

Prediction of Future Nitrogen Loading to  
Lake Rotorua

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## ABSTRACT

Groundwater that feeds streams and springs in the Lake Rotorua catchment has 15 - 130 years mean residence times in the aquifer. These long residence times of the water in the ground result in large time-delays of nitrogen loading from historical agricultural and urban development in the catchment. Currently observed increases in nitrogen loading in surface and groundwater are mostly due to the delayed impact of catchment development that occurred around 55 years ago. Further increases in nitrogen are expected.

The time-dependence of the arrival of water to the Lake that was recharged since landuse development in the 1950's was calculated using the age distribution of the water derived from tritium, CFC and SF<sub>6</sub> data. The arrival of post-landuse water over time was then used to estimate the nitrogen load to the Lake for the time prior to landuse development, for the time since then, and for the future. Excellent matches between measured N loads over the last decades and predicted loads demonstrate the robustness of the approach, and that the model assumptions used for future predictions are reasonable.

Future groundwater-derived nutrient loads are listed below. No changes are expected in phosphorus loads via groundwater as long as landuse-derived P continues to be absorbed by the volcanic soils in the catchment.

	Total N loading [t/y]						Total P loading [t/y]	
	pre-landuse	2005	2055	2105	2155	2205	steady-state	steady-state
<b>Major streams</b>								
Utuhina	6	31	39	42	43	43	43	2.5
Ngongotaha	6	34	35	35	35	35	35	2.2
Waiteti	4	40	49	51	52	52	52	1.6
Awahou	7	57	77	85	89	91	92	3.3
Hamurana	11	53	78	92	102	108	118	6.3
Waiohewa	1	13	16	17	17	17	17	0.7
Waingaehe	1	10	20	25	28	30	35	0.7
Puarenga	5	42	51	52	53	53	53	3.6
Waiowhiro*	1	8	10	10	10	11	11	0.7
<b>Other</b>								
Minor streams	1	14	17	18	18	18	18	
Lake-side springs	1	13	14	15	15	15	15	
groundwater direct	15	104	124	129	130	131	131	
<b>Total</b>	<b>60</b>	<b>420</b>	<b>532</b>	<b>572</b>	<b>592</b>	<b>602</b>	<b>619</b>	

The nitrogen loading to Lake Rotorua prior to major landuse development in the catchment in the 1950's was calculated to be 60 t/year. This has slowly increased to a present nitrogen load of 420 t/y, delayed by long travel times of the groundwater. The nitrogen loading is expected to further increase to 532 t/y in 50 years (25% increase from current), 572 t/y in 100 years (35% increase from current), and to 619 t/y at steady-state (47% increase from current).

About 75% of the groundwater-derived nitrogen loading at steady-state enters Lake Rotorua via the nine major streams, and about 20% enters the Lake from direct groundwater inflow to the lake bed. The loading estimate for the direct groundwater has the largest uncertainty because very limited age and chemistry data is available. Lake side springs and minor streams together contribute only about 5% of the total nitrogen load to Lake Rotorua.

Hamurana, Awahou and Waingaehe streams are expected to show the largest increases in N loading in the future because they contain the oldest water, and Hamurana and Awahou streams will have the largest increase in nitrogen mass loading because they have the largest flow. Utuhina, Waiteti, and Puarenga streams are expected to have medium increases in nitrogen loading because of younger water age and lower flow. Ngongotaha, Waiohewa, and Waiowhiro streams are expected to have little further increase in N loading because of low flow or steady-state already reached.

Landuse intensification that has occurred within the last 20 years is not yet reflected in the current nitrogen prediction model because information on the timing and amount of intensification was not yet available. The present nitrogen prediction model assumes that the nitrogen input in the catchment from landuse development has remained relatively constant since the 1950's. The current predictions would therefore represent a lower limit to which the more recent nitrogen loads would have to be added.

If more information on timing and amount of landuse changes becomes available, the N load predictions can be refined to incorporate landuse change in several stages by calculating the predicted N load for each stage and adding these. Positive (intensification) or negative (retirement) changes can be considered.

The large groundwater system of the Lake Rotorua catchment responds delayed by decades to landuse changes. These timeframes will need to be considered carefully for any possible mitigation options in the catchment.

## **KEYWORDS**

Nitrogen contamination, groundwater, nitrogen predictions, age distribution, tritium, CFC, SF<sub>6</sub>

## 1.0 INTRODUCTION

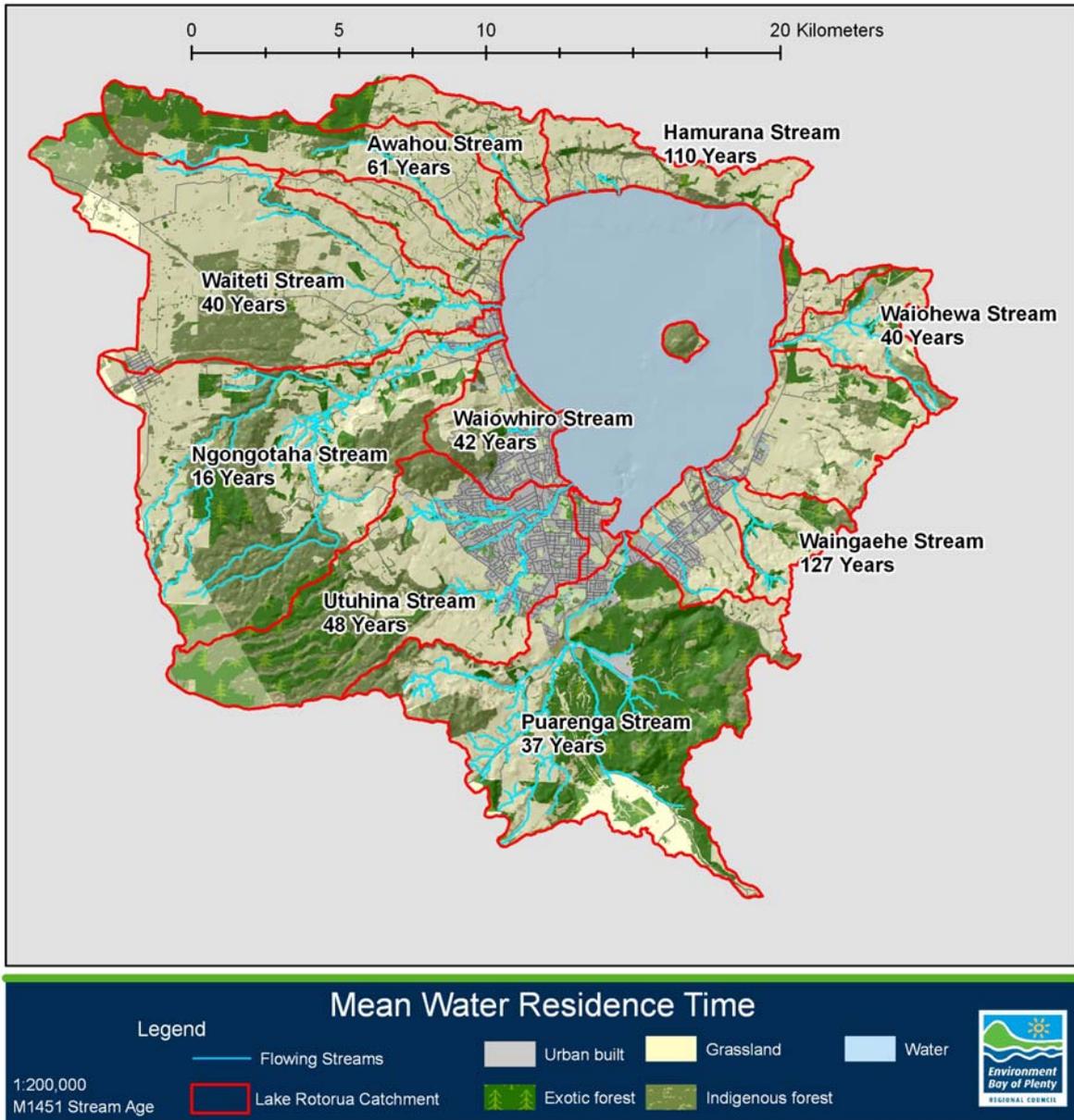
Environment Bay of Plenty is developing an action plan for Lake Rotorua to improve Lake water quality. An understanding of the future Lake catchment loads is needed for defining the nutrient reduction target for the Lake. This information is vital for guiding decision making for the action plan. Environment Bay of Plenty commissioned GNS Science to provide an updated analysis of the predicated nutrient contribution from the major surface and groundwater flows to the lake using the latest age dating and water quality information collected by GNS Science and Environment Bay of Plenty.

Morgenstern et al. (2004) showed that for the groundwater-fed major streams the mean residence times of the water in the aquifer are between 15 - 130 years (Figure 1.1). These long groundwater residence times result in large time-delays; nutrient loads from the historical agricultural and urban development of the catchment arrive at the lake only after many decades. Currently observed increases in nitrogen loading are mostly a result of the delayed impact of catchment development from around 55 years ago.

Time trends of nutrient loading of this report will focus on nitrogen only as no major change in phosphorus load is expected. Landuse derived phosphorus is absorbed by the volcanogenic soils in the catchment. This is demonstrated by the fact that until now no increased phosphorus levels were observed in younger groundwaters recharged after 1950 (Morgenstern et al., 2004). Landuse derived phosphorus has not yet leached into the older groundwater. Therefore, no change in P load is expected as long as landuse-derived P stays absorbed in the soil.

Previous chemical and age dating studies of groundwater and the nine major spring-fed streams in the Lake Rotorua catchment by Morgenstern et al. (2004) showed that the natural background N concentration in groundwater was 0.14 mg/L, as determined from old groundwater (pre-landuse intensification), and the average current N concentration is 1.6 mg/L, as determined from young groundwater (post-landuse intensification). This increase in N concentration is due to landuse intensification and will result in further increases in N loads to the Lake.

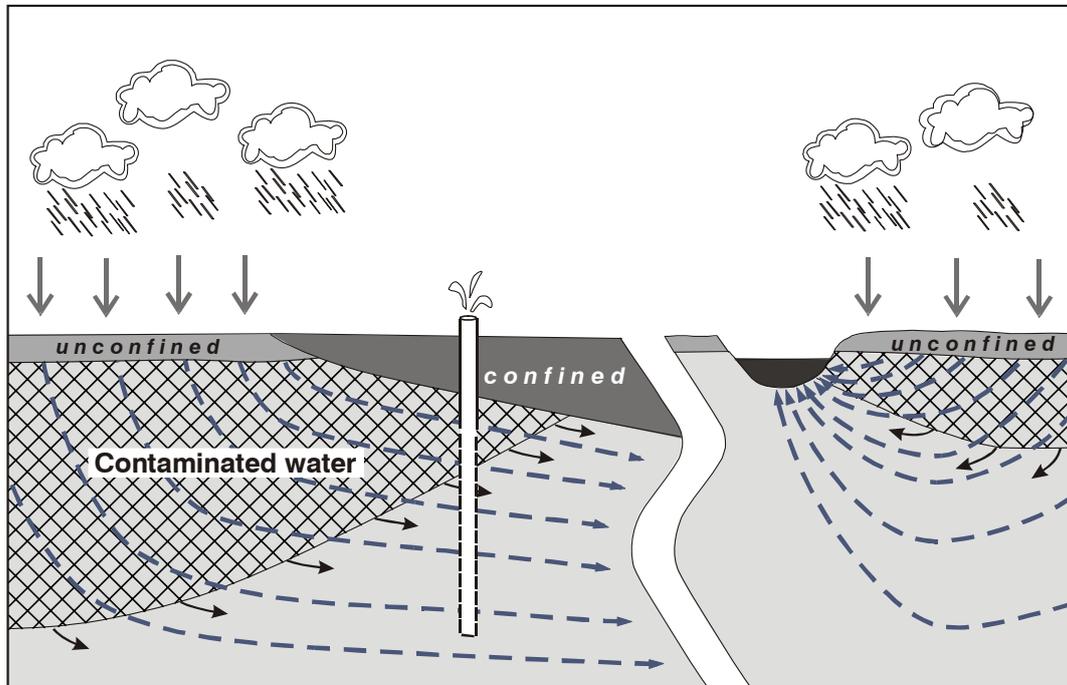
The objective of this report is to use the water age distribution to predict the arrival of post-landuse water in order to estimate the future nitrogen loads to Lake Rotorua from the nine major streams draining from the Lake Rotorua catchment, from minor streams, from lake-side springs, and from direct groundwater inflow through the lake bed.



**Figure 1.1.** Mean water residence time of the major streams to Lake Rotorua near the stream mouth. The related fractions of exponential (mixed) flow are listed in Table. 5.1.

## 2.0 METHODOLOGY OF PREDICTING FUTURE NITROGEN LOADS

The current dissolved nitrogen concentrations in waters that are now discharging to the lake are still relatively low due to dilution with old pristine waters. These concentrations are expected to increase further in the future because of the progressive arrival of water recharged after catchment development (Figure 2.1).



**Figure 2.1.** The tip of the iceberg. A water sample from a well or the stream or lake contains fractions of both young and old groundwater because long and short travel flowlines converge at the well or spring. For water mixtures with mean residence time >50 years, only a fraction of the water is young enough to show the contamination (hatched). Large fractions of the discharging water are still uncontaminated old groundwater. But in time, the front of contaminated water moves forward (see arrows), and a higher fraction of contaminated water will discharge into the well/stream/lake. A further increase in N loading is expected.

Large amounts of groundwater have insidiously become contaminated with nitrogen over the last 50 years because of the large groundwater reservoirs in the Rotorua aquifers with related long groundwater travel times. The response time of the groundwater system to lake water mitigation action will be similar. It will also take decades until the nitrogen contaminated water is flushed out of the aquifers.

The age distributions of the stream and groundwater (Morgenstern et al. 2004) are used to project the future arrival of water to the lake that was recharged since landuse development in the catchment. The future N loading was scaled up according to the increase in post-landuse water, assuming a constant N concentration of the post-landuse water which is specific for each sub-catchment.

The age distribution is defined by two parameters, mean residence time, and fraction of exponential (mixed) volume within the total flow volume of the combined exponential-piston flow (Morgenstern et al. 2004, Appendix 1).

For water with a short mean residence time of less than 20 years the increase in nitrogen load, starting 55 years ago, is now completed and steady-state has been reached. For waters with a long mean residence time of 50-100 years, the delay in nitrogen arrival is

beyond the current timeframe. The nitrogen load is therefore not yet at steady-state, and further increases in load are expected. Steady-state nitrogen load will only be reached after more than hundred years.

The predicted nitrogen loads in this report are calculated on the assumption that the nitrogen input to the groundwater started from a specific date (55 years ago for most of the catchment), and has continued to remain constant.

However, further landuse intensification has also occurred over the last 20 years. This recent landuse intensification is not yet considered in the following N load predictions because information on the timing and amount of intensification was not yet available. However, some recent landuse changes were considered in this report by using a more recent average start of N input (1965). This enabled for good matches between the calculated and the measured N loads in the past, confirming that this model assumption produces realistic N load predictions for the future.

If more detailed information on timing and amount of recent landuse intensification becomes available, the N load predictions can be refined to incorporate landuse change in several stages by calculating the predicted N load for each stage. To obtain the total predicted load, the predicted N load of the more recent landuse change is simply added to the predicted N load of the previous landuse change.

For the N load prediction only the present N load is used in combination with the age distribution. Previous N load data over the last decades are not necessary for the prediction but if they are available, they provide a valuable tool to check if the assumption of the average starting date in the catchment is realistic. For example, if the average starting point of nitrogen contamination was at a significantly different time than 1950, the measured N load data between 1950 and 1980 would not match the predicted curve. Checking against previous data is also possible for more recent landuse changes within the last 10 to 20 years by using annual N loads instead of the four yearly means.

The historic nitrogen data provide a useful tool for an additional calibration; calibrating the model against the past trend enables for a more robust prediction of the future trend.

### **3.0 NITROGEN COMPONENTS**

The previous study (Morgenstern et al. 2004) showed that nitrate ( $\text{NO}_3$ ) is clearly the major component of nitrogen in the Rotorua groundwater system. Nitrite ( $\text{NO}_2$ ) and ammonia ( $\text{NH}_4$ ) are negligible for most oxic waters. However, NNN nitrogen (NNN = nitrate ( $\text{NO}_3$ ) + nitrite ( $\text{NO}_2$ )) was used as the measure of nitrogen loading to the lake because most historic nitrogen data reported from Environment Bay of Plenty is available as NNN nitrogen. If  $\text{NO}_2$  was not reported, it was assumed zero.

Total Kjeldahl Nitrogen (TKN) was not considered in the N prediction via the groundwater because it mostly originates from decaying organic matter on the surface and therefore is not controlled by the groundwater.

## 4.0 TIME-TRENDS IN NITROGEN LOADING

In the following chapter, time-trends in nitrogen loading to Lake Rotorua are discussed for all significant nitrogen sources from streams and groundwater. The nitrogen loading for the major streams is based on excellent recent and historic data for N load and age dating. For minor streams, direct groundwater inflow via the lake bed, and springs near the lake, there is only sparse data available. Therefore, assumptions had to be used for the age distributions and nitrogen concentrations of the water. Geothermal water was not considered because the nitrogen load from this is negligible.

### 4.1. MAJOR STREAMS

Stream water dating is difficult because:

- Complementary dating methods like CFCs and SF<sub>6</sub> are not available for resolving ambiguous interpretations; the gases in the stream water equilibrate quickly with the air when the water gets in contact with the air, and
- Mixtures of water can potentially be very complicated if different hydrologic systems with different hydrogeology and different residence times discharge into the same stream.

However, reliable age distributions were obtained for most of the streams because high-quality historic tritium data are available that enable us to accurately track the passage of the 1960's bomb-tritium peak through the groundwater system. The age distribution data is summarised in Table 5.1 (p. 18). The methodology of age distribution is described in Morgenstern et al. (2004, Appendix 1), and the parameters of age distribution are summarised in Table 4 of this report.

Predicted nitrogen loads are calculated based on water quality and flow data collected by Environment Bay of Plenty for the period of 2003 to 2006 (Rutherford, 2006). Previous N load predictions combined flow data for 1976-1977 (from Hoare 1980) with nutrient data for 1992-1995 and 2002-2003 (from Rutherford 2003). However, flows were higher by ~10-20% in 1976-1977 than in 1992-2003. This resulted in slightly higher N load bias in Morgenstern et al., (2004). Rutherford 2006 collated data from several sources (principally NIWA and Environment Bay of Plenty hydrology archives) and showed that flows have been significantly lower in recent years (1992-2006) than during the earlier studies of Hoare (1975-1980) and Fish (1965-1970).

The rate of nitrogen discharge from the large reservoir in the aquifer is dependent on the rainfall rate. In a period of higher rainfall rate the discharge rate from the aquifer is also higher, with related higher total N load at this time. The N concentration was found to be relatively independent on the flow rate, in good agreement to the high degree of groundwater mixing in these highly porous volcanic aquifers. Because the rate of N discharge from the aquifer depends on the stream flow rate, wrong N load time trends could be indicated by changing stream flow. As an example, higher flow rates in the 1967-80 period with related higher N discharge compared to now could wrongly suggest reaching steady-state earlier.

Prediction of future nitrogen loading in this report is based on the current stream flow rate of the period 2002-06. Because the N discharge rate is dependent on the stream flow rate, all past N loads were adjusted to the current stream flow rate (i.e. actual N concentration multiplied with 2002-06 flow rate) to ensure that the same conditions are applied for calculation of past N loads and for calculation of time trends, and that both are comparable.

### 4.1.1 Hamurana Stream

Hamurana Stream water has a very high mean residence time of 110 years within its catchment, and therefore still contains a large fraction of pristine pre-landuse water. The pristine old water is progressively being flushed out of the aquifer, and accordingly the fraction of water recharged since landuse intensification will increase in the future. The nitrogen loading from Hamurana Stream will therefore continue to increase significantly. The continued increasing trend of measured N loads over the last decades (Figure 4.1) clearly indicates that Hamurana Stream has not yet reached steady-state N loading.

The predicted future nitrogen loads calculated from the increase in fraction of post-landuse water (Figure 4.1, solid line) shows that the N load will double when the steady-state situation is reached, increasing from currently 53 t/year to 118 t/y.

The excellent match between the measured historic nitrogen loads and the predicted load indicates that:

- (i) the assumptions used for future projection are realistic, and
- (ii) the groundwater reservoir is well mixed and/or the nitrogen contamination is widespread in the Hamurana Stream catchment.

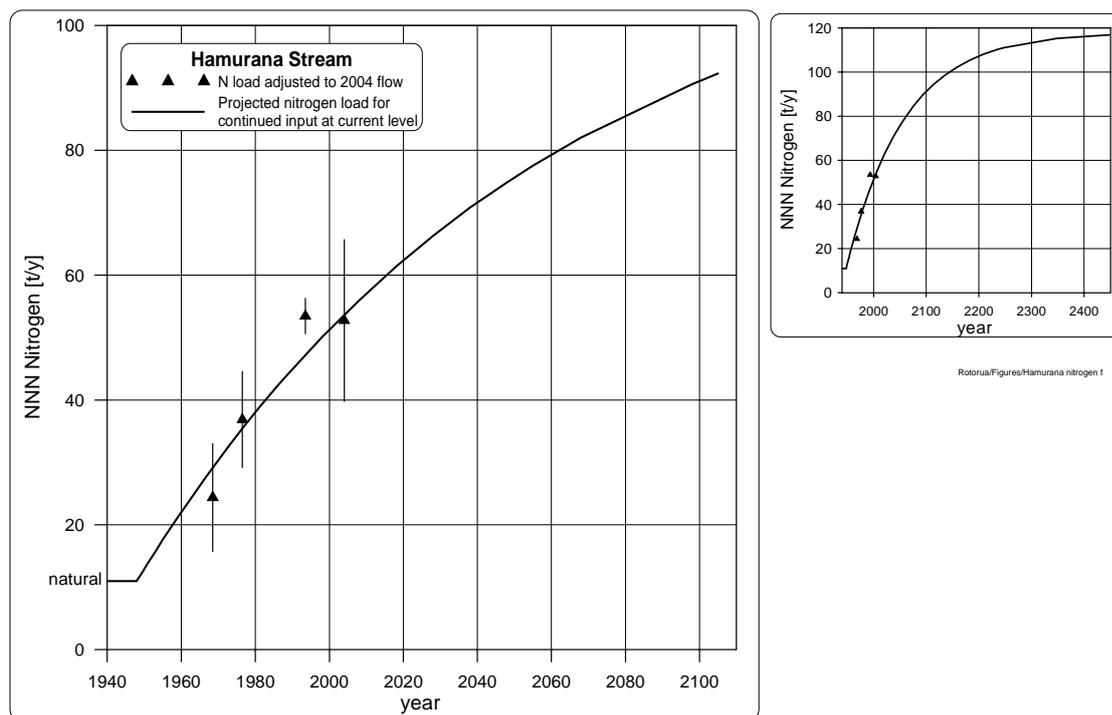


Figure 4.1. Predicted and measured NNN nitrogen loads for Hamurana Stream.

#### 4.1.2. Awahou Stream

The water of Awahou Stream has a mean residence time of 61 years and is closer to steady-state compared to the Hamurana Stream. Awahou Stream is expected to reach a nitrogen loading of 92 t/y in 2200 (Figure 4.2), an increase of 35 t/y above current measured levels of 57 t/y.

The excellent match between the measured historic nitrogen loads and the predicted loads calculated from the fraction of water from post catchment land development indicates that:

- (i) the assumptions used for future projection are realistic, and
- (ii) the groundwater reservoir is well mixed and/or the nitrate contamination is widespread in the Awahou Stream catchment.

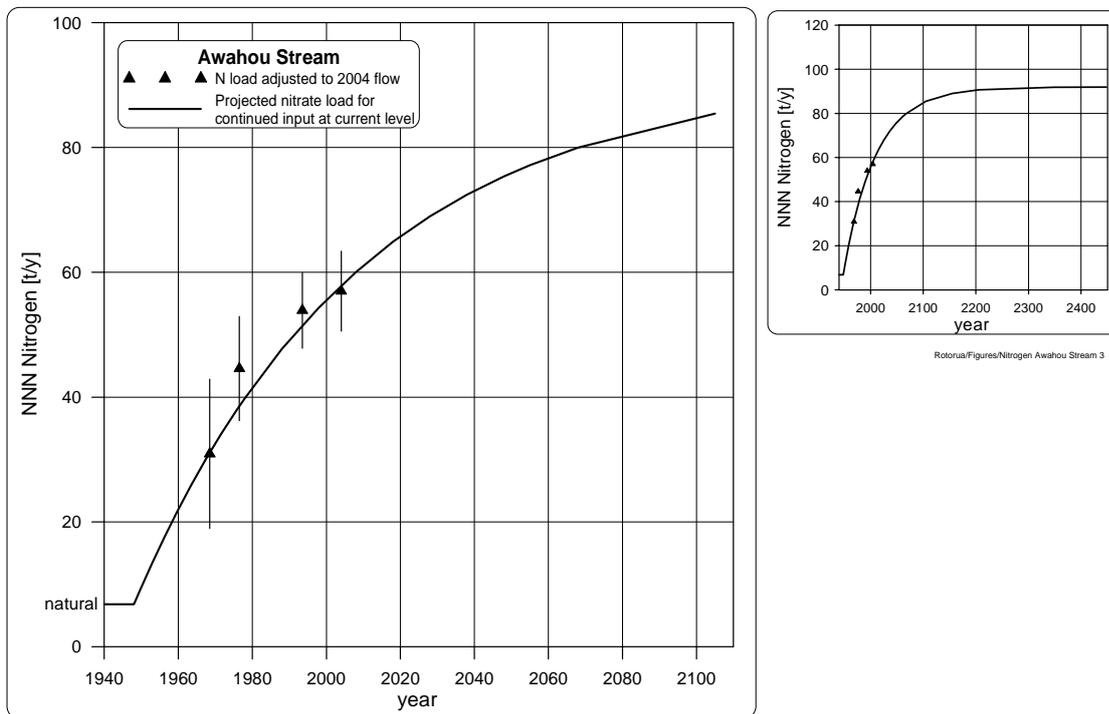


Figure 4.2. Predicted and measured NNN nitrogen loads for Awahou Stream.

### 4.1.3. Waiteti Stream

Waiteti Stream water has a mean residence time of 40 years which is significantly younger than that of Hamurana and Awahou Streams, which all drain the north-western Mamaku Plateau. Because the water is younger, Waiteti Stream is closer to steady state. Figure 4.3 shows that the expected increase in N loading is only 12 t/y above current loading of 40 t/year.

The good match between the measured historic nitrogen loads and the predicted loads calculated from the water fraction from post catchment land development (1950) indicates that:

- (i) the assumptions used for future projection are realistic, and
- (ii) the groundwater reservoir is well mixed and/or the nitrate contamination is widespread in the Waiteti Stream catchment.

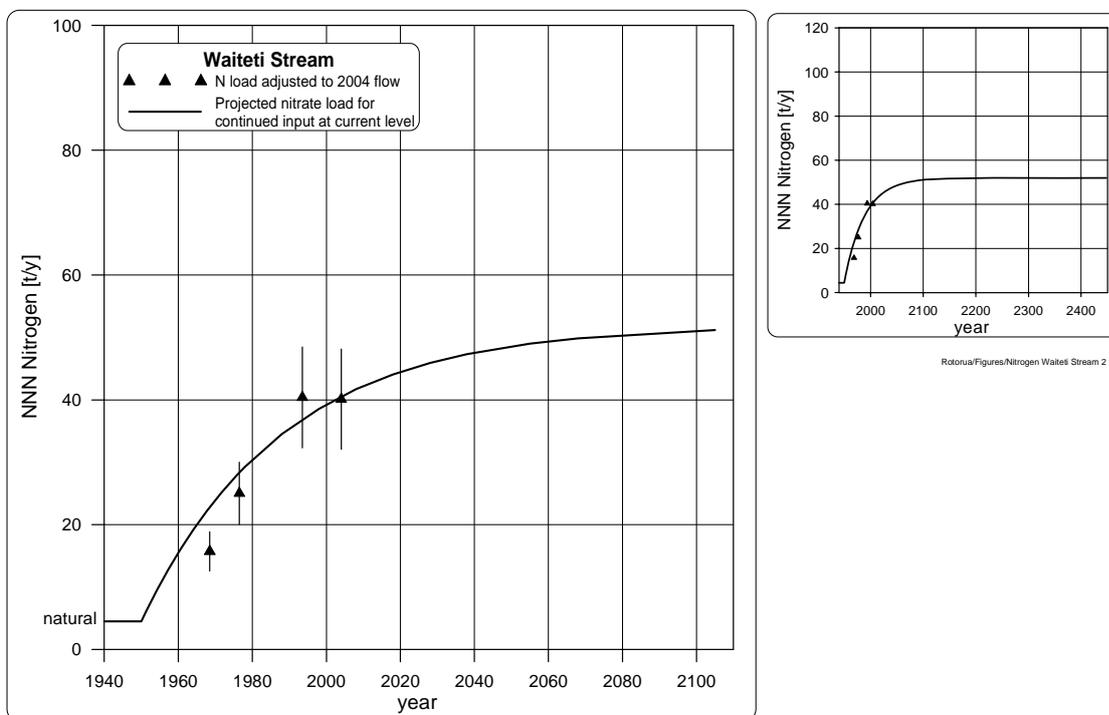


Figure 4.3. Predicted and measured NNN nitrogen loads for Waiteti Stream.

#### 4.1.4. Ngongotaha Stream

Ngongotaha Stream catchment discharges the youngest water to Lake Rotorua. It has a mean residence time of 15 years which is significantly younger than streams and springs sourced from the Mamaku ignimbrite aquifer (for example Te Waireka Spring 39 years, Hamurana stream 110 years). The Ngongotaha Stream receives significant recharge from the Ngongotaha lava dome that has significantly shorter residence time. This indicates that the lava dome formations have significantly lower aquifer water storage capacity than the Mamaku Ignimbrite aquifer.

With the mean residence time of 15 years, Ngongotaha Stream is expected to reflect already steady-state N load in relation to N inputs that occurred several decades ago.

When 1950 is used as the starting date for catchment landuse development the predicted N loading does not match the measured loads in the 1970s (Figure 4.4, broken line). The measured N loading in the 1970's was significantly lower than the prediction calculated with a starting date of 1950. This strongly suggests that average landuse development in the Ngongotaha catchment started later than in the other sub-catchments in north-western Lake Rotorua catchment. An excellent match between the calculated N loading and the measured previous N loading (Figure 4.4, solid line) is achieved by using 1965 as the commencement date in the prediction model.

However, the starting date of land-use development is not critical to the assessment of the steady-state nitrogen loading in the Ngongotaha Stream catchment because the water discharging from the Ngongotaha catchment is young enough to have reached steady-state already for catchment developments that occurred before 1965. Therefore the nitrogen loading for Ngongotaha stream catchment is expected to remain close to 35 t/y.

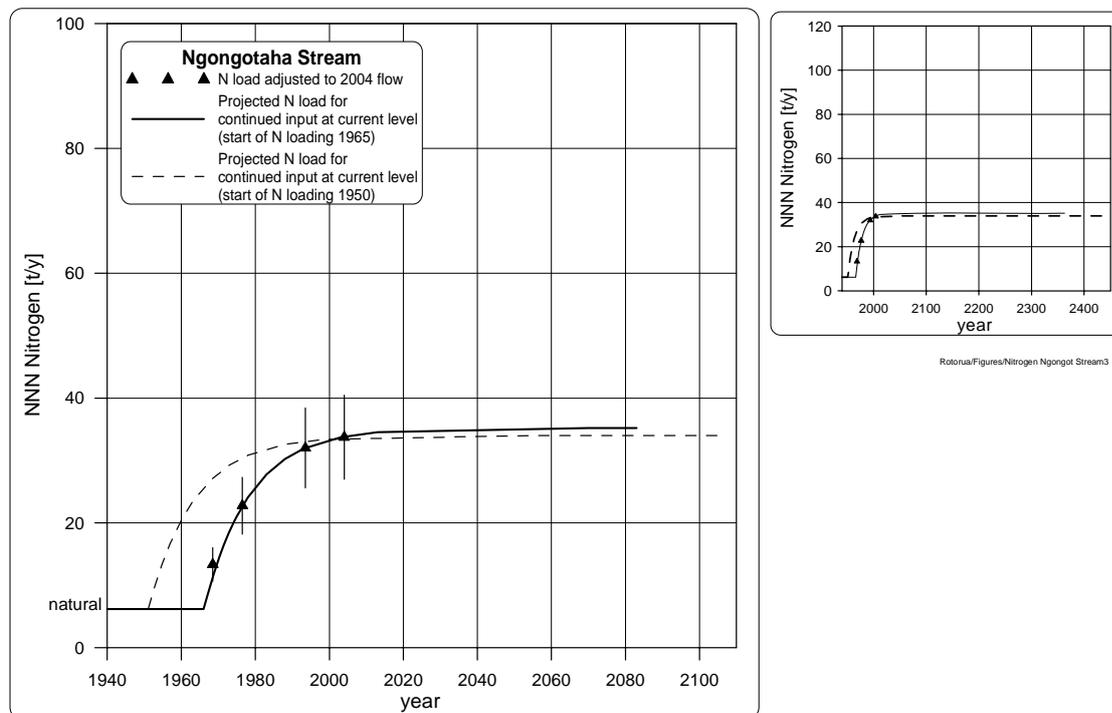


Figure 4.4. Predicted and measured NNN nitrogen loads for Ngongotaha Stream.

#### 4.1.5. Utuhina Stream

Water discharging from the upper catchment at the Utuhina Springs is very old water with mean residence time of 120 years. This water is sourced from the Mamaku Ignimbrite. However the age of the water discharging at the Utuhina Stream mouth is considerably younger with a mean residence time of 48 years. This is due to the significant contribution of younger age water that is received from the Ngongotaha rhyolite lava dome sub-catchment. Despite the mixture of waters from two different geologic formations, the age distribution in the water at the stream mouth is relatively continuous and can still be described by the exponential piston flow model (Morgenstern et.al. 2004, Appendix 1). This is indicated by the long-term tritium data, and supported by the reasonably good match between the measured historic nitrogen loads and the predicted loads calculated from the fraction of post-landuse water (Fig. 4.5).

Steady state N loading is expected to increase to 42 t/y at 2100, which is an increase of 10 t/year above the currently measured N load of 31 t/y.

The good match between the measured and predicted nitrogen loads calculated from the water fraction from post catchment land development (1950) indicates that the groundwater reservoir is well mixed and/or the nitrate contamination is wide-spread in the catchment.

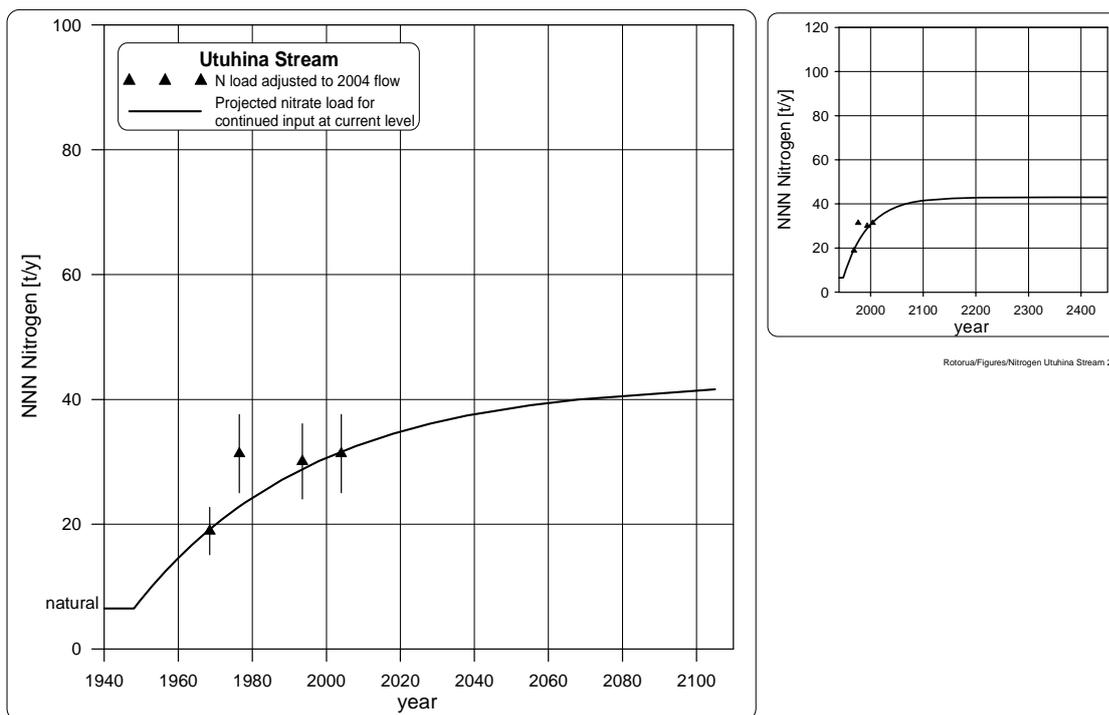


Figure 4.5. Predicted and measured NNN nitrogen loads for Utuhina Stream.

#### 4.1.6. Waiohewa Stream

Steady-state nitrogen loading has nearly been reached for the water discharging from the Waiohewa catchment with a mean residence time of 40 years (Fig. 4.6). The N loading in 2100 is expected to reach 17 t/year, an increase of 4 t/y above current measured N load of 13 t/y.

The good match between measured and predicted nitrogen loads calculated from the water fraction from post catchment land development (1950) indicates that:

- (i) the assumptions used for future projection are realistic, and
- (ii) the groundwater reservoir is well mixed and/or the nitrate contamination is widespread in the Waiohewa Stream catchment.

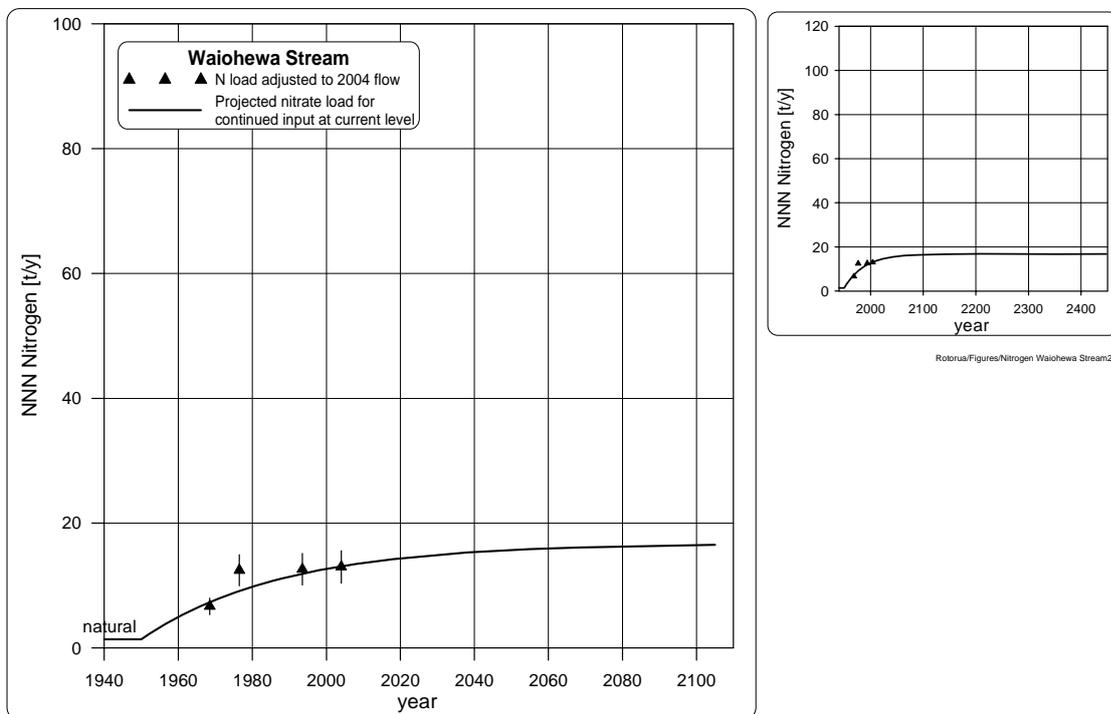


Figure 4.6. Predicted and measured NNN nitrogen loads for Waiohewa Stream.

#### 4.1.7. Waingaehe Stream

Water discharging from the Waingaehe catchment has a mean residence time of 127 years. This is the oldest water of all of the catchments. Waingaehe stream will therefore take the longest of all streams to Lake Rotorua to reach steady-state. Steady-state nitrogen loading for the Waingaehe catchment will be reached at 2400 with a load of 34 t/y, an increase of 14 t/y above current measured level of 20 t/y (Figure 4.7).

When 1950 is used as the starting date of catchment landuse development the measured nitrogen loading does not match the predicted loads very well (Figure 4.7, broken line). This suggests that the average nitrogen loading started later in the Waingaehe Stream catchment compared to the total Rotorua catchment average of 1950. Using alternatively 1965 as the commencement date for the prediction model provides a good match to the measure data.

A good match between the measured and the predicted nitrogen loads calculated from the water fraction from post catchment land development in 1965 indicates that the assumptions used for future projection sufficiently describe the catchment landuse change.

The later starting date (1965) of N loading results in a steeper curve with a 30% increased steady-state N load compared to using the Rotorua catchment average of 1950 (the difference between the broken and the solid line, Figure 4.7).

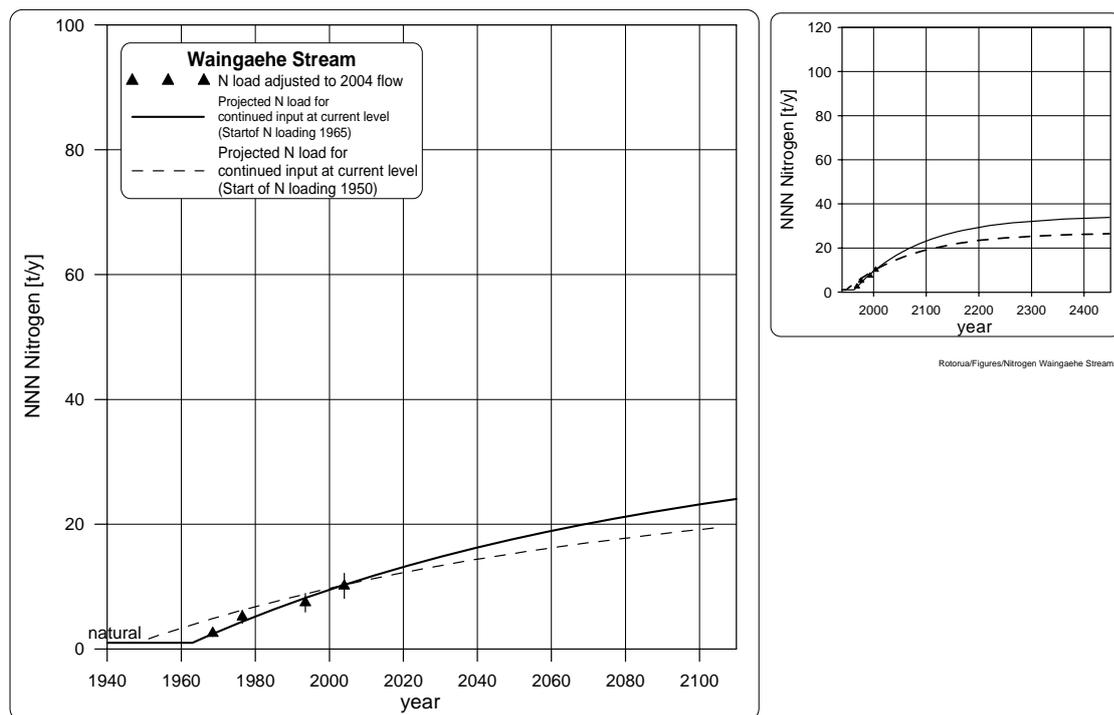


Figure 4.7. Predicted and measured NNN nitrogen loads for Waingaehe Stream.

#### 4.1.8. Puarenga Stream

The current nitrogen load of Puarenga Stream is dominated by leakage from the recent land disposal of treated sewage from Rotorua into Waipa stream via irrigation at Whakareware waForest (Rutherford 1989, 2003, Park 1999, 2003). Therefore, the methodology of N load prediction from the wider Puarenga catchment has to be applied only to the data prior to the treated sewage disposal which commenced in 1991.

Puarenga Stream water has a relatively young mean residence time of 37 years that is already close to steady-state relative to land-use changes that started in the 1950's. Therefore, the expected increase in N loading from landuse changes in the catchment (excluding the treated sewage disposal) is only 6 t/y (Figure 4.8, solid line).

The measured post-1990 data in Figure 4.8 clearly demonstrates that the treated sewage disposal has significantly increased the N loading in Puarenga Stream above the expected N load from landuse (solid line).

For calculation of the future N load in Puarenga Stream we added to the predicted N load from landuse a constant N load of 30 t/y (broken line), which is the consent limit for the sewage treatment plant. The consent limit was considerably exceeded between 1998 and 2003 as reported by Park (2003). The N load average at 2002 in Figure 4.8 is therefore higher than the predicted total N load at steady-state. Since 2003 the N load in Waipa stream has returned to just below the consent limit (Park 2003).

The total N load of Puarenga Stream is expected to reach about 53 t/y at steady-state if the load from the sewage treatment plant remains constant at 30 t/y.

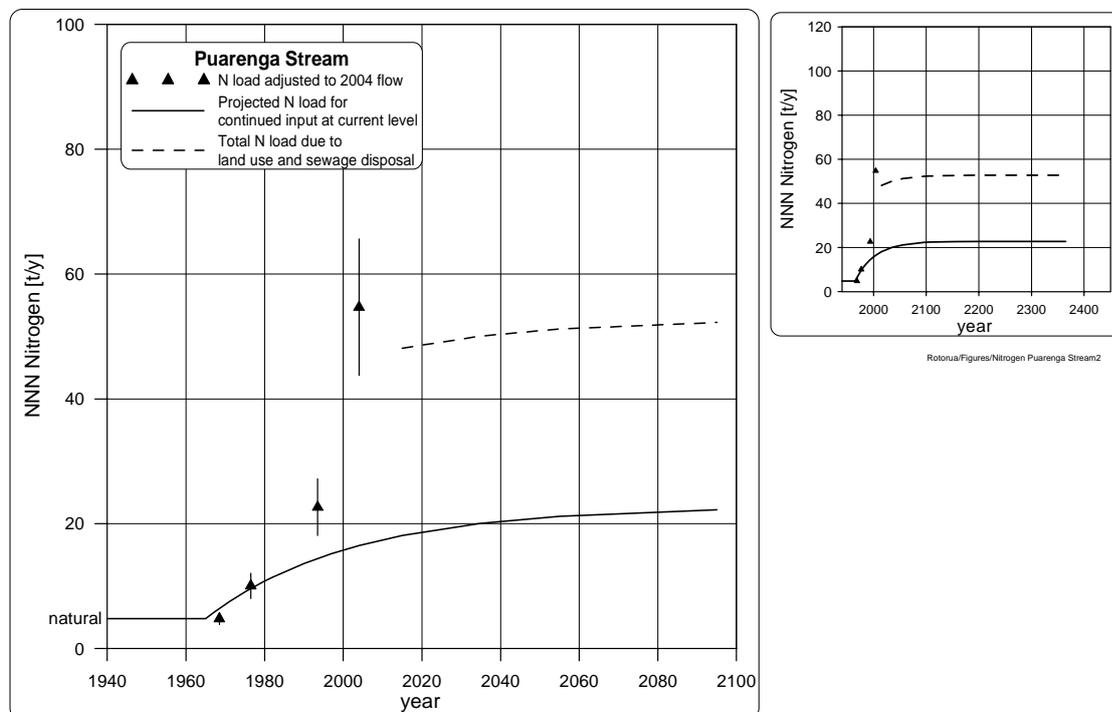


Figure 4.8. Predicted and measured NNN nitrogen loads for Puarenga Stream.

#### 4.1.9. Waiowhiro Stream

Water in the Waiowhiro Stream has a mean residence time of 42 years. This is deduced from Rainbow Spring because Waiowhiro Stream was not sampled in 2003. Rainbow Spring is the main contributor to Waiowhiro Stream.

The measured N load in the 1970's is higher than the predicted load (Fig. 4.9). This may indicate that N loading started earlier than 1950, or that some of the water from the Waiowhiro catchment that is derived from the Ngongotaha rhyolite lava dome aquifer has a high fraction of piston flow in the groundwater system. This means that the landuse nitrogen load signal would have a sharper front. However, this is not critical for the future nitrogen load prediction because Waiowhiro Stream is already near steady-state. No significant increase in nitrogen load is expected.

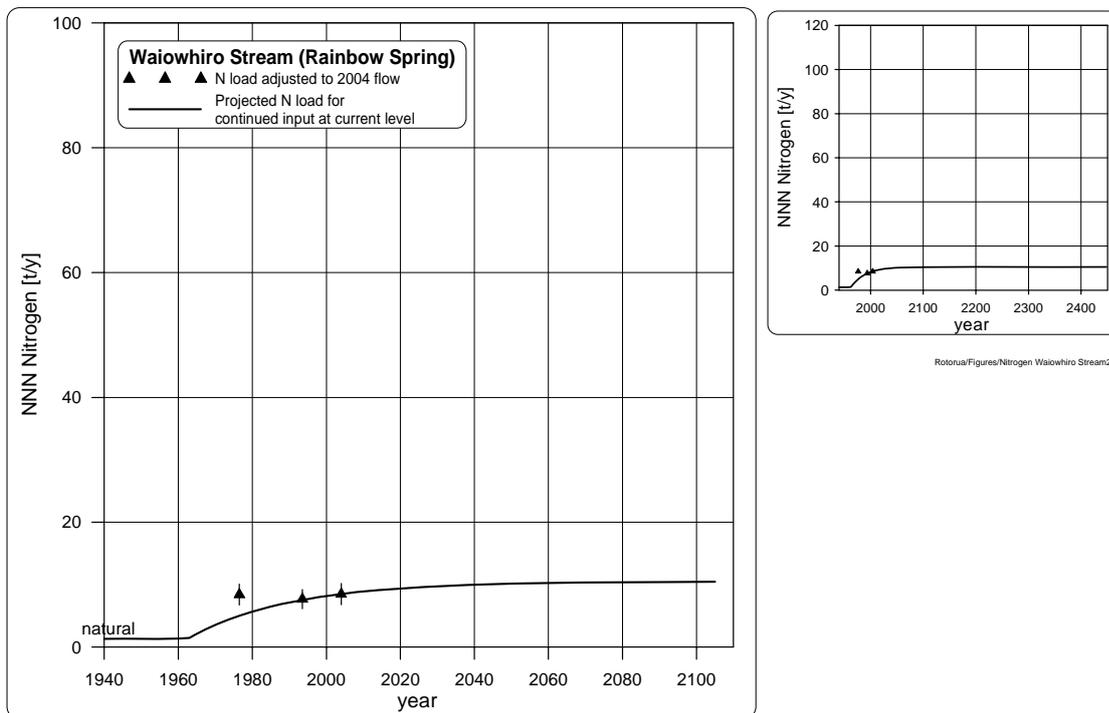


Figure 4.9. Predicted and measured total nitrogen loads for Waiowhiro Stream.

#### **4.1.10. Summary of Major Streams Time Trends**

Excellent matches between the modelled and measured nitrogen loads have been achieved for most of the streams. This indicates that the model assumption of a starting date of the nitrogen loading to the groundwater at around 1950 is realistic for most of the Lake Rotorua catchment. Only the Ngongotaha and Waingaehe streams have measured historic nitrogen loads in the 1970s that lagged the modelled nitrogen loads, thereby showing that significant landuse changes occurred more recently than 1950 in these catchments. An average starting date of 1965 provides a good match between the model output and measured data.

The current nitrogen load of Puarenga Stream is dominated by recent leakage from land disposal of treated sewage from Rotorua. The methodology of N load prediction from the wider Puarenga catchment can therefore only be applied to the nitrogen load data prior to the treated sewage disposal.

Only Ngongotaha stream has water with a relatively young mean residence time of 15 years and therefore is therefore already at steady state with historic landuse changes. No future increase in nitrogen load is therefore expected in relation to changes that occurred several decades ago.

The following streams have a mean residence time that is similar to the length of time when the major land-use changes occurred: Waiteti, Utuhina, Waiohewa, Puarenga, Waiowhiro. Only slight increases in nitrogen loading are expected.

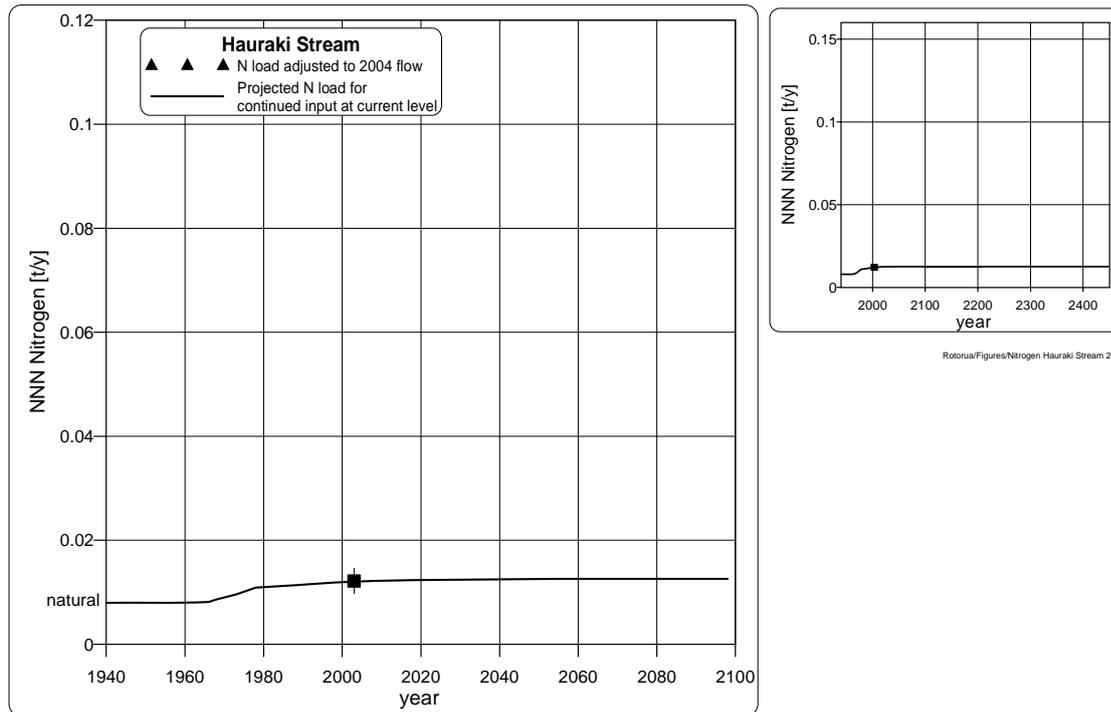
Hamurana, Awahou and Waingaehe Streams have mean residence times significantly greater than the length of time to the landuse changes. Therefore, these streams are still far from steady-state. The nitrogen load from Hamurana and Waingaehe streams is expected to more than double in the future, and the load from Awahou Stream is expected to nearly double.

More recent land-use changes (within the last 20 years) have not yet been considered in the prediction model, because detailed information on landuse changes is not yet available.

The results of the predicted nitrogen loads are summarised in Table 5.1.

## 4.2 MINOR STREAMS

Of the minor streams, only Hauraki Stream had been sampled for age dating, giving a mean residence time of 40 years. Figure 4.10 shows the nitrogen load prediction for Hauraki Stream. The nitrogen load is negligible compared to major streams (note the different scale on the axis). The measured nitrogen concentration in Hauraki Stream of 0.2 mg/L (Morgenstern et al. 2004) is near background level, despite the nitrogen load being already at steady-state. The low nitrogen concentration in Hauraki Stream may be explained by N uptake in the channel due to the normally very low or ephemeral flow.



**Figure 4.10.** Predicted and measured total nitrogen loads for Hauraki Stream.

To predict the nitrogen load from the combined minor streams, a total flow of 249 L/s (Rutherford, 2006), and an average nitrogen concentration of 1.8 mg/l (deduced from the total nitrogen load) was used. A mean residence time of 40 yrs with 95% mixed flow (which best reflects the age distribution of other small streams and lake side features) were assumed. The predicted nitrogen load for minor streams is calculated to be 18.5 t/y (Table 5.1).

## 4.3 LAKE-SIDE GROUNDWATER SPRINGS

A total flow of 141 L/s was estimated by White (personal communication) for small lake-side spring inflows that are not captured in major stream flows. These form part of the 'ungaged catchment' of Hoare (1980). The data source for these lake-side springs is from Reeves et al. (2005).

Three mg/L total nitrogen is used for calculating the nitrogen load, which is approximately the average total nitrogen concentration of spring water near the lake. Groundwaters near the

lake appear to have higher nitrogen concentrations than the large springs and streams that discharge water recharged from further up in the catchment.

Water age has been analysed up to now for only one lake-side spring that discharges near the Rotorua airport. The age distribution of the airport spring is used here to represent all lake side springs. The airport spring has a mean residence time of 27 years and 70% mixed flow. The small springs near the lake appear to contain younger water than the large springs and streams that discharge water that travelled from further up the sub-catchments.

With these assumptions, the total nitrogen load of all lake-side springs at steady-state is calculated to be 14.5 t/y (Table 5.1).

#### **4.4 DIRECT GROUNDWATER FLOW VIA THE LAKE BED**

No direct groundwater flow via the lake bed has been sampled so far for age dating or chemistry analysis. The following assumptions were used for the calculation of the nitrogen load via direct groundwater flow: mean residence time of 37 years with 100% mixed flow (near-lake springs appear to have younger water than the major streams), and a nitrogen concentration of 1.0 mg/L. However, there are indications that the N concentration of 1 mg/L is too low to represent the groundwater direct inflow. Near-lake groundwaters generally seem to contain nitrogen concentrations of about 3 mg/L. Until such time as there is data available to verify the N concentration, 1.0 mg/L is used. The N load below may therefore be considered as a minimum value only.

The direct groundwater inflow to Lake Rotorua via the lake bed has been estimated by White (2006) via groundwater flow modelling to be 4.5 m<sup>3</sup>/s. Hoare (1980) calculated the groundwater direct flow from the water balance to be 2.1 m<sup>3</sup>/s. We used the mean value between Hoare and White of 3.3 m<sup>3</sup>/s.

On the basis of these assumptions, the total nitrogen load of the direct groundwater flow via the lake bed was calculated to be 131 t/y at steady-state. However, it must be emphasised that all data used for calculation of the direct groundwater inflow are rough estimates and therefore the total nitrogen load of the direct groundwater flow via the lake bed is subject to large errors.

#### **5.0 PREDICTED NITROGEN LOADS**

Table 5.1 summarises the predicted total nitrogen loads into Lake Rotorua for the nine individual major streams, the minor streams, the lakeside springs, and the direct groundwater inflow via the lake bed. The total nitrogen loads were calculated for:

- Pre-land-use (background),
- Present time (2005),
- Future: 50 years (2055), 100 years (2105), 150 years (2155), 200 years (2205), and
- Steady state (nitrogen load after all old pristine pre-land-use water in the aquifer is replaced by landuse-affected water).

**Table 5.1.** Total nitrogen load before land-use development, for the present, for the years 2055, 2105, 2105, and 2155, and for steady-state. The age distribution parameters **E%PM** and **MRT** are the fraction of exponential (mixed) flow volume, and mean residence time (see Morgenstern et al. 2004). The listed **nitrogen concentrations** are the **current** concentrations, and the **bkg** concentrations are the background concentrations from the time before land-use development (deduced from old groundwaters in Morgenstern et al. 2004). For calculation of the **Total Nitrogen loading**, the background N concentration is used for the **pre-land-use** load, the present N concentration is used for 2005 and the future predictions. % in the last column is the percentage of each nitrogen contributor at steady-state. For the major streams, flow rates and present nitrogen concentrations were obtained from Rutherford 2006. For minor streams, lake-side springs and groundwater direct, assumptions were used for the flow rates and present nitrogen concentrations, as explained in the text.

	E%PM [%]	MRT [yrs]	Flow rate [m <sup>3</sup> /s]	NNN Concentr.		NNN Nitrogen loading [t/y]							
				Currently [g/m <sup>3</sup> ]	Bkg [g/m <sup>3</sup> ]	pre- landuse	2005	2055	2105	2155	2205	steady-state	%
<b>Major streams</b>													
Utuhina	100	48	1.461	0.679	0.14	6.5	31.3	39.1	41.6	42.5	42.8	43.0	6.9
Ngongotaha	80	15.5	1.408	0.759	0.14	6.2	33.7	35.2	35.2	35.2	35.2	35.2	5.7
Waiteti	95	40	1.016	1.251	0.14	4.5	40.1	49.0	51.2	51.7	51.9	52.0	8.4
Awahou	100	61	1.530	1.18	0.14	6.8	57.0	77.1	85.4	89.0	90.6	91.9	14.8
Hamurana	100	110	2.490	0.671	0.14	11.0	52.7	77.5	92.3	101.7	107.6	118.0	19.1
Waiohewa	95	40	0.325	1.266	0.14	1.4	13.0	15.9	16.6	16.8	16.8	16.8	2.7
Waingaehe	100	127	0.234	1.37	0.14	1.0	10.1	20.2	24.9	28.1	30.2	34.7	5.6
Puarenga	100	37	1.684	1.029	0.09	4.8	41.7	51.2	52.4	52.7	52.8	52.8	8.5
Waiowhiro*	65	41.5	0.293	0.917	0.14	1.3	8.5	10.2	10.5	10.5	10.5	10.5	1.7
<b>sub total Major Streams</b>						<b>43</b>	<b>288</b>	<b>375</b>	<b>410</b>	<b>428</b>	<b>438</b>	<b>455</b>	<b>73.3</b>
<b>Other</b>													
Minor streams (cold)	95	40	0.249	1.8	0.14	1.1	14.1	17.4	18.2	18.4	18.5	18.5	3.0
Lake-side springs	70	27	0.141	3	0.14	0.6	13.3	14.4	14.5	14.5	14.5	14.5	2.3
groundwater direct	100	37	3.300	1	0.14	14.6	104	124	129	130	131	131	21.2
<b>total</b>						<b>60</b>	<b>420</b>	<b>532</b>	<b>572</b>	<b>592</b>	<b>602</b>	<b>619</b>	<b>100</b>

The predicted nitrogen loads in Table 5.1 are calculated from the increasing fraction of post-landuse development water that is going to arrive at the lake (see section 2.0). These predictions are for the assumption that the nitrogen input in the catchment from landuse development has remained constant and will remain constant in the future. The post-landuse water that is moving through the large groundwater aquifer system in the lake Rotorua catchment will discharge to the lake with a time delay of up to more than 100 years. Therefore, there is still a significant fraction of pristine pre-landuse water flowing into Lake Rotorua at the present, but in future more landuse affected water will flow into the lake thereby increasing the N loading to the Lake.

Denitrification processes within the groundwater system are insignificant because the majority of the groundwaters in the Lake Rotorua catchment are oxidised (Morgenstern et al. 2004). Despite the extremely long travel times through the aquifer, no significant losses of dissolved nitrogen within the aquifer can occur.

The nitrogen loads of the nine major streams now have slightly lower estimates than previously reported (Morgenstern 2004) because new flow and water quality data has been used (see 4.1).

The three largest nitrogen contributors to Lake Rotorua at steady state are Hamurana and Awahou Streams, and groundwater direct via the lake bed. Due to the old age of the water in Hamurana and Awahou Streams, the nitrogen load in those two streams will almost double in future.

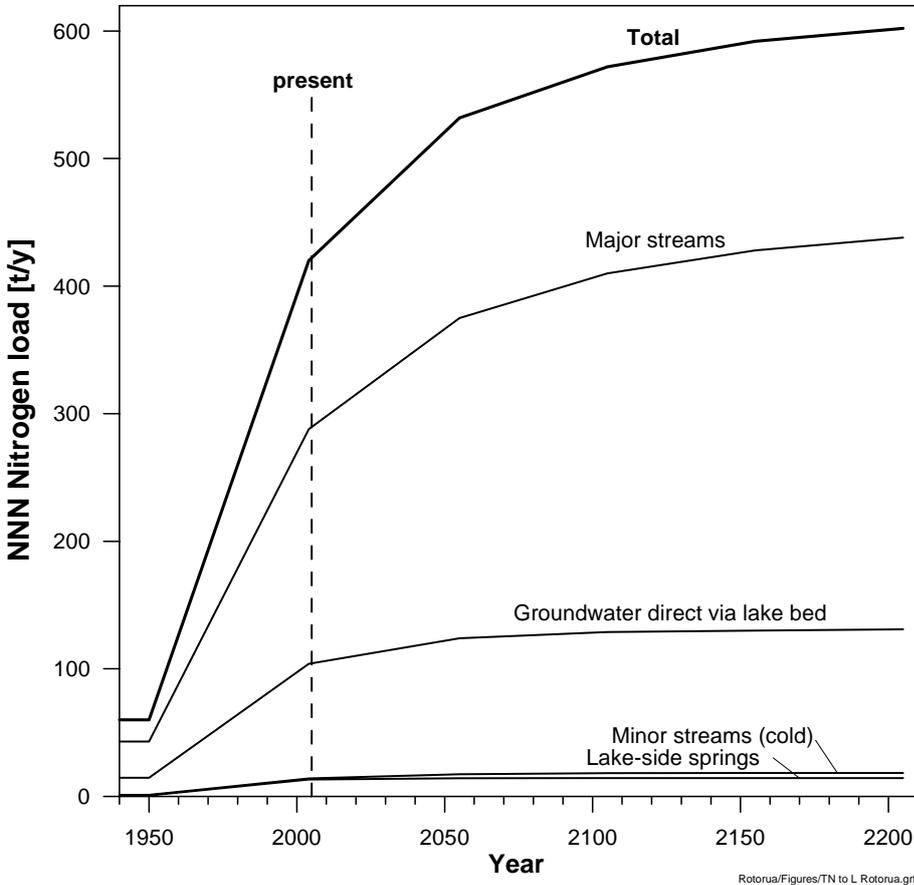


Figure 5.1. Predicted NNN Nitrogen loading to Lake Rotorua

Figure 5.1 summarises the nitrogen loads presented in Table 5.1. Despite high uncertainty in the estimates of nitrogen loading via groundwater direct, the following patterns have emerged:

- The largest contribution of nitrogen loading to Lake Rotorua is via the nine major streams. This is about 75% of the steady-state N load to the Lake.
- The nitrogen loading via direct groundwater is the second largest component. This is about 20% of the total N load to the Lake.
- Lake side springs and minor streams together only contribute about 5% of the total nitrogen load to the Lake.
- Due to the long residence time of the water in the large aquifer system, nitrogen loading has not yet reached steady-state in respect to landuse changes from 55 years ago. The future N loading to Lake Rotorua is expected to further increase by approximately 40%.
- The natural pre-landuse nitrogen loading to Lake Rotorua is estimated to be 60 t/y, the current N loading to be 420 t/y, and the future steady-state N loading is expected to increase to 619 t/y. Compared to the pre-landuse situation, this is an increase of nitrogen loading by a factor 7 at present, and by a factor 10 at steady-state.

## 6.0 CONCLUSIONS

Past, present, and future nutrient loads to Lake Rotorua are shown in Figure 6.1. Nitrogen loads are shown for each major stream, and for the combined minor streams, the lake-side springs, and the direct groundwater flow via the lake bed.

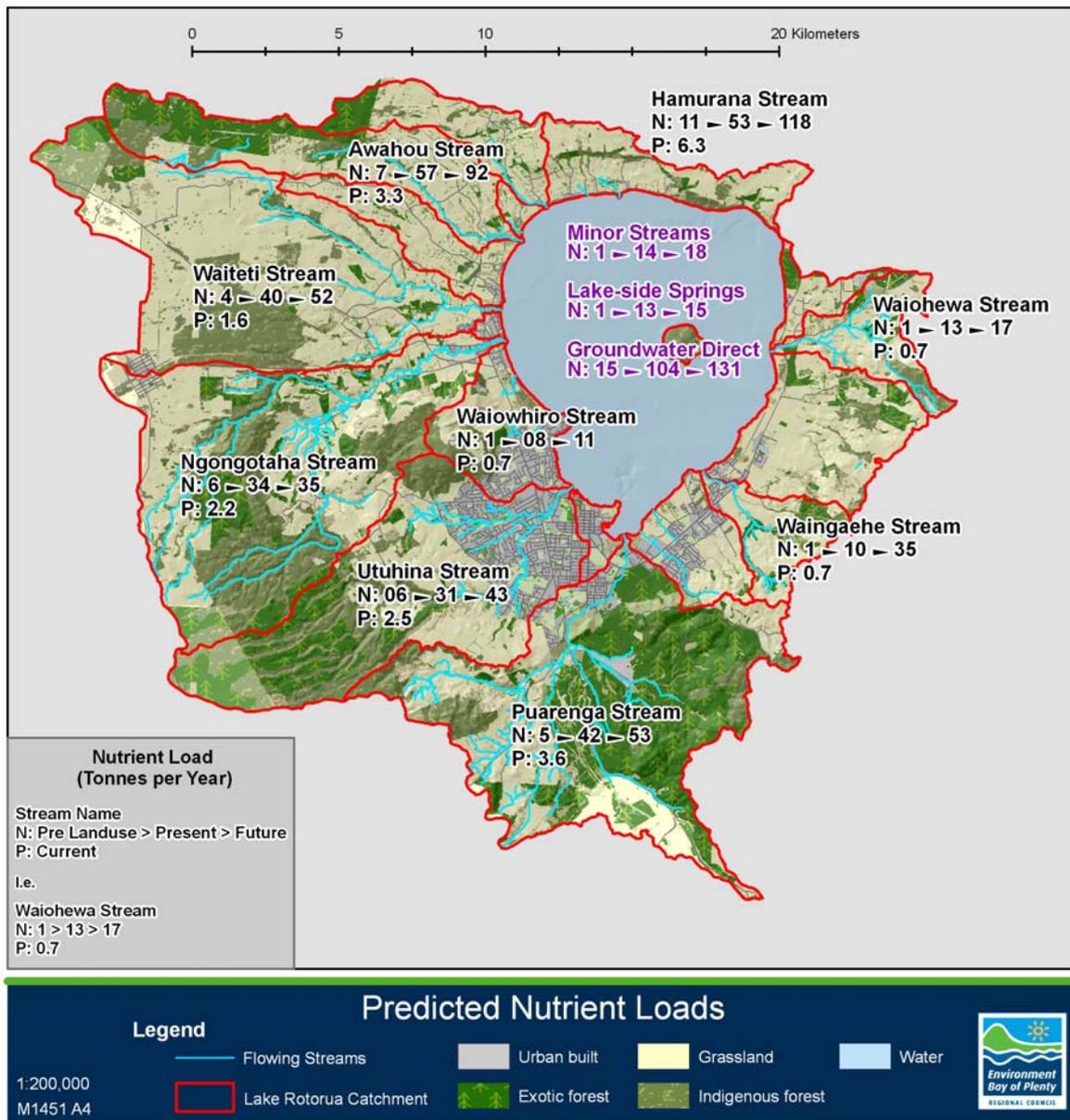


Figure 6.1: Past, present, and future nutrient loads to Lake Rotorua. For the NNN nitrogen loads, the first (left) N number is the N load at the time before landuse intensification at around 1950, the second (middle) N number is the present N load, and the third (right) N number is the future N load at steady-state. Steady-state is reached when all old pristine pre-landuse water is flushed out of the aquifer, and only water recharged since landuse intensification flows to the lake.

No changes are expected in phosphorus loads via groundwater as a result of landuse development in the Rotorua catchment because until now landuse-derived P is absorbed by the volcanic soils in the catchment. The occurrence of P in the old groundwater is due to

natural leaching from the volcanic aquifer material. P loads shown in Figure 6.1 are the current Total Phosphorus loads reported in Rutherford (2006), and these are expected to remain constant as long as landuse-derived P stays absorbed in the soil.

Nitrogen loads, however, are related to landuse changes. Nitrogen travels to the lake with the groundwater which drains the catchment, with a time delay of up to more than 100 years. This is the time that the water takes to pass through the large groundwater aquifer system on its way to the Lake. In order to predict future landuse-derived nitrogen loads, time-trends were established using age dating of the groundwater to identify the arrival of landuse-derived nitrogen to the lake, and how much more nitrogen is expected to arrive in the future. Using the present nitrogen load and the water age time trend data, we have established the nitrogen load to the Lake for the time prior to landuse development, and into the future.

The NNN nitrogen loading to Lake Rotorua prior to major landuse development of the Rotorua catchment in the 1950's was 60 t/year. This has slowly increased to a present NNN nitrogen load of 420 t/y, delayed by long travel times of the water through the groundwater aquifers. This loading is expected to further increase in the future to 532 t/y in 50 years, to 572 t/y in 100 years, and to 619 t/y at steady-state. This is a further 110 t/y increase in 50 years (25%), and 150 t/y increase in 100 years (35%).

The majority of the nitrogen loading of about 75% at steady-state enters Lake Rotorua via the nine major streams. The second largest component of about 20% enters the lake with the direct groundwater inflow via the lake bed. This component has the largest uncertainty because no age and chemistry data are available so far from direct groundwater flow to the lake bed. Lake side springs and minor streams together contribute only about 5% of the total nitrogen load to Lake Rotorua.

If significant landuse intensification has occurred within the last 10 years, then this will not yet be captured by the present model because landuse intensification in several stages is not yet considered in the nitrogen load predictions because information on the timing and amount of intensification is not yet available. The current predictions would therefore represent a lower limit to which the most recent nitrogen loads would have to be added.

The present prediction model assumes that the nitrogen input in the catchment from landuse development has remained relatively constant and will remain constant in the future. If more information on timing and amount of landuse changes becomes available, the N load predictions can be refined to incorporate landuse change in several stages by calculating the predicted N load for each stage. To obtain the total predicted load, the predicted N load of the more recent landuse change is added to the predicted N load of the previous landuse change. Positive (intensification) or negative (retirement) changes can be considered.

The large groundwater system of the Lake Rotorua catchment responds delayed by decades to landuse changes. These timeframes will need to be considered carefully for any possible mitigation options in the catchment.

## 7.0 ACKNOWLEDGEMENT

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