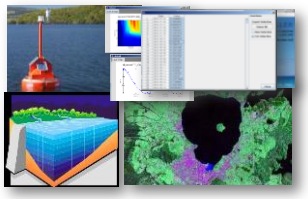
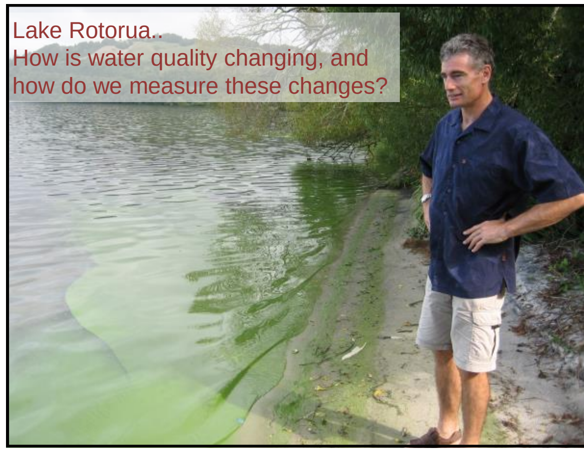
Monitoring and modelling to support management and policies for Lake Rotorua

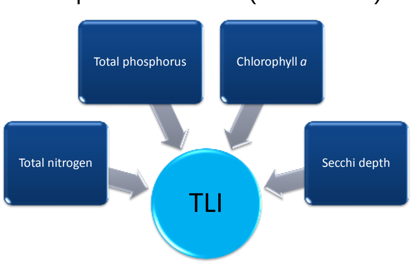


David Hamilton and Chris McBride
The University of Waikato

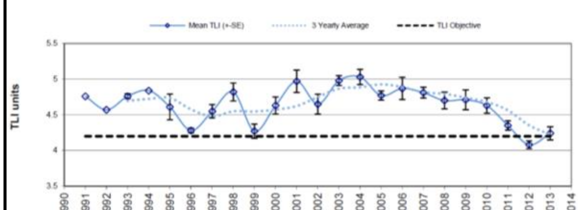


What is the TLI?

Trophic Level Index (Burns 1999)



Lake Rotorua TLI

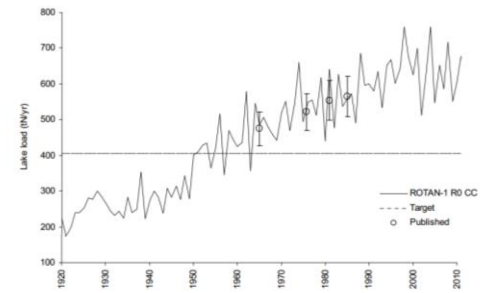


Source: BoPRC (Scholes 2013)

Rotorua TLI target: TLI ≤ 4.2

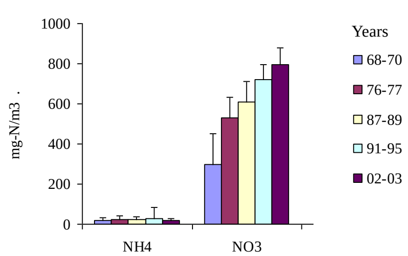
- TLI target for Lake Rotorua of 4.2 was specified in the Lake Rotorua and Rotoiti Action Plan (BoPRC 2006)
- TLI > 4.2 (3-yr avg) does not conform to the Regional Water and Land Plan (Rule 11). It equates to:
  - Poorer water quality, with increased nuisance cyanobacteria (algae) blooms and greater depletion of oxygen in deep waters
- Long-term management and remediation are needed, because:
  - Large surface flows to the lake are driven by groundwater with time lags often > several decades.

Nitrogen inputs to Lake Rotorua (ROTAN model)



NIWA Taihoro Nukurangi K. Rutherford & C. Palliser

Example: nitrate in Ngongotaha Stream



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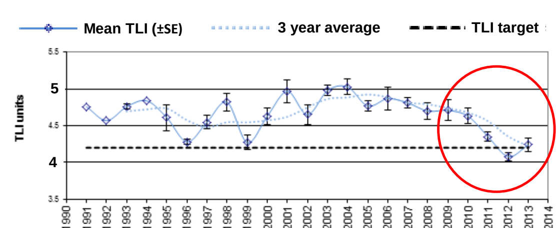
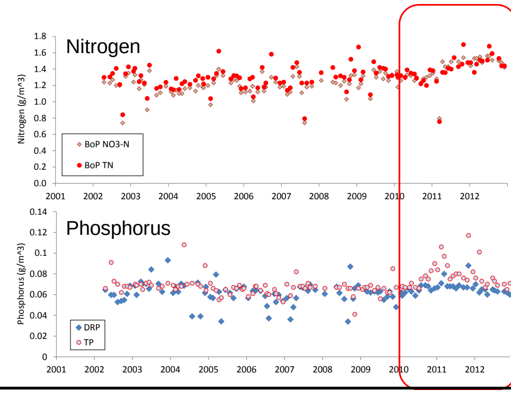
Lake Rotorua TLI



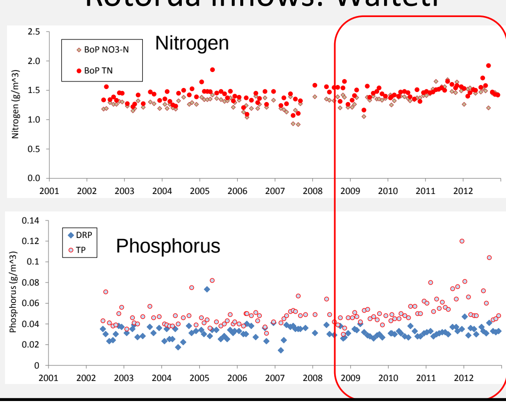
Source: BoPRC (Scholes 2013)

Are changes to water quality in the surface inflows to Lake Rotorua driving recent improvements in lake water quality?

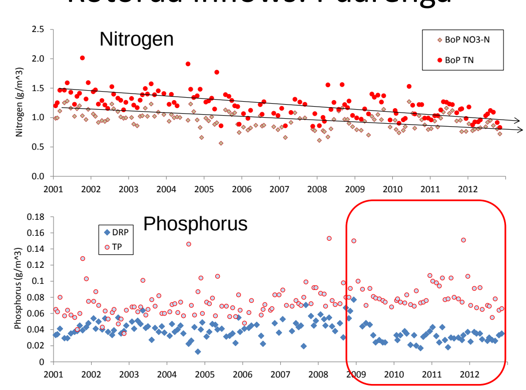
Rotorua inflows: Awahou



Rotorua inflows: Waiteti



Rotorua inflows: Puarenga

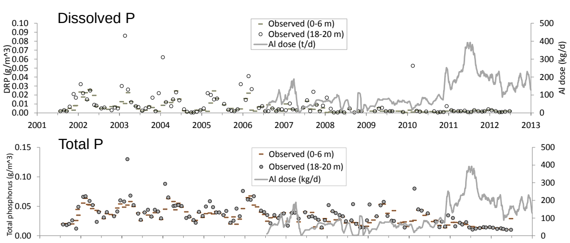


Could alum explain recent improvements in lake water quality?

Restoration method: Alum

- **Aluminium sulfate:** Used around the world for some decades to bind (inactivate) phosphorus in water treatment and aquatic ecosystems.
- Often dosed in bulk, either once or periodically. However, for Lake Rotorua it is “drip-fed” into two of the lake’s inflows (Puarenga and Utuhina streams).
- Some alum likely makes its way to the basin of the lake without being bound by P in these inflows.

Alum and phosphorus in Lake Rotorua

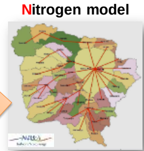


What tools are available to assess the relative effects of…

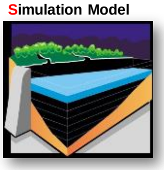
- Alum dosing of inflows
- Changes in catchment land use and/or surface inflow water quality

Coupled catchment-lake ecology models

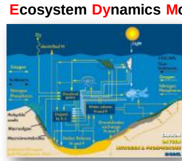
ROTAN – Rotorua Taupo Nitrogen model



DYRESM - Dynamic Reservoir Simulation Model



CAEDYM - Computational Aquatic Ecosystem Dynamics Model



Model calibration and validation

Assessing the model performance:

Visual inspection by plotting model output against observed data and high frequency measurements

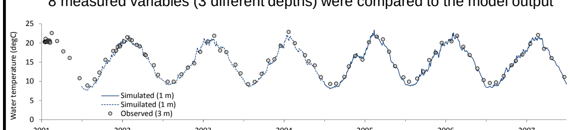
Statistical comparison:

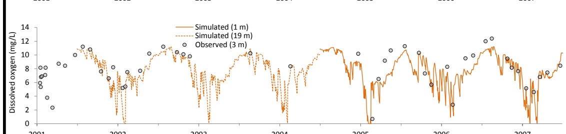
Mean Absolute Error (MAE)
Normalised MAE (NMAE)
Root Mean Square Error (RMSE)
Normalised RMSE (NRMSE)
Pearson correlation coefficient (R)

Lake Rotorua monitoring buoy

Model calibration and validation

8 measured variables (3 different depths) were compared to the model output

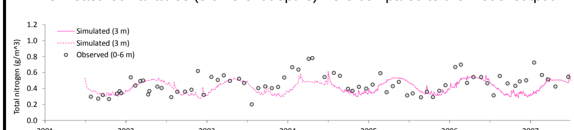


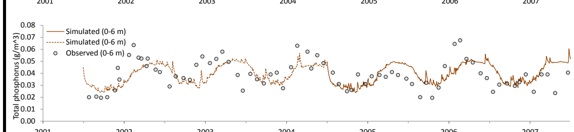


Examples: Surface water temperature and bottom dissolved oxygen concentration

Model calibration and validation

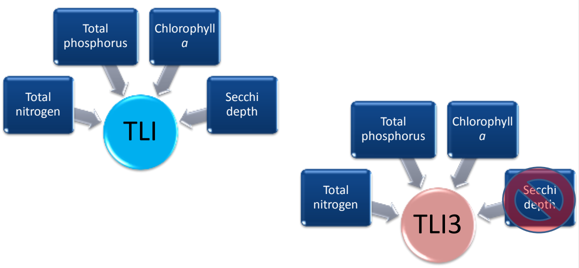
8 measured variables (3 different depths) were compared to the model output



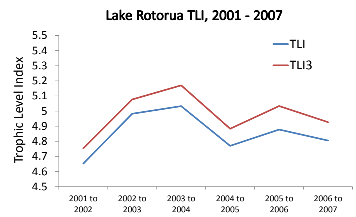


Examples: Total nitrogen and total phosphorus concentrations

Model calibration and validation: TLI vs TLI3



Model calibration and validation:



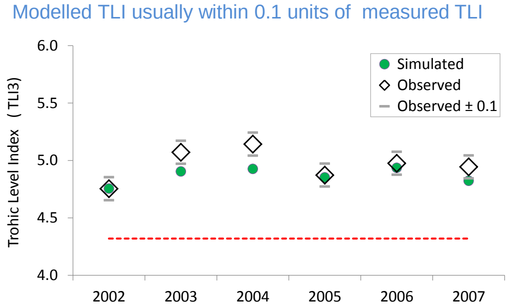
Lake Rotorua TLI target = 4.2

But..TLI3 is an average of 0.12 TLI units higher than TLI

Therefore, TLI3 target considered to be 4.32

Model calibration and validation: TLI3

Modelled TLI usually within 0.1 units of measured TLI



Model scenarios

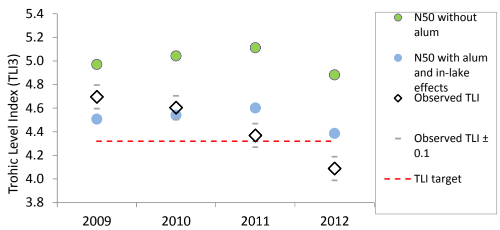
Alum dosing of the Puarenga and Utuhina streams has been estimated to bind ~12% of the whole-catchment dissolved P load.

Questions for the model: can the binding of ~12% catchment P explain recent improvements in lake TLI, and if not, to what extent might *in-lake* effects of alum dosing be responsible?

Four modelled scenarios for the period 2007 - 2012

Scenario	Alum dose to Puarenga and Utuhina?	Increased flocculation (of POM) in-lake?	Suppression of internal P release?	Catchment TN load (t/y)	Catchment TP load (t/y)	Catchment PO4 load (t/y)	Internal P release (g/m^2/d)
N642_noAl	-	-	-	641.5	34.5	23	0.0400
N642_Al	√	-	-	641.5	34.5	20.3	0.0400
N642_Al.Floc.	√	√	-	641.5	34.5	20.3	0.0400
N642+Al.Floc.intP	√	√	√	641.5	34.5	20.3	0.0200

Model scenarios



Comparison of observed Lake Rotorua Trophic Level Index (TLI) with simulated TLI for a scenario without any inflow alum dosing (green dots), and of alum dosing with in-lake effects (blue dots) including increased sedimentation of organic particulate matter (flocculation) and suppression of internal DRP release (50% reduction). The dashed red line is the TLI3-adjusted for Lake Rotorua (4.32).

Model scenarios

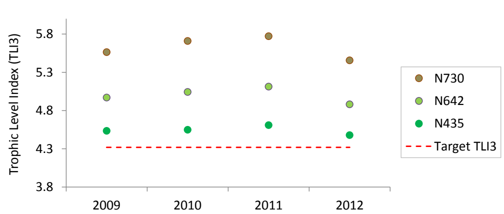
Catchment nutrient loads are projected to increase over coming years, before a target catchment nutrient export load reduction is achieved.

Model questions: how might changes in catchment nutrient loads affect Lake Rotorua TLI, and what changes might meet the target TLI?

Seven modelled scenarios for the period 2007 - 2012

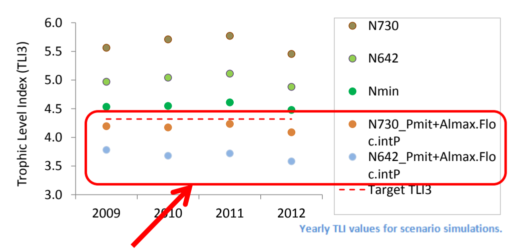
Scenario	Alum dose to all inflows?	Catchment TN load (t/y)	Catchment TP load (t/y)	Catchment PO4 load (t/y)	Increased flocculation (of POM) in-lake?	Internal P release (g/m^2/d)	Sediment oxygen demand
N435	-	435	23	0	-	0.0271	0.46
N642	-	642	35	23	-	0.0400	2.90
N642+Al.Floc.intP	Pua & Utu	642	35	20.3	-	0.0200	2.90
N642_Pmit+Almax.Floc.intP	ALL INFLOWS	642	35	7.6	√	0.0066	1.47
N730	-	750	40	0	-	0.0690	4.36
N730_Pmit	-	750	30	0	-	0.0366	4.36
N730_Pmit+Almax.Floc.intP	ALL INFLOWS	750	30	0	√	0.0088	2.22

Model scenarios: nutrient loads, no alum



Yearly TLI values for scenario simulations.

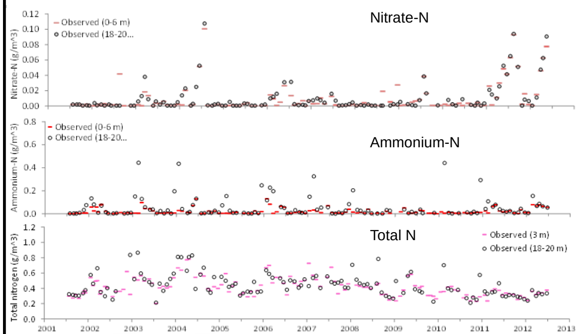
Model scenarios: all load scenarios including those with alum



Yearly TLI values for scenario simulations.

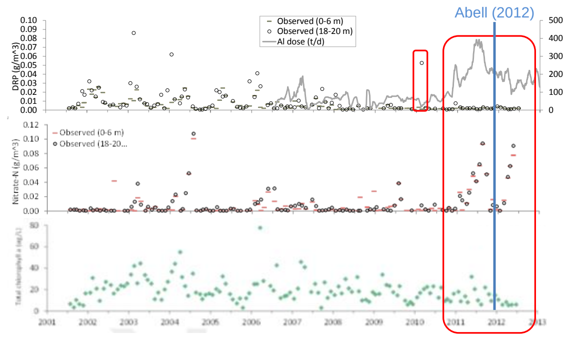
These scenarios include high alum dose rates to ALL inflows, and full in-lake effects including flocculation, internal load suppression and reduced bottom-water dissolved oxygen consumption!

In lake monitoring data



In-lake measurements for nitrate, ammonium, total nitrogen, dissolved reactive phosphorus (DRP), and total phosphorus at the surface (0 - 6m) and bottom (18 – 20m), and total chlorophyll a at the surface (0-6 m) from 2001 to 2013.

Potential for P-limitation (2011 – present), co-incident with increased alum dosing of inflows



Q1: What evidence is there to show that Lake Rotorua is not phosphate limited?

Previous bioassay studies indicate that it has been co-limited (e.g. Burger et al. 2007; Meads, unpubl.; Abell et al. 2013). Abell's study (in December 2011) was conducted at a time of very low inorganic nitrogen concentrations which are not generally representative of earlier in 2011 or of 2012. There is a strong possibility that P is the dominant limiting nutrient but there are likely to also be times of the year when N is limiting (when inorganic nitrogen concentrations are very low).

Q2: How much of the water inflow into Lake Rotorua is not accounted for from within the catchment?

The surface topography provides a good indication of water discharge to the lake. For Hamurana, however, the surface topography is too small to explain this large discharge of nearly 3 cumecs. This means that around 30-60 sq. km need to be added to the surface topography. It is likely that this area is in the flat, upper part of the Hamurana catchment where there is a groundwater catchment that is disconnected from the surface topography.

Q3: What is the relationship between N and P levels in the lake and achieving the TLI of 4.2?

- TLI is the combination of surface water TN, TP, chl *a*, and Secchi depth (clarity).
- It may be possible to ↓chl and ↑clarity by severe management of solely N *or* P, but the improved water quality will have low resilience to any increase in the limiting nutrient. It is clear that despite reduced P in the lake in recent years, there is still a high likelihood of N limitation at certain times of year.
- Effective management should involve management of N and P in order to achieve resilient improvements in water quality.

Q4: What factors are driving the improved TLI results in recent years?

- Little evidence that changes in inflows are responsible although there is suggestion of some improvements in the Puarenga. Other inflows show some concerning trends, .e.g. Awahou:

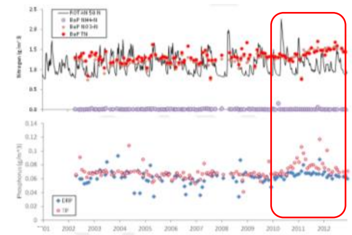
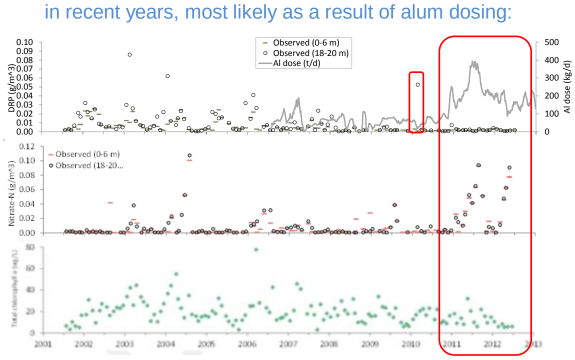


Figure 5. Time-series plots of Bay of Plenty inflow monitoring data (dots) and ROTAN output (lines) for the Awahou stream sub-catchment, for A) daily flow, B) nitrogen, and C) phosphorus.

Q4: What factors are driving the improved TLI results in recent years?

- Internal loads of PO_4 appear to have reduced markedly in recent years, most likely as a result of alum dosing:



Q5: If alum dosing is improving the TLI by locking up P, is there scope to achieve a similar TLI by substituting alum dosing with comprehensive P mitigation on farms and other land?

- The immediate effects of alum may be larger than that achievable by managing catchment P (particularly with Rotorua's volcanic soils naturally high in P).
- However, in the long-term, severe management of catchment inputs of P could reduce the nutrient pool available for internal loading, thus having an effect similar to the presently observed effects of alum treatment.

Q6: How do storms affect the lake and its TLI?

- Jonathan Abell's work has been very important in contributing understanding of how storms affect two inflows that have a relatively high component of surface water. These inflows are Puarenga and Ngongotaha. Nitrogen concentrations varied little with rainfall and discharged, so loads vary more or less linearly with flow. However, 50% of estimated two-year loads of TN, TP and TSS were transported in 202-207, 76-126 and 1-8 days respectively in these two streams. This emphasises the importance of reducing sediment erosion and associated losses of phosphorus from the landscape.

Q7: When will the RDC sewage reticulation and treatment upgrades affect the TLI?

- RDC has been more or less continuously upgrading the standard of their wastewater treatment over recent years and this is reflected in reductions in total nitrogen and nitrate concentrations in the Puarenga Stream. However, RDC is also challenged by more wastewater coming in as larger numbers of lakeside communities from outside (and inside) the catchment have reticulated wastewater.

Q8: What are the trends in lake sediment nutrients and the release of those nutrients, and how does that affect the lake's TLI?

- There is some evidence of reductions in the N and P pools in the bottom sediments since sewage diversion in 1991 (Trolle et al. 2009). In terms of sediment releases to the water column, however, these are now barely detectable though the exact mode of action is not clear (i.e. less severe reductions in oxygen in bottom waters vs some capping effect of alum on the bottom sediments vs alum quickly 'mopping up' P releases into the water column.

Q9: Given the advice that Lake Rotorua algal growth is "co-limited" for N and P, are there combinations of N and P load reductions that could give a N load target that is easier to meet than 435 tN?

- Meeting the TLI target (1960s water quality) without internal load management (e.g. alum) will likely require reducing catchment loads for N *and* P *below* 1960s levels (due to the inertia of the present sediment N and P pools). We should not expect 1960s water quality with N or P loads that are greater that that time (unless we are prepared to indefinitely manage internal loads artificially).

Q10: How much N is lost (attenuated) in aquifers and streams before reaching the lake?

There will be very little attenuation in the larger aquifers as conditions remain fully oxygenated between the spring and its point of entry to the lake. Smaller inflows may offer some opportunity for attenuation (via denitrification such as with wetlands or denitrification beds (as at Tikitere)) but overall, denitrification is probably limited because of the volumetric dominance of large aquifers which are fully oxygenated.

Q11: What is the level of certainty around the science used to set the 435 tN/yr target, including the catchment and lake models used?

- 435 tN/yr roughly equates to the modelled ROTAN N load for the period 1955 – 1965. The measured TLI in the late 1960s (the earliest period of consistent data) was around 4.3. Statistical measures of uncertainty have been quantified for the lake model.

Q12: Could new science work change the 435 tN target? If yes, what sort of science?

- The science is continually being updated and informed as new results arise. One such example is alum dosing in which the science has now contributed a fair amount of certainty that improvements in the TLI are being driven mostly by alum dosing and not other factors such as changes in nutrient loading from the catchment. In this regard we are getting new knowledge about combinations of N and P in the lake that lead to the TLI target of 4.2.

Q13: Does lake weed affect the TLI? If so, how, and are there possible solutions, including carp?

Lake weed probably affects the TLI in complex ways. When it is growing it effectively competes with phytoplankton (the microscopic suspended algae) to reduce the TLI but when it decays in bulk (as can be the case with the invasive varieties in the lake) then it will increase oxygen consumption and may increase nutrient levels through decay of plant material and releases from the bottom sediments.

The are two types of carp in NZ: koi (the highly invasive species that liberates nutrients and resuspends bottom sediments) and grass carp. Gras carp are not recommended in the Rotorua lakes; their grazing on weed will liberate nutrients to the water column and blooms have become commonplace in other lakes in NZ where they have been introduced.

CONCLUSIONS

- Monitoring data from the lake and the record of alum dosing, suggest lake eutrophication would have continued unabated without in-lake effects of alum dosing
- Increases in DRP and TP have occurred in most major inflows, ~2008 - present.
  - An exception is the Puarenga stream, where nutrient concentrations have varied, but are decreasing for most nutrients.
- Increasing prevalence of nitrate (above detection limits) in surface waters of the lake, along with very low DRP concentrations suggest increasing potential for P-limitation of phytoplankton over the past few years. Relatively low chl *a* concentrations 2009 – 2012 are consistent with increased P-limitation.

CONCLUSIONS…cont.

- Modelling results suggest alum has had a major influence on internal nutrient loads, to the extent that the impacts of variations in external load on lake TLI have been mitigated substantially.
- We hypothesise that ongoing and severe eutrophication would have occurred in the lake in the absence of alum dosing.
- We consider that the current situation is extremely tenuous, as external loads have continued to increase unabated, whilst there is a risk of adverse ecological impacts from alum.