Lake Rotokakahi water quality update 1990-2011

2012

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Prepared for Bay of Plenty Regional Council
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Te Whare Wānanga o Waikato

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EXECUTIVE SUMMARY

Lake Rotokakahi is an Iwi-owned lake administered by the Lake Rotokakahi Board of Control on behalf of lake owners who are descendants from the Ngāti Tumatawera and Tūhourangi hapū of Te Arawa. It is a mesotrophic (moderate water quality) lake with an area of 4.4 km^2 and catchment area of 19.7 km^2 comprised of exotic forestry (57.1 %), pasture (26.3 %) and regenerating indigenous forest/scrub (16.6 %).

Of particular significance is the high rate of water quality degradation over the last 6 years despite a history of relatively low intensity land use practices within the catchment. This degradation was likely associated with the occurrence of the first recorded algal bloom in May 2011 which resulted in a trout fish kill within the Lake Outlet (Te Wairoa stream).

The Lake Trophic Index (TLI) value has recently increased into the eutrophic range (i.e. 4 < TLI < 5) meaning water clarity has reduced due to increased algal biomass resulting from excessive phosphorus and nitrogen concentrations. In-lake monitoring data suggest high levels of phosphorus are present resulting from stream inflows, phosphorus releases from the bottom sediments and as a result of forestry harvesting works around the lake margins. Other sources of phosphorus are thought to come from ephemeral stream flows during heavy rain events and various other groundwater flows currently unmonitored.

Based on the conclusions derived from current monitoring data the following recommendations have been formulated to further understand nutrient sources and improve water quality in Lake Rotokakahi:

- As only one permanent surface water inflow is present at Rotokakahi, groundwater quality monitoring at selected locations should be conducted to determine if groundwater stream flows into Rotokakahi are in fact nutrient-enriched. This could enable clarification on whether excessive nutrients arise from "natural" nutrient enrichment from local geology or could reflect land use activities in the catchment or be a combination of both. This information will assist with targeting nutrient management of inflows to the lake.

- Identify and monitor additional surface flows through ephemeral stream channels during heavy rain events to account for ephemeral nutrient loads from both farmland and forested areas.

- Develop a nutrient budget and use the data from this budget combined with monitoring data to develop a water quality model and assess variations in water quality based on actions taken to improve water quality. Use the lake modelling as well as remote sensing images of the catchment through time, in order to better understand the dynamics of the recent changes in water quality that have occurred in the lake.

- In collaboration with the Lake owners and Bay of Plenty Regional Council develop a community Lake Action Plan to outline further monitoring and actions required to help improve lake water quality. Quantify the effect on Lake Tarawera of any water quality degradation or improvement in Lake Rotokakahi as the Lake Outlet (Te Wairoa stream) forms one of the major inflows to Lake Tarawera.

ACKNOWLEDGEMENTS

Thank you to Professor David Hamilton (the Bay of Plenty Regional Council Chair in Lake Restoration), Deniz Ozkundakci (University of Waikato Environmental Research Institute Research Fellow) for reviewing this document. This project is supported financially through the Lake Biodiversity Restoration program funded by the Ministry of Business, Innovation and Employment (Contract UOWX0505) and funding for the Bay of Plenty Regional Council Chair in Lake Restoration.

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INTRODUCTION

Lake Rotokakahi is an Iwi-owned lake administered by the Lake Rotokakahi Board of Control on behalf of lake owners who are descendants from the Ngāti Tumatawera and Tūhourangi hapū (subtribes) of Te Arawa Iwi (tribe).

Lake Rotokakahi has an area of 4.4 km^2 and catchment area of 19.7 km^2 comprised of exotic forestry (57.1 % Pine and Douglas Fir), pasture (26.3 % sheep and beef farm) and regenerating indigenous forest/scrub (16.6 %) (Figure 1). The lake is monomictic (waters undergo mixing and density stratification once annually) with a maximum depth of 32 m (mean depth of 17.5 m). It is predominantly groundwater fed, with the Lake Outlet (Te Wairoa Stream) draining at the north eastern end and flowing into Lake Tarawera. Historically, water quality has fallen within the mesotrophic range (medium), however more recent data suggest water quality has degraded and can now be classed as eutrophic (poor water quality).

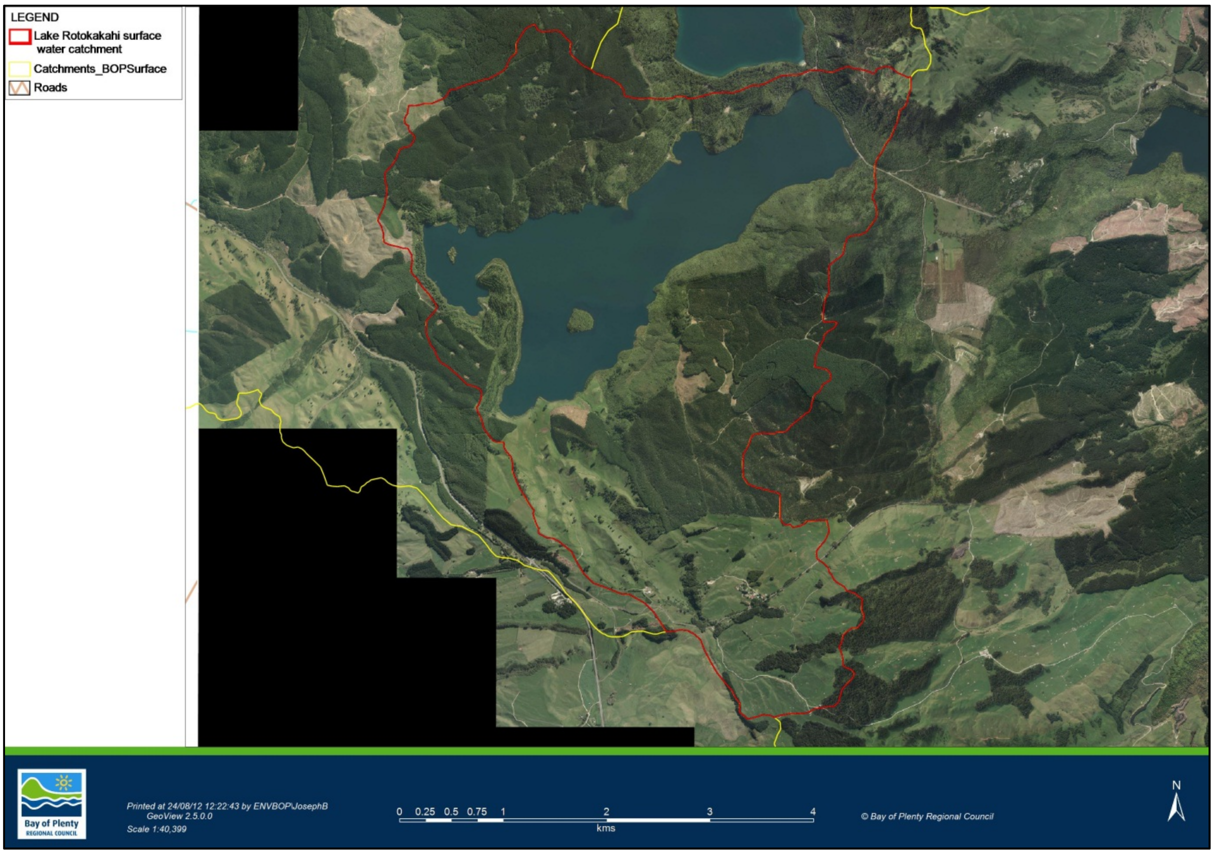

Figure 1: Lake Rotokakahi surface water catchment boundary (in red). Aerial photography from 2011.

Between 1990 to 1996 Lake Rotokakahi was sampled monthly by the Bay of Plenty Regional Council (BoPRC). However following 1996 access onto the lake was denied due to the wishes of the lake owners. From 2000 – present the Lake Outlet has been sampled as a surrogate measure for the lake itself. From 2006-2007 water quality sampling was re-established on the lake as part of a Master of Science thesis (Butterworth 2008) and from 2009-present sampling has remained consistent.

Of approximately 432 ha of pasture within the lake catchment there is one sheep and beef farm (Highlands Station) bordering the southernmost corner of the lake including Kaiteriria Bay. From 2007 to 2008 plantation forestry harvesting took place around approximately 44% of the lake margin. Conservative harvesting practices were used by selective thinning, with trees extracted by helicopter in order to minimise ground disturbance and sediment runoff into the lake. Following harvesting, replanting was conducted with both native and redwood plantings.

Other monitoring conducted by NIWA (National Institute of Water and Atmospheric Research) includes LakeSPI (Submerged Plant Indicators) surveys commencing in 2005 to assess the ecological condition of Rotokakahi and 11 other Rotorua lakes every two years under contract to BoPRC.

Of particular significance is the high rate of water quality (with respect to TLI) degradation observed in Rotokakahi over the last 20 years despite relatively low intensity land use practices within the catchment. It therefore remains unclear as to the direct source of nutrients fuelling algal growth and rapid de-oxygenation that is currently being observed. Rotokakahi has only one small surface inflow, suggesting the lake is mainly groundwater fed. Generally, groundwater flow direction and chemical composition within the greater Tarawera catchment are relatively unknown. Therefore identifying where a large portion of nutrient load to the lake is sourced from becomes complicated. Recent observations of a rapid decline in water quality are evident by the first recorded surface algal bloom during May 2011. It is likely that the decay of the algal bloom within the lake and subsequently in the Lake Outlet brought about the occurrence of a trout kill within the Lake Outlet. This trout kill was observed over a 12-hour period.

The objective of this report is to review long term water quality trends within Rotokakahi, depict potential effects on water quality from recent forestry land use changes, and suggest recommendations for future monitoring and intermediate actions taken to help understand nutrient sources and improve water quality in Lake Rotokakahi.

METHODS

From 2006-present water quality sampling was conducted monthly at both a central lake sampling station near the Lake's deepest point (Figure 2, A) and at the only known surface inflow comprising of a small spring fed stream (Figure 2, B). From 2000-present Bay of Plenty Regional Council staff has monitored the Lake Outlet (Te Wairoa stream) monthly (Figure 2, C).

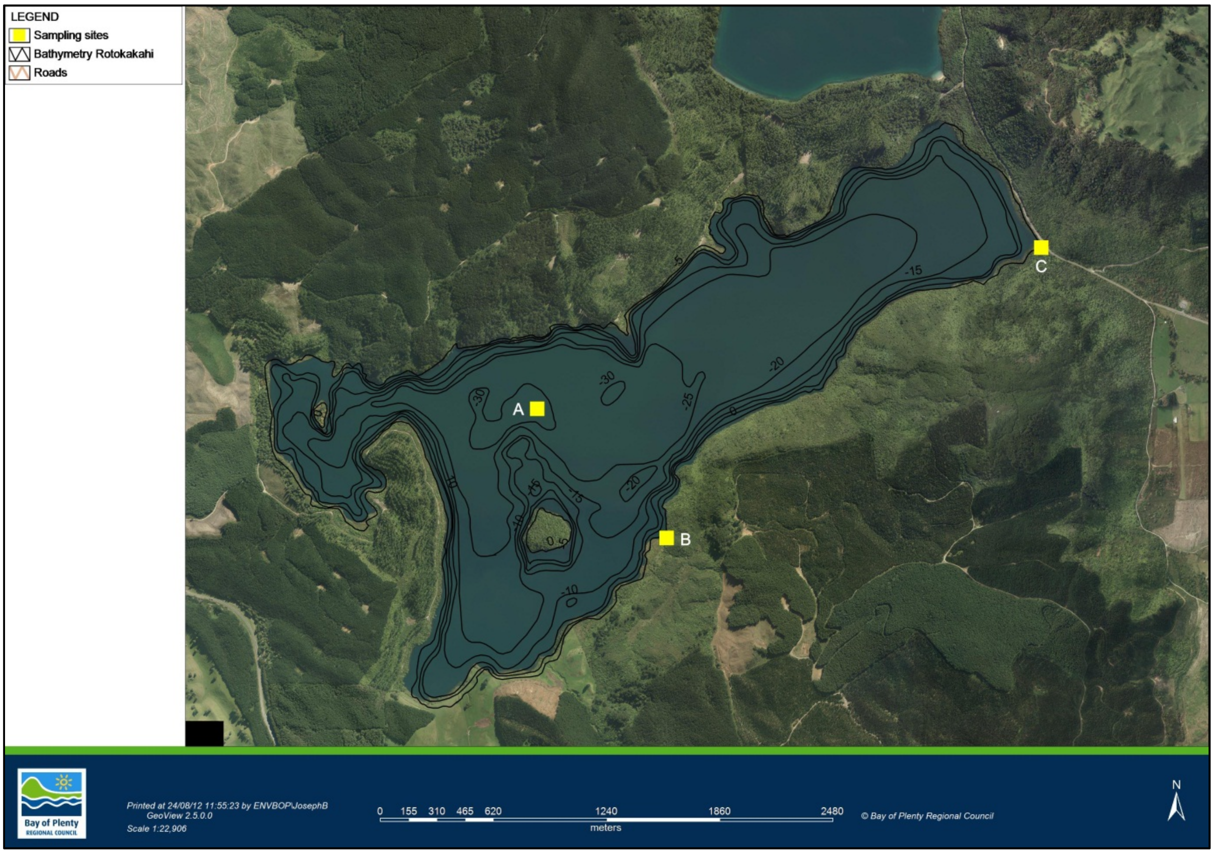

Figure 2: Lake Rotokakahi sampling locations. A = central-lake station, B = small spring-fed inflow, C = Lake Outlet (Te Wairoa Stream). Image from aerial photography in 2011.

At the central-lake station sampling depths were established to attempt to represent the full length of water column, including surface samples (0 m), an integrated tube sample (0-10 m), 15 m and 29 m. At each of these depths water samples were taken and analysed for chlorophyll *a*, total phosphorus (TP), total nitrogen (TN), nitrate (NO_3-N), ammonia (NH_4–N) and dissolved reactive phosphorus (DRP). In addition a conductivity-temperature-depth (CTD; Seabird Electronics Ltd) cast was taken to measure temperature, dissolved oxygen and chlorophyll *a* fluorescence throughout the water column. Secchi Disk Depth (water clarity) measurements were also recorded.

Between the historical and recent data there was a period when no sampling was conducted on the lake for approximately 10 years (1996 – 2006). Historical (1990-1996) sampling was conducted between 4-6 times per year. Following 2000 The Te Wairoa Stream (Lake Outlet) was sampled as a surrogate measure for the lake itself. To compare Black Disk water clarity data taken in the Lake Outlet with Secchi Disk Depth measurements taken in the lake, recorded Black Disk measurements were increased by 25% according to Ministry for the Environment water quality guidelines (1994). All the above data is kept in the BoPRC database and reported annually in the BoPRC Rotorua Lakes Water Quality Reports.

The Trophic Level Index (TLI) is used extensively to indicate water quality in New Zealand lakes (Burns *et al* 2000) including the Rotorua Lakes district. It is therefore a priority tool used to monitor annual changes in water quality. Values of TLI are comprised using four factors that impact on water quality and include Secchi disk depth, chlorophyll *a*, total phosphorus and total nitrogen. Increasing TLI values indicate poorer water quality (Table 1). TLI values quoted for Rotokakahi in this report have been sourced from the BoPRC lakes database.

For the purposes of this report in-lake water chemistry values are reported as either within the epilimnion (surface integrated 0-10 m surface waters) or hypolimnion (greater than 20 m bottom waters).

Table 1: TLI values with associated water quality type and local lake example

http://www.boprc.govt.nz/environment/water/rotorua-lakes/trophic-level-index/

Trophic Level Index (TLI)	Lake Type	Example
< 2	Very good water quality (microtrophic)	Lake Sumner (Canterbury)
2 - 3	Good water quality (oligotrophic)	Lake Rotomā
3 - 4	Average water quality (mesotrophic)	Lake Rerewhakaaitu
4 - 5	Poor water quality (eutrophic)	Lake Rotoehu
> 5	Very poor water quality (supertrophic)	Lake Ōkaro

RESULTS

Recent water clarity values (2006-2011) as indicated by Secchi Disk Depth (Figure 3) in both the lake and Lake Outlet are much lower (mean 4.1 m) when compared to historical data 1990-1996 (mean 6.6 m). Algal biomass, as indicated by chlorophyll *a* values (Figure 4) in the Lake Epilimnion and Lake Outlet have shown a marked increase in recent times from 2006-2011 (mean = 11.4 mg m^{-3}) in contrast to historical data (mean = 3.7 mg m^{-3}). Two large peaks in chlorophyll *a* were evident at both sites during 2007 and 2009, reaching values in excess of 40 mg m^{-3}, however from 2010 onwards values have stabilised. Chlorophyll *a* values when compared to Secchi disk depth values show an approximate negative linear relationship (R^2 = 0.2) suggesting algal growth a key factor limiting water clarity.

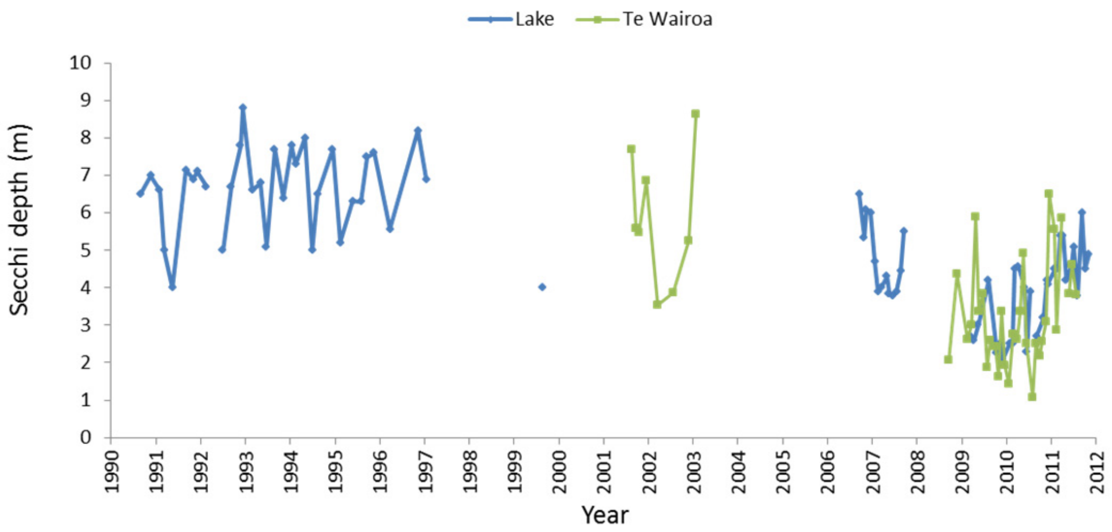

Figure 3: Secchi Disk depths in Lake Rotokakahi and in Te Wairoa (Lake Outlet) from 1990 to 2011. Note: Te Wairoa Black Disk Depth values have been converted to Secchi disk depth to allow direct water clarity comparisons (see text). See text also for details of breaks in the data.

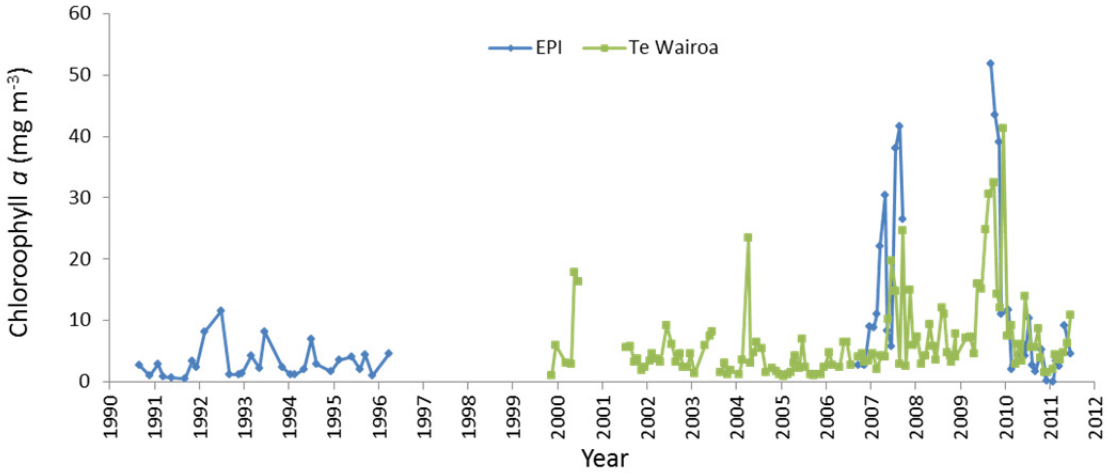

Figure 4: Chlorophyll *a* concentrations in Lake Rotokakahi surface waters and Te Wairoa (Lake Outlet) from 1990 to 2011. EPI is the depth integrated value (0-10 m) for the epilimnion. See text for details of breaks in the data.

Both total phosphorus (TP) and to a lesser extent total nitrogen (TN) have increased gradually since 1990 -1995, (Figures 5 & 6), however during 2009-2010 a more rapid increase can be noted, particularly for TP. High values in TP are evident in the hypolimnion during summer months reaching in excess of 120 mg m^{-3}. TP concentrations in the inflow are much elevated compared to in-lake concentrations, ranging from 60 to >150 mg m^{-3}.

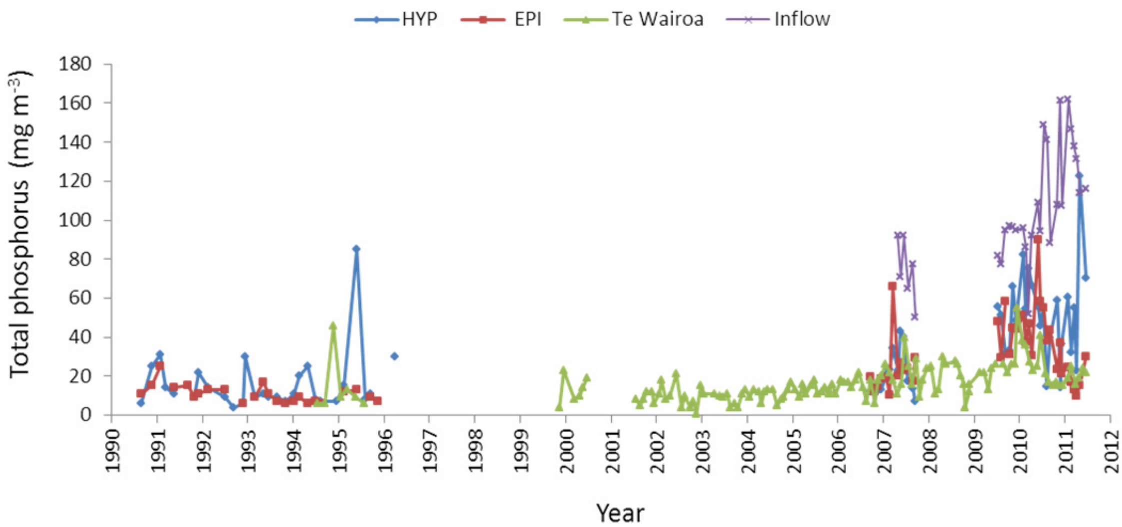

Figure 5: Total phosphorus concentrations in Lake Rotokakahi from 1990 to 2011. EPI is the depth integrated (0-10 m) value for the epilimnion, HYP is the value at depth (> 20 m) for the hypolimnion, Te Wairoa is the Lake Outlet and inflow is the small spring-fed inflow. See text for details of breaks in the data.

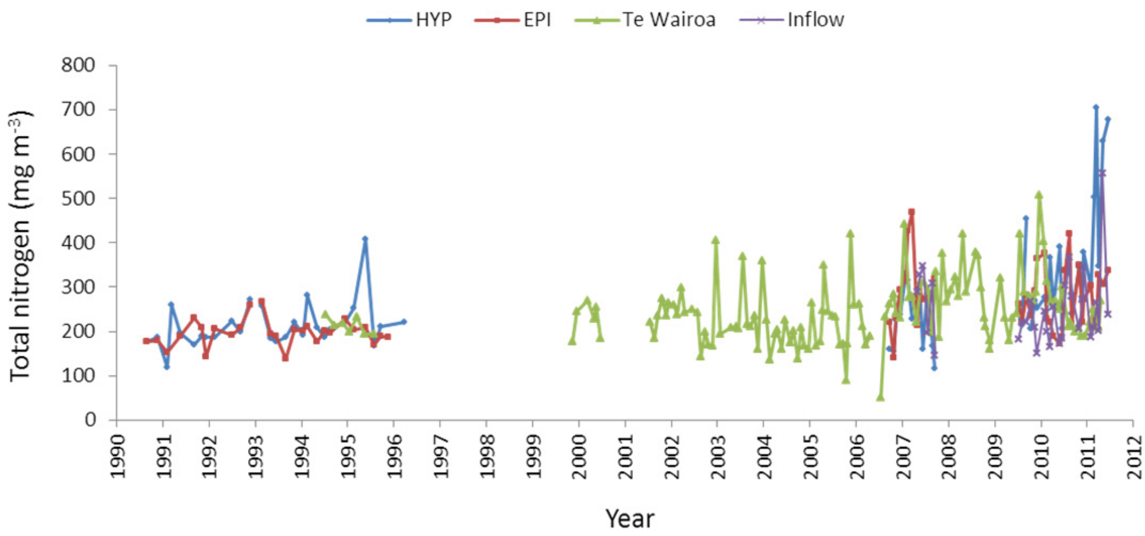

Figure 6: Total nitrogen concentrations in Lake Rotokakahi from 1990 to 2011. EPI is the depth integrated (0-10 m) value for the epilimnion, HYP is the value at depth (> 20 m), Te Wairoa is the Lake Outlet and inflow is the small spring-fed inflow. See text for details of breaks in the data.

The total nitrogen to total phosphorus ratio (TN:TP ratio) averages around 20 for in-lake values and ranges between 1 and 60 (Figure 7). From 2008 onwards the ratio is much reduced, averaging 9, with low variability between sites (Table 2). Ratios for the inflow are reasonably stable between 1 and 4.8. Over time the ratio has decreased and therefore algal growth in the lake is more likely to be nitrogen limited. Note that the inflow was not sampled during earlier years so no comment can be made about any long-term changes in its composition.

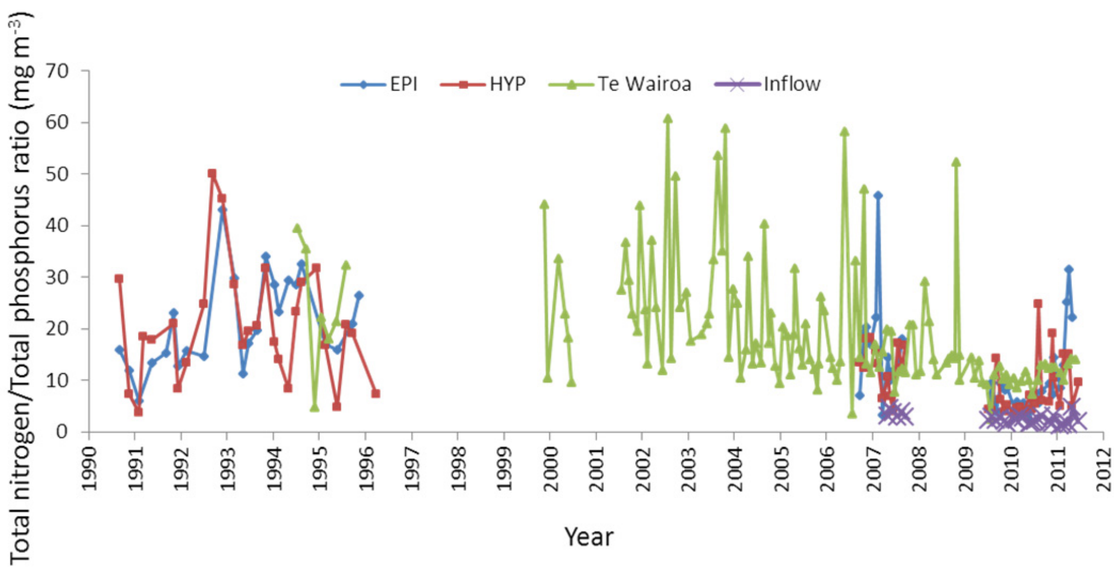

Figure 7: Total nitrogen to total phosphorus ratio in Lake Rotokakahi from 1990 to 2011. EPI is the depth integrated (0-10 m) value for the epilimnion, HYP is the value at depth (> 20 m) for the hypolimnion, Te Wairoa is the Lake Outlet and inflow is the small spring-fed inflow. See text for details of breaks in the data.

Table 2: Summary statistics for total nitrogen/total phosphorus ratio averaged across all sites during the periods 1990-2007 and 2008-2011.

	1990-2007	2008-2011
Average (mg/m^3)	20	9
Range	3 - 60	1-52
Standard deviation	11	7
Sample size (*n*)	162	114

The peaks in dissolved reactive phosphorus (> 50 mg m^{-3}) in the hypolimnion (Figure 8) are likely to be strongly related to releases from the bottom sediments (internal loading) and they are most evident during summer and autumn when there has been a sustained period of thermal stratification and the dissolved oxygen at depth 22 m decreases below 2 mg L^{-1} (Figure 9). Recent dissolved oxygen levels have reduced in the hypolimnion and from 2007-2010 bottom waters have been anoxic with levels sustained below 1 mg L^{-1} over a longer period compared with historical data. Once again inflow DRP concentrations are elevated (mean = 67 mg m^{-3}) compared to in-lake concentrations in both surface and bottom waters (mean = 7 mg m^{-3}).

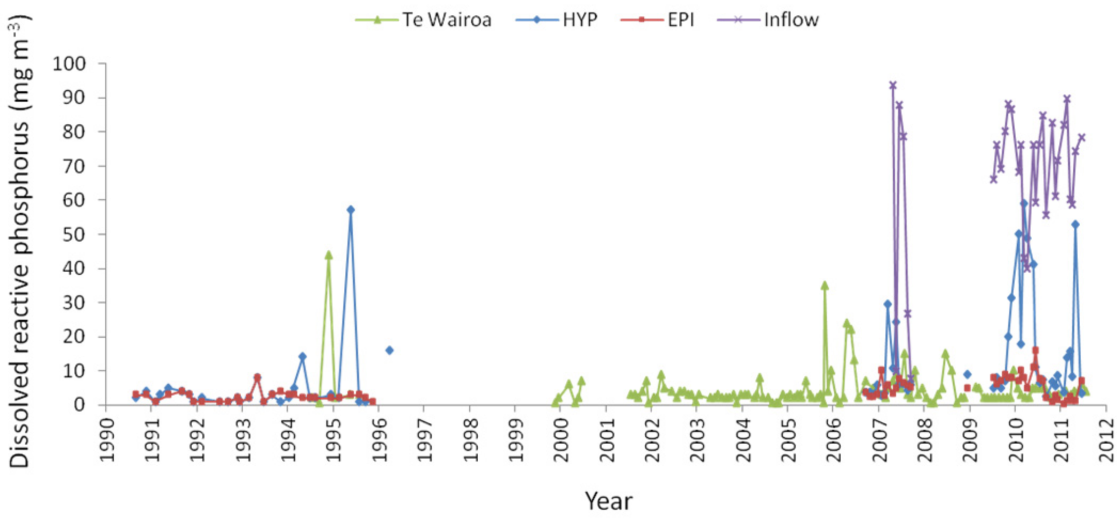

Figure 8: Dissolved reactive phosphorus concentrations in Lake Rotokakahi from 1990 to 2011. EPI is the depth integrated (0-10 m) value for the epilimnion, HYP is the depth (> 20 m) value for the hypolimnion, Te Wairoa is the Lake Outlet and inflow is the small spring fed inflow. See text for details of breaks in the data.

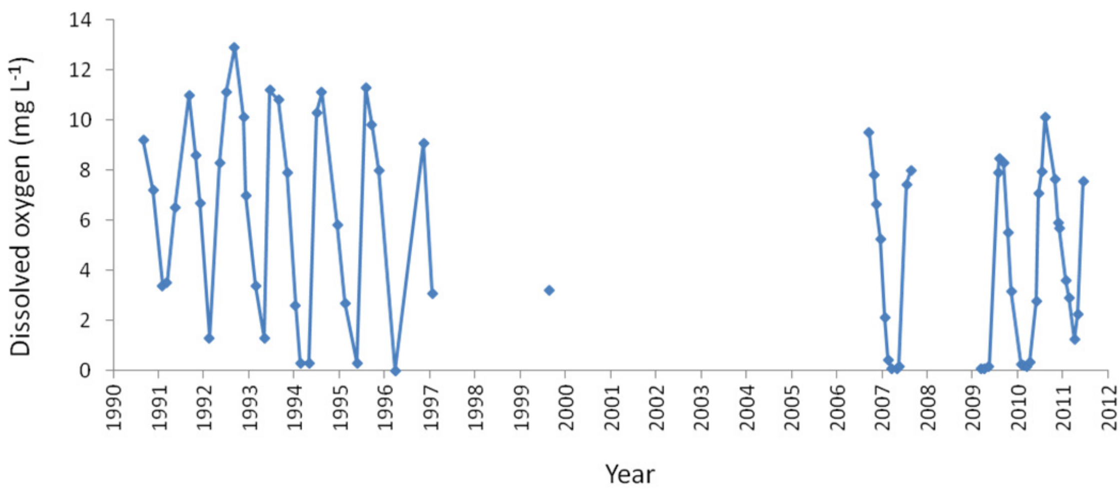

Figure 9: Dissolved oxygen concentrations at a water depth of 22 m in Lake Rotokakahi from 1990 to 2011. See text for details of breaks in the data.

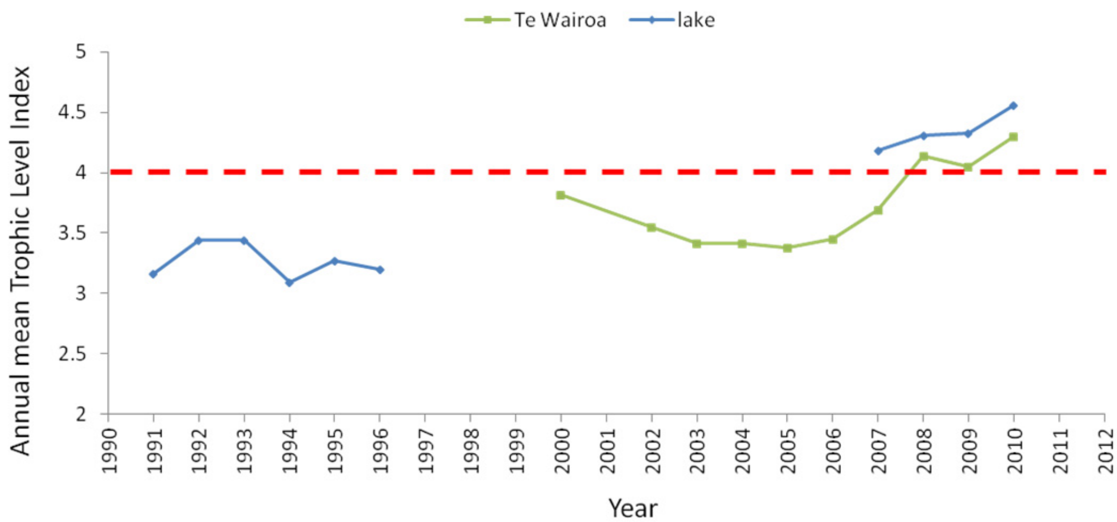

Figure 10: Trophic Level Index values for Lake Rotokakahi and Lake Outlet from 1990 to 2011. The dashed line indicates the eutrophic TLI value threshold. See text for details of breaks in the data.

The Trophic level index for Rotokakahi has been calculated from data collected from both the lake and Lake Outlet. Over the majority of the monitoring period the lake and Lake Outlet have remained within the mesotrophic range (3 < TLI ≤ 4). In the 1990s TLI values within the lake remained within the lower mesotrophic range (3-3.5). From 2005 onwards TLI Lake Outlet values have steadily increased, surpassing the lower eutrophic range (4 < TLI ≤ 5) in 2008. Since in-lake TLI measurements were re-established in 2007 values have remained in the eutrophic category. The most rapid deterioration in water quality was observed after 2007.

DISCUSSION

Water clarity and algal biomass

In common with the majority of the Rotorua Lakes, increased algal biomass has caused reduced water clarity. Lake monitoring has indicated that water clarity in the lake has reduced by about 2.5 m over the entire monitoring period. Excess nutrients entering Rotokakahi are fuelling excessive algal growth making the water surface appear "green" in colour and turbid. This was particularly evident in May 2011 when the first recorded algal bloom on Rotokakahi occurred (see Figure 11). The dominant bloom species identified by BoPRC staff was the cyanobacterium *Anabaena lemmermannii,* a known cyanotoxin producing species (Matt Bloxham pers. Comm.).

On the morning of 23 May 2011 light south to south-west winds appeared to cause the algal bloom to accumulate against the lake shore near the Lake Outlet. By afternoon the bloom had become highly concentrated and cells were likely entering the Lake Outlet in high concentrations, subsequently resulting in the death of many trout within the stream overnight. As fish kill events resulting from cyanobacteria blooms alone are very unusual, a possible scenario is that the short but highly concentrated pulse of algal cells created multiple unfavourable conditions within the stream. These conditions may have included short-term low dissolved oxygen levels which likely combined with an elevated pH level within the stream. The cyanobacteria may also have caused some "clogging" of the gills which would have restricted gaseous exchange (Matt Bloxham, pers. Comm.), however this was not confirmed (for more detail on this fish kill event refer to the appendix). This event was of particular concern to Eastern Fish and Game New Zealand as mature spawning trout within the Te Wairoa Stream are used as brood stock for the Rotorua Trout Hatchery.

Figure 11: Surface bloom of Anabaena lemmermannii at the southern access boat ramp. Photographed on the 3 May 2011, 20 days before the Te Wairoa Stream fish kill.

Nutrients

Nutrient concentrations have increased overtime most notably from 2009. Increased ground disturbance during forestry harvesting operations in 2007 may have led to increased runoff to the lake of sediments which may be phosphorus-rich and entered the lake via ephemeral drainage channels, therefore elevating TP concentrations (Kreutzweiser et al 2008, Hamilton 2005).

The loss of oxygen in the hypolimnion during summer-autumn results in the release of DRP stored in bottom sediments, which is a well-known phenomenon known as internal loading (Mortimer 1971; Hupfer & Lewandowski 2008). Summer-autumn DRP sediment releases are predominantly influenced by thermal stratification that renders bottom waters void of oxygen and in turn promotes the release of high levels of phosphorus stored within lake sediment.

High TP and DRP concentrations were measured in the inflow. This inflow is only approximately 40 m from its spring source to the lake edge would largely represent groundwater in its spring catchment. Given land use is relatively "natural" in the immediate area including native forest/scrub and pine plantation in the upper catchment, this suggests elevated levels of TP and DRP may be natural in occurrence in the spring rather than a result of land use practices. As soils of volcanic origin are high in phosphorus, spring-fed streams in the Rotorua lakes area are known to have naturally elevated levels of phosphorus (Timperly 1983). Given Lake Rotokakahi is predominantly groundwater fed, other groundwater streams currently not monitored could be contributing additional naturally enriched phosphorus to the lake.

The majority of Rotorua lakes are naturally "nitrogen limited" (Abell et al 2010) where primary production or algal growth can be limited by nitrogen rather than phosphorus, or by the combination of the two nutrients (Co-limitation). Comparing nitrogen to phosphorus levels is important for the Rotorua lakes as it can help to understand the occurrence of nuisance bloom-forming algae, particularly some cyanobacteria that are able to fix atmospheric nitrogen when nitrogen resources are low, and effectively out-compete other algae. As the TN:TP ratio has reduced over time due to excessive P entering Lake Rotokakahi, apparent N limitation is likely due to excessive P availability rather than N scarcity (Abell et al 2010). Furthermore recent elevated phosphorus concentrations following 2009 have further enhanced nitrogen limitation and contributed to the occurrence of the first cyanobacterial algal bloom recorded in May 2011. Other sources thought to contribute disproportionately to phosphorus would be from ephemeral flows down steep valley channels during heavy rain events (Abell et al 2011a).

Dissolved Oxygen

Dissolved oxygen concentrations within the bottom waters of a lake are a useful indicator of lake water quality as the loss of oxygen promotes the release of DRP bound in bottom sediments which in turn fuels algal growth. When bottom oxygen levels remain close to 0 mg/L^{-1} over 3-4 months in Rotokakahi during the summer-autumn period, peak DRP concentrations within bottom waters are observed. From autumn-winter the lake waters begin to mix, effectively making DRP-rich bottom waters available to algae present at the surface, which can ultimately result in an algal bloom at the surface in autumn. With seasonal bottom dissolved oxygen concentrations reaching below 1 mg L^{-1}, release into the water column of DRP bound in sediments will continue to be a problem.

Trophic Level Index

The Trophic Level Index, which combines four water quality indicators (Secchi Disk Depth, TP, TN and algal choloropyll *a* concentration) is used to report water quality variation in the Rotorua lakes. Historically Rotokakahi water quality has been within the mesotrophic (medium) range (McColl 1972; Butterworth 2008), however from 2008 onwards the TLI values have increased to fit within the eutrophic range in both the Lake and the Lake Outlet. Specifically this means that water clarity has reduced as a result of increased TP, TN and subsequent algal biomass. To compare, current examples of eutrophic lakes include Lake Rotorua, Rotoehu while some mesotrophic lakes include Rotomahana, Ōkāreka and Rotoiti.

LakeSPI Index

The LakeSPI Index (which measures submerged plants as an indicator of lake ecological condition) suggests that the declining condition in Rotokakahi is due to a reduction in water quality rather than invasive weeds dominating native weeds (Edwards & Clayton 2009). As illustrated by data collected by Edwards & Clayton (2011) from 1988 to 2010 the LakeSPI index has almost halved largely due to a decline in native charophyte meadows, however the dominant invasive weed species *Elodea canadensis* has remained the same. In addition other indicators of poor lake heath were observed during recent LakeSPI surveys such as filamentous algae prevalent on submerged vegetation and blue-green algal mats covering sediments below the maximum depth of plant growth (Edwards & Clayton 2009). Lake Rotokakahi is now the last of the Rotorua lakes to remain relatively free of significant invasive weed species, presumably due to restricted public access on to the lake.

Potential impact of phosphorus

Over the past 20 years water quality in Rotokakahi has reduced steadily due to rising phosphorus levels leading to increased algal biomass that has further reduced water clarity. However in recent years a more rapid deterioration has been observed. As a result of forestry harvesting that began in 2007, less vegetation present around the lake margin increases the likelihood of sediment runoff (rich in phosphorus) into the lake. Abell et al (2011b) studied the relationship between catchment land use and nitrogen and phosphorus in 101 New Zealand lakes found that exotic forestry accounted for 18.8% of in-lake TP concentrations in their dataset. Similarly, studies by Quinn and Ritter (2003) in the Purukohukohu catchment near Rotorua found stream TP yields 24-fold higher in the year following pine harvesting, however they decreased to 3-fold higher four years after harvesting and replanting. This demonstrates that rapid elevations in TP due to harvesting occur but that they may be short lived in terms of stream responses. As harvested areas within the Rotokakahi catchment have been replanted, post-harvest phosphorus leaching in ephemeral flows should be reduced as plantings take up phosphorus and nitrogen throughout their active growth phase. However once the active growth phase slows and pine forests approach maturity exports of nitrogen and phosphorus in particular can increase though relative to pastoral land, nutrient yields are substantially lower (Hamilton 2005). Considering over 50% of the Lake Rotokakahi catchment is in plantation forestry, further investigation into P-export particular to Lake Rotokakahi is required.

Considering the pulse of phosphorus from forestry harvesting in 2007 in addition to high phosphorus concentrations already contributing from the inflow, internal (bottom-sediment) loading, intermittent ephemeral flows and possibly other groundwater flows, it is likely that combined phosphorus loads from the above sources have predetermined recent rapid water quality deterioration, subsequent algal bloom formation and increase in the TLI value from mesotrophic to eutrophic. With forestry harvesting operations no longer present and harvested areas replanted, in the short term it is envisaged water quality will gradually improve to a mesotrophic state but the time scales for this change are somewhat uncertain because internal loading will act to extend elevated levels of phosphorus compared with the response time of phosphorus in stream inflows.

Recommendations

- As only one permanent surface water inflow is present at Rotokakahi, groundwater quality monitoring at selected locations should be conducted to determine if groundwater stream flows into Rotokakahi are in fact nutrient-enriched. This could enable clarification on whether excessive nutrients arise from "natural" nutrient enrichment from local geology or could reflect land use activities in the catchment or be a combination of both. This information will assist with targeting nutrient management of inflows to the lake.

- Identify and monitor additional surface flows through ephemeral stream channels during heavy rain events to account for ephemeral nutrient loads from both farmland and forested areas.

- Develop a nutrient budget and use the data from this budget combined with monitoring data to develop a water quality model and assess variations in water quality based on actions taken to improve water quality. Use the lake modelling as well as remote sensing images of the catchment through time, in order to better understand the dynamics of the recent changes in water quality that have occurred in the lake.

- In collaboration with the Lake owners and Bay of Plenty Regional Council develop a community Lake Action Plan to outline further monitoring and actions required to help improve lake water quality. Quantify the effect on Lake Tarawera of any water quality degradation or improvement in Lake Rotokakahi as the Lake Outlet (Te Wairoa stream) forms one of the major inflows to Lake Tarawera.

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APPENDIX:

Matt Bloxham (former BOPRC freshwater ecologist) file note to Rob Donald (BOPRC science manager)– summary Te Wairoa stream fish kill

FILE NOTE

Environment Bay of Plenty
REGIONAL COUNCIL
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File Note From:	Matthew Bloxham, Freshwater Ecologist EnvBOP
To:	Rob Donald
File Reference:	Date: 14th June 2011
Subject:	**File note Rob Donald – Summary Te Wairoa Stream Fish Kill.**

Hi Rob

Below is a brief summary of events surrounding the recent Te Wairoa fish kill and some of the fallout from that.

SUMMARY, TIMELINE OF EVENTS:

Monday 23rd May:

- Two Dutch/German anglers visited the Lake Rotokakahi outlet on Monday afternoon and noted that the lake and stream [i.e. the lake outlet and upstream limit of Te Wairoa Stream] was "very green". They estimated this to be 4.30pm.
- [Downstream sections of Te Wairoa Stream] was however still clear and they began fishing.
- About 6.00 pm the two fishermen noticed the green colour had now spread to this downstream section and the anglers could no longer see their boots when standing in a foot of water.
- They continued fishing until about 7.30pm when they noted "sick fish flapping about and laying on their sides behind them" (upstream of where they were standing but below the fish trap).

Tuesday 24th May:

- Mark Sherburn (Fish and Game Officer) received a call from anglers mid-morning on the Tuesday and went out immediately.
- Remnants of the bloom were still evident in the bay below the Te Wairoa stream[1] (where Mark collected the water sample), in the stream itself through the *Buried Village* and [upstream] at the Lake Rotokakahi by the outlet.
- Mark found 20 dead fish at the trap and saw another 20 or so through the buried village and in the stretch along the road and immediately below the Lake Rotokakahi.
- Mark has a skin reaction after direct exposure to bloom material. What began as stinging sensation became an intense itch that lasted until the following morning.

Wednesday 25th May

- Mark speaks with the two Dutch/German anglers who gave him an account of events on Monday the 24th.
- Rob Pitkethley, Manager of Fish and Game Eastern Region, contacts BOPRC Pollution hotline at 9:45am. File given to John Holst to investigate at 1:21pm. John begins investigation straight away.

Thursday 26th May

- Fish and Game and Pam McGrath, General Manager Buried Village made contact with Bay of Plenty Regional Council.
- Bay of Plenty Regional Council and Toi te Ora sample the lake and stream.
- Buried Village advised against continuing to use water from stream.

Wednesday 1st June

- First cyanotoxin results (analysed via liquid chromatography – mass spectrometry; LC-MS). Results for anatoxin-a and homoanatoxin-a (neurotoxins) and cylindrospermopsin (hepatotoxin) all negative.
- Susie Wood indicates that “None of 13 common microcystins variants or nodularin were detected via LC-MS. The LC-MS data indicate that other microcystins may be present in the sample”. Microcystins are hepatotoxins.

Thursday 2nd June

- Two additional tests run on 2nd June to investigate the presence of microcystins further, the first test involves extracted DNA and screening the sample for the presence of genes involved in microcystins production– a presence/absence test. The second test is an ELISA – which quantifies the total microcystins present in a sample.

Monday 6th June

- Results screening for microcystins genes: positive

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[1] Lake Tarawera end.

- ELISA test produced a positive result for total microcystins. The levels were approximately 10 ug/L.
- A Jellet Rapid Kit was used to screen the sample for saxitoxins (paralytic shellfish poisons; PSP's), this was negative.

The initial alarm was raised by trout fishers fishing Te Wairoa Stream on the evening of the 24th of May. What began as slight discoloration in the stream at the beginning of fishing at around 6:00pm, in an hour and a half had become an intensive bloom with visibility in the Te Wairoa reduced to just a few centimetres as bloom material passed through the system.

It is unclear exactly how long it took for all the fish in the stream to succumb. Clearly the fish observed by the German anglers were experiencing difficulty ("flapping about and laying on their sides") as the bloom swept through the system. It appears therefore to have been a rapid kill (within 2-3 hours) and potentially one brought on by the bloom itself and the conditions it created. Most of the fish mortalities (I understand around 40 trout in total and an undisclosed number of native fish deaths) were retrieved by Mark Sherburn, the investigating Fish and Game officer. Mark retrieved twenty dead trout at Fish and Game's fish trap on the Te Wairoa and saw another twenty through the buried village and in the stretch along the road and immediately below Lake Rotokakahi (Figures 1 and 2). Te Wairoa makes up the basis for stock selection for all the Rotorua lakes (plus the rest of North Island) so it is a very important stream (pers. comm. Rob Pitkethley).

Figure 1: Rainbow trout retrieved from Te Wairoa Stream by Fish and Game staff.

Figure 2: Rainbow trout as found by Fish and Game staff at the Te Wairoa Stream fish trap. Photograph taken by Mark Sherburn on the 24th May (the morning after the evening 'event'). Note stream milky though not obviously green in the way it would be if transporting bloom material.

While the initial focus was on the fish deaths, simply because fish kills resulting directly from cyanobacteria bloom activity is a relatively unusual phenomenon; it became clear that potential human health issues might also stem from the event. For one, Mark had a reaction to the bloom as the hand he sampled the scum with became inflamed upon contact with the bloom material and later became intensely itchy (figure 3)[2]. To add to concerns (given Mark's skin reaction), at least one property[3] was identified as taking drinking water from the stream.

[2] Despite the fact what he was targeting was concentrated scum material, Mark was initially sceptical that such short duration exposure to bloom material could cause such a reaction.
[3] The Buried Village.

Figure 3: Scum material similar to that sampled by Mark Sherburn the investigating Fish and Game officer on the 24th May (the morning after the evening 'event'). Photograph taken by Mark Sherburn.

John Holst (Bay of Plenty Regional Council compliance officer) visited Te Wairoa stream on the 25th of May followed by Ross Price (Toi Te Ora Health Protection Officer) on the 26th. Both took samples and reported back to me. By then the stream had returned to its pre-bloom state and there was little or no residual bloom material still evident in the stream though the stream water was still cloudy (Figure 4) and as later images will show, significant surface blooms were still present in Lake Rotokakahi two days further on (Figure 5). Mark noted a light onshore breeze blowing into the Te Wairoa stream inlet on the 24th and saw surface bloom material massing around the outlet in the lake itself (pers. comm. Rob Pitkethley), suggesting how wind action could have concentrated lake surface bloom material further out in the lake and carried it into the stream.

Figure 4: Te Wairoa Stream photographed by Pam McGrath, 26th May (two days after the bloom event).

We analysed Mark's Te Wairoa scum sample (Figure 3) and confirmed that it was dominated by *Anabaena lemmermannii, a* known cyanotoxin producing species. Arrangements were therefore made to send a sample off for cyanotoxin analysis. Mark Sherburn's May 24th sample[4], the most concentrated sample collected, was sent away to Cawthron for analysis.

As for any new site and/or species, the approach taken is to screen for all known cyanotoxins. Cawthron uses the three following methods, which in combination give a good indication of whether any particular cyanobacteria strain is producing toxins:

1. **LCMS**: The sample is initially sent off to an independent lab to carry out LC-MS, a chemical method that quantifies all major cyanotoxins including the 13 most common microcystin variants. No cyanotoxins were detected including anatoxin-a/homoanatoxin-a (neurotoxin) and cylindrospermopsin (hepatotoxin), microcystins (hepatotoxin). Saxitoxins (PSP's) were screen using a Jellet Rapid kit – no saxitoxins were detected.

2. **Gene method**: DNA is extracted from the sample and a PCR undertaken that detects the presence of specific genes involve in microcystins production. The gene was detected in the sample

3. **ELISA method**: The ADDA-ELISA used antibodies (known as ADDA) that have been raised to a amino-acid unique to microcystins. This therefore gives a measure of the total microcystins present in a sample. The ELISA was positive with an approximate value of 10 ug/L.

[4] I.e. the same sample that caused his skin reaction.

These microcystins levels are just below the threshold for action level (12 ug/L) in the New Zealand guidelines for managing cyanobacteria in recreational water (MfE/MoH 2009). It is unlikely that microcystins at these levels would cause a skin reaction as intense as the one Mark experienced (pers. comm. Susie Wood, Cawthron).

Susie suggested that endotoxins (lipopolysaccharides (LPS) - a component of the cells walls of many gram negative bacteria) are probably what caused Mark's skin reaction - some people are more susceptible to these. Susie suggested also that it may be that this species just produces a lot of LPS.

Susie is currently culturing a cyanobacteria sample which may provide an indication of:

1. What percentages of the colony are producing cyanotoxins (within species, some genetic strains produce cyanotoxins while others don't).
2. The amount of toxin being produced by individual cells.

Fish deaths

Despite the fact it was obviously an intense event; doubts arose over whether a bloom would cause the rapid deaths of so many fish. Initial effort therefore went into investigating other possible causes. The initial focus was on investigating whether anoxic lake water associated with lake turnover, had entered the stream causing a sag in dissolved oxygen (DO). Had such a situation occurred, one might have expected to see fish kills around the lake also, in addition to signs that the lake had turned over. The stream is small and water residence in the lake probably lengthy so we also expected to see signs of anoxia (low DO) in surface waters in the days following the event. We wanted also to confirm whether the bloom material observed in the stream had originated in the lake.

Two days after the initial fish kills were reported, Joseph Butterworth, Brooke Thomas and Ross Powell carried out water sampling and measured the lakes DO profile using the CTD. A number of profiles where undertaken down the length of the lake to investigate whether the lake had become destratified and/or whether there were any abnormalities of note. Figure 6 shows the location of the casts.

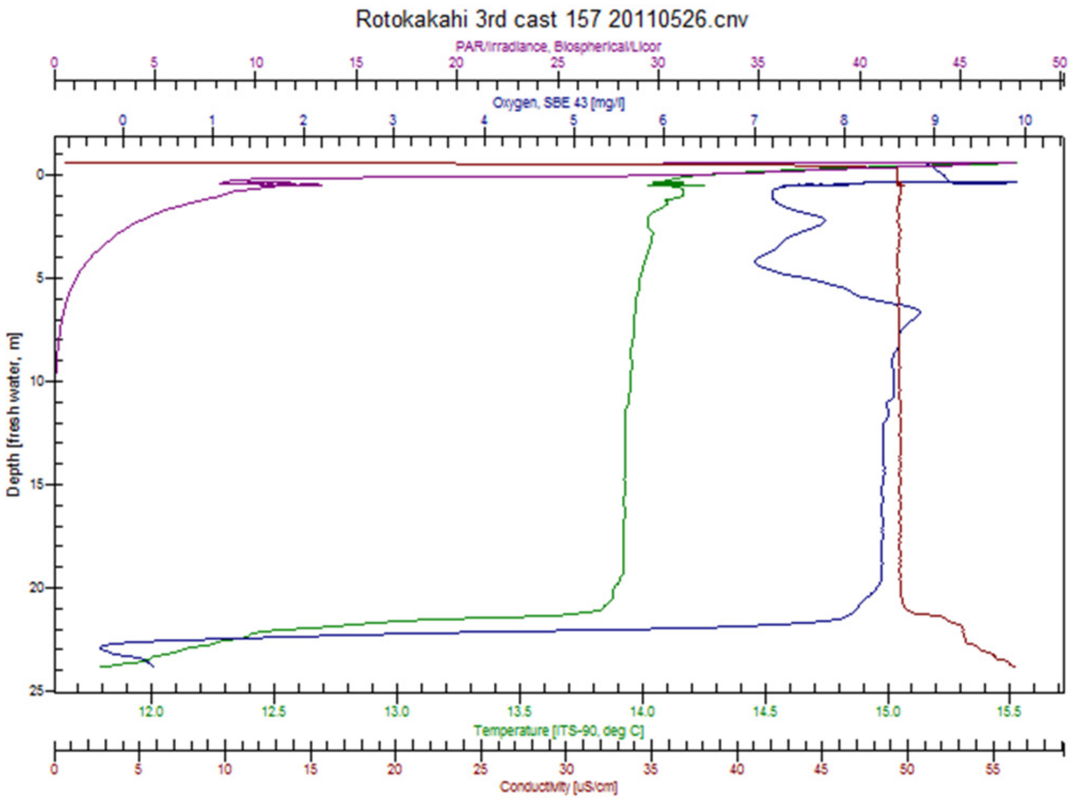
Weather was poor with high winds and rain. The high winds forced Joseph and Ross to launch at the sheltered southern end of the lake. Wind was blowing onshore at the Tarawera Road end of the lake. Bloom material was observed at the launching point similar to this earlier surface bloom (Figure 5) at the opposite (southern) end of the lake.

Figure 5: Scum material at the southern end of Lake Rotokakahi photographed by Joseph Butterworth on the 3rd of May 2011, 20 days before the Te Wairoa fish kill).

Cast 3 in the lake's deeper sections confirmed that the lake was still stratified days after the event as water in the bottom three to four metres of the lake was anoxic and had a different temperature gradient[5]. It has been variously suggested that a smaller expulsion of anoxic water from the hypolimnion could have occurred. However, the tendency is not for anoxic water to upwell in concentrated slugs but for surface waters to gradually mix down at turnover, making an anoxic event, in the lake at least, less likely (pers. comm. John McIntosh).

[5] David Hamilton noted that the mixed layer is certainly deep but not turned over yet and oxygen is being maintained relatively high as the surface layer deepens.

Light was only penetrating to ten metres depth indicating the water clarity was only in the order of a few metres. Conductivity shows a well-mixed epliminion, with varying conductivity in the hypolimnion as might normally be expected. Fluorescence sensor also shows algae were well mixed through the epliminion and at levels lower than more eutrophic lakes.



Figures 6 and 7: Schematic showing location of CTD casts and graph showing results for cast 3 (middle of lake) and DO, conductivity, PAR/irradiance Temperature depth profiles from 26th May (3 days after the Te Wairoa Stream event).

While it now seems unlikely that an episodic anoxic event in lake waters drove down DO in Te Wairoa Stream, it is possible that the pulse of cyanobacteria/algae moving down the stream would have created a very short term low DO environment. In a dense "bloom" the pH is also likely to be elevated[6]. The cyanobacteria could also have caused some "clogging" of the gills and asphyxiation. There are documented cases of algae clogging the gills of fish, preventing gaseous exchange and leading to fish kills (Agatha 2011)[7].

The suggestion therefore is that fish in Te Wairoa Stream were affected by multiple stressors (over this point, there is general agreement). David Hamilton produced a paper in which neurotoxins uptake across the gills had caused fish deaths. As suggested earlier, only microcystins were detected and these have a slower and altogether different mode of action from neurotoxins and are unlikely to be passively absorbed across the skin and gills (pers. comm. Susie Wood)[8]. But while they are unlikely to have killed the trout, the microcystins present could also have contributed another stress (pers. comm. S. Wood). Susie also suggested that the dinoflaggelate *Ceratium*, a genus that has the potential to irritate the gills of the trout, was also present (although not quantified) in Mark Sherburn's sample.

Potential for future events and possible intervention

From speaking with a nearby resident Norman Donald (8th of July), fish (including trout) have since re-populated the stream with apparently no on-going ill effects. Although they haven't necessarily been on the same scale as the May 24th event, further bloom material has entered the stream since. Pam McGrath, who manages the Buried Village, commented that *"the stream seems to nearly clear (to the eye) and then we get a cold wind and it turns dark green again. I found the sample in a small eddy of the stream* (Figure 8)*. This is about the 3rd maybe 4th time it's done it since the 24th of May"* (pers. comm. P. McGrath).

[6] While it is an unlikely scenario in this instance, trout are susceptible to elevated levels of nitrite and/or ammonia. For every one point change in pH, the toxicity of nitrite increases 10-fold. Notwithstanding the fact the lake is still stratified Susie asked whether a small mixing event could also have mobilized some metals in the anoxic hypolimnion – i.e. trout are very susceptible to zinc (pers. comm. Susie Wood).

[7] Agatha A. Nwabueze 2011. Health implications of harmful algal blooms in tank culture of catfish. Agriculture and Biology Journal of North America. ISSN Print: 2151-7517, ISSN Online: 2151-7525, doi:10.5251/abjna.2011.2.1.56.60 © 2011, ScienceHuβ, http://www.scihub.org/ABJNA.

[8] In collaboration with two of Cawthron's fish pathologists, Steve Webb and Kevin Heasman.

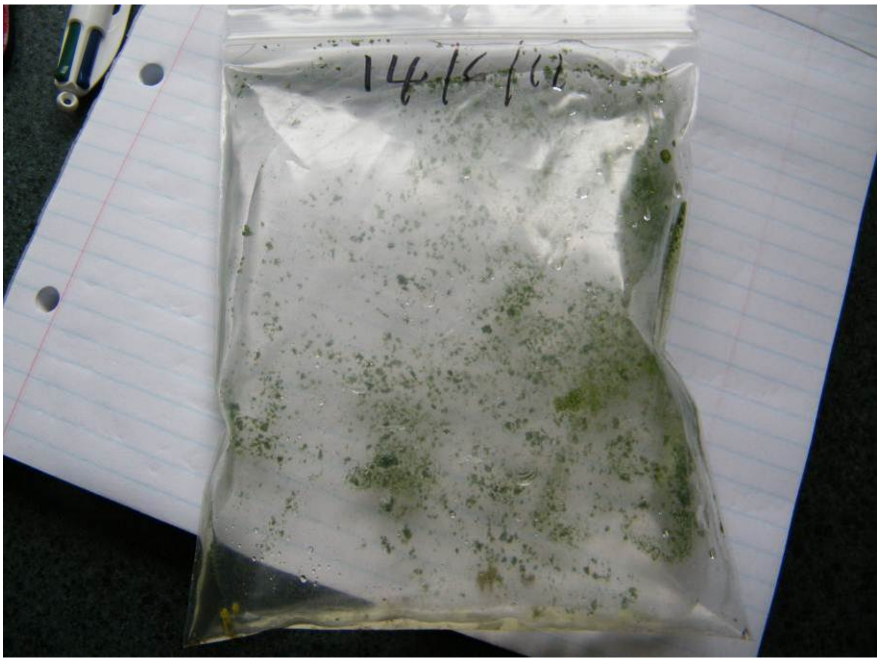
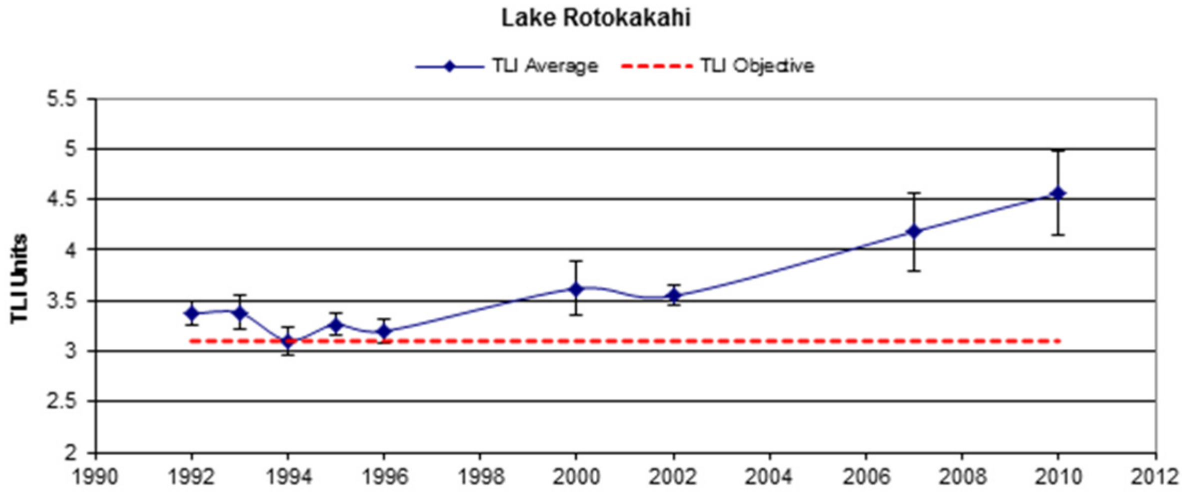


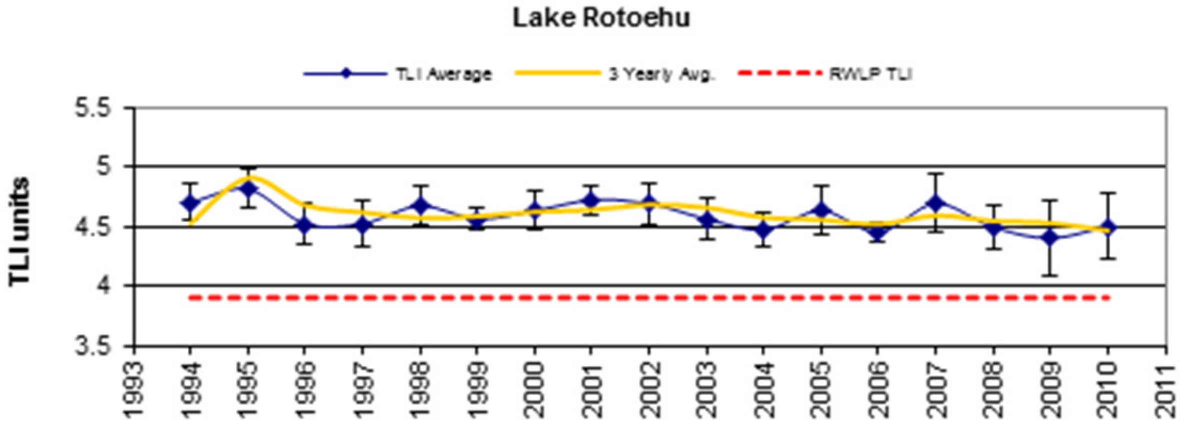
Figure 8: Bloom material sampled by Pam McGrath from a small back eddy in Te Wairoa Stream on the 14th of June.

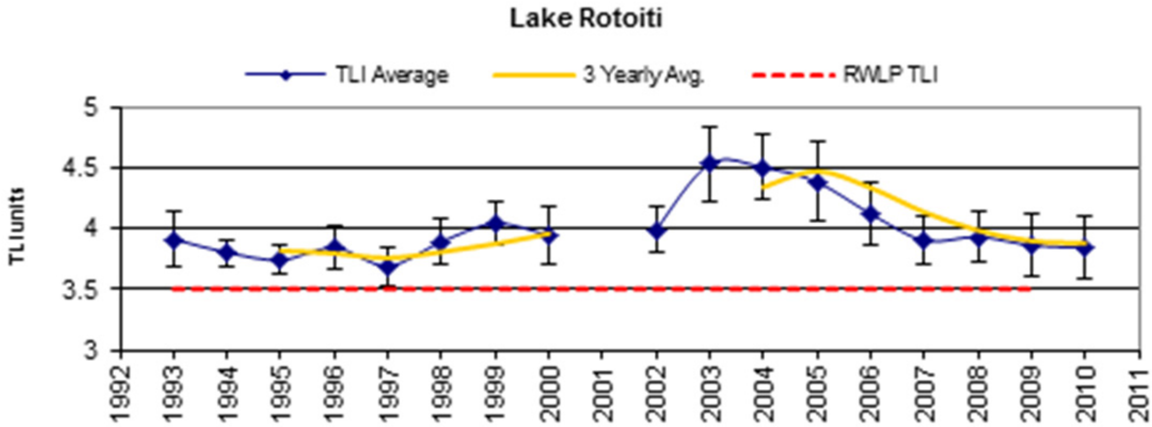
While surface lake scums remain in the lake, blooms of a magnitude comparable to the 24th event could occur again and with similar results. All that is needed is for light airs to transport concentrated surface scums towards the stream intake/lake outlet.

This is the second recorded cyanobacteria bloom on Lake Rotokakahi[9], although it is possible that there have been others. May and June have been unusually warm in the North Island and we have recorded late bloom activity in Lake Rotorua also. It is difficult to tell whether cyanobacteria blooms will become a perennial problem in the lake. Lake Rotokakahi has shown a gradual deterioration (general lake health and in water quality) over a number of years so the possibility cannot be discounted. For example, in terms of the LakeSPI index, Lakes Rotokakahi along with Lake Tikitapu have shown the biggest change in lake condition over the last 20 years, resulting in a notable reduction in the quality and extent of native submerged vegetation present in both lakes (Edwards et. al. 2010)[10]. There have been no additional exotic invasive plant species introduced to the lake since full lake survey began in 1998, so these changes are likely the result of deteriorating water clarity and quality. Indeed, since TLI records began, the trophic level index for Lake Rotokakahi has increased from 3.4 in 1992 to 4.55 in 2010. As an indication of Lake Rotokakahi's cyanobacteria bloom potential, perennial blooms in Lakes Rotoehu began at a time (1993) when the TLI was sitting around 4.5 (and has remained more or less at this figure since). In Lake Rotoiti the first recorded perennial bloom activity began in 1997 at a time when the TLI was sitting at around 3.9 and it has ranged between this figure and 4.5 since (Figure 9).

[9] The other being the bloom observed by Joseph Butterworth on the 3rd of May 2011.
[10] Edwards, T. and Clayton, J. 2010. The ecological condition of the Rotorua Lakes using LakeSPI. Prepared for Environment Bay of Plenty. NIWA project BOP10201. NIWA client report HAM2010-047, May 2010. Pg 34.







Figures 9: Annual average TLI for Lakes Rotokakahi, Rotoehu and Rotoiti with standard error bars, three-yearly average TLI and RW&LP TLI objectives (source Scholes, P. 2010. 2009/2010 Rotorua Lakes TLI update ISSN: 1175-9371 online).

Rotokakahi is not currently one of the lakes routinely sampled by the BOPRC as part of our lakes cyanobacteria sampling programme, which has a public health focus. While the risk to water abstractors has been circumvented[11], the incident has certainly highlighted the risk of episodic blooms to anglers fishing the stream. However, other than monitoring general algal build up in the lake (with the local Iwi's permission); the potential to reliably predict the onset of similar intensive bloom events in the stream is limited where the threat is from surface blooms[12] (as opposed to blooms dispersed evenly throughout surface waters). Indeed at a time when significant but spatially disparate surface blooms were present, we were returning cell counts for *Anabaena lemmermannii* no higher than 1707 cells/ml[13]. This lake edge sample was collected at the northern end of the lake on the 26th of May, the same day that elevated bloom activity was photographed at the southern end of the lake (refer figure 5).

The May 24th event highlights the speed at which blooms can form and impact the stream. And while this does not assist at all with the management of this important trout fishery[14], my suggestion to safeguard anglers would be to request that Toi Te Ora issue a general health advisory backed up with permanent signs at all major access points requesting that fishers avoid fishing the stream when the stream is showing signs of bloom activity.

If such an event occurred again it would be useful sending samples to a fish pathologist as provided samples are fresh, tell-tale signs can be quite obvious. As Rob Pitkethley and Susie Wood have suggested, there may be signs of DO starvation or impaired gill function and the blood can reveal other potential aggravating factors including high ammonia concentrations, which in trout gives rise to 'brown blood' (pers. comm. Rob Donald).

Please don't hesitate to get back to me if there is anything further you would like discuss.

Regards

Matt Bloxham

[11] The Buried Village, the only property confirmed as having a domestic water take from Te Wairoa Stream, is investigating alternative water sources and has stopped taking water from the stream for domestic purposes. Other properties initially identified as having potential stream takes (Mike Romans and Norman Donald) have now been discounted.

[12] Rather than cellular material dispersed evenly throughout the water column.

[13] The recreational trigger is 15,000 cells/ml.

[14] As stated earlier, Te Wairoa makes up the basis for stock selection for all the Rotorua lakes (+ the rest of North Island) so it is a very important stream (pers. comm. Rob Pitkethley).