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Dear Andy

Lake Rotorua catchment boundary

1.0 INTRODUCTION

The Lake Rotorua catchment includes surface water (Hoare, 1980) and groundwater components (White et al., 2007). Baseflow from the catchment is larger than estimated from the surface catchment alone (White et al. 2007). Therefore it is likely that the catchment boundary location is controlled by topography and groundwater flow.

Bay of Plenty Regional Council (BOPRC) requested that GNS Science review estimates of the Lake Rotorua catchment boundary to define a catchment boundary, based on published assessments, for policy purposes. BOPRC also requested an assessment of uncertainty in the boundary. The boundary will be used in BOPRC policies and rules associated with restoration of Lake Rotorua water quality. In particular, these policies and rules aim to restrict nitrogen losses from land inside the catchment (MacCormick, 2013).

This letter report summarises methods used to identify surface and catchment boundaries by Rutherford et al., 2009 and White et al., 2007. Definition of a preferred Lake Rotorua catchment boundary follows a comparison of catchment boundaries used by these authors. This report also recommends an assessment of uncertainties in the location of the boundary.

BOPRC will, after considering the Lake Rotorua catchment boundary described in this report, make a decision on the boundary to be used in policies and rules. This decision will consider factors such as regional council boundaries, simplicity and enforceability (MacCormick, 2013).

2.0 CATCHMENT BOUNDARY

Water budget measurements indicate that the catchment of Lake Rotorua is larger than the surface catchment (White et al., 2004, 2007). In particular, the catchments of Hamurana and Awahou springs are larger than their surface catchments. This is because the flows in these springs are much larger than would be estimated by rainfall recharge to groundwater on the surface catchment.

Two terms have been used to describe the catchment in previous analyses of the Lake Rotorua water flows and land use (e.g., Rutherford et al., 2008 and 2009; White et al., 2007):

- 'surface catchment', which is the land area associated with flowing streams or dry stream beds described by topographic analysis; and
- 'groundwater catchment', which is the land area associated with flow in streams (generally baseflow) and direct groundwater flow to the lake.

The groundwater catchment of Lake Rotorua is larger than the surface catchment to accommodate the large flows in Hamurana, Awahou, and some smaller springs. The following text summarises published estimates of the surface catchment and groundwater catchment.

2.1 SURFACE CATCHMENT

At least two models of Lake Rotorua surface catchment boundaries have been developed. Surface catchments of Lake Rotorua were defined by the BOPRC to have an area (including Mokoia Island) of approximately 441 km^2 (White et al., 2004), Figure 1. The National Institute of Water and Atmospheric Research (NIWA) estimated the total surface catchment area to be approximately 417.3 km^2 in 22 surface catchments, including Mokoia Island (Rutherford et al., 2008).

Catchment areas estimated by these models are different. Therefore the boundaries of surface catchments will differ between the models. This is relevant to BOPRC's assessment of the outer boundary of the Lake Rotorua catchment for policy purposes because:

- the surface catchment defines part of the Lake Rotorua catchment boundary, particularly in the east and south of the catchment (see following);
- council boundaries may differ from those used by NIWA (Rutherford et al., 2008).

2.2 GROUNDWATER CATCHMENT

Water budget measurements show that the catchment of Lake Rotorua is larger than the surface catchment estimated with topographic analysis. Estimates of the groundwater catchment area include:

- 501.5 km^2 (White et al., 2004);
- 479.9 km^2 (White et al., 2007), Figure 2, excluding Mokioa Island, as the groundwater model that was developed in the catchment area excluded the Island;

- approximately 60 km^2 larger than the surface catchment (Rutherford et al., 2008; their 'most likely' estimate);

- a range 5 – 80 km^2 larger than the surface catchment (Rutherford et al., 2008; their uncertainty in the area based on an assessment of the uncertainty in rainfall and actual evapotranspiration).

Several areas fall inside the groundwater catchment and outside the surface catchment. In particular, the northwest corner of the groundwater catchment (Figure 2) extends further up the Mamaku Plateau than the surface catchment (Figure 1); this is primarily to account for the relatively large baseflows observed in the Hamurana and Awahou springs. Lake Rotokawau and Tikitere are other areas where the groundwater catchment extends outside the surface catchment.

Evidence that groundwater catchment boundaries are larger than surface catchment boundaries, discussed in White et al., (2007) includes:

- baseflow in Hamurana Springs is an estimated 2750 L/s (White et al., 2007) and rainfall recharge from Hamurana surface catchment is an estimated 230 L/s (from data in White et al., 2004);

- baseflow in catchments on the northwest boundary of the Lake Rotorua surface catchments are quite low, indicating that groundwater flows from this area towards the south.

Groundwater divides were identified where well observations of groundwater elevation datasets are available, including near Mamaku village and north of the Hamurana surface catchment (White et al., 2007). Generally, however groundwater divides are not identified because of a lack of suitable groundwater level data.

2.3 ROTAN MODEL

The pixelated outer ROTAN model boundary aims to accommodate the surface and groundwater catchments (Rutherford et al., 2009), Figure 3. This catchment has an area of 466.1 km^2 including Mokioa Island. The boundary is drawn with two sources of information (Figure 3):

- topographic analysis alone, e.g., for the eastern, southern and southwestern boundaries;

- topographic analysis and water budget calculations, e.g., for the northern and northwestern boundaries.

The ROTAN boundary is compared with the groundwater model boundary in Figures 4 to 8. The difference between boundaries in the northwest (Figure 4) is approximately 13 km^2, which is equivalent to about 480 L/s of rainfall recharge, or 11 % of the combined baseflow of Hamurana and Awahou springs (4450 L/s; White et al., 2007; White and Rutherford, 2009).

The differences of boundaries between Lake Rotorua and Lake Rotoiti, north of the Ohau Channel, are due to differences in the digital terrain models used by Rutherford et al. (2009) and the BOPRC-defined surface catchment boundary. Differences in boundaries in the balance of the area to the east (Figure 6), south (Figure 7) and southwest (Figure 8) are

probably due to different digital terrain models used by White et al., (2007) and Rutherford et al. (2009).

3.0 UNCERTAINTY

Some uncertainties in model areas and water budgets were addressed by Rutherford et al., 2008; 2009 and White and Rutherford (2009). They addressed the relationship between land area, rainfall recharge to groundwater and observed flows associated with the northwestern catchments.

The uncertainty in topographic elevations in regards of the Lake Rotorua catchment boundary was not assessed, to the writer's knowledge.

4.0 DISCUSSION

The surface water catchment, and most of the groundwater catchment, of Lake Rotorua is represented by the outer boundary of the ROTAN model boundary (Figure 3). Therefore this boundary, though pixelated, represents a good approximation to the Lake Rotorua catchment boundary and is suitable for the purposes of water budget assessments and modelling of the effects of land use change on nitrogen inflows to Lake Rotorua, in the writer's opinion.

A high standard of proof is required in the definition of the Lake Rotorua catchment boundary for policy purposes. However, discrepancies between catchment boundaries in the ROTAN and BOPRC models are identified. Uncertainties in the catchment area will also occur that are related to uncertainties in the water budget. For example, the groundwater catchment may be 5 – 80 km^2 larger than the surface catchment (Rutherford et al., 2008).

These discrepancies require resolution before: 1) the definition of a Lake Rotorua catchment boundary for policy purposes; and 2) assessments of the uncertainty in this boundary. The following recommendations are formed to address these two aims.

5.0 RECOMMENDATIONS

5.1 TASK 1) THE DEFINITION OF A LAKE ROTORUA CATCHMENT BOUNDARY FOR POLICY PURPOSES

This task requires agreement between BOPRC and NIWA on catchment boundaries where these boundaries are identified by topographic data alone. Differences between NIWA and BOPRC topographic models may include data and interpolation processes. New topographic data may have been collected by these organisations since the work of Rutherford et al. (2008) and White et al. (2007). BOPRC, NIWA and GNS Science could agree on catchment boundaries where boundaries were defined by topographic and water budget assessments. Various methods have been used by Rutherford et al. (2008) and White et al. (2007) to estimate the groundwater catchment area and boundary location including rainfall maps, AET estimates, rainfall recharge estimates and base flows.

Therefore it is recommended that:

- NIWA and BOPRC identify the topographic model to use in assessment of the boundaries of surface catchments relevant to the Lake Rotorua catchment boundary and this assessment is completed with a non-pixelated GIS map at a 1:50,000 scale, e.g., approximately 1 point per linear 100 m;
- NIWA, BOPRC and GNS Science identify the location and area of groundwater catchment beyond the surface water catchment. This will probably include agreement on surface flow calibration values, rainfall maps and AET estimates. The long-term (1960 – 2006) average rainfall map of Tait et al. (2006) and the AET map of Woods et al. (2006), scaled to a 500 m by 500 m grid are suggested as relevant to the project. Calculation of baseflow and runoff may be relevant to this project where the groundwater catchment beyond surface water catchment.

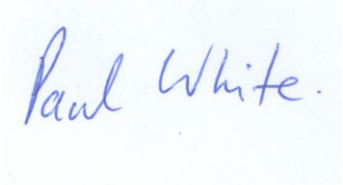
5.2 TASK 2) ASSESSMENT OF THE UNCERTAINTY IN THIS BOUNDARY

The uncertainty of topographic boundaries has not been assessed in the Lake Rotorua catchment. The uncertainty of the groundwater catchment has been assessed in part, but this has not included an identification of uncertainty limits as polygons for the whole catchment.

Therefore it is recommended that:

- the method of assessing uncertainty is determined and the following is suggested;
- uncertainty of the topographic model is assessed by standard methods;
- the long-term (1960 – 2006) average rainfall map of Tait et al. (2006) and the AET map of Woods et al. (2006), scaled to a 500 m by 500 m grid are used to calculate rainfall recharge to groundwater and possibly runoff;
- NIWA, BOPRC and GNS Science identify the area and boundary where rainfall recharge to groundwater, and possibly runoff is within +/- 5% of the value calculated for catchments bordering the boundary identified in Task 1. These areas are to be represented with a GIS map at a 1:50,000 scale, e.g., approximately 1 point per linear 100 m.

Yours sincerely



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Scientist – Groundwater/Hydrogeology

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FIGURES

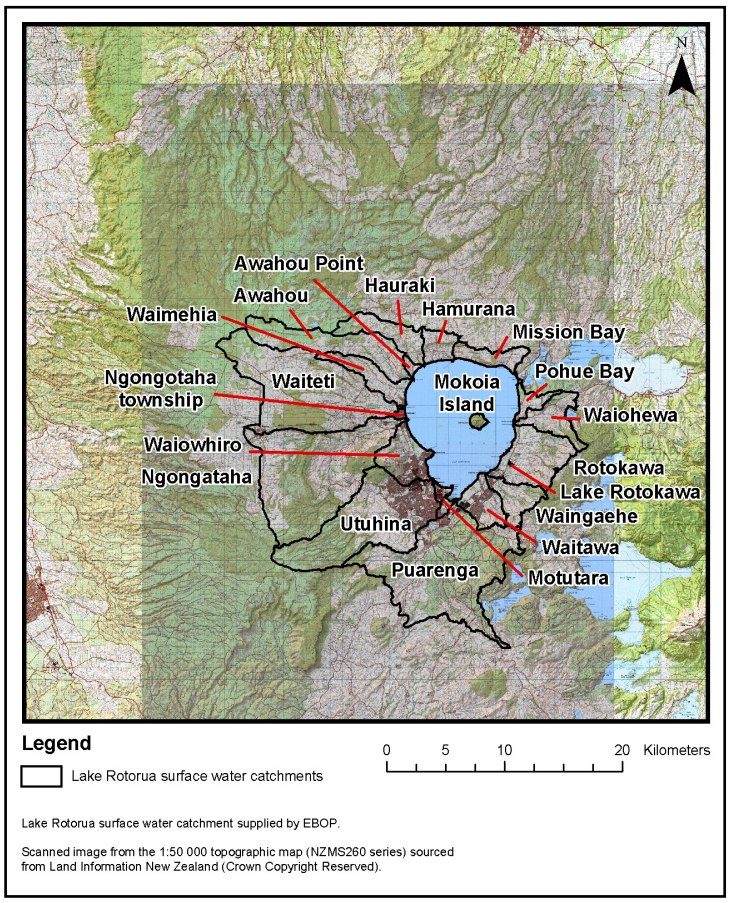

Figure 1 Lake Rotorua surface catchments (White et al., 2007; Environment Bay of Plenty pers. comm).

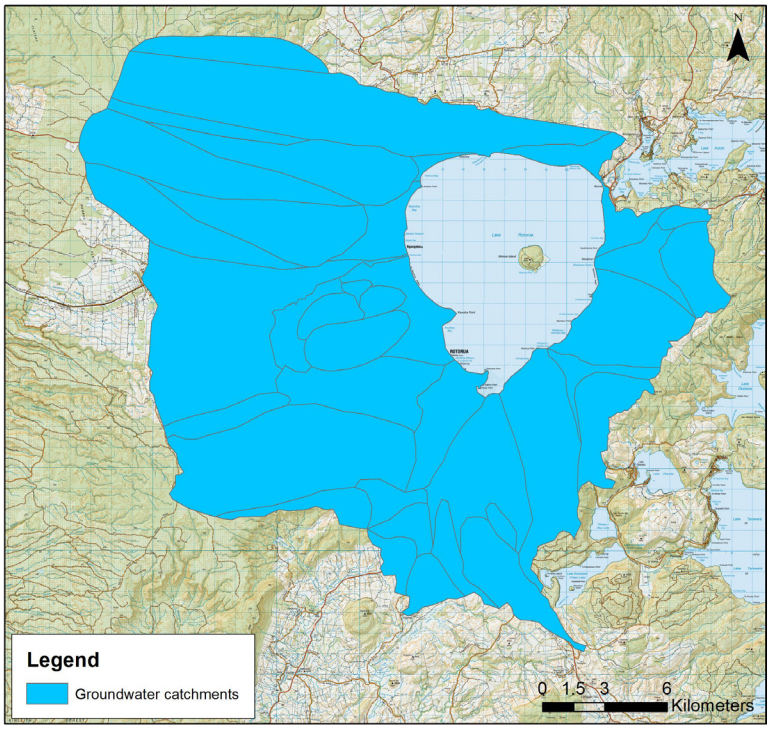

Figure 2 Groundwater catchment boundaries include an external model boundary and internal model boundaries developed in the groundwater flow model White et al. (2007) including groundwater catchments around Mt Ngongotaha (Kovacova and White, 2009).

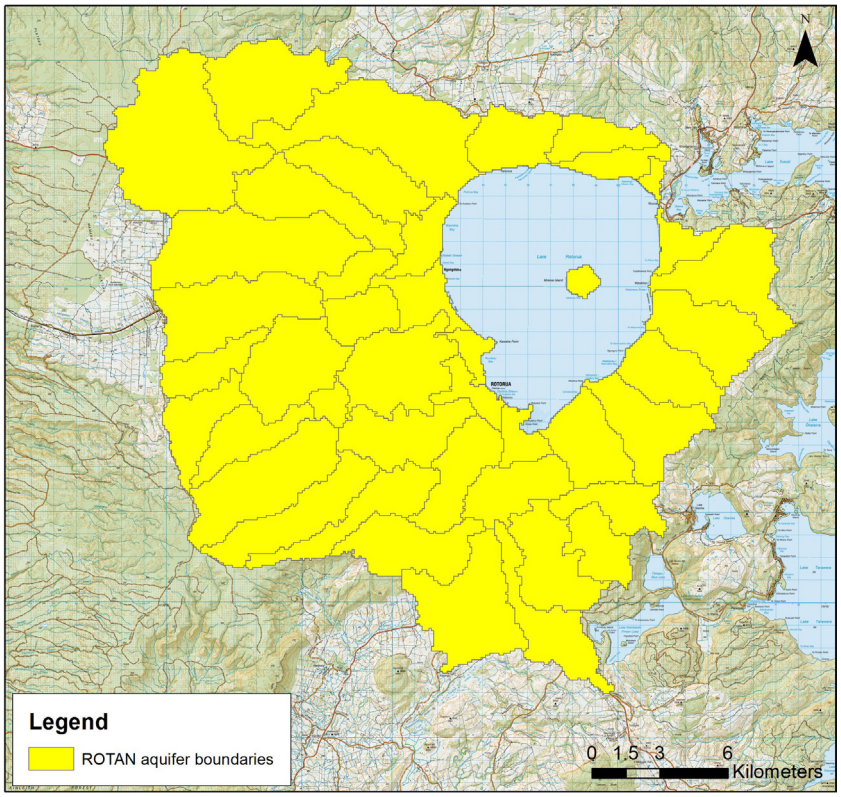

Figure 3 ROTAN model boundaries (Rutherford et al. 2009) include an external model boundary and internal model boundaries.

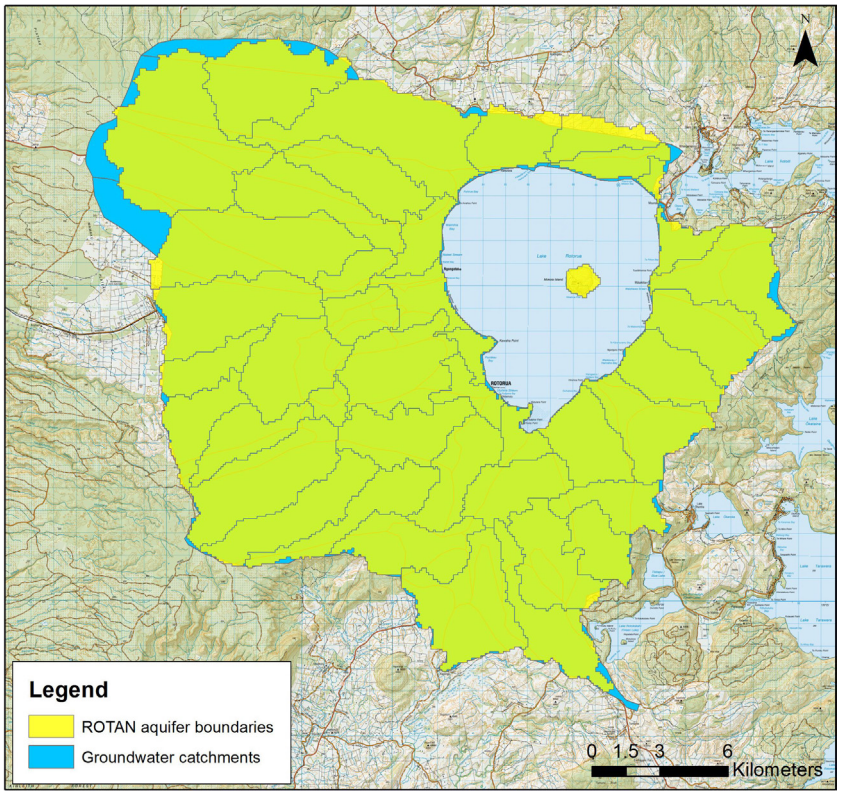

Figure 4 Comparison of Lake Rotorua catchment external boundaries.

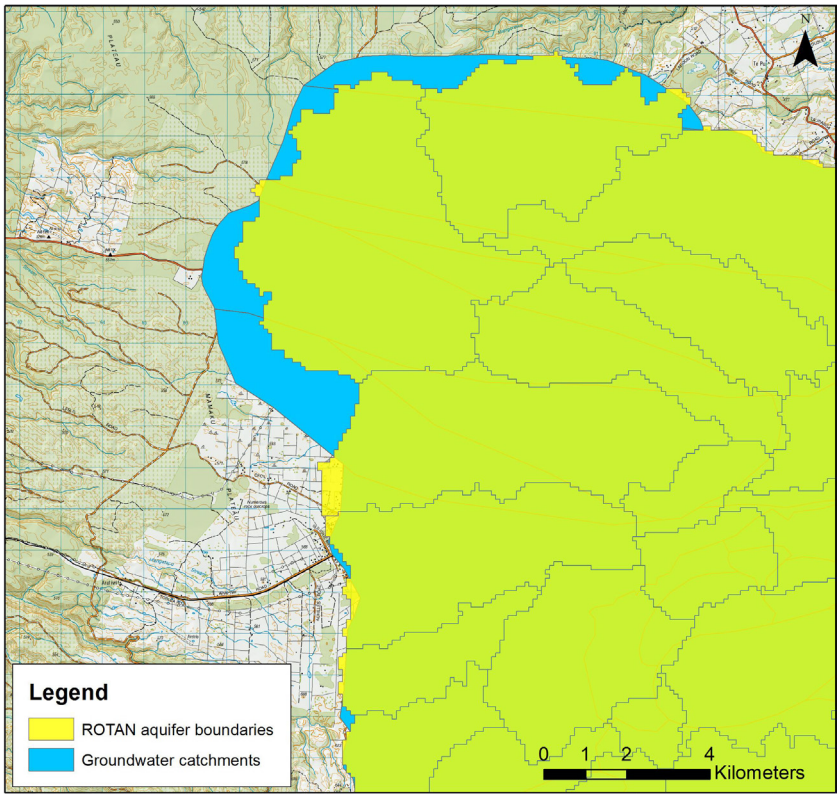

Figure 5 Comparison of Lake Rotorua catchment external boundaries, northwest area.

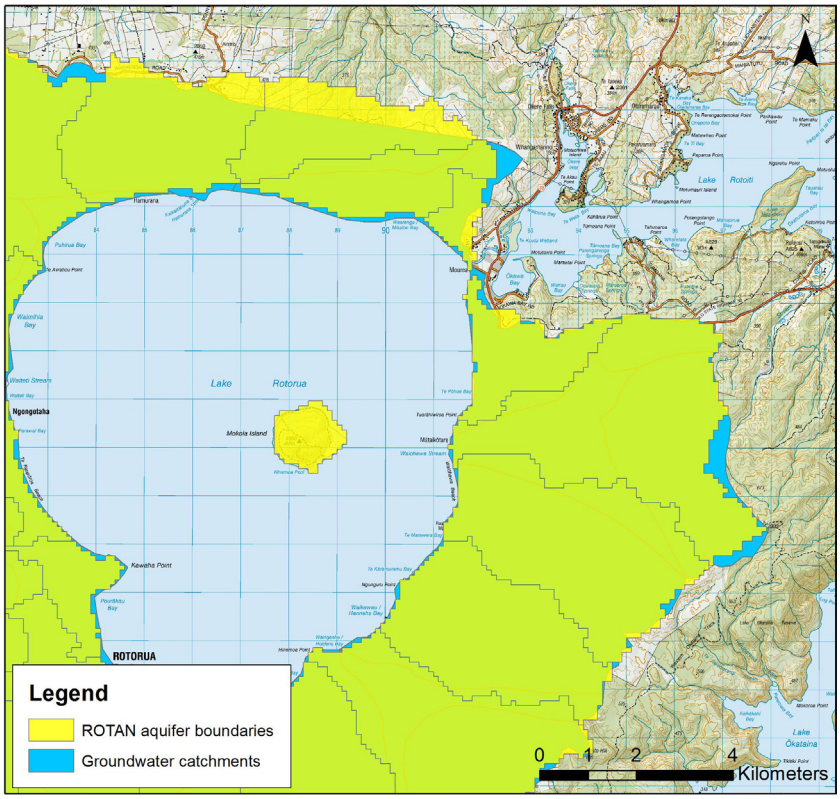

Figure 6 Comparison of Lake Rotorua catchment external boundaries, northeast area.

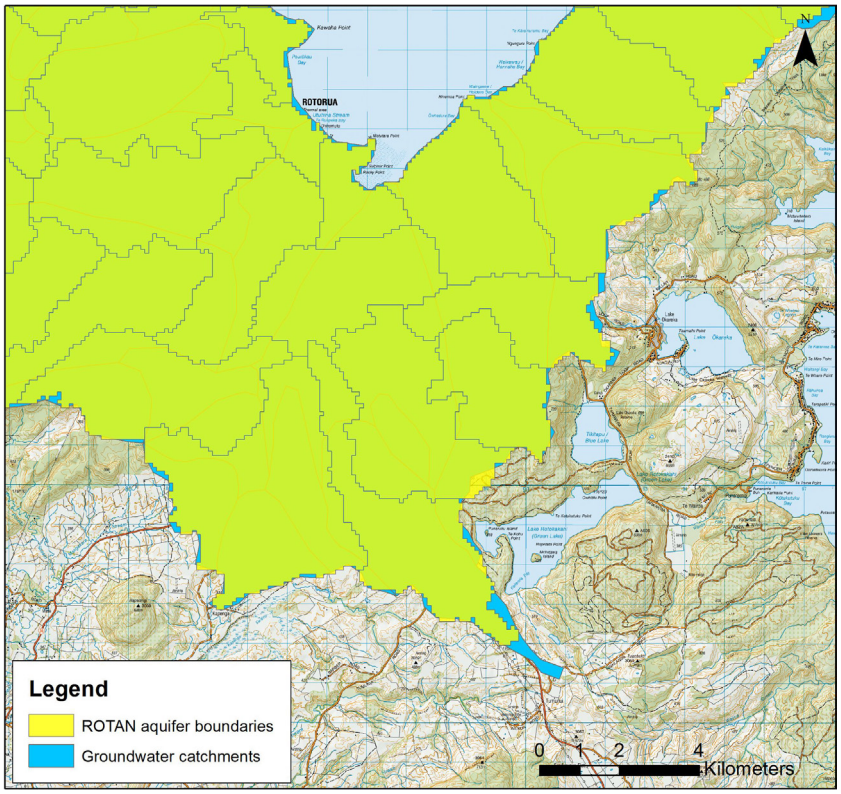

Figure 7 Comparison of Lake Rotorua catchment external boundaries, southeast area.

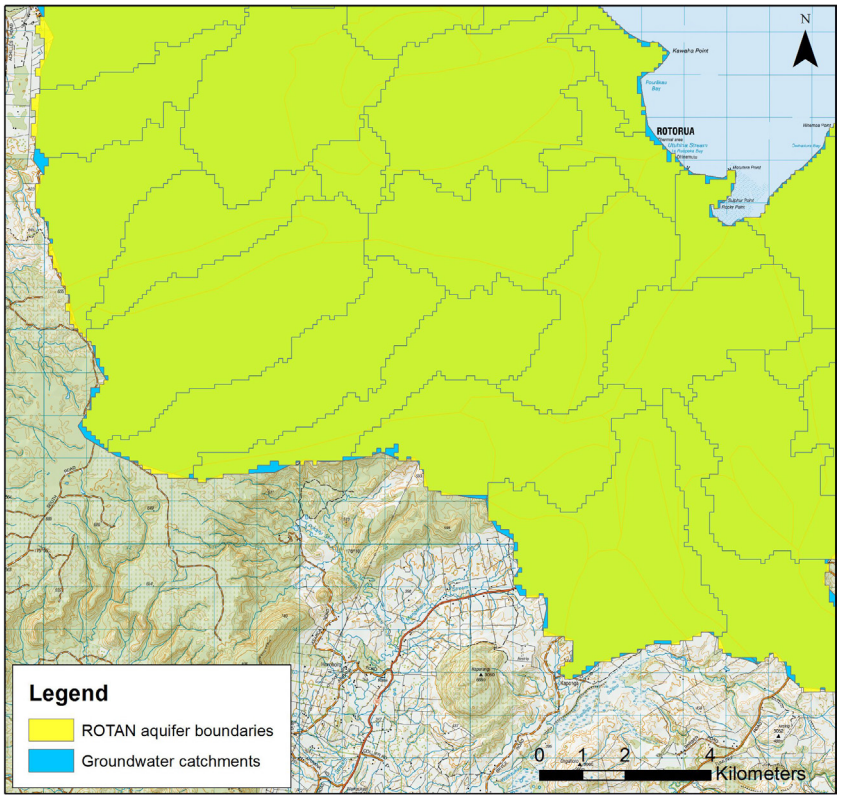

Figure 8 Comparison of Lake Rotorua catchment external boundaries, southwest area.