Groundwater in the greater Lake Tarawera catchment: Notes and Summary of GNS Science Reports

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Introduction

The Bay of Plenty Regional Council commissioned GNS Science to assess groundwater resources and groundwater quality in the greater Lake Tarawera catchment. The greater Lake Tarawera catchment is complex and includes eight lakes (Tarawera, Okareka, Ōkaro, Rotomahana, Rerewhakaaitu, Ōkataina, Tikitapu and Rotokakahi). Figure 1 shows the study area with eight 'lake zones' in the greater catchment. These 'lake zones' are based on BOPRC's surface catchments.

This work involved a three-phase study:

Phase 1: Drilling groundwater bores to measure key aquifer properties including hydraulic conductivity, quality and groundwater age,

Phase 2: Prepare a geological model for the greater catchment which identified key aquifers, and

Phase 3: Prepare a groundwater flow model ('the model') of the greater catchment. This is described in the final report. The model was applied to an assessment of land use that calculated nitrogen discharge to surface streams and lakes in the greater catchment under different scenarios.

Reports that were produced by the project are listed at the end of this report. Groundwater modelling assists in the identification of the groundwater catchments of lakes, which may differ from lake zones.

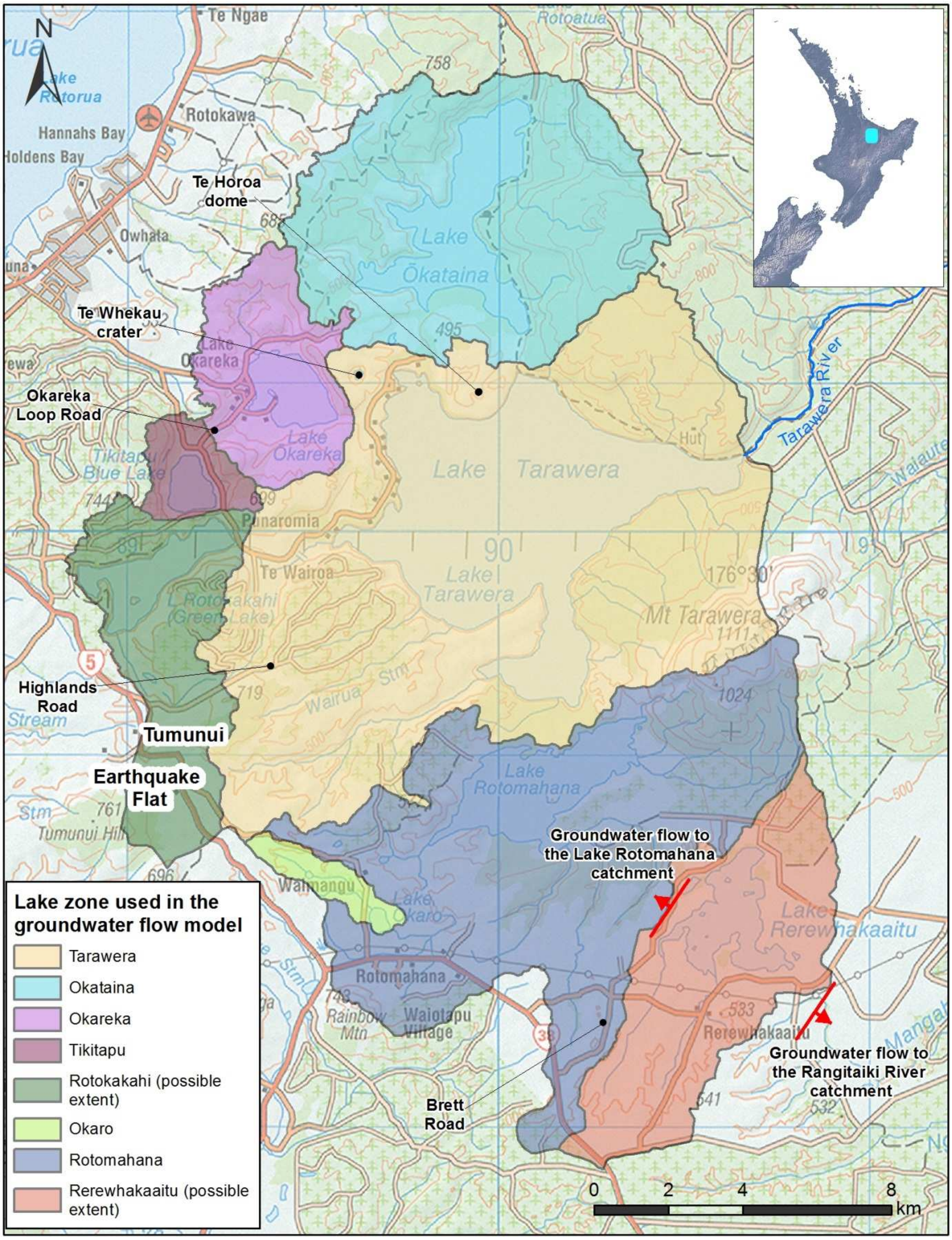

Figure 1 Lakes in the greater Lake Tarawera catchment and associated lake zones.

Surface flow information from stream monitoring was used to calculate water budgets and inform the development of the groundwater flow model. Interactions between surface flow and groundwater flow were calculated by the model. The model showed some specific behaviour of water bodies in the greater catchment:

- In some areas groundwater flows into streams and lakes,
- In other locations lake water is lost to groundwater,
- Groundwater flows between lake zones.

The report summarises that generally the lakes are recharged by groundwater as groundwater levels are typically more elevated than lake levels. An exception to this is Lake Rerewhakaaitu, which is generally perched above the groundwater system.

The model has been applied to a range of land use scenarios to estimate nitrogen inflows to lakes and streams in the greater catchment. The model calculated that the current land use intensity has a large effect on nitrogen in the groundwater in the west and south of the catchment. This includes the areas of Earthquake Flat and parts of the Rotomahana and Rerewhakaaitu zones. More intensive land use was predicted to increase nitrogen loadings to all lakes, except Rerewhakaaitu.

The boundaries of lake zones and groundwater catchments do not always align. The main areas where there are differences between these boundaries are identified in Figure 1; Te Whekau Crater, Ōkāreka Loop Road, Highlands Road, Earthquake Flat, Tumunui, the headwaters of Lake Tarawera, Ōkaro Zone and Brett Road. The report suggested that the definition of these boundaries could be improved by better understanding the groundwater catchment boundaries; application of the model to determine groundwater flow direction; groundwater catchment water budgets; analysis of the surface terrain; and additional measurements of groundwater level (being a combination of spring and bore monitoring).

The report makes a number of recommendations with respect to further work that could be undertaken to improve our understanding of the groundwater system in the greater catchment. These have been summarised at the end of the report.

The groundwater study provides a greater source of information for other components of research and investigation around the behaviour of the catchment water and nutrient flows. This work is invaluable in providing support for updating lake nutrient budgets and better identifying potential sources of nutrients in parts of the catchment.

Groundwater monitoring bores

Phase 1 of the programme included the installation of a number of monitoring bores. The location of these bores is shown in Figure 1. A monitoring bore provides a hole into the ground that can identify underlying geology, groundwater flows, water levels, water quality and age. This provides basic information for the next stage of the programme in developing the geological and groundwater models.

The bores that were installed range in depth up to 120 m. The bores are permanent installations that can be monitored on an on-going basis to provide groundwater level, flow and quality information. However these bores are yet to be included into the BOPRC's Regional Groundwater Monitoring Network.

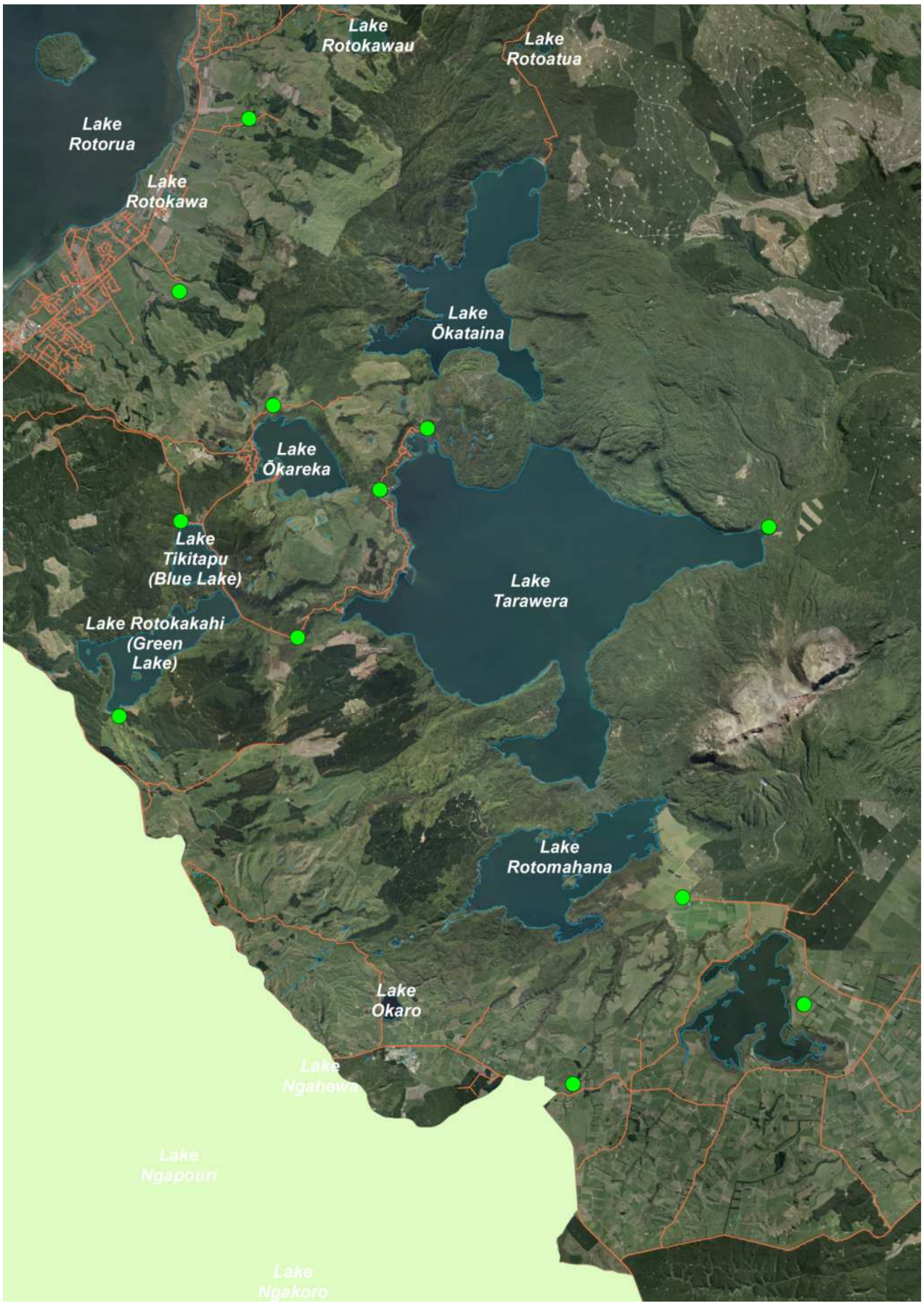

Figure 2 Greater Tarawera lakes and location of BOPRC monitoring bores (green dots).

The Geological model

Figure 2 provides a 3D conceptual model of the catchment geology. From the model it can be seen that the geology is complex and is dominated by volcanic units. A more detailed explanation of the geology is presented in the report.

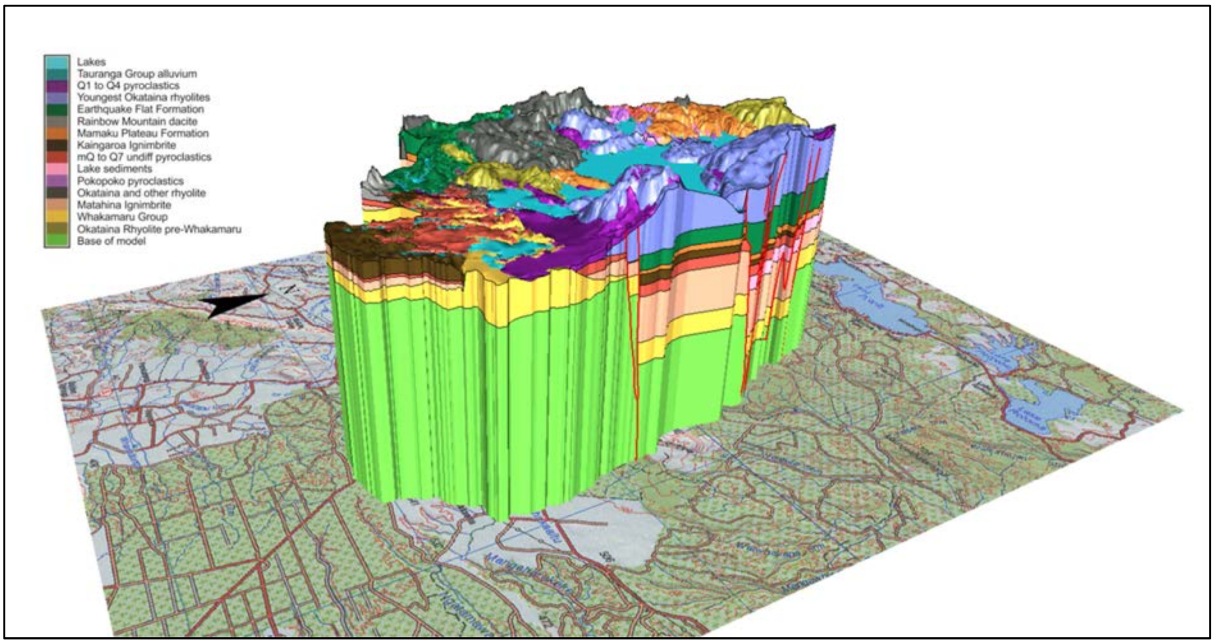

Figure 3 3D conceptual geological model of the greater Tarawera lakes catchment

Water budgets and groundwater flow

In development of the groundwater model, White has used the lake water budget work undertaken by Gillon in 2008 which focussed on the Lake Tarawera catchment, but did not extend to the catchments of the contributing lakes. This work took account of changes in lake levels as well as calculated lake inputs and outputs to establish an estimate of the importance of various inputs and outputs for each lake. For example for Lake Tarawera, surface inflows (streams and rainfall) contribute only 42% of the lake inflows. Groundwater comprises the largest inflow to Lake Tarawera. For Lake Tarawera various rainfall scenarios were tested that indicate relatively small changes in rainfall can have a massive impact on groundwater discharge from the Tarawera catchment. This water budget information was then used in the groundwater flow model to estimate nitrogen discharge from a range of land use scenarios.

As mentioned earlier, the geological model was a key component to developing the groundwater model. The groundwater model development has used an updated water budget and nitrogen flow work along with more detailed estimates of water inflows and outflows (rainfall, stream flows, groundwater flows and evapotranspiration). Figure 3 presents a schematic water budget for the greater catchment.

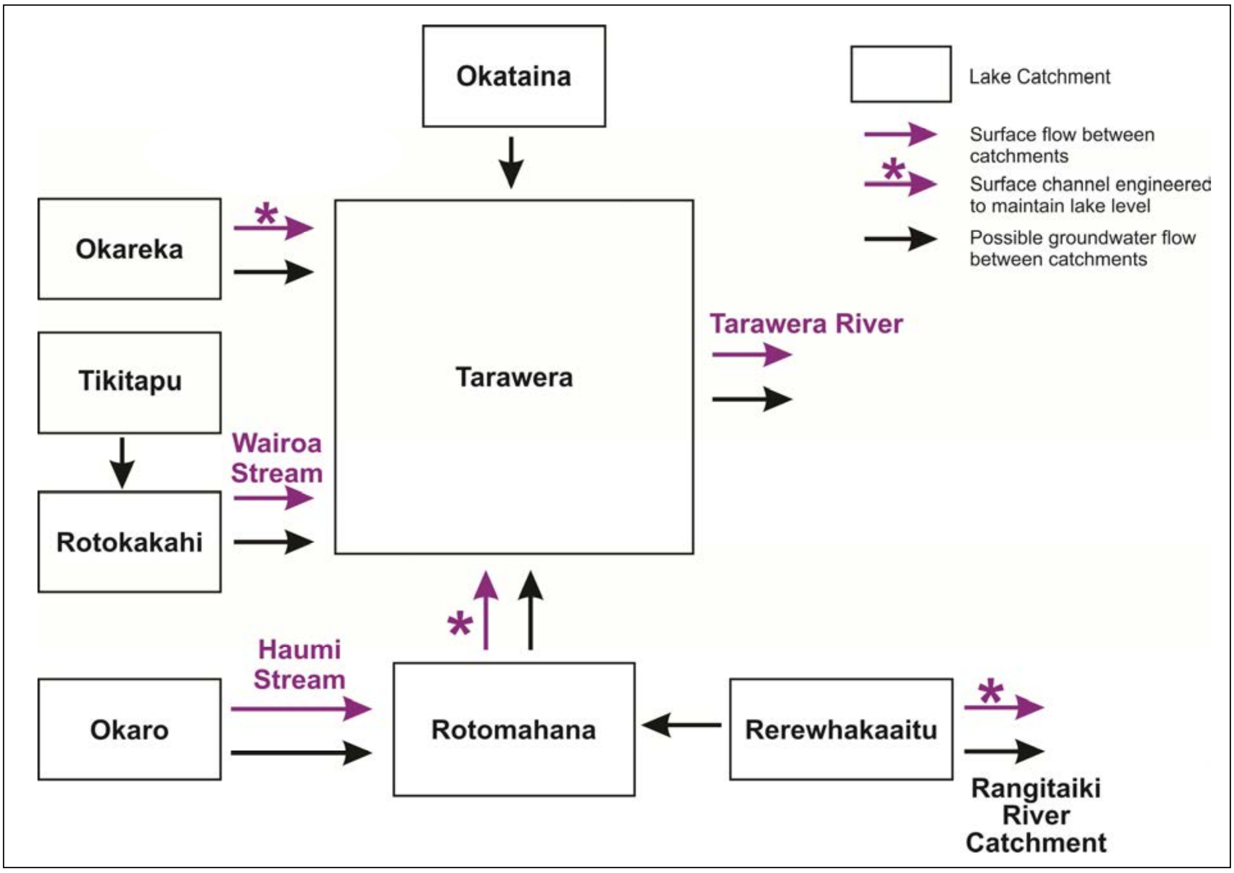

Figure 4 Water budget schematic for the greater Lake Tarawera catchments.

Figure 5 below shows the groundwater model boundary conditions.

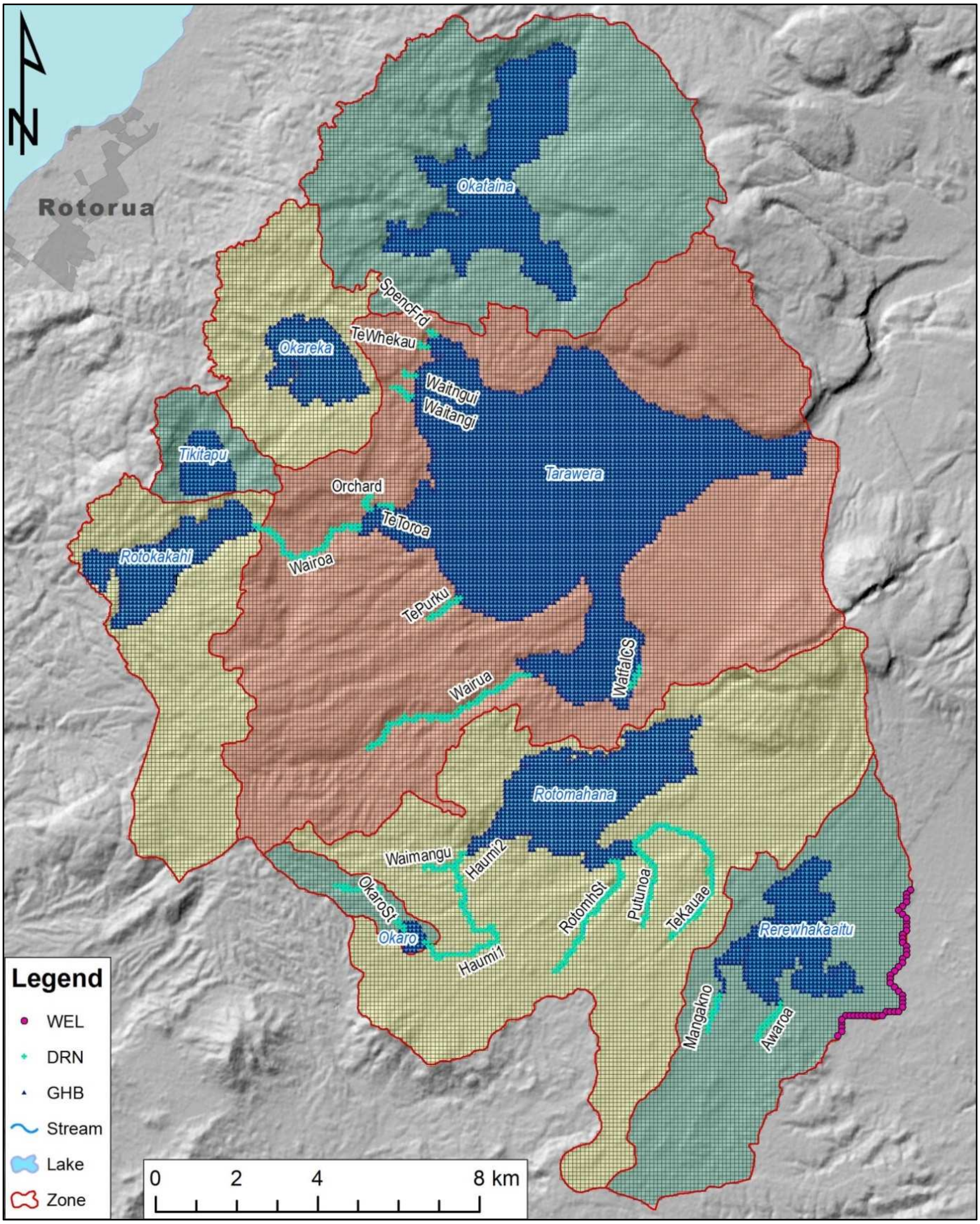

Figure 5 MODFLOW boundary conditions on the fine 100 m resolution grid.

The groundwater model is calibrated to static water level measurements from 40 wells in the catchment area.

Results

Figures 6, 7 and 8 show the main inflows to Lake Tarawera. These comprise cold and hot springs and streams.

Figure 6 Lake Tarawera: location of surface hydrological features associated with inflows to, and outflows from, the lake. The thin blue lines on the background map are watercourses (Department of Lands and Survey, 1982 and 1987). These watercourses are generally dry, except as noted by the features described in the legend.

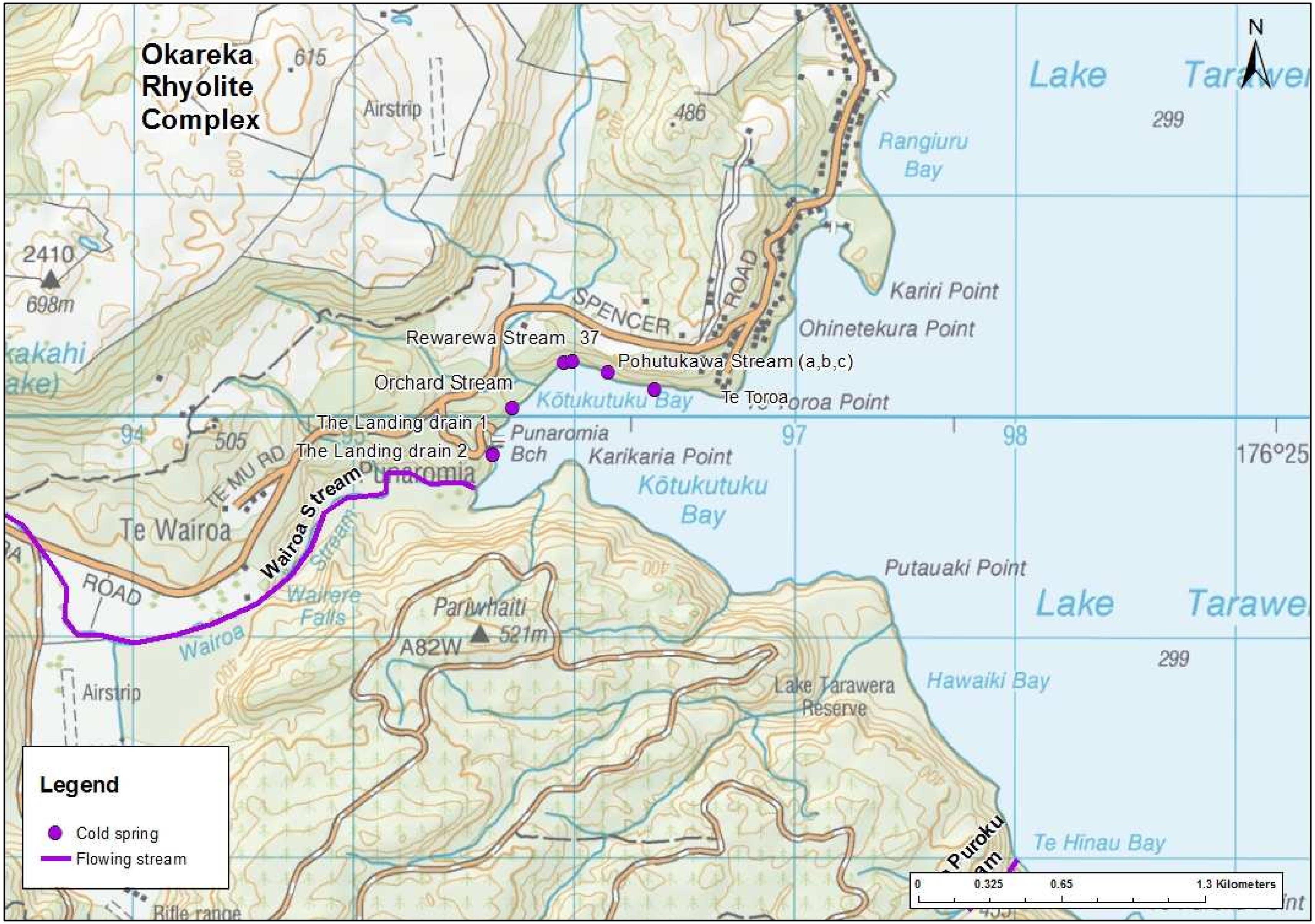

Figure 7 Lake Tarawera: surface hydrological features in Kotukutuku Bay. The thin blue lines on the background map are watercourses (Department of Lands and Survey, 1982). These watercourses are generally dry, except as noted by the features described in the legend.

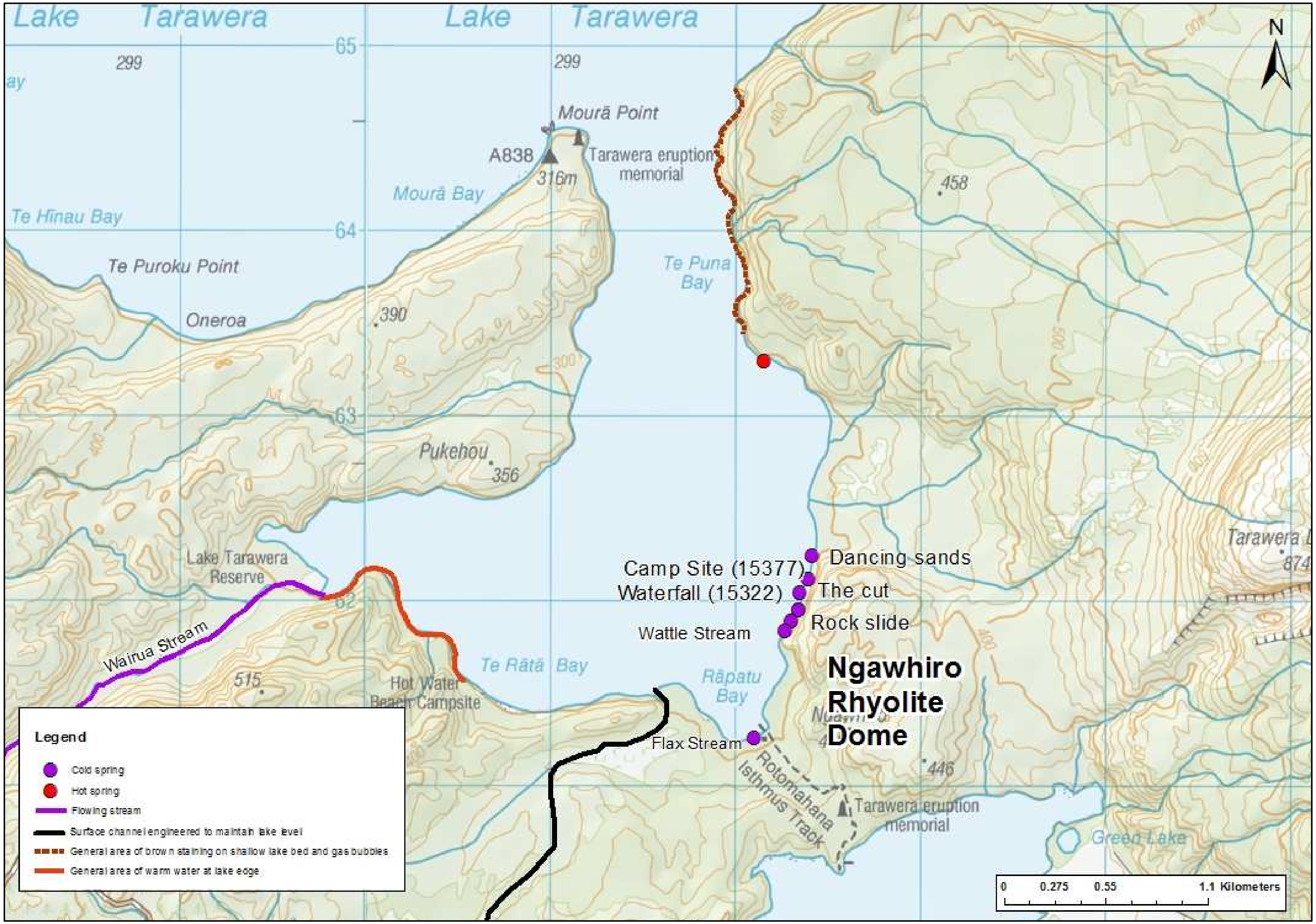

Figure 8 Lake Tarawera: surface hydrological features in the southeast area. The thin blue lines on the background map are watercourses (Department of Lands and Survey, 1982 and 1987). These watercourses are generally dry, except as noted by the features described in the legend.

Some interesting findings within these figures include:

- Cold water springs are most common in Kotukutuku Bay and the south east of Lake Tarawera,
- Surface features of Lake Tarawera related to geothermal activity include hot springs, seeps and iron staining of lake side sediments,
- The Tarawera River is the sole surface outflow from Lake Tarawera (groundwater may also flow out in this area).

River and stream monitoring at different locations can be used to establish estimates for groundwater inflows over various stream reaches as well as identify groundwater outflows from lakes, by arithmetic difference. Some key findings on this are estimates of groundwater flows out of Lake Tarawera in the area of the Tarawera River of 0.9 to 1.5 m^3/s and the Te Wairoa Stream out of Lake Rotokakahi, with estimated groundwater flows of about 36 L/s.

Further details of surface features in the other seven lakes is covered in detail in the report and identified in the following maps; figures 9 to 13.

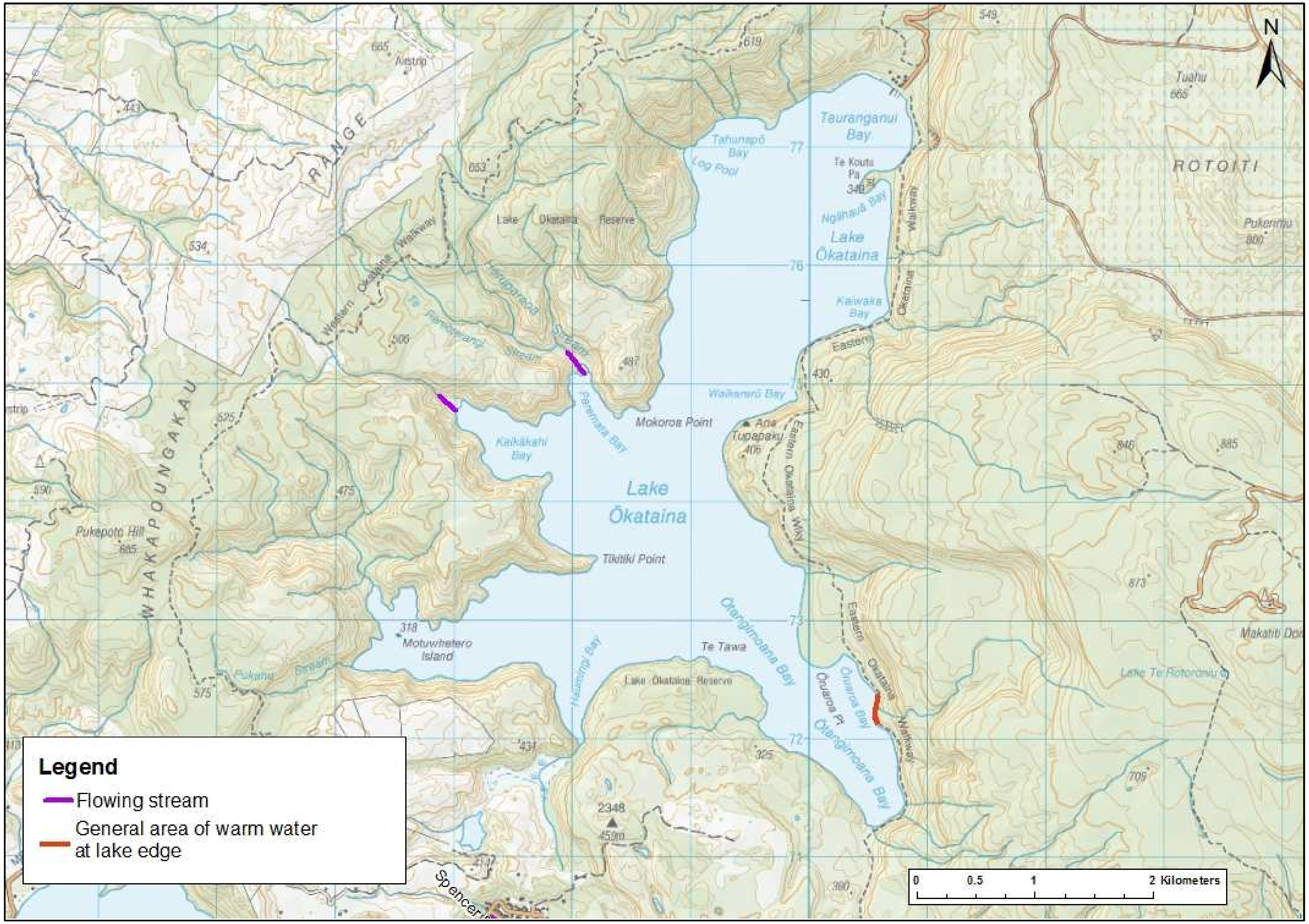

Figure 9 Lake Okataina: location of surface hydrological features associated with inflows to, and outflows from, the lake. The thin blue lines on the background map are watercourses (Department of Lands and Survey, 1982 and 1987). These watercourses are generally dry, except as noted by the features described in the legend.

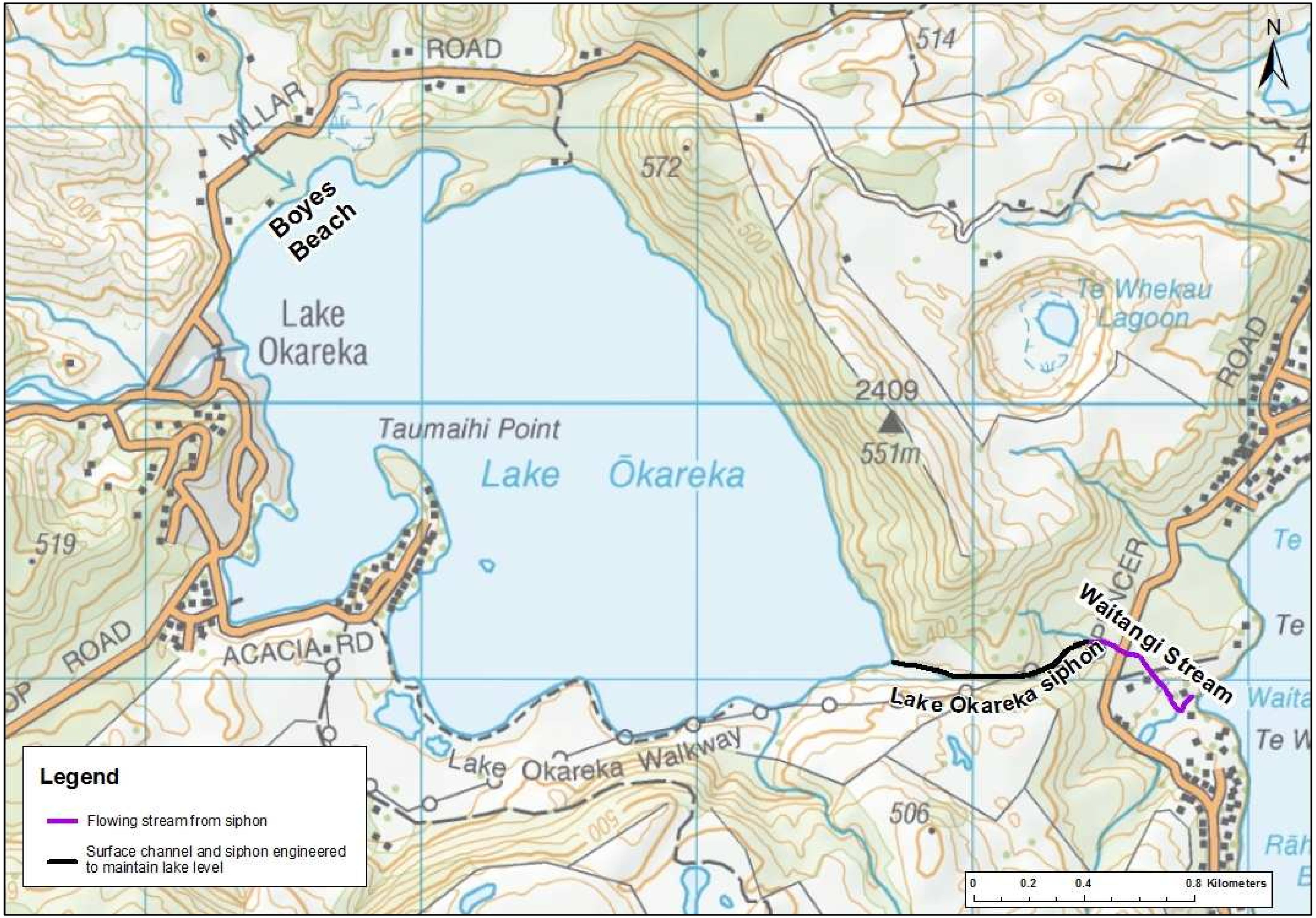

Figure 10 Lake Okareka: location of surface hydrological features associated with inflows to, and outflows from, the lake. The thin blue lines on the background map are watercourses (Department of Lands and Survey, 1982). These watercourses are generally dry, except as noted by the features described in the legend.

Figure 11 Lake Tikitapu and Lake Rotokakahi: location of surface hydrological features associated with inflows to, and outflows from, the lake. The thin blue lines on the background map are watercourses (Department of Lands and Survey, 1982). These watercourses are generally dry, except as noted by the features described in the legend.

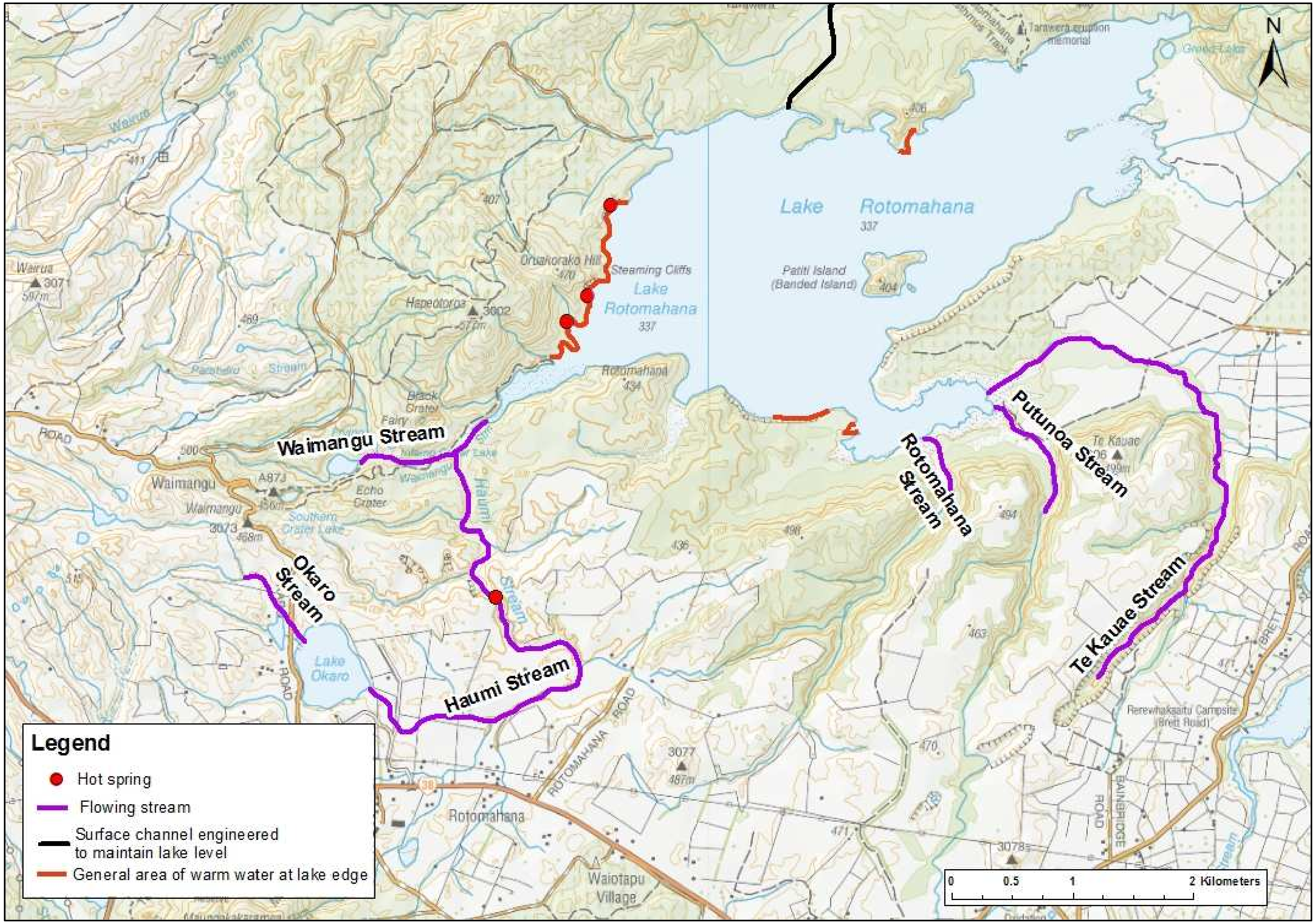

Figure 12 Lake Okaro and Lake Rotomahana: location of surface hydrological features associated with inflows to, and outflows from, the lake. The thin blue lines on the background map are watercourses (Department of Lands and Survey, 1982 and 1987). These watercourses are generally dry, except as noted by the features described in the legend.

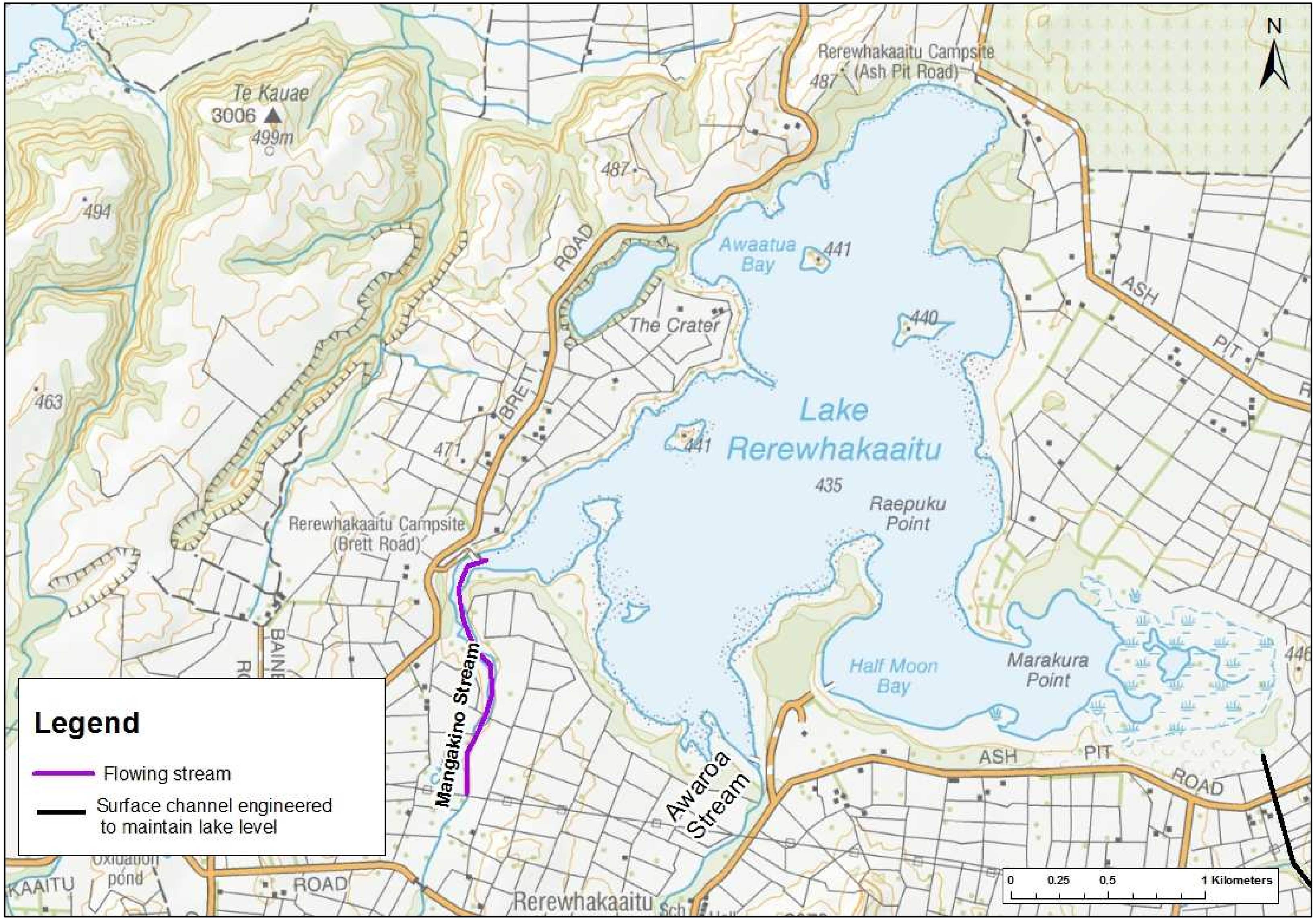

Figure 13 Lake Rerewhakaaitu: location of surface hydrological features associated with inflows to, and outflows from, the lake. The thin blue lines on the background map are watercourses (Department of Lands and Survey, 1987). These watercourses are generally dry, except as noted by the features described in the legend.

Groundwater flow model: water flows

The heart of the study is the production of groundwater flow maps for the catchment. These maps are attached as figures 14 to 18. The maps can be used to identify the modelled flow paths between lakes, but importantly they provide more information on the flows between lakes and groundwater catchments that can be used to support a detailed assessment of lake water and nutrient budgets. This will be undertaken in the next phase of study lead by the University of Waikato.

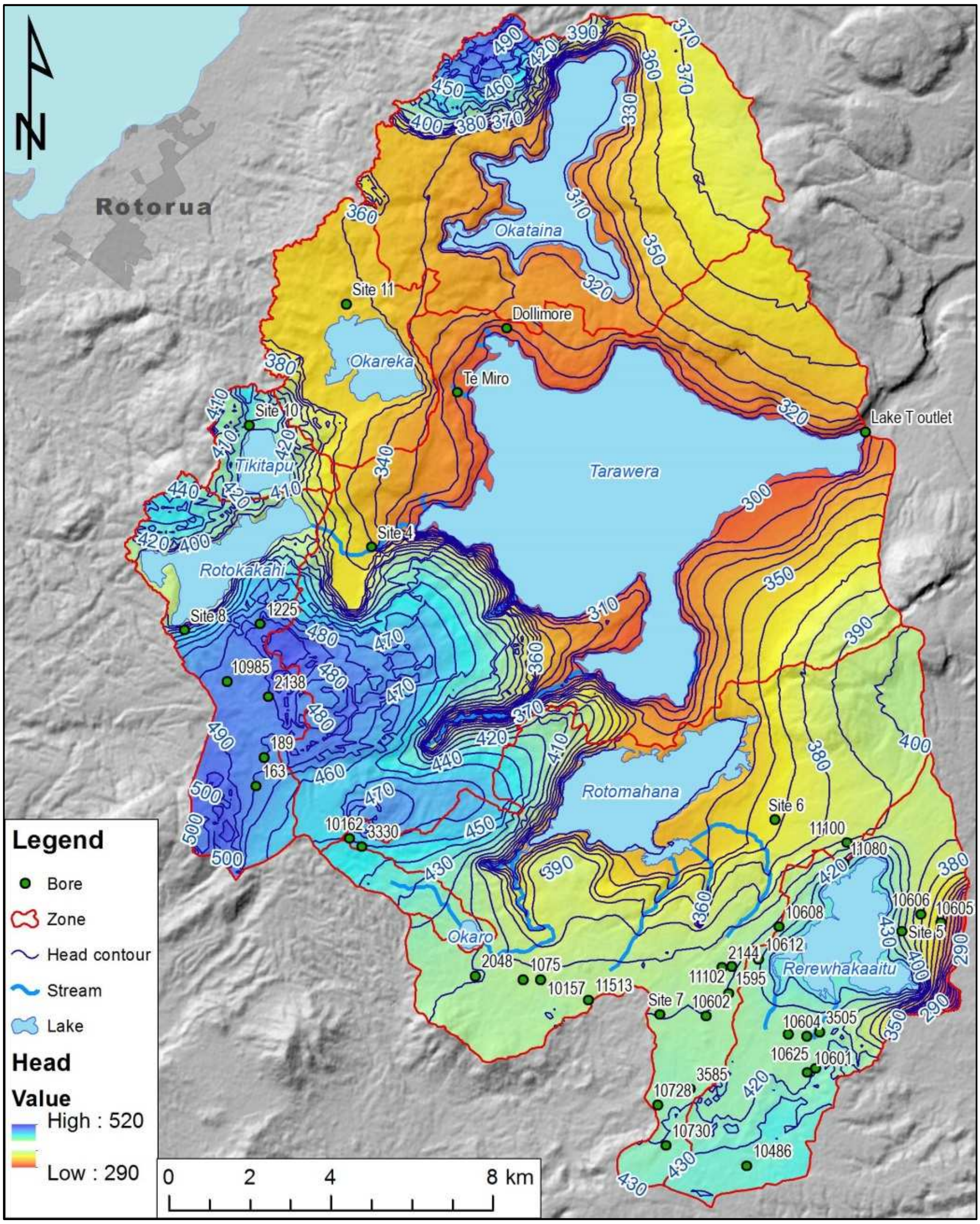

Figure 14 Simulated groundwater levels (head) across the greater lake Tarawera catchment. Model groundwater heads in the lake areas represent head in the aquifer below the lake bed.

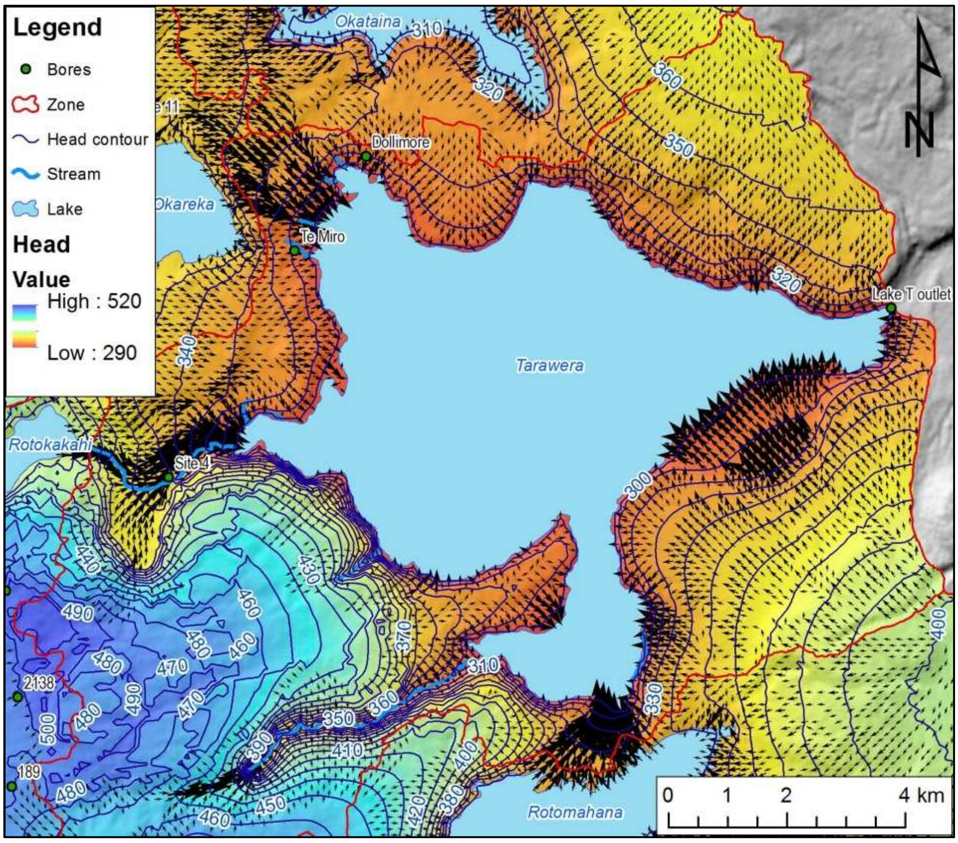

Figure 15 Simulated groundwater levels (head) and flow directions in the Lake Tarawera zone.

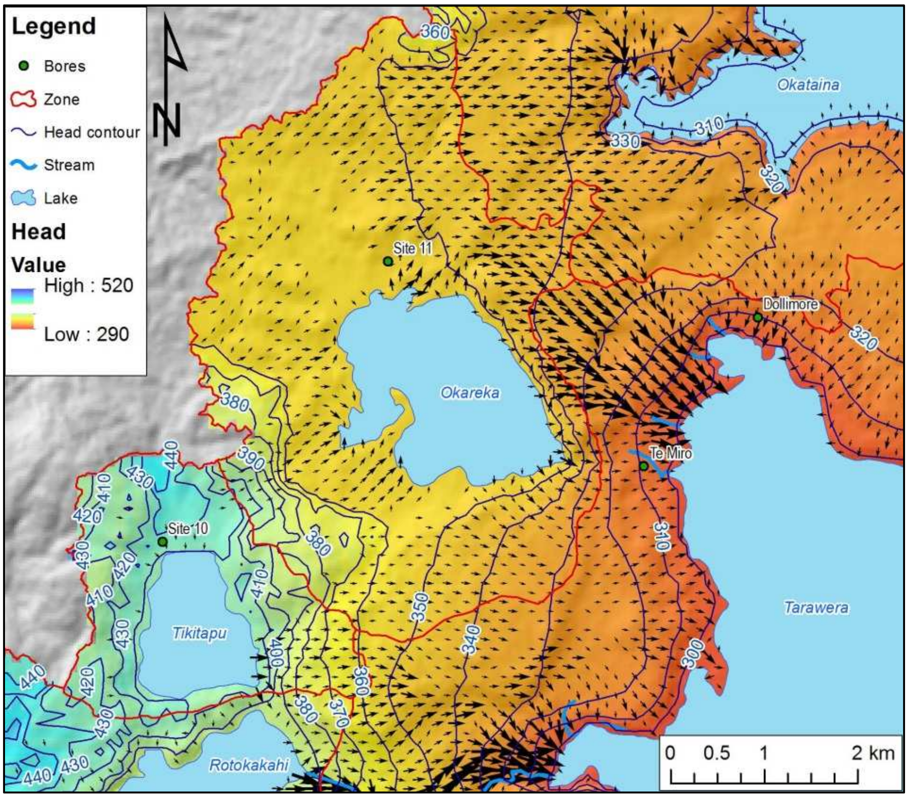

Figure 16 Simulated groundwater levels (head) and flow directions in the Lake Tikitapu and Lake Okareka areas.

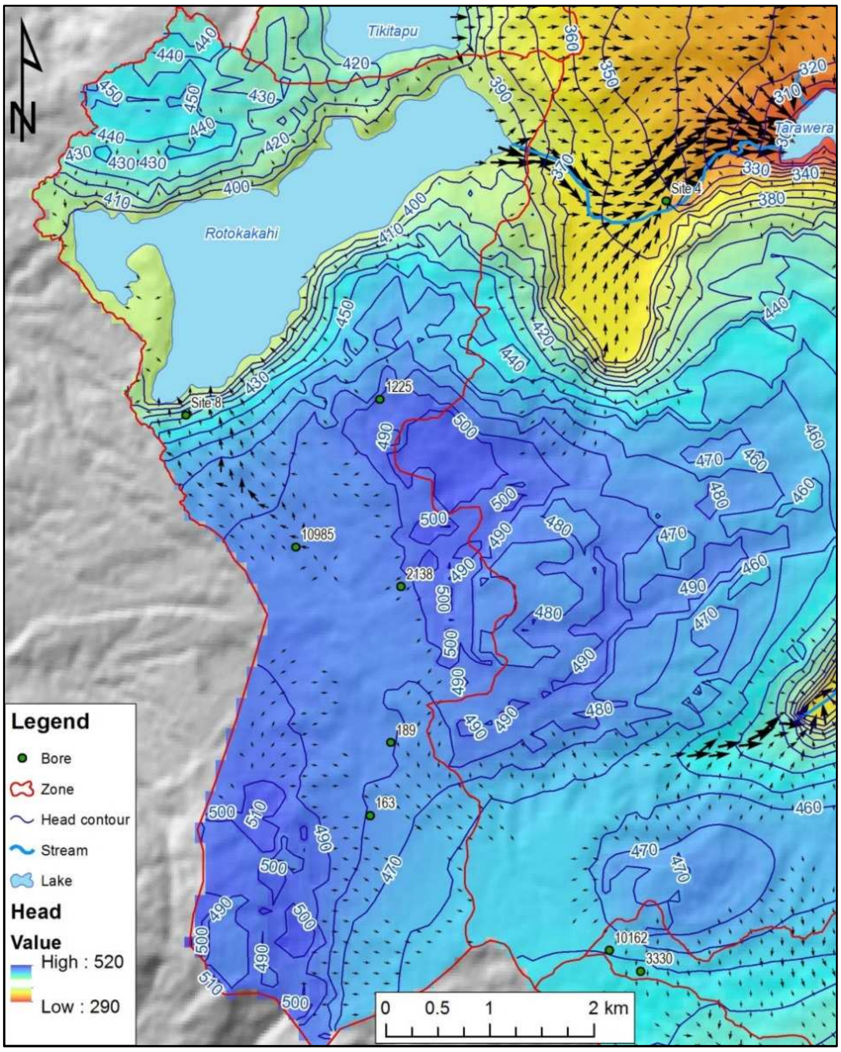

Figure 17 Simulated groundwater levels (head) and flow directions in the Lake Rotokakahi zone.

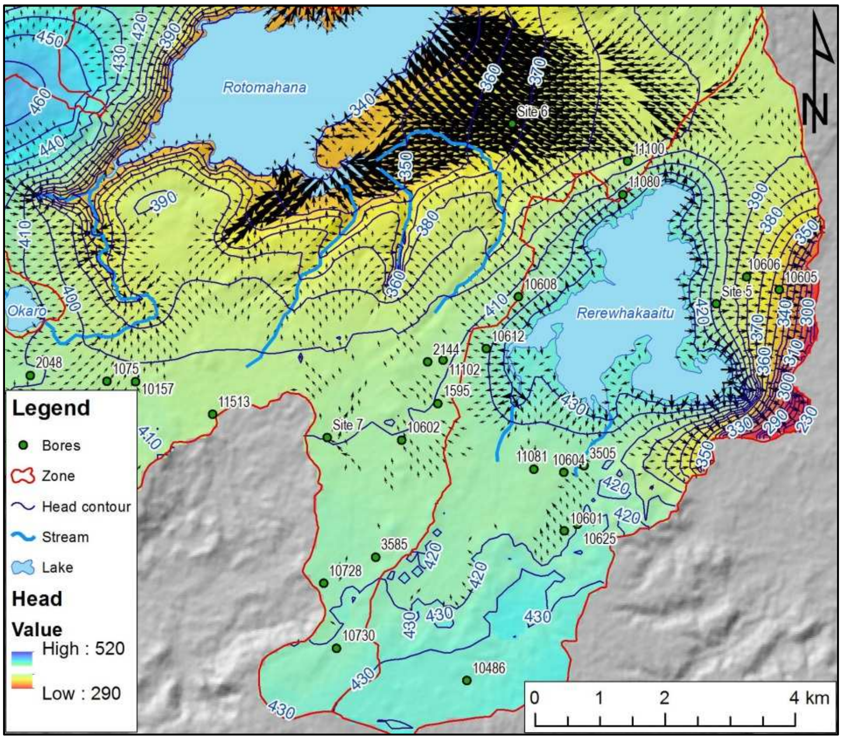

Figure 18 Simulated groundwater levels (head) and flow directions in the Lake Rerewhakaaitu area.

Groundwater flow model: nitrogen flows

Nitrogen loadings to lakes and streams have been calculated to assess the potential impacts of land use on water quality. Five land use scenarios were developed identifying current land use and then developing both less intensive, as well as more intensive, land use. The scenarios tested are:

1. Forested land use,
2. Low-intensity agricultural,
3. Current land use,
4. Moderate expansion of high producing grassland,
5. Large expansion of high producing grassland.

The aim of scenarios 3 and 4 were to represent foreseeable intensification of land use in the catchment. The scenarios did not test the impact of expansion of agricultural land into current forested areas. Figure 19 shows the nitrogen concentrations for each scenario as land use changes.

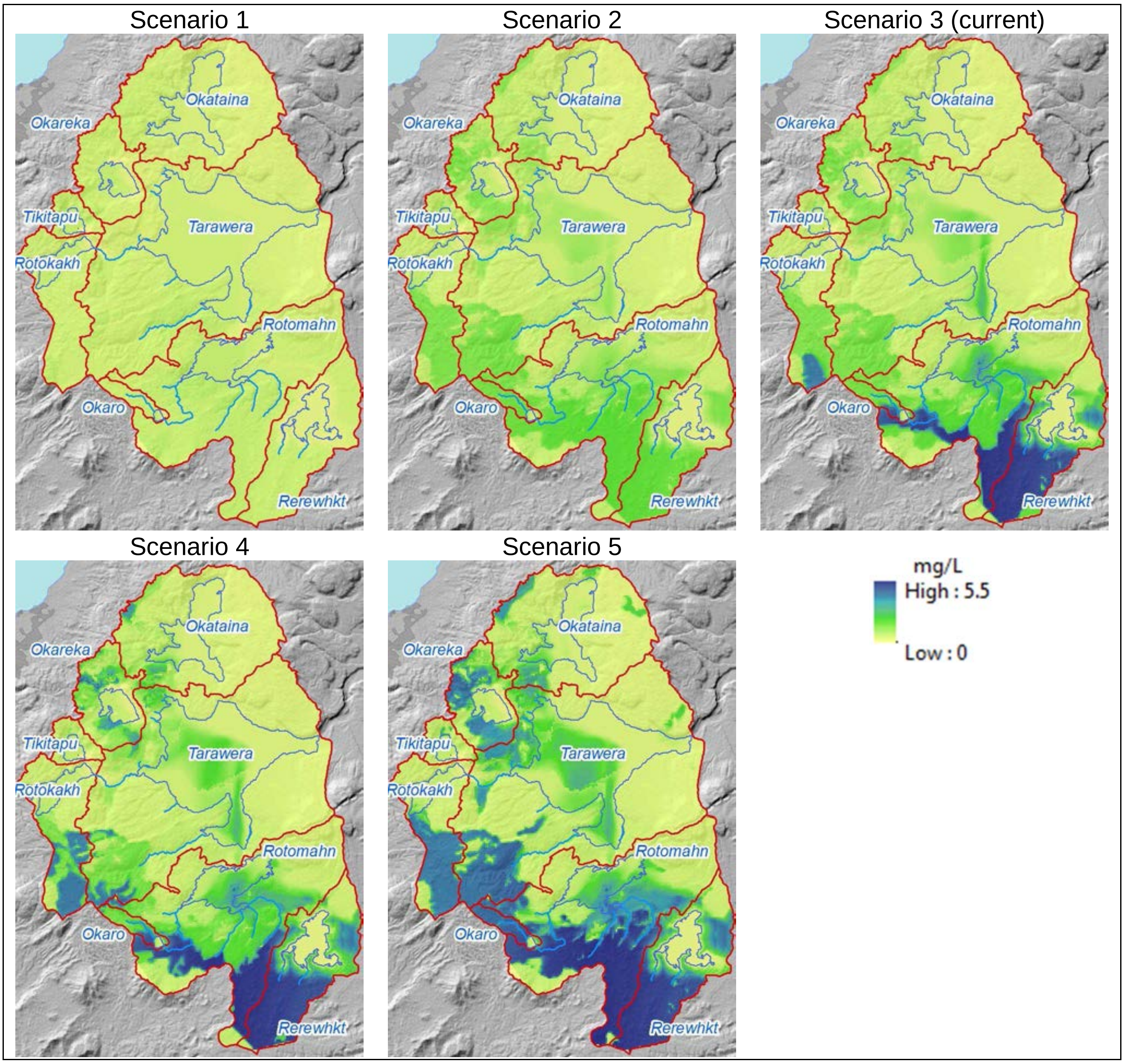

Figure 19 Concentrations of nutrients in the uppermost flowing layer of the groundwater model for five scenarios. Zone boundaries are shown lakes so that calculated nutrient concentrations are visible below lake beds.

Some key findings from the modelling work include:

- Nitrogen concentrations in the uppermost flowing layer increases with land use intensity,
- Intensification beyond current levels has a large effect on groundwater nitrogen in the west and south. This includes Earthquake Flat, and parts of Rotomahana and Rerewhakaaitu groundwater catchments,
- Nitrogen concentrations remain low over the large areas that are in native or forestry,
- Intensification scenarios show that the current Lake Tarawera inflow of about 138 tonnes of nitrogen could increase to about 237 tonnes of nitrogen annually,

Discussion and conclusions

Lake Tarawera and catchment:

- Catchment boundaries of Lake Tarawera may differ from groundwater catchment boundaries in the areas of Te Whekau crater, Te Hora dome, and Highlands Road (see Figure 1)
- The inflow from Lake Rotomahana occurs through the isthmus between Tarawera and Rotomahana, including springs from the Ngawhiro Rhyolite Dome (Figure 8). This indicates that more groundwater flows from the Rotomahana groundwater catchment than measured at the springs,
- Inflow from the Ōkāreka groundwater catchment appears to occur through the area around Te Karamea Bay. The groundwater velocity vectors do not provide strong evidence of groundwater flow from Lake Ōkataina to Lake Tarawera,
- Generally groundwater flows directly to lakes and less to streams. This has the potential to transport nitrogen directly to Lake Tarawera by-passing opportunities for in stream de-nitrification,
- Lake Tarawera receives groundwater inflow and consequently nitrogen from all surrounding zones. Therefore land use management in the surrounding zones is relevant to water quality in Lake Tarawera. The modelling however, has not taken account of de-nitrification by lakes and streams so simple addition of loadings taken from the model will overestimate the nitrogen load to Lake Tarawera,
- There is some uncertainty around catchment boundaries in the areas already mentioned,
- For Lake Ōkataina, the surface water boundary and groundwater boundary mostly coincide,
- For Ōkāreka most of the nitrogen that is produced in the catchment flows out to Lake Tarawera through the Okareka Rhyolite complex and the Te Whekau Crater,
- The extent of the Rotokakahi zone boundary is uncertain in the areas of Earthquake Flat and Highlands Road,
- For Lake Ōkaro the catchment boundary and zone boundary are similar,
- The Rotomahana zone receives as well as discharges groundwater to three zones (Tarawera, Ōkaro and Rerewhakaaitu),
- Lake Rerewhakaaitu is perched above the groundwater, so groundwater flows from the lake to the surrounding groundwater catchments. Nitrogen discharge with groundwater to the lake is small. Two streams to the south of the lake provide the only route for nitrogen to enter the lake. Nitrogen generated in the Rerewhakaaitu zone travels with groundwater either to the east or to the Rotomahana groundwater catchment.

The report has included a number of recommendations for further work, summarised below:

- Groundwater catchment boundaries may differ from topographic analysis in the areas of Te Whekau Crater, Ōkāreka Loop Road, Highlands Road, Tuminui, Earthquake Flat, the head waters of Lake Tarawera and Okaro zones, and Brett Road,
- Consider evaluation of de-nitrification in streams and lakes in the summary of nitrogen loadings,
- BOPRC could improve the understanding of the surface hydrology of the area by measuring flows into Lake Tarawera in Kotukutuku Bay and the south east of the lake,
- Identify if the two streams flowing into Lake Okataina are perennial and measure flow rates,
- Further investigations of the Lake Ōkaro groundwater system to asses if groundwater flows out of the lake,
- Review water budget info particularly for Lake Rerewhakaaitu to seek more evidence of perched lakes,
- Calculation of nitrogen inflows to Lake Rerewhakaaitu from both surface and groundwater could be improved by characterisation of the streams that enter the lake and the land and groundwater levels to the north of the lake.

References

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