THE STATE OF THE ROTORUA LAKES IN 2017

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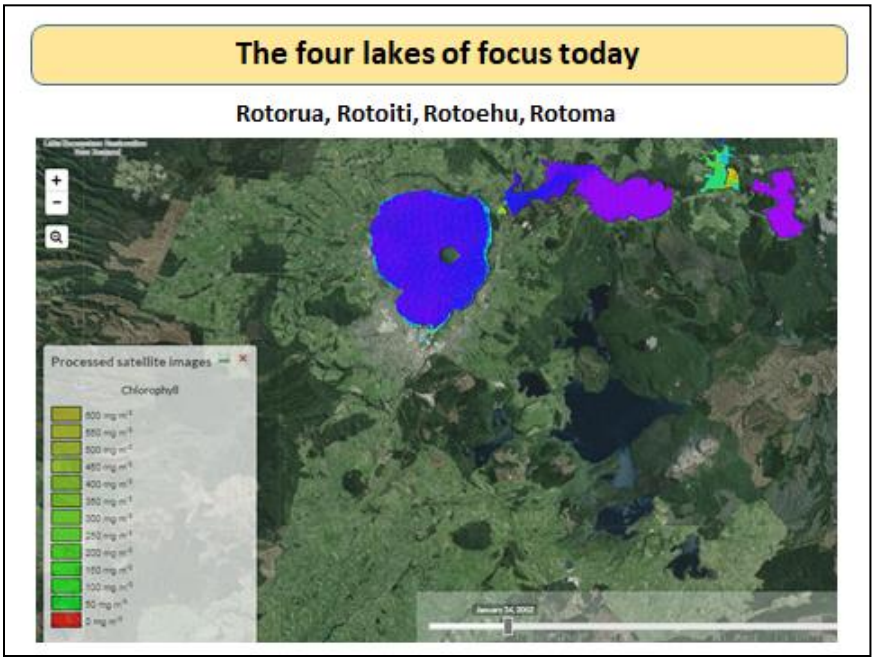
David Hamilton is currently Deputy Director of the Australian Rivers Institute, Griffith University, Brisbane. He served as the inaugural Bay of Plenty Regional Council Chair in Lake Restoration, University of Waikato, for 15 years (2002-2017) following 12 years at the Centre for Water Research, University of Western Australia. His Ph.D. research at the University of Otago initiated a career in which he has linked research in lake water quality modelling with practical solutions for lake restoration.

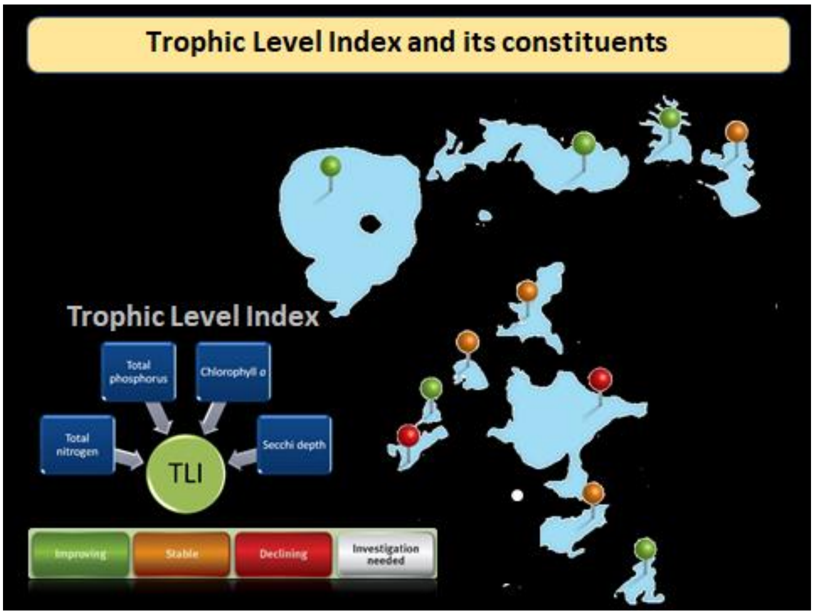
TRANSCRIPT

Tena koutou katoa

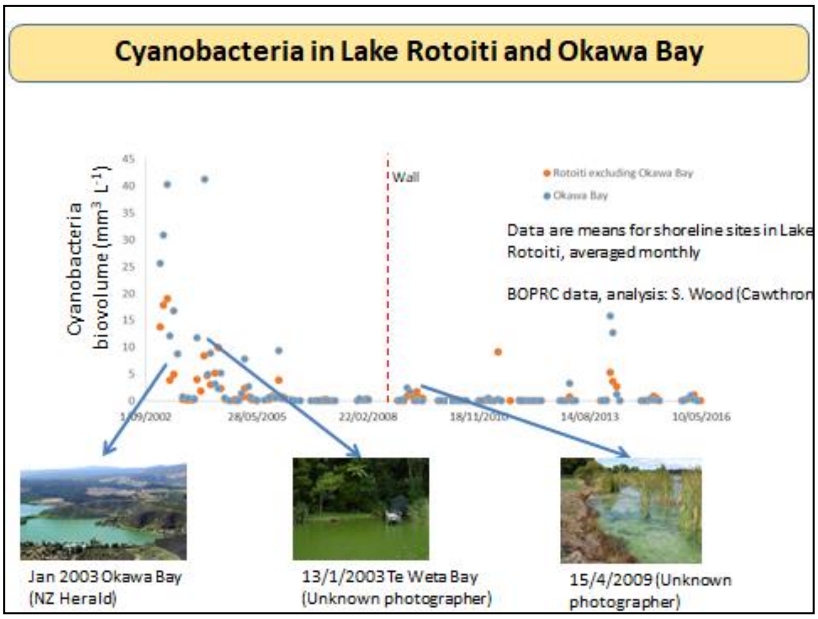
I have been asked to give an overview of the Rotorua Te Arawa Lakes and then focus on just four of the lakes. Chris McBride will pick up other lakes. I would like to acknowledge Warwick Silvester who set up the Lakes Chair, Simon Stuart who is working outside the rohe, on Lake Taupō, but has a great body of knowledge on the food chain in that lake, with potential applications to the Te Arawa lakes. Also to Kohji Muraoka who helped me over the last 24 hours, putting data together which enabled me to synthesise my thoughts on these lakes.



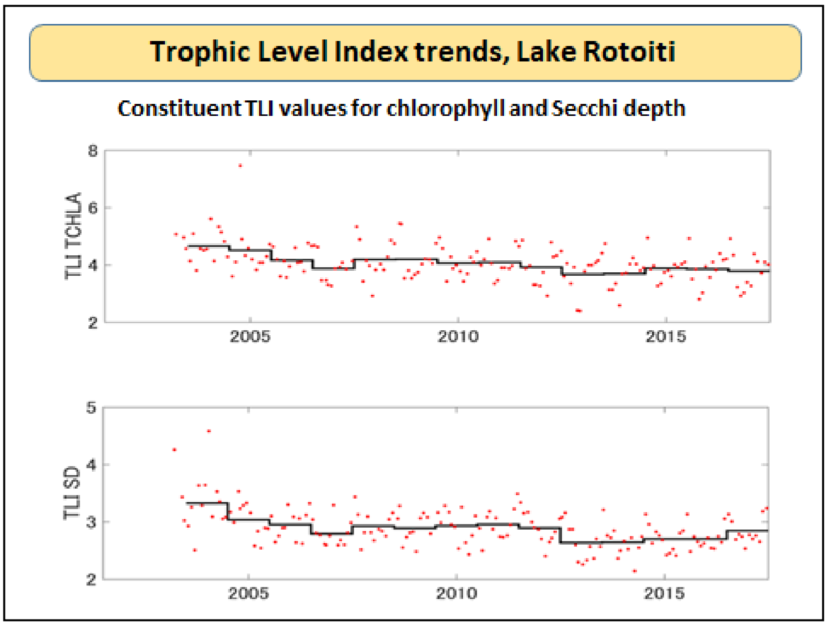
This slide shows the focus today, Rotorua, Rotoiti, Rotoehu and Rotoma, in a satellite image taken in 2002. It was opportune that I picked the image to show Rotoehu in bloom, given by the colour. The same red colour is also shown in Okawa Bay at that time.



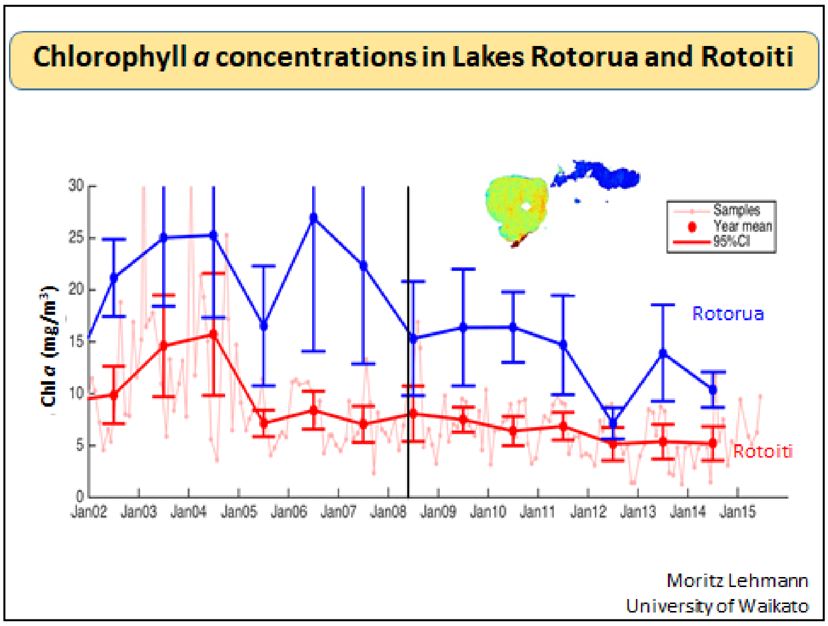
The Bay of Plenty Regional Council uses these lakes as an opportunity to measure the Trophic Level Index (TLI) which is an indicator embedded in their regional plan and policy. It is used to give an indication of whether the lakes are improving, stable or declining. This slide indicates that there is a variety of different trophic level states, and lakes may be improving or declining. It is one of our scientific challenges to put this information together.



This illustrates some of the things that happened that drove public expectations that it has to get better: in Okawa Bay, Te Weta Bay and near the diversion wall. High cyanobacteria concentrations mean the algae become visible and the public respond to this particular group of phytoplankton because they tend to float and get pushed into bays. Their proliferation is the most obvious manifestation of changes in water quality. During 2004/5 there was a period in Lake Rotoiti and Okawa Bay when things were quite nasty. Blooms have occurred occasionally since that time, for example, after the wall was put into Lake Rotoiti.

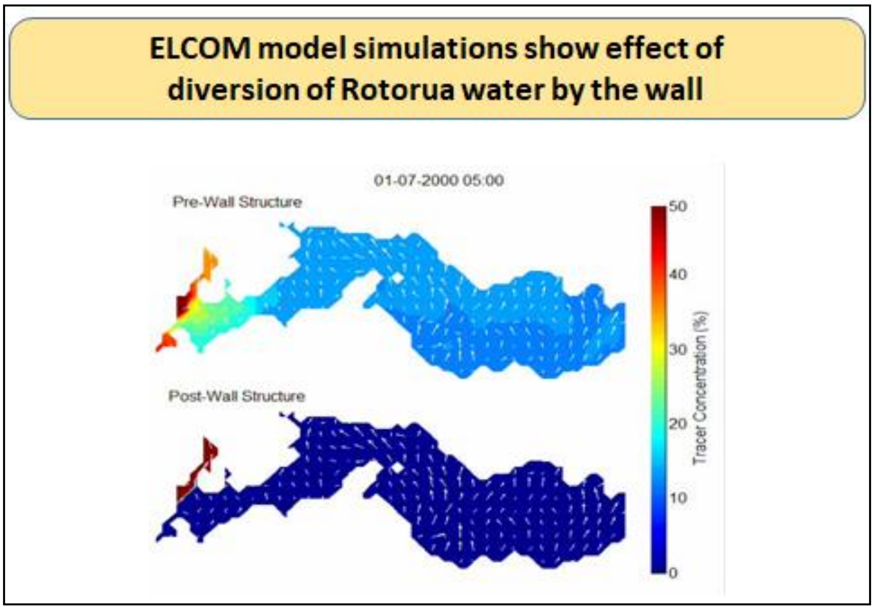


You can look at this in terms of four different constituents included within the Trophic Level Index Looking at these constituents individually, total nitrogen and total phosphorous tend to be drivers of water quality and chlorophyll *a* and Secchi depth give an indication of water clarity.

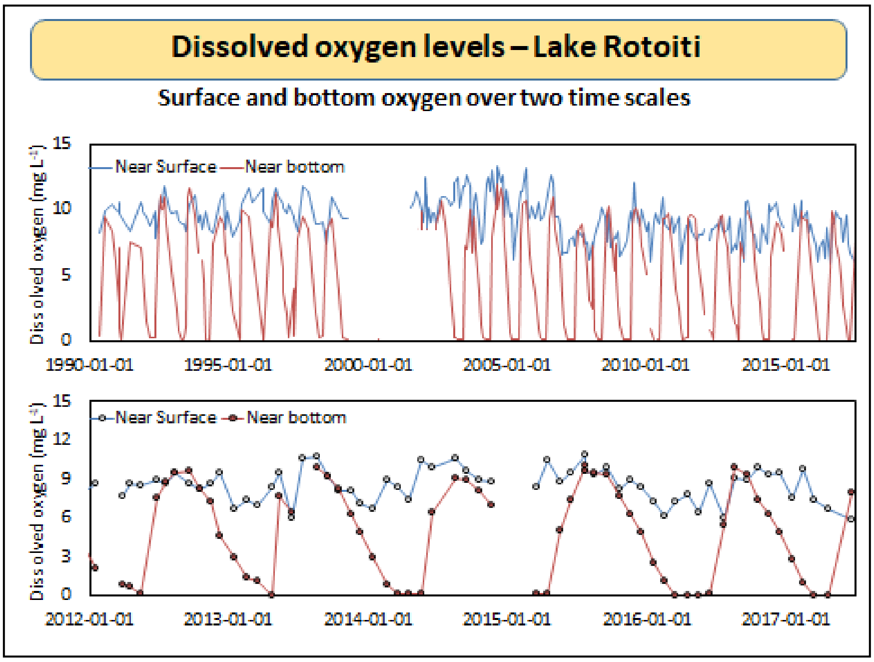


Here chlorophyll *a* has decreased progressively and clarity has improved. However, in more detail there are quite large changes that have occurred in the last decade. The black line represents the wall implementation. The period is from 2002 to 2016 and shows that Rotorua has a higher level of chlorophyll *a* than Rotoiti does. Many people attribute the wall to the improvement in water quality, and it has, but things had improved immediately before the wall implementation as well as since that time. There was a shift in Rotorua around 2006/2007. It is no coincidence that alum dosing started in 2006 and was reinforced with dosing another inflow in 2010. Rotorua has continued to improve.

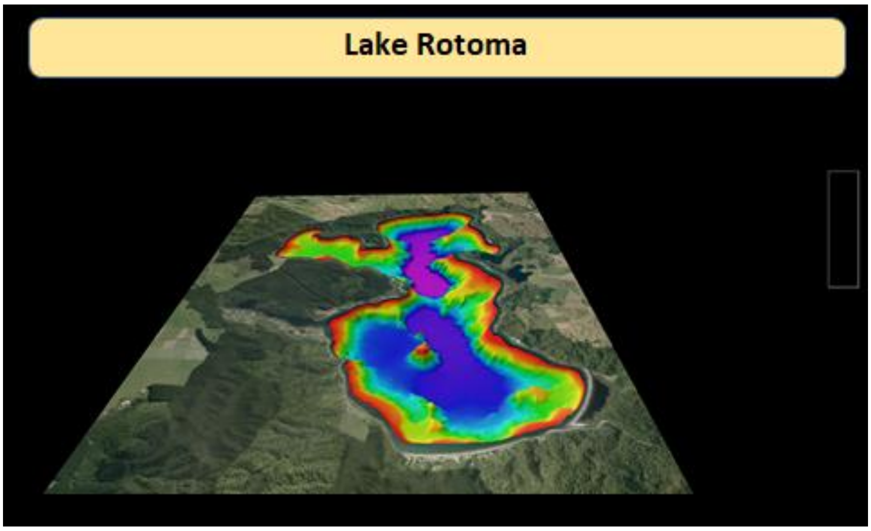
That is not the full story. The wall has cut off the connection between Rotorua and Rotoiti and that is very obvious from this photo. The models below show very little exchange now between those two lakes. The top one shows pre-wall with a tracer put through the Ohau Channel. That tracer is dispersed throughout the lake as opposed to the current situation where the tracer comes in through the Ohau Channel and is moved out to the Kaituna River.



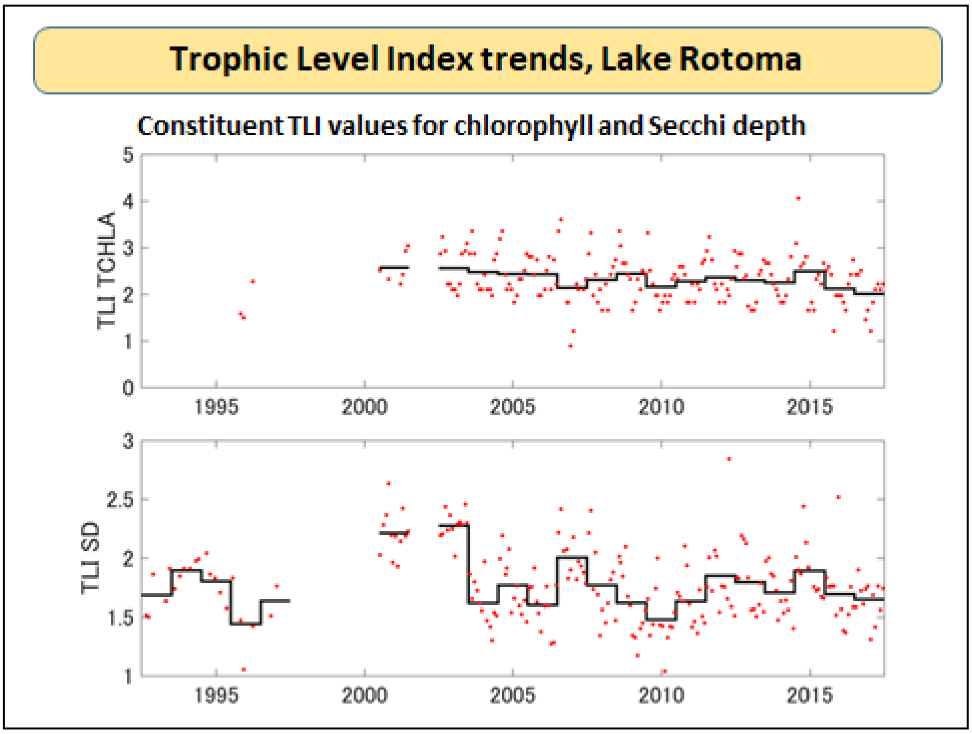
I get back on my old hobby horse here. The Trophic Level Index is a good indicator but, for me, ultimately the state of the lakes is given by the levels of dissolved oxygen. I want to again thank Kohji Muraoka for putting this slide together. The graph below shows near-surface and near-bottom concentrations in Lake Rotoiti, showing a very strong annual cycle. Oxygen goes up when the lake mixes with aeration from the water surface; a healthy case. For about 9 months of the year the lake does not mix and oxygen in the bottom waters declines at a rate that is dependent on quantities of algal production from the surface. What stimulates that algal production is nutrients. At times there is complete loss of oxygen in the bottom waters. In the last decade trophic state has improved considerably in Lake Rotorua. Overall, the best integrators of many the diverse processes operating in a lake are dissolved oxygen levels in bottom water.

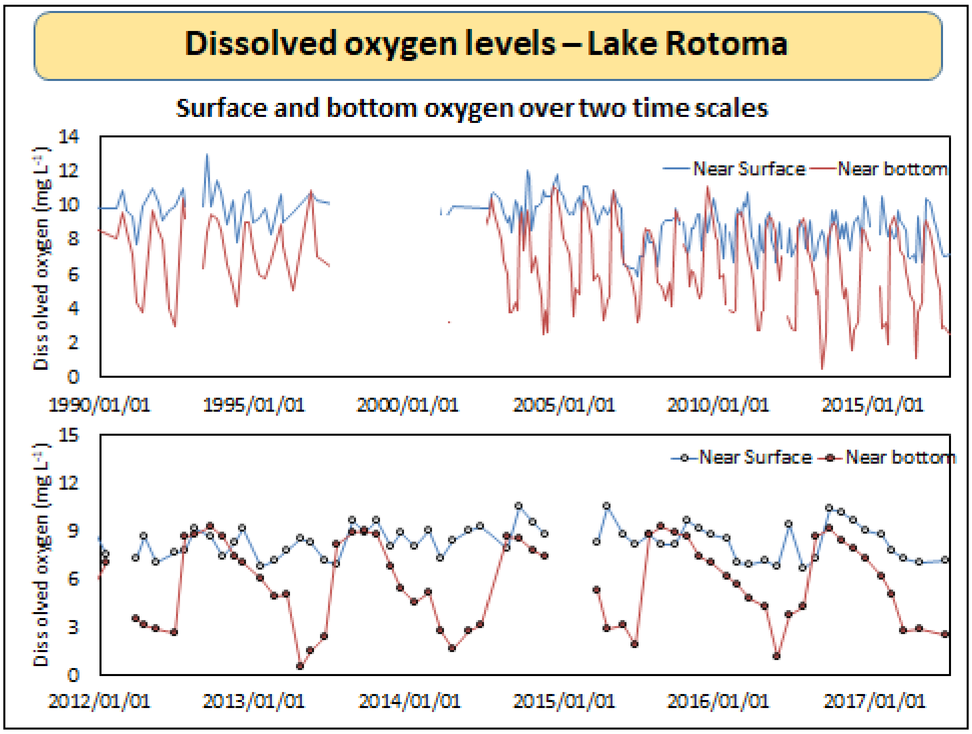


In the Rotorua Te Arawa Lakes sampled by Bay of Plenty Regional Council I regard Rotoma as being closest to the native condition. This is Rotoma looking to the north. The little island sometimes appears in the lake but not at the moment. The Trophic Level Index values show the trends, which are generally fairly positive. Levels are going down and therefore water quality may be improving. (Slide next page)



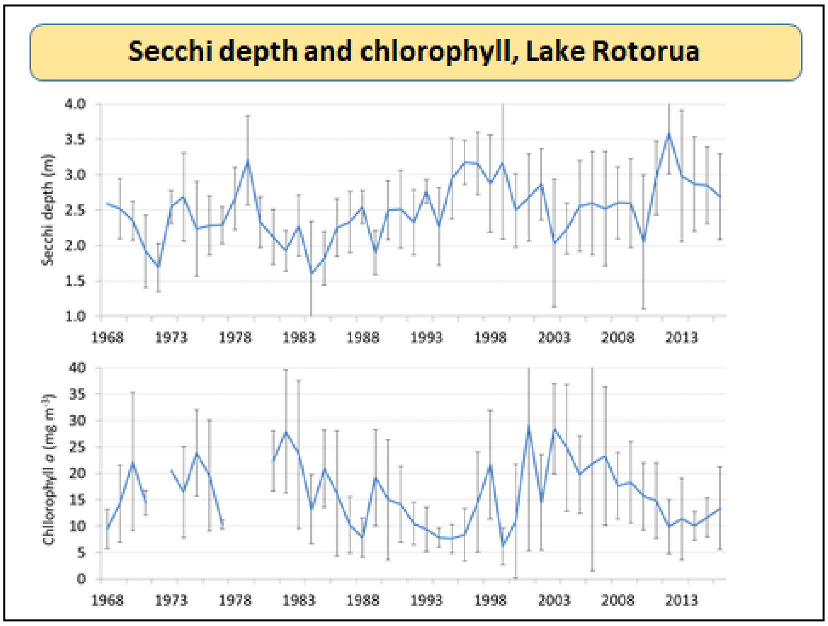
But I look to dissolved oxygen as the best indicator in those bottom waters. (Slide next page) Of particular significance is that none of the monitoring in the 1990s indicated there was a huge loss of dissolved oxygen. It is similar through to 2002 but looking more closely, the dissolved oxygen levels appear to have got lower. For example in 2013 there was a very low level of dissolved oxygen. What is going on? Well that is why we have scientists who are interested in probing this; I cannot offer you a definitive answer at this stage.


Trophic Level Index trends, Lake Rotoma
Constituent TLI values for chlorophyll and Secchi depth
TLI TCHLA
TLI SD
1995
2000
2005
2010
2015


Dissolved oxygen levels – Lake Rotoma
Surface and bottom oxygen over two time scales
Dissolved oxygen (mg L⁻¹)
Near Surface
Near bottom
1990/01/01
1995/01/01
2000/01/01
2005/01/01
2010/01/01
2015/01/01
2012/01/01
2013/01/01
2014/01/01
2015/01/01
2016/01/01
2017/01/01

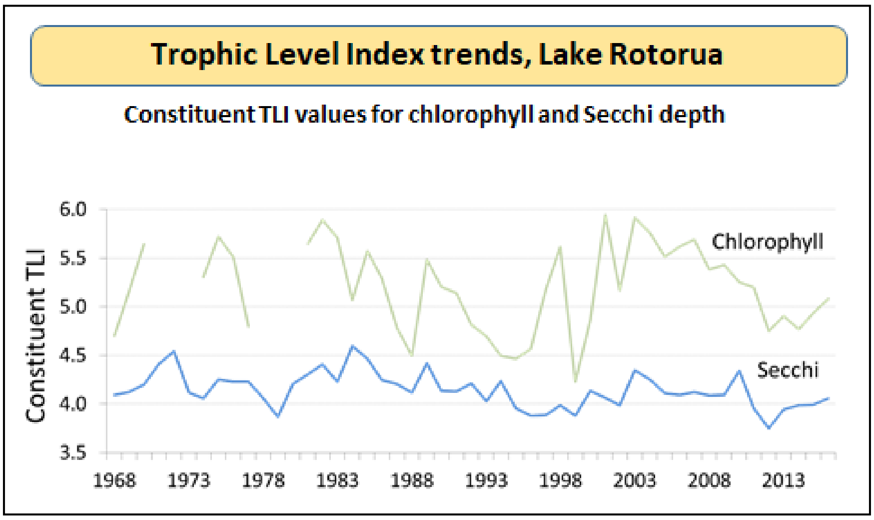
I want to acknowledge Kit Rutherford. Chris McBride has effectively become a curator of the Lake Rotorua data and been able to synthesise the historical work on this lake.

This slide shows the Secchi depth and chlorophyll *a* values as an indicator of the algal concentrations in Lake Rotorua. It is hard to say what is going on in this lake. However we can say that the 1990s was a period when chlorophyll *a* levels were quite low and visibility, i.e., Secchi depth values, were quite high. This high clarity brought a false level of comfort that the improvements in removing the Rotorua wastewater in 1991 had improved the lake.

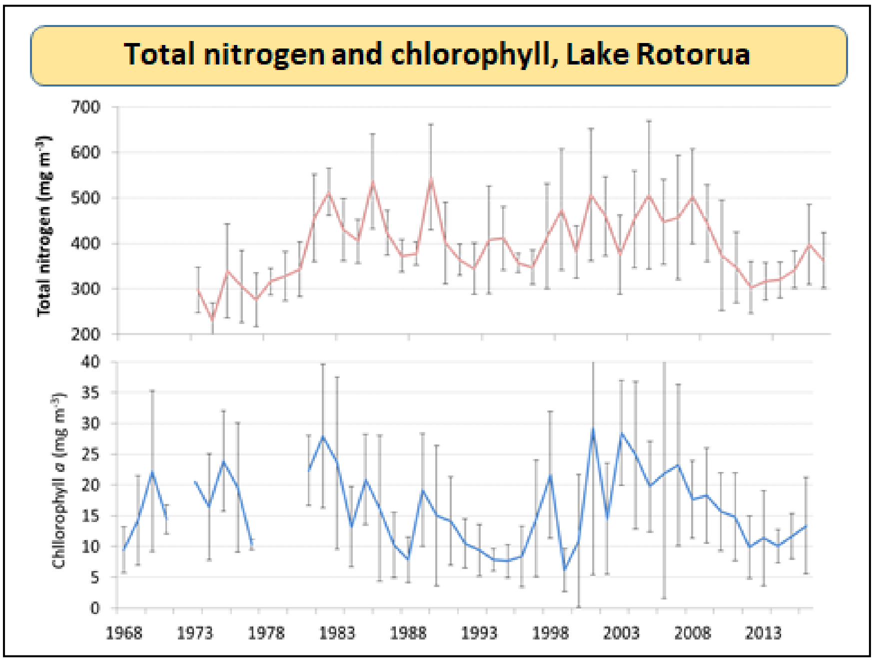


But by 2003/2004 things had got markedly worse. Chlorophyll *a* levels were way above what we had seen before and brought massive blooms. I show relationships between clarity and chlorophyll. They are not straightforward but generally the lower the clarity the higher the level of algal concentrations in the lake, but suspended sediment also contributes to loss of water clarity.

This slide shows a remarkable record of nearly 50 years of data from 1968 thanks to several people in the room who have assisted greatly with bringing it together. It shows chlorophyll *a* concentrations and Secchi depth values.



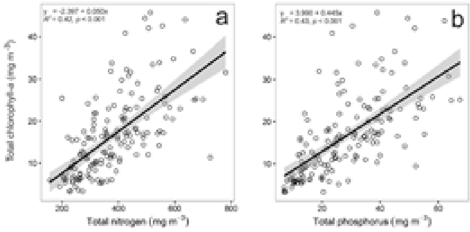
The slide below shows that total nitrogen has gone up and down over the years but it is no coincidence that it was down to relatively low levels around 2012-13, comparable to the 1960s/1970s, as a result of alum dosing. You can see in the mid-2000s very high concentrations of total nitrogen and correspondingly very high concentrations of chlorophyll *a*. I could show you a very similar plot for phosphorus through time as well.



Just to re-emphasise that point about the importance of nitrogen and phosphorus, when you add these nutrients they stimulate algal growth. The slide on the next page is a paper synthesising all of the work that was done to add nutrients and see whether nitrogen or phosphorous stimulated algal growth in Lake Rotorua. I do not think you can separate these to nutrients – is it nitrogen and phosphorus? It is both. You might try to limit one nutrient, for example, but you immediately run into limitation by another. So both nitrogen and phosphorus are extremely important, and at certain times of the year, or at certain depths or locations, nitrogen might be limiting algal growth to a greater extent than phosphorus or vice versa.

Nutrient bioassays, TN/TP vs chlorophyll, Lake Rotorua

Experiment organisation level	Observed response +N	Observed response +P	Relative response	Co-limit. response	Incubation/ simulation duration	Study
Lab bioassays (0.25 L)	Yes	No			5 d	White and Payne (1978)
Lab bioassays	Yes	No		>N	2 h, 24 h	White et al. (1985)
In situ mesocosm (3 L)	Yes	Yes	P>N	>N, >P	4 d, 6 d	Burger et al. (2007)
In situ mesocosm (1 m³)	Yes	No		>>N	1-9 d	Meads (unpub. data 2009)
Lab bioassays (1)	No	No		No	1 d	Abell and Hamilton (2015)
Lab bioassays (2)	Yes	No		≈N	1 d	Abell and Hamilton (2015)
Lab bioassays (3)	No	Yes		No	1 d	Abell and Hamilton (2015)
Lab bioassays (4)	Yes	Yes	N≈P	≈N, ≈P	1 d	Abell and Hamilton (2015)
Model simulations	Yes	Yes	N >>P	>N, >>P	5 d	Abell and Hamilton (2015)

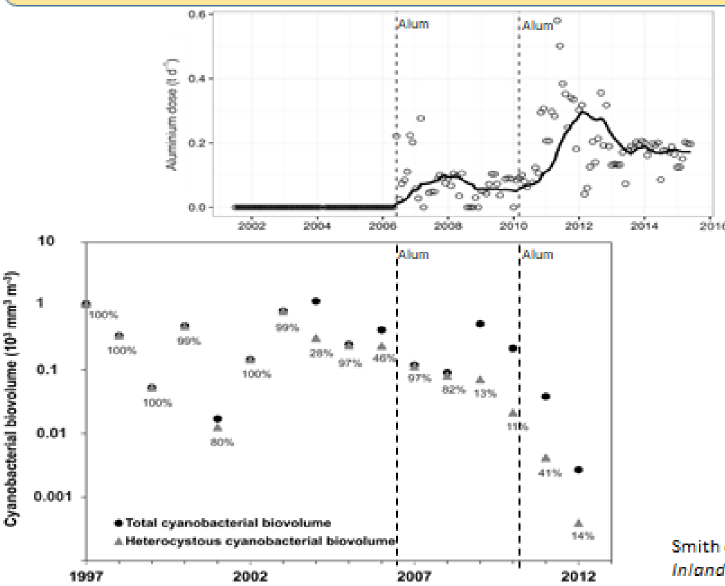


a: TN vs chlorophyll
B: TP vs chlorophyll

Smith et al. (2016)

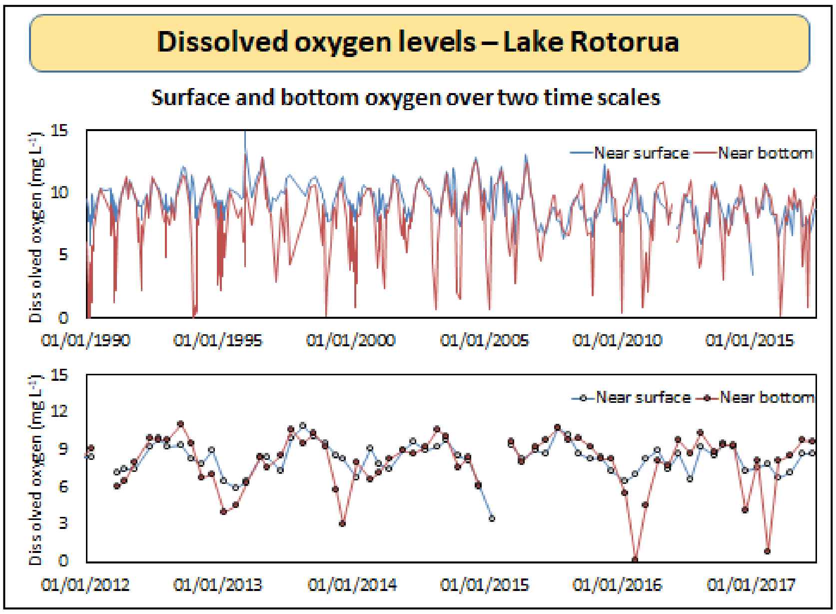
To re-emphasise the importance of alum, particularly in terms of water clarity in Lake Rotorua, dosing started in 2006 and ramped up in 2012. Below shows the percentage as well as the concentration of cyanobacteria. By 2012, at the maximum dose rate, we had reduced cyanobacteria to low concentrations. Unfortunately we do not have time to discuss the pros and cons of using alum.

Alum dosing and annual cyanobacteria volumes, percent

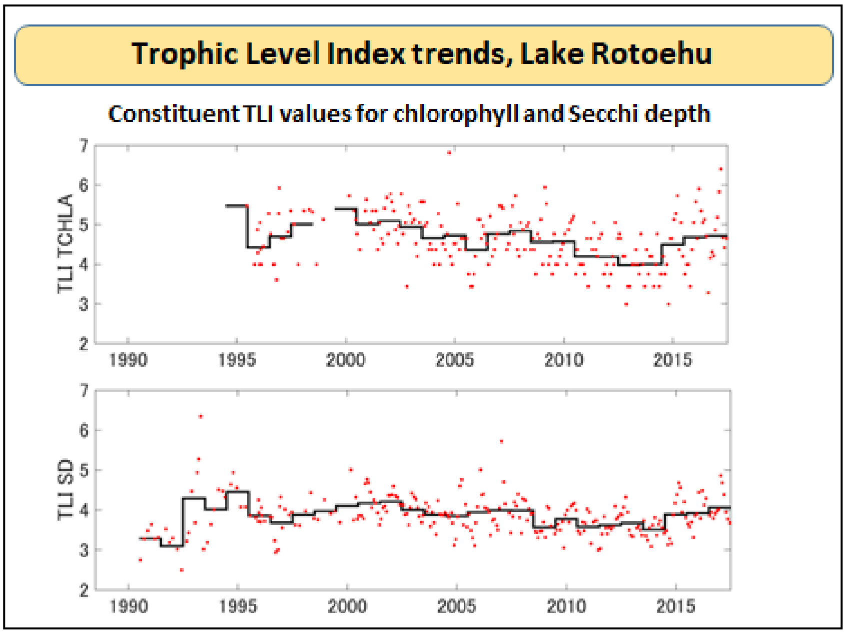


Smith et al. (2016). *Inland Waters*

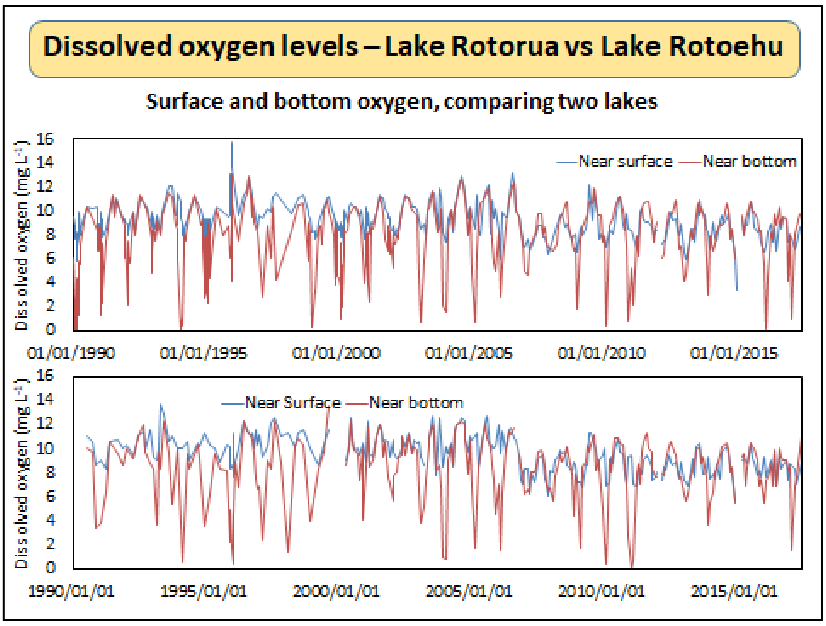
Again, I go back to dissolved oxygen in the next slide but we have to be very careful about using it as an indicator in Lake Rotorua because the lake has quite a different mixing regime from the deep lakes. The deeper lakes stay stratified for about nine months of the year. Rotorua mixes intermittently for most of winter and at times during summer. That mixing can be intermittent, interspersed with periods of calm when the lake stratifies.



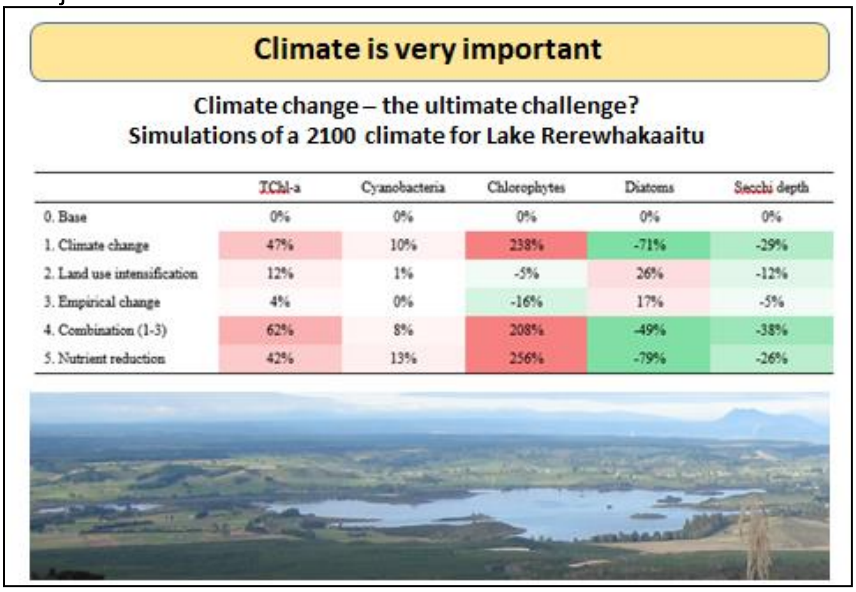
The consequence of the mixing regime is that dissolved oxygen decreases quite markedly and through the 1990s dissolved oxygen reached concentrations of zero. But these are monthly samples and it can be quite difficult to interpret them in a lake that mixes intermittently. What you can say is that the period through the 1990s, when the wastewater was first taken out, looked quite promising for water quality improvement, but overall there are periods of quite marked decline in dissolved oxygen. More recently, from 2012 to 2015, dissolved oxygen in the bottom waters did not decline much at all. As alum has been reduced it clearly shows that dissolved oxygen again goes back into decline – decreases. However it is not only the alum, it is also the climate.



Lake Rotoehu is the last of the four lakes I will talk about and is very similar to Lake Rotorua in that it is shallower and mixes intermittently, dispersed with periods of stratification. Looking at chlorophyll *a* levels we see that the TLI value has declined over time, which is very positive. The clarity has increased slightly. Turning to dissolved oxygen in the graph below and plotting Rotorua at the top and Rotoehu down the bottom of the graph it is clear that dissolved oxygen is almost a mirror image through time in the two lakes. If it is very hot during the summer these lakes stratify for longer and lose dissolved oxygen from the bottom waters.

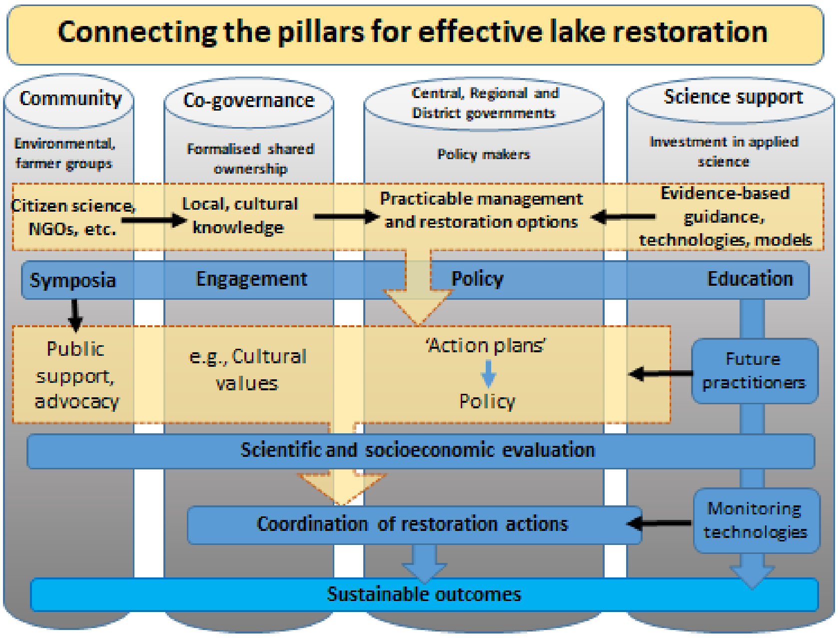


Basically you can pick out the hot years in these two lakes. Both of the lakes have had alum dosing which may have improved conditions. Last summer was very hot. The dissolved oxygen decline has a remarkable similarity in the two lakes, which suggests that climate is a major driver.



	TChl-a	Cyanobacteria	Chlorophytes	Diatoms	Secchi depth
0. Base	0%	0%	0%	0%	0%
1. Climate change	47%	10%	238%	-71%	-29%
2. Land use intensification	12%	1%	-5%	26%	-12%
3. Empirical change	4%	0%	-16%	17%	-5%
4. Combination (1-3)	62%	8%	208%	-49%	-38%
5. Nutrient reduction	42%	13%	256%	-79%	-26%

Last night I spoke at a farmers' meeting at Lake Rerewhakaaitu and suggested that climate change maybe the ultimate challenge. The slide above models chlorophyll *a* and cyanobacteria, as two indicators of water clarity. We looked at a 2100 climate comparing various scenarios using models, to see how much things would change. Overall, looking at chlorophyll *a*, we can see that with climate change alone we will be dealing with major changes, particularly with lakes that are shallower and mix intermittently such as Rerewhakaaitu, Rotoehu and Rotorua. We know we have major challenges ahead as the climate warms and can expect, based on the best knowledge that we have, that things are going to change quite substantially. Rerewhakaaitu, for example, will have a 50% increase in chlorophyll *a* and 30% decrease in water clarity.



This slide demonstrates what I call the pillars of lake restoration, which can be transferable all around the world. These concepts are a linear flow of community co-governance and the way in which governments are able to address lake restoration with science support. What makes the Rotorua Te Arawa Lakes programme particularly valuable is the way the pillars are interconnected. The LakesWater Quality Society and Te Arawa Iwi are key drivers.

Andy Bruere and the Bay of Plenty Regional Council have done a tremendous job too. Here in Rotorua the community has come together to achieve sustainable outcomes. That is pretty unique right around the world. The University of Waikato has a key role to play with the Chair in Lake Restoration, being able to connect with research globally and providing opportunities for future practitioners here. Dr Ian Kusabs' graduation is one of my proudest achievements. It is a privilege being able to watch over people passing through the education system and becoming practitioners working in their rohe. My colleague, Chris McBride is another example and is driving world leading technology development.

Please feel free to contact me. To finish I want to acknowledge people who have supported me, many of whom are in this audience and made this possible. Thank you.

- Chris McBride, Kohji Muraoka
- New Zealand Ministry of Business, Innovation and Employment (UOWX1503). Enhancing the health and resilience of New Zealand lakes
- Bay of Plenty Regional Council – Lakes Chair
- NIWA: long-term data sets