Water Quality Technical Advisory Group

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Lake Rotomā water quality and catchment nutrient sources.

Lake Rotomā has the highest water quality of the 12 lakes within the Rotorua Lakes Programme. Recent monitoring data suggests lake total phosphorus (TP) concentration may be increasing (Figure 1). Maintaining low water column nutrient concentrations and a high N:P ratio is highly desirable for Lake Rotoma (Water Quality TAG resolution, 2007).

Target water quality for Lake Rotomā is defined in Bay of Plenty Council's (BoPRC) Water and Land Plan as a Trophic Level Index not exceeding 2.3 TLI units. The Lake Rotomā Action Plan (BoPRC 2009) specified targets for total nitrogen (TN) of 128.6 mg N m^{-3} and TP of 3.22 mg P m^{-3}, commensurate with the target TLI value. Mean TP for all surface water measurements was 4.7 mg m^{-3} for 1990 to 1995 and approximately 6 mg m^{-3} for July 2010 to April 2014. There appear to be no substantial long-term changes in either chlorophyll *a* concentrations or Secchi disk depths (clarity).

The TAG considers that TN and TP targets for Lake Rotomā could be revised to ***120 mg N m^{-3}*** *and* ***5 mg P m^{-3}****, whilst maintaining the ability to meet the overall TLI target and therefore achieving the desired outcome for the lake.*

The Lake Rotomā Action Plan estimated sustainable catchment nutrient loads to the lake. Two complimentary methods were used:

1. *The Vollenweider (1975) method;* the relationship between in-lake nutrient concentrations, hydraulic load, and a predicted retention coefficient, were used to estimate total catchment loads corresponding to 'present' (c. 2006) and 'target' (c. 1994) lake water N and P concentrations. The difference between estimated 'present' and 'target' loads defines the catchment nutrient reduction required to maintain the lake at its target water quality.
2. *Aerial nutrient export rates*; estimated discharge rates of N and P to the lake from each land use within the catchment were used to estimate contribution to the total catchment load.

Here we revisit the above approaches using the latest available water quality and catchment land use data, and the revised target TN and TP concentrations.

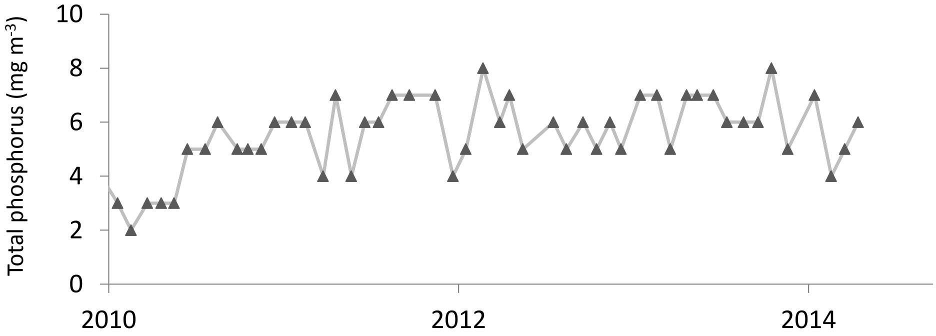

Figure 1. Total phosphorus in surface waters (0 – 17 m) of Lake Rotoma, 2010 to 2014 (data: BoPRC).

1. Vollenweider method.

Action plan (2009) estimates of catchment N and P load for 2003 to 2006 were 19,730 kg N y^{-1} and 720 kg P y^{-1}, and the targets for lake water quality yielded an estimated required reduction of 1,320 kg N y^{-1} and 250 kg P y^{-1} from the catchment (Table 1). However, Action Plan estimates did not account for evaporation from the lake and, furthermore, the water quality targets have since been revised to 120 mg N m^{-3} and 5 mg P m^{-3}. Therefore, the estimates in Table 1 have been superseded by the revision presented in Table 2.

Table 1. Catchment nutrient load estimates using the Vollenweider method, from the Lake Rotoma Action Plan (BoPRC 2009, Appendix 3).

Rainfall	2100 mm			
	Area	Evaporation[32]	Rain minus Evaporation	Volume
Forest	1,022 ha	1000 mm	1100 mm	11,242,000 m^3/yr
Pasture	646 ha	800 mm	1300 mm	83,980,000 m^3/yr
Total from land	1,668 ha			19,640,000 m^3/yr
Lake	1,110 ha		2,100 mm	23,310,000 m^3/yr
Lake area	11,100,000 m^2		Catchment runoff	19,640,000 m^3/yr
Lake volume	395,000,000 m^3		Rainfall on lake	23,310,000 m^3/yr
Residence time	9.2 years		Total input	42,950,000 m^3/yr
Median N & P concentration from 2003 - 2006	137.8 mg-N/m^3	5.00 mg-P/m^3		
Target (1994)	128.6 mg-N/m^3	3.22 mg-P/m^3		
Estimated current load	19,730 kg-N/yr	720 kg-P/yr		Load (M) = CQ/(1-R)
Estimated target load	18,410 kg-N/yr	460 kg-P/yr		R ~ 0.7[33]
Estimated load reduction	**1,320 kg-N/yr**	**250 kg-P/yr**		

Table 2 gives revised estimates of catchment N and P loads based on the reconsideration of target N and P concentrations, hydraulic load, and latest available monitoring data. Predicted TP retention was calculated using the equation of Vollenweider (1975), and retention of TN was assumed to be the same as for TP. Additionally, loads were estimated using upper and lower bounds for R_{pred} of ±10 %, to account for uncertainty in predicted retention. Estimated present (2010 to 2014) catchment loads were approximately 14,500 kg N y^{-1} and 850 kg P y^{-1}. TN in Rotomā is presently well below target levels and hence the calculated target reduction is negative. In the absence of any specific actions or changes within the catchment, the reasons for the reduction in TN observed since 2009 (and hence the potential for future increases) are as yet unclear. Lake TP is presently above target levels, and achieving this target may require a reduction of c. 15% of the catchment P load.

Table 2. Updated Vollenweider catchment nutrient load estimates using water quality data for 2010 – 2014, and revised lake TN and TP targets.

	Lake TN (mg m^{-3})	**Lake TP** (mg m^{-3})		**Est. TN load** (kg)			**Est. TP load** (kg)	
			R_{pred} -10%	**Estimate**	R_{pred} +10%	R_{pred} -10%	**Estimate**	R_{pred} +10%
R_{pred}			0.706	**0.784**	0.863	0.706	**0.784**	0.863
Present water quality	100.7	5.9	10630	**14492**	22761	623	**849**	1334
Target water quality	120	5	12667	**17269**	27123	528	**720**	1130
Reduction (kg)			-2037	**-2777**	-4362	95	**130**	203
Reduction (%)				-19.2%			15.3%	
Action Plan Hydraulic load	42,950,000							
Evaporation	11,890,000							
Revised hydraulic load (Q)	31,060,000							
Lake area (A)	11,600,000							
Lake Volume (V)	410,000,000							
Residence time	13.20							

2. Aerial nutrient export rates

Septic tanks: Action Plan estimates for nutrient contributions from septic tanks assumed full occupancy of houses within the catchment. A recent re-evaluation by Rotorua District Council (RDC) found greater equivalent household numbers and lower average occupancy (to 1.15 persons household^{-1} y^{-1}) resulting in a lower estimate of nutrient inputs from septic tanks compared to the Action Plan. Revised estimated septic tank loads are 1410 kg N y^{-1} and 141 kg P y^{-1} (Table 3). However, it should be considered that potential increases in both household numbers and occupancy rates could considerably increase the sewage load within the catchment. For example, RDC's 'Ultimate HEU' projection of 432 households combined with a change in average occupancy from 1.15 to 1.5 persons household^{-1} y^{-1} would increase estimated septic tank P loads from 141 to 237 kg P y^{-1}.

Agriculture: Literature estimates of P export to waterways from farming range from 0.3 to 1.7 kg P ha^{-1} y^{-1}. The Rotoma Action Plan (2009) used a relatively low leaching rate of 0.38 kg P ha^{-1} y^{-1}, on the basis that agricultural land within the catchment does not drain directly to the lake but is intercepted by two lagoons, where some P will be retained. Additionally, this resulted in good agreement between the calculated total catchment load and the Vollenweider estimates at the time. However, in consideration of the proportion of agricultural land drained by the lagoons (<50%), and in light of revised Vollenweider estimates for total catchment loads (described above), it is now considered that the mid-range of literature estimates (1 kg P ha^{-1} y^{-1}) is more appropriate for the Rotoma catchment (Water Quality TAG, 2014).

Table 3 summarises the relative contributions of nutrient sources within the catchment. Estimates of total load are in reasonable agreement with Vollenweider estimates for N and P. By applying the percentage reduction calculated by the Vollenweider method to the total estimated catchment load, the required catchment P reduction is 160 kg y^{-1}(Table 3), which is lower than the previous BoPRC (2009) estimate of 250 kg y^{-1} (Table 1).

Table 3. Catchment land use nutrient load estimates, as at 2014.

Land cover	Area	% area	kg N yr^{-1} ha^{-1}	kg P yr^{-1} ha^{-1}	kg N yr^{-1}	kg P yr^{-1}	%N	%P
Bare ground	8	0.3	5	1	40	8.0	0.3	0.8
Native forest	643	23.1	3.67	0.12	2360	77.2	14.8	7.4
-with sheep/beef grazing	24	0.9	5	0.15	120	3.6	0.8	0.3
-with dairy grazing	18	0.6	10	0.15	180	2.7	1.1	0.3
Exotic forest	265	9.5	2.81	0.18	745	47.7	4.7	4.6
-with dairy grazing	126	4.5	10	0.15	1260	18.9	7.9	1.8
Scrub	59	2.1	6	0.6	354	35.4	2.2	3.4
Sheep/beef	415	14.9	11.5	1	4773	415.0	29.9	39.7
Dairy grazing	16	0.6	28.8	1	461	16.0	2.9	1.5
Recreational area	14	0.5	14	4	196	56.0	1.2	5.4
Wetlands	32	1.1	0	0	0	0.0	0.0	0.0
Urban built	48	1.7	3	0.7	144	33.6	0.9	3.2
Septic tanks (336 HUE)	n/a	n/a	n/a	n/a	1410	141.0	8.8	13.5
Rainfall to lake	1116	40.1	3.5	0.17	3906	189.7	24.5	18.2
Totals	**2783**	**100**			**15948**	**1045**	**100**	**100**
Adjusted target load*					**19005**	**885**		
Adjusted target reduction					**-3057**	**159**		

*Adjusted target load is calculated by applying the % reduction target from Vollenweider calculations to the estimated total aerial load.

Lake water TN concentration is presently below the target value (Figure 1), however, from 2000 to 2009 it was substantially higher and the drivers of recent reductions are as yet unclear. Therefore, actions that reduce N coincident with P reduction may also contribute to meeting water quality targets in the long term.

Lake Rotomā TP is presently higher than target levels. Possible drivers of this include:

1. *Agricultural land use;* according to latest analyses, P export from agricultural land is likely to be higher than the value of 0.38 kg P ha^{-1} y^{-1} estimated in the Action Plan (2009).
2. *Septic tank leaching;* as soil around septic tanks nears drainage field capacity, nutrient loads will increase. Septic tank monitoring in the early 1990s showed very little P leaching from septic tanks in the area, but more recent BoPRC data has provided evidence of elevated dissolved P concentrations in groundwater near the Rotomā settlement (BoPRC, unpubl.).
3. Other factors that have not been quantified in existing analyses, e.g. in-lake effects from weeds.

Lake Rotomā Action Plan (2009) estimates implied that the catchment P reduction needed to achieve target water quality could be met solely by reticulating sewage out of the catchment. Revised load estimates likewise suggest that the majority of the catchment target can be met by removal of nutrients from wastewater (141kg P y^{-1}, Table 3). However, considering some degree of uncertainty in the calculations, the P reduction target could be as high as 200 kg y^{-1} (Table 2) leaving a shortfall of up to 60 kg P y^{-1} to be removed. This reinforces the need to deal with identifiable sources of P to the lake as comprehensively as possible.

The TAG advises that preventing discharge to the lake of nutrients from septic tanks is vital to the management of Lake Rotomā, because they represent the majority of the P reduction target, and because the proximity to the lake of many septic tank drainage fields means that removal of septic tank loads is likely to yield a relatively immediate benefit to the lake. A rapidly realised reduction in lake TP concentration is a highly desirable outcome.

The impact of nutrients from sources at greater distances from the lake (i.e. much of the agricultural land) is less certain due to the potential for P attenuation between the land and the lake. Although removing nutrient loads to the lake from sewage will achieve most of the target catchment reduction, some reduction of P sources from land use may be required in order to consistently meet water quality targets. The lake water quality targets should be considered upper limits for annual nutrient concentrations.

The TAG also advises that actions additional to sewerage reticulation are necessary to address the P load reaching Lake Rotomā from its catchment. A review of the Action Plan is necessary to ensure that sufficient P reduction initiatives are implemented to protect Lake Rotomā from water quality decline.