Groundwater catchments for individual springs in Ngongotaha and Waiowhiro surface catchments, Lake Rotorua

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GNS Science Report 2008/41
April 2009

GNS SCIENCE
TE PŪ AO

BIBLIOGRAPHIC REFERENCE

Kovacova, E.; White, P. A. 2008. Groundwater catchments for individual springs in Ngongotaha and Waiowhiro surface catchments, Lake Rotorua, *GNS Science Report* 2008/41. 80 p.

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ISSN 1177-2425
ISBN 978-0-478-19654-2

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ABSTRACT

Recent groundwater research by GNS Science and Environment Bay of Plenty (White et al. 2007) estimated the catchment areas of major hydrological features such as springs and spring-fed streams, in the whole Lake Rotorua catchment as part of investigations into groundwater and Lake Rotorua water quality.

This report aims to assess groundwater catchments of two Lake Rotorua surface catchments in greater detail than recent research by identifying catchment of 50 major and minor springs in the Ngongotaha and Waiowhiro surface catchments:

The catchments of 47 springs in the Ngongotaha catchment and three springs in the Waiowhiro catchment are estimated using:

- measurements or estimates of spring flow or baseflow in streams;
- a model of rainfall and estimates of rainfall recharge to groundwater;
- geology and geomorphology at the site of the spring.

Many small springs are observed in Paradise Valley in the Ngongotaha catchment. Flow in many of these springs is probably supported by land immediately around the springs. Groups of large springs in the Ngongotaha catchment (e.g. Barlow Springs) require relatively large catchments which probably include land on Mamaku Plateau and may include land outside the Ngongotaha surface catchment.

The land area of Mt Ngongotaha is mostly sufficient to support baseflow in springs (i.e. Fairy, Rainbow, McRae, Maori and Hatchery springs) around Mt Ngongotaha.

The land area of Waiowhiro catchment is probably not sufficient to support baseflow of springs in the catchment (Fairy Spring, Rainbow Spring and McRae Spring). Therefore land in the surrounding Ngongotaha surface catchment and Utuhina surface catchment is probably part of the catchment of these springs.

Recommendations from this project include:

- measure stream baseflow at two sites in Ngongotaha Stream to identify as-yet unmeasured flow gain from springs and adjust spring catchment areas accordingly;
- measure spring flows in 20 small springs in Ngongotaha catchment;
- collect samples for groundwater chemistry in the McRae Spring and in Ngongotaha catchment springs to:
    - estimate source (either Mamaku Ignimbrite or Mt Ngongotaha rhyolite lava);
    - compare nitrate-nitrogen concentrations in springs that probably have a small local catchment with nitrate-nitrogen concentrations in springs that have a relatively large catchment.

KEYWORDS

Lake Rotorua groundwater, Ngongotaha, springs.

1.0 INTRODUCTION

Recent groundwater research by GNS Science and Environment Bay of Plenty (White et al. 2007) estimated the catchment areas of hydrological features in the Lake Rotorua catchment as part of investigations into groundwater and Lake Rotorua water quality restoration. Hydrological features include springs and seeps which supply much of the flow of surface water in the Lake Rotorua catchment.

Groundwater investigations included development of a groundwater flow model which was used to assess the catchment area of major inflows to surface water including major springs. Identification of catchment areas of surface water, including springs is important because of the link between land use and groundwater quality. For example nitrate concentrations in streams are typically increasing over time and this increase is probably due to increasing intensification of land use in the Lake Rotorua catchment.

Groundwater flow model calibration to flows associated with major hydrological features provides only part of the picture of groundwater hydrology in the Lake Rotorua catchments; many small springs are observed in Lake Rotorua catchment (White et al. 2007) and the individual catchments of these features have not been assessed.

This work aims to assess the catchments of springs and seeps (small and large) in two Lake Rotorua catchments by:

- estimating the groundwater catchments of the large and small springs located in Ngongotaha catchment that are not considered by the current groundwater flow model (White et al. 2007);
- estimating the groundwater catchments of the Fairy and Rainbow springs and other springs located in Waiowhiro catchment on the eastern side of Mt. Ngongotaha;
- investigating the hypothesis that Fairy and Rainbow springs, and other springs in Waiowhiro catchment on the eastern side of Mt. Ngongotaha are recharged from land in the Ngongotaha catchment.

The study area is the Ngongotaha and Waiowhiro catchments located in the Rotorua district within the Bay of Plenty region, North Island, New Zealand (Figure 1).

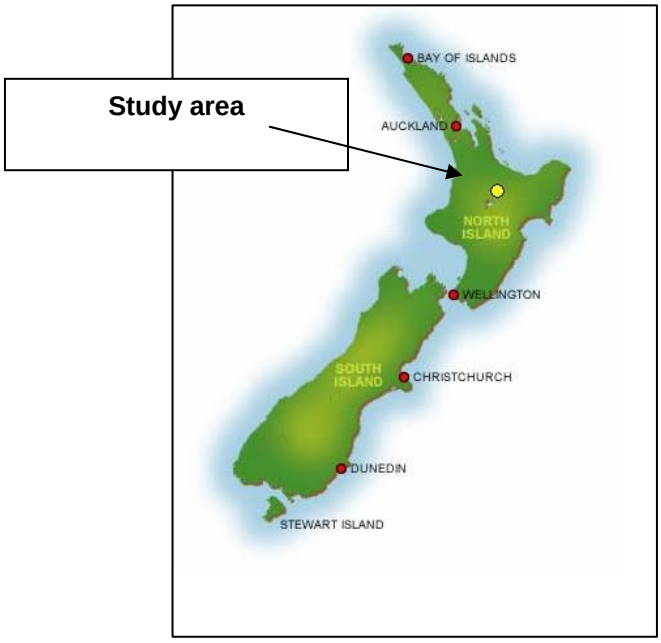
Ngongotaha surface catchment is part of the Lake Rotorua catchment located on the western side of Lake Rotorua (Figure 1). Waiowhiro surface catchment is the adjacent catchment located on the eastern side of Ngongotaha catchment (Figure 1).

This report reviews geology (Section 2), hydrology and hydrogeology (Section 3), and geochemistry (Section 4) of study area. New field work is summarised in Section 5. This report includes photographic documentation of mapped springs (Appendix 1) with location and text description of springs (Appendix 2). Estimated groundwater catchments of springs in the Ngongotaha and Waiowhiro catchments are discussed in Section 6 and summarised in Section 7.

This report includes the results of three GNS Science reports on groundwater in the catchment of Lake Rotorua:

- review of groundwater in the Lake Rotorua catchment (White et al. 2004);

- Lake Rotorua groundwater study: study of the 2004-2005 field programme (Reeves et al. 2005);
- Lake Rotorua groundwater and Lake Rotorua nutrients Phase 3 (White et al. 2007).



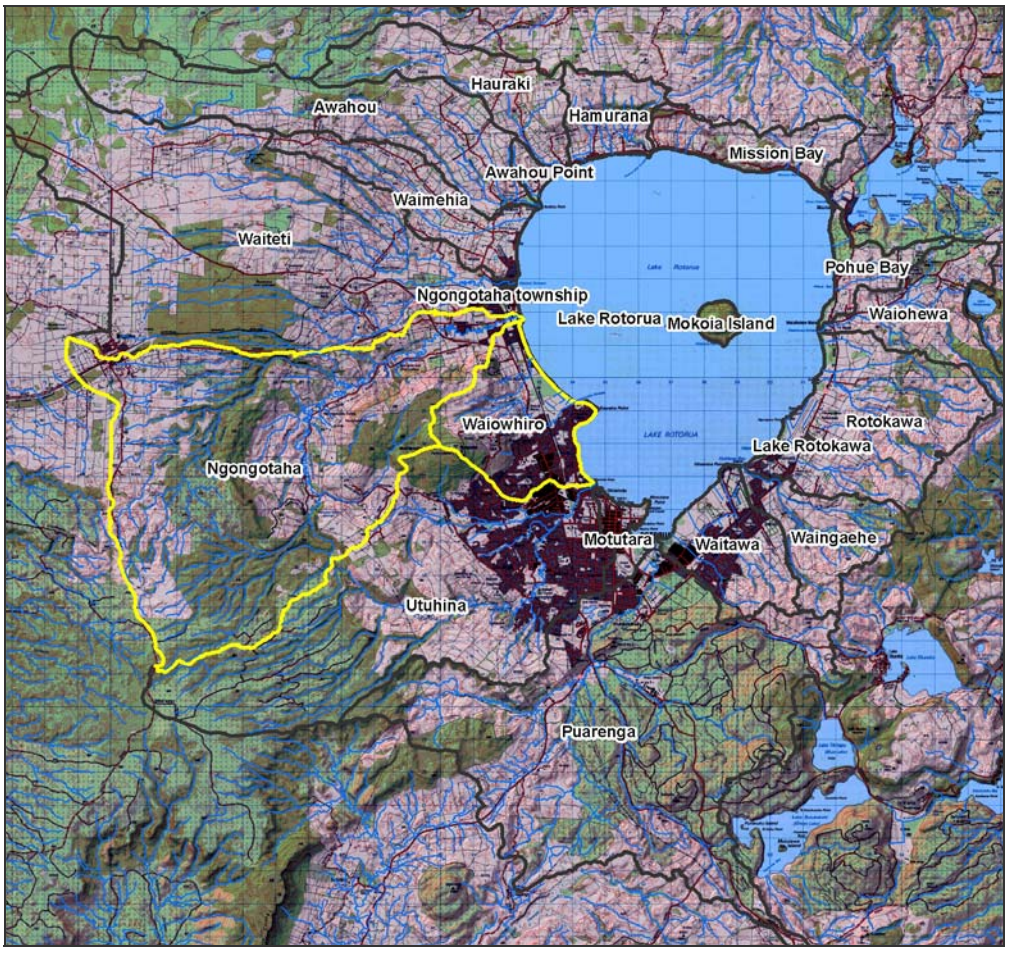


Figure 1.1 Location of Ngongotaha and Waiowhiro catchments (yellow lines) in the Lake Rotorua catchment with surrounding catchments (black lines).

2.0 GEOLOGY

2.1 Regional geology

The study area is located in the active Taupo Volcanic Zone (TVZ, Figure 2.1). The TVZ is about 300 km long and up to 60 km wide and is caused by subduction of the Pacific plate beneath the Australian plate off the North Island of New Zealand's east coast (Wilson et al. 1995, and Milner et al. 2002).

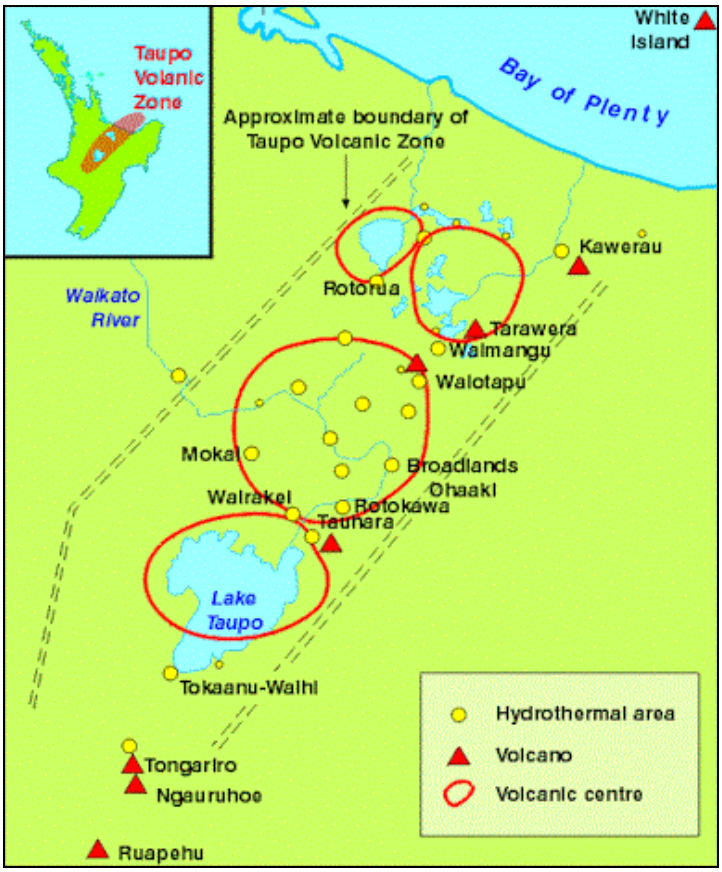


Figure 2.1 The Taupo Volcanic Zone.

Lake Rotorua occupies the Rotorua caldera which was built in 4 main geological stages, in the interval approximately 2 million years ago until post 60 thousand years ago (White et al. 2004):

Stage 1: Taupo Volcanic Zone (TVZ): 2 million to 220 thousand years ago

A series of eruptions from calderas of the TVZ produced and deposited ignimbrites in the Lake Rotorua catchment.

Stage 2: Rotorua Caldera: 220 thousand to 200 thousand years ago

The Mamaku eruption was associated with Rotorua Caldera collapse and eruption of the Mt Ngongotaha dome complex.

Stage 3: Okataina Volcanic Centre: 200 thousand to 60 thousand years ago

A period of relatively quiet volcanic activity in the Rotorua Caldera with the Rotoiti eruption 60 thousand years ago.

Stage 4: Okataina Volcanic centre: post 60 thousand years ago

A series of relatively small, but frequent eruptions from Okataina Volcanic Centre deposited tephras layers in the lake Rotorua catchment. (White at al. 2007).

Geology of the Lake Rotorua catchment, including Ngongotaha and Waiowhiro catchment, (Figure 2.2 and Figure 2.3) is summarised as a geological model (Figure 2.4 and Figure 2.5).

2.2 Geology of Ngongotaha catchment

The Ngongotaha catchment includes four main stratigraphic units (Table 2.1, Figure 2.3)

- Mamaku Pyroclastics;
- Rotorua Young TVZ rhyolite lava;
- Huka Group sediments;
- Holocene Alluvium.

Table 2.1 Surface extent of the main geological units in Ngongotaha catchment.

	Mamaku Ignimbrite	Rotorua Young TVZ rhyolite lava	Huka Group sediments	Holocene Alluvium	Whole Ngongotaha catchment
Area (km²)	46.7	15.38	11.01	5.19	**78.30**
Percentage of area	59.8%	19.7%	14.1%	6.6%	**100%**

Mamaku Ignimbrite

The Mamaku ignimbrite is the main geological unit in the Ngongotaha catchment (Figure 2.5). Mamaku Ignimbrite covers 46.7 km² on the west side of the Ngongotaha catchment which is almost 60% of the whole catchment area.

The maximum thickness of the ignimbrite is greater than 1 km within the caldera, the ignimbrite thins with increasing distance from the vent (Rogan, 1982 in White, 2007).

Milner at al. (2002) divided the Mamaku Ignimbrite sequence into lower, middle and upper facies. The upper and lower facies are non-welded and fine-grained. The middle facies is strongly welded with cooling joints. The main aquifer in the area is the Mamaku Ignimbrite lower non-welded facies.

Rotorua Young TVZ rhyolite lava

The Rotorua Young TVZ rhyolite lava is represented by the Mt. Ngongotaha dome with 12 km² and the Endean dome with 3.4 km² of areal extent. Mt. Ngongotaha dome (757 m asl) is located on the south-east side of the study area. The east side of this dome is in the Waiowhiro catchment. The Endean dome is located in the middle of the catchment with maximum elevation 732 m asl.

Huka Group sediments

The surface extent of Huka group sediments in Ngongotaha catchment is 11 km². That is 14 % of the Ngongotaha catchment area.

The Huka Group sediments contain lake sediments (sandstone and siltstones) deposited after the Mamaku eruption by Lake Rotorua. The thickness of Huka Group sediments vary

across the caldera floor due to fluctuations in the lake level since the Mamaku eruption (White et al. 2007).

Holocene alluvium

The surface extent of Holocene alluvium in Ngongotaha catchment is 5.2 km². That is 6.6 % of the Ngongotaha catchment area.

Holocene alluvium in the Ngongotaha catchment is deposited in the stream beds and river channels of Ngongotaha, Waitetahi, Ohinenui, Umurua and Otamaroa streams.

Sediments contain ash and pumice gravel derived by the erosion of the pyroclastic deposits. Sediments are eroded into Huka Group sediments (White et al. 2007). The maximum thickness of sediments (including Holocene alluvium and Huka Group sediments), assumed from a cross section in the northern part of study area, is approximately 200 m (Figure 2.5).

The Waiowhiro catchment has three geological units exposed at the ground surface (Table 2.2, Figure 2.3).

Table 2.2 Surface extent of the main geological units in Waiowhiro catchment.

	Rotorua Young TVZ rhyolite lava	Huka Group sediments	Holocene Alluvium	Whole Waiowhiro catchment
Area (km²)	6.78	1.34	6.42	**14.54**
Percentage	46.6%	9.2%	44.2%	**100%**

2.3 Faults

One fault has been identified in the Ngongotaha catchment (Figure 2.6). Milner et al. (2002) traced this fault on southern boundary of the Endean dome located on the western side of the Ngongotaha catchment. Between the Endean and Pukehangi (located outside the study area to the south) domes, Mamaku Ignimbrite forms significant bluffs that are thought to be a fault scarp (Milner et al. 2002).

Scarps occur where Mamaku Ignimbrite rises steeply from lake sediments and are more prominent where they cut pre-caldera rhyolite domes (Milner et al. 2002). Therefore a fault, or fissure, may occur in the western part of Paradise Valley (Figure 2.6), where Mamaku Ignimbrite rises from Huka Group Sediments and where the group of high yielding springs occur (Barlow Spring, N23 – N28). These springs are evidence of outflow from Mamaku Ignimbrite as observed in the field.

No faults in the catchment have been identified from GNS Science's Active Fault database. Within the Lake Rotorua catchment, active faults collated from the GNS Science database are predominantly located to the southeast and northeast of Lake Rotorua (i.e. outside the study area).

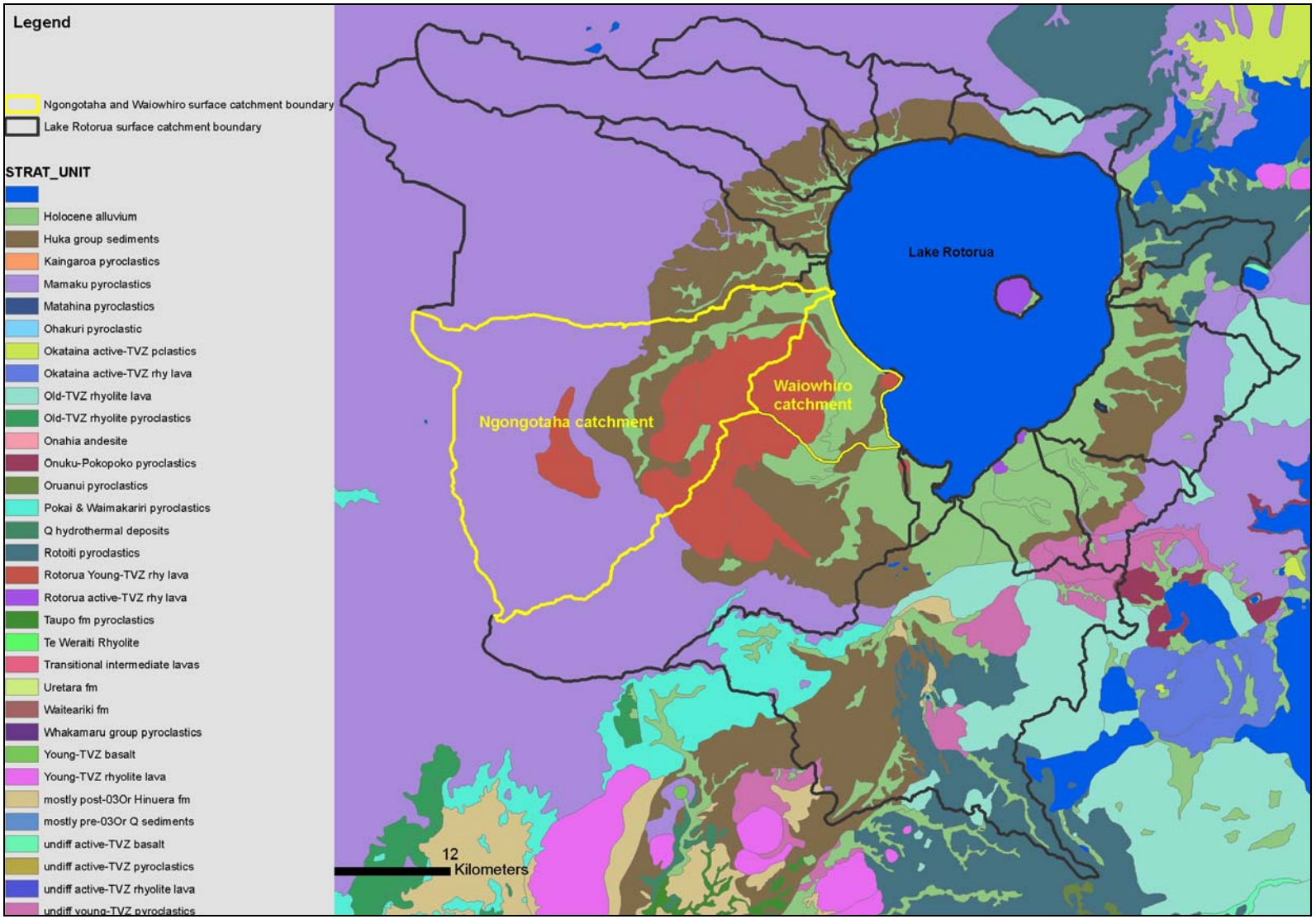


Figure 2.2 Geology of study area in Lake Rotorua catchment (from White et al. 2007).

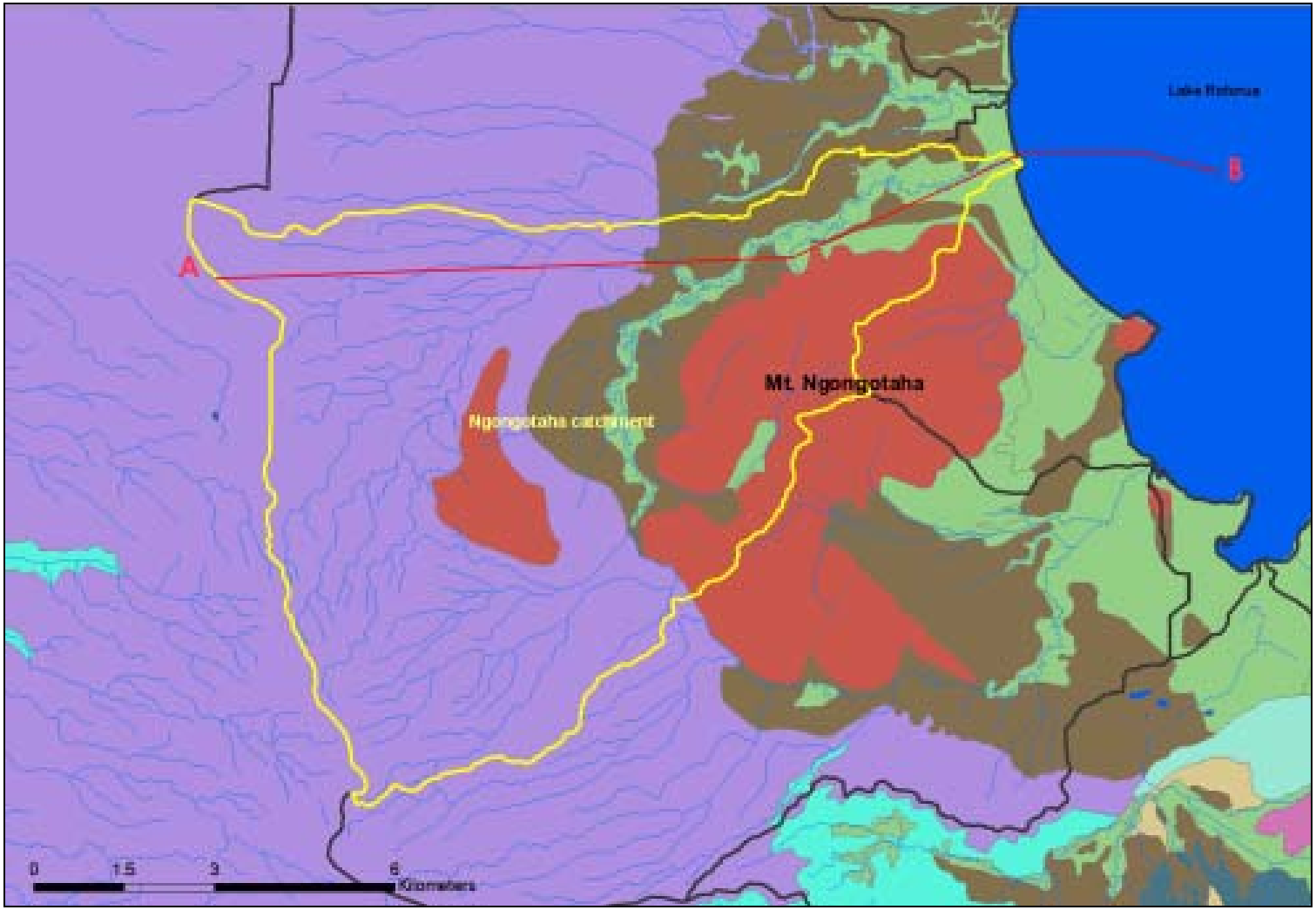


Figure 2.3 Geology and position of cross section line in Ngongotaha catchment.

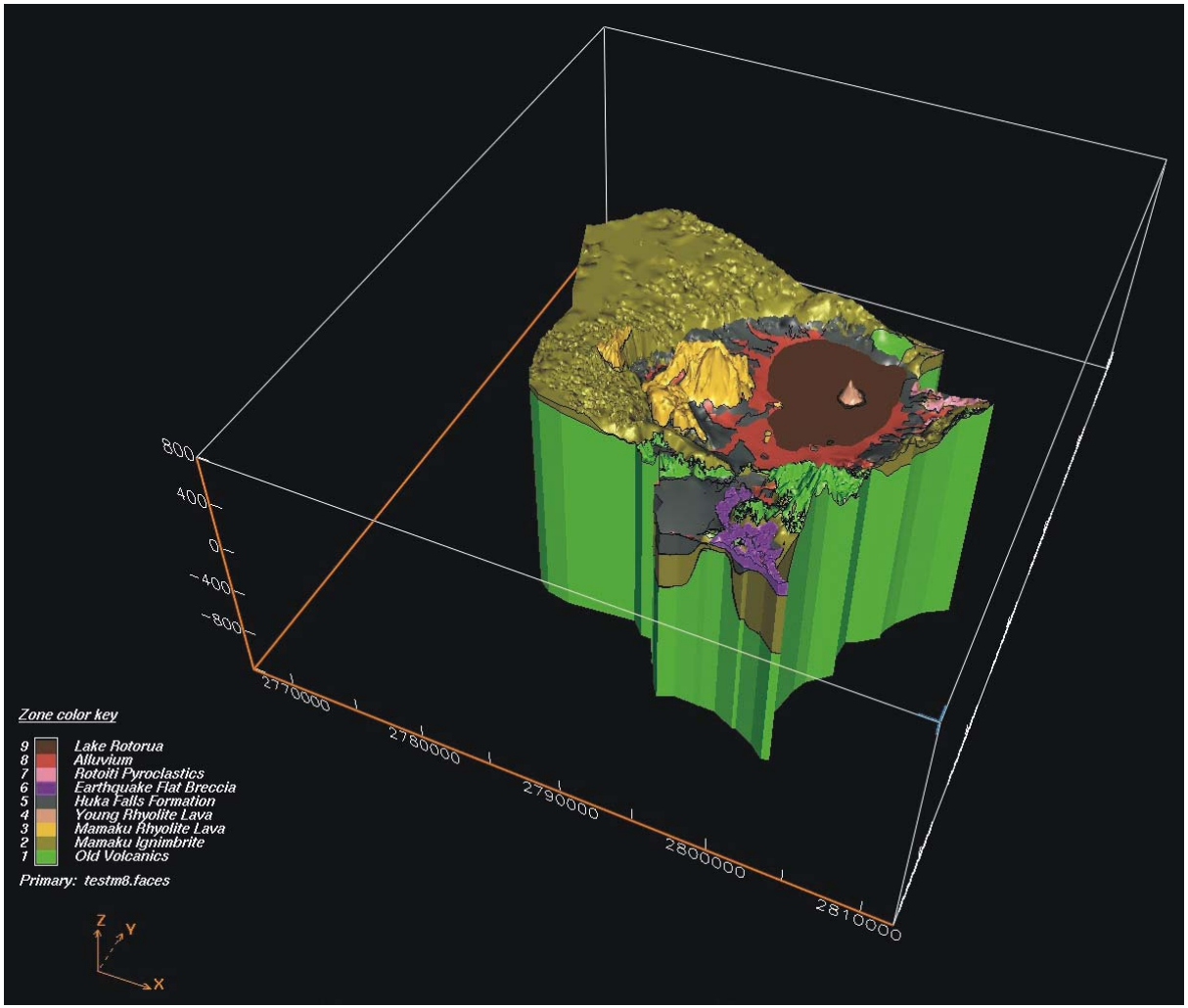


Figure 2.4 Lake Rotorua geological model, and Lake Rotorua, viewed from the south-east (from White et al. 2007).

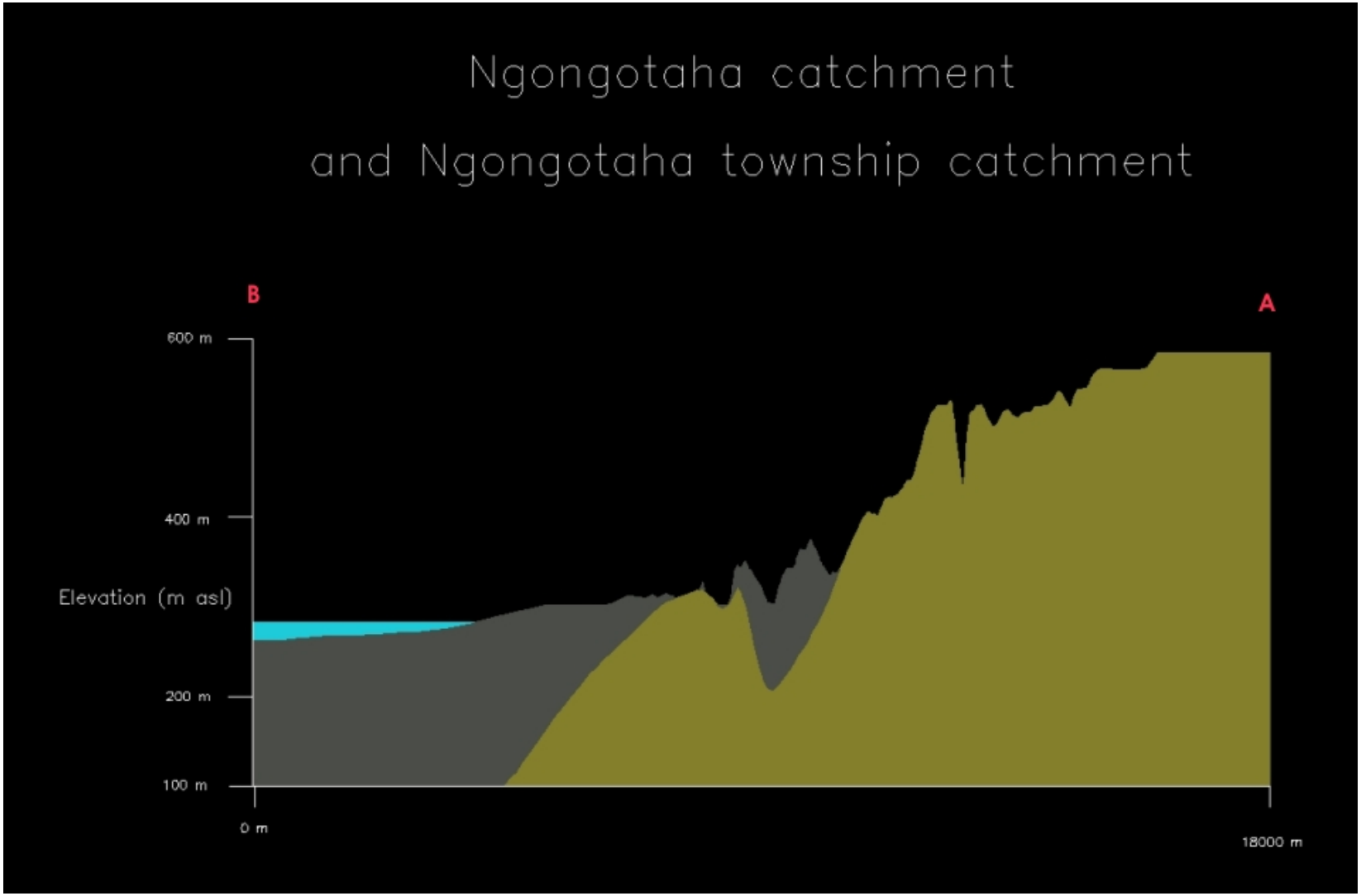


Figure 2.5 Geological cross section of the Ngongotaha catchment. Lake = blue, sediments = grey, ignimbrite (Mamaku Ignimbrite and older units) = olive green (from White et al. 2007).

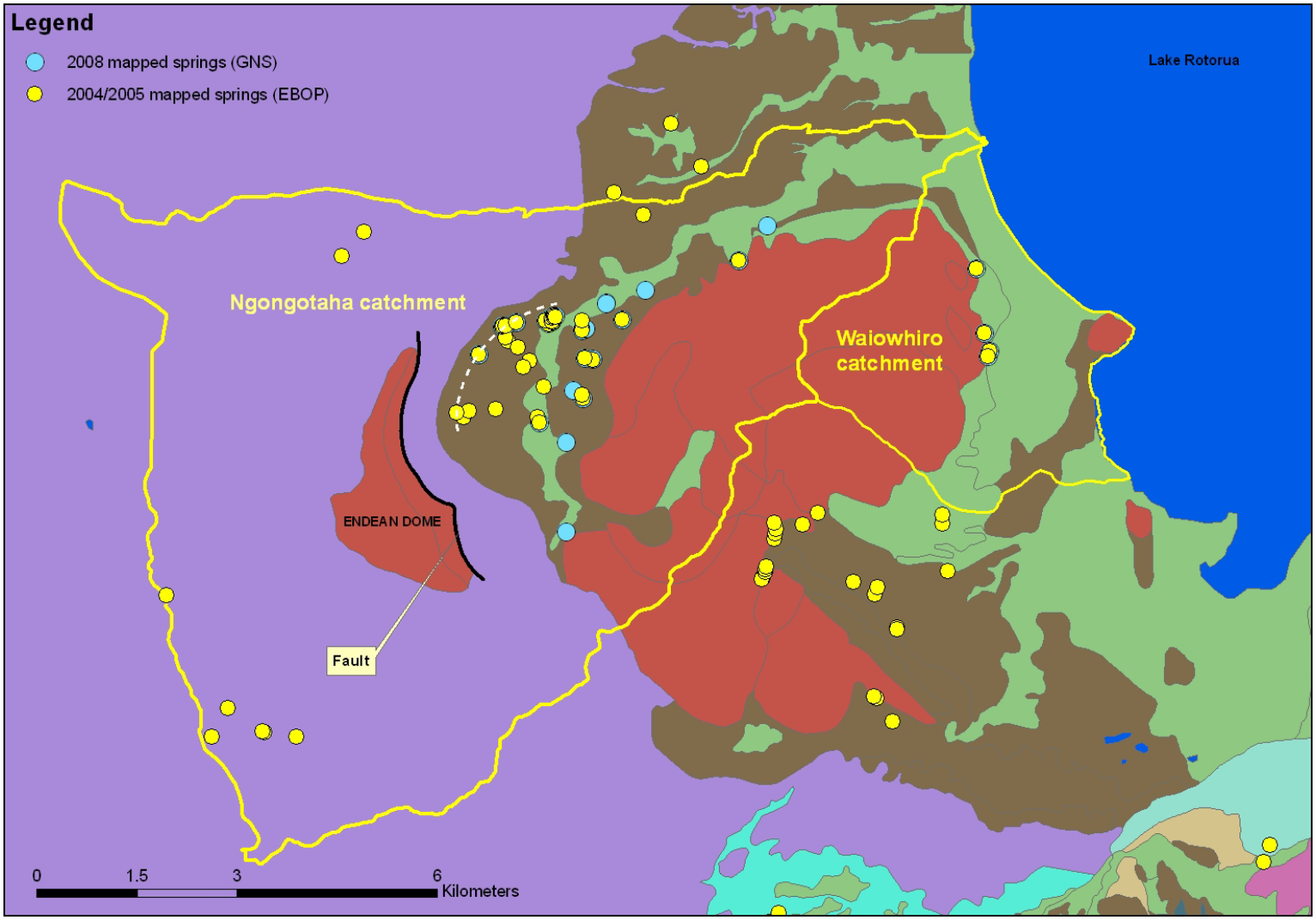


Figure 2.6 Fault (black line) in Ngongotaha catchment identified by Milner (2002) and presumption of fault or fissure (white dashed line). The dots show locations of springs.

3.0 HYDROLOGY AND HYDROGEOLOGY

The Ngongotaha catchment is drained by five main surface streams and three main springs.

Main surface streams:

- Ngongotaha Stream (main stream inflow into Lake Rotorua);
- Ohinenui Stream (left-side inflow into Ngongotaha Stream);
- Otamaroa Stream (left-side inflow into Ngongotaha Stream);
- Umurua Stream (left-side inflow into Ngongotaha Stream);
- Waitetahi Stream (left-side inflow into Ngongotaha Stream);
- plus several small, unnamed streams.

Main springs:

- Barlow Spring No.1 (180 L/s);
- Barlow Spring No.2 (58 L/s);
- Hatchery Spring (120 L/s);
- plus several large, and small, unnamed springs.

Waiowhiro catchment is drained by two main surface streams and three main springs.

Main surface streams:

- Waiowhiro Stream (main stream inflow into Lake Rotorua);
- Waikuta Stream (main stream inflow into Lake Rotorua).

Main springs:

- Rainbow Spring and Fairy Spring (280 L/s);
- McRae Spring (70 L/s).

3.1 Surface water and groundwater base flow

Surface baseflow in the study area comes from Mamaku Ignimbrite, rhyolite domes and lake sediments.

3.1.1 Ngongotaha catchment

Base flow in the Ngongotaha catchment (Figure 3.1) is defined by White et al. (2007) with addition of new data observed in July 2008. Baseflow estimates from White et al. (2007) are summarised in Appendix 4.

New data observed in July 2008 are summarised in Table 3.3 and Appendix 2.

Ngongotaha stream - main stem of the stream

- no change in stream flow between the lake and Ngongotaha Road (assumed);
- flow of 1700 L/s at Ngongotaha Road, being the average baseflow (rounded) of 1975-80

(Rutherford 2006) and the average baseflow rounded in 1973/74 (spot measurement on 7 February 1973);

- flow of 1300 L/s being average of 6 measurements in 1973;
- flow of 320 L/s at Paradise Valley below springs being average flow in 1973/74 rounded;
- flow of 150 L/s above the Otamaroa confluence, being flow measured in April 2006 rounded;
- flow of 4 L/s from spring in headwaters, being the flow measured in July 2006, rounded.

Otamaroa Stream

- flow of 140 L/s being the flow above Ngongotaha confluence measured in April 2006 , rounded.

Umurua Stream

- flow of 390 L/s being the flow above the Ngongotaha confluence in 1973/74, rounded;
- flow of 230 L/s being the flow upstream of the Waitetahi confluence in April 2006, rounded;
- flow of 4 L/s being the flow from a spring in the headwaters in July 2006, rounded.

Waitetahi Stream

- flow of 70 L/s being the flow upstream to the Umurua confluence in April 2006, rounded.

Small streams flowing into Ngongotaha Stream

- flow 8 L/s, unnamed stream, being flow measured in April 2006;
- flow 6 L/s, being that measured at Relph Road in April 2006;
- flow 4 L/s, unnamed stream, flow measured in July 2008 (N3 in Appendix 2);
- flow 1.9 L/s, unnamed periodic stream, dry in summer, flow measured in July 2008 (N7 in Appendix 2);
- flow 5.8 L/s, unnamed stream, flow measured in July 2008 (N8 in Appendix 2).

Springs

- Hatchery Spring 120 L/s, being average flow measured in 1972/1973, rounded;
- Barlow's No.1 Spring 58 L/s being average flow measured in 1973/74;
- Barlow's No. 2 Spring 180 L/s being average flow measured in 1973/74, rounded;
- Te Waireka Spring 3 L/s, being flow measured in April 2006;
- Awaroa Farm Spring 0.8 L/s being flow measured in July 2008 (N2 in Appendix 2);
- unnamed confluence of two unnamed springs 2.5 L/s, flow measured in July 2008 (N9, N10 in Appendix 2);
- unnamed spring 0.8 L/s, flow measured in July 2008 (N15 in Appendix 2);
- unnamed spring 0.1 L/s, flow measured in July 2008 (N22 in Appendix 2);
- unnamed confluence of 2 springs 1.8 L/s, flow measured in July 2008 (N25, N26 in Appendix 2).

3.1.2 Waiowhiro catchment

Base flow in the Waiowhiro catchment (Figure 3.1) is defined as in White et al. (2007).

Waiowhiro Stream

- flow of 300 L/s is assigned to the combined flow of Fairy Springs and Rainbow Springs at a location representing Fairy and Rainbow Springs. This location is at the estimated confluence of Fairy Springs and Waiowhiro Stream, down stream of Fairy and Rainbow Springs.

Waikuta Stream

- flow of 70 L/s is assigned to this stream, being the flow measured at McRae Spring in July 2006, rounded.

Lakeside features (springs and seepages)

- flow of 4 L/s at site 69 of the 2004/2005 survey;
- flow of 3 L/s at site 139 of the 2004/2005 survey being the rounded flow at site 139;
- flow of 3 L/s at site 155 of the 2004/2005 survey;
- flow of 1 L/s at site 165 of the 2004/2005 survey being the sum of flows at sites of the 2004/2005 survey: 157 (0.25 L/s), 159 (0.3 L/s), 163 (0.13 L/s), 164 (0.13 L/s), 165 (0.5 L/s) and 166 (0.05 L/s), rounded.

3.2 Changes in baseflow

3.2.1 Ngongotaha Stream catchment

Measured stream flows in the Ngongotaha Stream catchment indicate that the flow increases markedly in two sections of the catchment (Table 3.1, Figure 3.2).

Section A - B: between Paradise Valley Springs and upstream of Hatchery Stream;

Section C - D: between confluence Waitetahi Stream into Umurua Stream and confluence of Umurua Stream with Ngongotaha Stream.

Baseflow in Section A - B increases from about 320 L/s to about 1300 L/s.

Baseflow in Section C - D increases from about 300 L/s to about 390 L/s.

Table 3.1 Increases in stream flow, by reach, of Ngongotaha Stream.

Section	Stream flow increase L/s	Total increase on flow L/s	Increase from gauged streams	Increase from gauged springs	Unknown (ungauged) increase
Reach A - B	from 326 to 1300	974	410	247	**317**
Reach C – D	from 300 to 390	90	?	?	**90**

Total baseflow increase in reach A - B is estimated as 974 L/s in Ngongotaha Stream. Of this, the known (gauged) increase from side streams is 410 L/s and increase from springs is 247 L/s.

Therefore, **unknown unmeasured** (i.e. ungauged) increase from springs, small streams or groundwater discharge is 317 L/s in this reach.

The total increase in reach C - D is estimated as 90 L/s for Umurua Stream. There is no gauged stream flow or spring flow in this section of Umurua Stream. Groundwater is probably the source of this flow increase.

3.2.2 Waiowhiro catchment

Catchment water balance estimated by the groundwater flow model (White et. al. 2007) indicates that rainfall recharge to groundwater in the Waiowhiro catchment (439 L/s, Table 3.2) is less than calculated groundwater discharge into Lake Rotorua (1181 L/s, Table 3.2) and surface water baseflow (424 L/s, Table 3.2). Therefore, a total of 1166 L/s is 'missing' from the groundwater flow model water balance in the Waiowhiro catchment (Table 3.2).

Rainfall recharge in the Waiowhiro surface catchment is not sufficient to cover observed baseflow in Fairy, Rainbow and McRae springs (Table 3.3). Groundwater catchment boundaries could be adjusted to better represent baseflow in these springs.

Table 3.2 Water balance of catchments estimated from the groundwater flow model (White et al. 2007).

Surface catchment	Rainfall recharge to groundwater (L/s)	Calculated direct groundwater discharge to Lake Rotorua (L/s)	Calculated surface water baseflow: groundwater discharge to surface water (L/s)	Catchment Imbalance: outflux (+) or influx (-) (L/s)
Ngongotaha	2673	232	1800	642
Waiowhiro	439	1181	424	-1166

Table 3.3 Groundwater catchments of springs (White et al. 2007).

Surface catchment	Groundwater catchment name	Area (Ha)	Mean rainfall (mm/yr)	Rainfall (L/s)	Rainfall recharge to groundwater at 50% of rainfall (L/s)	Observed baseflow (L/s)	Imbalance in baseflow (L/s)
Ngongotaha	Hatchery Spring	105	1849	62	31	120	89
Ngongotaha	Fairy and Rainbow springs	309	1801	176	88	300	212
Waiowhiro	McRae Spring	151	1786	86	43	70	27

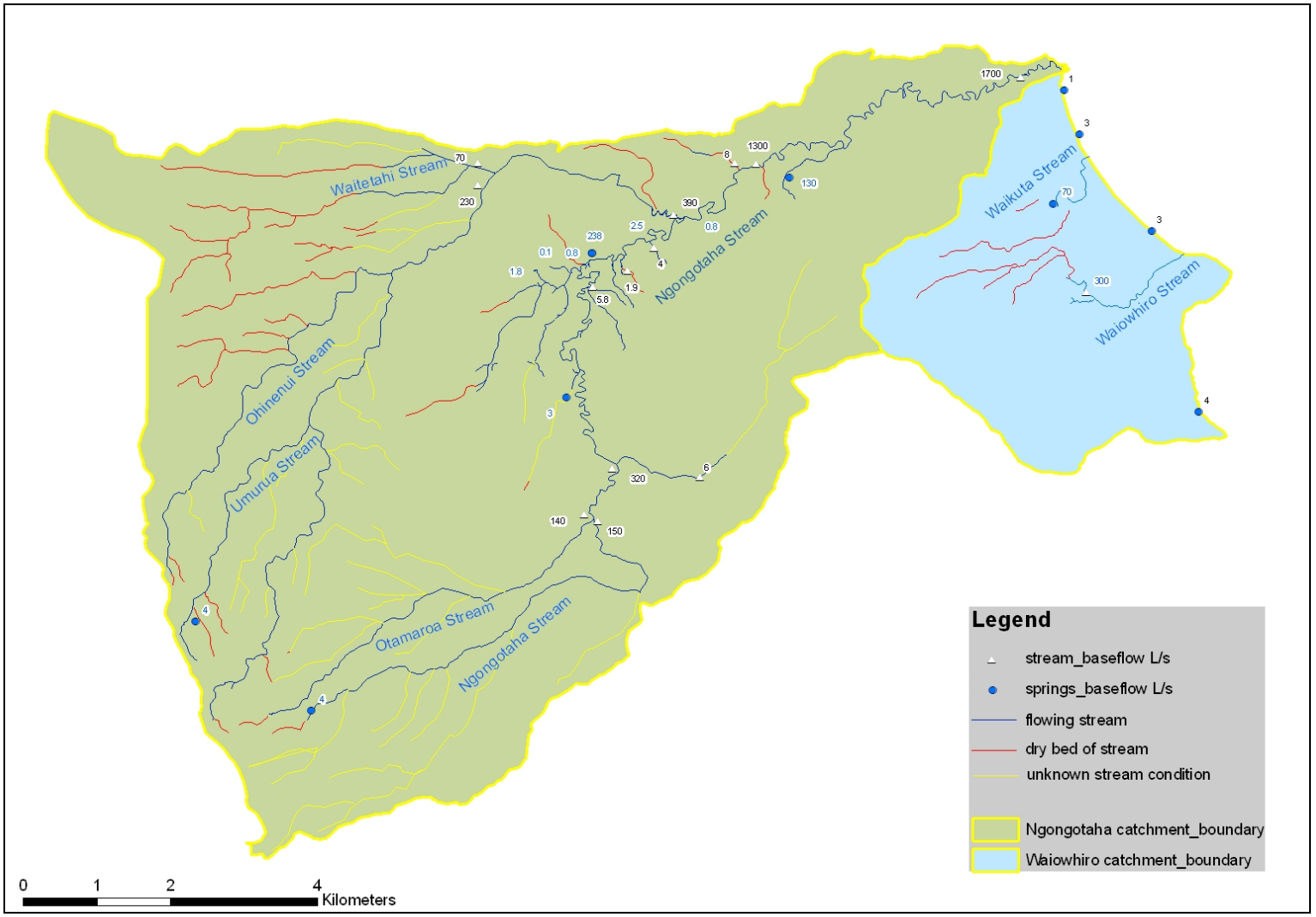


Figure 3.1 Model of baseflow and location of flow measurement sites in Ngongotaha and Waiowhiro catchments.

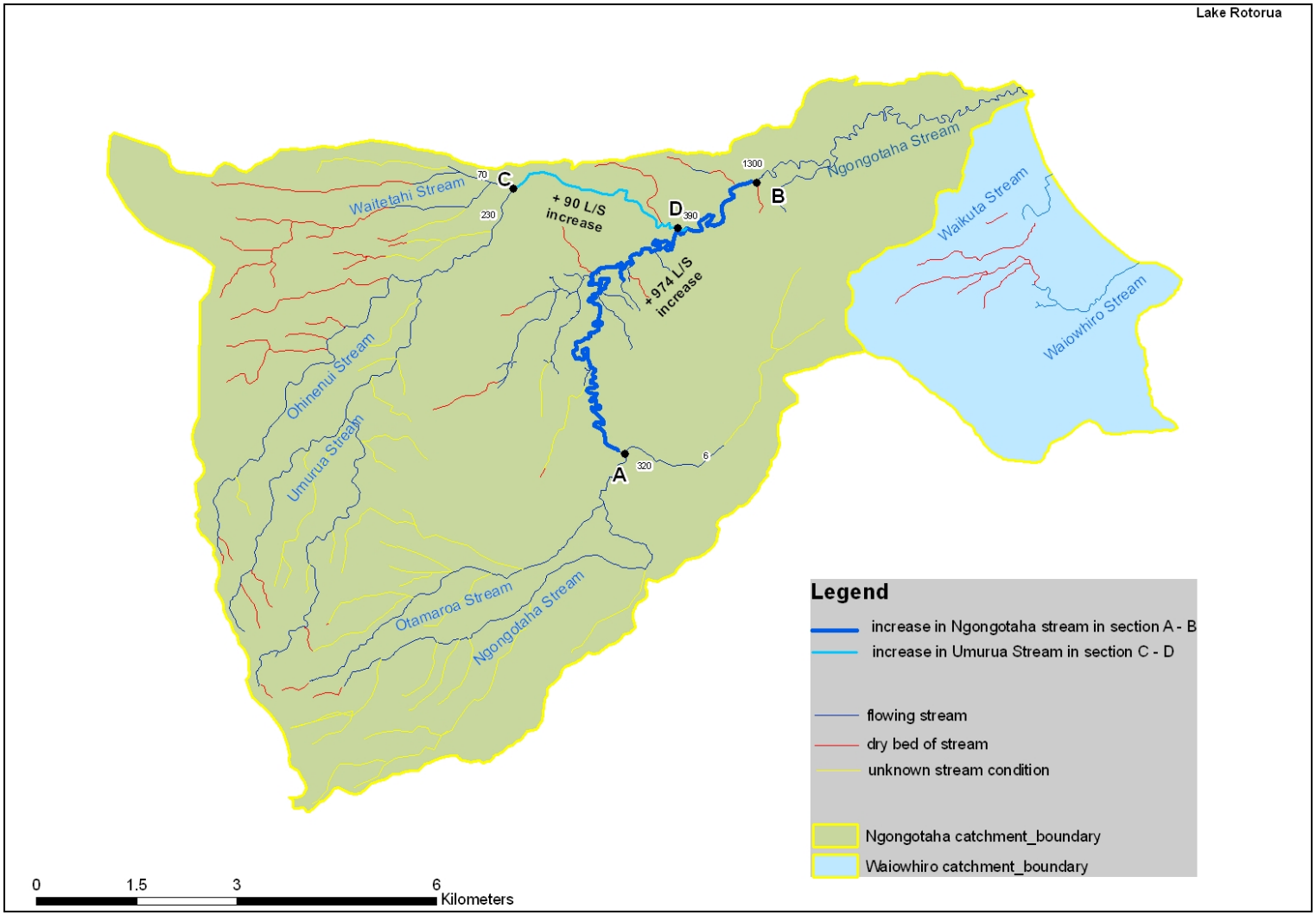


Figure 3.2 Increase in baseflow in the Ngongotaha catchment.

3.3 Hydrogeological properties of aquifers

Two pump tests were undertaken during the 2004-2005 field programme (Reeves et al. 2005) to provide aquifer transmissivity and storativity values of the Mamaku Ignimbrite aquifer and the Huka Group Sediment aquifer (Table 3.4).

The Mamaku Ignimbrite aquifer is considered to be a leaky - confined, or confined aquifer with hydraulic conductivity of 6 m/day for 100 m assumed aquifer thickness.

The Huka Group Sediment aquifer is considered to be a leaky – confined aquifer with hydraulic conductivity of 4.5 m/day for 43 m assumed aquifer thickness.

Table 3.4 Hydraulic properties of Mamaku Ignimbrite and Huka Group Sediment aquifers evaluated by pump test in Reeves et al. (2005).

Geology Unit	Hydraulic conductivity (m/day)	Aquifer transmissivity (m^2/day)	Storativity
Mamaku Ignimbrite	6 with 100 m aquifer thickness	600	4×10^{-3}
Huka Group Sediment	4.5 with 43 m aquifer thickness	200	2.0×10^{-3}

In general, Mamaku Ignimbrite and rhyolite domes probably have greater hydraulic conductivity than sedimentary sequences (Huka Group Sediments or Holocene Alluvium). Sedimentary sequences are probably aquitards for the ignimbrite and rhyolite aquifers. These sediments include beds of permeable pumiceous tephra, and gravel and sand, but with limited lateral extent and usually surrounded by impermeable muddy sands and silts (Wood, 1992).

Mamaku Ignimbrite has a relatively high permeability and porosity and also a good fracture permeability (Wood, 1992). Most wells drilled in fractured Mamaku Ignimbrite and rhyolite domes have low-to-moderate bore yields. Much of Rotorua's water supply comes from high flow springs that outflow from this formation (Gordon in White et al. 2001).

4.0 GEOCHEMISTRY

Water quality has been measured (White et al., 2007) at 11 sites within the study area; eight sites in the Ngongotaha catchment and three sites in the Waiowhiro catchment (Figure 4.1).

Field data from sampling (i.e., conductivity, pH, and temperature) obtained in July 2008 are provided in Table 4.1 and Appendices 2 and 5. Results showing major ions and water type are listed in Table A5.1 (Appendix 5). Data for surrounding catchments is also presented in Appendix 5.

Groundwater obtained from wells drilled into Mamaku Ignimbrite usually has higher chloride and lower bicarbone concentrations that groundwater obtained from wells drilled into rhyolite domes (Wood, 1992). Water quality data in Appendix 5 is consistent with this observation in that chloride levels in groundwaters from Mamaku Ignimbrite are higher than for groundwaters from the Ngongotaha Rhyolite dome. Further, the dominant anion in all of the groundwater samples in both the Ngongotaha and Waiowhiro catchments is bicarbonate.

A further noteworthy result is nitrate-nitrogen concentrations in groundwater from springs

with relatively large catchments (Section 6) are lower than groundwater from springs located in small farmland catchments. For example, springs from larger catchments had nitrate-nitrogen levels in the 0.1 to 0.8 mg/L range while spring N38 in Paradise Valley had a nitrate-nitrogen concentration of 6.75 mg/L (Appendix 5).

Water types were defined by the AquaChem computer program (White, et al., 2007). Water types characteristic of geology in the vicinity of the spring outflow (as interpreted from observations during field work and the geological map) are as follows:

1. Spring discharges from Mamaku Ignimbrite:
    - Na-Ca-HCO_3-Cl (Waitetahi Springs, East);
    - Na-Ca-HCO_3-Cl (Waitetahi Springs, West);
    - K-Ca-Mg-HCO_3-Cl (Barlow Spring No. 1);
    - K-Mg-Na-Ca-HCO_3-Cl (Barlow Spring No. 2).
2. Spring discharges from the Ngongotaha Rhyolite dome:
    - K-Na-HCO_3-Cl (Hathery Spring);
    - Na-HCO_3-Cl (Fairy Spring);
    - Na-Ca-HCO_3-Cl (Rainbow Spring).
3. Discharges from Huka Group sediments:
    - K-Na-HCO_3 (Paradise Valley Spring);
    - Ca-Na-HCO_3 (groundwater from a temporary piezometer).

The two Waitetahi Stream springs (numbers 144 and 145 in Figure 4.1) flowing from Mamaku Ignimbrite have the same type groundwater (Na-Ca-HCO3-Cl) as Rainbow and Fairy Springs flowing from the Ngongotaha Rhyolite Dome. Sodium is the dominant cation for all of these springs and bicarbonate the dominant anion.

The groundwater type of Paradise Valley Spring (number 39 in Figure 4.1 with K-Na-HCO_3 type water) is similar to water from Hatchery Spring (K-Na-HCO_3-Cl type water) which discharges from the Ngongotaha Rhyolite Dome. Therefore, it is likely that Paradise Valley Spring also receives groundwater from rhyolite to the southeast. However, it is also possible that it receives groundwater from Mamaku Ignimbrite to the west because, in general, it appears that groundwater samples from both Mamaku Ignimbrite and Ngongotaha Rhyolite Dome had similar chemical compositions.

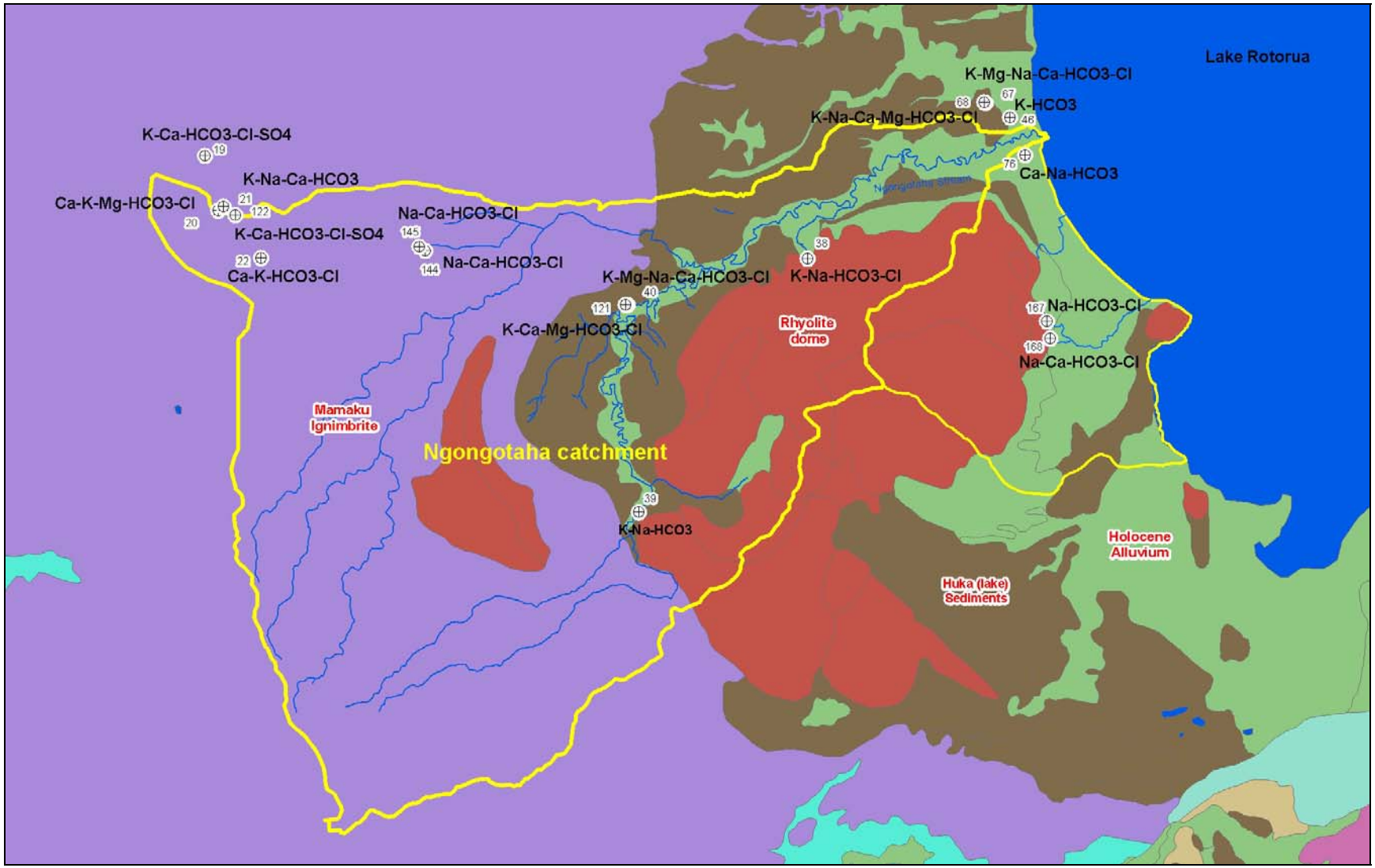


Figure 4.1 Location of water quality sites (springs and wells) and water types (White et al. 2007).

Table 4.1 Ngongotaha and Waiowhiro catchment field chemistry data (conductivity, temperature, pH, SiO_2).

GNS ID	EBOP ID	Name of spring	Surface Catchment Location	Source Type	Spring outflow Geology	Measures in 2008			From White et al. (2007)			
						Cond	pH	Temp	Cond	pH	Temp	SiO_2
N1			Ngongotaha	Spring	Rotorua Young-TVZ rhy lava	74	6.6	11.2				
N4			Ngongotaha	Spring	Huka group sediments or rhyolite lava?	65	6.4	13.2				
N8			Ngongotaha	Stream	Huka group sediments or rhyolite lava?	65	6.5	9.4				
N11	40	Barlow spring # 1	Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite	74	6.2	10.8	5			60
N16			Ngongotaha	Spring	Holocene alluvial sediments	92	6.2	7.8				
N17			Ngongotaha	Spring	Holocene alluvial sediments	75	6.2	10.5				
N18			Ngongotaha	Spring	Holocene alluvial sediments	75	6.1	10.4				
N19	121	Barlow Spring # 2	Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite							74
N20			Ngongotaha	Stream	Huka group sediments or rhyolite lava?	70	6.4	9.8				
N22			Ngongotaha	Spring	Huka group sediments	41	6.7	9.1				
N23			Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite	68	6.6	11.0				
N25			Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite	68	6.6	11.0				
N26			Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite	68	6.5	11.3				
N27			Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite	68	6.3	11.2				
N28			Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite	74	6.4	11.0				
N29			Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite	45	6.3	11.6				
N30			Ngongotaha	Stream	Huka group sediments	62	6.6	7.5				
N31			Ngongotaha	Stream	Holocene alluvial sediments	68	6.1	10.9				
N32	38	Hatchery Spring	Ngongotaha	Spring	Rotorua Young-TVZ rhy lava				5			63
N33			Waiowhiro	Stream	Rotorua Young-TVZ rhy lava	79	6.6	11.5				
N34	167	Fairy Spring	Waiowhiro	Spring	Rotorua Young-TVZ rhy lava				46	7.15	11.8	61
N35	168	Rainbow Spring	Waiowhiro	Spring	Rotorua Young-TVZ rhy lava				45	7.02	12.8	57
N38	39	Paradise Valley Spring	Ngongotaha	Spring	Holocene alluvial sediments				36	7.10	10.7	66
	22		Ngongotaha	Well	Mamaku pyroclastics - Ignimbrite				91			
	76		Waiowhiro	TP	Holocene alluvial sediments				118	6.23	15.1	24
	122		Ngongotaha	Well	Mamaku pyroclastics - Ignimbrite				101			75
	144		Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite				72	5.66	9.8	34
	145		Ngongotaha	Spring	Mamaku pyroclastics - Ignimbrite				72	5.57	9.6	34

5.0 FIELD WORK IN THIS PROJECT

The aims of field work in this project are:

- identification and location of new springs and review of springs identified by EBOP in its 2004/2005 field programme;
- measurement of groundwater flow (springs) or surface water flow (streams).

Methods in the identification and location of springs included:

- location of the spring using GPS;
- photograph of the spring (including a photograph showing the detail of the outflow and a photograph showing the surrounding environment);
- identification of the geology at the outflow;
- identification of the geomorphology at the outflow.

Flow measurements were made using one of the following two methods:

- volumetric measurement (if access was possible);
- visual estimation for low flows or for flow where flow was impossible to measure volumetrically.

Field work took place in two surface water catchments:

- Ngongotaha catchment (Paradise Valley);
- Waiowhiro catchment.

Springs and streams were identified in June and July 2008.

Results

The survey identified 36 springs in Ngongotaha and Waiowhiro catchments in 2008 (Figure 5.1 and Figure 5.2). Eight new springs are identified by this work. Flow measurement was made for 7 springs and 3 streams (Figure 5.3). A total of 28 springs were visited that were identified by EBOP in 2004/2005.

Photographic documentation of the springs (Appendix 1) includes photographs and location of the springs. A description of the springs (Appendix 2) includes detailed location, geology and geomorphology at the outflow, spring type and outflow type, flow measurement values and text description. A total of 18 springs with conductivity, temperature and pH measurements are presented.

Two springs (N37, N38) identified in White et al. (2007), are included in these data; these springs were not visited during the spring survey of 2008.

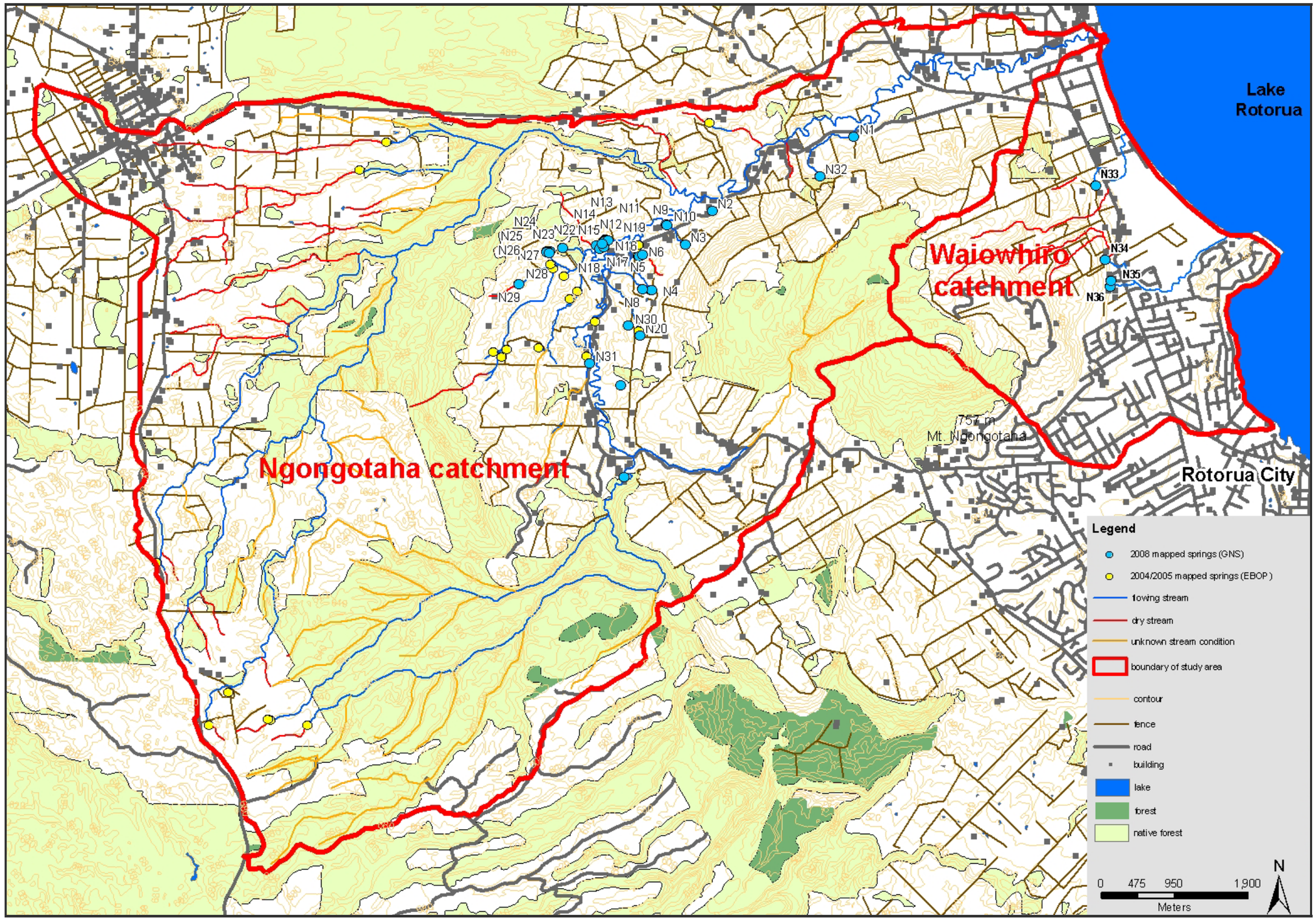


Figure 5.1 Location of springs in Ngongotaha and Waiowhiro catchments.

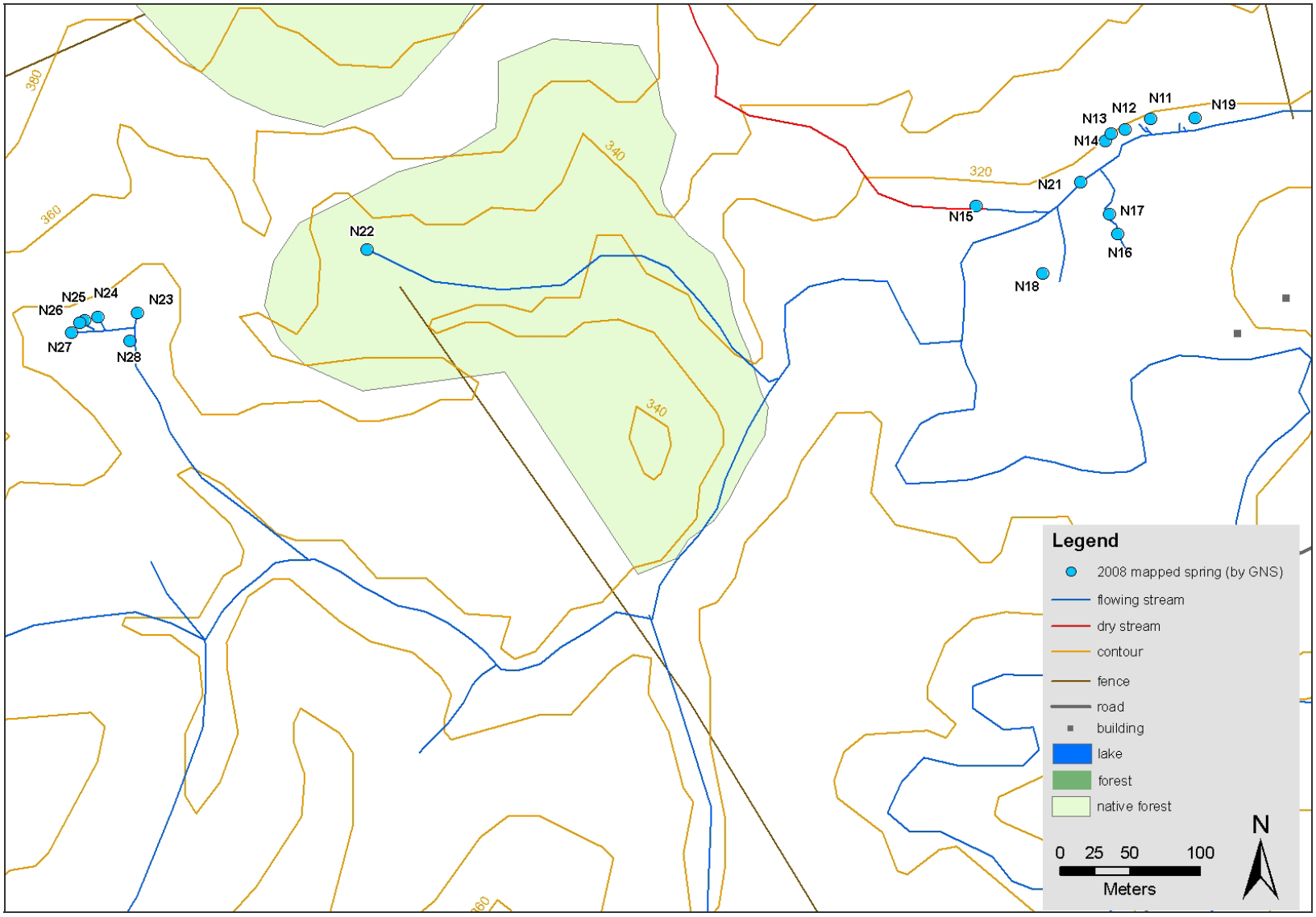


Figure 5.2 Detailed view of springs in Paradise Valley.

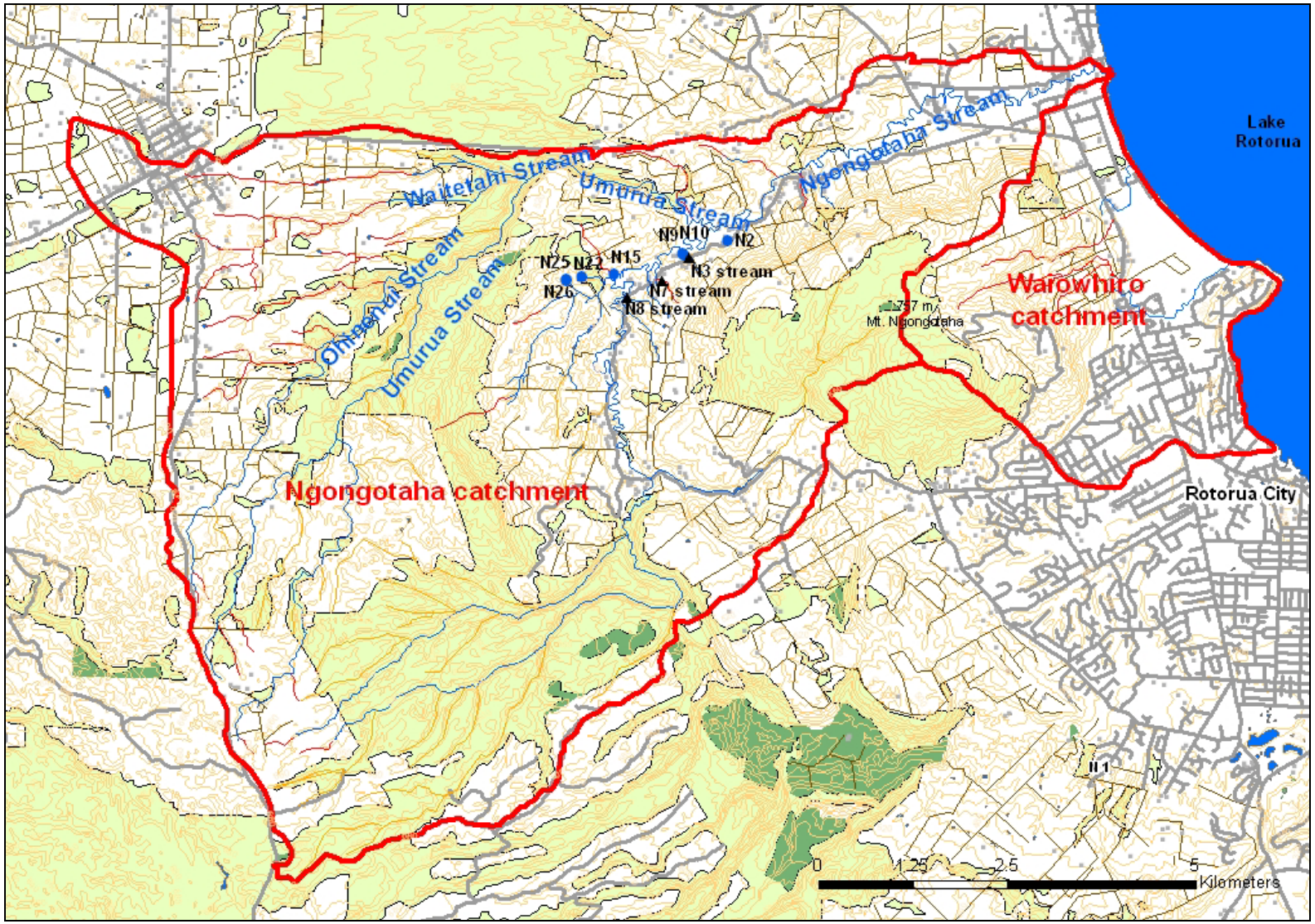


Figure 5.3 Location of 2008 flow measurement sites.

6.0 GROUNDWATER CATCHMENTS OF SPRINGS

6.1 Existing data for groundwater catchments of springs

Groundwater catchment boundaries for Hatchery Spring of Ngongotaha catchment and Fairy, Rainbow and McRae springs of Waiowhiro catchment were estimated by White et al. (2007), Table 6.1 and Figure 6.1. For all three of these springs the proposed groundwater catchment area, and rainfall recharge value, by White et al. (2007) is not sufficient to cover the measured baseflow.

Groundwater catchments of other parts of Ngongotaha and Waiowhiro surface catchments were estimated in White et al. (2007), Table 6.2 and Figure 6.1.

The recharge area for Hatchery, Barlows, Paradise and Rainbow springs was estimated by Pang (et al. 1996), Table 6.3.

6.2 Groundwater catchments of the springs and streams proposed in this project

Groundwater catchments of springs are the land area where rainfall water, surface water and groundwater enter the groundwater system and discharge to the surface from a spring feature. The groundwater recharge area does not have to correspond with the surface water catchment area. The groundwater recharge area may be smaller, or many times bigger, than the area of corresponding surface catchment; depending on underlying geology and aquifer extent.

6.2.1 Methodology

Groundwater and surface water catchment polygons are drawn in GIS software on the basis of the following data.

Major data used to calculate groundwater catchments and surface water catchments:

- x, y position of spring; x, y position of stream measurement site;
- average spring and stream flows;
- GIS rainfall model within the area on a 1 km by 1 km grid (White et al. 2007);
- rainfall recharge to groundwater (assuming 50% of rainfall estimated in White et al. 2007).

Minor data used to estimate catchment of the spring:

- geology;
- geomorphology;
- hydrology;
- geochemistry.

Table 6.1 Proposed groundwater catchments and comparison with observed baseflow data (White et. al. 2007).

Groundwater catchment number	Groundwater catchment name	Area (Ha)	Mean rainfall (mm/yr)	Rainfall (L/s)	Rainfall recharge to groundwater at 50% of rainfall (L/s)	Observed baseflow (L/s)	Imbalance in baseflow (L/s)
19	Fairy and Rainbow springs	309	1801	176	88	300	212
21	McRae spring	151	1786	86	43	70	27
23	Hatchery Spring	105	1849	62	31	120	89

Table 6.2 Proposed groundwater catchments of Ngongotaha and Waiowhiro surface catchment (White et al. 2007).

Groundwater catchment number	Groundwater catchment name	Area (Ha)	Mean rainfall (mm/yr)	Rainfall (L/s)	Rainfall recharge to groundwater at 50% of rainfall (L/s)
14	Ngongotaha South	2705	2016	1730	865
18	Ngongotaha - Umurua	1946	2081	1284	642
22	Ngongotaha middle valley	885	1946	546	273
28	Waiowhiro	1177	1718	641	321
29	Ngongotaha flats	944	1737	520	260

Table 6.3 Springs recharge zones estimated by Pang (et al. 1996).

Spring Name	Recharge area (km^2)	Age (year)	Aquifer Type	Flow (L/s)	Storage (km^3)	Thickness (m)*
Hatchery	6	55-110	Rhyolite	119	0.206-0.413	137-275
Barlows	11	50	Ignimbrite	239	0.307	137
Paradise Valley	3	10	?	56	0.018	24
Rainbow	14	50	?	298	0.470	134

* assuming effective porosity = 0.25

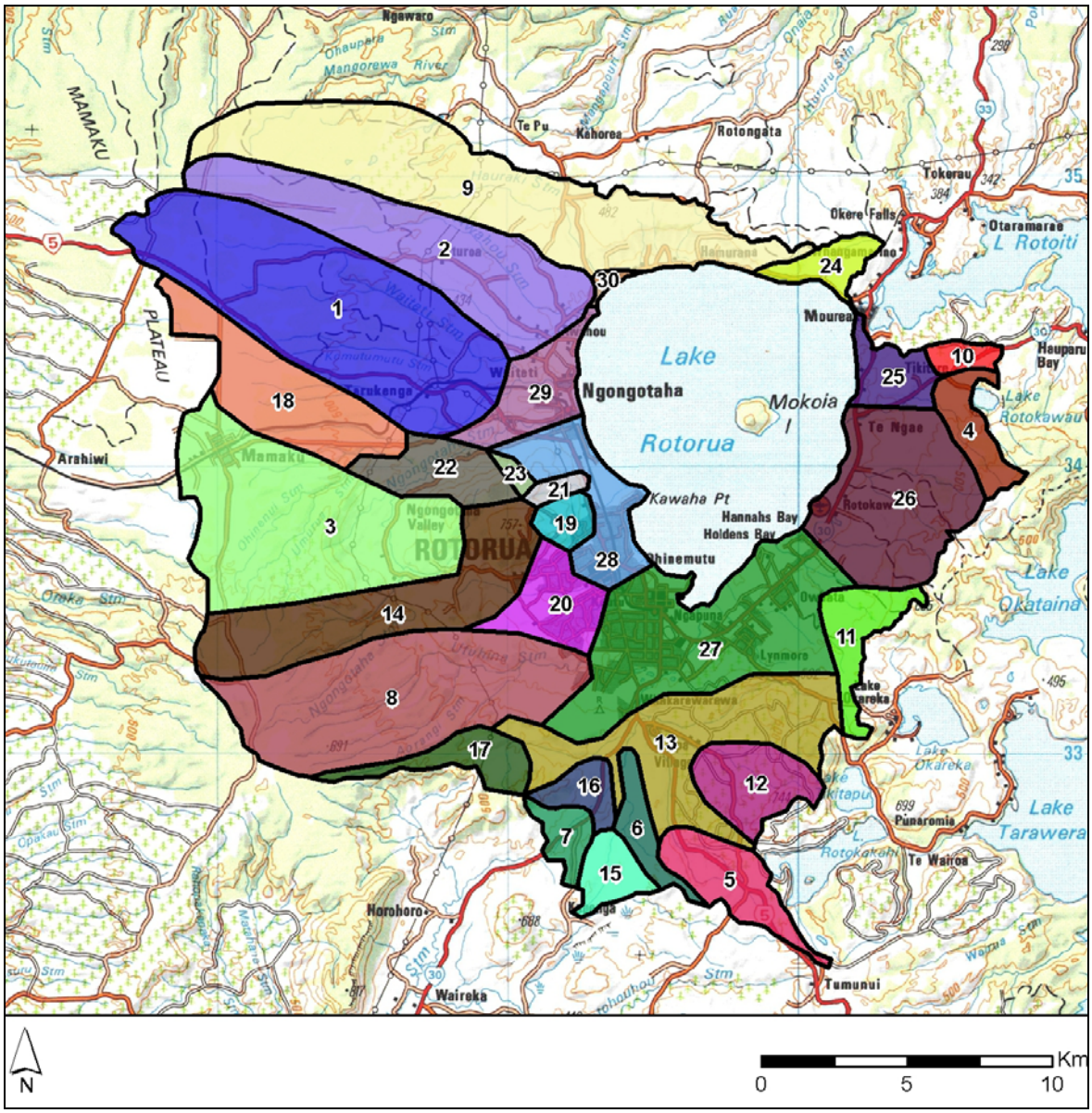


Figure 6.1 Groundwater catchments proposed in White et al. (2007).

Step 1 - Identify a proposed catchment for each spring

Possible spring catchment areas are defined in GIS ArcGis 9.2 using the following process:

- draw a polygon around the stream outflow site representing the possible catchment area of the spring assuming the geology, geomorphology, geochemistry and hydrology data;
- calculate the area of the proposed catchment using GIS “Calculate Area” function;
- calculate mean rainfall in the zone of the proposed catchment from a 1 km by 1 km rainfall model using GIS Statistic tool;
- calculate rainfall recharge value (50% of mean rainfall);
- compare rainfall recharge value with spring flow; the value of rainfall recharge should equal the value of spring flow;

- if rainfall recharge is not the same as spring flow, then repeat the above steps to adjust the possible spring catchment area so that the value of rainfall recharge equals the value of spring flow.

Step 2 - Identify a proposed catchment for stream that is not mapped from spring flow method

- draw a polygon around the flow measurement site representing the possible catchment area of the stream assuming the geology, geomorphology, geochemistry and hydrology data;
- calculate area of the proposed catchment using GIS "Calculate Area" function;
- calculate mean rainfall in the zone of the proposed catchment from a 1 km by 1 km rainfall model using GIS Statistic tool;
- calculate rainfall recharge value (50% of mean rainfall);
- compare rainfall recharge value with spring flow; the value of rainfall recharge should equal the value of stream flow;
- if rainfall recharge is not the same as stream flow value then repeat the above steps to adjust the possible stream catchment area so that the value of rainfall recharge equals the value of stream flow.

Step 3 - Adjust spring catchments boundaries for overlap with proposed springs and stream catchments

- identify land areas where possible catchments of springs or streams overlap;
- adjust possible spring catchment area to remove overlaps.

6.2.2 Results

6.2.2.1 Step 1 - proposed groundwater catchments of springs

The estimated groundwater catchments of springs (Table 6.4) includes the recharge area of the possible catchment, mean rainfall, rainfall recharge and flow of the spring. All proposed catchments are plotted in Figure 6.1.

Rainbow and Fairy Springs (N34, N35) – Waiowhiro catchment

The possible groundwater catchments of these springs cover approximately half the surface extent of Mt. Ngongotaha. Apparently the Waiowhiro catchment area is not sufficient to supply enough water for these high yielding springs. Therefore, two thirds of the estimated groundwater catchment of Rainbow and Fairy springs is in the Ngongotaha and Utuhina surface catchments.

McRae Spring (N33) – Waiowhiro catchment

This spring has a proposed groundwater catchment lying on the north-east part of the rhyolitic dome of Mt. Ngongotaha. A small part of the catchment lies on the Ngongotaha surface catchment.

Table 6.4 Proposed groundwater catchments of springs including area, rainfall, groundwater recharge and observed spring baseflow.

#	Spring and catchment ID	Name of spring	Surface catchment	Spring catchment area (Ha)	Mean rainfall (mm/y)	Rainfall recharge (mm/y)	Rainfall recharge (L/s)	Spring flow (L/s)	Method to obtain flow
1	N1	"Maori Spring"	Ngongotaha	0.87	1828.259	914.13	25	25	Estimated
2	N2	Awaroa Farm Spring	Ngongotaha	0.02	1938.96	969.48	1	0.83	Measured
3	N4		Ngongotaha	0.13	1966.014	983.01	4	4	Estimated
4	N5+N6		Ngongotaha	0.06	1946.604	973.30	2	2.5	Estimated
5	N9 + N10		Ngongotaha	0.09	1949.409	974.70	2	2.5	Measured
6	N11+ N19	Barlow Spring No1 + No2	Ngongotaha	7.55	1984.29	992.14	238	238	Measured
7	N12 + N13 + N14+N21		Ngongotaha	1.26	1978.65	989.32	40	40	Estimated
8	N15		Ngongotaha	0.02	1966.469	983.23	1	0.76	Measured
9	N16+N17+N18		Ngongotaha	0.16	1956.115	978.06	5	5.8	Estimated
10	N20		Ngongotaha	0.24	1989.013	994.51	8	8	Estimated
11	N22		Ngongotaha	0.01	1982.13	991.07	0.1	0.1	Measured
12	N23 + N24+N25+N26+N27+N28		Ngongotaha	0.60	1982.13	991.07	19	19.8	Measured
13	N29		Ngongotaha	0.31	1996.818	998.41	10	10	Estimated
14	N30		Ngongotaha	0.09	1974.335	987.17	3	3	Estimated
15	N31		Ngongotaha	0.15	1988.426	994.21	5	5	Estimated
16	N32	Hatchery Spring	Ngongotaha	3.94	1917.45	958.73	120	120	Measured
17	N33	McRae Spring	Waiowhiro	2.50	1777.97	888.98	70	70	Measured
18	N34 + N35	Rainbow/Fairy Spring	Waiowhiro	9.88	1917.89	958.95	300	300	Measured
19	N37	Paradise Valley Spring	Ngongotaha	0.95	2000.00	1000.00	30	30	Measured
20	N38	Te Waireka Spring	Ngongotaha	0.10	1990.41	995.20	3	3	Measured
21	328,451, 470, 476, 477, 481, 482, 504, 514, 516, 517, 520	EBOP unnamed springs	Ngongotaha	5.59	1974.54	987.27	175	175	Estimated

Hatchery Spring (N32) and Maori Spring (N1) – Ngongotaha catchment

The proposed groundwater catchments of these springs are on the northern part of the Mt. Ngongotaha rhyolitic dome. Spring recharge is from groundwater of the Ngongotaha surface catchment but some water may be recharged from the Waiowhiro catchment to the east.

Paradise Valley Spring (N38) - Ngongotaha catchment

The groundwater catchment of this spring lies to the west in Mamaku Ignimbrite. On the basis of water type (K-Na-HCO_3), which is similar to water from Ngongotaha rhyolitic structure (K-Na_HCO_3_Cl), it is possible that the some flow may be derived from the rhyolitic structure of Endean dome in the west.

Barlow Spring No1 and Barlow Spring No2 (N11, N19) – Ngongotaha catchment

These springs seem to be recharged by groundwater from Mamaku Ignimbrite to the west. The proposed groundwater catchment may extend in part beyond the Ngongotaha surface catchment to the north and probably takes some groundwater from the Waiteti catchment. It is also possible that groundwater is recharged entirely from the Mamaku Plateau to the west (Figure 6.2) and not from Waiteti catchment.

Spring area of N12, N13, N14, N15, N21 and spring area of N22, N23, N24, N25, N226, N27, N28 - Ngongotaha catchment

The groundwater catchments of these springs overlap the groundwater catchment of Barlow Springs. Springs are apparently recharged from the groundwater in Mamaku Ignimbrite to the west.

Springs N16, N17, N18 - Ngongotaha catchment

These springs seem to be recharged by groundwater from Holocene Alluvial sediments and/or by Huka Group sediments near Ngongotaha Stream.

Spring N29 - Ngongotaha catchment

This spring has proposed groundwater catchment predominantly to the west in Mamaku Ignimbrite and part in the Huka Group sediments but some flow may come from the rhyolitic structure of Endean dome.

Spring N31 - Ngongotaha catchment

The proposed groundwater catchment of this spring is in part in Holocene Alluvial sediments and in part Huka Group sediments. Groundwater may be recharged from one, or from both, of these geological units.

Springs N9, N10 - Ngongotaha catchment

The proposed groundwater catchment of these springs lies in part in Holocene Alluvial sediments and in part in Huka Group sediments. Groundwater may be recharged through one, or from both, of these geological units.

Springs N2, N5, N6, N37 - Ngongotaha catchment

All these springs have outflows on the geological boundary of Holocene Alluvium with Huka Group sediments. The proposed groundwater catchments of these springs are in Huka Group sediments through which groundwater is probably recharged.

Springs N4, N20, N30 - Ngongotaha catchment

All these springs have outflows in Huka Group sediments. Their groundwater catchments are predominantly in Huka Group sediments but also possibly in part Mt. Ngongotaha.

Other EBOP mapped springs (328,451, 470, 476. 477, 481, 482, 504, 514, 516, 517, 520) - Ngongotaha catchment.

The groundwater catchments of these 12 springs were estimated to possibly cover increase in surface flow of Ngongotaha Stream (317 L/s in reach A – B, Table 3.1, Figure 3.2). Flow is not measured at these springs.

Groundwater catchments of these springs lie mainly in Huka Group sediments and in part in Holocene Alluvium. The groundwater catchments of springs 514, 516 and 520 may include Huka Group sediments, Mamaku Ignimbrite and Endean rhyolite dome.

6.2.2.1.1 Comparison of obtained baseflow imbalance in Ngongotaha Stream (Section A – B) and flow from estimated groundwater catchments of springs

Measured stream flow in the Ngongotaha catchment indicate a baseflow increase of 974 L/s in reach A – B (Figure 3.2). The increase is 564 L/s after subtracting the baseflow from gauged side streams (Table 3.1)

Estimated groundwater catchment of the springs in this reach of Ngongotaha Stream may produce 518 L/s (Section 6.2.2.1) which is very similar to the baseflow increase (564 L/s, Table 6.5). This indicates that rainfall recharge on the Ngongotaha catchment may support the baseflow increase in reach A – B of Ngongotaha Stream.

Table 6.5 Baseflow in Ngongotaha Stream (reach A – B) and estimated groundwater discharge from springs.

	Baseflow increase L/s	**Total increase in baseflow L/s**	**Increase in baseflow without flow from side streams (L/s)**	**Discharge from estimated springs catchments (L/s)**
Reach A - B	from 326 to 1300	974	564	518

6.2.2.2 Step 2 - surface catchments of streams

The estimated surface catchments of streams (Table 6.6) include recharge area of the catchment, mean rainfall, rainfall recharge and stream flow. All proposed catchments are plotted in Figure 6.2.

Stream S1 – Umurua Stream (reach C – D in Figure 3.2) - Ngongotaha catchment

The proposed surface catchment in part overlaps with the proposed groundwater catchment of Barlow Springs to the west and in small part extends to the Waiteti surface catchment to the north.

Stream S2 – Umurua Stream (upstream) and Ohinenui stream

The proposed surface catchment of these streams overlap in part with the proposed groundwater catchment of Barlow Springs.

Stream S3 – Waitetahi Stream

The proposed surface catchment overlaps in part with the proposed groundwater catchment of Barlow Springs.

Stream S4 – Ngongotaha Stream and Stream S5 – Otamaroa Stream

The proposed surface catchments of these streams lie in Mamaku Ignimbrite to the south – west.

Stream S6 – unnamed stream at Relph Road

The proposed surface catchment of this low - flow stream lies in part in Huka Group sediments and in part in Mt. Ngongotaha rhyolite.

Stream S7, S8, S9, S10 – unnamed streams

The proposed surface catchment of these low - flow streams lie in Huka Group sediments.

6.2.2.3 Step 3 - adjusted spring catchments

The possible groundwater catchment of Barlow springs (Figure 6.1) overlaps with groundwater catchments of springs N12, N13, N14, N15 N21, N22, N23 - N28 and spring 481 and in part of surface catchments S1, S2, S3. Therefore the groundwater catchment of Barlow springs is enlarged and extended to the west on Mamaku Plateau (Figure 6.3).

Table 6.6 Proposed surface catchments of the streams including area, rainfall, groundwater recharge and observed stream baseflow.

#	Stream catchment ID	Name of stream	Surface catchment	Stream catchment area (Ha)	Mean rainfall (mm/y)	Rainfall recharge (mm/y)	Rainfall recharge (L/s)	Stream flow (L/s)	Method of obtain of flow
1	S1	Umurua Stream (downstream)	Ngongotaha	2.90	1950.89	975.44	90	90	Measured
2	S2	Umurua Stream (upstream) + Ohinenui Stream	Ngongotaha	7.23	2002.35	1001.18	230	230	Measured
3	S3	Waitetahi Stream	Ngongotaha	2.20	2009.57	1004.79	70	70	Measured
4	S4	Ngongotaha Stream	Ngongotaha	4.72	2000.00	1000.00	150	150	Measured
5	S5	Otamaroa Stream	Ngongotaha	4.40	2000.00	1000.00	140	140	Measured
6	S6	Ngongotaha Stream at Relph Road	Ngongotaha	0.18	2006.00	1003.00	6	6	Measured
7	S7	Unnamed Stream	Ngongotaha	0.25	1940.07	970.04	8	8	Measured
8	S8 (N3)	Unnamed Stream	Ngongotaha	12.00	1946.604	973.30	4	4	Measured
9	S9 (N7)	Unnamed Stream	Ngongotaha	4.56	1946.604	973.30	1	1.85	Measured
10	S10 (N8)	Unnamed Stream	Ngongotaha	15.00	1966.014	983.01	5	5.8	Estimated

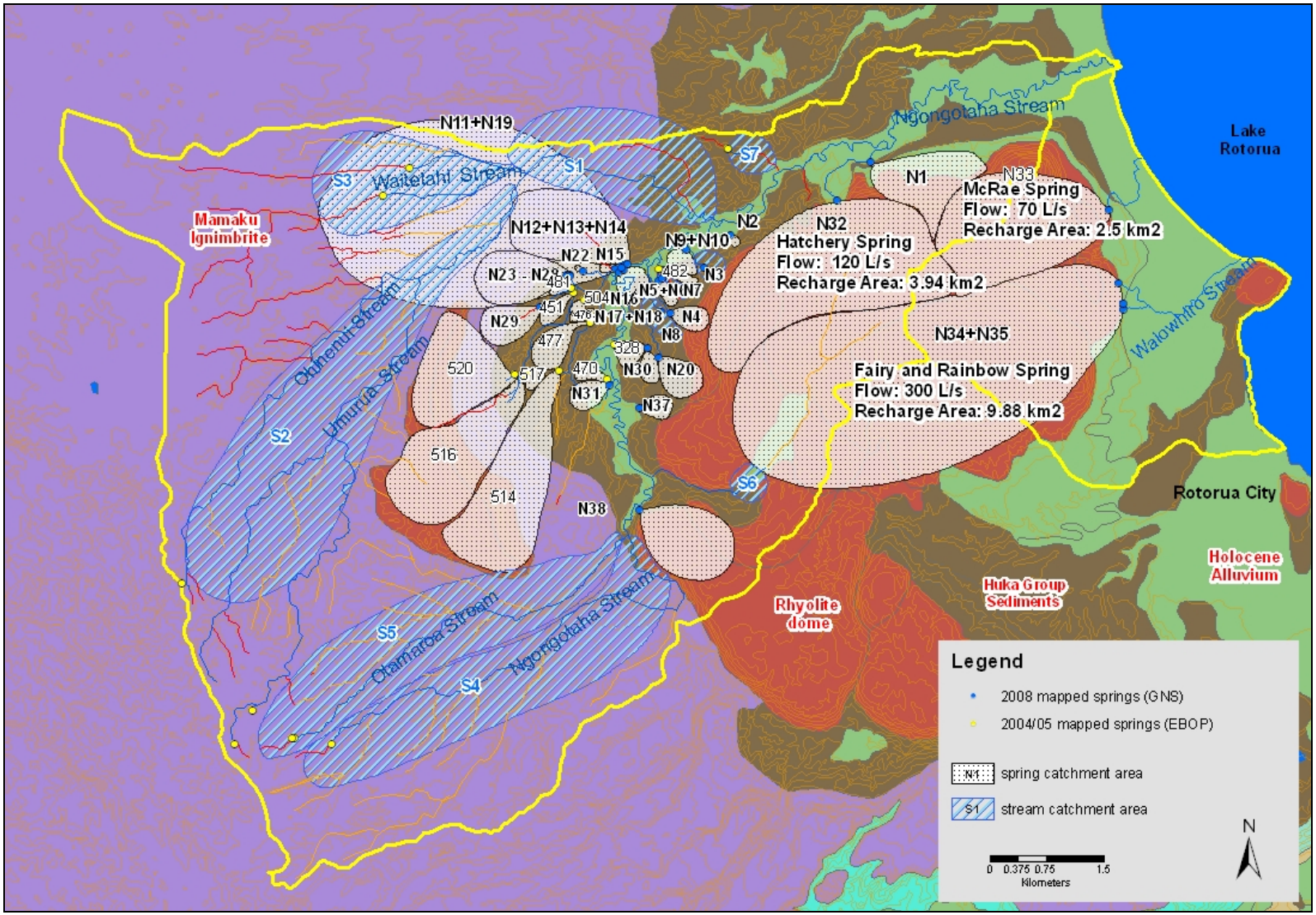


Figure 6.2 Step 1 and Step 2: proposed groundwater catchment of springs and streams in Ngongotaha and Waiowhiro surface catchments.

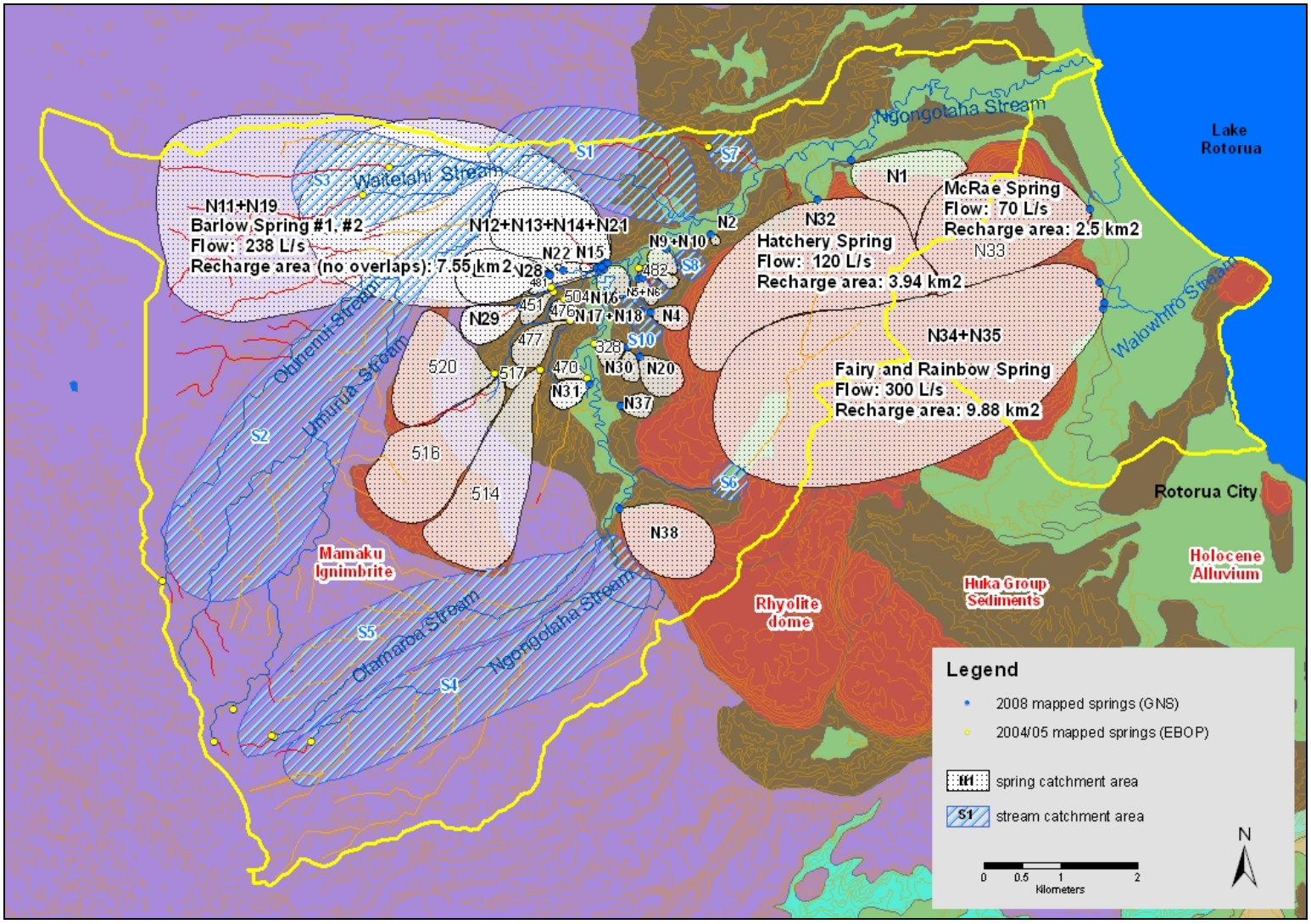


Figure 6.3 Step 3: proposed groundwater catchment of springs and streams in Ngongotaha and Waiowhiro surface catchments with catchments adjusted for overlap.

7.0 SUMMARY

The groundwater catchment is estimated for a total of 50 springs of the Ngongotaha and Waiowhiro catchments. Forty seven springs are located in the Ngongotaha surface catchment and three springs are located in the Waiowhiro surface catchment

Estimated groundwater catchments of the springs in the section A – B reach of Ngongotaha Stream (Figure 3.2) may produce 518 L/s which is similar to the stream baseflow increase (564 L/s) in this reach. This indicates that rainfall recharge to groundwater on the Ngongotaha catchment may support baseflow in the reach A – B of Ngongotaha Stream (Figure 3.2).

The land area of the Waiowhiro catchment is not sufficient to support flow from Fairy, Rainbow and McRae springs. Therefore land from two surrounding surface water catchments may be required to support baseflow in these springs:

- Ngongotaha catchment - to support baseflow in Fairy, Rainbow and McRae springs;
- Utuhina catchment – to support baseflow of Rainbow and Fairy springs;

Land in the Waiowhiro catchment may support spring flow of Hatchery Springs and Maori Spring.

Land in the Waiteti catchment, to the north of Ngongotaha catchment, may support flow in Umurua Stream and Barlows Springs.

8.0 CONCLUSIONS

Conclusions from this study are:

- the current survey has found more springs in the catchment than we previously knew about;
- the land area of Mt Ngongotaha is mostly sufficient to support baseflow in springs around Mt Ngongotaha;
- many small springs are observed in Paradise Valley; flow in many of these springs can be supported by land immediately around the springs;
- groups of large springs (e.g. Barlow Springs) in the Ngongotaha catchment require a relatively large catchment to support their flow; these springs may require a catchment outside the Ngongotaha surface catchment;
- the land of Ngongotaha catchment is mostly sufficient to support baseflow of springs and streams in the Ngongotaha catchment;
- springs in the Ngongotaha catchment may receive recharge from the Waiteti surface catchment north of the Ngongotaha catchment;
- the land area of Waiowhiro catchment is probably not sufficient to support baseflow of Fairy Spring, Rainbow Spring and McRae Spring. Therefore land in the surrounding Ngongotaha surface catchment and Utuhina surface catchment is probably part of the catchments of these springs.

9.0 RECOMMENDATIONS

Following the results of this project we recommend flow measurements and chemical analyses to further refine estimates of catchment boundaries.

Recommendations are ordered from high priority to low priority. All recommended sites are plotted in Figure 9.1.

Spring identification recommendation:

Brad Scott (pers. comm.) mentions that small springs occur on the flanks of Mt Ngongotaha in the Utuhina catchment. These springs are not yet mapped and flows are not measured. The locations of these springs could be identified after approaching local land owners.

Stream flow measurements recommendation:

1. **Ngongotaha Stream** – measurement of Ngongotaha Stream flow above and below group of springs N11 – N19 (stream flow measurement 1 and stream flow measurement 2 on Figure 9.1);

   There is visual evidence of spring inflow directly into Ngongotaha Stream from the stream bed. Significant discharge of groundwater is evident on this section.

   The implications of this measurement could be considerable for the catchments of some springs in Paradise Valley. For example, the area of springs in Paradise Valley where spring flow is assumed (Section 6.2.2.1) to match Ngongotaha Stream flow gain (i.e. the catchments coloured in yellow in Figure 9.2) will reduce if the flow gains in Ngongotaha Stream are greater than present measurements indicate.

Spring flow measurements recommendation:

1. **N1** Maori Spring – flow measurement of this high-flow spring above the confluence with Hatchery Stream, approximately 10 m below the spring itself;
2. **N23, N24, N27, N28** – flow measurement below their confluence. The spring outflows join into one stream approximately 50 m below the spring locations;
3. **Small springs of Ngongotaha Valley** (N2, N3, N4, N5, N6, N7, N8, M9, N10, N16, N17, N18, N20, N30, N31) – revisit sites in summer and measure flow and compare with winter baseflow estimates obtained in this study.

Chemical analyses recommendation:

1. **N1** Maori Spring and **N33** McRae Spring – analyse groundwater from the outflow area to investigate the hypothesis that these high-flow springs have the chemical composition of water from Rotorua young-rhyolite lava (Mt. Ngongotaha) and a similar composition to groundwater from Hatchery Spring, McRae Spring, Fairy Spring and Rainbow Spring;

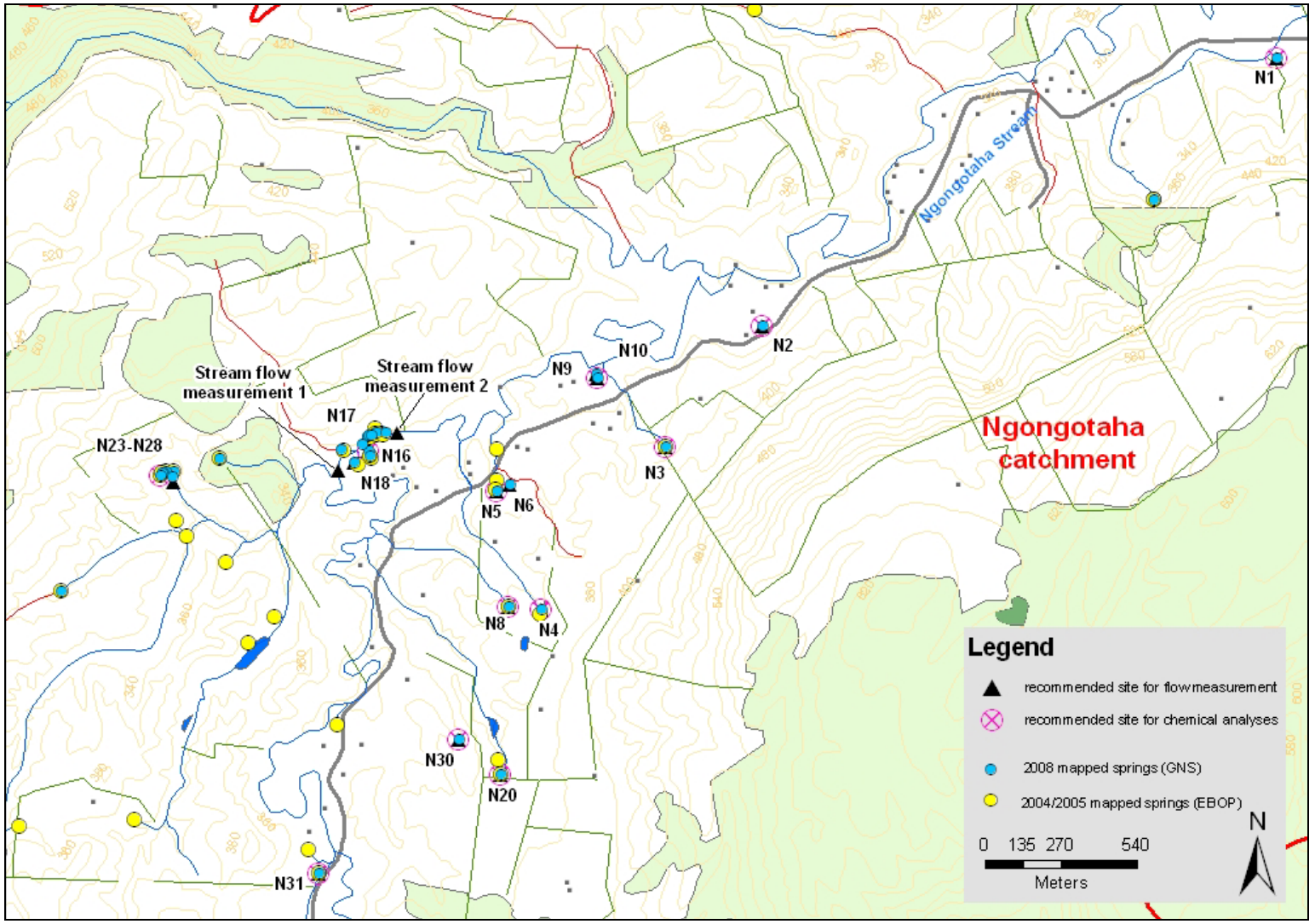


Figure 9.1 Location of recommended sites for flow measurement and chemical analyses.

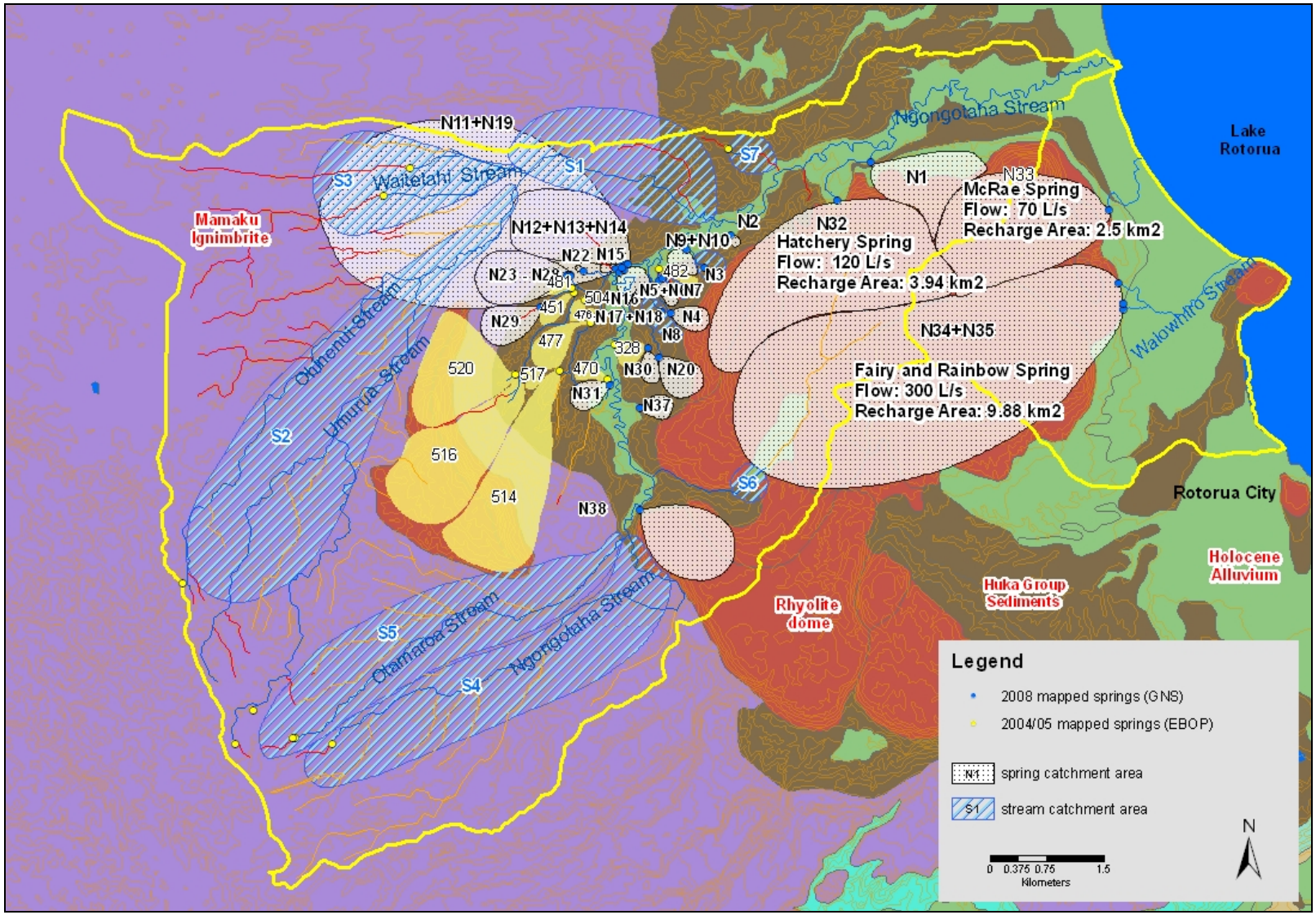


Figure 9.2 Location of possible spring catchments (yellow) where the flow is assumed to sum to 371 L/s (Section 6.2.2.1).

2. **N23, N24, N25, N26, N27, N28** – analyse groundwater chemistry from one of these springs to investigate the hypothesis that groundwater comes from Mamaku Ignimbrite;
3. **N4** spring – analyse groundwater from the outflow area to investigate the hypothesis that groundwater comes from Rotorua Young TVZ rhyolite lava or from Huka Group sediments;
4. **Small springs of Ngongotaha Valley** (N2, N3, N4, N5, N6, N7, N8, N9, N10, N16, N17, N18, N20, N30, N31) – analyse nitrate in spring discharge to identify nitrate concentrations in springs with relatively small catchments and compare with nitrate concentrations in springs with relatively large catchments.

10.0 ACKNOWLEDGEMENTS

Our thanks go to land owners in Paradise Valley who provided access to springs. Funding for this project was provided by GNS Science and by University of Waikato through their Lakes Protection Programme, led by Prof. David Hamilton.

Thanks also to Gil Zemansky, GNS Science for providing useful comments on a draft of this report and to Constanze Tschritter, GNS Science for drafting some figures.

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APPENDICES

APPENDIX 1 PHOTOGRAPHIC DOCUMENTATIONS OF SPRINGS OF NGONGOTAHA SURFACE CATCHMENT AND WAIOWHIRO SURFACE CATCHMENT IDENTIFIED BY HYDROGEOLOGICAL MAPPING IN JUNE - JULY 2008

This Appendix presents photographs of springs in the Ngongotaha catchment and, the Waiowhiro catchment west of Lake Rotorua.

The observed spring information (X, Y, Z position, type of outflow, spring yield, access etc.) are summarised Appendix 2.

These springs are observed by Erika Kovacova and Peter Tucek, GNS Science, in periods:

- 18 and 19 June 2008 observed by E. Kovacova;
- 03 and 04 July 2008 observed by E. Kovacova and P. Tucek;
- 28 and 29 July 2008 observed by E. Kovacova and P. Tucek.

SPRING N1: MAORI SPRING, NGONGOTAHA CATCHMENT

Figure N1.1 Maori Spring at Paradise Valley Road, part of the outflow, looking south.

Figure N1.2 Maori Spring at Paradise Valley Road, another part of the outflow, looking south.

Figure N1.3 Confluence of Maori Spring with Hatchery Spring stream, 20 m from outflow.

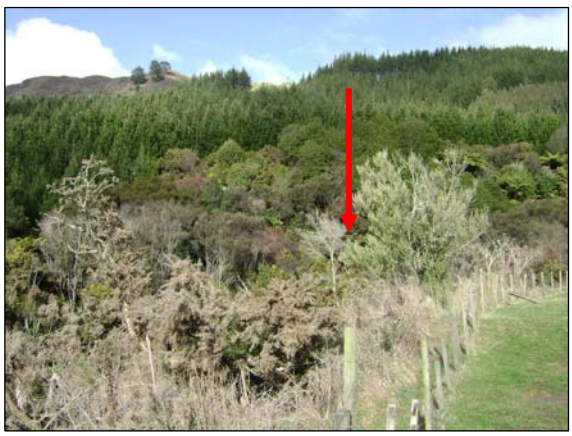

Figure N1.4 Maori Spring from Paradise Valley Road, looking south.

SPRING N2: HEATHER FARM SPRING, NGONGOTAHA CATCHMENT

Figure N2.1 Spring outflow in Heather Farm, Paradise Valley Road, looking north.

Figure N2.2 Spring outflow in Heather Farm, Paradise Valley Road, looking west.

Figure N2.3 Name of the farm where spring is located, Paradise Valley Road, looking north.

SPRING N3: NO NAME, NGONGOTAHA PARADISE VALLEY ROAD

Figure N3.1 Location spring in farm land, Paradise Valley Road, looking south-east.

Figure N3.2 Outflow area of spring, Paradise Valley Road, looking north-west.

Figure N3.3 Concrete pipe across the Paradise Valley Road, approximately 200 m from spring.

Figure N3.4 Concrete pipe across the Paradise Valley Road, approximately 200 m from spring.

SPRING N4: NO NAME, NGONGOTAHA CATCHMENT

Figure N4.1 Spring outflow area, looking north-west from gravel road.

Figure N4.2 Spring outflow in boggy vegetation, looking upstream south-west.

Figure N4.3 Spring flow hidden in boggy vegetation, 10 m from spring, looking downstream north-east.

Figure N4.4 Spring flow hidden in boggy vegetation, 30 m from spring, looking upstream south-west.

SPRING N5 AND SPRING N6: NO NAME, NGONGOTAHA CATCHMENT

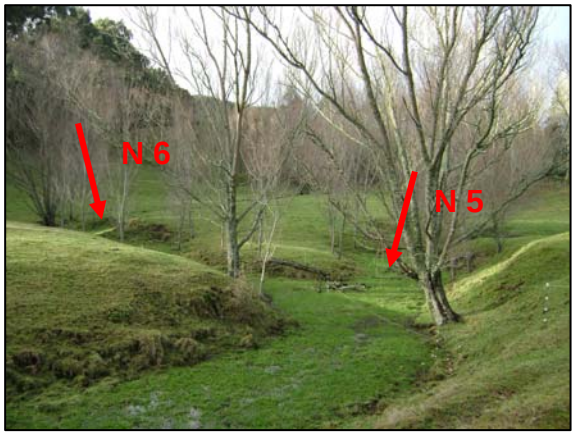

Figure N5.1 Outflow area of spring N5 and spring N6, Paradise Valley Road, looking south-east.

Figure N5.2 Outflow of N5 spring, Paradise Valley Road, looking south-east.

Figure N5.3 Outflow area of spring N6, Paradise Valley Road, looking south-east.

Figure N5.4 Outflow of N6 spring, Paradise Valley Road, looking south-east.

SPRING N7: NO NAME, NGONGOTAHA CATCHMENT

Figure N7.1 Temporary stream flow at Paradise Valley Road, approximately 20 m left from spring N6, looking south-east.

Figure N7.2 Location of flow measurement place of temporary flow (4 July 2008 by E. Kovacova and P. Tucek, Appendix 2).

SPRING N8: NO PICTURE, NO ACCESS, NGONGOTAHA CATCHMENT

SPRING N9 AND SPRING N10: NO NAME, NGONGOTAHA CATCHMENT

Figure N9.1 Outflow area of spring N9 and spring N10, Paradise Valley Road, looking south-west.

Figure N9.2 Outflow area of spring N9 and spring N10, Paradise Valley Road, looking north-east.

Figure N9.3 Spring N9 and spring stream, Paradise Valley Road, looking north-west.

Figure N9.4 Outflow of spring N10, Paradise Valley Road, looking south-west.

Figure N9.5 Mt. Rangihakahaka view from location of spring N9 and spring N10, looking south-east.

SPRING N11: BARLOW SPRING #1 , NGONGOTAHA CATCHMENT

Figure N11.1 Barlow Spring # 1: Paradise Valley Road, looking north.

Figure N11.2 Barlow Spring # 1 outflow with pump, Paradise Valley Road, looking north-west.

Figure N11.3 Barlow Spring # 1 outflow, Paradise Valley Road, looking north.

Figure N11.4 Outcrop and gravel road above Barlow Spring # 1 outflow, looking west.

SPRING N12: NO NAME, NGONGOTAHA CATCHMENT

Figure N12.1 Spring outflow area includes 3 outflow points of spring N12, from Ngongotaha stream bank, Paradise Valley Road, looking north.

Figure N12.2 First outflow point of spring N12, heading downstream of Ngongotaha, Stream, Paradise Valley Road, looking north.

Figure N12.3 Second outflow point of spring N12, heading downstream of Ngongotaha. Stream, Paradise Valley Road, looking north.

Figure N12.4 Third outflow point of spring N12, heading downstream of Ngongotaha Stream, Paradise Valley Road, looking north.

SPRING N13: NO PICTURE, NGONGOTAHA CATCHMENT

SPRING N14: NO NAME, NGONGOTAHA CATCHMENT

Figure N14.1 Spring outflow area hidden in vegetation, from Ngongotaha river bank, Paradise Valley Road, looking north.

SPRING N15: NO NAME, NGONGOTAHA CATCHMENT

Figure N15.1 Plastic drain pipe with spring flow from soil bank, Paradise Valley Road, looking west.

Figure N15.2 Soil bank from other side with boggy spring area, looking east.

SPRING N16: NO NAME, NGONGOTAHA CATCHMENT

Figure N16.1 Pond with outflow, approximately 20 m from Ngongotaha Stream, looking east.

SPRING N17: NO NAME, NGONGOTAHA CATCHMENT

Figure N17.1 Swampy area with outflow, beside spring N16, looking west.

Figure N17.2 Confluence of spring N16 and spring N17 with Ngongotaha Stream, looking east.

SPRING N18: NO NAME, NGONGOTAHA CATCHMENT

Figure N18.1 Pond with outflow, approximately 20 m from Ngongotaha Stream.

Figure N18.2 Pond with outflow, approximately 20 m from Ngongotaha Stream, looking north-east.

SPRING N19: BARLOW SPRING # 2, NGONGOTAHA CATCHMENT

Figure N19.1 Barlow Spring # 2 at the confluence with Ngongotaha Stream, outflow from stream bank is located approximately 8 m from Ngongotaha Stream, looking north.

SPRING N20: STREAM OF SPRING N20, NGONGOTAHA CATCHMENT

Figure N20.1 Stream of spring N20, crossing Paradise Valley Road, looking south–east. "Black Forest" private property.

SPRING N21: NGONGOTAHA STREAM BED SPRING, NGONGOTAHA CATCHMENT

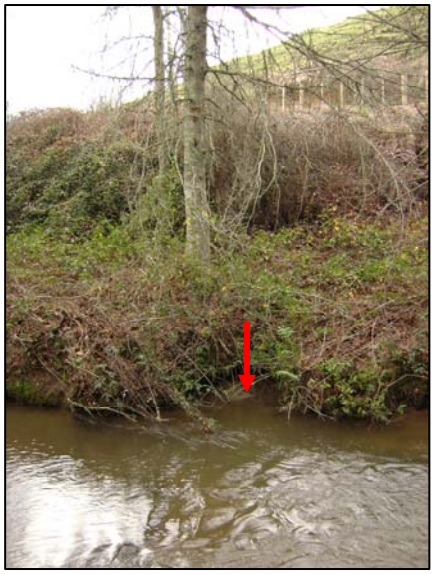

Figure N21.1 Spring emerges from Ngongotaha Stream bed, looking north.

Figure N21.2 Detail of stream bed outflow, looking north.

SPRING N22: NO NAME, NGONGOTAHA CATCHMENT

Figure N22.1 Spring outflow, looking north-west.

SPRING N23–N27: SPRING AREA OF N23, N24, N25, N26, N27, N28, NGONGOTAHA CATCHMENT.

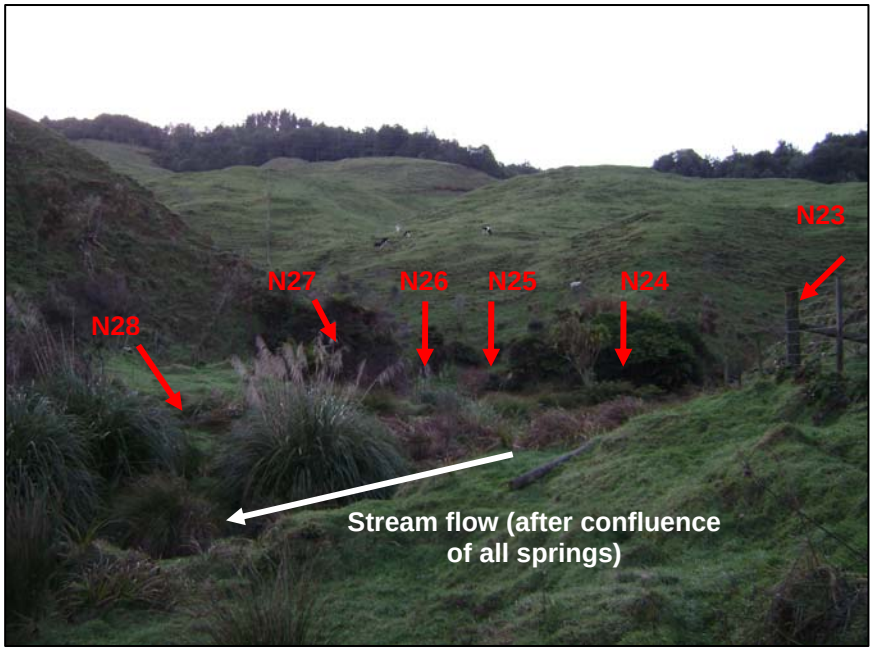

Figure N23.1 Spring outflow area of N23, N24, N25, N26, N27, N28 springs, looking north - west. Spring N28 is located approximately 20 m below other springs.

SPRING N28: NO NAME, NGONGOTAHA CATCHMENT

Figure N28.1 Spring outflow, looking west. Bubbling outflow is making dancing sand.

SPRING N29: NO NAME, NGONGOTAHA CATCHMENT

Figure N29.1 Spring outflow, looking south-west.

SPRING N30: NO PICTURE, NGONGOTAHA CATCHMENT

SPRING N31: NO NAME, NGONGOTAHA CATCHMENT

Figure N31.1 Spring outflow, looking south–west approximately 10 m from Paradise Valley Road.

SPRING N32: HATCHERY SPRING, NGONGOTAHA CATCHMENT

Figure N32.1 Hatchery Springs flow in Fish and Game breeding hatchery, at Paradise Valley Rd. looking south-east.

Figure N32.2 Major Hatchery Spring outflow from steep hillside of Mt. Ngongotaha, at Paradise Valley Rd. looking south-east.

SPRING N33: MCRAE SPRING, WAIOWHIRO CATCHMENT

Figure N33.1 McRae Spring on Ngongotaha Road, looking upstream and south (Observed by E. Kovacova and P. Tucek, 4 July 2008).

Figure N33.2 Springs at S6 block, on Ngongotaha Road, looking north (Observed by Sally Grant, GNS Science, 6 December 2004, in Reeves 2005).

The following springs are observed by Erika Kovacova, GNS Science, on 18 June 2008.

SPRING N34: FAIRY SPRING, WAIOWHIRO CATCHMENT

Figure N34.1 Fairy Spring and start of flow of Waiowhiro Stream, looking east. The spring is located approximately 250 m north from Rainbow Spring in the Rainbow Springs Natural Park area, Fairy Springs Rd, Rotorua.

Figure N34.2 Fairy Spring and start of flow of Waiowhiro Stream, looking north. The spring is located approximately 250 m north from Rainbow Spring in the Rainbow Springs Natural Park area, Fairy Springs Rd, Rotorua.

Figure N34.3 Fairy Spring bottom outflow, looking west. The spring is located approximately 250 m north from Rainbow Spring at Rainbow Springs Natural Park area, Fairy Springs Rd, Rotorua.

SPRING N35: RAINBOW SPRING, WAIOWHIRO CATCHMENT

Figure N35.1 Rainbow Spring at Rainbow Springs Nature Park, looking south-west, Fairy Springs Rd, Rotorua.

Figure N35.2 Rainbow Spring at Rainbow Springs Nature Park, looking south-east, Fairy Springs Rd, Rotorua.

SPRING N36: SPRING NEXT TO THE RAINBOW SPRING, WAIOWHIRO CATCHMENT

Figure N36.1 Spring approximately 30 m south from Rainbow Spring at Rainbow Springs Nature Park. The spring emerges from bottom of trout water viewing pool, looking south-west, Fairy Springs Rd, Rotorua.

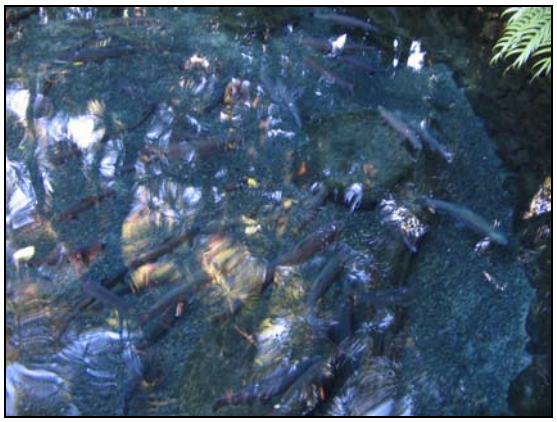

Figure N36.2 Spring approximately 30 m south from Rainbow Spring at Rainbow Springs Nature Park, looking south, Fairy Springs Rd, Rotorua.

APPENDIX 2 FIELD DATA OBSERVED FROM HYDROGEOLOGICAL MAPPING OF SPRINGS IN NGONGOTAHA SURFACE CATCHMENT AND WAIOWHIRO SURFACE CATCHMENT, 2008

Table A2.1 Field data observed by Erika Kovacova and Peter Tucek, GNS Science. Note: Observations on 28-29.07.2008 was after a period of large rainfall (2 weeks of rain). Flow measured in this period is greater than baseflow because of rain.

Spring ID	EBOP ID	X	Y	Elevation (m)	Name of Spring	Spring type	Outflow type	Geomorphology	Geology at outflow	Stream (Right or Left side inflow into)	Main stream (catchment)	Flow measurement method	Spring flow (L/s)	Date of measurement	T (ºC)	pH	Conductivity (µS/cm)	Photo ID (in App 1)	Comments	Mapped by
N1	no mapped before	2789239	6340537	293	"Maori Spring"	Fracture/Fault spring	areal outflow (10x5m)	foot of Mt. Ngongotaha or terrace?	Rotorua Young-TVZ rhy lava	R inflow into Hatchery Spring stream	Ngongotaha	Visual estimate	**25.00**	03.07.2008	11.2	6.6	74	N1	Spring is situated 50 m from the Paradise Valley Road and approximately 500 m from Hatchery Spring in west-east direction. Outflow is hidden in boggy vegetation. Stream flow measurement can by easily done with hydrometric propeller, 20 m from outflow before the confluence with Hatchery Spring stream.	P. Tucek E. Kovacova
N2	no mapped before	2787404	6339576	308	"Awaroa Farm Spring"	talus spring	areal outflow (5x10m)	foot of Mt. Ngongotaha	Huka group sediments	Ngongotaha; R inflow	Ngongotaha	Spot measurement	**0.83**	03.07.2008				N2	Spring is located at Awaroa Farm; 10 m from the road. Name of owner: Neil Heather, Owner contact: 3574 517.	P. Tucek E. Kovacova
N3	435	2787061	6339141	345	no name	talus-fracture spring	spot outflow	end of soft valley, foot of Mt. Ngongotaha	Rotorua Young-TVZ rhy lava	Ngongotaha; R inflow	Ngongotaha	Spot measurement	**3.97**	03.07.2009				N3	Spring is located app. 200 m from Paradise Valley Road looking south-east. Concrete pipe across the Paradise Valley Road. Measurement made across the road, on stream, flow greater than baseflow due rainy period.	P. Tucek E. Kovacova
N4	436	2786619	6338557	362	no name	talus spring	areal outflow (10x20m)	end of soft valley, pasture land	Huka group sediments or rhyolite lava?	Ngongotaha; R inflow	Ngongotaha	Visual estimate	**4.00**	03.07.2008	13.2	6.4	65	N4	Spring is located in boggy vegetation app. 40 m on right side from gravel road which is heading from Paradise Valley Road. From Paradise Valley Road heading west turn left at "Duncan" sign, #816. Fence around spring outflow.	P. Tucek E. Kovacova
N5	324	2786461	6338983	322	no name	talus spring	areal outflow (3x6m)	not steep hill of Ngongotaha	Huka group sediments	Ngongotaha; R inflow	Ngongotaha	Visual estimate	**1.25**	03.07.2008				N5	Spring is located in "Duncan" farm, #816, app. 40 m from Ngongotaha Valley Road looking south-east. Good visible from the road.	P. Tucek E. Kovacova
N6	323	2786505	6339005	326	no name	talus spring	areal outflow (3x5m)	not steep hill, below pasture land	Huka group sediments	Ngongotaha; R inflow	Ngongotaha	Visual estimate	**1.25**	03.07.2008				N6	Spring is located in "Duncan" farm, #816, app. 40 m from Ngongotaha Valley Road looking south-east. Visible from the road. Spring N6 is located app. 30 m from the spring N5.	P. Tucek E. Kovacova
N7	dry bed before				no name	temporary spring		foot of Ngongotaha hill	Huka group sediments or rhyolite lava?	Ngongotaha; R inflow	Ngongotaha	Spot measurement	**1.85**	03.07.2008				N7	Spring flow is located just 20 m left from spring N6, visible from Paradise Valley Road looking south-east. This is probably a temporary spring, flowing only in rainy periods and dry in summer. Measurement made above the road, on stream.	P. Tucek E. Kovacova

Spring ID	EBOP ID	X	Y	Elevation (m)	Name of Spring	Spring type	Outflow type	Geomorphology	Geology at outflow	Stream (Right or Left side inflow into)	Main stream (catchment)	Flow measurement method	Spring flow (L/s)	Date of measurement	T (ºC)	pH	Conductivity (µS/cm)	Photo ID (in App 1)	Comments	Mapped by
N8	437	2786500	6338568	360	no name			foot of Ngongotaha hill	Huka group sediments or rhyolite lava?	Ngongotaha; R inflow	Ngongotaha	Spot measurement	**5.84**	28.07.2008	9.4	6.5	65	no picture	Volumetric measurement made below the road, on stream. No outflow had been seen (private property, no access found).	P. Tucek E. Kovacova
N9	no mapped before	2786001	6339182	315	no name	talus-fracture spring	spot outflow	Ngongotaha Stream valley, almost flat backyard	Holocene alluvial sediments	Ngongotaha; R inflow	Ngongotaha	Spot measurement	**0.33**	04.07.2008				N9	Spring is located in private farm yard app. 100 m from the owners house and app. 70 m from Paradise Valley Road, looking north. Number of house: 865. Spring is water supply for owners.	P. Tucek E. Kovacova
N10	no mapped before	2786011	6339185	317	no name	talus-fracture spring	spot outflow	Ngongotaha Stream valley, almost flat backyard	Holocene alluvial sediments	Ngongotaha; R inflow	Ngongotaha	Spot measurement	**2.21**	04.07.2008				N10	Spring is located in private farm yard app 100 m from the owners house and app. 70 m from Paradise Valley Road, looking north. Number of house: 865. Spring is water supply for owners.	P. Tucek E. Kovacova
N11	468?	2786026	6339206	318	Barlow Spring # 1	fracture spring	spot outflow	bank foot	Mamaku pyroclastics - Ignimbrite with pumice inclusions	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**58.00**	Estimated in 1973-74 (App. 8 in White et al. 2007)	10.8	6.2	74	N11	Spring is located at Ngongotaha Stream bank, just below gravel road. Turn right from Paradise Valley Road heading west at number 801 at the "Paradise Cottages" sign. Continue until first bridge and walk on gravel road from this bridge upstream of Ngongotaha Stream. After app 80 m Barlow Spring # 1 is located, with access steel gate and concrete stairs. Outflow on river bank app. 10 m from spring.	P. Tucek E. Kovacova
N12		2786011	6339185	317	no name	fracture spring	contour outflow in spring line 2 m	bank foot	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**20.00**	04.07.2008				N12	Spring line of 4 outflow points of one spring, 1 m interval between each outflow. Located app. 3 m upstream from spring N 11, at Ngongotaha Stream bank. Use the same access as for Barlow Spring #1 (N11).	P. Tucek E. Kovacova
N13		2786001	6339182	315	no name	fracture spring	spot outflow	bank foot	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**5.00**	04.07.2008				N13	Spring is located app. 5 m upstream from Barlow Spring #1 , at Ngongotaha Stream bank. Use the same access as for Barlow Spring # 1 (N11).	P. Tucek E. Kovacova
N14		2785997	6339177	316	no name	fracture spring	spot outflow	bank foot	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**0.80**	04.07.2008				N14	Spring is located app. 8 m upstream from Barlow Spring #1 , at Ngongotaha Stream bank. Use the same access as for Barlow Spring # 1 (N11).	P. Tucek E. Kovacova
N15	458	2785905	6339130	312	no name	fracture spring	spot outflow	end of soft valley, below pasture land	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Spot measurement	**0.76**	04.07.2008				N15	Spring is located after the end of gravel road (access as to springs N11, N12, N13, N14), upstream. Plastic pipe set in soil bank is used to drain water from small valley.	P. Tucek E. Kovacova

Spring ID	EBOP ID	X	Y	Elevation (m)	Name of Spring	Spring type	Outflow type	Geomorphology	Geology at outflow	Stream (Right or Left side inflow into)	Main stream (catchment)	Flow measurement method	Spring flow (L/s)	Date of measurement	T (ºC)	pH	Conductivity (µS/cm)	Photo ID (in App 1)	Comments	Mapped by
N16	460	2786000	6339124	312	no name	talus spring	areal outflow (10x10m)	Ngongotaha Stream valley, almost flat backyard	Holocene alluvial sediments	Ngongotaha; R inflow	Ngongotaha	Visual estimate	**0.80**	04.07.2008	7.8	6.2	92	N16	Spring is located app. 20 m from Ngongotaha Stream bank, looking east. Pond with outflow situated on opposite side across Ngongotaha Stream where Barlow Spring # 1 is located.	P. Tucek E. Kovacova
N17	461	2786006	6339110	320	no name	talus spring	spot outflow	terrace of Ngongotaha river?	Holocene alluvial sediments	Ngongotaha; R inflow	Ngongotaha	Visual estimate	**2.50**	04.07.2008	10.5	6.2	75	N17	Spring is located app. 10 m from Ngongotaha Stream bank, looking east and app. 10 m below spring N16. Flow joins stream of N16 after 2 m and after another app. 8 m stream flows into Ngongotaha Stream.	P. Tucek E. Kovacova
N18	456	2785952	6339082	315	no name	talus spring	areal outflow (10x20m)	Ngongotaha Stream valley, almost flat backyard	Holocene alluvial sediments	Ngongotaha; R inflow	Ngongotaha	Visual estimate	**2.50**	04.07.2008	10.4	6.1	75	N18	Spring is located app. 60 m from spring N16 heading upstream of Ngongotaha Stream and app. 20 m from Ngongotaha Stream bank, looking south-east. Outflow is to a pond. Below pond several bottom springs bubbling from sand (2 or more).	P. Tucek E. Kovacova
N19	469	2786060	6339207	317	Barlow Spring # 2	fracture spring	spot outflow	bank foot	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**180.00**	Estimated in 1973-74 (App. 8 in White et al. 2007)				N19	Spring is located app. 10 m from Barlow spring # 1, heading downstream of Ngongotaha Stream. Is visible from opposite side of the river. Outflow from river bank is hidden in vegetation, app. 8 m from flow with no good access.	P. Tucek E. Kovacova
N20	454, 455	2786471	6337964	360	no name			end of soft valley, below pasture land	Huka group sediments or rhyolite lava?	Ngongotaha; R inflow	Ngongotaha	Visual estimate	**8.00**	04.07.2008	9.8	6.4	70	N20	Visual estimate of measurement made near the road. ("Black Forest" wooden table).	P. Tucek E. Kovacova
N21	not mapped before	2785980	6339147	elevation of Ngongotaha Stream bed	River Bed Spring		river bed outflow	stream bed	Mamaku pyroclastics - Ignimbrite	inflow into Ngongotaha Stream directly from the bed	Ngongotaha	impossible make visual estimate	impossible to estimate	04.07.2008				N21	Spring is located in stream bed of Ngongotaha Stream app. 50 m from Spring N14 upstream of river. Spring is bubbling and is visible from the other side of the river, from river bank. Impossible to make measurement of flow.	P. Tucek E. Kovacova
N22	512	2785470	6339099	336	no name	contact spring	spot outflow	end of soft valley, below pasture land	Huka group sediments	Ngongotaha; L inflow	Ngongotaha	Spot measurement	**0.15**	28.07.2008	9.1	6.7	41	N22	Spring is located app. 500 m west from N15, at the end of valley, below the pasture land. There are more, smaller, outflow points around the main spring. Mapped after a period of high rainfall, notice that flow is greater than base flow.	P. Tucek E. Kovacova
N23	511	2785306	6339054	340	no name	contact spring	spot outflow	end of soft valley, below pasture land	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**7.00**	28.07.2008	11.0	6.6	68	N23-N27	Springs are located in a line width app. 50 m with 5 other springs(N23-N27). Spring area is located app. 200 m south-west from spring N22. Spring N23 is the first spring from the east. Outflow is hidden in vegetation.	P. Tucek E. Kovacova

Spring ID	EBOP ID	X	Y	Elevation (m)	Name of Spring	Spring type	Outflow type	Geomorphology	Geology at outflow	Stream (Right or Left side inflow into)	Main stream (catchment)	Flow measurement method	Spring flow (L/s)	Date of measurement	T (ºC)	pH	Conductivity (µS/cm)	Photo ID (in App 1)	Comments	Mapped by
N24	510	2785265	6339047	339	no name	contact spring	areal outflow (10x2m)	end of soft valley, below pasture land	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**3.00**	28.07.2008				N23-N27	Springs are located in a spring line in width app 50 m with 5 springs (N23-N27). Spring area is located app 200m south-west from N22. Spring N24 is the second spring from the east. Outflow is aeral (10x2m) and hidden in vegetation.	P. Tucek E. Kovacova
N25	509	2785259	6339040	339	no name	contact spring	spot outflow	end of soft valley, below pasture land	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Spot measurement	**0.61**	28.07.2008	11.0	6.6	68	N23-N27	This spring is located in a spring line width app 50 m with 5 springs (N23-N27). Spring area is located app 200m south-west from N22. Spring N25 is the third spring from the east.	P. Tucek E. Kovacova
N26	509	2785259	6339040	339	no name	contact spring	spot outflow	end of soft valley, below pasture land	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Spot measurement	**1.19**	28.07.2008	11.3	6.5	68	N23-N27	This spring is located in a spring line in width app. 50 m with 5 springs (N23-N27). Spring area is located app. 200m south-west from spring N22. Spring N26 is the fourth spring from the east.	P. Tucek E. Kovacova
N27	508	2785278	6339051	340	no name	contact spring	spot outflow	end of soft valley, below pasture land	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**5.00**	28.07.2008	11.2	6.3	68	N23-N27	This spring is located in a spring line in width app. 50 m with 5 springs (N23-N27). Spring area is located app 200m south-west from N22. Spring N27 is the fifth spring from the east.	P. Tucek E. Kovacova
N28	no mapped before	2785301	6339034		no name	contact spring	spot outflow	end of soft valley, below pasture land	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**3.00**	28.07.2008	11.0	6.4	74	N28	Spring is located app. 20 m below N23-N27 spring area. The spring is bubbling from the bottom - dancing sand.	P. Tucek E. Kovacova
N29	505	2784905	6338623	341	no name	contact spring	spot outflow	end of soft valley, below pasture land	Mamaku pyroclastics - Ignimbrite	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**10.00**	28.07.2008	11.6	6.3	45	N29	Spring is located in the next valley east of N23-N27 spring area, in pasture land.	P. Tucek E. Kovacova
N30	no mapped before				no name	temporary spring		no outflow was seen	Huka group sediments	Ngongotaha; R inflow	Ngongotaha	Visual estimate	**3.00**	28.07.2009	7.5	6.6	62	no picture	Spring is located in smooth valley on private property. Stream is crossing the Paradise Valley Road. Flow measured on stream, across the road. Flow is greater than baseflow due to rain. Swampy areas around.	P. Tucek E. Kovacova
N31	471	2785823	6337609	340	no name			end of soft valley, on pasture land	Holocene alluvial sediments	Ngongotaha; L inflow	Ngongotaha	Visual estimate	**5.00**	28.07.2010	10.9	6.1	68	N31	Spring is located app. 80 m above the place where Ngongotaha Stream crosses Paradise Valley Road and app. 30 m west of road. Flow increase in distance of 50 m from measured 0.3 L/s to app. 5 L/s.	P. Tucek E. Kovacova

Spring ID	EBOP ID	X	Y	Elevation (m)	Name of Spring	Spring type	Outflow type	Geomorphology	Geology at outflow	Stream (Right or Left side inflow into)	Main stream (catchment)	Flow measurement method	Spring flow (L/s)	Date of measurement	T (ºC)	pH	Conductivity (µS/cm)	Photo ID (in App 1)	Comments	Mapped by
N32	382, 398	2788800	6340025	326	Hatchery Spring	contact spring?	few spot outflows	steep hillside of Mt. Ngongotaha	Rotorua Young-TVZ rhy lava	R inflow into Ngongotaha River	Ngongotaha	Spot measurement	**120.00**	Estimated in 1973-74 (App. 8 in White et al. 2007)				N32	Springs are situated in Fish and Game breeding hatchery, at Paradise Valley Rd. All emerge from steep hillside of Mt. Ngongotaha, behind the trout pools, looking south-east. The main spring emerges in elevation 326 m asl, but there are 2, maybe more, springs seeping around main spring at different elevations.	E. Kovacova
N33	389	2792324	6340000	283	Mc Rae Spring	contact spring?	4 outflow points of spring	not steep hill of Ngongotaha	Rotorua Young-TVZ rhy lava	L inflow into Waikuta Stream	Waiowhiro	Spot measurement	**70.00**	Estimated in July 2006 (App. 8 in White et al. 2007)	11.5	6.6	79	N33	Spring is located at farm called the S6 block, on Ngongotaha Road. Spring emerges in 4 outflow points (Observed by Sally Grant GNS Science, on 6 December 2004, Reeves, 2005)	P. Tucek E. Kovacova
N34	386	2792492	6338939	303	Fairy Spring	contact spring?	areal bottom outflow	foot of Mt. Ngongotaha	Rotorua Young-TVZ rhy lava	Spring and start of flow of Waiowhiro stream	Waiowhiro	Spot measurement	**confluence 300**	Estimated 1972-73,2004-05,06 (App. 8. in White et al. 2007)				N34	Spring is located app. 250 m north from Rainbow Spring at Rainbow Springs Natural Park area. Spring and start of flow of Waiowhiro stream.	E. Kovacova
N35	384	2792562	6338671	296	Rainbow Spring	contact spring?	areal bottom outflow	foot of Mt. Ngongotaha	Rotorua Young-TVZ rhy lava	P inflow into Waiowhiro Stream	Waiowhiro							N35	Spring is located at Rainbow Springs Natural Park area, 10 m ahead of the entry door in the park, heading west. Spring emerges from bottom of trout water viewing pool.	E. Kovacova
N36	385	2792547	6338598	301	next to Rainbow spring	contact spring?	areal bottom outflow	foot of Mt. Ngongotaha	Rotorua Young-TVZ rhy lava	P inflow into Waiowhiro Stream	Waiowhiro	No estimate						N36	Spring is located app. 80 m south from Rainbow Spring at Rainbow Springs Natural Park area. Spring emerges from bottom of trout water viewing pool and can be see in the glass viewer in front of pool.	E. Kovacova
N37		2786220	6337318		Te Waireka Spring				Huka group sediments	Ngongotaha; R inflow	Ngongotaha	Spot measurement	**3.00**	Estimated in July 2006 (App. 8. in White et al. 2007)						
N38		2786267	6336140		Paradise Valley Spring				Mamaku pyroclastics - Ignimbrite	Ngongotaha; R inflow	Ngongotaha	Spot measurement	**30.00**	Estimated in July 2006 (App. 8 in White et al. 2007)						

APPENDIX 3 LOCATION AND ELEVATION OF SPRINGS AND SEEPS MAPPED BY EBOP IN 2004/2005 (FROM WHITE ET AL. 2007)

Easting	Northing	Spring and seep feature number	Estimated elevation (m)	Notes	Catchment
2786461	6339020	323	322	Fork, left hand side dry bog, right hand side very moist bog	Ngongotaha
2786454	6338988	324	325	Start of flow out of the bog	Ngongotaha
2785889	6338140	328	321	Start of flow into boggy area	Ngongotaha
2782849	6340093	339	519	Flowing, spring from bank. Dry above according to farmer	Ngongotaha
2783193	6340451	340	500	Spring, start of flow	Ngongotaha
2781152	6333355	346	640	Spring start of flow for left hand channel	Ngongotaha
2781691	6332996	348	640	Spring, start of flow	Ngongotaha
2781661	6333003	349	640	Very wet bog, multiple springs	Ngongotaha
2782178	6332925	350	640	Spring/bog, very moist, start of flow	Ngongotaha
2780902	6332925	352	652	Fork, wet bog (possible start of flow)	Ngongotaha
2780226	6335027	361	619	Spring below road (start of flow according to farmer)	Ngongotaha
2788800	6340025	382	326	Fish and Game breeding hatchery, multiple seeps from bank including large spring and main source of flow	Ngongotaha
2792562	6338671	384	296	Spring in first pool at Rainbow Springs	Waiowhiro
2792547	6338598	385	301	Spring in under water viewing pool at Rainbow Springs	Waiowhiro
2792492	6338939	386	303	Spring and start of flow at Fairy Springs.	Waiowhiro
2792370	6339896	389	295	Spring and start of flow (pump station beside spring)	Waiowhiro
2787379	6340709	395	351	Just above main spring (of many in area)	Ngongotaha
2788800	6340025	398	326	Couldn't climb any higher but at least one spring approx 10 meters higher	Ngongotaha
2787061	6339141	435	345	Spring	Ngongotaha
2786612	6338537	436	360	Spring	Ngongotaha
2786500	6338568	437	360	Spring	Ngongotaha
2787379	6340709	450	351	On hill just above main spring, other small seeps in area	Ngongotaha
2785354	6338820	451	320	Flowing from both with addition swampy area to north	Ngongotaha
2786471	6337964	454	360	Spring	Ngongotaha
2786463	6338017	455	360	Spring	Ngongotaha
2785964	6339076	456	320	Pond with outflow	Ngongotaha
2785912	6339128	458	319	Spring	Ngongotaha
2786012	6339099	460	320	Pond with outflow	Ngongotaha
2786006	6339110	461	320	Spring	Ngongotaha
2786009	6339174	463	321	Spring	Ngongotaha
2786024	6339204	464	323	Spring	Ngongotaha
2786026	6339186	465	321	Spring	Ngongotaha
2786030	6339181	466	320	Just below spring	Ngongotaha
2786050	6339189	468	319	Spring	Ngongotaha
2786054	6339184	469	319	Inaccessible spring joins flow	Ngongotaha
2785786	6337693	470	340	From dam. Duck pond above and marshy area with outflow below. Pond below level of outflow pipe	Ngongotaha
2785823	6337609	471	340	Marshy area with outflow	Ngongotaha
2785666	6338529	476	336	Swamp, start of flow from side, adding to flow	Ngongotaha
2785573	6338434	477	339	Swamp, start of flow from side	Ngongotaha
2785315	6338876	481	322	Swampy area with outflow	Ngongotaha
2786460	6339133	482	320	Dry from left channel, moist from right but no flow	Ngongotaha
2785492	6338725	504	333	Spring adding to flow	Ngongotaha
2784905	6338623	505	341	Swamp with outflow and start of flow	Ngongotaha
2785278	6339051	508	340	Spring and start of flow	Ngongotaha
2785259	6339040	509	339	Spring (joins flow from 61)	Ngongotaha
2785265	6339047	510	339	Spring (joins flow from 61)	Ngongotaha
2785306	6339054	511	340	Spring and start of flow	Ngongotaha
2785470	6339099	512	336	Spring and start of flow (flows towards Dingwalls')	Ngongotaha
2785169	6337801	514	343	Swamp with outflow	Ngongotaha
2784687	6337683	516	360	Swamp with outflow	Ngongotaha
2784757	6337779	517	360	Swamp with outflow	Ngongotaha
2784582	6337750	520	360	Bottom of swampy area with outflow	Ngongotaha

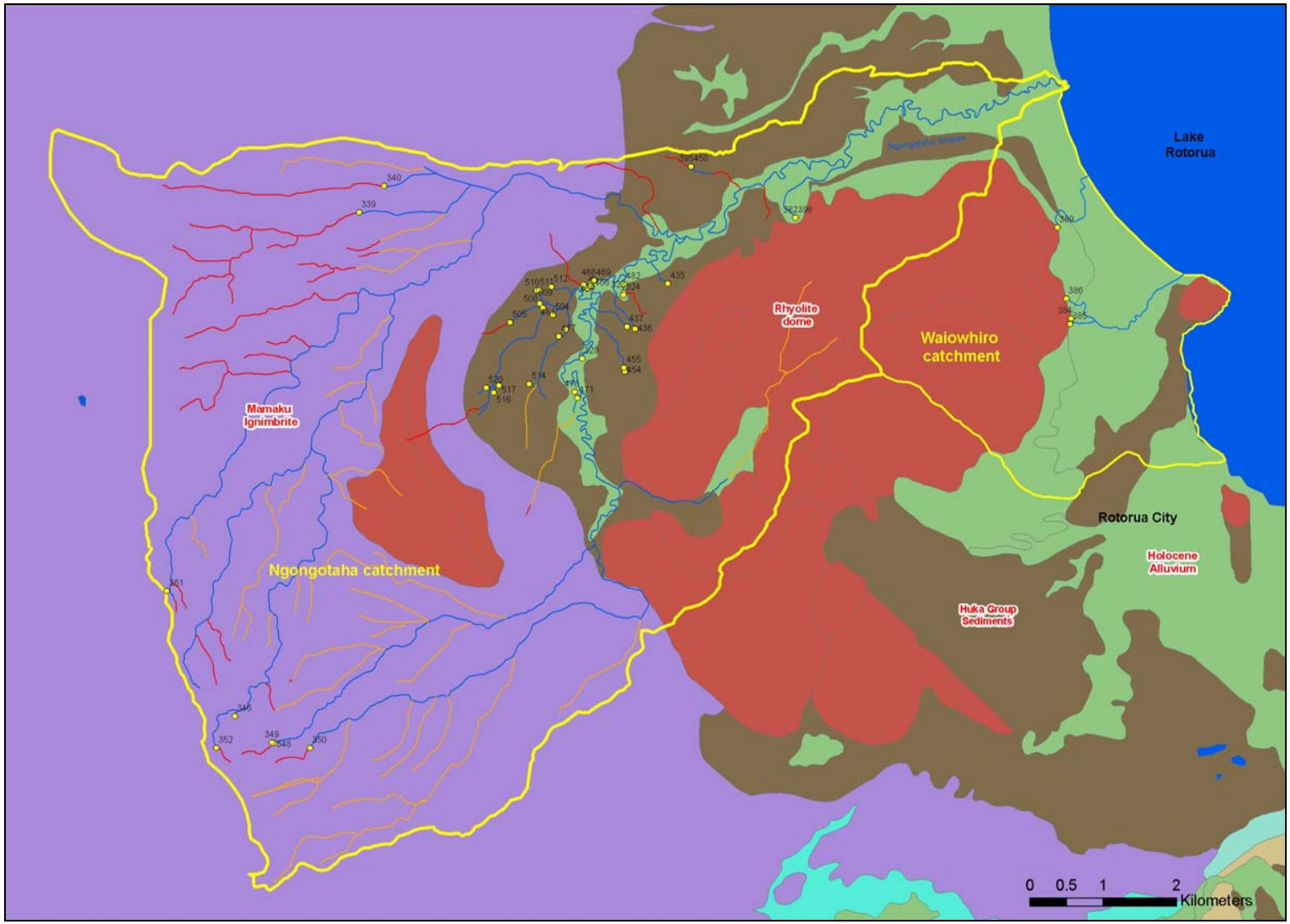

Figure A3.1 Location of springs and seeps mapped by EBOP in 2004/2005 (from White et al. 2007).

APPENDIX 4 BASEFLOW ESTIMATES IN STREAMS AND SPRINGS IN PHASE 3 (FROM WHITE ET AL. 2007)

Surface catchment	Feature	Description	Site name	Period	Reference, site number PW site numbers	Easting	Northing	Flow (L/s)	Comments
Waiowhiro	Catchment	Waiowhiro Stream	Rainbow/Fairy confluence	1972-73, 2004-2005, 2006	EBOP203, RLNBR site	2792774	6338749	300	Spot measurement
Waiowhiro	Catchment	Waikuta Stream	McRae Spring	Jul-06	Site 31	2792326	6340002	70	Spot measurement
Waiowhiro	Feature type not recorded	Lake front	South of Kawaha Pt	2004-2005	EBOP69	2794313	6337115	4	Spot measurement
Waiowhiro	Feature type not recorded	Lake front	North of Waiowhiro Stream	2004-2005	EBOP139	2793655	6339602	3	Spot measurement
Waiowhiro	Feature type not recorded	Lake front	North of Waiowhiro Stream	2004-2005	EBOP155	2792677	6340901	3	Spot measurement
Waiowhiro	Feature type not recorded	Lake front	North of Waiowhiro Stream	2004-2005	EBOP 165	2792466	6341501	1	Spot measurement
Ngongotaha	Stream	Ngongotaha Stream	Upstream of Hatchery Stream	1973-1974	MWDA14602	2788280	6340499	1600	Spot measurement, rounded
Ngongotaha	Stream	Ngongotaha Stream	Paradise Valley	1973-1974	MWDA14606	2786334	6336347	320	Average of 6 measurements
Ngongotaha	Stream	Ngongotaha Stream	U/s of Otamaroa confluence	Apr-06	NGON3	2786130	6335621	150	Spot measurement, rounded
Ngongotaha	Stream	Ngongotaha Stream	Headwaters spring	Jul-06	Site 25	2782238	6333047	4	Spot measurement, rounded
Ngongotaha	Stream	Hatchery Stream	Hatchery Rd culvert	1973-1974	MWDA14601	2788732	6340303	120	Spot measurement, rounded
Ngongotaha	Stream	Ngongotaha Stream	Unnamed stream	2006	NGON8	2788000	6340500	8	Spot measurement
Ngongotaha	Stream	Ngongotaha Stream	Barlow No. 1 spring	1973-1974	MWDA14604	2786051	6339282	58	Average of 6 measurements
Ngongotaha	Stream	Ngongotaha Stream	Barlow No. 2 spring	1973-1974	MWDA14605	2786051	6339282	180	Average of 6 measurements
Ngongotaha	Stream	Ngongotaha Stream	Te Waireka spring	Apr-06	NGON7	2786220	6337318	3	Spot measurement
Ngongotaha	Stream	Ngongotaha Stream	Relph Rd	Apr-06	NGON1	2787519	6336222	6	Spot measurement
Ngongotaha	Stream	Otamaroa Stream	Upstream of Ngongotaha Stream	Apr-06	NGON2	2785950	6335718	140	Spot measurement
Ngongotaha	Stream	Umurua Stream	Upstream of Ngongotaha Stream	1973-1974	A14603	2787163	6339799	390	Average of 6 measurements
Ngongotaha	Stream	Umurua Stream	Upstream of Waitetahi Stream	Apr-06	NGON5	2784500	6340200	230	Spot measurement
Ngongotaha	Stream	Umurua Stream	Headwaters spring	Jul-06	Site 23	2780662	6334264	4	Spot measurement
Ngongotaha	Stream	Waitetahi Stream	Upstream of Umurua Stream	Apr-06	NGON4	2784500	6340500	70	Spot measurement
Ngongotaha Township	Drain	Lake front	Culvert	2004-2005	EBOP174	2792278	6342617	3	Sum of flows

APPENDIX 5 GEOCHEMISTRY

Table A5.1 Ngongotaha and Waiowhiro catchment major ions and water types (White et. al. 2007, their Appendix 15). Locations of sites are plotted on Figure 5.1.

#	Name of spring ID	Station ID	Surface Catchment Location	Water Type	Dominant Ions							Source Type	Cations (mg/L)						Anions (mh/L)				
					Ca	Mg	K	Na	HCO_3	Cl	SO_4		Ca	Fe	Mg	Mn	K	Na	HCO_3	Cl	F	NO_3-N	SO_4
22		1361	Ngongotaha	Ca-K-HCO_3-Cl	x				x			Well	4.1		1.5		7.7	3.1	26	6.9		1.760	3.7
38	Hatchery spring	3003	Ngongotaha	K-Na-HCO_3-Cl			x		x			Spring	2.0	<0.02	1.2	<0.0005	7.1	3.3	21	5.3	0.13	0.945	3.0
39	Paradise Valley Spring (N 38)	3004	Ngongotaha	K-Na-HCO_3			x		x			Spring	2.4	<0.02	1.2	<0.0005	8.2	4.4	26	4.3	0.06	6.775	2.3
40		3005	Ngongotaha	K-Mg-Na-Ca-HCO_3-Cl			x		x			Spring	2.3	<0.02	1.5	<0.0005	6.9	2.7	27	4.4	0.06	0.567	1.4
121		1344-1348	Ngongotaha	K-Ca-Mg-HCO_3-Cl			x		x			Spring	8.4	0.05	4.9	0.004	23.7	3.8	83	20.5	0.10	0.104	1.8
122		1353-1355	Ngongotaha	K-Ca-HCO_3-Cl-SO_4			x		x			Well	3.4	0.01	1.5	0.000	11.5	3.5	31	8.7	0.13	0.630	8.2
144	Waitetahi Spring_east	Wai_Spg-E	Ngongotaha	Na-Ca-HCO_3-Cl				x	x			Spring	3.4	<0.02	1.3	<0.005	2.7	8.8	21	6.9	0.01	2.160	4.0
145	Waitetahi Spring_west	Wai_Spg-W	Ngongotaha	Na-Ca-HCO_3-Cl				x	x			Spring	3.4	<0.02	1.2	<0.005	2.7	8.8	21	6.9	0.01	2.240	4.0
46		3013	Ngongotaha Twnshp	K-HCO_3			x		x			Well	2.5	3.78	1.0	0.162	11.4	2.7	49	3.6	0.14	0.012	0.1
67		10113	Ngongotaha Twnshp	K-Mg-Na-Ca-HCO_3-Cl			x		x			Well	2.8	1.30	2.1	0.340	8.2	3.3	23	6.4	0.16	1.680	3.2
68		10114	Ngongotaha Twnshp	K-Na-Ca-Mg-HCO_3-Cl			x		x			Well	4.2	0.03	1.9	0.014	11.5	5.2	19	6.7	0.09	6.330	0.8
47		3015	Utuhina	K-HCO_3			x		x			Spring	2.5	0.01	1.5	0.003	8.9	2.1	32	4.0	0.06	0.405	2.3
76		10128	Waiowhiro	Ca-Na-HCO_3	x				x			TP	12.5	<0.02	1.2	<0.005	4.9	5.1	38	4.0	0.03	2.230	8.5
167	Fairy Spring (N 34)	FAI_Spg	Waiowhiro	Na-HCO_3-Cl				x	x			Spring	2.0	<0.02	0.9	<0.005	2.7	6.6	19	4.9	0.11	0.830	2.6
168	Rainbow Spring (N 35)	RAIN_Spg	Waiowhiro	Na-Ca-HCO_3-Cl				x	x			Spring	2.2	<0.02	0.9	<0.005	2.8	6.6	20	4.9	0.08	0.867	2.7
20		1356	Waiteti	Ca-K-Mg-HCO_3-Cl	x				x			Well	9.3		3.5		11.8	3.4	25	10.7		9.310	4.5
21		1360	Waiteti	K-Na-Ca-HCO_3			x		x			Well	4.5		1.7		12.1	5.6	56	4.7		1.760	4.5
42		3007	Waiteti	K-Ca-HCO_3-Cl			x		x			Well	2.9	<0.02	1.4	<0.0005	7.9	1.9	25	4.3	0.03	1.400	3.0
51		3470	Waiteti	K-HCO_3			x		x			Well	2.3	5.38	1.5	1.080	12.0	1.9	50	4.5	0.31	0.006	0.3
19		1352	Waiteti	K-Ca-HCO_3-Cl-SO_4			x		x			Well	3.6	0.03	1.5	0.000	11.3	3.4	28	9.0	0.13	0.630	8.0

Table A5.2 Ngongotaha, Waiowhiro catchment and surrounding catchments water quality database (White et al. 2007, their Appendix 15). Locations of sites are plotted on Figure A5.1.

#	Site ID[1]	Easting	Northing	Site Geology/Land Use/Soil Type[2]				Samples[3] Date	Field Variables[4]							
				Surf_Geo	Sub_Geo	Land use	Soil type		Count	Cond	DO	ORP	pH	Temp	Turb	SiO_2[4]
1	147	2789100	6341500	Huka	Huka_H3	Forestry	Ngakuru sandy loam	4-May-06	1	73			6.70	13.3	32.2	
3	165	2787900	6342200	Huka	MkIg_L	Scrub	Ngongotaha loamy sand	7-Mar-06	1	94			6.30	12.0	27.9	
4	235	2776900	6342800	MkIg	MkIg_L	Outside_catch	Outside_catch	19-Jun-06	1	94			6.10	10.8	38.1	
5	242	2788300	6335200	NgongRhy	Ngong_Rhy	Sheep/beef	Ngongotaha loamy sand	4-May-06	1	83			6.40	12.5	21.4	
11	1063	2789300	6344700	Huka	MkIg_L	Scrub	Oturoa sand	1-Mar-06	1	84			6.40	12.8	33.3	
12	1098	2780200	6341800	MkIg	MkIg_L	Sheep/beef	Mamaku loamy sand	22-Mar-06	1	163			6.00	12.0	67.6	
17	1212	2787800	6336700	NgongRhy	Ngong_Rhy	Other	Ngakuru hill soils	2-May-06	1	74			6.30	13.2	0.0	
18	1214	2788700	6339800	NgongRhy	Ngong_Rhy	Sheep/beef	Arahiwi steepland soils	4-May-06	1	99			6.20	13.5	27.9	
19	1352	2779500	6341500	MkIg	MkIg_U	Outside_catch	Outside_catch	14-Aug-00	1	101						
20	1356	2779700	6340660	MkIg	MkIg_U	Other	Mamaku loamy sand	14-Aug-00	1	171						
21	1360	2779790	6340720	MkIg	MkIg_U	Other	Mamaku loamy sand	16-Aug-00	1	118						
22	1361	2780370	6339930	MkIg	MkIg_U	Dairy	Mamaku loamy sand	16-Aug-00	1	91						
23	1462	2791500	6338100	NgongRhy	MkIg_L	Scrub	Ngongotaha hill soils	May-06	1	69.5			7.05	12.8	20.3	
24	1561	2792910	6345900	Huka	MkIg_L	Scrub	Oturoa sand	1991-2006	12	84	6.9		6.60	13.6		70
25	1609	2780400	6338800	MkIg	MkIg_L	Indigenous Forest	Mamaku loamy sand	22-Mar-06	1	97			6.20	11.2	36.0	
32	2404	2784400	6343200	MkIg	MkIg_L	Scrub	Mamaku loamy sand	9-Mar-06	1	94			6.20	11.4	37.1	
34	2576	2778200	6342300	MkIg	MkIg_L	Outside_catch	Outside_catch	19-Jun-06	1	111			5.70	9.4	21.4	
35	2594	2788600	6341500	Huka	MkIg_L	Sheep/beef	Ngakuru hill soils	28-Feb-06	1	85			6.40	12.8	34.9	
37	3002	2791832	6345487	Huka	Huka_H1	Sheep/beef	Oturoa sand	2003-2005	2	41	8.2	328	6.60	10.9	6.1	55
38	3003	2788810	6339920	NgongRhy	Ngong_Rhy	Scrub	Arahiwi steepland soils	10-Jul-03	1	5						63
39	3004	2786200	6336000	Huka	Huka_H1	Indigenous Forest	Ngakuru hill soils	2003-2005	2	36		247	7.10	10.7	0.6	66
40	3005	2786036	6339206	Huka	Huka_H1	Scrub	Ngongotaha hill soils	10-Jul-03	1	5						60
43	3008	2792917	6346011	Huka	Huka_U	Cropping	Oturoa sand	11-Jul-03	1	7						70
44	3009	2792871	6346460	Huka	Huka_U	Deer/Beef/Sheep	Oturoa sand	11-Jul-03	1	20						54
46	3013	2791945	6342100	Huka	Huka_U	Urban	Waiowhiro sand	21-Aug-03	1	6						74
47	3015	2791553	6333538	Huka	Huka_H1	Deer	Ngakuru sandy loam	21-Aug-03	1							73
51	3470	2791350	6343100	Huka	Huka_U	Sheep/beef	Oturoa sand	1997-2006	7	99			6.75	12.8		40
52	3654	2782000	6340800	MkIg	MkIg_L	Dairy	Mamaku loamy sand	7-Mar-06	1	85			6.30	11.6	32.3	
55	4006	2791010	6343970	Huka	Huka_H3	Scrub	Oturoa sand	1-Mar-06	1	88			6.50	12.7	32.0	
56	4007	2789360	6344720	Huka	Huka_U	Sheep/beef	Oturoa sand	1996-June 2006	37	86	8.4		6.61	12.9		66
59	4378	2791100	6344500	Huka	Huka_H2	Cropping	Oturoa sand	3-Mar-06	1	88			6.70	12.6	29.5	
60	4386	2779970	6340590	MkIg	MkIg_L	Urban	Mamaku loamy sand	22-Mar-06	1	124			5.70	13.3	33.8	
67	10113	2791570	6342319	Huka	Huka_U	Urban	Ngakuru sandy loam	04-May-05	1	75	4.0	239	6.50	11.8	78.0	56
68	10114	2791545	6342328	Huka	Huka_U	Urban	Ngakuru sandy loam	04-May-05	1	108	7.4	399	6.05	14.7	30.2	76
76	10128	2792178	6341517	Huka	Huka_H1	Urban	Waiowhiro sand	28-Apr-05	1	118	5.5	321	6.23	15.1	9.9	24
77	10129	2792985	6345196	Huka	Huka_H1	Indigenous Forest	Waiowhiro sand	28-Apr-05	1	172	2.1	170	7.01	15.5	>600	52
80	10183	2788200	6344700	MkIg	MkIg_L	Dairy	Oturoa hill soils	3-May-06	1	72			6.10	12.6	19.6	
90	10964	2792870	6346460	Huka	Huka_H2	Deer/Beef/Sheep	Oturoa sand	2-Mar-2006	1					6.0	13.9	
91	10965	2788710	6346600	MkIg	MkIg_L	Dairy	Oturoa sand	2005-Jun 06	7	94			6.40	11.6	38.6	
92	10966	2791540	6342330	Huka	Huka_H2	Urban	Ngakuru sandy loam	2005-Jun 2006	8	111			6.01	14.7	23.8	
93	10967	2791580	6342320	Huka	Huka_H3	Urban	Ngakuru sandy loam	2005-Jun 06	7	95			6.30	13.8	27.0	
94	10968	2791580	6342320	Huka	Huka_H2	Urban	Ngakuru sandy loam	2005-Jun 06	7	99			6.60	14.5	31.1	
97	10978	2784410	6345310	MkIg	MkIg_U	Dairy	Mamaku hill soils	11-May-06	1	88			6.20	10.9	36.7	
103	11063	2791110	6344510	Huka	MkIg_L	Cropping	Oturoa sand	3-Mar-06	1	87			6.50	12.8	30.6	
111	11077	2780180	6342500	MkIg	MkIg_L	Sheep/beef	Mamaku loamy sand	22-Mar-06	1	94			6.40	11.6	43.4	
116	11118	2788480	6336000	NgongRhy	Ngong_Rhy	Deer/Beef/Sheep	Ngakuru sandy loam	4-May-06	1	60			6.20	13.1	15.4	
117	11119	2790990	6340800	Huka	Ngong_Rhy/Huka	Forestry	Ngakuru sandy loam	4-May-06	1	67			6.60	11.9	18.7	
118	11132	2778120	6344550	MkIg	MkIg_U	Outside_catch	Outside_catch	19-Jun-06	1	96			6.50	9.4	41.4	
119	4008D	2788058	6346365	MkIg	MkIg_L	Forestry	Oturoa hill soils	15-Feb-05	1	70	7.5	331	6.86	9.7	17.0	68
120	4008S	2788058	6346365	MkIg	MkIg_L	Forestry	Oturoa hill soils	13-Dec-04	1	73	8.6	357	6.08	11.0	12.6	40
121	1344-1348	2786000	6339200	Huka	Huka_H1	Sheep/beef	Ngongotaha hill soils	1996-2004	4	211						74
122	1353-1355	2779970	6340590	MkIg	MkIg_L?	Urban	Mamaku loamy	Aug-Nov 00	3	101						75
123	1609_Spg	2780400	6338800	MkIg	MkIg_U	Indigenous Forest	Mamaku loamy sand	22-Mar-06	1	65			5.90	13.0	16.8	
124	AND_Spg	2785920	6338100	Huka	Huka_H1	Road	Ngongotaha loamy sand	10-May-06	1	101			5.90	15.0	23.8	
128	Gleghorn_Well	2791080	6344690	Huka	Huka_U	Sheep/beef	Oturoa sand	4-Apr-06	1	88			6.30	12.7	29.2	
129	GOLF_Spg	2786534	6344088	MkIg	MkIg_U	Sheep/beef	Waiteti hill soils	28-Jul-06	1		5.3		4.80	8.3		
130	HAWK_Spg	2786327	6343975	MkIg	MkIg_U	Scrub	Pohaturoa steepland soils	28-Jul-06	1		11.0		5.40	11.1		
134	Mamaku	2779724	6340715	MkIg	MkIg_U	Other	Mamaku loamy sand	19-Jun-06	1	128			5.90	11.3	43.9	
136	Maxwell	2780330	6337020	MkIg	MkIg_U	Other	Mamaku loamy sand	11-May-06	1	115			5.80	12.0	41.6	
137	MCR_Spg	2792326	6340002	NgongRhy	Ngong_Rhy	Sheep/beef	Ngakuru sandy loam	28-Jul-06	1		7.9		5.70	11.8		
138	NGON_Spg	2782238	6333047	MkIg	MkIg_U	Sheep/beef	Mamaku hill soils	26-Jul-06	1		3.3		5.00	10.8		
140	OTA_Spg	2782193	6333267	MkIg	MkIg_U	Sheep/beef	Mamaku hill soils	26-Jul-06	1		6.8		3.40	6.8		
141	ROE_Spg	2780460	6334100	MkIg	MkIg_U	Sheep/beef	Mamaku hill soils	9-May-06	1	60			5.50	11.5	12.6	
142	TUP_Spg	2787269	6341158	Huka	Huka_H1	Indigenous Forest	Ngongotaha loamy sand	26-Jul-06	1		5.2		6.00	12.8		
143	UMU_Spg	2780662	6334264	MkIg	MkIg_U	Indigenous Forest	Mamaku hill soils	26-Jul-06	1		5.1		4.70	10.5		
144	Wai_Spg-E	2782900	6340042	MkIg	MkIg_U	Indigenous Forest	Mamaku hill soils	14 May 2005	1	72	5.6	146	5.66	9.8	0.9	34
145	Wai_Spg-W	2782807	6340099	MkIg	MkIg_U	Indigenous Forest	Mamaku hill soils	14 May 2005	1	72	6.5	149	5.57	9.6	1.6	34
146	WAI_Spg-C	2785800	6345750	MkIg	MkIg_U	Dairy	Waiteti hill soils	19-Jul-06	1	96	5.4		6.55	11.2		
147	WAI_Spg-U	2785795	6345750	MkIg	MkIg_U	Dairy	Waiteti hill soils	19-Jul-06	1	65	6.3		6.40	6.8		
167	FAI_Spg	2792512	6338948	Huka	Huka_H1	Scrub	Ngakuru sandy loam	22-Nov-2003	1	46	10.3		7.15	11.8		61.000
168	RAIN_Spg	2792562	6338681	Huka	Huka_H1	Scrub	Ngakuru sandy loam	22-Nov-2003	1	45	10.1		7.02	12.8		57.000
169	AWA_Spg	2791151	6345435	Huka	Huka_H1	Scrub	Oturoa sand	16-Dec-2003	1	73	7.5		7.04	12.4		55.000

[1] Site identification. Where available, EBOP well numbers were used for identification. Otherwise, a number assigned by GNS Science or an abbreviation defined in the "Identifying Information" column was used. Blue shading indicates noteworthy item (e.g., well pair nests, close to designated catchment, or outside of DTM).

[2] Owner/Location information. Where identified in EBOP records, the name of the owner is listed. In other cases, identifying information about the site is listed. Easting and northing coordinates (NZMG), and surface catchment, are also listed. Asterisk and blue shading by surface catchment name indicates located a short distance outside of the actual catchment.

[3] Type of site (spring, well, or temporary piezometer or TP), static water level (SWL) in m where known, depth of casing in m where known, total depth (TD) of well where known, and ground level (GL). Depth is categorized as shallow (i.e., equal to or less than 30 m) or deep (i.e., greater than 30 m). Centre of lake determined by Arcmap to be 2797131 Easting and 6341879 Northing (NZMG coordinates). Sample site locations measured in Arcmap with respect to that location.

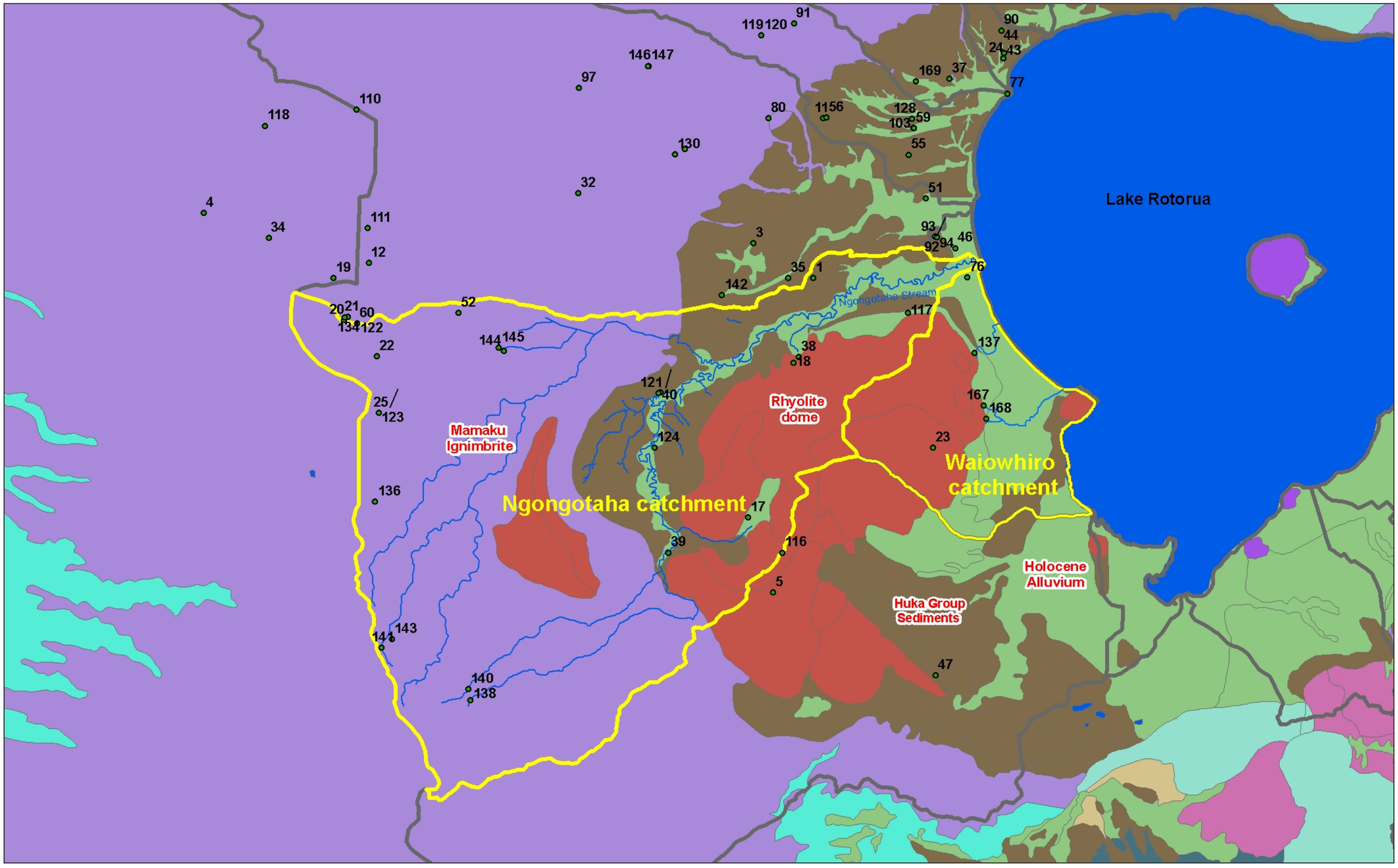

Figure A5.1 Location of water quality database sampled sites (from Table A5.2).

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