



NEW ZEALAND  
DEPARTMENT OF  
SCIENTIFIC AND  
INDUSTRIAL  
RESEARCH

*DSIR  
Marine and  
Freshwater*

*Making Science Work For New Zealand*

**A DESK STUDY OF THE NUTRIENT LOAD  
ON LAKE TARAWERA, WITH AN ASSESSMENT  
OF PROSPECTS FOR LAKE WATER QUALITY  
MANAGEMENT BY MANIPULATION OF LAND  
USE OR POINT NUTRIENT SOURCES**

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*Marine and Freshwater*

## **1. EXECUTIVE SUMMARY (FINAL)**

**INVESTIGATION NO: P740**

**CORPORATE OBJECTIVE: S3040**

**INVESTIGATION TITLE:** A desk study of the nutrient load on Lake Tarawera with an assessment of prospects for lake water quality management by manipulation of land use or point nutrient sources.

**STUDY VENUE:** Lake Tarawera

**INVESTIGATION LEADER:** Dr E White

**INVESTIGATION STATUS:** Completed

**CLIENT:** Department of Conservation

**INVESTIGATION SUMMARY:** Hydraulic and nutrient load assessments were made based on existing information. For some hydrological components there is little or no information about nutrient concentrations. As a consequence the nutrient load assessments are subject to massive uncertainty. The best estimate of the phosphorus load was assessed to be a quantity between 10.8 and 37.9 tonnes  $\text{yr}^{-1}$ . For nitrogen the load was assessed to be between 98 and 197 tonnes  $\text{yr}^{-1}$ . This uncertainty limits the usefulness of comments made about management options. A maximum of 25% of the water and phosphorus input might be amenable to manipulation. For nitrogen the figure might be as high as 47% of the total load. However, it can be said that septic tank effluents associated with the existing residential population do not contribute massively to the lake's nutrient load. A limited sampling exercise would improve the precision of the nutrient load assessments which, in turn, may allow more confident statements about management options.

### **OBJECTIVES:**

- (a) To provide an assessment of the nutrient load on Lake Tarawera.
- (b) To provide a reasoned assessment of the reliability of the nutrient load estimate.
- (c) To identify information needed to improve the reliability of the nutrient load estimate.
- (d) To assess prospects for modifying the nutrient load on Lake Tarawera for the benefit of nature conservation, the recreational fishery, and eutrophication control, by manipulation of land use or point sources of nutrients.

**METHODS:** The nutrient load was assessed by reference to existing hydrological and nutrient data, supplemented by consideration of known geological and land-use impacts on water in the Rotorua lakes area. Possible changes to nutrient loads by manipulation of land use were related to existing water quality conditions in order to assess likely impacts.

**RESULTS:** The hydrological components of the lake's water balance could be assessed reasonably but the nutrient contents of these components were often uncertain and sometimes unknown. As a consequence the assessment of nutrient load associated with several hydrological components were subject to great uncertainty. The best estimate of the phosphorus load was assessed to be a quantity between 10.8 and 37.9 tonnes  $\text{yr}^{-1}$ . For nitrogen the load was assessed to be between 98 and 197 tonnes  $\text{yr}^{-1}$ .

**CONCLUSIONS:** The uncertainty associated with the nutrient load assessments prevented much useful comment about water quality changes that might be achieved by manipulating land use. A maximum of 25% of the water and phosphorus input might be amenable to manipulation. For nitrogen the figure might be as high as 47% of the total load. However, it can be said that septic tank effluents associated with the existing residential population do not contribute massively to the lake's nutrient load.

**RECOMMENDATIONS:** Refinement of the nutrient load estimates would be possible by further investigation of the components. This should be approached sequentially. Firstly, the geothermal groundwater component needs better quantification, in terms of both volume and nutrient content. This is amenable to investigation in parts of the Wairua Arm. If a substantial proportion of the supposed geothermal water can be found, this will allow major reduction of uncertainty about nutrient loads from this source, and further investigation of stream flow loads would be justified. Satisfactory characterisation of load with streamflow would remove much of the uncertainty imposed by the limitations of the 'indirect' method of assessment. These refinements of the load estimates may be sufficient to allow more useful assessments of the impact of land use changes.

## **2. Introduction**

This desk study of the nutrient load on Lake Tarawera was commissioned by the Department of Conservation as part of a need to better understand the lake's resources.

Concerns have been expressed recently about the declining quality of the trout fishery, and about the occasional appearance of cyanobacteria (blue-green algae) forming surface scums on the lake. At some time the nutrients from septic tanks which get into the lake will be a factor in considerations about the need for alternative forms of sewage treatment, and the intensification of agriculture and exotic forest development in the place of natural vegetation may have had, and continue to have, consequences for lakewater quality.

A previous assessment of nutrient load on Lake Tarawera was produced by Howard-Williams and Gibbs (1987) at a seminar which was arranged to consider the opportunities for reducing nutrients discharged from small sewage treatment plants. This load assessment was made without the benefit of any inflow nutrient concentration measurements specific to Lake Tarawera. A reasonable expectation of the present study might be more precise estimates of nutrient loads.

## **3. Objectives**

The specific objectives of the study were

- (a) to provide an assessment of the nutrient loads on Lake Tarawera
- (b) to provide a reasoned assessment of the reliability of the nutrient load estimates

- (c) to identify further information needed to improve the reliability of the nutrient load estimates
- (d) to assess the prospects for modifying the nutrient load on Lake Tarawera for the benefit of nature conservation, the recreational fishery and eutrophication control, by manipulation of land use or point sources of nutrients.

## **4. Results**

### **4.1 The hydrological balance**

Before an assessment of the nutrient loads on Lake Tarawera can be made the sources of water carrying these nutrients need to be defined. For Lake Tarawera, as for other lakes in the area, this is not a simple task.

The surface outflow from Lake Tarawera is well documented, an annual average of 6800 litres  $s^{-1}$  being derived from continuous data collected between November 1971 and March 1987 (information provided by DSIR Water Resources Survey, Rotorua). However this surface outflow does not represent the total outflow from the lake. A gauging survey of the Tarawera river by DSIR Water Resources Survey on 4 May 1987 gave flows at the lake outlet and just below the falls of 6200 litres  $s^{-1}$  and 8075 litres  $s^{-1}$ , respectively. There is only a 17 km<sup>2</sup> topographical catchment between these two sites and this area could reasonably be expected to yield no more than 500 litres  $s^{-1}$ , so the remaining 1374 litres  $s^{-1}$  could represent groundwater outflow from Lake Tarawera and/or its catchment.

The Meteorological Service (1973) used rainfall data collected between 1941 and 1970 to construct an isohyetal map for New Zealand. From this it is judged that the annual rainfall in the Lake Tarawera catchment averages 1600 mm.

Finkelstein (1973) used long term records (>20 years) of tank evaporation to construct a map of average annual open-water evaporation. He claimed such estimates of open water evaporation equate to lake evaporation. Examination of his map suggests that annual evaporation from Lake Tarawera will be between 600 and 800 mm, and for the purposes of calculation a figure of 700 mm was adopted.

The estimates of average lake outflow, rainfall and evaporation may be converted to annual volumes as follows -

Outflow is either  $((6800/1000) \times (31.54 \times 10^6)) = 214.44 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$

or  $((8175/1000) \times (31.54 \times 10^6)) = 257.84 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$

Rainfall is  $((1600/1000 \times (\text{lake area i.e. } 41 \times 10^6)) = 65.60 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$

Evaporation is  $((700/1000) \times (\text{lake area i.e. } 41 \times 10^6)) = 28.70 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$

The average volume of water that drains into Lake Tarawera can be calculated as

Outflow + Evaporation - Rainfall

which yields estimates of  $177.5 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$  and  $220.9 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$ . These two volume estimates equate to 5630 litres  $\text{s}^{-1}$  and 7004 litres  $\text{s}^{-1}$ .

The total land drainage can be thought of as water from a variety of sources which are likely to contain quite different concentrations of

nutrients. Such sources might be water of geothermal origin or from septic tanks, the remainder being streamwater and groundwater uninfluenced by geothermal water and septic tank effluent.

There can be no guarantee of total separation of these source waters but it is attempted as follows and seems to be the best that can be achieved.

Water discharged from *septic tanks* situated about Lake Tarawera is of miniscule volume relative to total land drainage reaching the lake. This can be exemplified as follows. If 1000 people each put 250 litres per day through septic tanks in the area, this totals  $91250 \text{ m}^3 \text{ yr}^{-1}$  or about  $3 \text{ l s}^{-1}$ . This equates to less than 0.1% of total land drainage. Inspection of the distribution of houses about Lake Tarawera relative to the position of surface streams indicates that very little of the septic tank water discharge will enter streams, so almost all of the nutrients associated with septic tank effluent which stay in solution will discharge to the lake with groundwater.

Timperley & Vigor-Brown (1986) in a study of major ion concentrations in lakes of the Taupo Volcanic Zone, carried out calculations which allow the amount of *water of geothermal origin* to be estimated. For Lake Tarawera, using chloride as a tracer of geothermal water, the amount from this source is estimated to be  $231 \text{ l s}^{-1}$ . However, the work of Sheppard (1986) showed that geothermal spring waters entering the Wairua Arm of Lake Tarawera had chloride concentrations of  $153\text{--}425 \text{ g m}^{-3}$  with a flow weighted average concentration of  $416 \text{ g m}^{-3}$ , much less than that for hot concentrated geothermal fluid for which Timperley & Vigor-Brown suggest a content of  $2290 \text{ g m}^{-3}$ . The implication is that the geothermal waters entering the

Wairua Arm have been diluted with groundwater about 5.5 times. If this is typical of the geothermal input to the lake, then the quantity of diluted geothermal fluid will total  $1272 \text{ l s}^{-1}$ .

The combined volume of *streamflow and groundwater* uninfluenced by geothermal water will therefore average between 5630-1272 and 7004-1272 litres  $\text{s}^{-1}$ , that is between 4358 and 5732 litres  $\text{s}^{-1}$ .

On three occasions streams entering Lake Tarawera have been gauged. From these gaugings it can be calculated that streams contributed close to 29% of the surface outflow on each date, or  $1972 \text{ litres s}^{-1}$  on an annual basis. Of this surface flow about  $322 \text{ litres s}^{-1}$  came from Lake Rotokakahi via the Wairoa Stream so  $1650 \text{ l s}^{-1}$  is derived from streams draining the topographical catchment. This leaves an unaccounted flow of between 2386 and  $3760 \text{ litres s}^{-1}$  which is taken to represent input from *non-geothermal groundwater*. Some of this groundwater will be derived from Lake Tarawera's topographical catchment but its magnitude suggests groundwater is entering the lake from outside this immediate area.

It is possible to indirectly estimate the flow entering Lake Tarawera from its immediate catchment by combining land use information with estimates of specific flow ( $\text{l s}^{-1} \text{ km}^{-2}$ ) for each land use. The topographical catchment of Lake Tarawera is  $109 \text{ km}^2$  and the areas in each land use, as at 1967, are given in Livingston *et al* (1986). Subsequent to 1967 there has been an expansion in exotic forestry, and an estimate of the current areas in each land use is given in Table 1. Using water balance data for the Purukohukohu land use catchments (Dons 1987), it is possible to calculate



runoff/rainfall ratios for pasture, pine, and native forest of 0.451, 0.253, and 0.296, respectively. With an annual rainfall estimate for the immediate catchment of Lake Tarawera of 1600 mm, specific flows ( $\text{l s}^{-1} \text{ km}^{-2}$ ) become 24, 13, and 15 for the pasture, exotic forest, and native forest, respectively. There are no data from which to estimate specific flows from the lowland and sub-alpine scrub, but analysis of the effects of afforestation on Tarawera river flows (Dons 1986) suggests that specific flows from scrub may be higher than from forested areas but not as high as from pasture (Dons, pers. comm.); a specific flow of  $21 \text{ l s}^{-1} \text{ km}^{-2}$  was selected.

The average inflow to Lake Tarawera from its immediate catchment is estimated from specific flows in Table 1 as  $2032 \text{ l s}^{-1}$ . The difference between this and the estimate derived from streamflow gauging (i.e.  $2032-1650 \text{ l s}^{-1}$ ) yields an estimate for groundwater flow from the topographic catchment of  $382 \text{ l s}^{-1}$ .

A summary statement of estimates of average flow from a variety of sources is shown in Table 2. This water balance is potentially frail but is the best that can be achieved with existing information.

The large external groundwater flow into Lake Tarawera estimated in Table 2, may be interpreted reasonably by presuming that it is derived from surrounding lakes at higher elevation which have no surface outlets of their own. Fig. 1 shows how the lakes about Lake Tarawera are distributed in relation to elevation and their maximum depths. Of these only Lake Rotokakahi has a permanent surface flow to Lake Tarawera. Lake Rotomahana receives water by surface flow from Lake Okaro, and indirectly

by spring discharge from Lake Rerewhakaaitu. Flow from Lake Rotomahana to Lake Tarawera is likely and is probably influenced geothermally.

Groundwater derived from the Lake Okataina catchment is likely to be cold, although a minor hot spot does occur near Otumutu Island. Lake Okareka has its maximum level controlled by an outlet structure which discharges to Lake Tarawera from time to time. At lower lake levels seeps discharge to Lake Tarawera via the Waitangi Stream. Lake Tikitapu may also be expected to discharge to Lake Tarawera via Lake Rotokakahi.

If all of the water from all of these lakes drains to Lake Tarawera then the catchment area external to the topographical catchment (but including lake surfaces) is 236 km<sup>2</sup>. Flow from this area may total between 3598 and 4972 litres s<sup>-1</sup> (i.e. externally derived flow + geothermally influenced groundwater in Table 2), giving specific flows of between 15.2 and 21.1 litres s<sup>-1</sup> km<sup>-2</sup>. By comparison with Table 1, such specific flows seem reasonable and add weight to the presumption that most of the water from the surrounding lakes passes into Lake Tarawera.

## **4.2 An estimate of the nutrient loads on Lake Tarawera**

### **4.2.1 Nutrient inputs from aerial sources**

Nutrients arriving at a water surface from the air are very difficult to quantify. Dry fallout and impaction of salts on solid surfaces of rainfall collectors confound attempts at accuracy. The figures used here are calculated from data of White & Downes (1977) from the Taupo catchment. The concentrations added to Lake Tarawera from aerial sources and found in

rainfall collectors are estimated to be 5-15 mg m<sup>-3</sup> for reactive phosphorus and 200-400 mg m<sup>-3</sup> of inorganic nitrogen. This amounts to 0.3-1.0 tonnes of phosphorus and 13.1-26.2 tonnes of nitrogen per year associated with 1600 mm rainfall.

#### **4.2.2 Nutrient inputs from septic tank effluent**

While the estimated flow from septic tanks about Lake Tarawera is only about 3 l s<sup>-1</sup>, the nutrient concentrations within such effluent are high. Gibbs (1977) reports figures of 43 and 76 g N m<sup>-3</sup> and for phosphorus 12 and 22 g m<sup>-3</sup>. Some nutrient reduction occurs as the effluent percolates through soil and subsoils (Hoare 1984, Gibbs 1977) and the contribution to Lake Tarawera suggested by Howard-Williams & Gibbs (1987) seems reasonable, namely 3.1-4.9 tonnes N yr<sup>-1</sup> and 0.03-0.7 tonnes P yr<sup>-1</sup>.

#### **4.2.3 Nutrient inputs from geothermal sources**

The flow weighted average concentration of ammonia from 5 geothermal springs of the Wairua Arm of Lake Tarawera is 0.82 g m<sup>-3</sup> (Sheppard 1986). This is equivalent to 0.68g N m<sup>-3</sup> and at a flow of 1272 l s<sup>-1</sup> totals 27.3 tonnes yr<sup>-1</sup>. Nitrate-nitrogen concentrations are not reported for these waters but usually this form of nitrogen is in small concentrations relative to ammonia and may be ignored.

The concentrations of phosphorus in the geothermal waters of the Wairua Arm were not reported by Sheppard (1986). It seems that concentrated hot geothermal fluid contains low concentrations of phosphorus

relative to diluted geothermal fluid. Taupo Research Laboratory analyses of geothermal water collected from the general area range from 4 to 750 mg P m<sup>-3</sup>. In the absence of any data related directly to geothermal waters in the Lake Tarawera catchment there is clearly difficulty in estimating the phosphorus load to the lake. A guess that the average concentrations may fall between 100 and 500 mg P m<sup>-3</sup> gives load estimates of between 4.0 and 20.1 tonnes yr<sup>-1</sup>. Such figures are massively in excess of the estimate of <0.2 tonnes yr<sup>-1</sup> suggested by Howard-Williams & Gibbs (1987). They do not describe how they arrived at this figure, but it seems that it must have been based on the concentrations found in hot concentrated geothermal fluid.

#### **4.2.4 Nutrients in streamflow**

##### **4.2.4.1 Direct method**

The DSIR Taupo Research Laboratory measured the nutrient concentrations of all surface streams entering Lake Tarawera on 8 February 1990, a date on which the DSIR Water Resources Survey measured stream flow. The location of the streams is shown on Fig. 2, and their flow rate and nutrient content is listed in Table 3.

The flow weighted average concentrations found in the streams from the immediate catchment on 8 February 1990 were 63.2 mg P m<sup>-3</sup> and 399.8 mg N m<sup>-3</sup>, most of these elements being as dissolved reactive phosphorus (59.0 mg m<sup>-3</sup>) and nitrate-nitrogen (314.4 mg m<sup>-3</sup>). On the basis of these figures the nutrient load contributed by stream flow within the immediate catchment is 3.29 tonnes yr<sup>-1</sup> for phosphorus and 20.80 tonnes yr<sup>-1</sup> for nitrogen. The contributions from the Wairoa Stream that drains Lake

Rotokakahi are estimated as 0.14 tonnes yr<sup>-1</sup> phosphorus and 1.77 tonnes yr<sup>-1</sup> nitrogen.

#### 4.2.4.2 Indirect method

An alternative means of estimating streamflow nutrient loads to Lake Tarawera is to combine information on the catchment area in each land use (Table 1) with an appropriate nutrient export coefficient (kg km<sup>-2</sup> yr<sup>-1</sup>). Extensive work has been done on nutrient export from catchments in the Central Volcanic Plateau, but results serve to highlight variability rather than unifying principles. Nevertheless, a summary of this information, listing a 'middle' value, together with lower and upper bounds, is presented in Tables 4 and 5. The only directly usable data is that of Cooper & Thomsen (1988) for three headwater catchments at Purukohukohu and those Taupo catchments reported by Schouten *et al.* (1981) that were predominantly in one land use and developed from volcanic parent material. This information did not allow a meaningful distinction to be made between native forest and lowland scrub but the data for sub-alpine vegetation gathered by Schouten was sufficiently different (especially for N) to warrant its separation. Other studies (e.g. Hoare 1987; White & Downes 1977) were not able to be used directly because either they gave data from mixed land uses or did not measure total nutrient.

Combination of information in Tables 1, 4 and 5 allows indirect estimates of the nutrient load to Lake Tarawera to be made for its immediate catchment (Table 6). Because of the uncertainties in export coefficients there is about a four-fold variation in estimates of N load and a five-fold variation in estimates of P load. Estimated N:P ratios are more constant.

The estimate of streamflow N load made by the direct method of 20.80 tonnes yr<sup>-1</sup> is close to the lower bound estimate arrived at by the indirect method. The tendency for the direct method to give lower estimates may reflect that it was based on the nutrient concentrations of samples collected under baseflow conditions. Nutrient concentrations (especially particulate forms) increase under stormflow conditions. The phosphorus estimates derived from the indirect method straddle the direct estimate of 3.29 tonnes yr<sup>-1</sup>.

#### **4.2.5 Nutrients in non-geothermal groundwater**

There are no measurements of nutrient content of non-geothermal groundwater in this catchment. In this circumstance the best estimate that can be made is to reuse the streamflow data of the 8 February 1990 but to include only low temperature streams in the belief that they are spring fed and have travelled only short distances from their groundwater sources. Those used to calculate flow weighted nutrient concentrations are marked with an asterisk on Table 3. On this basis the average phosphorus content is 61.4 mg m<sup>-3</sup> and average nitrogen content is 430 mg m<sup>-3</sup>, which yields estimated loads of 4.61-7.26 tonnes P yr<sup>-1</sup> and 32.36-51.00 tonnes N yr<sup>-1</sup>.

#### **4.2.6 Cyanobacteria**

Cyanobacteria with the potential to fix nitrogen exist in Lake Tarawera, but a significant contribution to the nitrogen load from this source is not likely (White *et al.* 1991).

#### 4.2.7 Total nutrient load

The estimated nutrient load from all sources is summarised in Table 7 and totals 10.8-37.9 tonnes P yr<sup>-1</sup> and 98-197 tonnes N yr<sup>-1</sup>.

### 5. Reliability of the nutrient load estimates

The reliability of the estimates is very poor. While some of the hydrological components are satisfactorily estimated, geothermal water flow could vary from 231 l s<sup>-1</sup> to be in excess of the 1272 l s<sup>-1</sup> used in Table 7, and such changes would impact directly but in the opposite direction on the estimate of flow for non-geothermal groundwater. Furthermore, there remains a large uncertainty in the outflow from Lake Tarawera and this is reflected, again, in an uncertainty in the load from non-geothermal groundwater.

However, the main problem is seen as uncertainty about many of the average nutrient concentrations used to make the assessments. This is particularly significant for the geothermal component, where there are no estimates of phosphorus concentration for waters in the catchment, and massively variable concentrations (from 4-750 mg m<sup>-3</sup>) are known to occur in geothermal waters of the Rotorua-Taupo area. The reliability of the nitrogen load from geothermal sources may not be good either. It is based on the concentration found in <3 l s<sup>-1</sup> of water and that flow is multiplied up to 1272 l s<sup>-1</sup>, even though it is known that the nitrogen concentrations in geothermal water can vary massively.

The load assessments for streamflow are poor; the direct method is based on nutrient analyses for only one set of sampled collected at baseflow,

while the indirect method has low precision because of the variability in reported export coefficients.

A Taupo Research Laboratory study during 1989/90 provides precise estimates of the average nutrient content of Lake Tarawera, namely 7.5 mg P m<sup>-3</sup> and 94 mg N m<sup>-3</sup>. This allows prediction of input concentrations by way of an OECD (1982) study which compared input and in-lake concentrations of nutrients, using 101 lakes for phosphorus, and 42 lakes for nitrogen. On this basis the average input concentrations to Lake Tarawera are predicted as 30 mg P m<sup>-3</sup> and 168 mg N m<sup>-3</sup> which are equivalent to 7.3 tonnes P yr<sup>-1</sup> and 40.9 tonnes N yr<sup>-1</sup>. These figures are clearly at odds with even the minimum estimates in Table 7. However, the upper bounds of the OECD information predict loads for Lake Tarawera of 20.7 tonnes P yr<sup>-1</sup> and 111.9 tonnes N yr<sup>-1</sup> which overlap with the estimates in Table 7. Too much should not be read into these predictions from the OECD study because very substantial differences exist between central volcanic plateau lakes and those of the OECD (White 1989), and the nitrogen content of Lake Tarawera is only one third of the minimum concentration found among the OECD lakes, so it is doubtful that any comparison should be made.

A more useful comparison might be to examine nutrient loads and concentrations in other New Zealand lakes. In this respect Lake Taupo is of particular interest, because a major study by Schouten (1983) assembled a comprehensive nutrient load assessment. Lakes Taupo and Tarawera have very similar water residence times (11.5 yrs for Lake Taupo and 10.5 yrs for Lake Tarawera), so their loads can be compared directly when calculated as



nutrient added per unit area in a year. These specific surface loads for Lake Taupo are  $2.77 \text{ g N m}^{-2} \text{ yr}^{-1}$  and  $0.373 \text{ g P m}^{-2} \text{ yr}^{-1}$ . The estimates for Lake Tarawera, derived from Table 7, are  $2.40\text{-}4.80 \text{ g N m}^{-2} \text{ yr}^{-1}$  and  $0.26\text{-}0.93 \text{ g P m}^{-2} \text{ yr}^{-1}$ . Both lakes are oligotrophic and might be expected to have broadly similar specific surface loads. To this extent the overlap in the estimates is encouraging. In-lake concentrations for Lake Taupo are well-known and are listed by White (1983) as  $55 \text{ mg N m}^{-3}$  and  $5.5 \text{ mg P m}^{-3}$ . These are substantially less than for Lake Tarawera namely  $94 \text{ mg N m}^{-3}$  and  $7.5 \text{ mg P m}^{-3}$ . These higher concentrations lead to greater concentrations of chlorophyll *a*, namely  $1.30 \text{ mg m}^{-3}$  as opposed to  $0.61 \text{ mg m}^{-3}$  in Lake Taupo. The greater nutrient and chlorophyll *a* concentrations found in Lake Tarawera would generally be expected to be associated with greater specific surface nutrient loads than for Lake Taupo, so on this basis loads in the upper range of estimates in Table 7 may not be unreasonable.

## 6. Management implications

The N:P ratios which can be calculated from load estimates in Table 7 range from a low of 2.6 to a high 18.2. During 1989/90 a DSIR study, part funded by DOC (S3040/582), examined the algal flora, nutrient content and the demand of algae for those nutrients in Lake Tarawera (White *et al.* 1991). The findings of this study indicated substantial demand for nitrogen by the algal community. Nitrogen limitation of algal biomass appears to last the year through and was more intense than has been found in any lake of similar trophic status in New Zealand. Nitrogen limitation is a likely

consequence of low ratios of nitrogen to phosphorus in inputs, so it may be that the upper bound estimate of nitrogen load in Table 7 is too high, with perhaps the upper estimate of streamflow loads being over-estimated by the indirect method. Because of the nitrogen limitation of algal biomass, reduction of nitrogen loads might be expected to reduce its algal content. However, there is also the possibility that the further lowering of the N:P ratio would make conditions more favourable for the growth of undesirable blue-green algae.

Prospects for changing the nutrient load on Lake Tarawera by manipulation of land use or point sources of nutrients are not good. Of the nutrient loads presented in Table 7, nothing can be done about the loads in rainfall and geothermal waters. Furthermore, most of the phosphorus in non-geothermal groundwater is likely to be derived from rock dissolution and little affected by activities at the land surface. It is not known how the nitrogen content of non-geothermal groundwater is affected by land use, but any effect is likely to be small because a large proportion of these waters have been modified during passage through the other lakes. This leaves septic tank effluent and streams as possible sources for control and these maximally amount to only 25% of the inflow.

Septic tank effluents contribute between 0.1-6.1% of the total phosphorus load and between 1.6-4.9% of the total nitrogen load. Clearly, even complete removal of such loads would have a minimal impact. However, the upper bounds of these estimates are high enough to warrant a

cautious approach to any future proposals for large-scale urbanisation involving the use of septic tanks.

Streamflow inputs from the immediate catchment are estimated to contribute between 5.6-48.9% of the total phosphorus load and between 15.6-52.5% of the total nitrogen load. Although the bounds are wide, it seems that streamflow could be an important contributor to nutrient loads. The prospects for reducing these are poor. About 67% of the catchment is undeveloped (Table 1) and loads from these areas represent 'background' levels. It is possible to obtain a very crude indication of changes in nutrient load to the lake as a result of returning the remaining catchment to native forest. Using middle values from Tables 4 and 5, it is possible to estimate that phosphorus loads from the immediate catchment would decrease by 20.9%, nitrogen loads would decrease by 9.8%, and N:P ratios would increase from 9.8 to 11.2. It seems reasonable to suggest that any use of riparian retirement rather than whole catchment retirement will produce effects less than these. In terms of total load to the lake, this analysis indicates that reverting completely to native bush will reduce P load by about 1-10% and N load by about 1.5-5%. The errors involved make predicting changes in the overall input ratio of N:P a worthless exercise; suffice to say that any change would be extremely small.

For management it may also be useful to attempt an assessment of the consequences of increased development in the catchment. Given recent trends, it is perhaps reasonable to suppose that such development would be conversion of native forest and lowland scrub to exotic forest. Taking this

scenario to its extreme with all of the native forest and lowland scrub converted to exotic forest, then the middle estimate of N load from the immediate catchment would decrease from 47 to 40.5 tonnes  $\text{yr}^{-1}$  while the estimate for P load would rise from 4.79 to 5.86 tonnes  $\text{yr}^{-1}$ . The opposing direction of these changes leads to an estimated decrease in N:P ratio in waters from the immediate catchment from 9.81 to 6.9. Again, because of the uncertainties in the average N:P ratio of all source waters (estimated range 2.6-18.2) it is not possible to predict what effect such a change would have other than to say that the nitrogen limitation of the algal community would probably become more entrenched.

#### **7. Prospects for improving the nutrient load assessment**

The nutrient load assessments of Table 7 are amenable to refinement. The first step would be to investigate the volume of geothermal groundwater flowing into the Wairua Arm at the hot beach. Technology is available to achieve this (Lock & John 1978). The expectation is that the flow would be a substantial part of the total geothermally influenced water reaching the lake. Measurement of its chloride, nitrogen and phosphorus content would permit a much more precise estimate of the nutrient loads from this source. Following this, refinement of nutrient loads from streamflow and non-geothermal groundwater could be achieved by repeating the measurements of 8 February 1990 in May, August and November to give better seasonal coverage, supplementing this with one further investigation when streams are in flood. With this achieved it is unlikely that further refinement would

alter the direct nutrient load assessments to any extent, but greater confidence in these might allow more precise statement of management options.

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Table 1. Estimate of inflows to Lake Tarawera from its immediate catchment.

Land use	Area		Specific flow	Total flow
	(km <sup>2</sup> )	(%)	(l s <sup>-1</sup> km <sup>-2</sup> )	(l s <sup>-1</sup> )
Pasture	17	(16)	24	408
Exotic forest	19	(17)	13	247
Native forest	26	(24)	15	390
Lowland scrub	42	(39)	21	882
Sub-alpine scrub	5	(4)	21	105
Total catchment	109	(100)	18.6	2032

Table 2. Estimates of average annual flows from a variety of sources at Lake Tarawera.

	Measurement	Expressed as litres s <sup>-1</sup>
<b>Outputs</b>		
Tarawera River		
- surface	6800 l s <sup>-1</sup>	6800 l s <sup>-1</sup>
- subsurface	0-1375 l s <sup>-1</sup>	0-1375 l s <sup>-1</sup>
Evaporation	700 mm yr <sup>-1</sup>	910 l s <sup>-1</sup>
<b>Inputs</b>		
Rainfall on lake	1600 mm yr <sup>-1</sup>	2080 l s <sup>-1</sup>
Septic tank effluent	3 l s <sup>-1</sup>	3 l s <sup>-1</sup>
Geothermally-influenced groundwater	(see text)	1272 l s <sup>-1</sup>
<b>Immediate catchment</b>		
- stream flow	(see text)	1650 l s <sup>-1</sup>
- groundwater (non-geothermal)	(see text)	382 l s <sup>-1</sup>
<b>Externally derived</b>		
- stream flow (from L. Rotokakahi)		322 l s <sup>-1</sup>
- groundwater (non-geothermal)	(see text)	2004-3378 l s <sup>-1</sup>

Table 3. Flow, temperature and nutrient concentrations in streams entering Lake Tarawera on 8 February 1990.

Stream Number	Stream Name	Flow l s <sup>-1</sup>	Temperature °C	DRP mg m <sup>-3</sup>	TP mg m <sup>-3</sup>	NH <sub>4</sub> -N mg m <sup>-3</sup>	NO <sub>3</sub> -N mg m <sup>-3</sup>	TN mg m <sup>-3</sup>
015385	Wairoa	273	22.1	4.9	13.3	4.7	29.5	173.8
015386*		35.4	12.0	43.0	45.0	1.8	145.7	179.5
015387*		16.1	12.4	47.5	48.4	1.2	139.1	169.1
015388	Waitangi	120	25.5	5.5	12.7	1.9	50.4	220.6
1015328*		26.6	13.0	63.3	63.8	0.8	341.5	388.6
1015329*		226	13.8	55.7	56.1	1.0	1060.5	1151.7
015390*		16.5	13.5	53.2	57.4	7.3	749.3	809.7
015377*		60.9	16.5	113.6	120.4	5.7	96.3	174.3
015332*		160	16.7	115.0	116.0	2.4	106.2	167.7
015380	Wairua	178	23.7	86.1	108.8	5.3	167.6	335.8
015382*	Te Puroku No.1	151	14.5	40.1	40.8	3.5	246.6	317.3
015383*	Te Puroku No.2	406	12.2	43.4	43.5	1.9	183.5	230.7

Location of streams - see stream numbers on Figure 2.

DRP - dissolved reactive phosphorus  
TP - total phosphorus  
NH<sub>4</sub>-N - ammonium-nitrogen  
NO<sub>3</sub>-N - nitrate-nitrogen  
TN - total nitrogen

Table 4. Estimates of N export coefficients for various land uses on the Central Volcanic Plateau

Land use	Estimate (kg km <sup>-2</sup> yr <sup>-1</sup> )		
	Lower	Middle	Upper
Pasture	300	800	1200
Exotic forest	90	300	900
Native forest and lowland scrub	200	400	700
Sub-alpine scrub	50	150	300

Table 5. Estimates of P export coefficients for various land uses on the Central Volcanic Plateau.

Land use	Estimate (kg km <sup>-2</sup> yr <sup>-1</sup> )		
	Lower	Middle	Upper
Pasture	40	80	170
Exotic forest	10	50	75
Native forest & lowland scrub	12	35	60
Sub-alpine scrub	10	30	75

Table 6. Estimates of nutrient load to Lake Tarawera from the surface of its immediate catchment based on export coefficients.

	Nitrogen (tonnes yr <sup>-1</sup> )	Phosphorus (tonnes yr <sup>-1</sup> )	N:P ratio
Lower	20.6	1.73	11.91
Middle	47.0	4.79	9.81
Upper	85.7	8.7	9.85

Table 7. The nutrient loads on Lake Tarawera contributed by a variety of source waters.

	Average annual inflow (l s <sup>-1</sup> )	Phosphorus (tonnes yr <sup>-1</sup> )	Nitrogen (tonnes yr <sup>-1</sup> )
Rainfall	2080	0.3- 1.0	13.1-26.2
Septic tank effluent	3	0.03-0.7	3.1- 4.9
Geothermal water	1272	4.0-20.0	27.3
Stream flow - immediate catchment - indirect assessment	1650	1.73-8.70	20.6-85.7
- direct assessment		3.29	20.8
Stream flow from L. Rotokakahi	322	0.14	1.77
Non-geothermal groundwater	2386-3760	4.61-7.26	32.36-51.00
Total		10.8-37.9	98.0-197.0



**Fig 1. The elevations and maximum depths of those lakes which supply water to Lake Tarawera by streams or groundwater.**

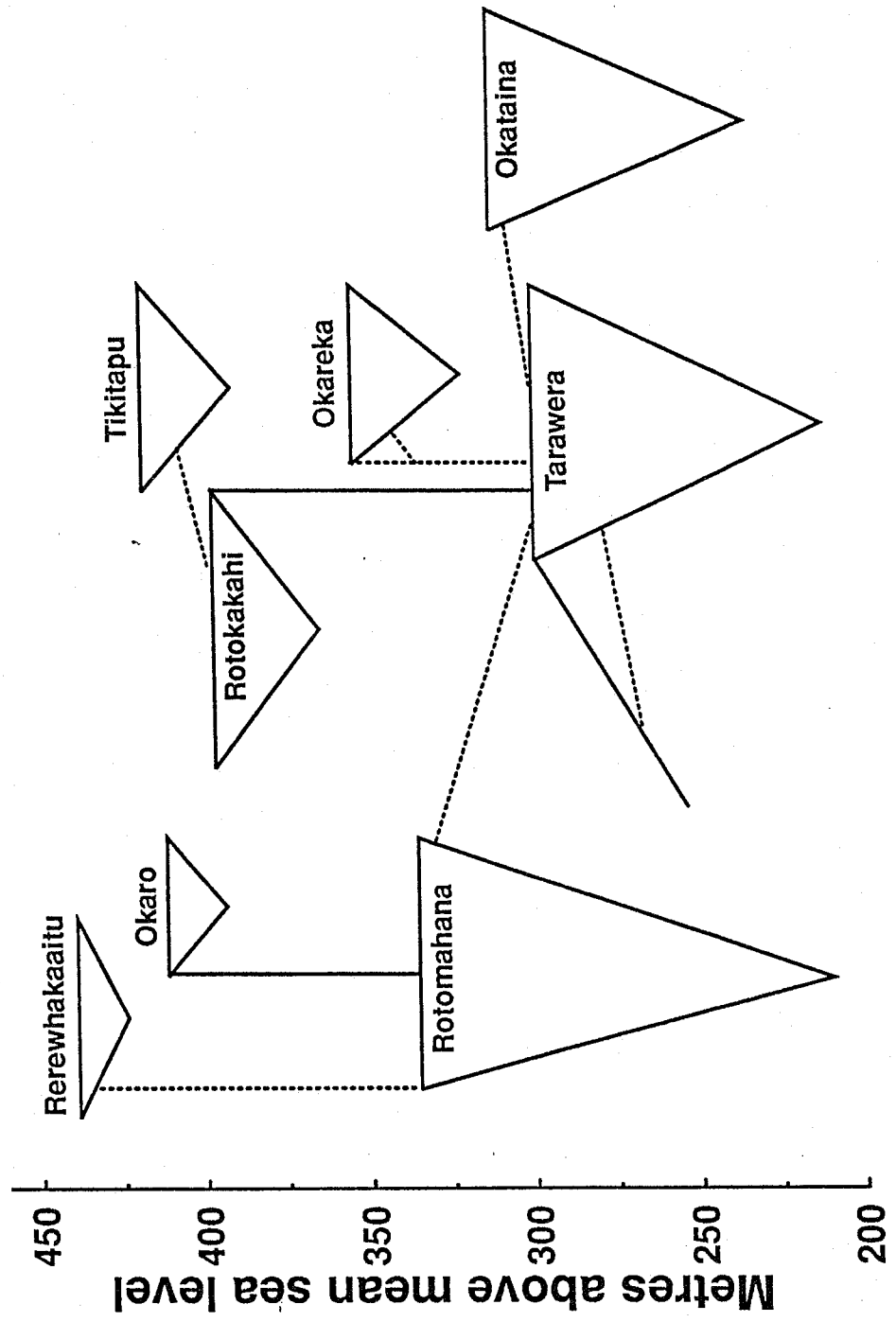


Fig 2. The location of streams sampled on 8 February 1990 at Lake Tarawera

