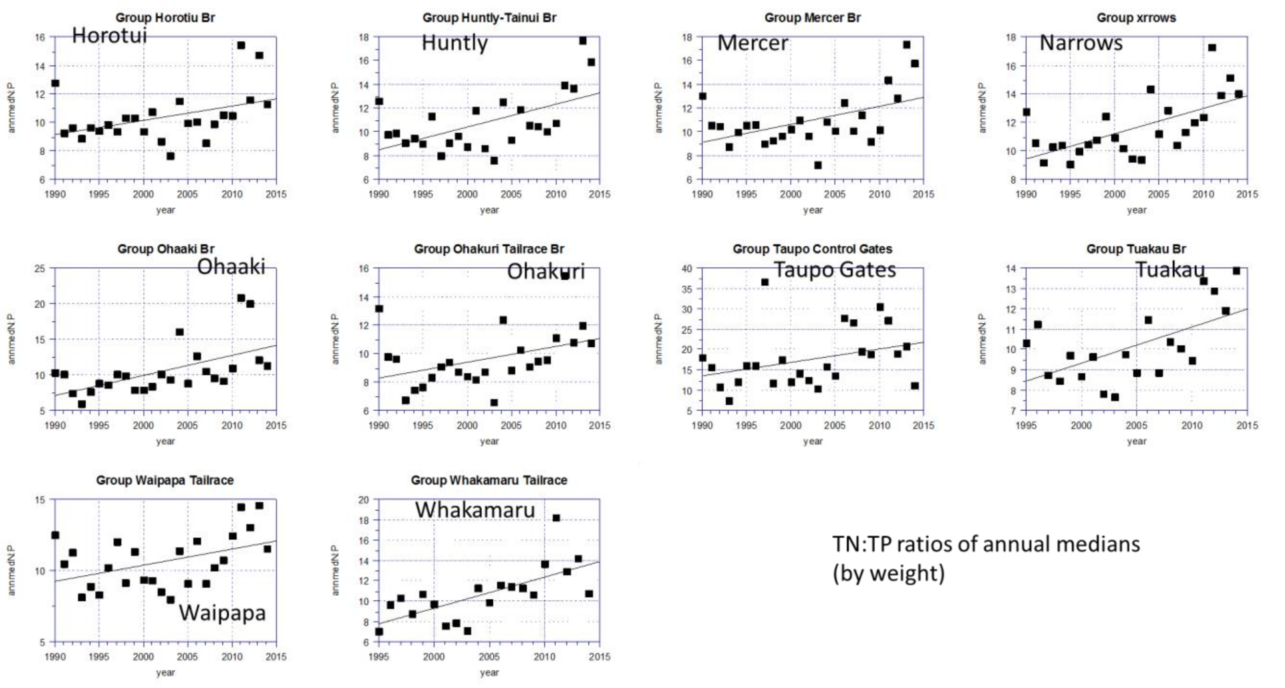

Figure 10: Trends in annual median TN/TP over 1990-2014 at Waikato main stem sites.

Zooplankton grazing

- It has been suggested that the invasion of exotic daphnid (water flea/Cladoceran, *Daphnia galeata*) zooplankton, that is an efficient phytoplankton grazer, may have contributed to the pattern of reduced Chl.a over time. However, literature (Duggan 2006) and unpublished data show that this species has been in the Waikato system for at least 18 years (first reported in 1997), so this is not likely to be the key driver in the observed reductions in Chl.a.

Seasonal patterns

- Chl.a is typically lowest in winter and higher in spring, summer and autumn (Fig. 11).
- In contrast, DIN (Fig. 12) and DRP (Fig. 13) show seasonal patterns of higher concentrations in winter and minima in summer (dissolved nutrients show stronger patterns than TP and TN).
- TN:TP ratios are lowest in summer and autumn and highest in winter at all sites from Ohakuri downstream to Tuakau (Fig. 14). **This is evidence that occasional N limitation may occur during summer and autumn.**

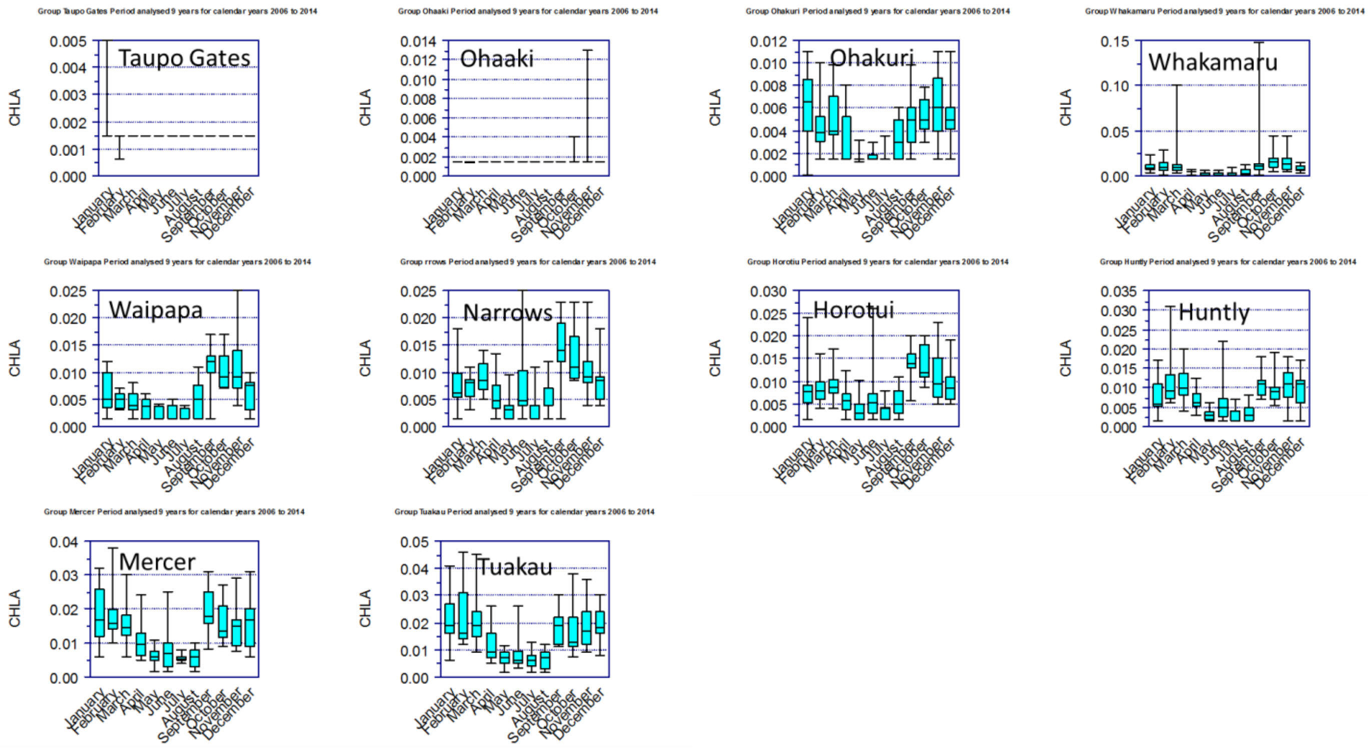

Figure 11: Monthly variations in Chlorophyll a shown as boxplots, 2006-2014. The box represents the 25th-75th percentile range of the data, the line within the box is the median (50th percentile) and the whiskers shown the data extremes.

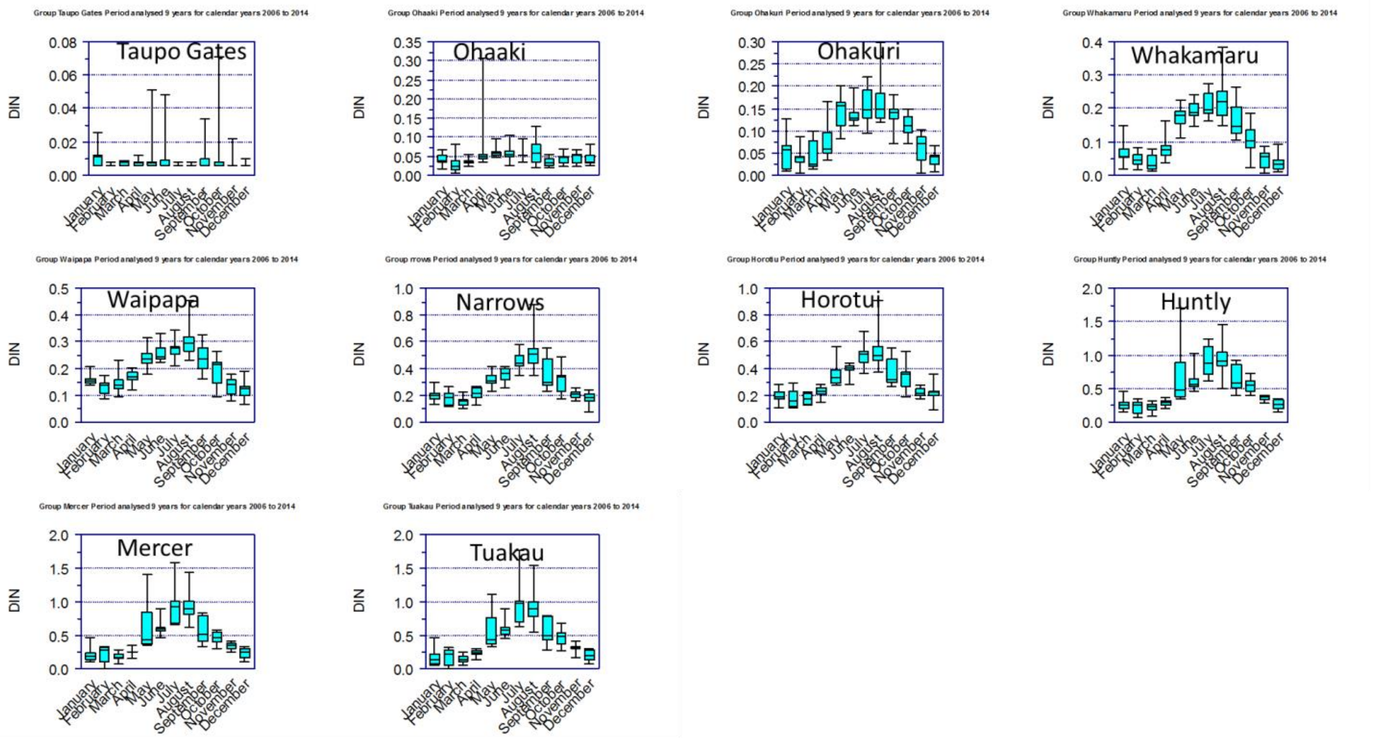

Figure 12: Monthly variations in dissolved inorganic N as boxplots, 2006-2014.

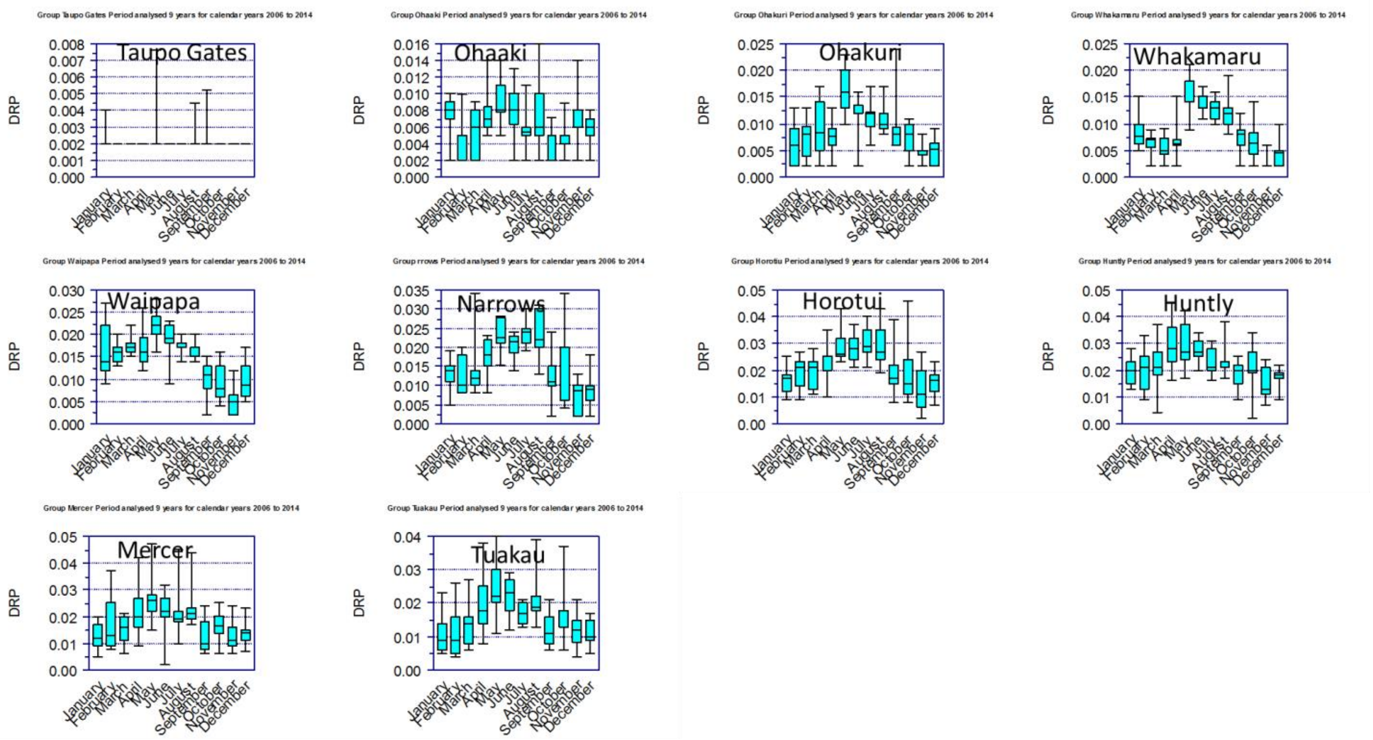

Figure 13: Monthly variations in dissolved reactive phosphorus as boxplots, 2006-2014.

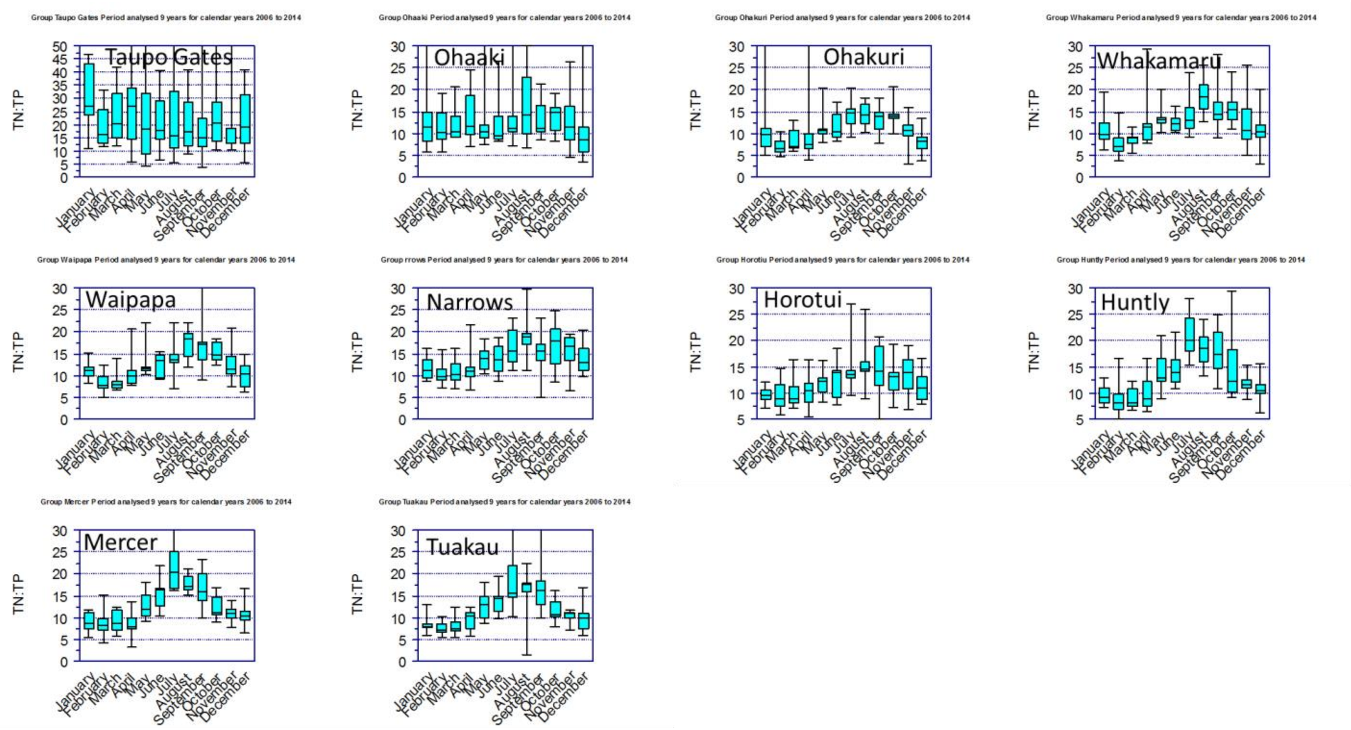

Figure 14: Monthly variations in TN:TP as boxplots, 2006-2014.

- These seasonal patterns in nutrient concentrations are likely a reflection of some combination of the following processes:
    - lower inputs from land in summer (less rain/runoff/drainage);
    - greater attenuation in summer when drainage is more focused through riparian wetland flow paths;
    - greater attenuation in headwater streams during summer because of lower flows, higher plant biomass and warmer temperatures; and
    - uptake by phytoplankton in the main stem (e.g., DRP was reduced from 18 ppb to near zero in 24 h bioassays in the laboratory).
- These contrasting seasonal patterns of phytoplankton Chl.a and nutrients are reflected in *negative* Chl.a/DRP and Chl.a/DIN correlations at individual sites using monthly data. This does not mean that Chl.a respond to low nutrients (phytoplankton need them to grow). It reflects the uptake of nutrients by phytoplankton and coincidence of high levels of several other drivers of phytoplankton growth with the period of high catchment retention of nutrients (as outlined above).

Bioassay evidence on limiting nutrients: N and/or P?

The results of three bioassay studies conducted in the last two years provide further information for inferences about nutrient limitation. The interpretation of trends (largely as described above in updated form) and results of 2 of the 3 bioassay studies were the subject of an expert panel caucusing exercise and associated report (dated 19 March 2015).

WRC commissioned NIWA (Gibbs et al. 2014 a) to undertake monthly nutrient bioassay and zooplankton grazing experiments at four river monitoring locations (Ohakuri, Karapiro, Ngaruawahia and Rangiriri) from November 2013 to April 2014. Within the constraints of the bioassay study, there was no clear indication that a single nutrient promoted phytoplankton growth at all sites and all times. The bioassay results showed spatial and temporal variations in chlorophyll-*a* responses to N and P. **These five-day laboratory bioassays showed that phytoplankton biomass most often increased with additions of both N and P, particularly below Lake Ohakuri.**

DairyNZ commissioned NIWA to measure primary production rates under four different flow regimes in Lake Karapiro between December 2013 and March 2014, and to understand stratification and mixing processes, dissolved oxygen dynamics, and in-lake nutrient limitation on one sampling occasion. In a 24-h duration, in-lake bioassay in March, Lake Karapiro chlorophyll-*a* concentration increased in response to added N, and this increase was not enhanced if P was also added. **This is evidence that, on this occasion, N was limiting and supports the evidence described above of occasional N limitation in summer-autumn deduced from an in-depth analysis of the monitoring data.**

The TLG commissioned NIWA to undertake further bioassay studies on the effects on phytoplankton growth response over 24 hours of increasing N, P and N+P, and also the effects of reducing N or P (by 40 and 70%, while maintaining the other nutrient at ambient levels). The bioassay study run in April 2015. The study attempted to assess the nutrient limitation status of the phytoplankton in the river water with nutrient addition bioassays. The results are reported in Gibbs (2015).

Due to unforeseen circumstances, the nutrient additions were lower than expected and interpretation of those results is based on a weight-of-evidence assessment rather than assessment of a direct response to the additions.

Within this limitation, the results showed that:

- the phytoplankton in the Waikato River at the time of sampling tended to be P-limited to growth
- the reduction of P and N nutrient concentrations by nominal 40% (actual reduction 21% for P) in the bioassay water resulted in a statistically significant reduction in growth relative to the control.

These bioassay experiments have their limitations, but do indicate that on occasion phytoplankton growth is nutrient limited, that limitation can vary between P and N and that reducing N or P can reduce phytoplankton growth.

Concluding remarks:

The weight of evidence from these analyses of spatial, temporal and seasonal patterns of chlorophyll a and nutrients, together with bioassay experiment results, indicates that:

- Phosphorus is more important than nitrogen in controlling the annual median phytoplankton biomass in the Waikato at present.
- However, nitrogen is likely to exert limitation of phytoplankton biomass at times and in places during summer and autumn when N levels are reduced by catchment retention processes (including in-river uptake by plants).
- This suggests that efforts to control phytoplankton biomass should focus most on controlling phosphorus. Nevertheless, the evidence suggests secondary focus on nitrogen control to: (i) help control summer/autumn chlorophyll a levels; (ii) as a precautionary approach against increased annual median phytoplankton abundance if the reductions in phosphorus seen in the last decade were reversed (e.g., by extreme climate events that

increase erosion processes and deposit more sediment-laden P into the river system); and (iii) as a precautionary approach against nuisance plant effects in downstream estuary/coastal environments.

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