CURRENT STATE OF THE ROTORUA LAKES

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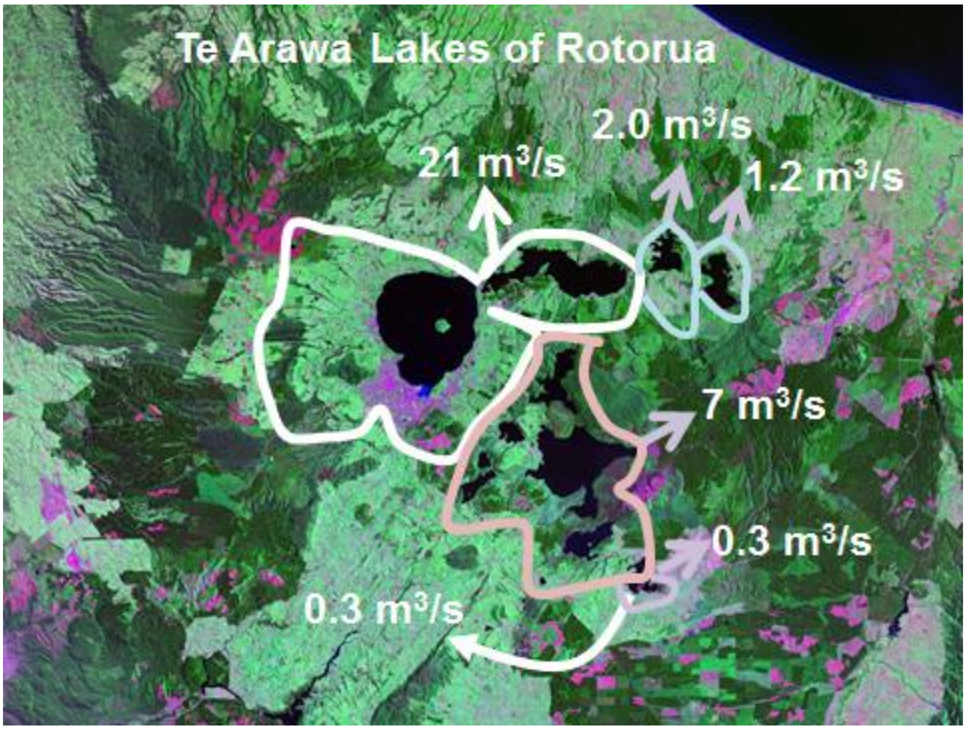
David Hamilton is a professor in Biological Sciences at the University of Waikato and is the inaugural holder of the Bay of Plenty Regional Council Chair in Lake Restoration. In this role he provides support for the Rotorua Te Arawa Lakes Programme including as a long-standing member of the Water Quality Technical Advisory Group for the programme. Hamilton is immediate past president of the New Zealand Freshwater Sciences Society (2010-2014), was a founding member of the Global Lake Ecological Observatory Network (GLEON; 2004) and helped establish the International Society for Limnology journal Inland Waters (2010). He holds an adjunct professorial position at the Nanjing Institute of Geography and Limnology in China. During his Ph.D. study at the University of Otago, Hamilton examined water quality of 10 lakes on the east coast of the South Island. He then held post-doctoral and faculty positions at the University of Western Australia where, as a member of the Centre for Water Research, he developed computer models that are widely used for lake modelling across the world today.

ABSTRACT
The Rotorua Te Arawa Lakes' programme of restoration has arguably been the most ambitious and effective of any for a group of lakes around the world. It has been characterised by willingness to 'try things', to be guided closely by scientific input, and to now have excellent structures for monitoring and implementation of actions. Still, major challenges remain. One of these is the potential for a sense of complacency, particularly when some lakes have responded extremely positively to in-lake treatments (e.g. Rotorua) or major one-off actions (e.g. Rotoiti). It is essential that these improvements in lake water quality, some of which may not be able to be maintained indefinitely in their current mode, not delay further catchment management actions.

Another challenge is exotic oxygen weeds, particularly where it is difficult to harvest large accumulations. The final challenge relates to climate. Recent years have been characterised by droughts and intense rainfall events that challenge land management practices. Further, surface water temperatures in the lakes in 2015 have been greater than at any time in the past. If these changes are symptomatic of a future climate, then there will need to be greater effort put into building resilience in the lakes and their catchments.

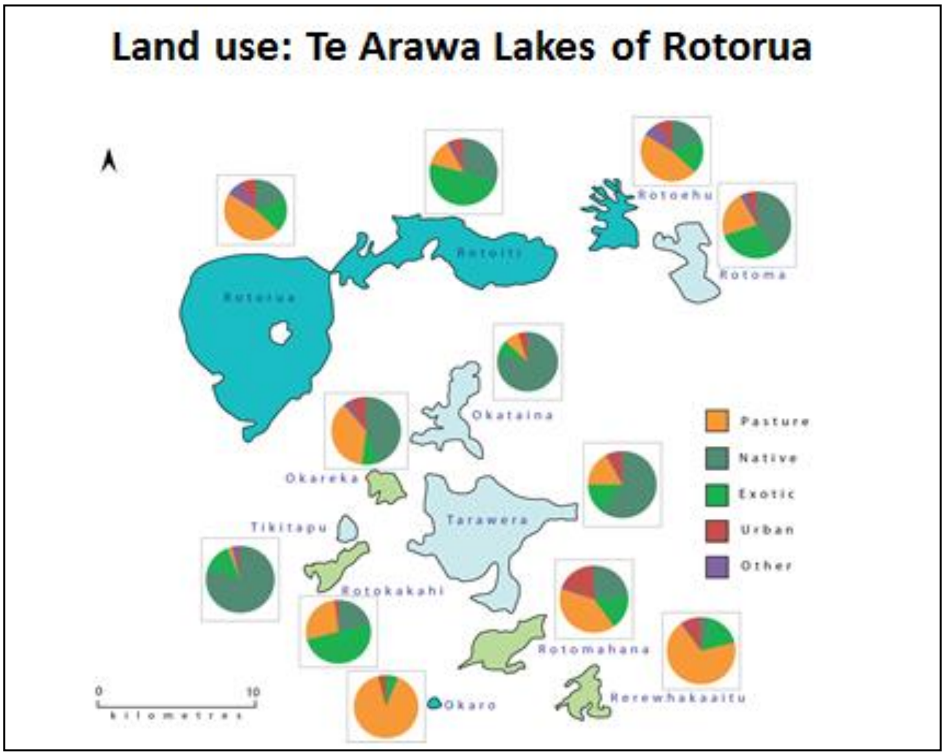
TRANSCRIPT
One of the most interesting things that I have been involved in recently has been considerations of wastewater treatment for many of the lake communities. The amount of wastewater that is produced is tiny by comparison with the amount that falls on the landscape and runs off, but it is a significant nutrient source and also one of the most expensive to treat. In terms of treatment costs, for example, we talk of more than $1,000 a kilo to remove phosphorus so that it does not have an impact on the lakes. Obviously one of the considerations is how we evaluate these relative sources of water and wastewater nutrients to the lakes.

Slide 1



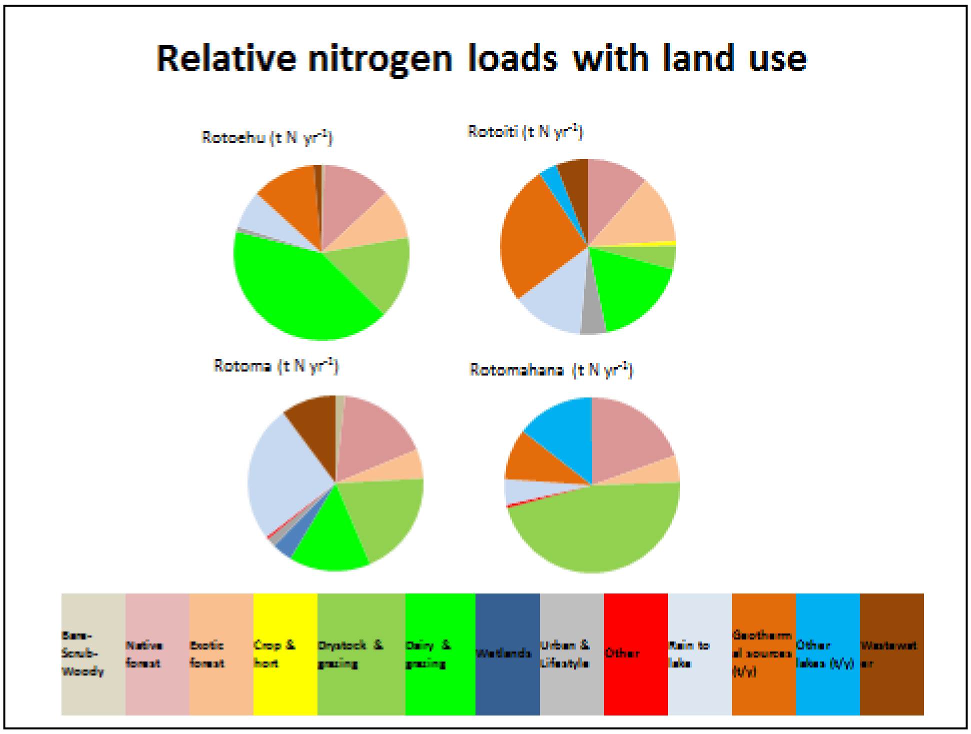
We do not often look at the bigger picture of what is happening with the amount of water being transported around these lakes. **Slide 1** shows that 21 cubic metres a second goes down the Kaituna River and out into the ocean through the Kaituna-Maketu system. There are small and largely unknown outflows for Rotoehu and Rotoma and 7 cubic metres a second exits through the Tarawera outflow. Lake Rerewhakaaitu to the south is interesting. The best we know is that roughly one third goes down the Waikato River, one third goes to the Rangitaiki and one third into the Tarawera catchment. It is a relatively small flow but for someone in Hamilton, they would have been drinking a few molecules of water from their tap that originally had fallen in the Rerewhakaaitu catchment.

Slide 2



Slide 2 (above) shows the land use of the 12 lakes that are included in the programmes of management and restoration by the Rotorua Te Arawa Lakes Strategy Group. Considering 14 lakes (including some of the southern Te Arawa lakes), there is a variety of different land uses. We would like to think that lakes with totally native catchments are pristine, but I am sure we are going to hear plenty on that today (with regard to weed invasions). On the other hand Lake Okaro, furthest south, is almost totally dominated by pasture.

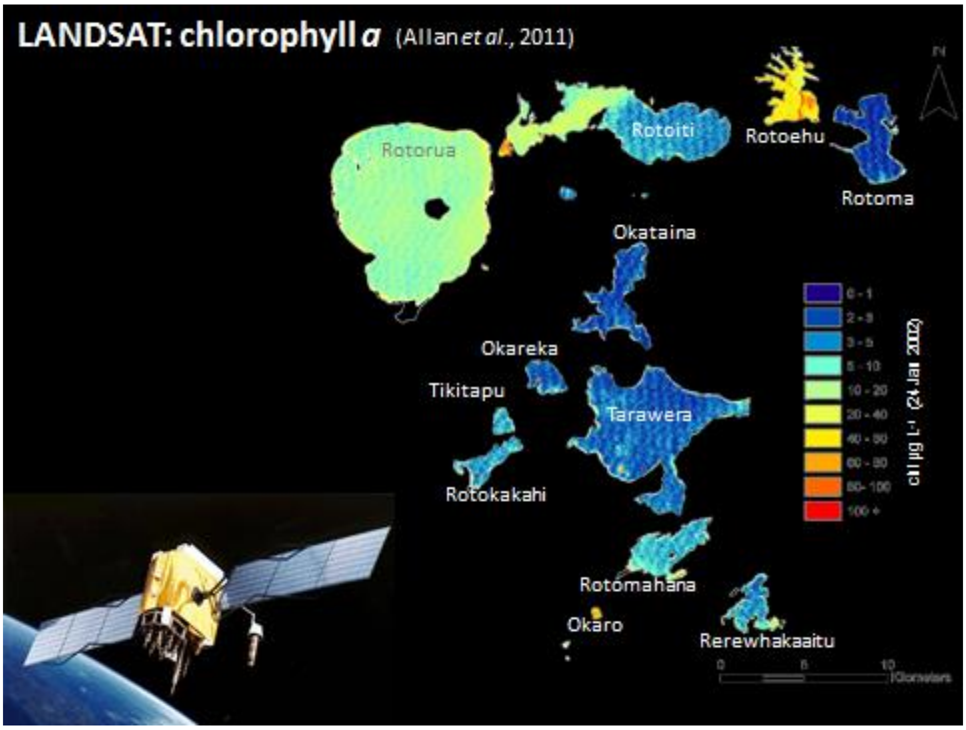
Slide 3



With this information we can look at different land use types and make a conversion assuming specific rates of nutrient export for each of those land uses. **Slide 3** shows the export of total nitrogen for four of these lakes. The scale at the bottom corresponds to different land uses. Of course for a lake like Rotomahana there is a large component of pastoral land use which impacts on the lake water quality. Lake Rotoiti itself has a relatively small pastoral component and hence part of the success of the Ohau Channel diversion wall was to take away the inputs from the Rotorua catchment, which is about 50% pastoral by area. In one hit, by constructing the diversion wall, we were able to remove a very substantial percentage of the nutrient inputs from Lake Rotoiti.

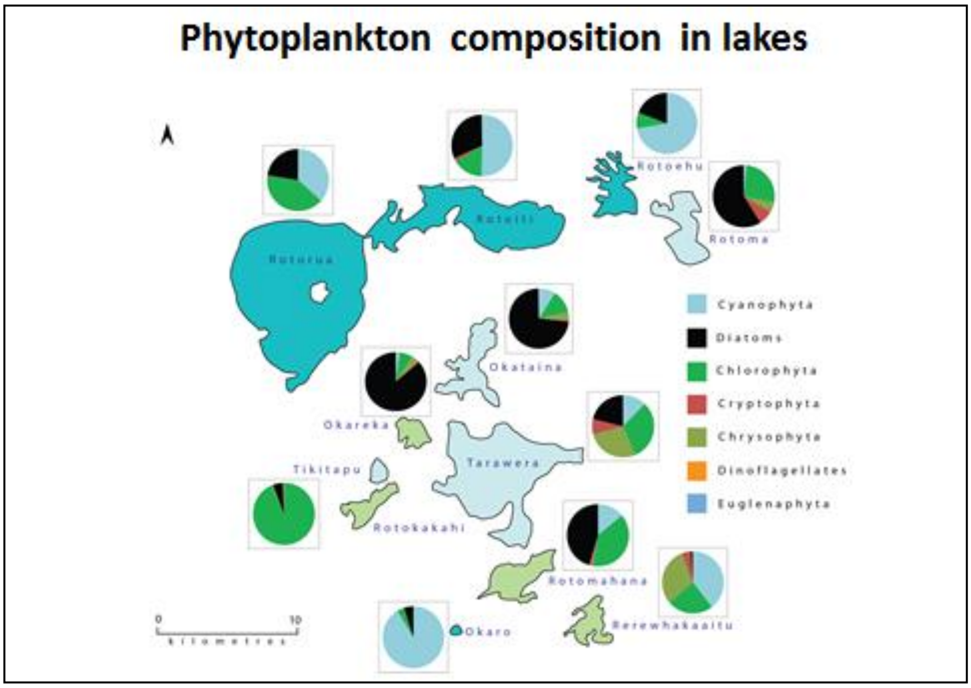
There are a couple of other factors that influence the water quality of these lakes. Shallow lakes tend to be more productive than deep lakes. With more light relative to the lake volume there are higher levels of chlorophyll *a*. **Slide 4** (over) is a LANDSAT chlorophyll *a* image taken pre diversion wall. For Lake Rotoiti, for example, there is a big chlorophyll gradient from west to east, which was largely due to the input of nutrients from Rotorua. As a result there was a lot of algal growth in the shallower part of the western basin compared with the eastern basin. Some of the other shallow lakes like Rotoehu and Okaro are dominated largely by pasture, and much more productive in terms of the amount of chlorophyll *a,* or algal concentrations

Slide 4

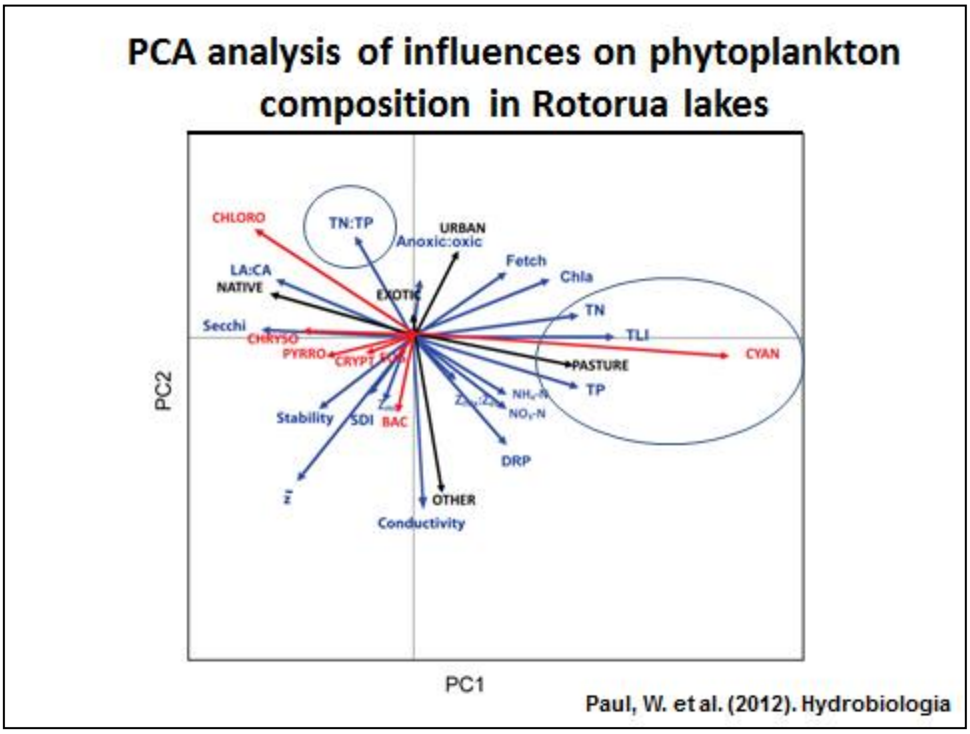


Water quality means different things to different people. One of the important influences on water quality is the phytoplankton composition (**Slide 5**); the different types of algae that grow in these lakes. A lake such as Tikitapu is predominantly one group, chlorophyta. Lake Okaro has another group, cyanophyta**,** or blue-green algae which dominate. Changing the composition with more and more nutrients changes the types of algae that grow in these lakes. Okaro for example is very nutrient enriched and has mostly blue-green algae. By contrast lakes such as Tikitapu have very low nutrient concentrations and as a consequence do not have high levels of blue green algae. These blue-green algae are the ones that tend to float and accumulate in bays and can cause health problems.

Slide 5

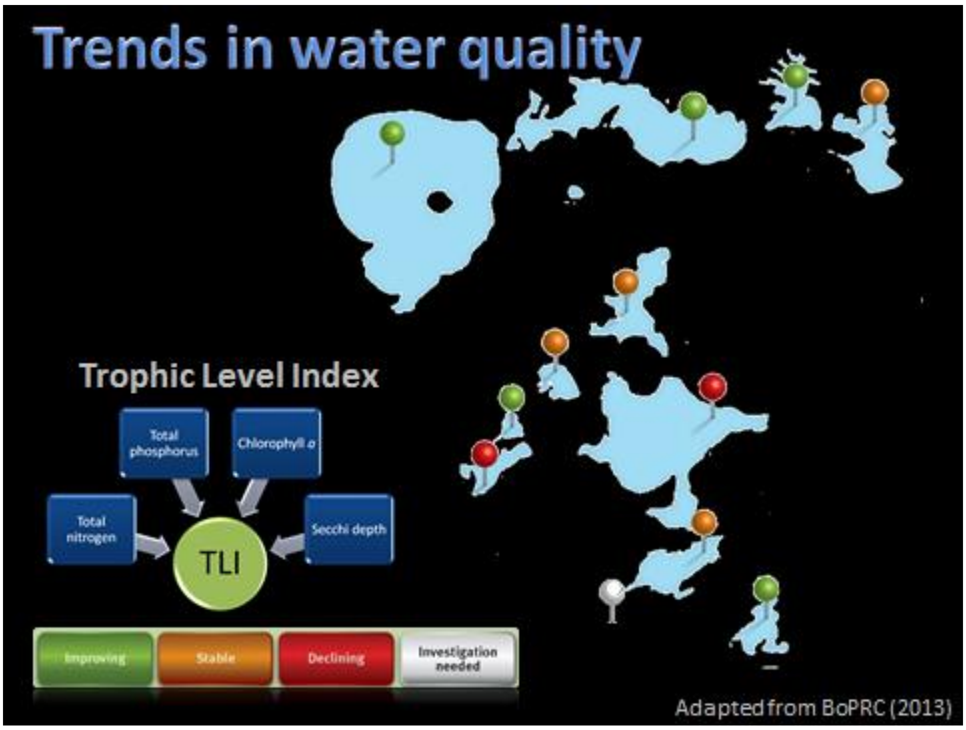


Slide 6



Slide 6 is a Principal Components Analysis of the influences on phytoplankton composition in the Rotorua Lakes but it is useful to point out the key features. The blue-green align statistically with some key drivers; total nitrogen, the Trophic Level Index (TLI) used to indicate the trophic state of these lakes, the amount of pasture in the catchment and total phosphorus concentrations. It is logical increases in nutrients lead to more blue-green algae (cyanobacteria). By contrast the 'good guys' of the phytoplankton communities, the chrysophytes, the chlorophytes and the diatoms, group out the other way aligning with lakes which have lower nutrient concentration in the lakes.

Slide 7

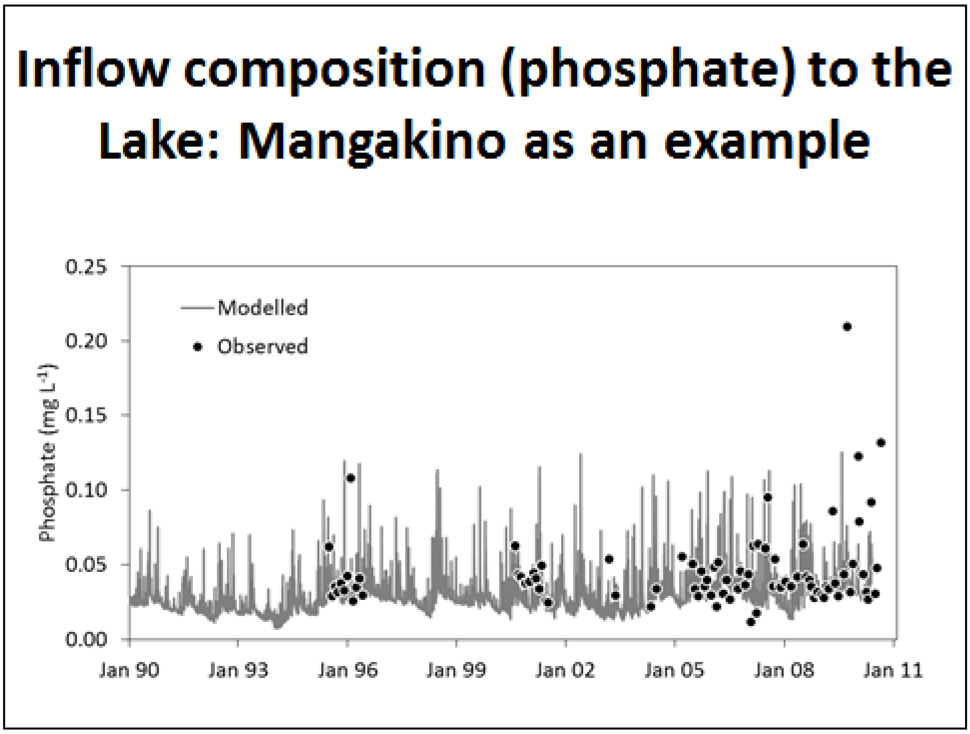


Nutrient ratios did not appear to have any bearing on the types of algae in the lakes. These ratios have been hugely contentious recently. There is pressure to limit just one nutrient (e.g., phosphorus), or alternately nitrogen, but in this particular case it is both nutrients that limit phytoplankton in the Rotorua lakes.

What about the trends? **Slide 7** (above) shows some of the lakes are improving and it is no coincidence that these lakes have had major engineering interventions to address their poor water quality. Alum dosing has been used in Rotorua and in Rotoehu and also in Okaro, and of course the diversion wall has been constructed in Lake Rotoiti. By contrast other lakes are stable. Some such as Tarawera are showing signs of decline.

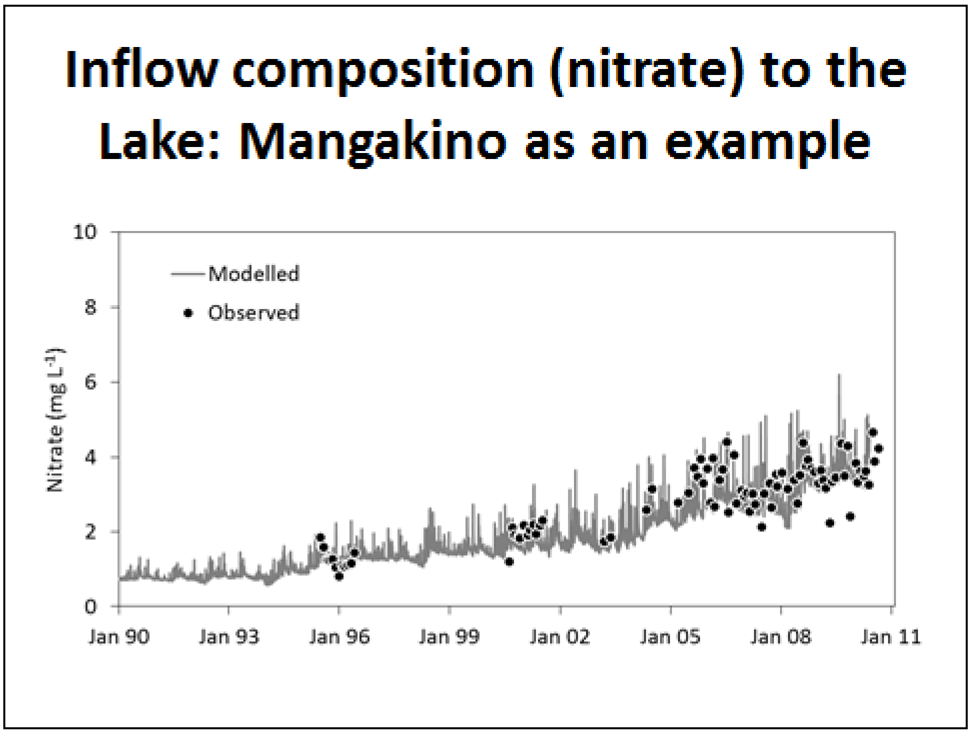
Rerewhakaaitu is a fascinating case study. Its catchment area is dominated by pastoral land use, particularly dairy. However, the catchment is comparatively tiny compared with the lake area which is one of its distinguishing features. Many of the lakes such as Rotorua have a very large catchment area relative to the lake area. We need to be cognisant of what the lake area is when making land use change within a catchment. Although Rerewhakaaitu is a small catchment the lake is still in pretty good shape - mesotrophic - in the middle range of trophic state.

Slide 8

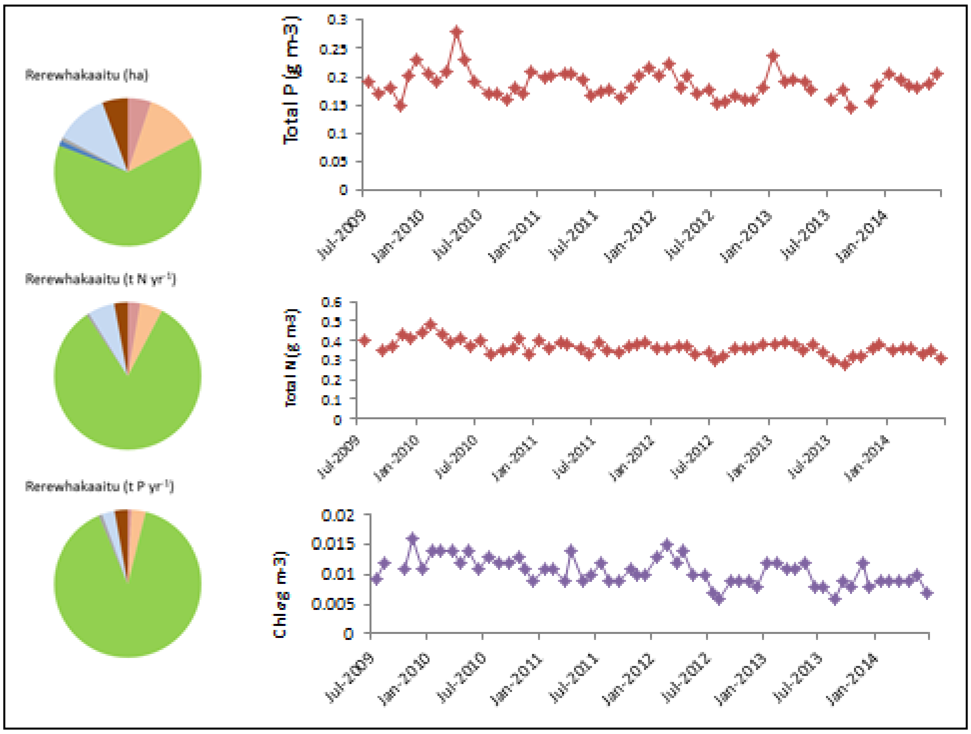


Slide 8 shows the Mangakino Stream inflow to Rerewhakaaitu. It shows no particular trend through time in phosphorus concentrations. If anything there may be a slight hint of decline. However, there may be some very high concentrations recently and these may be linked to extreme climate events rather than land use practices per se. In **Slide 9** (over) there is a very significant trend in nitrate shown in the Mangakino Stream which reflects gradual accumulation of nitrate from the impacts of land use change in the aquifer that ultimately supplies the Mangakino Stream and goes into the lake.

Slide 9



Slide 10

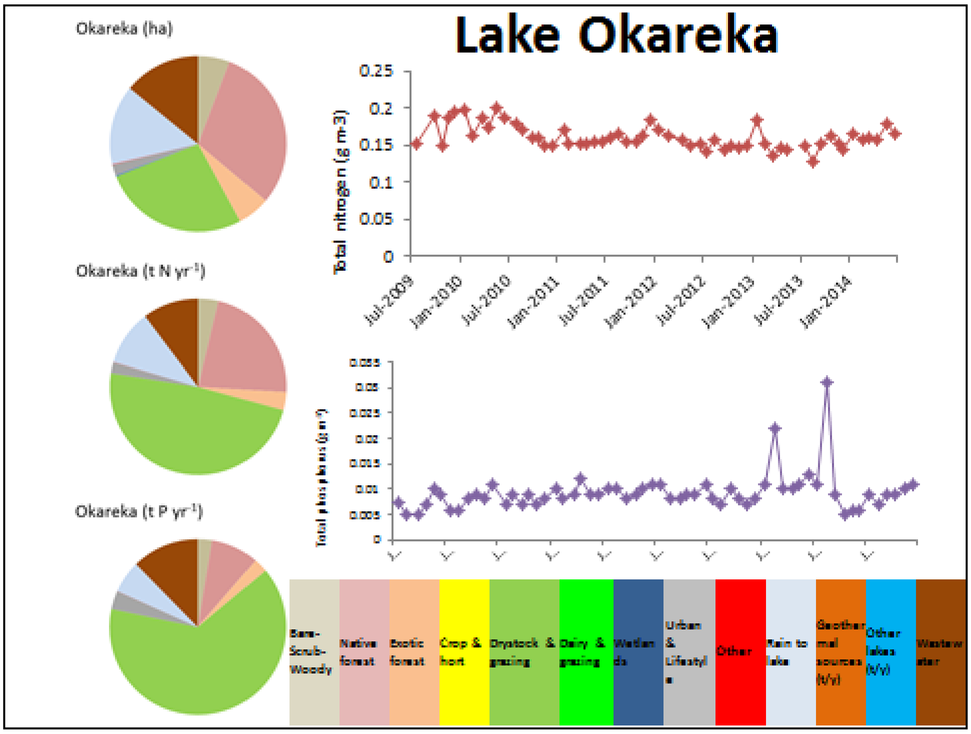


This trend in the stream inflow may appear as a potential driver of deterioration in the lake but in fact the time trend in **Slide 10** shows total phosphorus as relatively stable and perhaps even slightly declining; total nitrogen not changing; and chlorophyll *a* concentrations as probably declining slightly. A distinguishing feature of this catchment is that over the 10 or 20 years there have been improvements in the management of land, particularly in terms of phosphorus. As it happens phosphorus is the critical limiting nutrient in this lake. The soils in the catchment have a particular capacity to absorb phosphorus and as a consequence the changes that occurred in nitrogen are not reflected in changes in chlorophyll *a* as an indicator of the algal concentrations.

Slide 10 also shows that pastoral land use contribute a disproportionate amount of the nitrogen and phosphorus loads to Rerewhakaaitu, but this lake is being saved by two redeeming features:

1) The catchment area is so small relative to the lake area
2) The soils are very absorptive of the phosphorus that may get into the lake

Slide 11

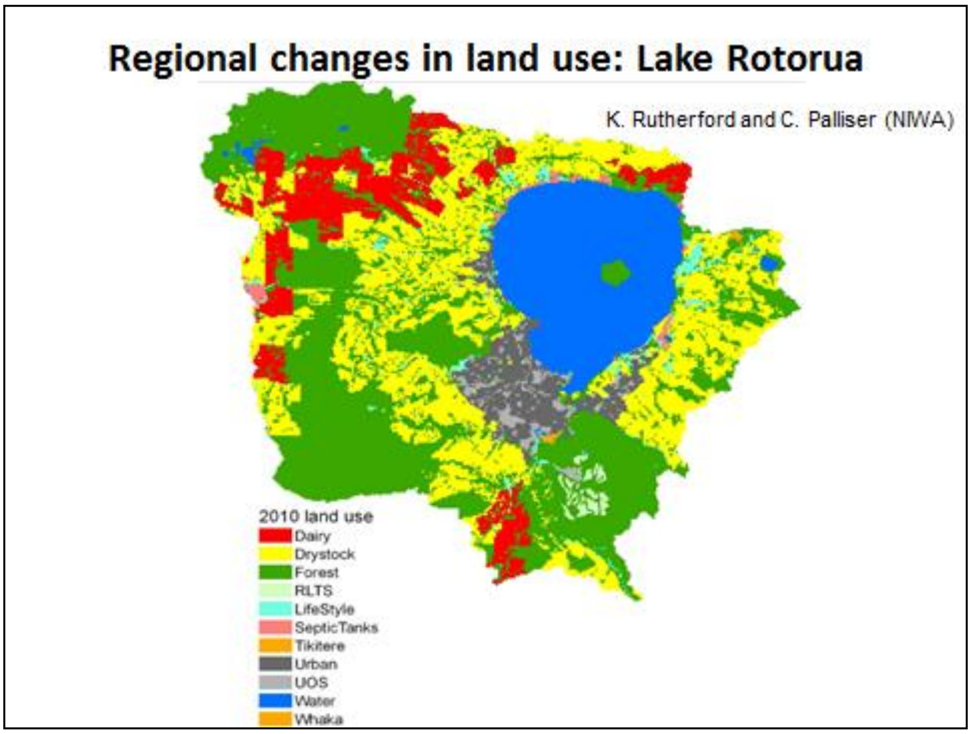


Lake Okareka **(Slide 11)** shows that the total phosphorus is trending up slightly. I have not looked at this trend statistically. The extreme high values are probably associated with some of the extreme rainfall events that we have had recently. There is not a lot of change in total nitrogen, maybe even a small decline that may possibly be related to the reticulation of wastewater in that catchment. Generally, despite the fact that that catchment underwent wastewater reticulation about 4 or 5 years ago, there has been very little change in the nutrient concentrations in the lake. In terms of chlorophyll *a* there has been a slight increase. So the changes that could have been brought about with either changes in land use practises or land use itself, have not taken place and as a consequence there is a small increasing trend, at least for phosphorus.

Rotorua has a 425 square kilometre catchment, 80 square kilometres of lake and is relatively shallow. One of the remarkable things that has occurred, which is often overlooked, is the fantastic work by Kit Rutherford examining changes in land use through time, from the 1940s to the current day **(Slide 12)**. The gradual change over a number of years ultimately led to changes in the catchment; from forest and scrub to pastoral and dairy farming.

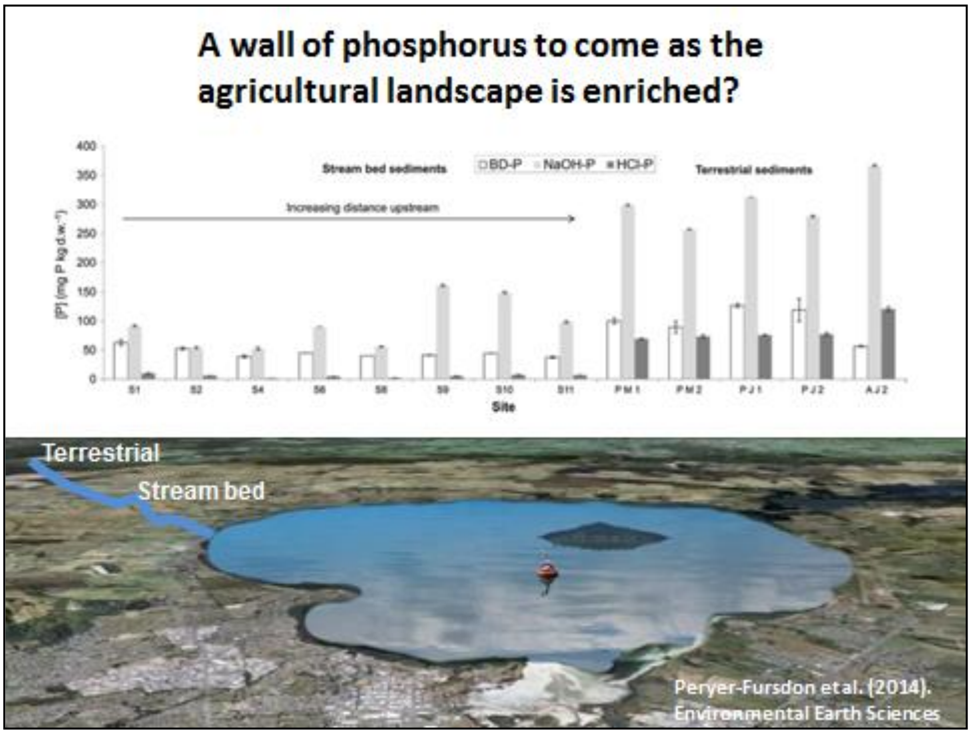
Part of the response to that changed the deterioration in lake water quality has been alum dosing, which has been designed to lock up some of the phosphorus arising from the Utuhina and Puarenga Streams

Slide 12



GNS has done a lot of examining transport of nitrogen from the catchment of Lake Rotorua to the catchment. We know that the groundwater aquifers in the Rotorua catchment are gradually enriching in nitrate, but we have not thought so much about phosphorus in terms of a potential load to come to the lake. **Slide 13** shows a longitudinal profile from a stream bed up into the terrestrial catchment. The size of the bars at difference locations represents the phosphorus concentrations of the sediment at that location. The agricultural sediments are enriched as we would expect but the stream beds have a much lower concentration of phosphorus. So it is at this point that we start to ask – what happens if these sediments get into the stream beds? They are obviously going to

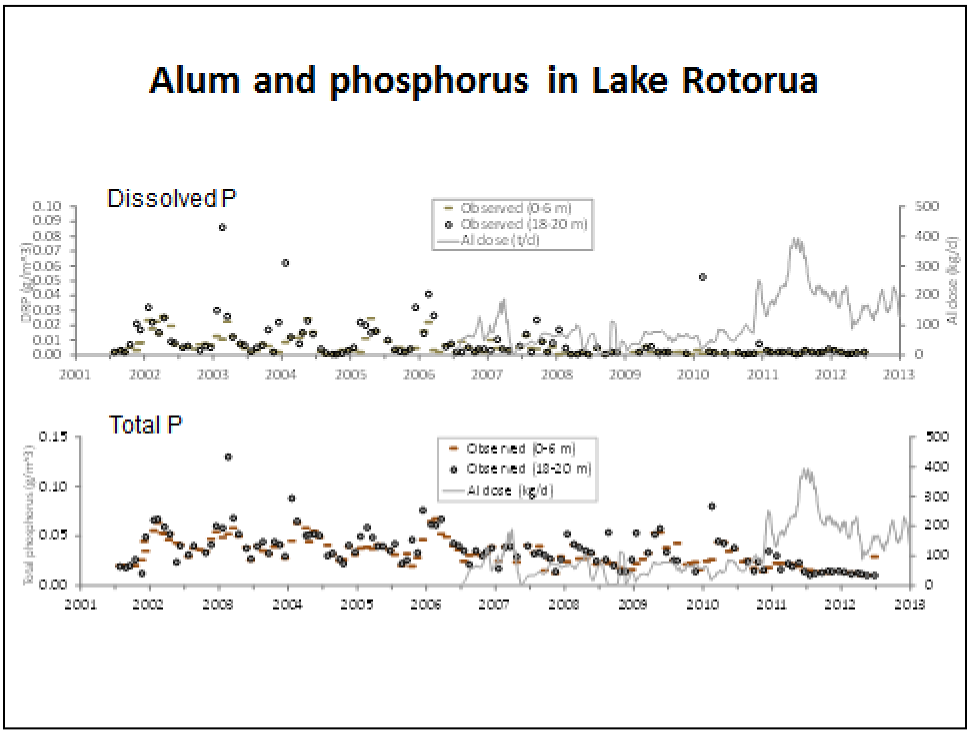
Slide 13



be more enriched in phosphorus and potentially contribute to phosphorus loads to Rotorua and as a result, will increase algal growth in Rotorua.

At the same time any increase in phosphorus loads are being offset by the alum dosing. **Slide 14** looks at dissolved phosphorus and total phosphorus concentrations in Lake Rotorua. There is a peak of alum dosing of nearly 400 kilos per day in 2011.The consequence of this was to sediment out the phosphorus, and concentrations decreased to about 15 milligrams per cubic metre. The average concentrations through the early 200's were about 40 milligrams per cubic metre and so they have more than halved over the period of alum dosing.

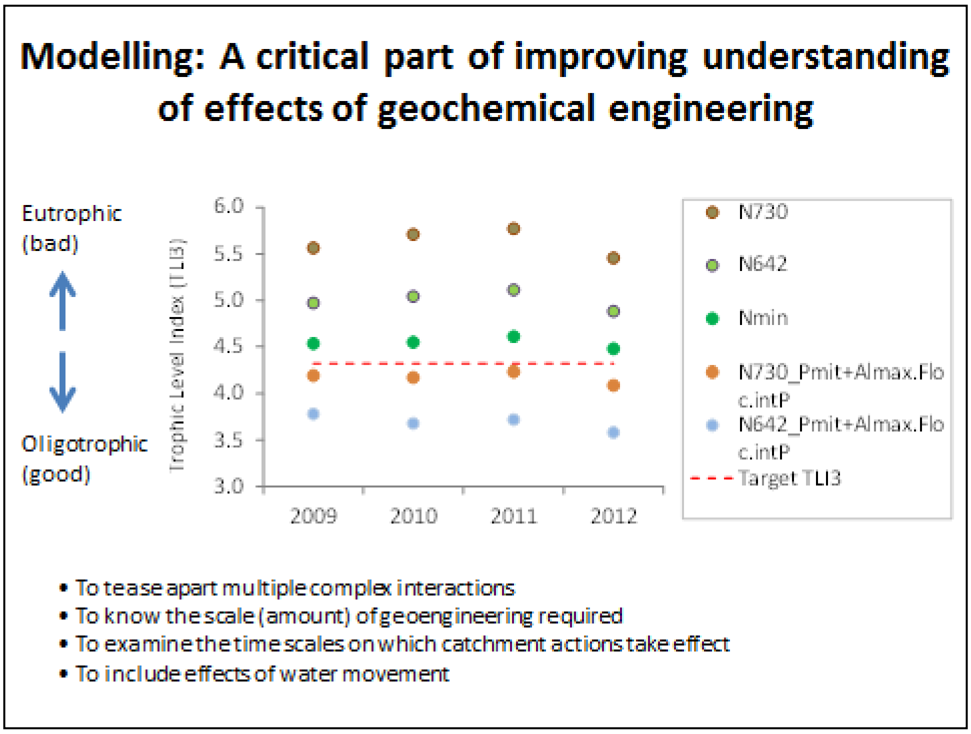
Slide 14



At the same time we looked very closely at the inflows to Lake Rotorua to ask if the inflows were the driver of the improvements in water quality. Not at all; in fact one of the challenges has been that with the climate of recent years the amount of phosphorus coming into the lake has, if anything, increased at the same time as the concentrations within the lake have decreased very substantially. We are obviously seeing the impact of the alum dosing.

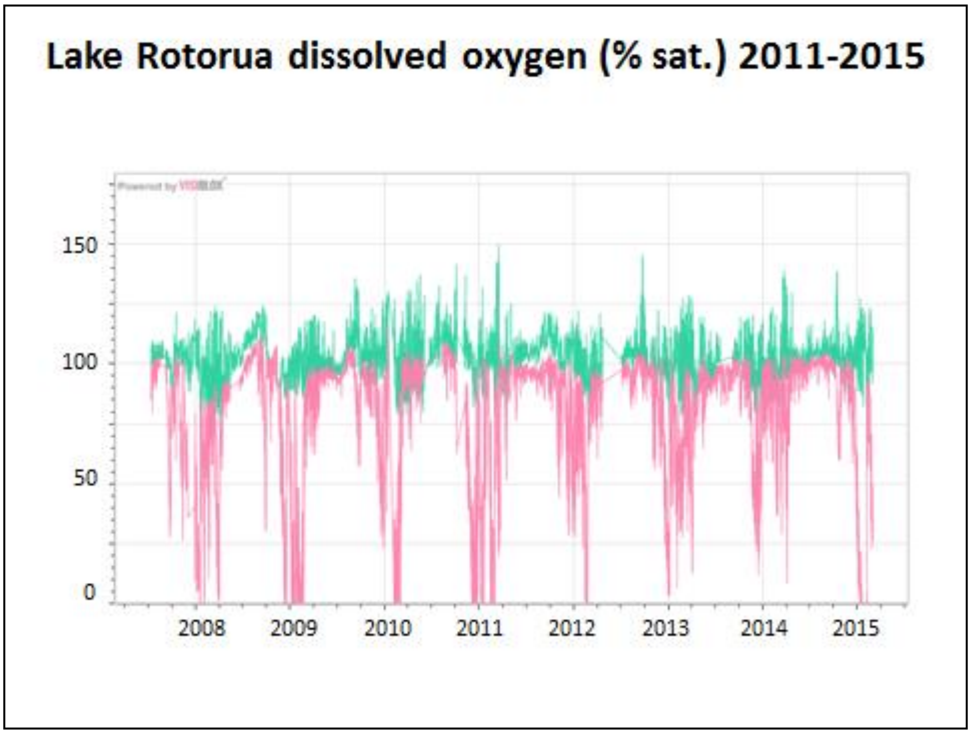
We supplement this information with some modelling to improve the understanding of the effects of geochemical engineering – in other words the alum dosing **(Slide 15)** (over). One of the goals is to say, 'What would have happened if we didn't alum dose? What would have happened if we applied some catchment management procedures?' We have gauged the modelling outcomes for these scenarios in terms of Trophic Level Index (TLI). The goal for Rotorua is 4.2 but because we use a slightly modified TLI level in the model, it is 4.3 in this particular slide. The consequence of not alum dosing would have been a TLI of around about 5, somewhere between the light green and the darker grey green khaki at the top. By contrast Rotorua has met its target, sitting around or just below the line over that period. So clearly the alum dosing has had a huge impact in improving water quality.

Slide 15



I have touched on the challenges of climate; the past summer of 2014-5 has been particularly interesting. **Slide 16** shows dissolved oxygen levels in percentage of saturation, where 100% is essentially a healthy system. There are two lines showing surface-water bottom-water concentrations of dissolved oxygen in Lake Rotorua. Typically the lake water dissolved oxygen is around 100% of saturation. When the lake stratified over the past (2014-5) summer, oxygen concentrations in bottom waters went down over a period of two or three weeks, stayed near zero for about three weeks and then shot back up. In the past we have had brief periods when there has been no oxygen present in bottom waters, usually interspersed with mixing that restores the oxygen, but because we

Slide 16



had such a hot summer, mixing was reduced and dissolved oxygen was depleted for a long period of time.

Briefly examining other lakes, Okaro is an example where alum has not been so successful but we have learnt quite a lot along the way. In this case the poor water quality in the lake has rendered the alum dosing largely ineffective, and this is related to the high pH value. High values of pH are often associated with algal blooms. Applying alum in this situation is not going to be effective. By contrast Rotorua has moderate variations in pH and alum has been highly effective.

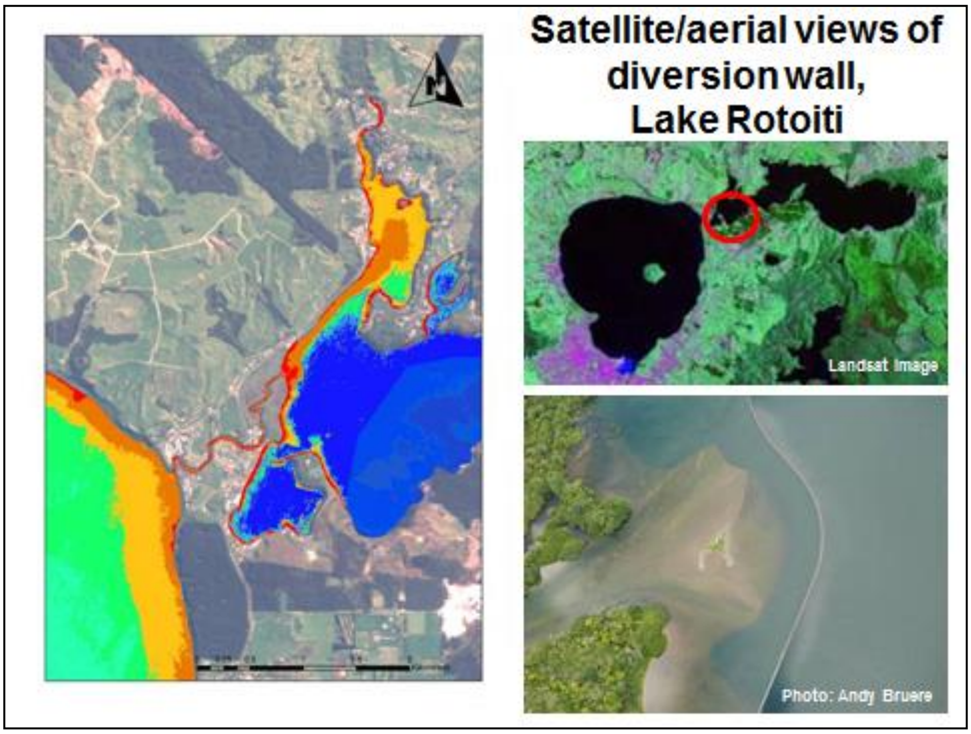
Slide 17

I cannot do justice to covering scientific aspects of the 12 (or 14) lakes in this region. **Slide 17** shows Rotoiti in the summer of 2003/4. We know that the Ohau Channel diversion wall was highly effective. **Slide 18** is the situation once the wall is in place. Water from the Ohau Channel is diverted by the wall down into the Kaituna System. One can see very clearly in **Slide 19** the sediment levels. Rotorua has moderate levels of suspended sediment that are reflected in the satellite image and they are transported

Slide 18

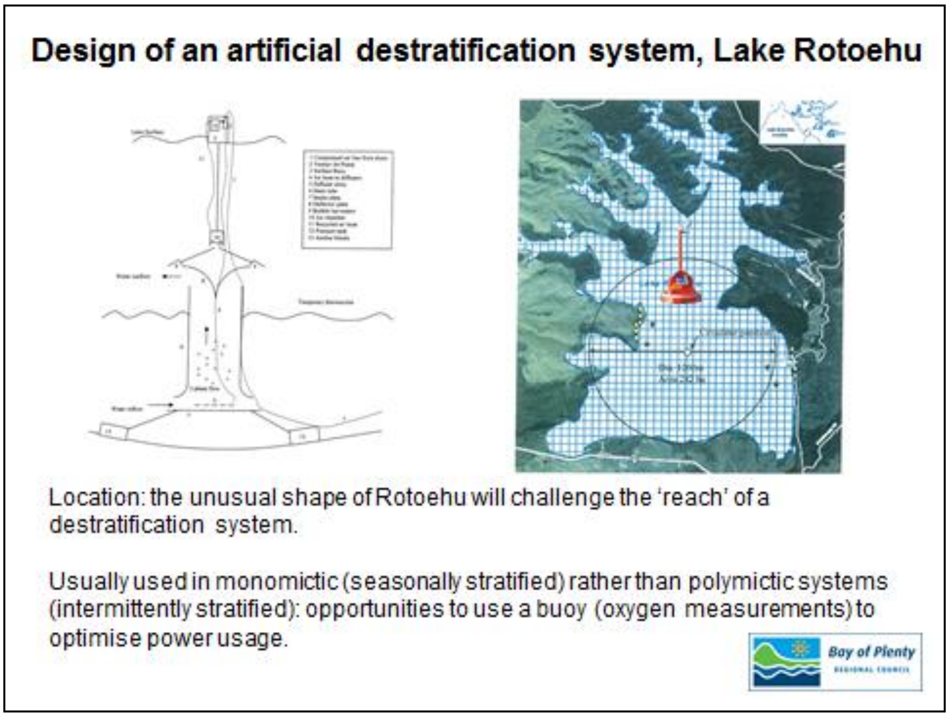
down the Kaituna Maketu system. The diversion is highly effective in taking that water away, and with it about 60% of the nutrient load from Lake Rotorua. The result has been quite a remarkable recovery of Lake Rotoiti. The final stage is to have oxygen persist in the bottom waters over the entire summer period.

Slide 19



Lake Rotoehu is a lake where different things have been tried to improve water quality and it makes a fascinating case study. **Slide 20** shows the effects of the artificial destratification system being used to aerate and destratify the water column, and prevent mixing events in Lake Rotoehu. It is a big lake and the original model predictions always indicated it would be a struggle to generate enough aeration to fully mix Rotoehu.

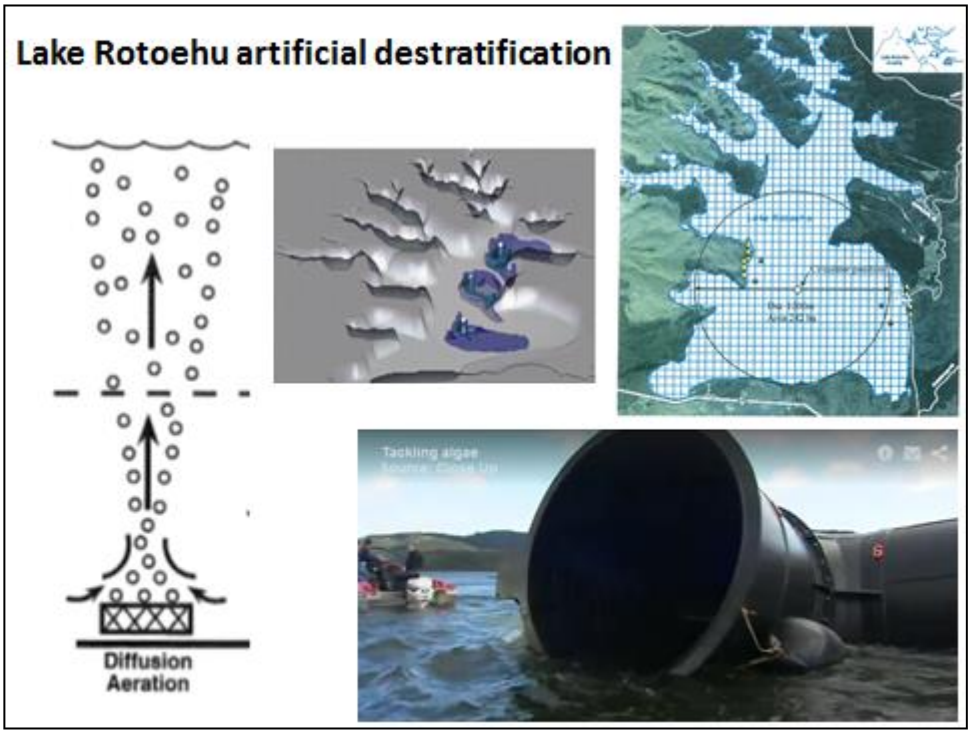
Slide 20



Slides 21, 22 and 23 show the large aeration device and the complimentary management programmes on the lake such as alum dosing and weed harvesting **(Slide 24)**.

Slide 21

Slide 22

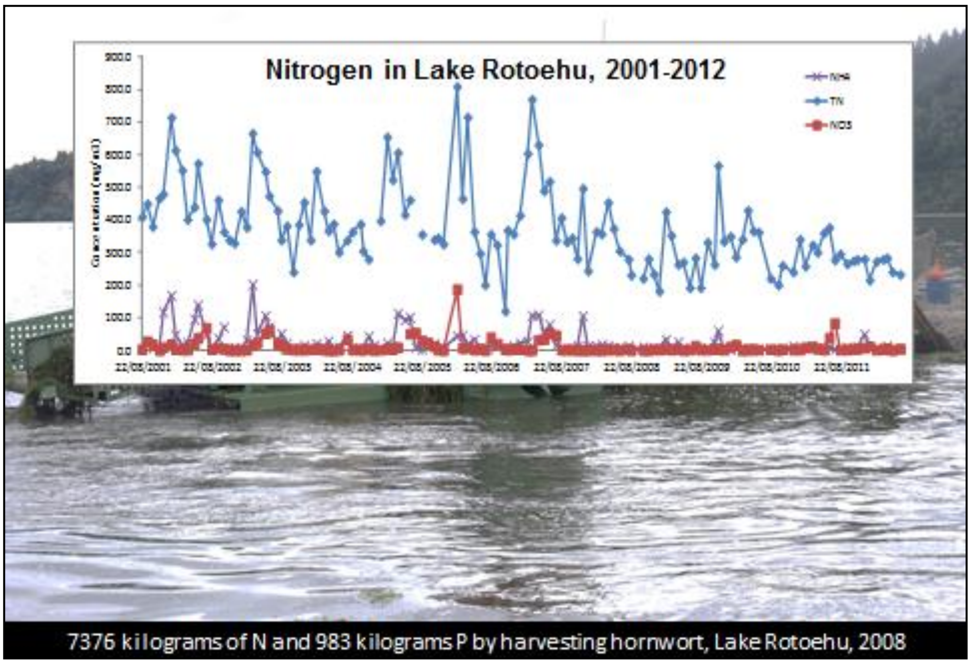


Slide 23

Slide 24

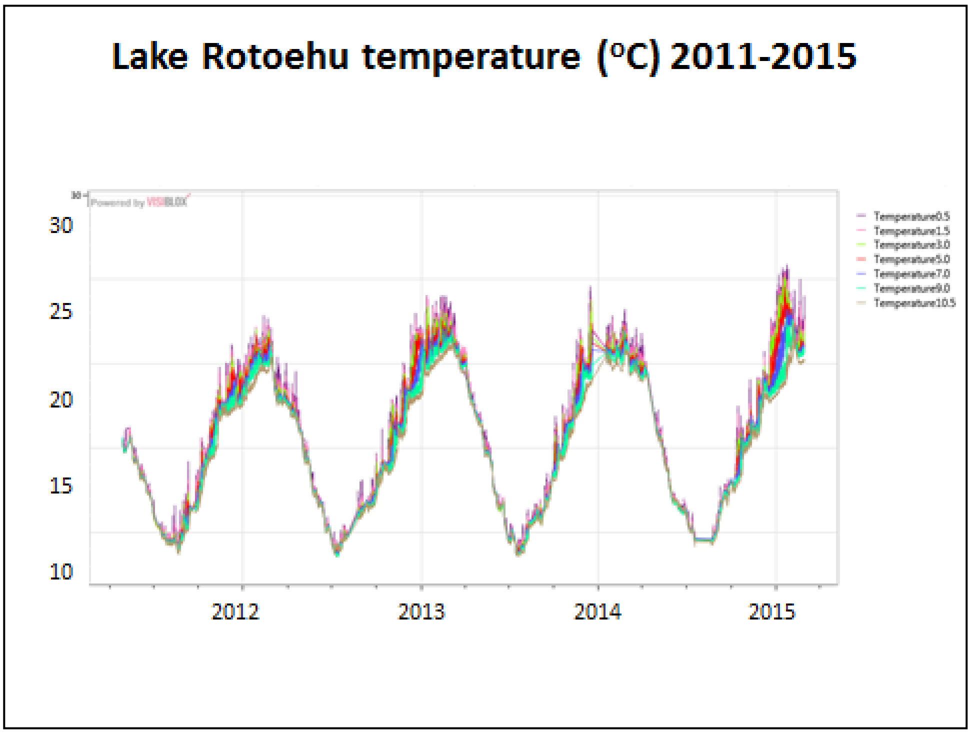
The weed harvesting has been used partly to meet the goals for nutrient reduction in Lake Rotoehu **(Slide 25)**. The graph shows that total nitrogen has progressively declined and the improvements have occurred over a number of years.

Slide 25



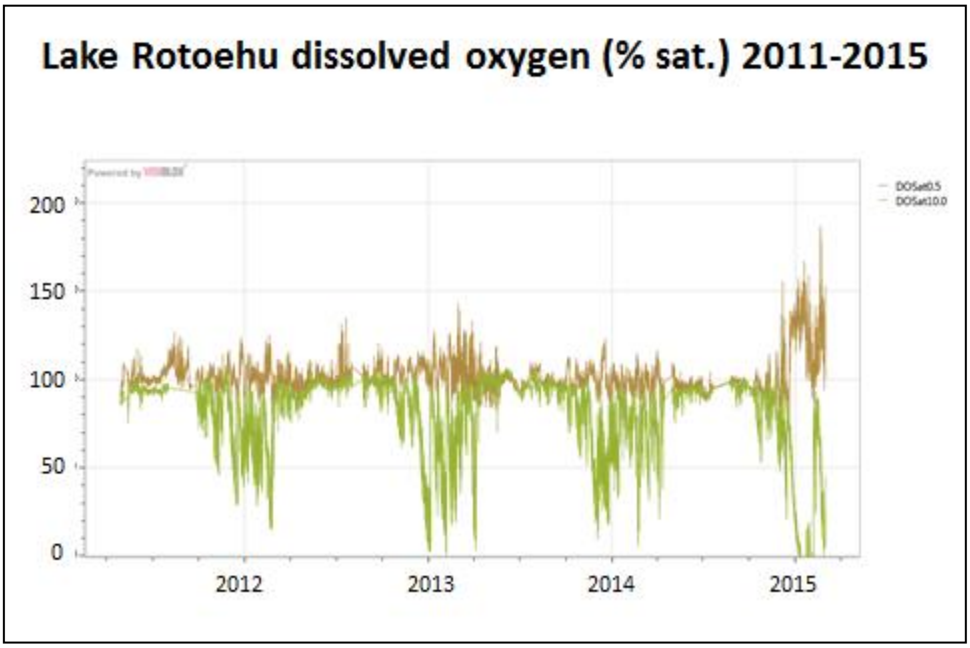
The climate over this summer of 2015 has been a challenge for lake management and this is illustrated in **Slide 26** by the variations in temperature. Typically there are small variations in temperature between the top and the bottom associated with the waters not mixing. This particular summer was exceptional and temperatures got over 27 degrees Celsius in Lake Rotoehu and there was prolonged stratification.

Slide 26



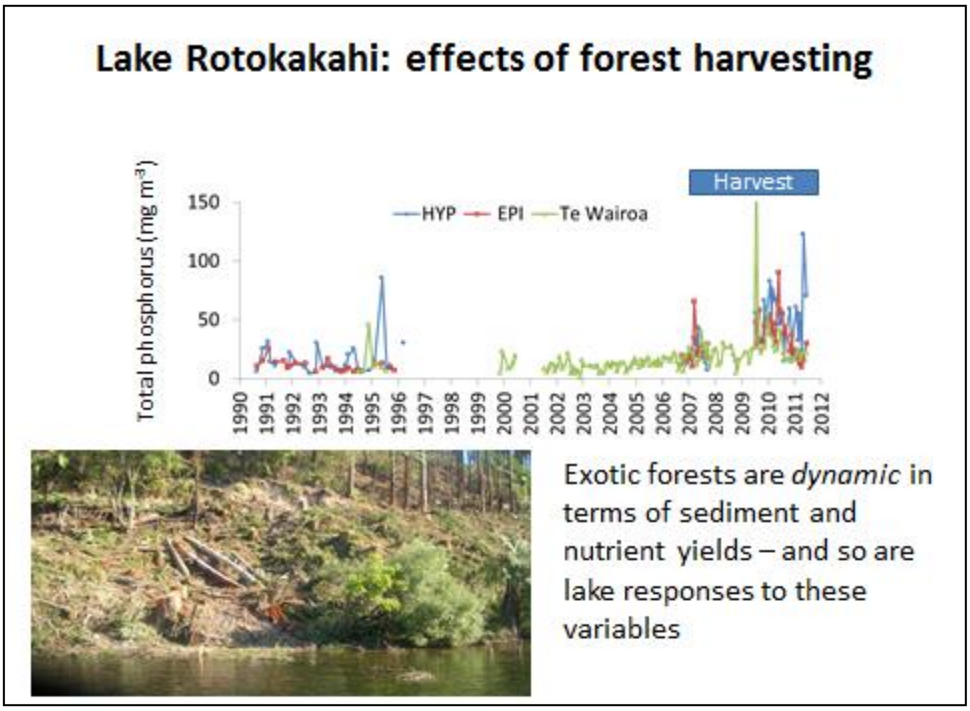
Slide 27 shows dissolved oxygen as a percent of saturation in Lake Rotoehu. There was no oxygen in the bottom waters of the lake for about 5 or 6 weeks. That loss of oxygen brings about a release of nutrients into the bottom waters and stimulates further algal growth. Instead there was limited response of algae to lack of mixing, likely as a consequence of alum dosing in both Lakes Rotoehu and Rotorua.

Slide 27



Slide 28 is a snapshot of Rotokakihi and points to the effects of harvesting right up to the edge of the lake. The impact has been most evident in increases in total phosphorus concentrations.

Slide 28



In summary I want to emphasise the importance of the Rotorua Lakes Water Quality Technical Advisory Group **(Slide 29)** which has endeavoured to throw away any preconceived ideas and get together quarterly for a day a year to look at what can be done to address issues in the lakes and make recommendations to others who ultimately make decisions on what needs to be done. It would be an interesting case study to look in particular at how closely science has aligned with implementation and policy as outcomes from the Water Quality Technical Advisory Group. I am not aware of too many other cases around the world where the science, the policy and the management actions have actually aligned together.

Slide 29

I would like to acknowledge particularly the Bay of Plenty Regional Council in the Chair that I hold, but also to the people that help put this work together, particularly Chris McBride and his work with the high frequency boys that are out on the lakes.