MODELLING THE EIGHT LAKES OF TARAWERA

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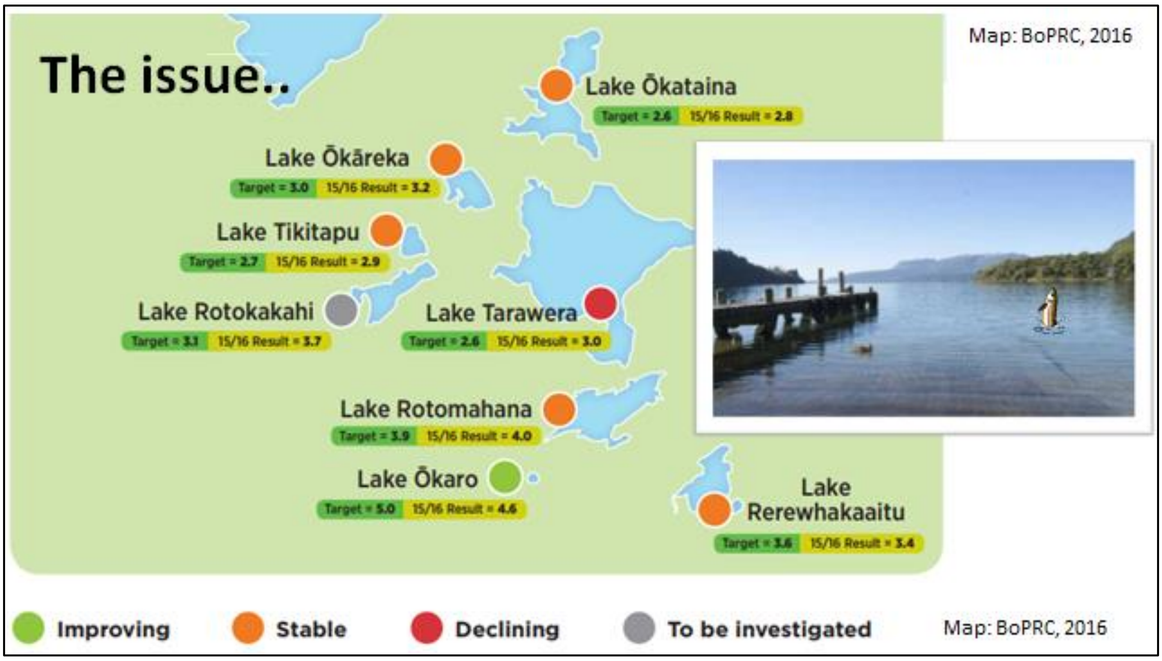
Chris began working on the Rotorua Te Arawa Lakes in 2003, studying food webs using stable isotopes. He has worked for Waikato University's Lakes Chair since 2005, developing and installing lake monitoring buoys, and undertaking lake modelling and nutrient budget studies.

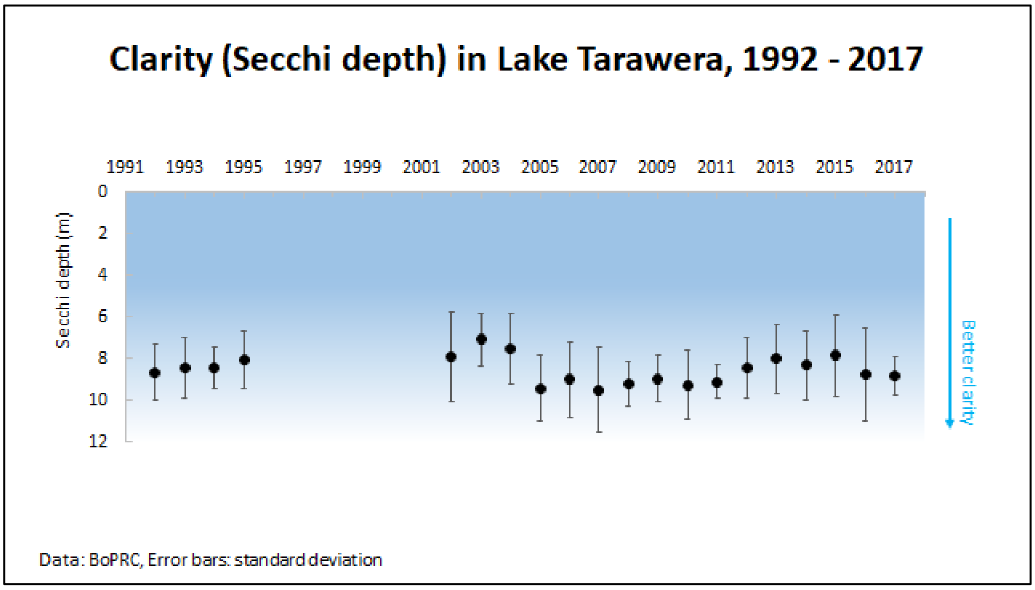
TRANSCRIPT

Thanks for a very generous introduction, and to the LakesWater Quality Society again for organising another fantastic symposium and for giving me an opportunity to present here.

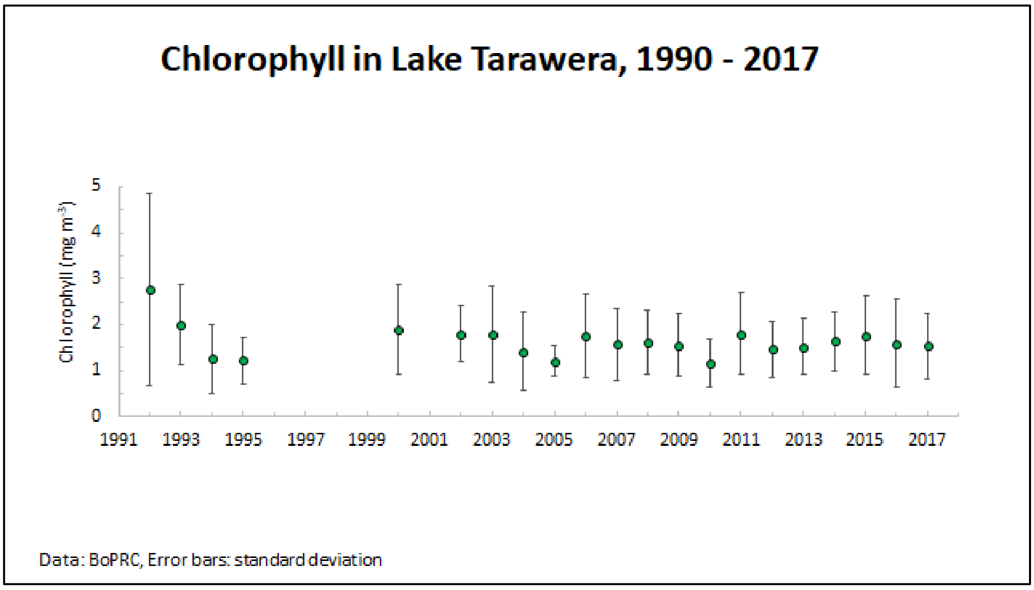
The work I am presenting today is on behalf of myself and the Waikato University team and also my collaborator Jonathon Abell, who is a former student of David's with our group. I am presently working towards a PhD, and some of this work will feed into that. Paul White has given a nice lead in to this talk and we will be leaning heavily on his great work. The project is to model water quality in Lake Tarawera and its response to climate and nutrient loading in particular. Obviously, modelling Lake Tarawera requires conceptualising and understanding the broader hydrological system, so that is a big part of this project too.



We are all well aware that Lake Tarawera can be a picture postcard perfect sort of environment, but in the most recent publicly available Lakes Water Quality Report it does stand out as a red dot on the map representing a declining TLI. That it does stand out as a red dot lake perhaps reflects the great work and success that we have had in some of the other lakes across the programme. Nevertheless that red dot is a little alarming and it is worth taking a deeper dive into some of the data behind that point on the map.

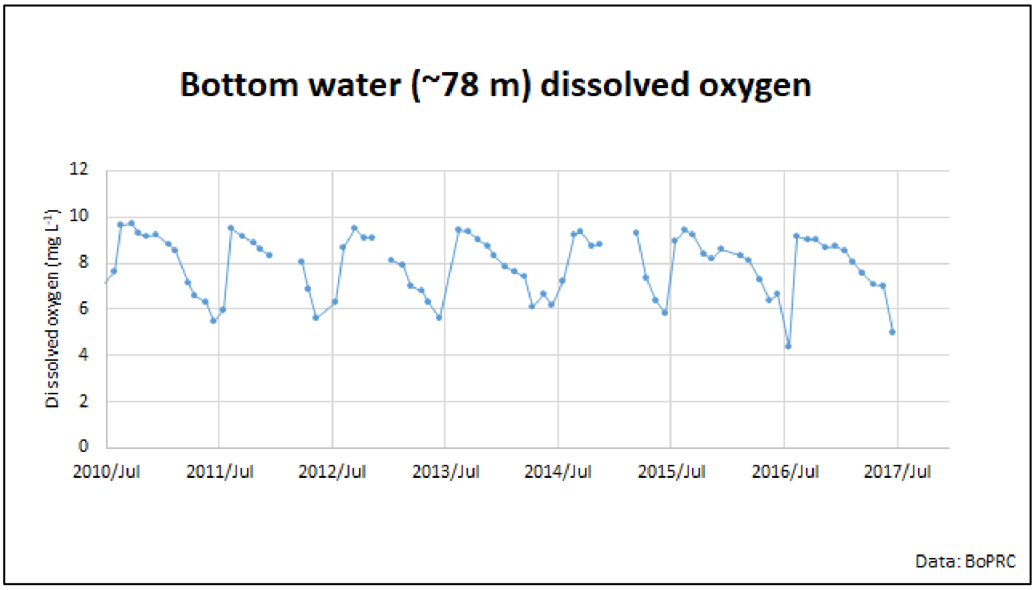


To follow on from the approach David took yesterday for the northern lakes in the region, we will look at the chlorophyll concentration and Secchi depth (which is indicative of water clarity). This is the long-term data set for Tarawera with values further down representing a deeper Secchi depth measurement, and better water clarity. There is certainly nothing too dramatic over recent years in any decline in annual average water clarity in the lake.



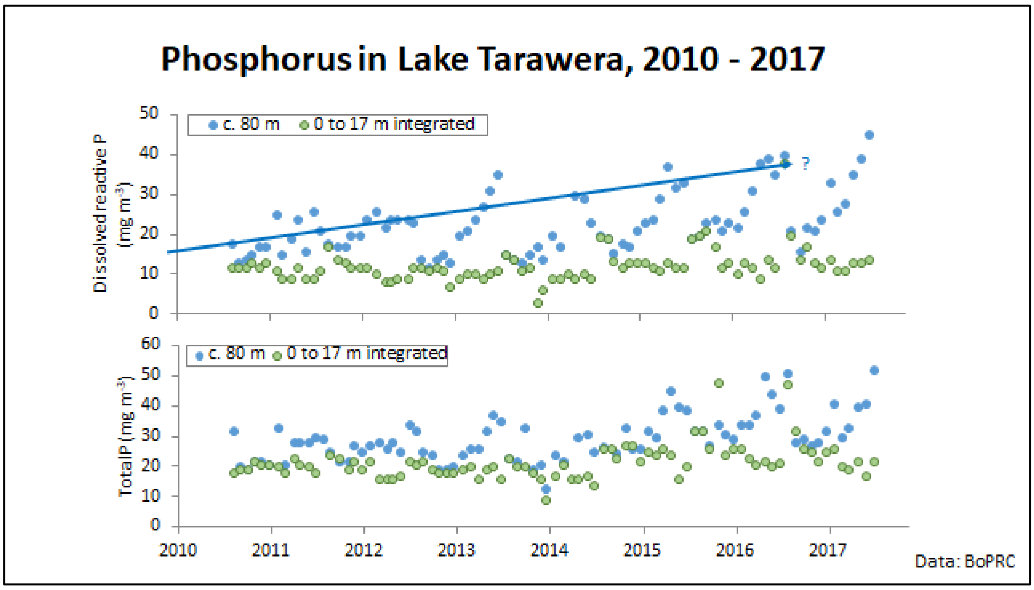
Likewise for chlorophyll, no dramatic rise over the recent decade or so in annual average values for the lake. So no dramatic changes, despite periodic anecdotal observations of blooms at the Hot Water Beach end, and also some green water coming in from Rotokakahi at times around the Landing.

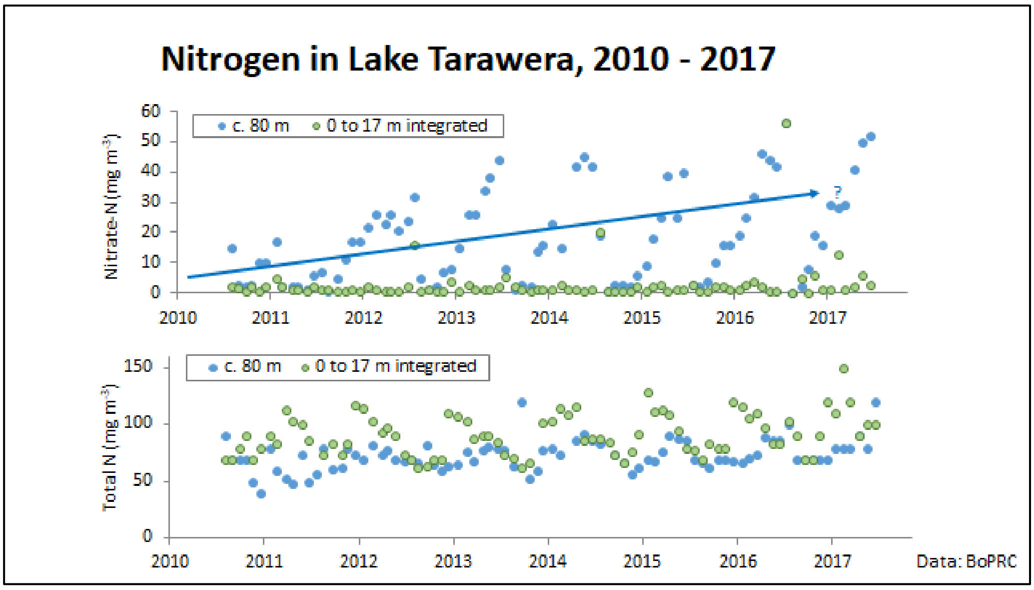
Again, in a similar plot to what David showed, (next page) bottom water dissolved oxygen in the lake looks fairly stable over the last 7 or so years, although maybe one month we did see some unprecedented low concentrations in bottom waters. When we get low oxygen concentrations in the bottom waters of stratified lakes, as David explained yesterday, that can lead to internal loading via release of nutrients that are stored within the sediments.



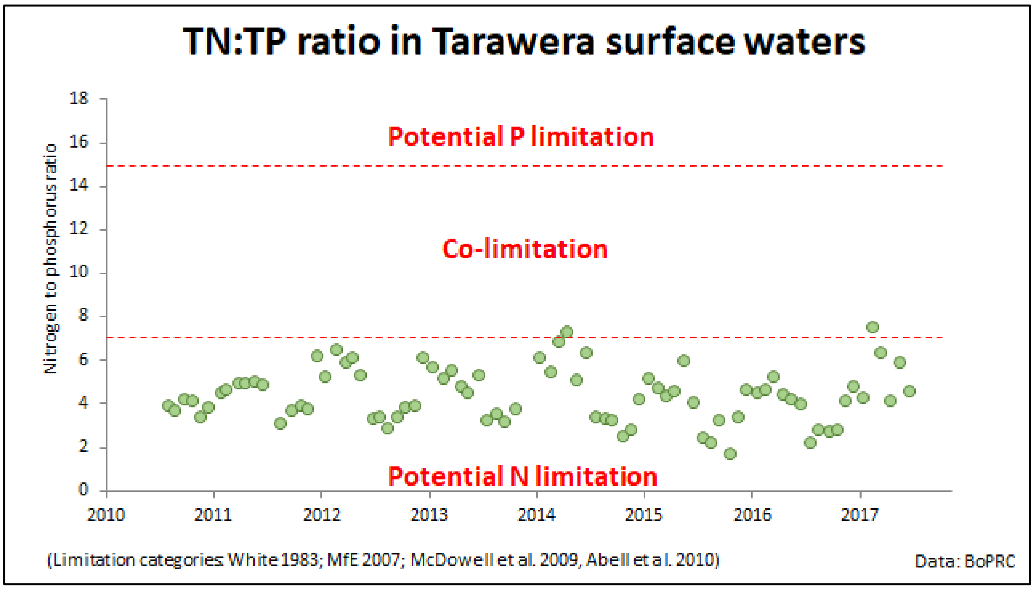
Below is the phosphorus data, dissolved phosphorus in the top panel and total phosphorus in the bottom panel, with blue dots representing bottom water concentrations over a 7 year period, and green dots representing surface waters. What we might be able to infer (with very non-scientific style regression lines), is some indication of an increase in bottom water concentrations over that last 7 year period, which is obviously cause for concern. Lakes can get into an internal feedback cycle with bottom sediments supplying nutrients to the water column, creating more organic matter growth and subsequent decay, then more deposition to bottom sediments. That kind of self-reinforcement is a critical aspect for managing and monitoring lakes.

There is a very similar pattern for nitrogen, (next page) with dissolved nitrogen on the top, nitrate and total nitrogen on the bottom, and an indication of an increase in bottom water N concentration and bottom sediment nutrient release. More research is needed to better understand these processes in Tarawera.



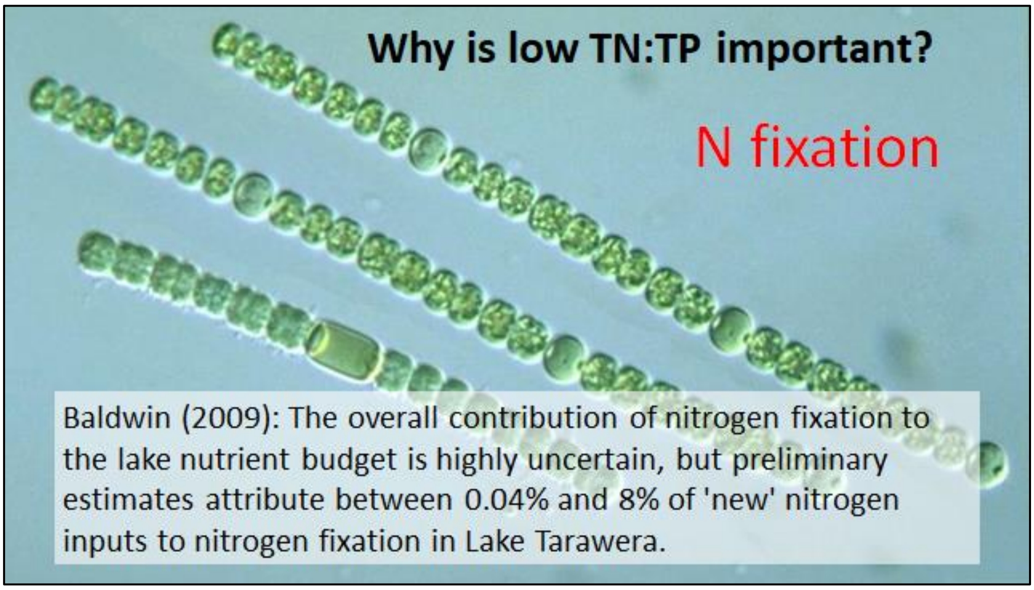


We can also look below at nitrogen and phosphorus levels in relative terms - as the nitrogen to phosphorous ratio. Chris Ingle mentioned how important this discussion has been in the Plan Change 10 process for Lake Rotorua, in terms of which is the most limiting nutrient for phytoplankton growth or algal production in the water of the lake. In the case of Lake Tarawera it is a unique and interesting system in that most of these values sit comfortably within the zone of what we would call 'potential nitrogen limitation'. Nitrogen is likely to be a stronger limitation on algal production than is phosphorus.



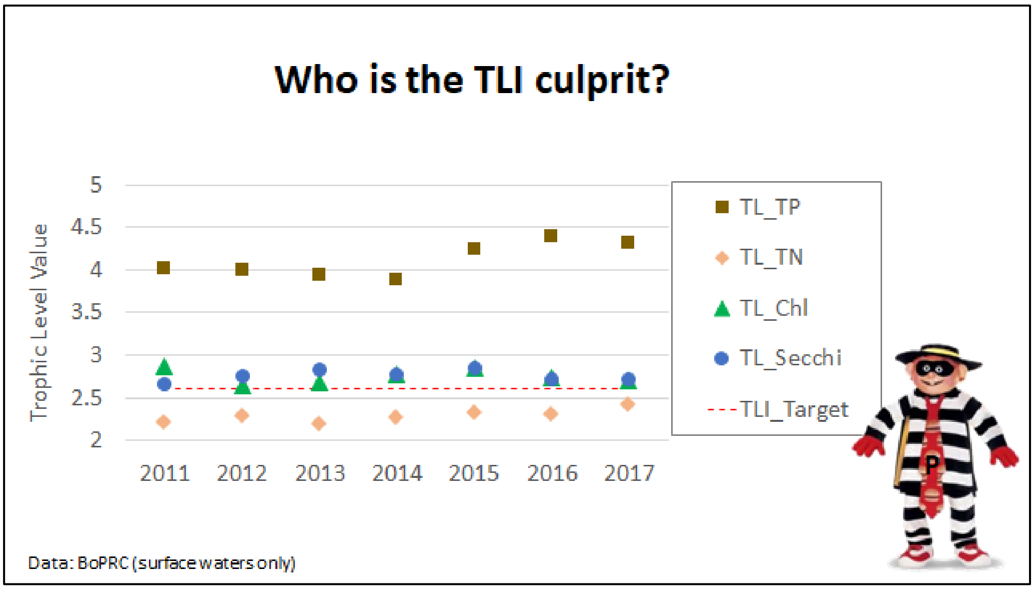
Why is that important? When we have a low N to P ratio this can favour the production of cyanobacteria due to the ability of some cyanobacterial taxa to fix atmospheric nitrogen. Those familiar with Lake Tarawera can be surprised by relatively dense flocks of cyanobacteria in the water column, when at other times the lake is very clear.

Amanda Baldwin, for her PhD research, studied nitrogen fixation in the lake between 2007 and 2009 and estimated that fixation might account for somewhere between almost nil and 8% of new nitrogen inputs to Lake Tarawera. Further to that we might expect that if



phosphorus inputs were to increase faster than nitrogen inputs then fixation may become a more substantial component of nitrogen input to the system, in a relative sense.

Taking all the four components that we have looked at - chlorophyll, nitrogen, phosphorus and Secchi depth or clarity, in the context of the TLI, we can plot these all on the same scale. The N to P ratio jumps out in this plot as something really quite interesting in that three of those TLI variables sit at or around the TLI target for the lake, but it is phosphorus that is most affecting the actual TLI for the lake.

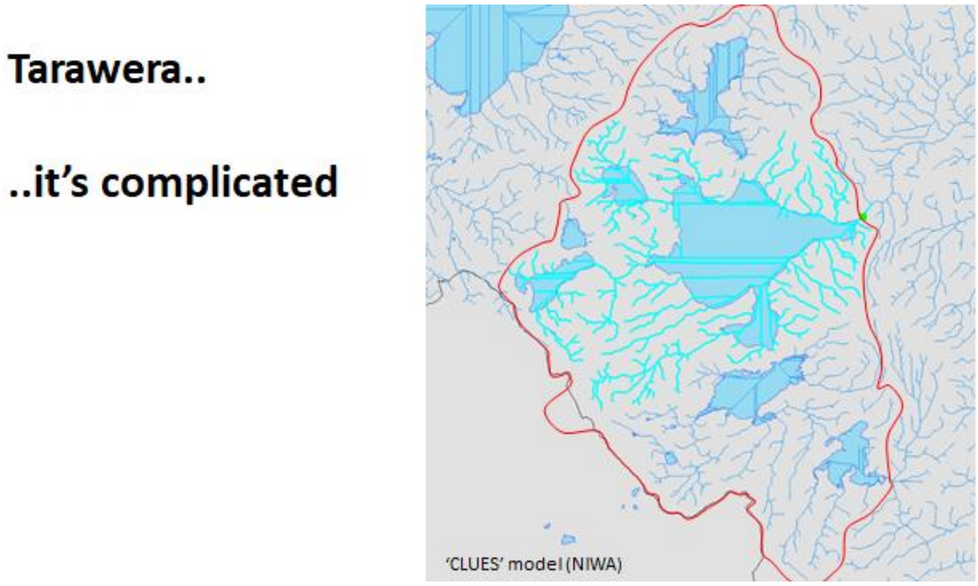


From this it might be tempting to think we only need to manage phosphorus. However, something really important to note is that, because of the oversupply of P, if we add any N to the system, we are likely to get a corresponding increase in chlorophyll and a reduction in clarity. So it becomes doubly important to manage both sources – this is now reflected in the Lake Tarawera Restoration Plan as a reduction in phosphorous in conjunction with nil increase in nitrogen.

Now that we have the context of broad water quality issues in Lake Tarawera, we can move onto the actual modelling project. The aims are multi-faceted. In the process of establishing these models we work to understand the system, the inputs, the hydrology and the nutrient loads. The aims of the project are:-

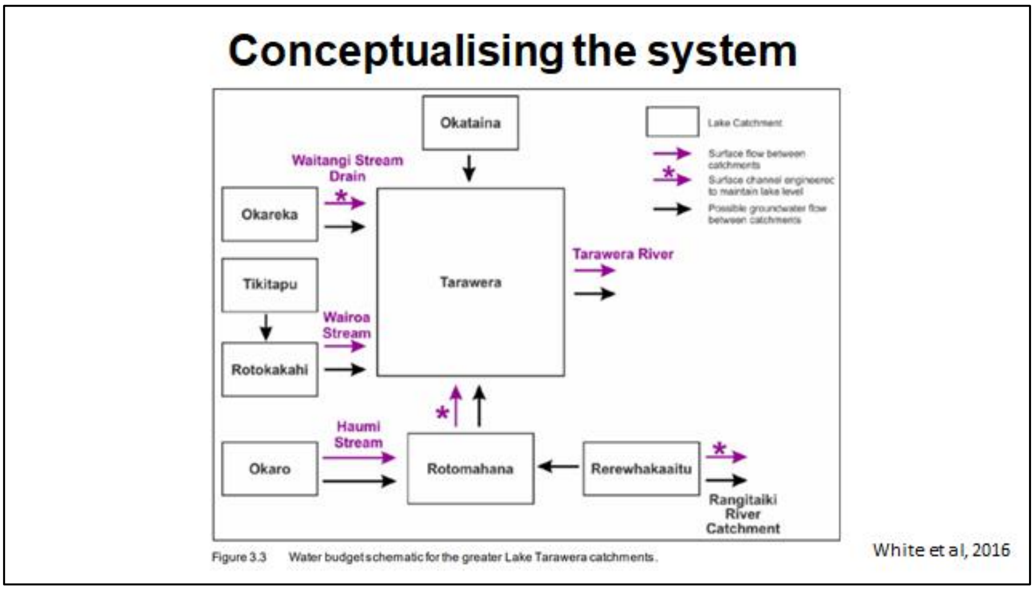
- Review and synthesise available budget information
- Configure a 1-dimensional computer model of Lake Tarawera, the DYRESM–CAEDYM model
- Validate the model using lake water quality data
- Simulate broad nutrient loading scenarios to understand how lake water quality responds to changes to nutrient loads (e.g., Δ P and N loads by 5%, 10%, 20%, etc.)

An intended outcome of this work is to identify sustainable nutrient load targets that will lead to, or achieve, the TLI target for the lake.

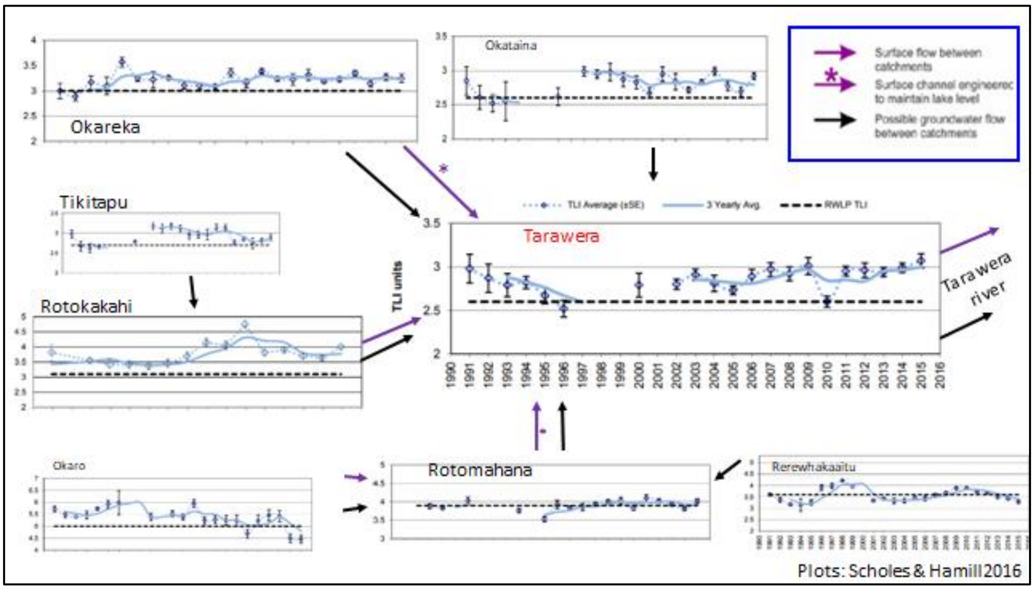


The modelling of lake water quality necessitates understanding and conceptualising the system. Paul White has done a fantastic job of this already, but I will reiterate that, as it is complicated. We have a number of lakes in the Tarawera system, some with surface water connections, which are shown by the connected blue lines in this CLUES model (NIWA), and some which have groundwater connections only.

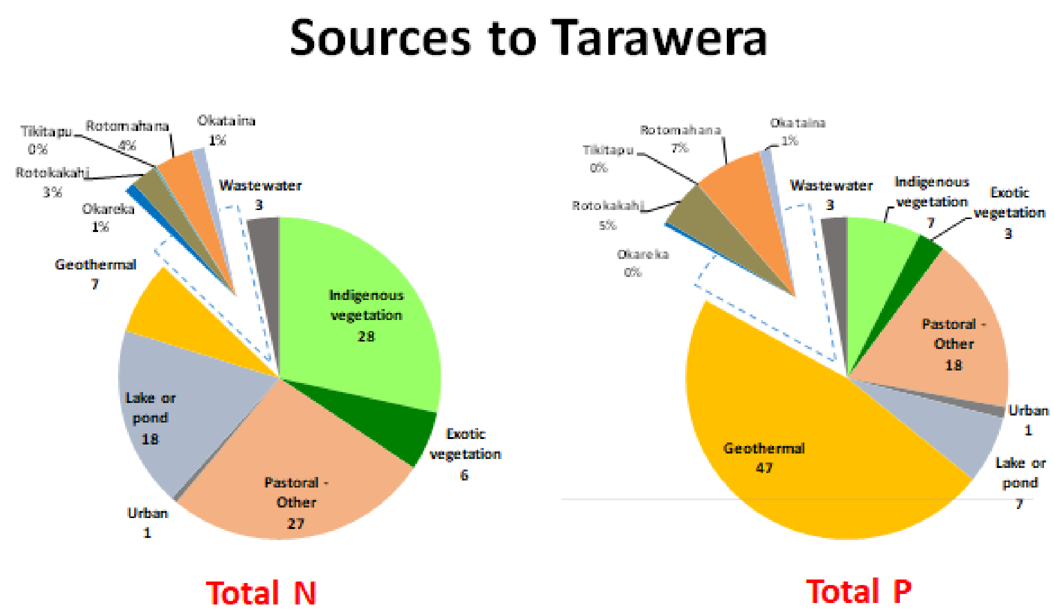
I am the third person to use the next slide, a great diagram that Paul White put together and we are all using it. It shows the connected lakes and the way that surface water and ground water connections flow between them.



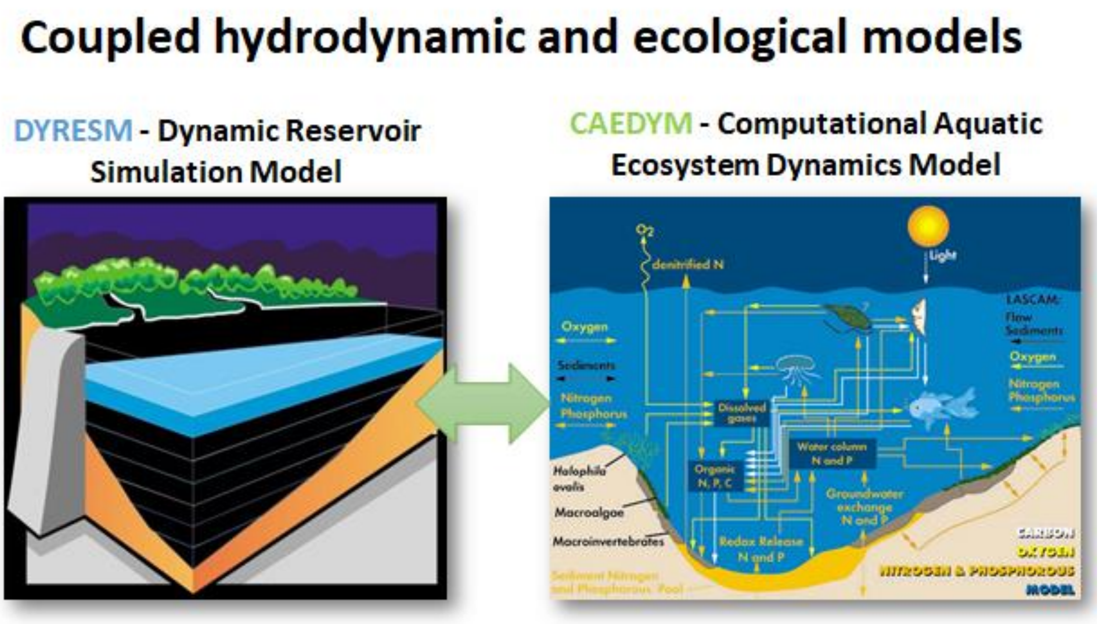
Expanding on that concept, I have replaced the boxes with TLI plots from each of those lake systems so we can see where gains might be made for Tarawera through approaching or achieving TLI targets in the other lakes. Looking at this plot it is tempting to say, 'Oh well, we can manage Tarawera just by hitting our targets in the other lakes', but unfortunately life is never quite that simple.



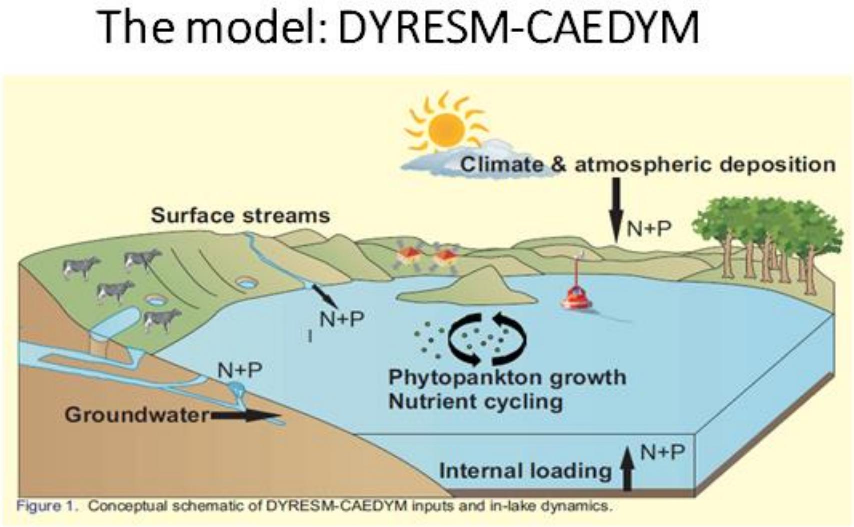
The pie charts on the next page show the nitrogen and phosphorus budget for the greater Tarawera catchment, including the smaller lakes. The zoomed out wedge of the chart represents inputs from other lakes, and is a relatively small contribution of both N and P to the system as a whole. Following on from Chris Ingle's comments, the geothermal load of phosphorus to Tarawera is potentially massive, but it is also worth noting that the yellow wedge is subject to a very high degree of uncertainty. I will touch on that again later. Nutrient budgets like those pie charts are a rather blunt instrument for managing the lakes. What we aim to do with this project is something a little more sophisticated.



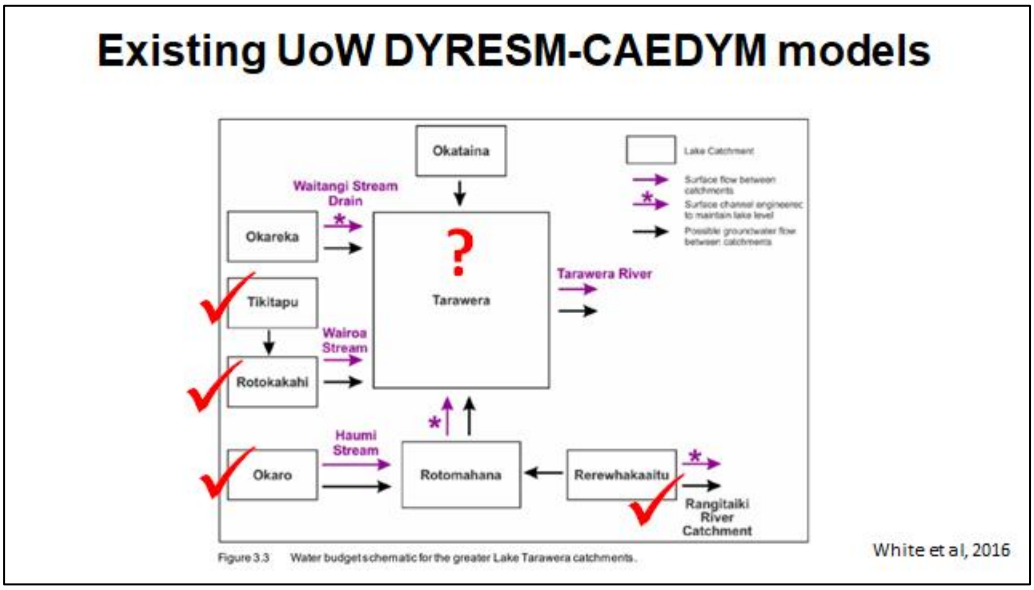
These are the DYRESM–CAEDYM models coupling the hydrodynamics of water movement with the biogeochemical (nutrient and biological) cycles in the water column. These diagrams can be simplified to show how the model accounts for all the various inputs - surface water, groundwater, climate, atmospheric deposition, phytoplankton growth and internal nutrient loading. The model represents all those processes to provide a best informed estimate of the water quality response to external forcing.



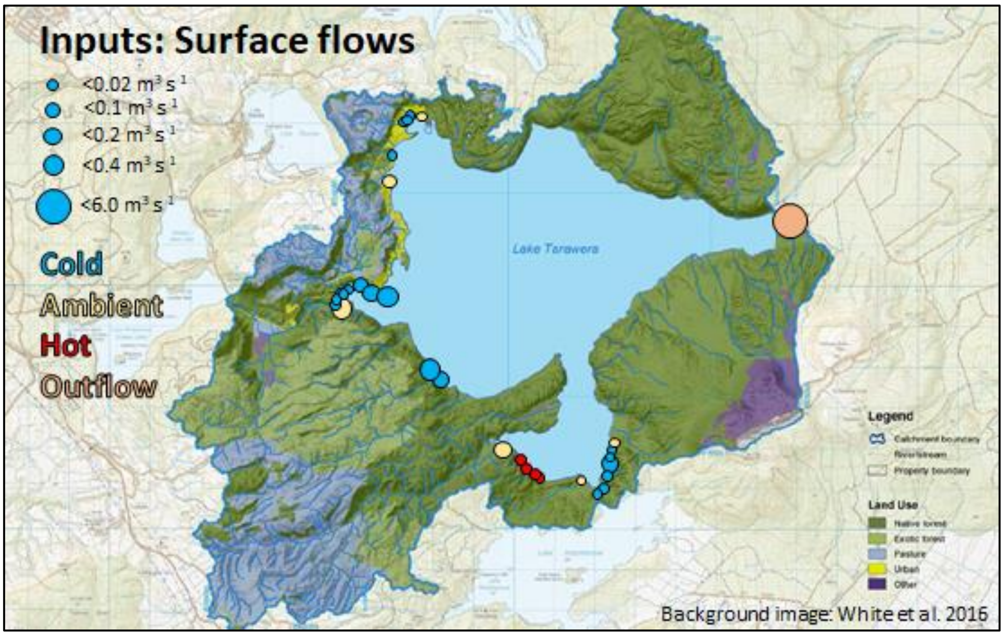
We have used the DYRESM–CAEDYM model (on the next page) across the Rotorua Lakes. For the greater Tarawera catchment we have models already established and published for Lakes Tikitapu, Rotokakahi, Ōkaro and Rerewhakaaitu. It is probably time to model the greater Tarawera catchment, the grandfather model of them all.



These models, with their multiple inputs, are data hungry. They provide a useful opportunity to aggregate all the data and knowledge that has been collected across this greater lake catchment into one tool, and use it to project water quality.

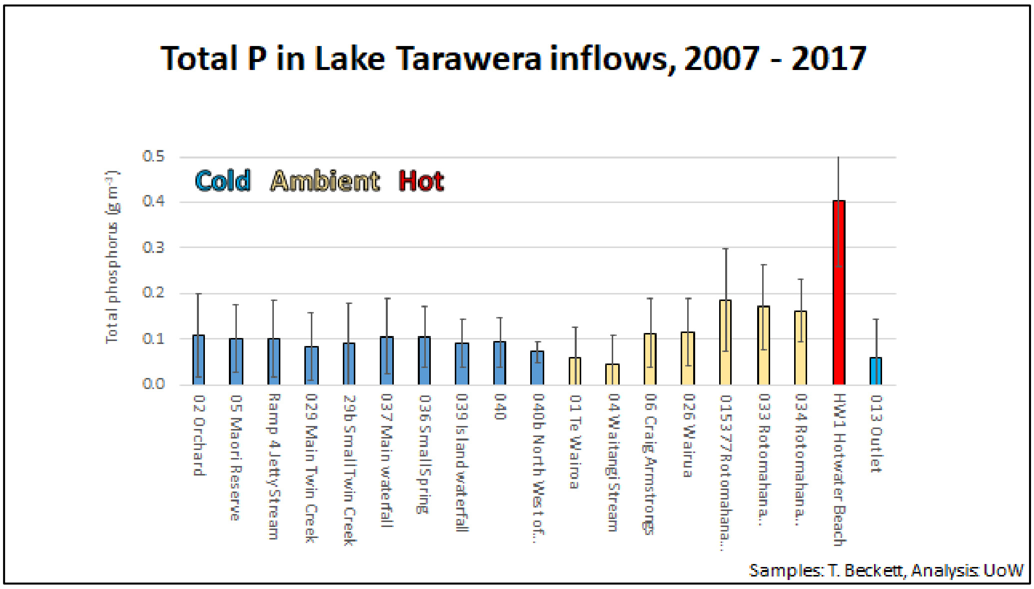


One of the primary inputs or data types we need is obviously water discharge and water quality inputs from the catchment. This is Matt Hamilton, a former student with us, who did some of the original nutrient budget work back in the mid-2000s. Since Matt's work we have been very fortunate to have the commitment of Terry Beckett, and some students as well, who have helped him to monitor the various inputs to the lake, quarterly since about 2007.

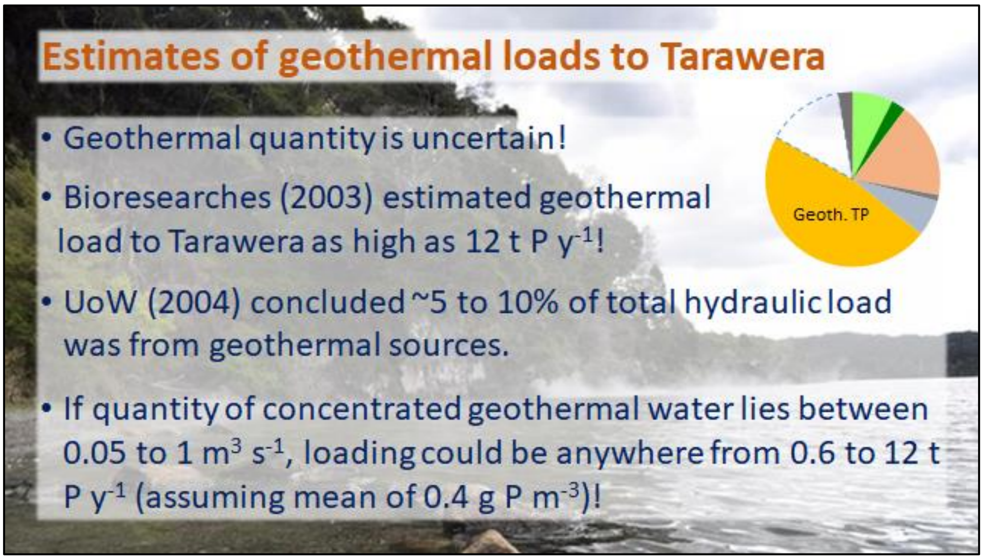


The dots on this chart represent categories of surface flow. The size reflects flow rate at those point sources and the colour indicates the type of flow. Blue is cold water, yellow is ambient temperature, basically surface streams, and red is hot geothermal loads which we will come back to later.

Terry has done a fantastic job of collecting samples for analysis at Waikato. From this we can calculate the long-term average nutrient concentrations for each lake input. This graph is for phosphorus; cold and ambient concentrations have moderate P concentrations. Ambient flows are a little higher, perhaps representing surface flows around some of the more intensively used land areas, but the one that sticks out is the very high P value in geothermal water, and this is the reason for the really large yellow wedge on the pie chart.

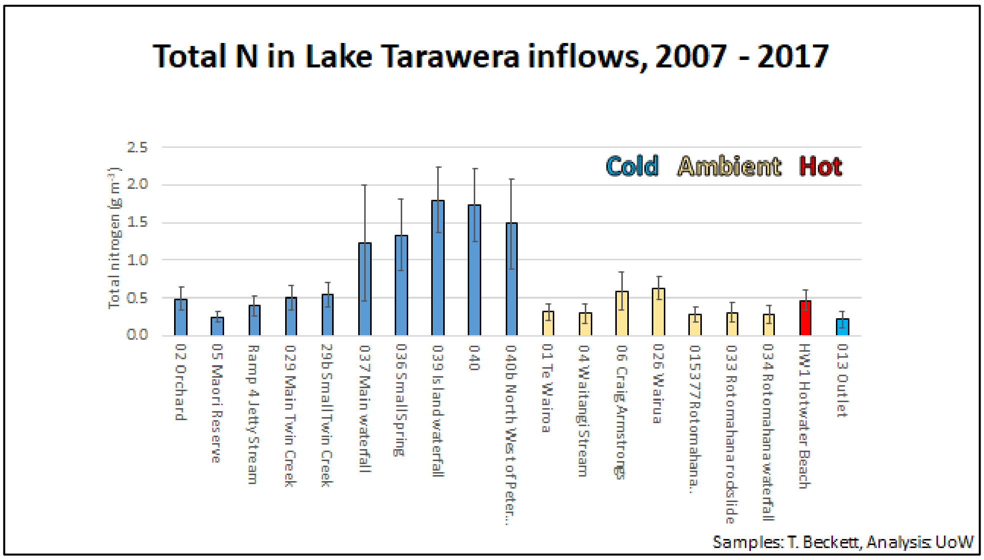


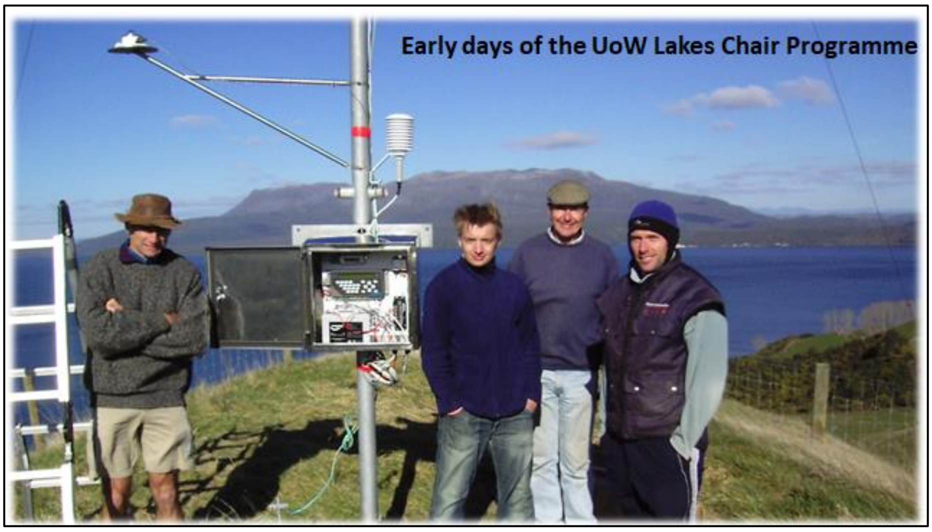
That wedge is subject to quite a lot of uncertainty. Although we have a good handle on what the concentration of that water is around the Hot Water Beach area, the actual volume is a lot harder to estimate because many of those inputs are diffuse and subsurface. Historical research in 2003 estimated the geothermal load might be as high as 12 tonnes of phosphorus, so that would be more than twice all the other P inputs combined.



A more recent study by Waikato University estimated that 5% to 10% of the total hydraulic load to the lake could be from geothermal sources. The 5 tonnes P estimate shown by the yellow wedge on the pie chart is based on a 5% geothermal water contribution, equal to slightly less than half a cubic metre of geothermal flow into the lake. This is one area in which we will do more work to tighten up our estimates of the volume of geothermal water going into the lake itself.

Switching back to Terry's monitoring data on inputs, looking this time at nitrogen, it is almost the reverse of P; there are quite high N inputs from some of the surface streams and springs. That follows logically from what Paul White described with the shallow ground water being N enriched up to approximately 3.5 milligrams per litre (grams per cubic metre).

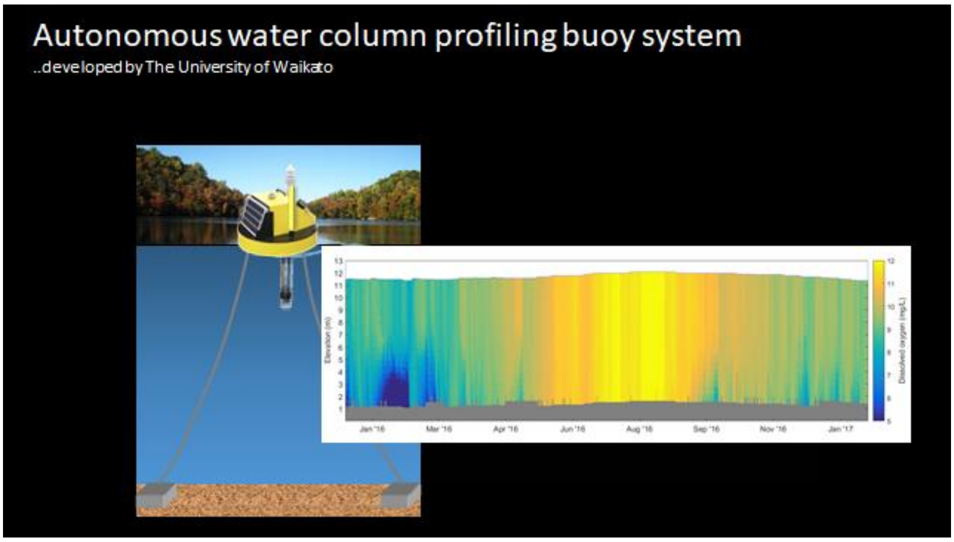




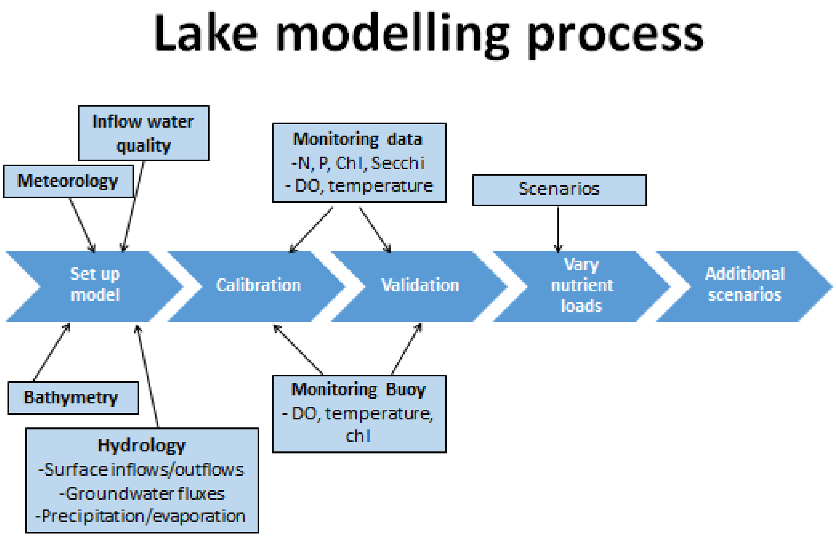
We have a nice handle on the water quality inputs in water quality of inflows to the lake. Another data type that we feed into the model is climate data. In the early days of the programme David Packman kindly donated a small space on the top of a hill on his farm where we could set up a weather station overlooking the lake. This has given us a good record of climate quite near to the lake for the last 10 years or so. You can see the Danish and British guys look pretty comfortable, but the kiwis are more rugged up. It was a pretty cold afternoon despite the sunshine!

Additionally we have high frequency lake monitoring buoys, which I have been quite involved with. These also have a climate station and right on the lake we have weather data as well as near real time water quality information at 15 minute intervals with occasional gaps. The Tarawera monitoring buoy has proved something of a problem child due to the depth and exposed nature of the site.

Over the last few years we have been developing these water column profiling buoys which use an automated winch to raise and lower a sensor package up and down through the water column. The advantage of this is that we can measure variables like oxygen, pH, chlorophyll fluorescence or water turbidity throughout the water column, rather than



just at one or two depths that we would be restricted to by a traditional buoy with fixed sensors. With this buoy we can generate nice plots and get a much better feel for the vertical dynamics in the system. That will be very beneficial for the future, particularly the 1D modelling, that we undertake. The data is from a year of uninterrupted recording from the prototype profiler buoy, which was deployed at Lake Rerewhakaaitu. Periods of oxygen loss from the bottom waters are evident in this plot. This is the type of data we will be generating for Lake Tarawera going forward.

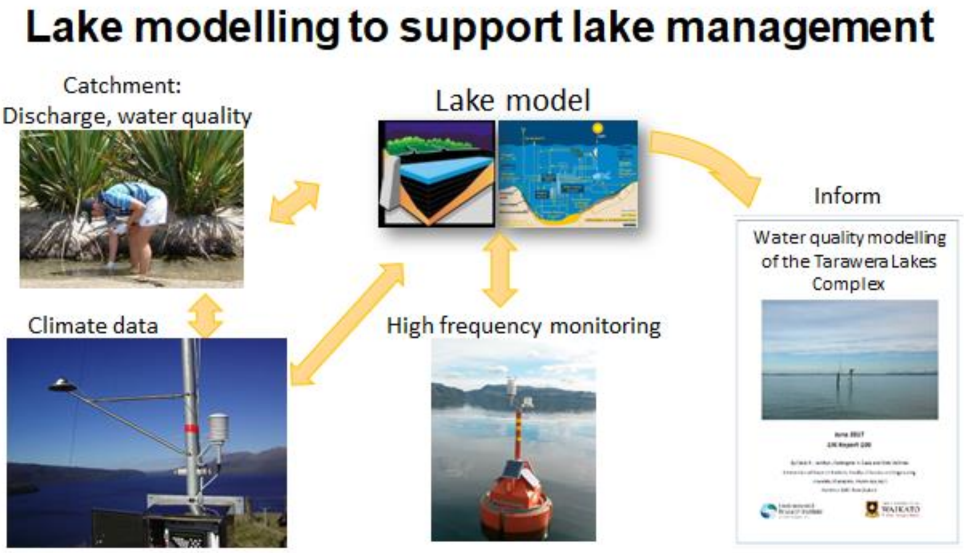


This flowchart shows the process for the modelling project. There are no results at this stage but we will set up the model with the inputs that we have just considered. We then calibrate the model using the monitoring data that we summarised in the first five slides to optimise model performance and check that it reproduces the observations accurately. Then we will validate the performance of that model with an independent time series or separate time period of the monitoring data, so that we can have confidence in the model's projections. That will allow us to run scenarios, perhaps in two stages; firstly, some broad scenarios with broad assumptions, then more detailed, based for example, on Paul's White's modelling.

MODEL 'SCENARIOS'

- **Multiple simple nutrient load scenarios to identify sustainable nutrient loads that will achieve the TLI target:**
  - **e.g. 5, 10, 20% reduction in N and/or P?**
- **Additional scenarios, e.g.;**
  - **What if all tributary lakes met their TLI target?**
  - **Intercept geothermal loads?**
- **The lake model will provide a tool that could be integrated with future catchment modelling to understand how changes in individual sub-catchments will affect Lake Tarawera.**

Those model scenarios will have multiple simple nutrient load scenarios to try and identify sustainable loads that might achieve the TLI target. That might mean starting off by looking at 5%, 10%, 20% reductions for example in N and/or P to the lake. We could then use the model to run additional or more specific scenarios like, for example, what is the water quality outcome for Lake Tarawera if the TLI changed only in the tributary lakes. Or what if we were able to somehow intercept 20% of the geothermal P load, or similar.



As a longer term vision, the lake model might provide a tool that could be integrated into future catchment modelling, such as Paul White has completed with his MODFLOW groundwater study. This would help understand how changes in more specific parts of the greater catchment might impact the water quality at Tarawera.

The net result of that is we are bringing together the whole picture of monitoring and modelling, and using these tools to inform both the community and the process of management and implementation for the restoration plan.

In conclusion, Lake Tarawera water quality does currently exceed its TLI target and the TLI has increased over the period of 2000 to 2016, although there was a similarly high TLI observed in the early 1990s to mid-1990s. That is not to say that is where the water quality should be, because obviously water quality measurements in the lake only started relatively recently.

Nitrogen, chlorophyll and Secchi depth are roughly in line with the TLI target. However, phosphorus is a great deal higher and results in a low N to P ratio, which is a specific issue for consideration in Tarawera.

The hydrology of the lake is very complex and that presents a challenge for lake managers, but we do have this project under way to integrate the work that has come before, and try to identify sustainable nutrient loads to the lake. Our aim is that the model will prove to be a tool that can be integrated with other undertakings and other modelling endeavours, be they surface water catchment modelling, groundwater modelling, or other information from the greater catchment.

With that I will say thank you and acknowledge all the people below. You have been a great help towards getting this project going.

Paul White (GNS)
UoW Aquatic Team
David Hamilton (Griffith University)
Joseph Butterworth (JFB Environmental)
Paul Scholes, Alastair MacCormick (BoPRC)
Terry Beckett, David and Robyn Packman, and the Lake Tarawera Ratepayers Association

Thank you