Lake Rerewhakaaitu Nutrient Budget

Prepared for Bay of Plenty Regional Council

19 June 2012

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1 Introduction

There is a standard in the Bay of Plenty Regional Council's Water & Land Plan (W&LP) that sets a statutory limit for the quality for each of the Rotorua lakes. The Trophic Level Index (TLI) is an indicator of lake productivity (trophic state) and levels were set for each lake after public consultation in the early 1990s. The trophic state of a lake is determined by the quantities of nitrogen and phosphorus discharged to the lake and the index combines the measures of the resulting algal productivity with the nitrogen and phosphorus concentration in the lake. People wanted the quality of the lakes to remain as they were in the early 1990s but wanted to see some lakes improved *eg* Rotorua, Rotoiti, Rotoehu, Okareka and Okaro. For most lakes the statutory limit was set as the TLI of the lake in 1994.

When a lake exceeds its statutory TLI limit, changes in land use management and other remediation methods need to be considered to reduce nitrogen and phosphorus inflows to the lake. Policy in the Regional Council's W&LP prescribes a process where a non-statutory action plan is developed with the community to manage nitrogen and phosphorus flows to the lake. An option exists to underwrite this process with the development of a rule which would link the statutory TLI limit to the non-statutory action plan and give the action plan some status with the Environment Court.

A two-year study of Lake Rerewhakaaitu was carried out between 1972 and 1974, by Dr Geoff Fish, who was a scientist with the Fisheries Research Division of the Ministry of Agriculture and Fisheries and stationed in Rotorua at that time. Then from 1990 the Bay of Plenty Regional Council began regular monitoring of Rerewhakaaitu and the other Rotorua lakes. The Regional Council has recorded the trophic state of Lake Rerewhakaaitu ranging from a TLI of 3.2 to 4.2 from 1990 to 2011 compared to the TLI target in the W&LP of 3.6. From monthly measurements over the period 1972 to 1974 (Fish, 1977) the TLI can be calculated from the mean to be 4.3.

In the 1970s, the Bay of Plenty Catchment Board and Regional Water Board began regulating discharges to water under the Water & Soil Act. Dairy shed discharges were required to be treated in oxidation ponds and direct discharge of dairy shed wash-down to streams or ephemeral waterways was forbidden. That action had a marked effect on waterbodies such as Lake Rerewhakaaitu and the improvement in lake quality is seen in the TLI improvement by the 1990s against a background of increasing farm productivity.

Figure 1 shows the annual TLI over the period from 1990 to 2011 with the 3 year average TLI and the statutory upper limit. For about half the period catchment management has been consistent with maintaining the quality of the lake below a TLI of 3.6. The data used to calculate the TLI is displayed in Table 1. The long term average in the bottom line is used within the report to calculate the average sustainable load for the catchment as it is identical with the objective lake quality.

Water level in the lake shows some relationship with lake quality (Figure 2). Poorer quality water is weakly related to high lake level, which is assumed to be related to increased storm runoff flows with high nitrogen and phosphorus content and a more sustained load.

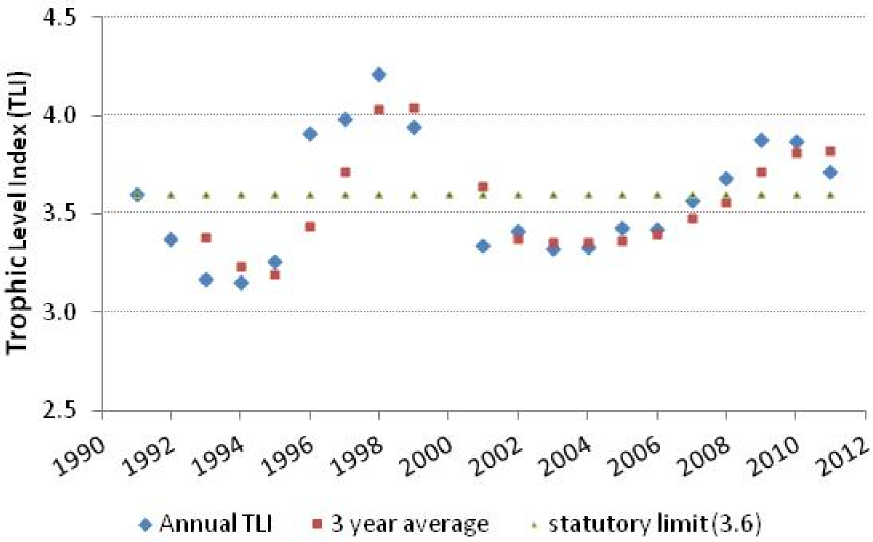

Figure 1 *The annual Trophic Level index (TLI) and 3 year average TLI for Lake Rerewhakaaitu compared to the statutory limit in the Bay of Plenty Regional Council's Water & Land Plan.*

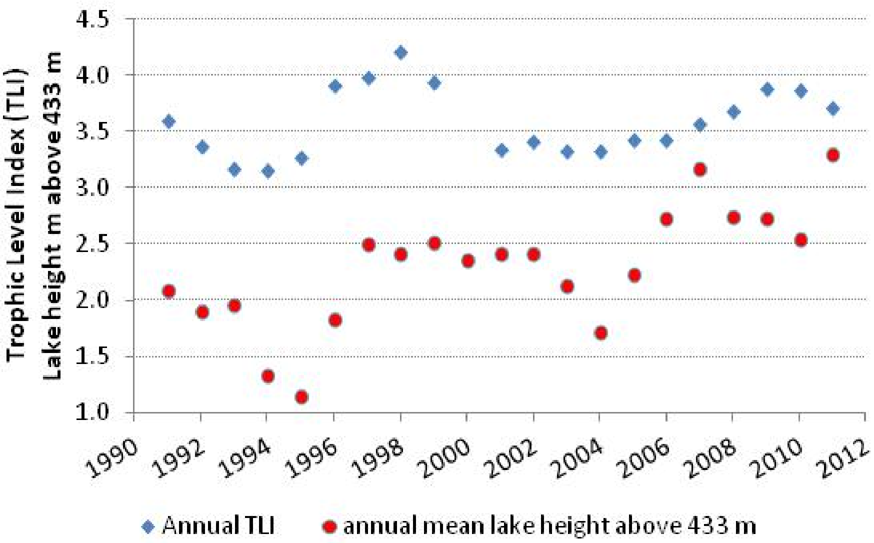

Figure 2 *Annual Trophic Level Index (TLI) for Lake Rerewhakaaitu and annual lake height (m) above 433 masl.*

Taking the 1970s data into consideration there have been three recorded periods when the TLI has exceeded 3.6. The first was when cowshed wash-down was discharged directly from dairy sheds to ephemeral channels. The second occurred at a time when oxidation ponds were in use and some land irrigation of dairy shed effluent was taking place. In the third period, the Rerewhakaaitu farmers' project had been in progress and innovations to reduce nutrient loss had been introduced. It may be a coincidence, but the peak TLI during the periods of poorer quality lake water has been reducing over time. More likely, it shows that land use management has been effective in reducing nitrogen and phosphorus loss.

The results show that there is a marginal decrease in nitrogen and phosphorus loss still to be achieved to maintain the lake TLI permanently below 3.6. Storm flows are likely to be the best source to target for further treatment and if the adoption of nutrient conservation practices has not been fully subscribed to by all landowners of the catchment then some measure should be adopted to encourage others.

Table 1 Trophic Level Index from 1990 to 2011 with constituent annual average data (from Scholes, 2011).

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average
Jul 1990 - Jun 1991	3.90	4.95	9.83	321.86	3.72	3.60	3.12	3.94	3.60
Jul 1991 - Jun 1992	3.14	7.34	8.00	356.96	3.48	3.08	2.86	4.07	3.37
Jul 1992 - Jun 1993	2.74	7.41	5.47	310.22	3.33	3.07	2.37	3.89	3.17
Jul 1993 - Jun 1994	2.20	6.92	5.40	334.14	3.09	3.16	2.36	3.99	3.15
Jul 1994 - Jun 1995	2.42	6.37	6.50	329.85	3.19	3.27	2.59	3.97	3.26
Jul 1995 - Jun 1996	7.80	3.78	8.86	398.14	4.49	3.95	2.98	4.22	3.91
Jul 1996 - Jun 1997	8.43	4.34	10.53	446.27	4.57	3.77	3.20	4.37	3.98
Jul 1997 - Jun 1998	17.18	4.45	9.67	547.67	5.36	3.74	3.10	4.63	4.21
Jul 1998 - Jun 1999	7.38	2.78	6.00	499.50	4.42	4.32	2.49	4.51	3.94
Jul 1999 - Jun 2000									
Jul 2000 - Jun 2001	2.97	5.62	5.74	359.46	3.42	3.44	2.43	4.08	3.34
Jul 2001 - Jun 2002	3.33	4.88	5.65	348.07	3.55	3.62	2.41	4.04	3.41
Jul 2002 - Jun 2003	2.93	6.68	6.93	333.33	3.40	3.21	2.67	3.98	3.32
Jul 2003 - Jun 2004	2.35	8.25	9.61	376.59	3.16	2.92	3.09	4.14	3.33
Jul 2004 - Jun 2005	3.42	5.88	7.50	338.63	3.58	3.38	2.77	4.00	3.43
Jul 2005 - Jun 2006	2.82	7.01	8.78	389.92	3.37	3.14	2.97	4.19	3.42
Jul 2006 - Jun 2007	2.87	5.77	10.98	406.80	3.38	3.41	3.26	4.24	3.57
Jul 2007 - Jun 2008	3.87	4.93	8.54	482.04	3.71	3.61	2.94	4.47	3.68
Jul 2008 - Jun 2009	5.15	4.29	12.17	429.70	4.03	3.79	3.39	4.32	3.88
Jul 2009 - Jun 2010	5.56	3.97	11.24	390.91	4.11	3.88	3.29	4.19	3.87
Jul 2010 - Jun 2011	3.98	4.44	10.90	361.05	3.74	3.74	3.25	4.09	3.71
Averages	**4.72**	**5.50**	**8.42**	**388.06**	**3.76**	**3.51**	**2.88**	**4.17**	**3.58**

2 Nutrient budget

The catchment boundary and land use type and area have been supplied by the GIS section of the Bay of Plenty Regional Council and their reference is: (Land Use Data: LandcoverUse_RotLakes03-2003 land use data from Rotorua Lakes. Catchment data: Catchments_RDCLiDAR-boundaries derived from 2006 LiDAR data).

Table 2 Nutrient budget for the catchment of Lake Rerewhakaaitu based on land-use nutrient loss estimates.

	Area	Rate of P loss	Rate of N loss	P Load	N Load
	ha	*kg/ha/yr*	*kg/ha/yr*	*kg/yr*	*kg/yr*
Cropping	407	1.20	32	488	13014
Exotic forest	795	0.40	5	318	3973
Indigenous forest & scrub	540	0.40	8	216	4321
Dairy + dairy grazing	2682	1.10	31	2950	83127
Sheep, beef, deer	188	1.20	12	226	2261
Urban stormwater	7	0.80	8	6	55
Road reserve	56	0.80	8	45	450
Septic tanks (100 persons, 3.65 kgN/p/y, 0.37 kgP/p/y.				37	365
Wetland	87	-1.00	-36	-87	-3121
Rainfall on lake	532	0.15	4	80	2126
Total	**5293**			**4278**	**106570**

The 2003 land use data is the latest available and if land use has changed since then an assessment can be made within the action plan. A significant change would most likely relate to either change to forestry of out of forestry and the effect could be quantified.

Table 2 shows the relative sizes of the nutrient contribution from different land use pools with the pastoral sector being the greatest source of nitrogen and phosphorus.

The coefficients describing the rate of loss of nitrogen and phosphorus are taken from the scientific literature and from the data posted for the Rerewhakaaitu farmers' project in project newsletters.

Cropping is assumed to be maize or fodder crops on dairy farm land and given a nominal increase over the nutrient loss coefficients for dairying. Nutrient loss from the farmed portion of the catchment is taken from the Overseer modelling data in Newsletter 5, ("Lake Rerewhakaaitu 3. Developing a Catchment Management Plan by Farmers", December 2011), for nitrogen and Newsletter No 3 for phosphorus.

The nutrient loss coefficients for exotic forest are from the high end of the range suggested in Meneer *et al* (2004) in view of comments based on Hamilton (2005) where forest harvest is implicated in enhanced nutrient loss.

A high nitrogen loss coefficient has been used from native forest and scrub due to the presence of large areas of broom.

Nutrient loss in urban storm water and from the road reserve has been taken from a storm water runoff study in a suburb of Hamilton city (Williamson, 1985). Septic tank leachate from the urban area, school and camping grounds is estimated as the load from a permanent population of 100 people.

Nitrogen removal rates of 5 – 15 $mg/m^2/d$ are quoted by Rutherford and Nguyen (2004) from natural wetlands and seeps and rates of 270 – 330 $mg/m^2/d$ for constructed wetlands (Sukias, 2010). Homestead Arm of Lake Rerewhakaaitu, although choked with aquatic weed, is probably functioning as an effective wetland. That is not included in the 87 ha of wetland area estimated from the aerial photos. A de-nitrification rate of 10 $mg/m^2/d$ is used in Table 2 for wetlands.

3 Catchment load from in-lake nutrient levels

Catchment nutrient load can be modelled based on in-lake nutrient concentrations (C), flow through the system (Q), and nutrient retention within the lake (R). This 'back calculation' is based on a method used by Hoare (1980) for Lake Rotorua. The general concept is shown in the figure below.

At Rerewhakaaitu it is not possible to measure an outflow so it is assumed that the out-flowing water is the same concentration as average lake water concentration. The flow rate through the lake cannot be measured so rainfall – evapo-transpiration is calculated for the catchment and added to the quantity of water falling directly on the lake - evaporation. There are empirical formulae for calculating the retention coefficient (Figure 3). In this case R is calculated to be 0.80 based on the method of Nurnberg (1984) as described in Rutherford and Cooper (2002).

An average annual rainfall of 1200 mm is used in the calculation from the rain gauge readings of M. Pacey and quoted in the farmers' project newsletters. An average Potential Evapo-transpiration (PET) rate of 900 mm/yr is used (Rutherford *et al* 2009) based on pasture PET of 800 mm/yr and forest PET of 1100 mm/yr. Evaporation from the lake surface is calculated to be 820 mm/yr, which is derived from evaporation pan data from Rotorua Airport. Only a portion of the water falling on the catchment is assumed to drain to Lake Rerewhakaaitu (White *et al* 2003). The Mangakino Stream is the only permanently flowing stream that enters Lake Rerewhakaaitu. The Awaroa has a low permanent flow in extreme rainfall years. There are a number of incised ephemeral flow paths, including the Awaroa channel that indicates considerable flood flows occur. Local comment supports this.

Figure 3 Schematic of lake model.

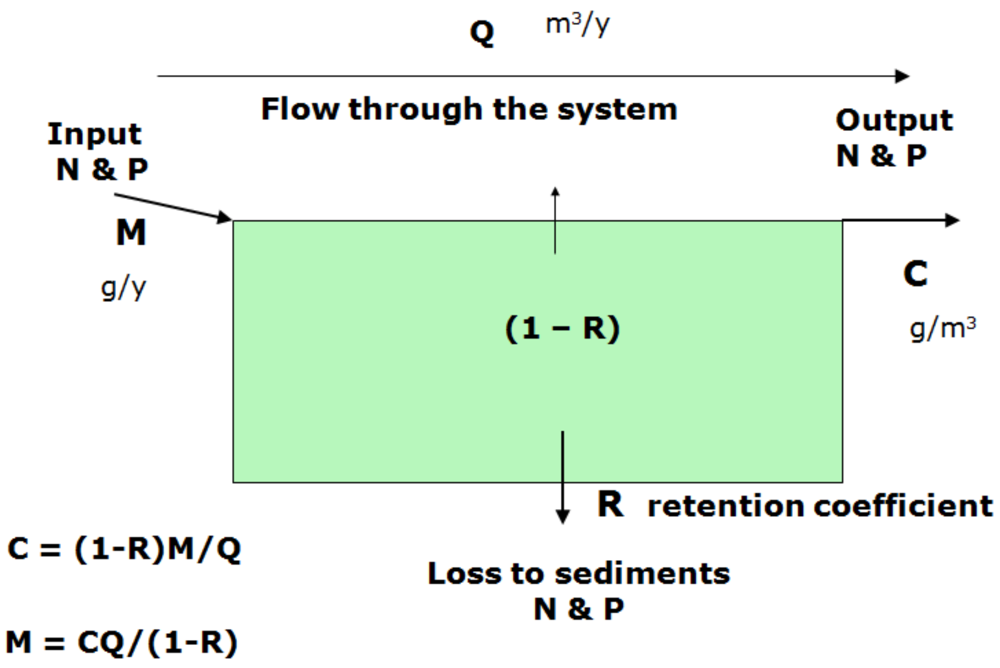

Figure 4 shows a schematic of the drainage patterns for the Lake Rerewhakaaitu catchment and demonstrates that a calculation has to be made to determine what proportion of catchment drainage enters Lake Rerewhakaaitu. This calculation is shown in Appendix 1.

Figure 4 Schematic of water and nutrient flows for the Rerewhakaaitu catchment

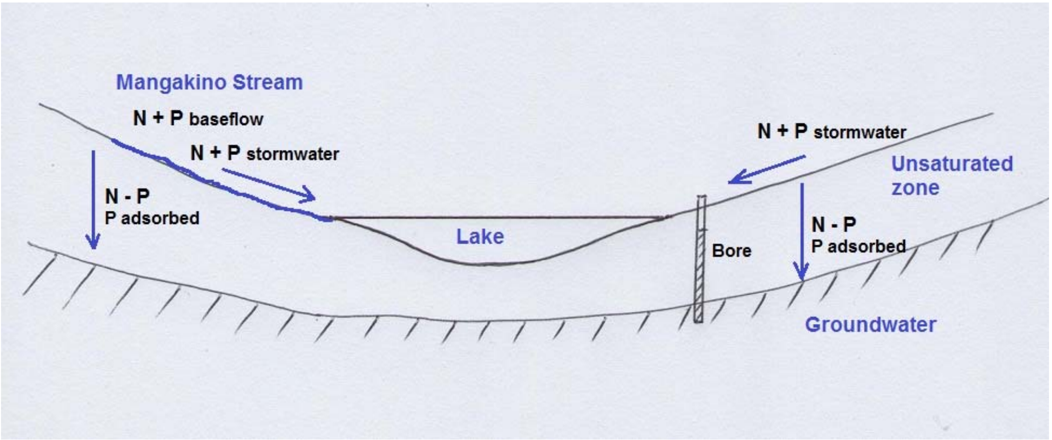

Figure 4 demonstrates that the lake inflow includes the permanent flow from the Mangakino Stream and stormwater flows. Stormwater flows includes some de-watering of the unsaturated zone into the lake after rain events, The catchment of the Awaroa Stream de-waters almost continuously for long periods after excessive rainfall. In the calculation in Appendix 1 these flows are included with stormwater and the total catchment flow to the lake is estimated at 54.7 L/s. This is about an eighth of the total flow estimated for the terrestrial portion of the catchment.

With these assumptions the catchment nutrient load (M) in the equation above can be calculated. Hoare (1980) found that the R value in Lake Rotorua was similar for nitrogen and phosphorus. This has been assumed for Lake Rerewhakaaitu in the first instance. In Table 2 the long term average in-lake nutrient concentrations have been used to estimate the sustainable catchment load discharged to the lake as they are identical to the objective concentrations. The highest in-lake nutrient concentrations, for the most recent period when the TLI exceeded 3.6, are used to estimate the peak catchment load in Table 3.

Table 2 Rerewhakaaitu catchment load derived from the objective in-lake nutrient concentrations (Scholes 2011).

	TP	**TN**		
lake concentration mg/m3	8.4	388		**C**
	land	**lake**	**total**	
Lake volume (m3)		36647000		
Area (ha)	4761	532	5293	
(rain on land -PET)/8, (rain on lake-evap) m	0.038	0.38		
flow (l/sec)	57		121	
flow/yr (m3)	1809180	2021600	3830780	**Q**
Hydraulic loading (Q/lake area A) m/y			0.7	**Q/A**
Retention R (15/(18+Q/A))			0.80	**R**
	TP	**TN**		
M=CQ/(1-R) kg/yr	162	7480		**M**

The load calculated as being discharged to the lake is much lower than the load calculated for the whole catchment in Table 2.

Table 3 Rerewhakaaitu catchment load derived from the peak lake nutrient concentrations since 2005 (Scholes 2011).

	TP	**TN**		
lake concentration mg/m3	12.2	482		**C**
	land	**lake**	**total**	
Lake volume (m3)		36647000		
Area (ha)	4761	532	5293	
(rain on land -PET)/8, (rain on lake-evap) m	0.038	0.38		
flow (l/sec)	57		121	
flow/yr (m3)	1809180	2021600	3830780	**Q**
Hydraulic loading (Q/lake area A) m/y			0.7	**Q/A**
Retention R (15/(18+Q/A))			0.80	**R**
	TP	**TN**		
M=CQ/(1-R) kg/yr	235	9292		**M**

A catchment discharge to Lake Rerewhakaaitu is estimated at 54.7 L/s in Appendix 1 with an annual nutrient load of 500 kg/yr phosphorus and 9900 kg/yr nitrogen. An average flow to the lake of 57 L/s was calculated from the rainfall – PET, divided by 8, to be consistent with the flow estimated in Appendix 1.

A sensitivity analysis has been carried out and the results are shown in Table 4. The retention coefficient was adjusted by ±0.1 and the catchment loads calculated. Changing the retention coefficient makes a large difference to the calculated catchment load. A retention coefficient of 0.8 provides the best fit for the Rerewhakaaitu nitrogen input load as calculated in Appendix 1. A retention coefficient of 0.9 provides the best fit for the catchment input load of phosphorus. The retention coefficient is not necessarily the same for both nutrients and as noted by Fish (1978) adsorption of phosphorus by suspended sediment with high levels of allophane may lower the in-lake concentration. A coefficient of 0.9 may be more accurate for phosphorus. If some phosphorus is adsorbed within the natural system there seems little point in including it in the nutrient reduction target, however.

Table 4 Sensitivity of the lake nitrogen and phosphorus loads to changes in the retention coefficient and in the hydraulic loading.

		Objective loads t/y		Maximum loads t/y	
adjust	R	TP	TN	TP	TN
R	0.7	107	4954	156	6155
R	0.8	162	7480	235	9292
R	0.9	322	14863	467	18464
125% rain	0.79	225	10410	327	12932
150% rain	0.77	274	12651	398	15716

Increasing the hydraulic loading by increasing rainfall also results in an increase in nutrient loading from the catchment. Lake level data indicates that this will also increase lake level. With a higher hydraulic loading the retention coefficient is reduced slightly.

4 Nutrient reduction target

The reduction target for Lake Rerewhakaaitu is assessed as the difference between the recent maximum load and the target load for the lake. The target load has been calculated from the long term average in-lake nutrient concentrations which are consistent with the lake quality objective TLI of 3.6. The maximum load is associated with elevated lake level.

A review of the original draft document suggested normalising the data for lake level. The same can be achieved by using the higher hydraulic loading estimates from Table 4. Three estimates of the reduction target are calculated in Table 5 using average rainfall, 125% rainfall and 150% rainfall. The retention coefficient is taken as 0.8, which is calculated from the empirical formula. A suggestion in the review that a retention coefficient of 0.9 should be used has not been carried out because the empirical formula produces a similar catchment load to that produced by the conceptual baseflow/stormflow assessment in Appendix 1.

Table 5 The nutrient reduction targets calculated for the Lake Rerewhakaaitu catchment for three rainfall (hydraulic loading) scenarios.

	average rainfall		125% rainfall		150% rainfall	
	TP kg/y	TN kg/y	TP kg/y	TN kg/y	TP kg/y	TN kg/y
Maximum load	235	9292	327	12932	398	15716
Target load	162	7480	225	10410	274	12651
Reduction target	73	1812	102	2522	124	3065

It seems logical to adopt a reduction target of 125 kg/y phosphorus and 3100 kg/y nitrogen as storm water runoff seems to be the factor that most influences poor lake quality.

From Table 6 in Appendix 1, it is noted that the target could be achieved by directing conservation efforts at storm flows in the Awaroa and Managkino Stream catchments in particular, but beneficial results would be obtained by targeting all storm flows.

Table 8 in Appendix 2 relates the rainfall runoff model to the nitrogen concentration (5 g/m^3) in the Mangakino Stream and the rate of nitrogen loss from land. This is compared to the average nitrogen loss from land (38 kg/ha/yr) estimated for the Rerewhakaaitu Project (Parker *et al* 2006) and the estimated concentration of nitrate nitrogen (5 g/m^3) in groundwater as a consequence of that nitrogen loss rate. The two assessments overlap and the target reduction calculated from the assessment using 150% rainfall in Table 5 seems to include a safety margin.

Figure 4 shows that nitrogen from the catchment is lost to groundwater with phosphorus tending to be retained by adsorption within the soil. An action plan for Lake Rotomahana may also adopt a nutrient reduction target which may include landuse in the Lake Rerewhakaaitu catchment. A common approach for the whole catchment and neighbouring catchments with respect to nutrient conservation is sensible.

5 Discussion

5.1 Inflow rate

The mean flow to Lake Rerewhakaaitu has been estimated as a lower figure than for the study of McIntosh *et al* (2001) and White *et al* (2003). A local rain-gauge has provided a more accurate measure of rainfall, which is lower than estimates previously used. Within the hydrology chapter of McIntosh *et al* (2001), Ellery estimated that an average inflow of 80 L/s was the best fit to match changes in lake level. An inflow of 57 L/s has been in this assessment.

About 90% of the load of nitrogen and phosphorus discharged from the Lake Rerewhakaaitu catchment disperses to Lake Aniwhenua on the Rangitaiki River, Lake Rotomahana within the Tarawera group of lakes or to the Waikato River system. All these locations have objectives in regional plans to maintain the environmental quality of waterways. At some point in the future the environmental risk due to the nutrient load from the Rerewhakaaitu catchment will be assessed for those catchments.

The only permanent surface inflow to Rerewhakaaitu is the Mangakino Stream where the flow rate has varied from 1 – 172 L/s in the Regional Council's gauging database and the mean flow is 15.7 L/s (Deniz Özkundakci pers. comm.). The majority of water, therefore, enters the lake in flood flow events. Flash flood flows from the Rerewhakaaitu catchment tend to enter Lake Rerewhakaaitu while the majority of groundwater flows to waterbodies outside the catchment. Remediation of nutrient levels in flood flows will improve the quality of Lake Rerewhakaaitu and management options to reduce leaching of nutrients will improve the quality of Rerewhakaaitu and the waterbodies of adjacent catchments.

5.2 Remediation

Through the Sustainable Farming Fund projects land management change and nutrient loss reduction methods have been implemented with more planned. There is some evidence that these actions have been effective in reducing the peak load of nutrients discharged to Lake Rerewhakaaitu.

The Regional Council is presently implementing or obtaining resource consent to implement methods to reduce the storm water and groundwater flow of nitrogen and phosphorus to the lake.

A treatment wall is proposed for the lower reach of the Awaroa Stream which is ephemeral in dry conditions. The wall will combine wood chip or corn cob as a carbon source and include melter slag to absorb phosphorus and maintain porosity. The design of the treatment wall will provide for treatment of groundwater flow by phosphorus absorption and by de-nitrification. In flood events the design is planned to provide for some phosphorus absorption.

Melter slag has been trialled within the Mangakino Stream and on races and bridge approaches and has proved to be effective in absorbing phosphorus (McDowell *et al* 2006, McDowell, 2007). McDowell concluded that a greater amount of melter slag than the 2 tonne used in the Mangakino Stream trial would be needed to effectively reduce phosphorus in the stream. The nutrient budget shows that storm flows are the most effective target source for reducing nutrient flow into Lake Rerewhakaaitu, therefore targeting nutrients on ephemeral flow paths, races and bridge approaches where runoff is likely to enter the stream should prove more productive.

In the stream study, slag absorbed 2600 mg/kg phosphorus. To absorb 125 kg/y of phosphorus about 50 tonnes/y of melter slag would need to be employed. However, the stream study was a long term trial and the storm flows would have a shorter contact time with the melter slag.

A trial wetland is planned to be constructed within the channel of the Mangakino Stream to provide de-nitrification before the stream discharges to the lake. A resource consent is being sought for this. There are impediments to placing extensive blockages in the stream channel as it is the only stream flowing into the lake and is an important spawning and juvenile fish rearing stream. In places willows grow over the stream and can form partial blockages allowing build-up of sediment. Native plants like Kahikatea planted under the present canopy along the stream banks or Pukatea with its root buttresses when mature, might perform a similar function in the long term.

6 Conclusion

The objective of the Regional Council's policy is to maintain the quality of Lake Rerewhakaaitu below a TLI of 3.6 consistently. The trigger in the Regional Water and Land Plan that activates the land control Rule 11 has a tolerance of 0.2 TLI units to prevent the rule being activated unduly.

The target load reduction to maintain Lake Rerewhakaaitu at a TLI of 3.6 is 125 kg/y phosphorus and 3100 kg/y nitrogen.

The TLI is an indicator of lake productivity and at Rerewhakaaitu productivity is more responsive to phosphorus than nitrogen. A greater effort which removes more phosphorus from flowing into Rerewhakaaitu will allow some tolerance for nitrogen to flow into the lake. For the leaching component of nitrogen and phosphorus which affects other catchments, nitrogen will be the more important nutrient to control. Phosphorus has less tendency to leach in these strongly phosphorus absorbing soils. The overall objective is to reduce nitrogen and phosphorus loss to the lowest levels possible. Given that stormwater flows are the greatest source of nitrogen and phosphorus flowing to Rerewhakaaitu the most effective strategy for Rerewhakaaitu is to strongly target phosphorus removal from stormwater flows.

The TLI has been cyclical over the record since 1990. If this continues into the future it would be possible to use this knowledge to trigger enhanced efforts to remediate storm flows once an initial trend is identified of increasing annual TLI.

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APPENDIX 1

Estimation of the annual inflow to Lake Rerewhakaaitu.

The daily average flow for the Mangakino Stream has been synthesised by comparison with the Ngongotaha Stream (D Özkundakci pers. comm.) and a good match is found. Rutherford and Timpany (2008) have analysed nutrient load data for the Ngongotaha and estimated stormflows and nutrient loadings for all of the streams of the Lake Rotorua catchment. The relationship of the Mangakino Stream with the Ngongotaha Stream is utilised to derive the proportion of stormflow and nitrogen and phosphorus loading for stormflow for the Mangakino Stream.

A comparative method is derived to estimate stormflows in the Rerewhakaaitu catchment based on runoff coefficients used for the Rational method of peak stormflow calculation. http://drdbthompson.net/writings/rational.pdf

Runoff coefficients for the rational method are;

Pasture	0.12 – 0.62
Cultivated land	0.08 – 0.41
Forest	0.05 – 0.25
Asphalt streets	0.70 – 0.95

In this case the coefficients are compared with the estimated stormflow for the Mangakino Stream. For the pumice soils of the Rerewhakaaitu catchment the high value is assumed to be similar to the upper level for cultivated soils and the low value is assumed to be the lower level for pasture (range 0.12 – 0.41). The Managakino Stream is given a runoff coefficient of 1 as all other stormflows will relate to occasions when stormflow actually occurs in the Mangakino Stream.

In flood events, water is conveyed to the Mangakino Stream and then is transported downstream in a continuous flow in a channel with a permanent baseflow. Stormwater in other catchments may be conveyed to a single ephemeral channel (Awaroa) or to several overland flow courses or may be dispersed across a relatively flat plain. Runoff in all these situations will be attenuated with respect to the Mangakino.

The range above is expanded from (0.12 - 0.41) to (0.29 - 1) by multiplying by 2.44, where 1 is the runoff coefficient in the Mangakino Stream and the other areas are assessed with respect to factors such as; slope, presence of permanent flow paths or dispersed flow paths, presence of humps and hollows. Some of the stormflow may be conveyed to the lake as a sub-surface flow in the unsaturated zone for a period after a storm event.

Table 6 Description of the runoff coefficient for equal sub-divisions of the Rerewhakaaitu catchment in comparison to the runoff in the Mangakino Stream catchment.

Rerewhakaaitu catchment	runoff coefficient	Description of flood flow
Mangakino base flow		
Mangakino flood	1.0	Stormwater conveyed in permanent flow of water
Awaroa flood	0.8	Stormwater conveyed in ephemeral channel with humps and hollows
Brett Rd flood	0.6	Gentle slope to lake with multiple overland flow courses
Ash Pit Rd 1 flood	0.5	Slope to flat land with multiple overland flow courses
Ash Pit Rd 2 flood	0.3	Relatively flat with few defined flow paths

Because the same landuse is carried out across the whole catchment, nutrient loads are assigned to each area based on the nutrient load for the Mangakino Stream. The baseload for the stream is from D. Özkundakci (pers. comm.). The stormflow for the Mangakino Stream is derived from the relationship of stormflow (44%) to baseflow (56%) for the Ngongotaha Stream (Rutherford and Timpany, 2008). Rutherford and Timpany, (2008) found that of the total annual nutrient load for the Ngongotaha Stream, 69% of total phosphorus (TP) and 54% of total nitrogen (TN) was conveyed in stormflows.

Table 7 Estimation of the total flow rate and nutrient discharge load (kg/y) to Lake Rerewhakaaitu by comparison with data for the Ngongotaha Stream.

Rerewhakaaitu catchment	runoff coefficient	L/s	TP	TN	ha
Mangakino base flow		15.7	60	2200	
Mangakino flood	1.0	12.2	130	2400	952
Awaroa flood	0.8	9.8	100	1920	952
Brett Rd flood	0.6	7.3	80	1440	952
Ash Pit Rd 1 flood	0.5	6.1	70	1200	952
Ash Pit Rd 2 flood	0.3	3.7	40	720	952
Total		54.7	480	9880	4760

The total flow for the Rerewhakaaitu catchment is calculated from rainfall – evapotranspiration as 453 L/s. From the above table only about an eighth of the flow generated in the catchment of Lake Rerewhakaaitu reached the lake.

APPENDIX 2

Rainfall runoff model compared to the nitrogen concentration in the Mangakino Stream

Table 8 compares the theoretical nitrogen loss rate from the land with nitrogen concentration in the Mangakino Stream and the rainfall/runoff model used in this report. Three rainfall scenarios were used and the final target taken from the 150% of annual rainfall assessment.

Table 8 Nitrogen loss rate from land with variation in the rainfall, to provide for the measured nitrogen concentration in the Mangakino Stream.

Annual rainfall	% annual rainfall	Evapo transpiration	runoff + drainage per ha	runoff + drainage per ha	nitrogen conc Mangakino Stream	nitrogen loss rate from land
mm		mm	mm	m^3	g/m^3	kg/ha/yr
1200	100	900	300	3000	5	15
1500	125	900	600	6000	5	30
1800	150	900	900	9000	5	45

The average nitrogen leaching rate for the Rerewhakaaitu catchment was 38 kg/ha/yr and the estimated groundwater concentration of nitrate nitrogen was 5 g/m^3 (Parker *et al* 2006).