Groundwater resource investigations of the Rangitaiki Plains stage 1 – conceptual geological model, groundwater budget and preliminary groundwater allocation assessment

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EXECUTIVE SUMMARY

Groundwater in the Rangitaiki Plains, Bay of Plenty, and surrounding catchments is taken by municipal, agricultural and commercial users. Municipal users, for example Whakatane District Council and Kawerau District Council, take groundwater from bores and springs (White 2005). Use of groundwater by agriculture and commercial users in the Rangitaiki Plains is predicted to increase in the future (White 2005). However, past development of groundwater resources has been without estimates of groundwater availability. To avoid inadvertent over-allocation of groundwater, Bay of Plenty Regional Council (BOPRC) commissioned GNS Science to complete a preliminary assessment of groundwater availability in the Rangitaiki Plains and surrounding catchments.

The area of this assessment, shown in Figure 1.1, includes the Rangitaiki Plains and the catchments of the Tarawera River and the Whakatane River north of the foothills (including the catchment of the Waimana River). This study involves a synthesis of geological information, hydrological data and hydrogeological information to identify the geological structure suitable for aquifers, to calculate groundwater budgets, and to estimate groundwater available for allocation (GAA).

The geology of Rangitaiki Plains area is summarised in this report in terms of:

- Jurassic to Early Cretaceous basement rocks;
- Quaternary volcanic and sedimentary deposits; and
- the structure of the Whakatane Graben.

Basement rocks are composed principally of greywacke characterised by complex deformation. Sedimentary rocks of Torlesse (composite) terrane crop out in the east of the area and range in age from Jurassic to Early Cretaceous.

Quaternary deposits in the study area are represented by lavas and pyroclastics of the Taupo Volcanic Zone (TVZ) and sediments of the Tauranga Group. Matahina Ignimbrite is an important pyroclastic unit underlying the Rangitaiki Plains and a large part of the hills surrounding the Rangitaiki Plains. Tauranga Group sediments are predominantly volcaniclastic, and are derived by reworking of TVZ eruption deposits. Tauranga Group sediments include marine deposits in interglacial periods, with a relatively warm climate like today, when sea levels were high, and terrestrial depositional phases that occurred in glacial periods when sea levels retreated to the edge of the continental shelf.

The present Holocene period commenced about 12 kyr. Sea level rose, invading the Rangitaiki Plains as far as Awakeri and almost to Te Teko. Holocene alluvium and swamp deposits are widely distributed across the Rangitaiki Plains, the former particularly around the courses of the Whakatane and Rangitaiki rivers, the latter particularly behind dune and marginal marine materials in the coastal strip. Holocene deposits from eruptions are common on the Rangitaiki Plains, including: Taupo Pumice Alluvium, an outwash deposit that followed soon after the c. 1.72 kyr Taupo eruption; Kaharoa Pumice Alluvium; and 1886 Tarawera Eruption deposits including scoria, sand, silt and mud thinly covering most of the Rangitaiki Plains.

The Whakatane Graben is a key structural feature of the study area that includes the Taupo

Rift and associated faults of the North Island Fault System. Four important Taupo Rift faults are the Edgecumbe, Otakiri, Awaiti and Braemar/Matata faults. The Edgecumbe Fault was the locus of the principal rupture plane in the M6.3 1987 Edgecumbe Earthquake. The Edgecumbe Fault carries the major displacement of the Whakatane Graben with an approximate vertical throw on greywacke basement of up to 2300 m.

Stratigraphic marker horizons represented in a geological model of the Rangitaiki Plains area include: Holocene terrestrial and marine sediments; the top of Last Glacial terrestrial deposits; the top of Last Interglacial marine deposits; the top of Matahina Ignimbrite; and the top of basement. Marine incursions to the Rangitaiki Plains are represented in the model, including the Holocene (Q1) and the last Pleistocene marine incursion (Q5) identified by shell deposits. The surface at the end of the Last Glacial period (Q2) is represented over the Rangitaiki Plains by sediments deposited in a terrestrial environment that are about 40 m deep at the coast.

Three major groundwater and surface water catchments are identified in the study area associated with the Tarawera, Rangitaiki and Whakatane rivers. Within these major groundwater catchments, the boundaries of 36 groundwater catchments are estimated in the Rangitaiki Plains with an analysis ground topography, surface water flows (including drainage scheme flows), geology and groundwater flow directions. Boundaries of groundwater catchments in the Tarawera River and Whakatane River catchments above Rangitaiki Plains are assumed to be the same as the surface catchment boundaries.

Catchment groundwater budgets are calculated using estimates of rainfall, actual evaporation (AET), surface water baseflow in streams (calculated from historical gaugings) and drains (using historical gaugings and estimates of specific discharge), and groundwater flow. For example, a summary of major groundwater flow budget components for the Rangitaiki major groundwater catchment has:

- inflow from rainfall of 14.8 m^3/s and outflow from AET of 9.2 m^3/s;
- groundwater inflow from the Tarawera major groundwater catchment of 2.9 m^3/s;
- groundwater outflow to surface water of 3.7 m^3/s, including the Rangitaiki River and the Tarawera River catchment; and
- groundwater outflow to the coast of 4.9 m^3/s.

GAA is estimated in each groundwater catchment using groundwater budget estimates of rainfall, AET and groundwater outflow to surface water. This approach aims to protect surface water features from over-abstraction of groundwater by generally assuming that groundwater outlfow to surface water (i.e. baseflow) is not available for allocation. Some conservative estimates of water budget components are made in the translation of groundwater budget components to estimates of GAA, for example 1) GAA is assumed to be zero where a groundwater catchment has estimated groundwater outflow that is greater than the difference between rainfall and AET; 2) groundwater inflows to groundwater catchments are not included in the GAA estimation; and 3) median flows are used in estimating surface baseflow. An example of the calculation of GAA is the Rangitaiki major groundwater catchment with:

- GAA approximately 2 m^3/s;

- zero GAA in the following allocation zones: Kope Orini 1, Kope Orini 2, Mangamako area, Old Rangitaiki Canal, Rangitaiki Dunes and Waikowhewhe area.

Annual allocation and estimated groundwater use are compared to GAA to assess the sustainability of current allocation to groundwater and geothermal consents in the study area. For example, in the Rangitaiki major groundwater catchment:

- annual groundwater allocation is approximately 1.6 m^3/s and estimated use is approximately 0.6 m^3/s;
- the Nursery Drain groundwater catchment has current groundwater allocation of 122 l/s, which exceeds the estimated GAA of 13 l/s; and
- the Ngakauroa Stream groundwater catchment has current groundwater allocation of 233 l/s, which exceeds the estimated GAA of 189 l/s.

This report makes recommendations including collection of driller's logs to improve the geological model, collection of environmental data to provide more robust estimates of groundwater allocation, and consideration of allocation policies on the Rangitaiki Plains, for example:

- BOPRC consider holding a workshop for drillers active in the Rangitaiki Plains, and other interested parties, to outline the geological model and explain the importance of good lithological data;
- surface low flows are measured in the Rangitaiki Plains streams and drains in summer to calculate baseflow discharge, for example from groundwater catchments where groundwater allocation is greater than GAA and in groundwater catchments with no, or very few, measurements of baseflow;
- measure groundwater level near the coast between Matata and the Rangitaiki River because groundwater level may be below sea level in this area and therefore the aquifer may be at risk from salt water intrusion; and
- consider surface water allocation policy for drains in the Rangitaiki Plains. Baseflow in drains may be crucial to the maintenance of important wetlands and therefore maintenance of baseflow in drains, through limits on groundwater allocation, may be of environmental importance. However, the intended purpose of the drains is to keep land suitable for farming and therefore protection of baseflow in drains may not be a priority for BOPRC. GAA will be larger than estimates in this report for groundwater catchments with drains, should there be no provision for maintenance of drain baseflow.

1.0 INTRODUCTION

Water resources in the Rangitaiki Plains area of the Bay of Plenty are coming under growing pressure as agricultural activity increases. Groundwater allocation in the Bay of Plenty area is increasing over time (White 2005).

Groundwater in the Rangitaiki Plains and surrounding catchments is extracted for agricultural, commercial and municipal uses. Use of groundwater by agriculture and commercial users in the Rangitaiki Plains is predicted to increase in the future (White 2005). Municipal users take groundwater from bores and springs. For example, Whakatane District Council takes groundwater from Braemar Springs and bores, and Kawerau District Council takes groundwater from the Tarawera Park borefield, Holland Spring and Pumphouse Spring (White 2005).

However, development of groundwater resources in the Rangitaiki Plains has occurred without regional estimates of groundwater availability. To avoid inadvertent over-allocation, Bay of Plenty Regional Council (BOPRC) commissioned GNS Science (GNS) to complete a preliminary assessment of groundwater availability in the Rangitaiki Plains and surrounding catchments (Figure 1.1).

The area of this assessment includes the surface catchments of the Tarawera River, north of Lake Tarawera, the Rangitaiki River north of Matahina Dam, and Whakatane River catchments north of the foothills (including the catchment of the Waimana River) (Figure 1.2). This assessment is completed with a synthesis of geological information and hydrological data to identify key aquifers and estimate groundwater available for allocation.

Groundwater catchment boundaries are identified on Rangitaiki Plains as part of this project. These boundaries are difficult to identify because surface hydrology on the Rangitaiki Plains between the major rivers is dominated by a drainage network that was developed and expanded in the 20th century. Boundaries estimated here also provide new information that is a useful contribution to the understanding of surface hydrology on the Plains.

Groundwater available for allocation (GAA) is assessed in the following steps:

- identify geological units important to groundwater flow and develop a geological model of these units;
- estimate surface water and groundwater catchment boundaries on the Rangitaiki Plains and other catchments;
- estimate average rainfall and average evaporation for groundwater catchments;
- estimate rainfall recharge and evaporation for groundwater catchments;
- estimate baseflow discharge from groundwater catchments via streams;
- estimate groundwater flow budgets; and
- estimate GAA from groundwater flow budgets.

The determination of the limits of groundwater allocation can be guided by estimates of GAA. However, the limits of groundwater allocation are not calculated in this report because decisions on allocation policy are required by BOPRC before limits can be established.

Current groundwater allocation and estimated groundwater use are compared with GAA to provide estimates of the sustainability of current groundwater allocation.

The geological model, groundwater budget and preliminary groundwater allocation estimates developed in this report are intended as the first steps in a BOPRC programme of investigations designed to assess groundwater sustainability in this economically important area of the Bay of Plenty Region.

2.0 RANGITAIKI PLAINS – A GEOLOGICAL REVIEW

2.1 Geological setting

The Rangitaiki Plains area lies upon the Australian Plate, about 200 km northwest of the Australia-Pacific plate boundary at the Hikurangi Trough, east of the Raukumara Peninsula coast of the North Island (Figure 2.1). From the Hikurangi Trough, the Pacific Plate is being subducted eastward beneath the Australian Plate. The Taupo Volcanic Zone (TVZ) traverses the central North Island, New Zealand, for approximately 250 km with an average NE-SW strike and here the Pacific Plate lies at a depth of about 150-180 km (Figure 2.2). The TVZ is the locus of arc-related rifting accommodating extension at a rate of up to 18 mm/yr (Davey and Lodolo 1995, Villamor and Berryman 2001, Wallace *et al.* 2004). Northeast of the Bay of Plenty coast, the twin submarine volcanic ridges, Colville and Kermadec, and their intervening backarc rift, the Havre Trough, strike towards the Rangitaiki Plains (Wright 1993, Wysoczanski *et al.* 2009).

New Zealand is a fragment of thick, low density, continental crust, largely surrounded by thin, high density oceanic crust. Basement rocks of the New Zealand continental crust comprise batholiths and fault-bounded tectonostratigraphic terranes that developed along, and were subsequently amalgamated and accreted against the eastern margin of Gondwana in the Paleozoic to Early Cretaceous (Figure 2.3) (Cooper 1989, Mortimer 2004). The Median Batholith separates early Paleozoic terranes of the Western Province from late Paleozoic to Cretaceous terranes of the Eastern Province (Mortimer *et al.* 1999). Only Eastern Province basement rocks are present in the Rangitaiki Plains area (Mortimer 1995, 2004, Mortimer *et al.* 1997, Edbrooke 2001, Kear and Mortimer 2003) and they belong to thick, complexly deformed, largely sedimentary rocks of the Waipapa and Torlesse (composite) terranes. Waipapa (composite) terrane crops out at Otamarakau and almost certainly underlies the western part of the area at depth and consists of indurated Manaia Hill Group sandstone and argillite of Late Jurassic age. Torlesse (composite) terrane rocks underlie most of the eastern side of the area, are found at depth beneath Kawerau and crop out in hill country to the south and east the Rangitaiki Plains. They comprise indurated sandstone and argillite of the Jurassic Kaweka, Early Cretaceous Pahau terranes, and mélange and broken formation of the Whakatane Mélange. These rocks are characterised by bedding parallel shear structures, the result of a compressional tectonic environment that culminated in the Early Cretaceous Rangitata Orogeny.

Basement rocks are overlain by a succession of little-deformed late Early Cretaceous mainly marine sedimentary rocks of the Matawai Group southeast of the Rangitaiki Plains. The eastern part of the area is cut by a number of active strike-slip faults of the North Island Fault System (NIFS). These almost certainly have an extended Late Miocene to Recent history of activity, although in the Miocene and Pliocene tectonic activity may have been largely reverse in sense.

The Taupo Volcanic Zone is a zone of volcanic activity that extends northeast from Mt Ruapehu to the Bay of Plenty coastline and beyond. It is studded with active volcanic and geothermal features and is also a belt of active extensional faulting, the Taupo Rift. On average the TVZ is 50 km wide. No volcanic rocks older than about 1.5 million years (Ma) have been found within the TVZ and it is thought to be entirely Quaternary in age. Volcanic pyroclastics, ashfall and lavas dominate deposits of the TVZ and the areas adjacent to it. These are mostly rhyolitic in origin, although minor intermediate and basic volcanics are present. On-going normal faulting of the Taupo Rift is at least partly associated with Quaternary volcanic activity in the TVZ. These faults are almost certainly restricted in age to about the same period as the age of the volcanic zone. The Rangitaiki Plains lie across the Taupo Rift, near where the strike-slip NIFS intersects and transfers most of its slip into the rift (Mouslopoulou *et al.* 2007, Begg and Mouslopoulou 2010).

In the TVZ, extension in the upper crust is primarily accommodated by fault-slip during large magnitude earthquakes (e.g., Beanland *et al.* 1989, Berryman *et al.* 1998, Villamor and Berryman 2001, Nicol *et al.* 2007, Begg and Mouslopoulou 2010). The 1987 M6.3 Edgecumbe Earthquake, for example, the largest historic earthquake in the rift, resulted in extensional slip at the ground surface on eleven traces of six faults (including the Edgecumbe Fault) within the Rangitaiki Plains (Beanland *et al.* 1989).

2.2 Review of existing geological information

Hochstetter (1864) first wrote of the sand dunes and great swamps of the Rangitaiki Plains, suggesting they represent former estuaries that "*…have filled up in the course of time*". In 1895 Gordon and McKay described the Rangitaiki Plains from the Whakatane River thus:

"*Five miles before reaching the coastline, the hill-slopes become precipitous, and form a line of escarpment which is a remarkable feature on this side of the valley to the sea. The low hills on the west side of the valley terminate about six miles from the sea, leaving an immense tract of low flat land between the Whakatane and Rangitaiki Rivers, a great portion of which is very swampy. Along the shoreline of the Bay of Plenty there is a ridge of low sand dunes, on the inland side of which the ground for some distance forms a dry alluvial belt. A deltaic branch of the Rangitaiki flows through the low swampy flat and joins the Whakatane River at about one mile above the township.*

On the east side of the Whakatane River, as well as on portions of the bank on the western side, there is a great depth of rich alluvial soil, resulting from the denudation of the sandstone and slate rocks – often highly calcareous – of the upper valley, mixed with finely comminuted pumice and other volcanic ingredients. During the late eruption of Tarawera, the lower valley and part of the Waimana was covered with from 1in. to 2in. of fine volcanic ash, which has been wholly beneficial to vegetation. Great apprehension was entertained by the settlers that this deposit would have an injurious effect on the land, but the whole of them now testify to the contrary.

Above the escarpment already referred to there are a series of rolling hills, the highest portions of which are for a considerable depth composed of pumice; these hills slope east and north, and disappear in a depression which connects the lower valley of the Waimana *with the low grounds surrounding the inlet, about halfway between Whakatane and Opotiki. It may be remarked here that there is some appearance that, before the gorge of the Waimana was cut, the river followed this course to the sea.*”

A more detailed description of the materials of the “Littoral” and “Fluviatile” parts of the Rangitaiki Plains followed and the report includes the first geological map of any detail of the area.

A generalised map with text coverage of the Rotoma area is included within Grange’s (1937) bulletin. McPherson (1944a) provided a more detailed account and map of the Rangitaiki Plains area, and the 1:250,000 scale geological map of the Rotorua region by (Healy *et al.* 1964) and in other publications (Healy 1964, Healy 1967) provided a good foundation for work in the area for the subsequent 40 years (e.g. Table 2.1 lists references to important works on Rangitaiki Plains or relevant to Rangitaiki Plains geophysics, geology and soils).

Table 2.1 Important earth science works relevant to the Rangitaiki Plains.

Work	Area	Type
TVZ gravity compilation (Stagpoole and Bibby 1999)	Central North Island	geophysics
Estler (in prep)	Rotorua	geology
TVZ resistivity compilation (Stagpoole and Bibby 1998)	Central North Island	geophysics
(Gordon and McKay 1895)	Bay of Plenty	geology
(Grange 1937)	Rotorua-Taupo	geology
(McPherson 1944b)	Rangitaiki Plains	geology
(Paltridge 1958)	Whakatane	geology
(Healy 1964)	Taupo	geology
(Vucetich and Pullar 1964)	Rotorua and Gisborne	geology
(Healy *et al.* 1964)	Rotorua	geology
(Pullar *et al.* 1967)	Whakatane area	soil
(Duncan 1970)	Mt Edgecumbe	geology
(Pullar and Selby 1971)	Rangitaiki Plains	soil
(Speden 1973)	Waioeka River	geology
(Manion 1974)	Waimana Valley	geology
(Speden 1975a)	Waimana Valley	geology
(Edbrooke 1977)	Whakatane	geology
(Beanland 1981)	Rotokawau	geology
(Carr 1984)	Matahina	geology
(Pullar 1985)	Rangitaiki Plains	soil
(Bailey and Carr 1994)	Matahina ignimbrite	geology
(Ota *et al.* 1988)	Matata	geology

Work	Area	Type
(Wilson *et al.* 1988a)	Oruanui	geology
(Broughton 1988)	Manawahe	geology
(Beanland *et al.* 1989)	Rangitaiki Plains	geology
(Nairn and Beanland 1989)	Rangitaiki Plains	geology
(Mortimer 1995)	Central North Island ranges	geology
(Beresford 1997)	Kaingaroa ignimbrite	geology
(Kamp 1999)	Hikurangi Margin	geology
(Rae 2002)	Pukehina-Matata	geology
(Nairn 2002)	Okataina area	geology
(Beetham *et al.* 2004)	Whakatane	geology
(Manville *et al.* 2005)	Rangitaiki Plains	geology
(Lamarche *et al.* 2006)	Bay of Plenty	geology
(Mouslopoulou 2006)	Bay of Plenty	geology
(Mouslopoulou *et al.* 2007b)	Bay of Plenty	geology
(Mouslopoulou *et al.* 2007a)	Bay of Plenty	geology
(O'Leary 2007)	Matata	geology
(Costello 2007)	Matata	geology
(Mouslopoulou *et al.* 2008)	Rangitaiki Plains	geology
(Begg and Mouslopoulou 2010)	Rangitaiki Plains	geology
Leonard *et al.* in press	Rotorua-Taupo	geology

Over a period of three decades, Pullar made a significant contribution to understanding the geology of the Rangitaiki Plains by clarifying the stratigraphy of Holocene volcanic ash in the Rotorua-Gisborne area (Vucetich and Pullar 1964). This work established a regional stratigraphy and therefore chronology for Holocene sediments and was followed by soil maps of the area (Pullar *et al.* 1967, Pullar *et al.* 1978, Pullar 1980, 1985) and location of Holocene shorelines across the Rangitaiki Plains on the basis of the preservation of airfall ash deposits within soil sections (Pullar and Selby 1971).

A number of student theses covering a variety of disciplines have contributed further to understanding the area of interest, including those of Paltridge (1958), Duncan (1970), Manion (1974), Edbrooke (1977), Beanland (1981), Carr (1984), Vergara (1987), Broughton (1988), Eynon-Richards (1988), Xi (1993), Manning (1995), Beresford (1997), Marra (1997), Rae (2002), Mouslopoulou (2006), O'Leary (2007) and Costello (2007). Paltridge (1958) and Edbrooke (1977) produced geological maps of the Whakatane to Ohiwa Harbour areas, with emphasis on the pumiceous deposits that cap the hilltops of the area. Manion (1974) geologically mapped a complex area of basement greywacke rocks in the Tauranga River (called the Waimana River in its lower reaches). Duncan (1970), Beanland (1981), Carr

(1984), Broughton (1988), Manning (1995) and Beresford (1997) studied volcanic rocks, mostly in the hills south and west of the area of interest. Mouslopoulou (2006) described the faults, paleoearthquakes and tectonics of the broader Bay of Plenty region. Eynon-Richards (1988), Marra (1997) and Rae (2002) studied aspects of sedimentary processes and landform development, and Vergara (1987) and Xi (1993) completed geophysical surveys of the area.

Active fault characterisation commenced in the Rangitaiki Plains with work by Ota *et al.* (1988) who quantified displacement on a strand of the Matata Fault. The 1987 M6.3 Edgecumbe Earthquake event was accompanied by surface rupture of several previously unrecognised faults across the Rangitaiki Plains and triggered further detailed investigation of faults and seismic hazard in the area (e.g. Nairn and Beanland 1989, Beanland *et al.* 1989, Berryman *et al.* 1998, Beetham *et al.* 2004, Begg and Mouslopoulou 2010).

Compilations of geophysical data of the region provide a useful supplement to understanding the structure of the area (Modriniak 1945; Studt 1958, Modriniak and Studt 1959, Stagpoole and Bibby, 1998 gravity, Stagpoole and Bibby, 1999, resistivity).

2.3 Stratigraphy

The geology of the Rangitaiki Plains area (Figure 2.4, after Leonard *et al.* in press) is summarised here in terms of:

- Jurassic to Early Cretaceous basement rocks;
- Quaternary volcanic and sedimentary deposits.

Basement rocks are characterised geologically by their complex deformation. Deposition pre-dated a profound tectonic event near the end of the Early Cretaceous. Jurassic to Early Cretaceous basement rocks (Table 2.2) include sandstone, argillite, broken formation and mélange, which crop out in the western and eastern parts of the area. In the east, basement rocks are discontinuously overlain by late Early Cretaceous mostly marine sedimentary rocks. Quaternary volcanic rocks of the TVZ are mostly rhyolitic. Quaternary sediments are widespread and either alluvial or marginal marine in origin.

2.3.1 Basement rocks of Torlesse (composite) terrane

Sedimentary rocks of Torlesse (composite) terrane (Begg and Johnston 2000) crop out in the east of the area and range in age from Jurassic to Early Cretaceous (175-110 Ma). These comprise principally indurated, poorly sorted, mostly lithic sandstone and siltstone with variably developed but ubiquitous bedding plane shear. Overall, terranes are distinguished by differing provenance, fossil ages, isotopic characteristics, detrital zircon populations, structural characteristics, or are structurally isolated from one another. Terranes may be separated by mélange or broken formation units or faults.

Within the Rangitaiki Plains area of interest, Torlesse (composite) terrane includes Kaweka and Pahau terranes. They are separated along much of their length by the Whakatane Mélange, although in the south they are juxtaposed across the Mohaka Fault (called Whakatane Fault in the Bay of Plenty).

Table 2.2 Geological units exposed within the Rangitaiki Plains area of interest.

Unit code	Main rock	Sub rocks	Map unit	Formation	Group
Quaternary age					
Q1nc	fill	sand, gravel, silt	reclaimed land	anthropogenic deposits	
Q1b	gravel	sand silt	Holocene beach deposits		Tauranga Gp
Q1d	sand	mud peat	Holocene dunes		Tauranga Gp
Q1as	peat	sand silt mud	Holocene swamp deposits		Tauranga Gp
Q1al	gravel	sand silt clay peat	Holocene alluvium		Tauranga Gp
Q1atw	sand	scoria sand silt mud	Tarawera scoria and alluvium	Tarawera alluvium	Tauranga Gp
Q1ak	sand	pumice gravel silt	Kaharoa alluvium		Tauranga Gp
Q1kap	tuff	pumice lapilli ash	Pyroclastics	Kaharoa Fm	Okataina Gp
Q1kar	rhyolite	pumice breccia	Lava	Kaharoa Fm	Okataina Gp
Q1at	pumice	sand silt gravel	Taupo pumice alluvium		Tauranga Gp
Q1af	gravel	sand silt	Holocene alluvial fan deposits		Tauranga Gp
Q1ed	andesite	scoria breccia dacite	Lava	Edgecumbe Fm	Okataina Gp
Q1wkp	tuff	pumice lapilli ash tuff	Pyroclastics	Whakatane Fm	Okataina Gp
Q1wkr	rhyolite	pumice breccia	Lava	Whakatane Fm	Okataina Gp
Q1mkp	tuff	pumice lapilli ash tuff	Pyroclastics	Mamaku eruption Fm	Okataina Gp
Q1mkr	rhyolite	pumice breccia	Lava	Mamaku eruption Fm	Okataina Gp
Q1rmp	tuff	pumice lapilli ash tuff	Pyroclastics	Rotoma Fm	Okataina Gp
Q1rmr	rhyolite	pumice breccia	Lava	Rotoma Fm	Okataina Gp
Q1ol	rhyolite	pumice breccia	Lava	undiff. lava	Okataina Gp
Q1vop	ignimbrite	pumice, lapilli, ash, tuff	Pyroclastics	undiff. Pyroclastics	Okataina Gp
Q2al	gravel	sand mud peat	Ohakean alluvial deposits		Tauranga Gp
Q2wip	tuff	pumice lapilli ash tuff	Pyroclastics	Waiohau Fm	Okataina Gp
Q2wir	rhyolite	pumice breccia	Lava	Waiohau Fm	Okataina Gp
Q2rep	tuff	pumice lapilli ash tuff	Pyroclastics	Rerewhaaitu Fm	Okataina Gp
Q2rer	rhyolite	pumice breccia	Lava	Rerewhaaitu Fm	Okataina Gp
Q2okr	rhyolite	pumice breccia	Lava	Okareka Fm	Okataina Gp
Q3trp	tuff	pumice lapilli ash tuff	Pyroclastics	Te Rere Fm	Okataina Gp
Q3trr	rhyolite		Lava	Te Rere Formation	Okataina Gp
Q3al	gravel	sand silt	Ratan alluvial terrace deposits		Tauranga Gp
Q3m	ignimbrite	pumice lapilli ash tuff	Lgnimbrite	Mangaone Fm	Okataina Gp

Unit code	Main rock	Sub rocks	Map unit	Formation	Group
Q3ma/Q4ro	tuff	Pumice	airfall member	Mangaone Fm	Okataina Gp
Q4ro	ignimbrite	pumice lapilli ash tuff	Ignimbrite	Rotoiti Fm	Okataina Gp
lQaf	gravel	sand silt	alluvial fan deposits		Tauranga Gp
lQal	gravel	sand silt	alluvial terrace deposits	(undiff.)	Tauranga Gp
lQls	debris	Blocks, sand, silt	landslide and rockfall detritus		Tauranga Gp
lQpd	dacite	pumice breccia	Lava	Puhipuhi Fm	Okataina Gp
mQlk	silt	sand clay pumice	Q4-6 lake sediments (undiff.)		
mQu	sand, silt	clay, pumice	marine, estuarine and non-marine		Tauranga Gp
Q7kiu	ignimbrite	pumice lapilli ash tuff	Ignimbrite	Kaingaroa Fm	ungrouped
Q78vp	tuff	pumice lapilli ash	pyroclastics	(undiff.)	
Q8ma	ignimbrite	pumice lapilli ash tuff	ignimbrite	Matahina Fm	Okataina Gp
Q9w	ignimbrite		ignimbrite	(undiff.)	Whakamaru Gp
Q9vor	rhyolite		lava	(undiff.)	Okataina Gp
Qd	dacite			Manawahe Fm	
mQvd	dacite	Pumice breccia	lava	(undiff.)	Ungrouped
mQvor	rhyolite	Pumice breccia	lava	(undiff.)	Okataina Gp
Q10vor	rhyolite		lava	(undiff.)	Okataina Gp
Q12vor	rhyolite		lava	(undiff.)	Okataina Gp
eQmw	dacite		[Incl. Awakaponga Fm]	Manawahe Fm	
eQu	mudstone	sandstone tuff	undiff. Early Quaternary		Tauranga Gp
Jurassic to Early Cretaceous					
Kew	Broken formation	Melange	melange	Whakatane Melange	
Ktww	sandstone	Mudstone	volcaniclastic greywacke	Waioeka petrofacies	Pahau terrane
Jtk	sandstone	Argillite	quartzofeldspathic greywacke		Kaweka terrane

2.3.1.1 Kaweka terrane

The rocks of the recently recognised Kaweka terrane (Jtk; Adams *et al.* 2009) are of limited extent at the surface, lying immediately east of TVZ deposits between the Matahina Dam and the Waiohau Basin. They are predominantly well-indurated, fine-grained, massive, quartzofeldspathic sandstones and are commonly strongly jointed and zeolite veined. Broken formation and melange textures are relatively common and limestone, chert and volcanic blocks are found locally.

Kaweka terrane is remarkably poorly fossiliferous, but where present, autochthonous fossils are Late Jurassic in age. The youngest detrital zircons recorded from Kaweka terrane (Adams *et al.* 2009) are 169-198 Ma indicating deposition continued to at least Middle Jurassic time. A Middle to Late Jurassic age is inferred. Metamorphic facies ranges from zeolite to lower prehnite-pumpellyite.

2.3.1.2 Pahau terrane

Following Adams *et al.* (2009), we adopt the term Pahau terrane for all Cretaceous Torlesse rocks east of Whakatane Mélange. Within the generally quartzofeldspathic Pahau terrane, a volcaniclastic suite (Waioeka petrofacies) and a quartzofeldspathic suite (Omaio petrofacies) can locally be distinguished (Mortimer 1995). All Pahau terrane rocks in the map area belong to Mortimer's (1995) Waioeka petrofacies.

Waioeka petrofacies (Ktw) outcrops in a belt on the eastern part of the map sheet, south and east of Waimana. The unit is dominated by well indurated alternating blue-grey to green-grey fine sandstone and dark grey siltstone (centimetre- to decimetre-bedded), commonly with well-preserved graded bedding and parallel lamination and more rarely with cross- or convolute lamination in sandstone units.

While veining, jointing and fracturing are observed, pervasive bedding plane shearing, boudinage and broken formation features are rare in comparison with Kaweka terrane and the adjacent Whakatane Mélange. Macrofossils are very rare, but good age control is provided by dinoflagellates, commonly present in concretions, indicating an Early Cretaceous age (Wilson *et al.* 1988b, Moore *et al.* 1989, Wilson 1989, Wilson 2005). Detrital zircon ages are as young as 116 Ma (Adams *et al.* 2009), indicating that deposition continued until late in the Early Cretaceous. Metamorphism is zeolite to pumpellyite-prehnite facies (Feary 1974, Hill 1974, Hoolihan 1977, Isaac 1977).

2.3.1.3 Whakatane Mélange

Whakatane Mélange (Kew; Mortimer 1995) occupies a wedge-shaped north-south belt on the eastern side of the map between Whakatane Heads and the southern extent of the map area in the Whakatane River. Whakatane Mélange is almost 20 km wide. Blocks are commonly lozenge-shaped, reaching tens of metres across (e.g. marble blocks near Ruatoki; see McKay 1895), and may be smeared or disaggregated along shear planes. Deformation varies from rocks no more deformed than surrounding terranes, through broken formation, to mélange. Quartzofeldspathic and volcaniclastic sandstones are scattered through the mélange (Mortimer 1995; Mortimer pers. comm. 2009) and blocks include massive sandstone, alternating sandstone and argillite, argillite, and chaotic diamictites with sandstone, argillite or exotic clasts. The argillite matrix usually has a scaly texture.

Blocks from the mélange include Early Jurassic bivalve indicator fossils, Late Jurassic belemnites (Stevens 1963) and dinoflagellates from one sample yield an age as young as Late Neocomian to early Aptian (127-118 Ma).

The Whakatane Mélange represents a tectonostratigraphic unit separating the petrographically, geochronologically and palaeontologically distinct Kaweka and Pahau terranes. The mélange incorporates materials from both neighbouring terranes. Bedding and shear fabric within the Whakatane Mélange is sub-vertical and predominantly parallel with the structural fabric of Kaweka and Pahau terranes.

2.3.2 Matawai Group

In the extreme southeast of the area, moderately indurated, fossiliferous marine deposits, of late Early Cretaceous age Matawai Group, crop out (Moore 1986, Moore *et al.* 1989, Mazengarb and Speden 2000). They include some of the best preserved Early and Late Cretaceous sequences in New Zealand (Wellman 1959, Speden 1975b, Crampton 1995). These rocks are coherent and little-deformed and rest unconformably upon Pahau terrane. The unconformity between the basement rocks and Matawai Group is considered to be of regional extent, although locally deposition may have continued through this period (Mazengarb and Speden 2000).

Speden (1975c) mapped up to 230 m of fine- to medium-grained green, carbonaceous sandstone, with minor conglomerate, grit, breccia and siltstone between the Waimana and Waiotahi valleys, here mapped as Waimana Sandstone (Kmu; Mazengarb 1993). Fossils recorded by Speden (1975c) range in age from Aptian to Albian (121-98.9 Ma).

2.3.3 Quaternary deposits

The Quaternary geology of the map area is represented by lavas and pyroclastics of the TVZ and sediments of Tauranga Group. TVZ deposits are dominated by widespread silicic ignimbrite sheets and lava domes, minor intermediate-composition stratovolcanoes, and scattered mafic scoria cones and lava flows. The boundaries of the TVZ are defined by Quaternary volcanic vents. Tauranga Group sediments are predominantly volcaniclastic, derived by reworking of TVZ eruption deposits. The major sedimentary events within the map area are commonly responses to pulses of volcanic activity, rather than climatic fluctuations. In most cases Quaternary volcanic rocks are described in terms of groups based upon spatial and temporal clustering of vents (often referred to as volcanic centres), usually coincident with a caldera structure.

In the accompanying map (Figure 2.4), which is derived from QMAP (a 1:250,000 scale geological map; Leonard *et al.* in press), boundaries have been simplified and Quaternary units are mapped where they are landscape-forming in nature. Unmapped younger “coverbeds” may overlie a mapped landscape-forming unit to depths up to 10 m.

Quaternary time is marked by repeated climatic fluctuations, represented by proxy in measured fluctuations of oxygen isotope ratios in rocks and sediments. A number of studies of oxygen isotope changes in deep marine foraminifera through sedimentary sequences (e.g. Shackleton and Opdyke 1973, Imbrie *et al.* 1984, Martinson *et al.* 1987, Bassinot *et al.* 1994) are used as a standard for estimating Quaternary time (Table 2.3). In the following discussion and in the classification of map units, reference to geological time is by means of oxygen isotope stages (Imbrie *et al.* 1984), signified by the prefix “Q”. In this scheme, Q1 represents the Holocene (0 – 12 kyr), Q2-Q4 represents the Last Glaciation (12 – 71 kyr), Q5 the Last Interglacial (71 – 128 kyr), and subsequent even numbers represent cold climatic regimes and odd numbers represent warm climatic conditions.

Table 2.3 Oxygen isotope stage boundaries as used in QMAP (right hand column). The stage boundaries of the listed publications (see references) were considered in deciding upon a suitable value for QMAP.

Stage boundary	Shackleton and Opdyke (1973)	Imbrie *et al.* (1984)	Bassinot *et al.* (1994)	Martinson *et al.* (1987)	QMAP age (thousand years)
1 and 2	13	12	11	12	**12**
2 and 3	32	24	24	24	**24**
3 and 4	64	59	57	59	**59**
4 and 5	75	71	71	74	**71**
5 and 6	128	128	127	130	**128**
6 and 7	195	186	186	190	**186**
7 and 8	251	245	242	244	**245**
8 and 9	297	303	301		**303**
9 and 10	347	339	334		**339**
10 and 11	367	362	364		**362**
11 and 12	440	423	427		**423**
12 and 13	172	478	474		**478**
13 and 14	502	524	528		**524**
14 and 15	542	565	568		**565**
15 and 16	592	620	621		**620**
16 and 17	627	659	659		**659**
17 and 18	647	689	712		**689**
18 and 19	688	726	760		**726**
19 and 20	706	736	787		**736**
20 and 21	729	763	820		**763**
21 and 22	782	790	865		**790**

Quaternary rocks and deposits are here briefly described in stratigraphic succession, from oldest to youngest.

2.3.3.1 Quaternary rocks and sediments

The oldest Quaternary rocks cropping out in the area are early Quaternary in age (c. 1 Ma – 500 kyr) and comprise the dacites of Manawahe and Awakaponga formations (Qd). These are of limited extent and crop out locally on the western side of the Rangitaiki Plains and immediately north of Kawerau.

Undifferentiated sediments of early Quaternary age (eQu; c. 1 Ma – 500 kyr) crop out on the west of the plains, near Matata and in the east, mantling basement rocks above Whakatane and the Waimana Basin. Materials are dominated by loose, pumiceous sandstone, but also contain minor mudstone. Lukes Farm Formation (Grindley 1965, Woodward-Clyde 1997) is a loosely defined unit comprising alluvial and lacustrine beds underlying Matahina Ignimbrite in the Matahina Dam area. While it is likely to be of early middle Quaternary age, because of stratigraphic position, Lukes Farm Formation is here included within this map unit (eQu) to avoid confusion with the unit mQlk, which is Q4-Q6 in age. Marine fossils, thought to be late Castlecliffian (c. 500 kyr) are known from correlative beds near Matata (Leonard *et al.* 2009) and Whakatane (Fleming 1955).

The following Quaternary lavas and ignimbrites have a large extent in the area:

- outcrop of undifferentiated middle Quaternary Okataina Group rhyolitic lava (mQvow) is present between Lake Rotoma and Kawerau;
- Whakamaru Ignimbrite (Q9w; of c. 347 000 yr age; hereafter shortened to 347 kyr) is exposed south of the Tarawera River and Kawerau in the Mangawhio Stream area. In this area Whakamaru Ignimbrite is commonly rose-coloured, soft and contains up to 10% of pumice clasts;
- Matahina Ignimbrite (Q8ma) is an important unit in the Rangitaiki Plains area, not only for its wide distribution, but also as a marker horizon. It underlies a large part of the hills surrounding the Rangitaiki Plains, crossing the Raungaehe Range in a corridor to the Taneatua Basin and across into the Waimana Basin. It is composed of welded to non-welded, blue to pink, cream or grey ignimbrite with c. 10% pumice clasts and a gritty, crystal-rich matix.

Many different units with a volcanic origin occupy small areas of outcrop, for example:

- a small area of undifferentiated pumice lapilli and ash of Q7-8 age (Q78vp; c. 303 – 186 kyr) crops out in the middle reaches Tarawera River;
- exposures of late Quaternary dacitic pumice breccia (lQpd) are found in the upper Tarawera River valley;
- undifferentiated Q2 (24 - 12 kyr) rhyolitic lava (Q2trr) and associated pyroclastic rocks (Q2trp) are present in the Tarawera Forest east of Lake Okataina;
- in the headwaters of the Tarawera River, northeast of Mt Tarawera, a dome of Okareka Formation (Q2okr; c. 22 kyr) rhyolite and pumice breccia crops out;
- Waiohau Formation (Q2wir, rhyolitic lava; Q2wip, pyroclastic deposits; 13.6 kyr) is found in the upper reaches of the Tarawera River. This consists of pumice breccia and pumice lapilli, ash and tuff.

Pre-Holocene lake deposits and alluvium are observed in the area. For example:

- small exposures of middle to late Quaternary (Q4-6; 186 – 59 kyr) lake deposits (mQlk) crop out in the upper Tarawera River valley and consist of sand, clay and pumice;
- Late Quaternary alluvium (lQal), fan (lQaf) and landslide (lQls) deposits of limited extent are distributed through the Lake Rotoma area, Raungaehe Range and north of Waimana;

- small, elevated remnant terraces of Q3 (59 – 24 kyr) alluvium consisting of loose greywacke cobble gravels are found in the Whakatane valley between Ruatoki and where the river enters the Rangitaiki Plains;
- areas of Q2 alluvium (Q2al) are preserved in the upper Whakatane River and Owhakatoro Stream catchments. These consist of loose greywacke-derived gravels.

Holocene (Q1) age deposits are common in the area, and these are summarised in the following text.

Rotoiti Formation (Q4ro; c. 61 kyr) is widely distributed between the Tarawera Falls and Te Teko and consists of loose, white, pumice-rich (20-50% pumice clasts) ignimbrite. Rotoiti Formation is commonly overlain by Managaone Formation ignimbrite (Q3m) and lapilli (Q3ma) across a similar area.

A tiny area of undifferentiated Q1 Okataina pyroclastics (Q1vop) is present in the southernmost part of the Tarawera catchment in the area. A small area of undifferentiated Holocene rhyolitic pumice breccia (Q1ol) crops out southwest of Lake Rotoma. Rhyolitic pumice breccia and pyroclastics of the Rotoma Formation (Q1rmr, Q1rmp; 9.5 kyr), Mamaku Formation (Q1mkr, Q1mkp; 8 kyr) and Whakatane Formation (Q1wkr, Q1wkp; 5.53 kyr) crop out in the same general area.

A dacite scoria, and breccia of the Edgecumbe Formation (Q1ed) forms Mt Edgecumbe, east of Kawerau, and is as young as 3.12 kyr.

Deposits from Holocene eruptions are common on the Rangitaiki Plains, including:

- Taupo Pumice Alluvium (Q1at), which consists of pumice sand, silt and gravel and is widely distributed around the course of the Rangitaiki River across the plains. This is interpreted as an outwash deposit that followed soon after the c. 1.72 kyr Taupo eruption (Manville *et al.* 2005, Manville *et al.* 2009);
- rhyolitic pumice breccia (Q1kar) and pyroclastics (Q1kap) of the Kaharoa Formation are mapped in the headwaters of the southern Tarawera catchment. Kaharoa Pumice Alluvium is mapped extensively from Kawerau across the eastern side of the Tarawera River almost as far as Matata (Nairn and Beanland 1989);
- scoria, sand, silt and mud from the 1886 Tarawera Eruption thinly covers most of the Rangitaiki Plains, but is not mapped separately. Alluvium derived from the eruption (Q1atw) choked the Tarawera River and forms low terraces around the river as far downstream as Kawerau.

Holocene alluvium (Q1al) and swamp deposits (Q1as) are widely distributed across the Rangitaiki Plains, the former particularly around the courses of the Whakatane and Rangitaiki rivers, the latter particularly behind dune and marginal marine materials in the coastal strip. Materials consist of gravel, sand, silt, mud and peat of variable thickness. Holocene alluvial fans (Q1af) have built from steep slopes along the margins of the Rangitaiki Plains, and from the eroded scarp of the Whakatane Fault.

Marginal marine deposits are present across the depth of the Rangitaiki Plains in the east, and as a coastal strip across the western part of the Bay of Plenty coast and include beach ridges (Q1b) and dunes (Q1d). Inland beach ridges are restricted to the area of the plains east of the Edgecumbe Fault.

2.4 Conclusions

The geology of the Rangitaiki Plains area is summarised as two major rock groups, basement rocks and Quaternary rocks and deposits. Surficial basement rocks belong to the Torlesse (composite) terrane, are indurated, but fractured, and from west to east comprise three units: Kaweka terrane, Whakatane Mélange and Pahau terrane. These basement units, and probably a further subsurface unit, the Waipapa (composite) terrane, are expected to be more or less continuous at depth across the area.

Quaternary rocks in the area are described in terms of age and lithology from oldest to youngest. They range in age from early Quaternary to Holocene deposits and are dominated by volcanic material primarily and secondarily derived from TVZ eruptions. Rapid subsidence of the Rangitaiki Plains has been accompanied by a voluminous contribution of volcanic (mostly pumiceous) debris, particularly from eruptions of the Okataina Caldera, which have kept pace with this subsidence, filling the developing void behind the coastline. Holocene alluvium deposits are widely distributed across the Rangitaiki Plains, particularly around the courses of the Whakatane and Rangitaiki rivers. Holocene swamp deposits occur behind dune and marginal marine materials in the coastal strip.

3.0 GEOLOGICAL STRUCTURE

3.1 Introduction

McPherson (1944a) summarised the geological setting of the Rangitaiki Plains well in his description:

"…*seemingly the Whakatane alluvial plain is a collapsed or sunken area bounded on the east and south by tension fractures. This collapsed segment may extend northward into the Bay of Plenty beyond Whale Island. The depression of this area was a comparatively recent event, probably occurring during the Pleistocene. It has since been deeply alluviated by the large streams traversing this part of the Taupo-Rotorua graben*".

Since McPherson's description, a substantial amount of geological and geophysical work has improved our knowledge of the subsurface of the Rangitaiki Plains.

Active volcanoes within the TVZ are one of the characteristic geological features of the geomorphology and geology of the central North Island. The TVZ has been active for at least 1.5 Ma, and its present margins are defined by its outermost volcanic vents. It is wedge-shaped and extends from Mt Ruapehu north-eastwards to the Bay of Plenty coast and beyond to the Havre Trough. Volcanism includes both basic and acidic materials, but surface materials are dominantly rhyolitic.

Volcanic activity of TVZ is one element of the extensional backarc rift tectonic regime. Another element is a series of sub-parallel normal faults, collectively known as the Taupo Rift faults, which dissect the rocks of the TVZ. Heat flow from the TVZ is high, and the crust (of the Australian Plate) is thinned through rifting to perhaps as little as 15 km (Davey *et al.* 1995) with 10 km thickness of seismogenic (brittle) rock. Thinning at the base of the crust is mirrored at the surface by development of a tectonic depression, with elevated rift shoulders and a depressed axis. The hills west of Matata and east of Whakatane/Awakeri represent the elevated shoulders of the rift. The Rangitaiki Plains lie across the north-eastern part of the axis of the onshore Taupo Rift and are underlain by a significant thickness of Quaternary fill, mostly of volcanic origin.

The 1987 M6.3 Edgecumbe Earthquake provided abundant evidence that a number of active faults traverse the Rangitaiki Plains. Work following the earthquake included compilation of a geological map of the surface deposits of the Rangitaiki Plains, older rocks that surround the plains (Nairn and Beanland 1989), and the faults that ruptured during that event (Beanland *et al.* 1989). Subsequent work, important in understanding the three dimensional structure of the Whakatane Graben, includes seismic reflection (Woodward 1988, O'Connor 1990) and gravity profiles and their interpretations (Mouslopoulou 2006, Mouslopoulou *et al.* 2008).

Structural and stratigraphic complexity can be expected across the Rangitaiki Plains because it is underlain by the axis the Taupo Rift and lies at the intersection between the active Taupo Rift and the NIFS (Figure 3.1). The predominantly strike-slip faults of the NIFS change in orientation from NE to N near Lake Waikaremoana as they approach their intersection with the Taupo Rift. The change in strike is accompanied by splaying and branching of faults that are remarkably linear through the length of the southern North Island. Mouslopoulou (2006) and Mouslopoulou *et al.* (2007a) documented a change from dominant strike-slip character south of this change, to oblique-slip north of it, resulting in transferral of NIFS slip to faults of the Taupo Rift near their intersection. In the Rangitaiki Plains area, the major NIFS faults involved are the Waiohau, Whakatane and Waimana faults (Mouslopoulou 2006, Mouslopoulou *et al.* 2008).

Subsequently, Begg and Mouslopoulou (2010) undertook a detailed analysis of the geomorphology and short term deformation across the Rangitaiki Plains based on high resolution LIDAR data. The resolution of this topographic data allows quantification of absolute deformation of a series of stranded beach ridges of differing Holocene ages. It also highlights the fact that a significant part of the Rangitaiki Plains lie below sea level, and deposits in this area overlie beach ridges that have subsided from a depositional elevation of 5-7 m above sea level. Such data allow the calculation of short term subsidence rates across the NE margin of the plains.

On the basis of the vertical deformation rates calculated for horizons of differing ages, it seems likely that the rate of deformation on the faults across the Rangitaiki Plains has varied through time (Mouslopoulou *et al.* 2008). In this section the various structural elements important in the three dimensional geological relationships in the Rangitaiki Plains area are discussed.

3.2 Structural elements

3.2.1 Taupo Rift

Faults of the Taupo Rift are normal in style, those on the northwest side of the Rangitaiki Plains mostly dipping southeast, and those on the southeast mostly dipping northwest. Most faults strike approximately northeast and dip either to the northwest or the southeast, probably at or about 60°. The northwest shoulder of the rift is formed by displacement on the Matata and Braemar faults; but the south-eastern shoulder is more difficult to define due to the presence of two of the NIFS faults, the Waiohau and Whakatane faults. The four most important Taupo Rift faults of the Whakatane Graben are the Edgecumbe, Otakiri, Awaiti and

Braemar/Matata faults, because their long term vertical displacements have a far greater impact on the top of the 322 kyr Matahina Ignimbrite than other faults.

3.2.1.1 Edgecumbe Fault

The Edgecumbe Fault was the locus of the principal rupture plane in the M6.3 1987 Edgecumbe Earthquake. Although the epicentre was located close to Matata, it was focused at 10 km depth, consistent with the northwest dip on the Edgecumbe Fault plane of c. 60°. The rupture associated with the earthquake had a maximum displacement of c. 2.5 m (Beanland *et al.* 1989). A trench across the 1987 scarp identified at least two previous ruptures on the fault, one probably c. 800 yrs ago, the other in the late stage of deposition of the Taupo Pumice Alluvium, <1.72 kyr ago (Beanland *et al.* 1989).

On the basis of a seismic line east from the Whakatane Hospital site, Modriniak (1945) estimated a depth of 700 ft (c. 210 m) to basement greywacke. Subsequent gravity and seismic data across the Rangitaiki Plains near the coast identifies the Edgecumbe Fault as carrying the major displacement of the south-eastern shoulder of the Taupo Rift in this area, with an approximate vertical throw on greywacke basement of up to 2300 m (Fig. 6.8 in Mouslopoulou 2006; Mouslopoulou *et al.* 2008; see Figure 3.2, this report). Depth to basement greywacke in the hospital area was estimated at c. 650 m. Vertical displacement on the top of the c. 322 kyr Matahina Ignimbrite across the Edgecumbe Fault is up to 1350 m (Fig. 6.9 in Mouslopoulou 2006; see Figure 3.3, this report). Because there is no high intensity seismic reflector above basement in the hospital area, the Matahina Formation is probably represented here by contemporaneous airfall deposits at an estimated relative level of c. 200 - 250 m.

Rates of vertical displacement calculated for the Edgecumbe Fault from this information are c. 1.8 mm/yr (assuming the age of the basement surface is 1.3 Ma) and 4.2 mm/yr of the top of the 322 kya Matahina Ignimbrite.

However, vertical fault displacement across the Edgecumbe Fault does not continue unchanged along strike. Seismic lines by Woodward (1988) and O'Connor (1990) indicate that the top of the Matahina Ignimbrite is little displaced across the Edgecumbe Fault in the Te Teko area. Further, they note that the trace of the Edgecumbe Fault that ruptured in 1987 in the Te Teko area had the smallest displacement on any of the faults identified in the seismic profiles and concluded it must be a very young feature.

Mouslopoulou (2006) showed that vertical displacement reduces rapidly south of the junction between the Edgecumbe and Waiohau faults. Fifteen kilometres south of the junction, vertical displacement on the top of the Matahina Ignimbrite is only c. 200 m (Woodward-Clyde 1997), and a proportional decrease in vertical displacement on the basement surface is inferred. Mouslopoulou (2006) concluded that the relationship between vertical displacement values indicates interaction between the faults, such that vertical displacement on the Waiohau Fault contributes to vertical displacement on the Edgecumbe Fault northeast of their intersection. Surface geological constraints suggest that the total vertical displacement on the top of the Matahina Ignimbrite across most of the eastern Taupo Rift faults in the Kawerau area does not greatly exceed 120 m.

3.2.1.2 Otakiri Fault

Prior to the 1987 Edgecumbe Earthquake no surface trace of the Otakiri Fault existed, and the fault was therefore unrecognised. The earthquake resulted in surface rupture c. 1.3 km long with up to 0.8 m vertical displacement, downthrown to the southeast. Beanland *et al.* (1989) mapped the location of this scarp and measured its displacement, and Woodward (1988) illustrates the fault on the extreme northern part of his Line 3. Begg and Mouslopoulou (2010) mapped a number of traces from LIDAR data considered to belong to the Otakiri Fault. Some traces are downthrown to the northwest and some to the southeast. One trace near the Rangitaiki River mouth carries up to three metres of vertical displacement associated with an earthquake that probably post-dated the Kaharoa eruption (640 yr BP; Lowe *et al.* 2008).

A significant change in the elevation of the top surface of the Matahina Ignimbrite (as determined by gravity and seismic reflection) lies close to the surface position of the Otakiri Fault (Mouslopoulou 2006, Mouslopoulou *et al.* 2008). With northwest dip of the significant strand of the Otakiri Fault near the Whakatane River mouth, this is likely to be one of the major structures of the graben. Alternatively, the displacement may be attributable to the Awaiti Fault to the northwest.

3.2.1.3 Braemar - Awaiti Fault

As with the Otakiri Fault, the Awaiti Fault was unknown prior to its rupture during the 1987 Edgecumbe Earthquake (Beanland *et al.* 1989). During the earthquake a 4 km long surface trace, striking northeast and downthrown by up to 1.2 m, was formed. In assessing LIDAR topographic data, Begg and Mouslopoulou (2010) extended the trace to the northeast and recognised other traces nearby that they grouped with the Awaiti Fault. Again, individual traces are downthrown both to the northwest and southeast. While the Awaiti Fault lies closest to the epicentre of the 1987 Edgecumbe Earthquake, it is unlikely to have been the principal rupture surface because a steep fault plane dip would be required and displacement would have been greater. No surface rupture was observed on the Braemar Fault in the 1987 Edgecumbe Earthquake. The Braemar Fault is here linked to the Awaiti Fault because it appears to splay northeast from the foot of the hills to join the Awaiti Fault (see also Begg and Mouslopoulou 2010).

3.2.1.4 Matata Fault

The Matata Fault Zone and the Braemar Fault are the principal north-western structural elements of the Whakatane Graben. Traces of the Matata Fault Zone were recognised, and one was investigated, prior to the 1987 Edgecumbe earthquake (Ota *et al.* 1988). Begg and Mouslopoulou (2010) identified a number of additional faults belonging to the Matata Fault Zone and quantified their short term surface displacements. Faults of the zone strike between north-northeast and east-northeast, and most are downthrown to the southeast. West of the Whakatane Graben, the Matahina Ignimbrite is exposed on ridge crests up to 450 m in elevation. The ignimbrite is progressively downfaulted eastwards from these ridge crests across strands of the Matata and Braemar faults to lie beneath the surface of the western Rangitaiki Plains. The cumulated vertical displacement on the top of the Matahina Ignimbrite across the Matata and Braemar fault zones amounts to about 800 m.

3.2.1.5 Te Teko Fault

The Te Teko Fault lies southeast of the Edgecumbe Fault and constituent scarps are generally downthrown and dip to the northwest (Beanland *et al.* 1989, Begg and Mouslopoulou 2010). Although it ruptured with up to 0.4 m vertical displacement during the 1987 Edgecumbe Earthquake, the preferred interpretation at the time was that this may have been a non-tectonic displacement, related more to soft sediment disturbance due to strong ground shaking (Beanland *et al.* 1989). Vertical displacement on basement across the Te Teko Fault is estimated at about 200 m (Mouslopoulou 2006 Figure 3.2), and LIDAR data (Begg and Mouslopoulou 2010) suggest that the Te Teko Fault merges along strike with the Waiohau Fault near Awakeri, close to where the Waiohau and Edgecumbe faults merge.

3.2.1.6 Rotoitipaku Fault

Secondary rupture with a vertical displacement of c. 0.1 m occurred on the fault line near Lake Rotoitipaku during the 1987 Edgecumbe Earthquake (Beanland *et al.* 1989). This fault is named 'Rotoitipakau Fault' by Beanland (*et al.* 1989), and others. However the fault is named 'Rotoitipaku Fault' in this report, following the name of the nearby lake. Note that the name 'Rotoitipakau Fault' is used in the New Zealand active faults database and in references to the fault cited in this report.

Following the Edgecumbe Earthquake, Berryman *et al.* (1998) completed further investigation, providing a much clearer picture of its significance. Again, some surface scarps dip to the southeast and some to the northwest. The fault has ruptured at least eight times in the last 8.5 kyr with a cumulative vertical displacement of up to 5 m. Begg and Mouslopoulou (2010) recognised previously undetected traces using LIDAR topographic data, extended the fault to the northeast and modelled its displacement profile.

3.2.2 North Island Fault System

Faults of the North Island Fault System (NIFS) are dominantly strike-slip and strike about north-south in the Rangitaiki Plains area. Following the 1987 Edgecumbe Earthquake a considerable amount of work was undertaken to characterise the recurrence interval and slip characteristics of NIFS faults (e.g. Beanland 1995, Woodward-Clyde 1997). Faults of the NIFS, as they approach the TVZ, exhibit an increasing component of dip-slip displacement (Mouslopoulou 2006). Development of basins such as Galatea, Waiohau, Taneatua and Waimana are a result of this component of vertical displacement. The three NIFS faults important in the geology of the Rangitaiki Plains area are the Waiohau, Whakatane and Waimana faults, discussed in a little more detail below.

3.2.2.1 Waiohau Fault

The Waiohau Fault extends 120 km north from where it splays from the Ruahine Fault and is truncated near Awakeri by faults of the Taupo Rift. At the point where it splays from the Ruahine Fault, it strikes about north-northeast, but it swings to strike north-south by the Murupara to Ruatahuna highway (SH38). About 20 km north of here, the fault emerges from the Urewera ranges to occupy the eastern margin of the Galatea basin. The presence of a steep topographic scarp and facetted spurs clearly indicate a significant dip-slip component, downthrown to the northwest (Beanland 1993, Mouslopoulou 2006, Mouslopoulou *et al.* 2007a, Mouslopoulou *et al.* 2009a). The fault continues northwards forming the eastern margin of the Waiohau basin and passes through the Matahina Dam (Woodward-Clyde

1997) before swinging to the northeast again, here changing in name to Awakeri Fault. At Awakeri, Modriniak (1945) located the fault using seismic and magnetic geophysical data several hundred metres west of the Awakeri railway station. Here, he recorded a sudden change in elevation of greywacke from c. 70 m to 200 m. Woodward's (1988) seismic lines 5 and 6 and O 'Connor's (1990) lines 102, 103 and 104, plus surface exposure of Matahina Ignimbrite provide further constraints on the location of the fault in the Awakeri area.

Nairn and Beanland (1989) reported locations of geothermal drillholes where depths to greywacke basement had been established in the Kawerau area. Basement lies at depth ranging from -650 m to -1220 m, and most of the overlying deposits are terrestrial in origin. They reported that a single estuarine shell (B.W. Christenson pers. comm.; Nairn and Beanland 1989) was reported from an elevation of -450 m in Well KA22, indicating the presence of a Quaternary marine incursion at least as far as Kawerau. Basement elevations in the drillholes require the presence of a number of concealed faults in the area; a number of faults were identified in the area from seismic lines (Woodward 1988, O'Connor 1990). Mouslopoulou *et al.* (2007b) documented a change in vertical displacement rate on the Waiohau Fault from c. 0.2 mm/yr 20 km south of the Bay of Plenty coast to c. 0.5 mm/yr near the coast.

3.2.2.2 Whakatane Fault

The Whakatane Fault is the northern extension of a fault that starts in Cook Strait, south of the Wellington coastline, extends northward to the Manawatu Gorge as the Wellington Fault, continues through western Hawkes Bay as the Mohaka Fault, and takes on its northern name about the Te Hoe River. It is the most continuous fault of the NIFS and carries the greatest slip rate along most of its length. It changes in strike from northeast to north about 20 km north of Ruatahuna and continues at about this strike to Whakatane, a distance of c. 55 km. While it is a dextral strike-slip fault, its component of dip-slip increases from south to north from Ruatahuna to Whakatane (Mouslopoulou 2006, Mouslopoulou *et al.* 2007a, Mouslopoulou *et al.* 2007b).

Data characterising displacement and timing of paleoearthquakes are available from Beanland (1995), Mouslopoulou (2006), and Mouslopoulou *et al.* (2007a, 2007b, 2009a, 2009b). The Ruatahuna fault-angle depression may represent deformation resulting from the change in strike of the fault from north-northeast to north (e.g. Beanland 1995). The Taneatua basin may represent increasing dip-slip resulting from increasing proximity to the Taupo Rift faults, an analogue of the Galatea and Waiohau basins on the Waiohau Fault (Mouslopoulou *et al.* 2007b). Between Ruatahuna and Taneatua the strike-slip component on the Whakatane Fault decreases from c. 3 mm/yr to c. 1.5 mm/yr while its dip slip increases from close to 0 to 1.5 ± 0.5 mm/yr (Mouslopoulou *et al.* 2007b).

The exact location of the Whakatane Fault through Whakatane is uncertain, although a feature close to Whakatane Hospital visible in LIDAR data may be a fault trace.

3.2.2.3 Waimana Fault

The Waimana Fault lies east of the main area of interest in this study, although there is little doubt that its influence extends into the Rangitaiki Plains. The Waimana Fault splays from the Whakatane-Mohaka Fault close to the Te Hoe River c. 110 km south of the Bay of Plenty coast. It strikes north from near Maungapohatu to cross the Bay of Plenty coast near the eastern end of Ohope. Strike-slip displacement dominates onshore, but some indication of an increasing dip-slip component is observed offshore (Davey *et al.* 1995, Mouslopoulou *et al.* 2007b).

The Waimana Fault has the second highest slip rate of the NIFS faults in the Bay of Plenty (Mouslopoulou *et al.* 2007b), and paleoseismological data (Beanland 1995, Mouslopoulou 2006, Mouslopoulou *et al.* 2009a) indicate a strike-slip displacement rate of c. 1 mm/yr with a dip-slip component of only c. 0.1-0.2 mm/yr.

3.3 Constraints on structure

Beanland (1995) states "*The Whakatane Graben is basement floored at about 2 km depth and has subsided at an average rate of 1-2 mm/yr over the past three hundred thousand years approximately. The faults at the eastern margin, including the Edgecumbe fault, have greater displacement rates than those at the western margin, forming an eastward-deepening wedge shaped depression (Nairn and Beanland 1989, Wright 1994). The southern end of the graben is obscured by the Kawerau geothermal field and volcanics. Prior to subsidence of the graben, the whole Bay of Plenty coastal area received marine sediments; graben subsidence has been accompanied by shoulder uplifts along both sides of the graben (Nairn and Beanland 1989).*"

The work of Mouslopoulou (2006, Mouslopoulou *et al.* 2007a, 2007b, 2008, 2009a, 2009b) and Begg and Mouslopoulou (2010) allows better quantification and refinement of this model. The presence of elevated marine deposits on the eastern shoulder of the Whakatane Graben (Fleming 1955) provides constraints on long term vertical deformation in the eastern Whakatane area. Ongoing work on correlation of marine deposits in coastal cliffs behind Matata (D. Gravely, D. Hikuroa, G. Leonard pers. comm.) is providing new information on long-term vertical deformation of the western shoulder of the graben. Interpretation of seismic lines (Woodward 1988, Woodward 1989, O'Connor 1990, Mouslopoulou *et al.* 2008; A. Nicol pers. comm.) including a recently acquired seismic/gravity line across the Rangitaiki Plains near the coast in conjunction with LIDAR topographic information (Begg and Mouslopoulou 2010), provides better constraints on the stratigraphy, structure and deformation of the Rangitaiki Plains.

3.3.1 Greywacke basement surface

Mouslopoulou (2006, Mouslopoulou *et al.* 2008) compiled existing information on the elevation of the basement surface across the Rangitaiki Plains (Figure 3.2). This important model has only been slightly modified during this project to honour BOPRC drillhole logs. Description of the model developed for this project follows in a later section.

3.3.2 Matahina Ignimbrite

The Matahina Ignimbrite was erupted at 322 ±7 kyr (Leonard *et al.* in press) during the high sea level stand of oxygen isotope stage 9 (Imbrie *et al.* 1984). The international sea level curve indicates that sea level at the time was close to today's sea level. Evidence from deposits beneath the ignimbrite near Matata and from water-related alteration of the ignimbrite itself suggests that the elevation of the land around the present Rangitaiki Plains/Matata area was close to today's sea level. If this was so, the top of the Matahina Ignimbrite, regardless of thickness, was likely to have been deposited as a planar feature at, or close to sea level. Thus, the difference between the elevation of the top of the Matahina Ignimbrite and the present day sea level approximates the accumulated deformation on that surface.

Mouslopoulou (2006, Mouslopoulou *et al.* 2008) constructed a model showing depth to the top of the Matahina Ignimbrite (Figure 3.3) on the basis of existing data. We have modified it only slightly during this project to accommodate more recent information.

3.3.3 Large Okataina Volcanic Centre eruptions

Late Quaternary rhyolitic eruptions from the Okataina calderas have each produced large volumes of pyroclastic debris, some of which were deposited as airfall lapilli and tephra. Large quantities of loose airfall were re-deposited as alluvial pumiceous outwash materials across the low country of the Rangitaiki Plains (e.g. Hodgson and Nairn 2000, Manville *et al.* 2005). Pumiceous alluvial deposits derived from the 1720 kyr Taupo eruption and the 640 yr Kaharoa eruption are particularly widespread across the Rangitaiki Plains surface. There is good reason to believe that earlier eruptions involving large quantities of pyroclastic debris generated similar sheets of pumiceous alluvium across the plains, but that these are now buried by the younger deposits. Such eruptions may include the Rotoiti Ignimbrite (61 kyr), the Okareka (21.8 kyr), Waiohau (13.6 kyr), Rotoma (9.5 kyr), Mamaku (8.01 kyr) and Whakatane (5.3 kyr) eruptions.

3.3.4 High sea level stand marine incursions

The Quaternary (c. 2400 kyr to the present day) has been characterised by periodic climatic changes with associated sea level change. The timing of sea level fluctuations are constrained by an international sea level curve constructed from, amongst other techniques, fluctuation of the isotopic composition of oxygen in the calcite shells of deep marine planktonic foraminifera (e.g. Imbrie *et al.* 1984). The international sea level curve provides a robust tool for correlating sequences of non-marine and marine deposits, using the principal of superposition.

Sea level high stands, analogous to today's, have been documented during about 6 other stages during the middle and late Quaternary (c. 500 kyr to the present). During these periods, it is possible that incursions of the sea penetrated into the Rangitaiki Plains area, depositing marine sediments that included fossil shells. Subsequent to deposition of the 322 kyr Matahina Ignimbrite and prior to the Holocene (the present warm climatic period that started c. 12 kyr), there were two periods of high sea level (similar in elevation to today's sea level), during Oxygen Isotope Stage OIS7 (245 to 186 kyr) and OIS5 (128-71 kyr). In the intervening periods, sea levels were low and shorelines retreated to the edge of the continental shelf, and deposits across the Rangitaiki Plains were non-marine.

The present warm climatic cycle commenced about 12 kyr and sea level reached its current elevation about 6.5 to 7 kyr and has essentially been stable since. Between 12 and 6.5 kyr as sea level rose rapidly, it invaded the Rangitaiki Plains as far as Awakeri and almost to Te Teko. When sea level ceased rising, the voluminous sediment supply from the hinterland brought down by major rivers was deposited at the beach face, re-worked by long shore drift resulting in a shoreline that prograded seaward. As the shoreline retreated seaward, non-marine sediments were deposited on top of marginal marine and marine sediments.

Previously available data (Pullar 1985) suggest that the depth at which marine sands are encountered beneath surficial alluvial and swamp deposits across much of the Rangitaiki Plains increases with distance from the coastline. Using BOPRC LIDAR data, rates of vertical deformation have been calculated from changing beach ridge elevations at the surface during the last c. 1.72 kyr across the Rangitaiki Plains (Begg and Mouslopoulou 2010). The locations and elevations of these beach ridges are reported in Begg and Mouslopoulou (2010). However, where subsidence rates are high, beach ridges crests, initially deposited to an elevation of 5-7 m above sea level, can be found at and below sea level, where they have been buried by non-marine deposits.

Drillhole information has been examined in an attempt to constrain the elevations of the tops and bases of the Holocene and previous marine incursions, providing a basis for better understanding the structure of the Rangitaiki Plains and constraining rates of tectonic subsidence uplift and subsidence.

These surfaces, originally deposited at a more or less consistent elevation above sea level, are relatively easily discriminated and correlated using drillhole logs. Similar surfaces can be defined for older marine incursions. However, the small number of drillholes that penetrated to suitable depths, and the difficulty of interpreting drillers' logs means.control on the top and base of the Last Interglacial marine incursion is limited.

The drillhole logs provide points across the Rangitaiki Plains that make up stratigraphic datums that can be used to define structure and quantify vertical deformation rates.

3.4 Overall basin structure

This method provides a stratigraphic and structural framework upon which lithological units important in defining the groundwater model can be hung.

Six stratigraphic marker horizons for the Rangitaiki Plains area have been defined using this technique:

- base of late Holocene non-marine deposits;
- base of Holocene marine deposits;
- base of Last Glacial non-marine deposits;
- base of Last Interglacial marine deposits;
- top of Matahina Ignimbrite; and
- top of basement surface.

The present day surface of the plains is defined by BOPRC's high resolution LIDAR data. This surface provides an independent marker horizon and analysis shows clearly that, although mostly very young, it is tectonically deformed (Begg and Mouslopoulou 2010).

The detailed analysis of existing geological, geophysical and drillhole information to generate a model for the deposits of the Whakatane Graben is described in Section 4. However, some derivative information resulting from the analysis is mentioned briefly below.

3.4.1 Rates of vertical tectonic deformation

The structure of the Whakatane Graben results from cumulative tectonic deformation through time. By defining the graben's structure, cumulative rates of deformation on defined horizons can be calculated. Underpinning these calculated rates is the assumption that the defined surfaces were essentially planar and close to sea level at the time of deposition. This assumption is least certain, but is assumed reasonable, for the surface on top of basement.

It is clear from the complexity of the structure of the graben that vertical rates have varied spatially (Figure 3.4). This is illustrated by the fact that the basement surface lies at >3 km below sea level in places below the Rangitaiki Plains, while nearby, it lies at the surface, hundreds of metres above sea level (Mouslopoulou 2006; Mouslopoulou *et al.* 2008). The same is true for the 322 kyr Matahina Ignimbrite, although here the maximum depth is less than 2 km below sea level. A "snapshot", single deformational event illustration of this variation was demonstrated by the vertical displacement that happened in the 1987 Edgecumbe Earthquake, where displacement on the fault trace was up to 2.4 m in one place, but that displacement reduced to zero in both directions along the fault trace (Beanland *et al.* 1989). Again, Begg and Mouslopoulou (2010) demonstrated different rates of vertical deformation across parts of the Rangitaiki Plains using the elevation of active and stranded beach ridges.

But as well as varying spatially, deformational rates have varied temporally. Mouslopoulou (2006, Mouslopoulou *et al.* 2008) identified changes of rates of vertical deformation through time in the Rangitaiki Plains area. While we considered it unlikely that vertical deformation patterns derived from 1.72 kyr old beach ridges using LIDAR would mirror longer-term rates, there is a first order similarity in pattern of deformation with longer term signals derived using other data. This means that rates of active deformation are adequate to generate a first order representation of long term pattern of deformation in only 1.72 kyr. Differences between the 1.72 kyr pattern and longer term equivalents is attributable to the fact that recurrence intervals for most of the faults may be significantly longer than the sample period.

Maximum rates of subsidence and uplift (Table 3.1) can be derived by taking the maximum depth below sea level for each defined horizon and dividing it by its age.

Table 3.1 Maximum subsidence and uplift rates calculated for stratigraphic horizons within the Whakatane Graben. Note that rates for each horizon are cumulative rates calculated from the ages stated to the present day.

Feature	Age (yrs)	Maximum depth (m)	Maximum elevation (m)	Maximum subsidence rate (mm/yr)	Maximum uplift rate (mm/yr)
1.72 kyr beach ridge elevation	1720	-6.8	7	-4.0	4.1
Base late Holocene non-marine	2500	-15	7	-6.0	2.8
Base Holocene marine	7000	-30	0	-4.3	0.0
Base Last Glacial non-marine	71000	-140	n/a	-2.0	n/a
Base Q5 marine	129000	-159	4.7	-1.2	0.0
Top Matahina	322000	-2000	400	-6.2	1.2
Basement surface (young)	1000000	-3000	600	-3.0	0.6
Basement surface (old)	1500000	-3000	600	-2.0	0.4

4.0 GEOLOGICAL MODEL DEVELOPMENT: METHODOLOGY

4.1 Geological model

This section lists the data sources used for this project (Section 4.1.1) and provides a general description of the main steps in the creation of a 3D geological model (subsections 4.1.2 to 4.1.8). Subsections are arranged in the typical order of work flow during model development, but note that there are often several iterations of data checking, development of property models, and identification of appropriate layer boundaries before the 3D geological model is finalised.

Hypothetical examples are used to illustrate the first few steps in the modelling process. These examples are presented in this section only for general illustration of the work flow involved in the development of a 3D geological model; interpretation of results will be discussed in Section 5.

4.1.1 Data sources

4.1.1.1 Topographic data

Topographic data estimate the land surface elevation across the study area. The topographic data are used to develop a digital terrain model (DTM), which interpolates ground elevation between points at which measurements have been made (Appendix 1).

4.1.1.2 Geological maps

Surface geology in the Rangitaiki Plains area has been mapped by Begg and Johnston (2000). Figure 2.4 shows a Geographic Information System (GIS) version of this map, which is used in the construction of the 3D geological model to define the boundaries between geological units at the ground surface.

4.1.1.3 Well log data

Well logs constitute the main source of data for the construction of the 3D geological model. A typical well log includes the following information: 1) a name or number that uniquely identifies the well; 2) location (easting and northing); 3) elevation of the ground surface or the top of the well casing (this study expresses all elevations relative to mean sea level); and 4) lithological descriptions with their associated depth intervals. Typically, this information is collected by drillers when the well is first installed, then passed on to BOPRC for archiving in an electronic database.

Well log data for this study are provided by Bay of Plenty Regional Council in the form of an Excel spreadsheet. The dataset is comprised of 505 individual well logs (Figure 4.1), of which most wells are located in the near coastal part of the study area (i.e. the Rangitaiki Plains). Very few wells with drill hole information are available for this 3D geological modelling project in the hills surrounding the Rangitaiki Plains. The base elevation of most wells is above sea level or between sea level and 50 m below sea level, with fewer than 5% of the wells penetrating to depths of more than 100 m below sea level (Table 4.1). In total, all 505 well logs include 2,243 individual lithological descriptions covering a total logged length of 17,275 m over all wells. The well log data were subjected to a series of checks, prior to use in construction of the 3D geological model, as described in Section 4.1.3 and Appendix 2.

Table 4.1 Elevation of the base of wells for which geological logs are available.

Elevation of the base of well	Number of wells
Above sea level	219
Between sea level and 50 m below sea level	243
Between 50 m and 100 m below sea level	21
Below 100 m below sea level	22
Total	**505**

4.1.1.4 Other data sources

Aside from the data sources described above, there are many other information sources that can feed into the development of a 3D geological model, including previously published geological investigations, cross sections and maps, geophysical data (e.g. seismic surveys), and radiometric dates obtained for sediment and other geological materials. Key information sources used in this study include the following:

- **Cross sections:** Geological cross sections (e.g. Nairn 2002) provide useful information on the subsurface distribution of formations, particularly in the area outside the Rangitaiki Plains where lithological information are sparse.
- **Geophysics:** Geophysical data, especially seismic data and to a lesser degree magnetic data, form the major source of information for the estimation of depth to the top of the Matahina Ignimbrite and to the top of the basement as only very few wells intersect these units in the Rangitaiki Plains.
- **Radiocarbon dates:** Radiocarbon dates are available for sedimentary material derived from surface sediments in the study area. However, radiocarbon dates were only available for surface material and no radiocarbon dates exist for deeper sediments from drill holes in the Rangitaiki plains, and the usefulness of this data is therefore limited.

4.1.2 Digital terrain model

The DTM (Appendix 1) serves four main purposes in this study. First, the DTM (Figure 4.2) is used to define the top (ground) surface of the 3D geological model. Second, the DTM is used to identify physiographic features such as strandlines, gravel fans or river terraces, etc. that may be important for the development of the 3D geological model. Third, the DTM is used to define the top surfaces of geological units that are mapped at the ground surface. Finally, the DTM is used to check the elevations reported in well logs (Section 4.1.3).

4.1.3 Data checking

The 3D geological model is dependent on the accuracy and consistency of the input data from which it is developed. Hence assessment, verification and, where necessary, correction of the input data are early and critical steps in the overall 3D modelling work flow. The following discussion focuses primarily on the procedures used to check well log data, although other data sources are also checked carefully before 3D geological modelling commences.

The first stage of checking the well log data involves editing the lithological descriptions to ensure consistent use of terminology and spelling (Figure 4.3). This checking is performed for each individual well log and also across the entire well log dataset. For example, the lithological descriptions in the Bay of Plenty Regional Council well log dataset use the terms “peat”, “wood”, “log” and “organic”, which are all indicators of a similar depositional environment. In this study, these are all replaced with the lithological descriptor “organic”. Spelling corrections are also required, for example to replace the word “course” with “coarse”, “ignambrite” with “ignimbrite” and so on. All of these changes to the terminology and spelling in the lithological descriptions are required for subsequent generation of pseudo-logs using the Excel *Find* function. The *Find* function is case-sensitive, and so all lithological descriptions must also be converted to lower case. Appendix 2 presents a summary of edits made to lithological descriptions in the Bay of Plenty Regional Council well log dataset.

In the second stage of data checking, the well logs are examined for geological inconsistencies that may represent errors in the lithological descriptions (Appendix 2). Figure 4.3 shows an example well log in which “greywacke” is reported to occur above gravel. This is geologically unlikely, and thus it is presumed that the original description refers to “greywacke gravel”, such that use of the descriptor “gravel” would be more appropriate in this case.

The third stage of data checking involves verification of reported well elevations and locations. The source and accuracy of elevation and location information in a well log database is generally unknown. Hence the DTM is used to provide independent verification of the ground elevation reported for each individual bore log. As the source of ground elevation reported in bore logs is often unknown, the elevation estimate from the DTM is generally favoured to ensure consistency across the whole topographic dataset.

Although the data checking procedure is initiated prior to the development of the 3D geological model, it often becomes clear throughout later steps of the modelling process that information from individual well logs is poor (e.g. lithological description, well location, etc.). For example, a particular well log observation may be contradicted by neighbouring wells when the lithology is viewed in three dimensions. In such cases, additional queries to BOPRC are made for verification, and consequently corrections to the well log dataset often need to be made throughout the development of the 3D geological model.

4.1.4 Assignment of lithological property codes and creation of pseudo-logs

Once the Excel file containing the well log data has been checked and corrected as described above, it is screened for lithological descriptions that are 1) frequent in well logs throughout the dataset, 2) characteristic of a distinct origin or depositional environment, and 3) likely to assist with definition of the 3D geological model layer structure. The lithological descriptions that meet these criteria are specific to the study area and intended use for the 3D geological model. There are several key lithological descriptors selected for their relevance to this study, namely “gravel”, “sand”, “shells”, “organic” and “greywacke”. In addition, different classifications of gravels are also differentiated (e.g. pea gravels which are characteristic for marginally marine environments vs. gravel) to provide further information on depositional environments and lithological boundaries.

Lithological property codes are assigned to each well log and for each of the key lithological descriptors. The lithological property code is one of two different arbitrarily selected numbers that indicate the presence or absence of each lithological descriptor at each depth interval. In this study, the number 200 is used to indicate the presence of certain lithology or marker, whereas the number 100 is used to indicate its absence. To illustrate, the hypothetical well log in Figure 4.3 lists shells as the main fraction and organics as the secondary fraction over the elevation interval 235.5 to 235.0 m. Correspondingly, shell and organic lithological property codes are assigned a value of 200 for this same interval, whereas shell and organic lithological property codes are assigned a value of 100 to other elevations (Figure 4.4).

Pseudo-logs are created from the lithological property codes by interpolation at 0.1 m increments for each well log (Figure 4.4). This study requires generation of ten pseudo-log datasets for the 2243 lithological layers identified in 505 individual well logs. In this report, all graphical depictions of pseudo-logs show the presence or absence of key lithologies using red or purple, respectively. For example, the pseudo-logs displayed in Figure 4.4 indicate the presence of gravel and sand (red) and the absence of all other lithologies (purple) for the elevation range 234.7 m to 233.0 m. The pseudo-logs are then imported into EarthVision®, where they form the basis for the development of the 3D geological model.

4.1.5 Generation of 3D lithological property models

Individual pseudo-logs datasets, corresponding to each different lithological property code, are imported separately into EarthVision®. The presence or absence of each lithological property can then be assessed spatially across the model area, making it possible to search for possible correlations between wells. The output from this process is illustrated in the upper panels of Figure 4.5, which show separate pseudo-log projections for the gravel, sand, shells and organic lithology properties. Figure 4.5 is presented here only for general illustration of the work flow involved in the development of a 3D geological model; interpretation of results will be discussed in Section 5.

Figure 4.5 also illustrates the generation of 3D *lithological property models* for a hypothetical area. Such property models are generated by interpolating lithology property codes between wells. For example, if one well has a gravel property code of 200 (coloured red, gravel is present), and another nearby well has a gravel property code of 100 (coloured purple, gravel is absent), the area between the two wells will have interpolated values and colours that correspond to the probability that gravel is present at each intermediate location. A property model therefore allows the probable occurrence of each key lithology to be assessed across the volume of the modelled area.

Lithological property models can be viewed in a variety of useful ways. It is straightforward to create a cross section, slice or irregular surface through the model at any orientation, to investigate the probable distribution of certain lithologies at particular locations. It is also possible to show only the areas in which the property code is above or below a certain threshold. For example, it is often useful to show those parts of the modelled area with a property code of 150 or above, i.e. where the lithology of interest is more probable to be present than to be absent. This approach (with a threshold of 150) is used in this study to calculate the total volume associated with each key lithology (Section 5).

4.1.6 Definition of boundary surfaces for major geological units

A 3D geological model is generally composed of a series of units (layers), that are assembled with respect to their chronology and structural relationships. These units are defined and demarcated by a set of boundary surfaces. Thus, a key step in the modelling work is to determine how many boundary surfaces there should be, and where they should be positioned in 3D space. Not all stratigraphic units identified on the geological map, or subsurface data, are included as separate units into the 3D geological model. For simplicity of the model, stratigraphic units are combined into model units. The decision on how many model units are chosen is primarily based on the available data, i.e. where the available data (lithological drill hole data and geophysical data) do not allow a detailed sub-division, it is preferable to keep the model as simple as possible. In addition, the number of layers is also based on the significance of stratigraphic units for groundwater processes in the study area.

Generally it is only necessary to develop a surface for the top of each model layer. The bottom of each model layer is then automatically represented by the top surface of the layer underneath it.

For example, the 3D model developed in this study includes a surface that represents the top of the (undifferentiated) basement. In the areas where basement units are in outcrop outside the plains of the study area, the surface that defines “top of basement” is developed using ground-surface elevation data from the DTM. Where not mapped in outcrop, the “top of basement” surface is based on well logs that penetrate as far as the basement or interpretation of geophysical data such as seismic or gravity surveys. Due to the limited number of wells that intersect basement in the Rangitaiki Plains, the depth to basement and the depth to the Matahina Ignimbrite is primarily estimated from seismic or gravity surveys. Elevation data and lithological descriptions from wells with lithological logs are used to define the surface that represents the geologic contact between different Quaternary units.

Other layers are defined in a similar manner. For example, the occurrence of shells may indicate a marine depositional environment, which is often characteristic of Holocene sediments in coastal regions of New Zealand. A 3D property model of shell occurrence may then be used to define the surface representing the boundary between Holocene and Pleistocene sediments. Likewise, transitions from gravel to shell or organic sediment, as viewed on 3D property models, may be useful for defining the layer boundaries between Pleistocene units corresponding to low and high sea level.

In this study, the layer boundaries are defined by using the EarthVision® cursor to pick points in 3D, and then a surface is fitted to these points. In addition, and as an independent verification, boundaries between stratigraphic units are also determined by manually studying the well logs, particularly the limited number of deeper wells in the Rangitaiki Plains (Figure 4.1). A layer boundary may be well constrained in some parts of the model domain but poorly constrained or absent in other parts, for example due to lack of wells in a particular area. Where a layer boundary is poorly constrained, an effort is made to correlate and merge different portions of what is inferred to be the same surface. Finally, the constructed surfaces are compared to the original pseudo-logs and the degree of fit is visually assessed. Where necessary, adjustments are made to the surface geometry.

4.1.7 Assembly of the 3D geological model without inclusion of faults

The 3D geological model is assembled from its component layers, which are defined from the boundary surfaces (e.g. Figure 4.6a). In this process, the surfaces that represent the top of each geological layer are added to the model in chronological order, and the types of contacts between the different layers are defined (e.g. depositional contacts and unconformities). Where faults are present in a study area and where displacement of model units along faults occurs, it is important to model the major faults. In the modelling procedure followed in this study, an 3D geological model is first developed from the boundary surfaces without inclusion of faults (e.g. Figure 4.6a and Figure 4.6b), followed by the modelling of faults in the three dimensional space (Section 4.1.8.1), and finally the integration of faults and boundary surfaces (Section 4.1.8.2).

4.1.8 Assembly of geological model incorporating faults

The Rangitaiki Plains are a structurally very complex geological setting. Several steps are necessary as part of the transition from an unfaulted geological model to a faulted geological model that incorporates the major faults along which displacement of model units occurs.

4.1.8.1 Identification of faults and development of fault tree

The integration of faults into the 3D geological model is an iterative process. As a first step, fault traces at the ground surface are sourced from the GNS Science Active Faults Database or identified from the LIDAR data (Begg and Mouslopoulou 2010). Due to the large scale of the model and the complexity of the geology in the model domain, it is not practical to include all faults in the 3D geological model. In addition, while the surfaces traces are well documented (Begg and Mouslopoulou 2010), there is not enough well log data available to evaluate displacement of the major model units along each fault. Therefore, the principal faults along which displacement of major model units can be inferred from the lithological data or geophysical data are identified and attributed with fault plane dips, and the downthrown sides are identified.

Identified principal faults, their dip and dip azimuth (in brackets) are shown below listed in order of their location from NW to SE:

- Matata Fault (60°, SE);
- Otakiri Fault (60°, NW);
- Rotoitipaku Fault (60°, SE);
- Edgecumbe Fault (60°, NW);
- Te Teko Fault (60°, NW);
- Waiohau Fault (65°, NW);
- Whakatane Fault (65°, W);
- Waiohau Fault (65°, W).

In addition to these NW trending faults, two ring faults binding the caldera of the Okataina Volcanic centre (Nairn 2002), labelled as Caldera 2 Fault and Caldera 4 fault, are included in the fault model.

The study area is sub-divided into ten fault blocks (Figure 4.7), resulting from fault tree modelling (Figure 4.8), forming the basis for the integration of the faults with the BOPRC well log data (Section 4.1.8.2).

4.1.8.2 Integration of faults and horizons

In Section 4.1.7, the procedure of the assembly of the unfaulted 3D geological model was described. The development of the fault tree framework is explained in Section 4.1.8.1. In this section, the integration of faults and horizons to derive a faulted 3D geological model is explained. For the integration of the faults and the horizons representing the tops of the different model units, it is necessary to assess whether the top of any particular horizon is continuous and un-faulted across faults, or whether a vertical displacement has occurred. If the top of any particular model unit has not been displaced across the fault which forms the boundary between two fault blocks, then there is no need to model the top separately for the two fault blocks, and the same 2D grid can be used. In the example of fault block 9 (Figure 4.7 and Figure 4.9) the absence of lithological information (due to the absence of drill holes with lithological information in this area) does not allow determination of displacement of the “Q1 non-marine” model unit in the fault block or neighbouring fault blocks. The 2D grid developed for the unfaulted 3D geological model (Section 4.1.7) and for the entire model domain is therefore used, resulting in an interpolated boundary surface as shown in Figure 4.10a. In contrast, displacement of the “Undifferentiated basement” and “Matahina Ignimbrite” model units has occurred, as indicated by gravity surveys, and individual 2D grids have therefore been developed for these units in fault block 9. This allows modelling of these units separately for fault block 9 as indicated by Figure 4.10b. The same procedure is repeated for each fault block where displacement of model units is inferred from lithological or geophysical data.

5.0 GEOLOGICAL MODEL

This section summarises the features of the 3D geological model, including the DTM (Section 5.1), the distribution of gravel, shells, and other indicators of depositional environment (Section 5.2), the visualisation of geology and geological structure of the Rangitaiki Plains in three dimensions and the distribution of key lithologies within geological model units (Section 5.3). Section 5.4 provides a summary of insights into the Rangitaiki Plains groundwater resource, based on the 3D geological model, and Section 5.5 addresses uncertainties in the geological model.

A plan view map of the simplified surface geology and topography is used in this chapter as a background map to place the areas of interest within the context of the regional geological framework and geographic zones (Figure 5.1).

5.1 Digital elevation model and identification of geographic features

The digital elevation model (DEM) (Figure 5.2 and Figure 5.3) is useful for the identification of surface features relevant to the groundwater resource and to the 3D geological model developed in this study. On the basis of the analysis of surface elements from LIDAR data, Begg and Mouslopoulou (2010) subdivided the Rangitaiki Plains into five distinct geomorphic zones (Figure 5.4).

Key surface elements that can be identified from the DEM include:

- **Dunes and beach ridges:** Modern dunes and beach ridges are found near the coast, and elsewhere where they are preserved in places further inland with elevations ranging from 0 m, but mostly approximately 4.5 to 7 m above sea level (Figure 5.3 a, c and d, Figure 5.4).

- **Natural levee systems and perched river**: The Rangitaiki River lies within elevated natural levees and is perched above its surrounding flood plain (Figure 5.3 b).
- **Peat swamps below present day sea level**: Most of the peat swamps are present in the northwestern part of the Rangitaiki Plains, occupying depressions often below sea level and located between elevated levees (Figure 5.3 c). Many of these peat swamps owe their existence to active tectonic subsidence of the area west of the Edgecumbe Fault.
- **Okataina Volcanic Centre**: the Okataina Volcanic Centre, a source of extensive ignimbrite pyroclastic flow deposits, is a dominant surface element in the south-western part of the study area (Figure 5.2).
- **Matahina Ignimbrite**: Dissected surfaces in sheets of Matahina Ignimbrite, erupted from the Okataina Volcanic Centre c. 322 kyr ago, are present across much of the model area (Figure 5.2 and Figure 5.4), including across the Whakatane Hills (Figure 5.4).
- **Mount Edgecumbe**: Located in the central part of the study area, the prominent volcanic cone of Mount Edgecumbe and lava flows originating from this volcanic centre are a characteristic landmark in the study area (Figure 5.4).
- **Currently active and ancient floodplains of the main rivers:** Current and abandoned incised, meandering or leveed stream channels of the Whakatane, Rangitaiki and Tarawera rivers are visible on the digital elevation model (Figure 5.3 a, b).

5.2 Key lithologies

5.2.1 Occurrence of key lithological descriptions in well logs

Determining statistical parameters, such as the total number of times mentioned and percentage of logged length, for certain descriptors in the BOPRC well log dataset is possible following editing of well log descriptions to ensure consistent terminology and spelling (Appendix 2, Table A2.1). This assessment is based only on the well logs, which have only one dimension (depth). Hence the summary statistics only apply to the exact locations that wells have been drilled. These statistics based on the well logs alone are independent of estimates of the volumes of lithologies in the 3D geological model given in later sections of this report.

Several meaningful interpretations can be derived from this analysis:

- Pumice/pumiceous is the most common lithological parameter documented in the well logs (906 occurences). While this clearly demonstrates that pumice is of great significance in the study area, its usefulness as a lithological marker in modelling is limited because it may indicate either primary pyroclastics or alluvially reworked deposits.
- Gravel is second most common lithology, recognised in 511 well logs. Different types of gravel are attributed to different source areas and depositional environments. For example, “pea gravel” (86 occurrences) is often found in marginal marine deposits, whereas greywacke gravels (occurs 36 times in the eastern part of the Rangitaiki Plains, i.e. the Whakatane Lower geographic zone) are distinct markers of a fluvial environment with greywacke basement as the source area.

- The lithological parameter “sand” occurs 383 times and, like “pumice”, is not a strong stratigraphic marker because it is found in diverse fluvial and marine environments (e.g. as dunes or beach ridges in the Rangitaiki Plains).
- Organic sediments are common in the Rangitaiki Plains (354 occurrences). While their ambiguous association with both marine and fluvial environments limits the usefulness to some extent, their frequency in the well log dataset is sufficient to suggest that they could be useful markers for identification of layer boundaries during the development of the 3D geological model.
- Shells are present in 125 well log descriptions. They are one of the most important lithological parameters and form the basis for the determining the stratigraphy of the basin due to their unambiguous association with marine deposits, and for correlation with sea level through the Quaternary.
- Clay (66 occurrences) is less common than sand or gravel, and where it occurs, it can be associated with sand, gravel or organic sediments. This suggests that the 3D geological model could be developed to show the distribution of gravels or shells but not clay. This is because clay is essentially ubiquitous and is described in sediments deposited across a range of environments in the Rangitaiki Plains area.
- The lithological descriptors “organics” and “shells” do not occur very often in the well log dataset, and so probably do not account for a volumetrically significant fraction of the sediments in the study area.
- The term “greywacke” (as hardrock) appears eight times in the well log dataset for the study area, and particularly to the east and south of Whakatane. No greywacke is encountered in wells in the actual Rangitaiki Plains, suggesting that the basement is too deep to be penetrated by wells.
- The colour of lithologies reported in well logs is subjective and difficult to interpret. Colour may indicate the presence of a particular lithology, the presence of organic materials, or even the occurrence of a chemical condition such as the absence of oxygen. Thus, colours reported in the well logs have not been used as primary variables for development of the 3D geological model, but may prove useful for making correlations between wells at a relatively small spatial separation.
- Drillers rarely record whether water is present or absent for a particular horizon. This means that it is not possible to infer which lithologies are more or less likely to be water-bearing from a simple summary of well log descriptions alone.

5.2.2 Distributions of key lithologies within the study area

Following from the summary of lithological descriptions in well logs, gravel and shells, and to a lesser extent organics, are chosen as the key lithological descriptors to consider in 3D geological modelling because of their importance as stratigraphic markers and indicators of environment of deposition. While pumice is also frequently found in well log descriptions, its usefulness as a tool for stratigraphic correlation is minimal due to its ubiquity and a lack of distinguishing characteristics discernible from well logs.

The general geographic distribution of these key indicator descriptors in shallow layers in geographic zones 1 and 3 of the Rangitaiki Plains study area (Figure 5.1) is assessed using 3D lithological property models (Section 4.1.5). The results obtained for these shallow occurrences are summarised as follows, and more detailed information including the occurrence of the key lithologies at depth is discussed in Sections 5.3.3.2 and 5.4:

- **Gravel:** Gravel occurs in specific portions of the study area (Figure 5.5). At the ground surface, gravel is present as isolated deposits in different parts of geographic zones 1 and 3. In the Rangitaiki Plains (geographic zone 1) west of the Edgecumbe Fault, shallow gravels primarily occur close to the present day Rangitaiki River channel (Figure 5.5). East of the Edgecumbe Fault in the “Whakatane Lower” geographic zone, gravels form smaller deposits near the surface, probably representing abandoned channels of the Whakatane River. Gravels also occur in this geographic zone to the north of the Rangitaiki Hills (geographic zone 2).
- **Shells:** Shell-bearing lithologies are common in the Rangitaiki Plains area at and below the surface at the coastline and further inland (Figure 5.6). Shell-bearing lithologies also occur inland at depth, indicating Pleistocene marine incursions across the Rangitaiki Plains area.
- **Sand:** The 3D property model shows that sand is volumetrically the most important lithology in shallow deposits in the study area (Figure 5.7). Sand deposits occur at the ground surface in association with A) Holocene marine deposits at the coast and further inland, and B) Holocene terrestrial (fluvial) sediments deposited primarily by the three major rivers (Whakatane River, Rangitaiki River and Tarawera River). Sand occurs at the surface both west and east of the Edgecumbe Fault, and is only absent at the surface in swamps. Holocene and Pleistocene sand deposits are also shown to be common below the ground surface.
- **Organics:** Lithologies with organic materials, such as wood or peat, occur in shallow layers a few kilometres inland from the coast (Figure 5.8), where swamps cover extensive areas particularly in geographic zone 1 in the Rangitaiki River plain (Figure 5.1), consistent with active subsidence in this area.
- **Pumice:** Lithologies with pumice occur primarily further inland in geographic zone 1 (Figure 5.9), where the distribution of pumice suggested by the property model matches well with the extent of pumice outwash (Taupo Pumice outwash and Kaharoa Pumice outwash) suggested by Begg and Mouslopoulou (2009) (Section 5.1). Pumice is less common east of the Edgecumbe Fault, in accordance with the lithology of the surrounding hills, which are dominated by greywacke.

5.3 Geology of the Rangitaiki Plains area in 3D

In this section, the three-dimensional geological model is presented and the differentiation, occurrence and extent of the major geological model units are introduced. Modelled geological structure is also discussed.

5.3.1 Major geological units included in the geological model

In describing the stratigraphy and structure of a thick sequence of deposits such as those that lie beneath the Rangitaiki Plains, decisions about what geological units can be represented usefully must be made. This section describes the geological layer boundaries identified in the study area used for subsequent construction of the 3D geological model. Geological layers are defined by their boundaries, and usually, the base of a unit defines the top of the underlying one. The geological layer boundaries defined in this study comprise the major known geological units (Chapter 2 and 3) and summarise the occurrence and distribution of key lithologies in the study area (see Sections 5.1.1 and 5.1.2).

Layer boundaries are only defined between 1200 m above and 2500 m below sea level. The elevations of layer boundaries at the greater depth, particularly in geographic zones 1 and 3 (Rangitaiki Plains and Whakatane Lower, Figure 5.1), are based exclusively on the assessment of seismic lines and gravity surveys because no wells penetrate to such depths (Table 4.1, Section 4.1).

We have chosen to discriminate eight major units within our model, with their three dimension extents based on available data. The rationale for defining these lithological units is in their perceived importance for assessment of groundwater flow. The eight major model units included in the Rangitaiki Plains model are:

- **Q1 (Holocene) non-marine:** This model unit includes shallow deposits of variable lithologies including gravels, peats, sands, organic sediments and pumice. The distribution of lithologies within this model unit is documented in Section 5.1.2.
- **Q1 (Holocene) marine:** The Q1 marine model unit includes marine deposits of Holocene age, and is based on the occurrence of beach ridge deposits at the surface and shells, usually in pumiceous marine sand, at the surface or at depth.
- **Q2-Q4 terrestrial:** The Q2-Q4 model unit includes all terrestrial sediments of a Q2-Q4 (Pleistocene Last Glacial) age. Based on available data and without the help of radiocarbon dates, Q2, Q3 and Q4 surfaces are difficult to differentiate in well logs, and so are grouped within a single layer in our 3D geological model. From a groundwater perspective, the primary aim is to distinguish between units of substantially different hydraulic properties (e.g. lower permeability marine sediments versus terrestrial sediments such as sands or gravels) and the Q2-Q4 sediments are likely to have similar hydraulic properties, so further subdivision is not necessary.
- **Q5 marine:** The Q5 marine model unit correlates with marine deposits of the last interglacial. While the Q5 marine unit does not constitute an aquifer in the study area, it is important to include this unit into the 3D geological model as it defines a structural entity and can hydraulically separate aquifers of Q2-Q4 and Q6-Q8 age.
- **Q6-Q8 non-marine:** The Q6-Q8 non-marine model unit includes all sediments of Q6 to Q8 (Pleistocene) age. These are probably largely non-marine in origin, although the possibility of a marine Q7 unit cannot be discounted.
- **Volcanics undifferentiated:** The “Volcanics undifferentiated” model unit includes all volcanic sediments or rocks of an age younger than “Matahina Ignimbrite”, regardless of lithological differences.
- **Matahina Ignimbrite:** While the top of this model unit corresponds to the actual top of the Matahina Ignimbrite, the base of this unit does not necessarily correspond to the actual base of Matahina Ignimbrite. For stratigraphic and hydrogeological reasons, the top of the Matahina Ignimbrite is defined by our model. Where present, the top of the unit is welded and provides a strong signal in seismic reflection data, whereas underlying material belonging to the Matahina Ignimbrite may be non-welded and porous and is obscured in the seismic reflection signal. Few drillholes penetrate to these depths in the Rangitaiki Plains. For these reasons, the Matahina Ignimbrite includes all older Pleistocene sediments or volcanics between the top of the Matahina Ignimbrite and the top of the basement.

- **Basement undifferentiated:** This model unit comprises all basement rocks in the study area. These are primarily greywacke basement, but might locally also include other pre-Quaternary lithologies.

5.3.2 Boundary surfaces of major geological units

This section describes the boundaries of geological layers identified in the study area and used for subsequent construction of the 3D geological model. The geological layer boundaries defined in this study are derived from existing geological data and are based on the occurrence and distribution of key lithologies and geophysical data (seismic and gravity) in the study area (see Sections 2, 4.1 and 4.2).

Layer boundaries are defined between the ground surface and an elevation of 2500 m below sea level.

5.3.2.1 Top of "Basement undifferentiated" model unit

Due to the general lack of groundwater potential, the top of the basement surface is considered to distinguish geologic basement from overlying deposits for our 3D geological model. Where exposed at the ground surface, e.g. in the Whakatane Hills (Figure 5.1), the ground surface elevation from the DEM is used to represent the top of the basement layer. The subsurface extent of the upper surface of the basement unit is constrained almost exclusively by geophysical interpretation (particularly seismic and to a lesser extent gravity) because very few wells penetrate the basement in the subsurface of the model domain.

5.3.2.2 Top of "Matahina Ignimbrite" model unit

The top of the Matahina Ignimbrite model unit is represented by ground surface elevation data from the DEM where the unit is exposed at the ground surface in the geographic zones 2, 4, 5, 9, 10 and 11 (Figure 5.1). In the subsurface, this unit is penetrated by wells in geographic zone 3, but due to the considerable depth of this surface in the western part of the plains west of the Edgecumbe Fault (Figure 5.1), where the Matahina Ignimbrite is down-faulted into the Whakatane Graben, definition of this surface is based exclusively on interpretations from seismic lines. In this zone, the top of the Matahina Ignimbrite is highly welded and provides a strong reflector in seismic profiles. In contrast, the Matahina Ignimbrite is not welded (or not highly welded) in the eastern part of the plains in geographical zone 3, and no such obvious reflector is visible in seismic profiles.

5.3.2.3 Top of "Volcanics undifferentiated" model unit

The top of the "Volcanics undifferentiated" model unit is represented by ground surface elevation from the DEM where the unit is exposed at the ground surface in geographic subdivisions 2, 9, 10 and 11 (Figure 5.1). This unit is absent in the subsurface of the Rangitaiki Plains (geographic zones 1 and 3) . Where it occurs in the subsurface in geographic zones 9, 10 and 11, the elevation of the top of the unit is based on published cross-sections where possible (e.g. Nairn 2002), or an arbitrary depth of ~50 m below the ground surface is assumed, due to the lack of drilling records in this area.

5.3.2.4 Top of “Q6-Q8 non-marine” model unit

The Pleistocene Epoch was a time of alternating climate with correspondingly alternating sea level. Warm climatic regimes are associated with high sea level stands (often similar to today’s sea level), and cold climatic regimes are associated with low sea level stands, commonly 75 to 120 m below today’s sea level (e.g. Imbrie *et al.* 1984). Consequently, the nature of Pleistocene lithologies indicates change. For example, non-marine deposits, including alluvial gravels, dominate deposition during cool, low sea-level periods, whereas sand lithologies, which may contain shells and/or organic materials, dominate deposition during warm, high sea-level periods. The locations of major river courses also provide controls on Pleistocene deposition. Above the Matahina Ignimbrite, the top of the Q6-Q8 model unit is the oldest Pleistocene boundary that can be reasonably correlated and identified throughout the study area. The top of this unit is based on the occurrence of deep gravels below a deep layer of shells (representing Q5 marine) in well logs. Additional points are generated based on the assumption that subsidence and deposition in the Rangitaiki Plains has been more or less constant throughout the Pleistocene since deposition of the Matahina Ignimbrite. The known depth of the top of the Matahina Ignimbrite provides a base for the unit and allows calculation of a thickness for the Q6-Q8 unit.

5.3.2.5 Top of “Q5 marine” model unit

Sediments of Q5 age (Last Interglacial) were deposited in marginal marine or marine environments, and are identifiable at depth by the presence of deep sands (typically more than 100 m), sometimes with shells, in geographic zones 1 and 3. The unit is defined by the base of correlative marine sand (± shells). As only relatively few deep wells exist in the study area, interpolation of Q5 data points between known data points was undertaken on the basis of subsidence/deposition rates derived from the top of the Matahina Ignimbrite and from Holocene data.

5.3.2.6 Top of “Q2-Q4” model unit

Late Pleistocene Q2, Q3 and Q4 sediments in the study area are correlated with the Otiran Glaciation. The grid representing the top of this layer is entirely based on subsurface data, and in particular the distribution of gravels, shells and organics. This unit is modelled to exclude the shallowest shell layer (Q1 marine), but includes gravel deposits below the uppermost marine and non-marine beds.

5.3.2.7 Top of “Q1 marine” model unit

Holocene marine sediments occur in geographic zones 1 and 3 of the Rangitaiki Plains (Figure 5.1). Where exposed at the surface, as for example in the stranded beach ridges of the eastern plains south-west of Whakatane, the ground surface is used to represent the top of the Holocene marine layer. Where the top is covered by Q1 non-marine sediments, the top of the Q1 marine model unit is represented by points on the base of the uppermost (youngest) layer in the 3D geological model.

5.3.2.8 Top of “Q1 non-marine” model unit

Holocene (terrestrial) sediments form the uppermost (youngest) layer in the 3D geological model. The ground surface is used to represent the top of the Holocene layer for all parts of the study area in which such sediments occur (Figure 5.1).

5.3.3 Geology of the Rangitaiki Plains area in 3D

5.3.3.1 Unfaulted model and location of faults

Following the definition of the surfaces that bound the major geological units as described in Section 5.3, the construction of the 3D geological model can commence. The model developed in this study represents the major geological units within the range from the ground surface to the depth of 2500 m below sea level. As described in sections 4.1.7 and 4.1.8, the model is first developed without inclusion of faults; the top of each geological model unit is described by a single boundary surface for the entire geological model domain. The resulting model (Figure 5.10) resembles the final model, but lacks displacement of model units across faults.

5.3.3.2 Final geological model

Development of the unfaulted model was followed by incorporation of fault information and construction of the final geological model. The final model developed in this study represents the major geological units between the ground surface and a basinal depth of 2500 m below sea level.

An overview of the final model showing all model units and their spatial dimensions is given in Figure 5.11, and a sequence of images showing the occurrence of individual model units in the three-dimensional space within the geological and structural framework is shown in Figures 5.12 to 5.19. In addition, a sequence of images showing the distribution of the key lithological markers “shell”, which signals deposition during warm, high sea-level periods, and (alluvial aggradational) “gravel”, which dominate deposition during cool, low-sea-level periods (and may represent productive aquifers) are shown in Figures 5.20 and 5.21, respectively.

Key features and inferences of the geology of the study area include the following, from older units to younger units:

- **Basement undifferentiated:** The “Basement undifferentiated” model unit is down-faulted in the Whakatane Graben. The vertical displacement of this model unit west of the Edgecumbe Fault is more than 2000 m relative to the basement to the east of the Edgecumbe Fault and west to the Matata Fault. The “Basement undifferentiated” model unit is also down-faulted in the Okataina Volcanic Centre with vertical displacement of several hundred metres, as is suggested by gravity data.
- **Matahina Ignimbrite:** This model unit is also down-faulted in the Whakatane Graben with a vertical displacement of more than 1000 m along the Edgecumbe Fault. The Matahina Ignimbrite model unit (which includes older volcanics and Pleistocene sediments) reaches a thickness of almost 1000 m in the centre of the Whakatane Graben. In the Okaitaina Volcanic Centre, the Matahina Ignimbrite is also down-faulted along several faults.
- **Volcanics undifferentiated:** The occurrence of this model unit is limited to the southern part of the model domain. This is a composite unit that includes deposits ranging in age from Holocene to early Quaternary (>500 kyr), and thus its treatment as a single unit results in a number of artefacts in the model. Elements of this unit are interbedded with other geological units, and in the Whakatane Graben, included within other units. Most importantly, south of the Rangitaiki Plains, it is not possible to strip this unit without creating topographic anomalies on remaining units. Relatively small fault displacements

on units younger than the Matahina Ignimbrite depicted beneath the Rangitaiki Plains are also an anomaly resulting from this complication. Because it is a composite unit, its thickness is highly variable, ranging from absent, or a few metres thickness to several hundred metres at the Okataina Volcanic Centre.

- **Q6-Q8 non-marine:** This model unit is displaced considerably along the major faults. The largest displacement occurs along the Edgecumbe Fault, where the vertical displacement is several hundred meters (Figure 5.16). The surface of the Q6-Q8 model unit generally slopes towards the centre of the Whakatane Graben, where the thickest accumulation of Q6-Q8 sediments (>500 m) is present. Its thickness east of the Edgecumbe Fault varies, but is typically ~100 m.
- **Q5 marine:** The Q5 model unit is also displaced substantially along the major faults in the northern part of the coastal plains. The thickness is highly variable, with only a few metres displacement in the south to more than 100 m displacement in the Whakatane Graben to the west of the Edgecumbe Fault.
- **Q2-Q4:** It is assumed for the model generation that the top of this model unit is little displaced along the major faults because there is only c. 12 k yrs of time since it was deposited. The thickness of this model unit is also highly variable, with the thickest accumulation of Q2-Q4 sediments occurring in the centre of the Whakatane Graben (west of the Edgecumbe Fault), where this unit reaches a thickness of more than 300 m.
- **Q1 marine:** Holocene marginal marine sediments are exposed at the surface as beach ridges on the southeastern side of the Edgecumbe Fault, south-west of Whakatane. They are present throughout the plains of the study area at a depth varying from approximately 10-20 m below the ground surface. Further inland, they are present beneath younger Q1 non-marine deposits southwest of the township of Edgecumbe. Thickness is variable, but typically does not exceed ~10-20 m.
- **Q1 non-marine:** These Holocene sediments form the shallowest layer in the near-coastal plain and further inland in river valleys in upstream catchments of the major rivers (Rangitaiki, Whakatane and Tarawera rivers) and their tributaries. In the upstream catchments, no subdivision between Q1, Q2-Q4 and Q6-Q8 sediments is possible due to the lack of well record data. Thickness is variable, but typically ranges from 15 to 50 m.

5.4 Three-dimensional geological model and groundwater flow in the Rangitaiki Plains

Having defined the 3D geological units of the area, in this section, groundwater flow, particularly within the geographic zones 1, 2 and 3 (Figure 5.1), is assessed using the model, a potentiometric surface map, a depth to water map and general information on geology and hydraulic properties of the major geological units in the model domain. In Chapter 6, the water budget is used to assess interactions between groundwater and surface water.

Water level readings from wells (Figure 5.22) are used to derive the depth to static water level (SWL) map (Figure 5.23) and the potentiometric surface map (Figure 5.24). The water level reading should represent the static water level (SWL), which is accurate only if no pumps are in operation. The initial data set was screened for extreme outliers, which are likely to represent either erroneous readings or readings that do not represent the static water level (e.g. readings taken while pumps were in operation).

5.4.1 Depth to static water level

The depth to water map (Figure 5.23) shows that the depth of the static water level below the ground surface is slightly greater in the “Whakatane Lower” geographic zone east of the Edgecumbe Fault than in the “Rangitaiki Plains” geographic zone west of the Edgecumbe Fault. As discussed in Section 5.1, swamps are a common geomorphic feature in the low-lying areas of the western part of the Rangitaiki Plains, a clear indication that the water level here lies close to the ground surface. Despite the presence of swamps west of the Edgecumbe Fault, areas with water levels less than 2 m below the surface are not well documented by Figure 5.23, probably indicating that there are insufficient observations close to the swamps, or that the measured water level does not represent the static water level. This may be the result of pumping by extensive dewatering schemes operating near the coast (Bay of Plenty Regional Council 2002).

5.4.2 Groundwater flow directions/potentiometric surface

The potentiometric surface map (Figure 5.24) depicts patterns of groundwater flow direction in geographic zones 1 and 3. Due to the relatively small number of wells available for this assessment and general lack of information on screened intervals, this assessment does not consider vertical gradients between different hydraulic units (e.g. aquifers/aquitards), which would be indicative of the potential for upwards or downwards movement of groundwater between units. As discussed in 5.4.1, it is not clear whether the recorded water levels accurately represent static water level in all areas. Therefore, a programme of groundwater level measurement is recommended (Section 8.4) for the middle – end of summer period with the aim of improving the piezometric map.

The potentiometric surface shows that groundwater in geographic zone 1 (Rangitaiki Plains) generally follows the topographic gradient from the higher elevation areas in the west and south-west towards the north and north-east, where groundwater outflows to the sea. Locally, swamps probably also form sinks for groundwater flow as suggested by a somewhat interrupted drainage pattern where a relatively high degree of variation of groundwater flow directions can be observed over small distances.

While there is also a comparatively high degree of variation of the groundwater flow direction in geographic zone 3 (Whakatane Lower), the potentiometric surface map suggests that the prevailing direction of groundwater flow is from south-east towards the north and north-west. The potentiometric surface map shows that the dominant groundwater flow is northwest across the Edgecumbe Fault at the boundary between geographic zones 1 and 3.

5.4.3 Insights into groundwater flow and recharge in the Rangitaiki Plains

Groundwater flow is influenced by a variety of factors including topography, aquifer lithology, aquifer geometry and interconnectedness between aquifers. A full assessment of groundwater flow generally requires the use of a numerical model, but certain inferences can be made from the 3D geological model, in particular in relation to groundwater recharge (Figure 5.25) including the predicted probability of the occurrence of gravels, which are typically permeable to groundwater flow and therefore likely to form important aquifers in the Rangitaiki Plains.

In this section, examples of such inferences for the different lithologies/geological model units are given.

5.4.3.1 Q1 non-marine model unit

Property codes projected on the top of the Rangitaiki Plains model domain (Figures 5.5 to 5.9) show that sand and pumice dominate the shallow lithology of the Rangitaiki Plains and Whakatane Lower geographic zones (Figure 5.1, Figure 5. 7 and Figure 5.9), although there is generally a high lateral variability of alternating sequences of sand, pumice, gravel, clay and organic sediments across the plains. Low permeability sediments such as clay or organic sediments can form zones of restricted groundwater flow, and it is therefore likely that there is not a single connected shallow aquifer system within the Q1 non-marine model unit of geographic zones 1 and 3 in the Rangitaiki Plains. The most extensive shallow gravel deposits occur near current river channels (especially near the Rangitaiki River) (Figures 5.5 and 5.21). Elsewhere, and particularly in the Whakatane Lower geographic zone east of the Edgecumbe Fault, gravels form scattered deposits at or near the ground surface, but despite their isolation, they may represent locally important flow systems.

The shallow aquifers are typically unconfined, or semiconfined, where clastic sequences may be confined by peat or clay. Recharge to the shallow aquifer systems within the Q1 non-marine unit is dominated by direct rainfall recharge on the surface, although river recharge and seepage from older units can also contribute towards groundwater recharge.

In addition to gravels, other lithologies contained within the Q1 non-marine model unit may also act as aquifers, as for example pumice and pumiceous sands. Where pumiceous outwash material (e.g. Taupo pumice alluvium or Kaharoa pumice alluvium, Figure 5.3) or airfall from the Last Glacial (particularly Mangaone Subgroup) forms laterally and vertically extensive deposits, these are likely to store a considerable amount of water and are also likely to be permeable and transmissive. Where these are present and where the marine layers of “Q1 marine” and “Q5 marine” are absent, they may also be vertically connected.

5.4.3.2 Q1 marine and Q5 marine model units

The significance of the marine sediments of Q1 marine and Q5 marine model units as aquifers is likely to vary throughout the plains because the composition of these sediments ranges from low-permeability marine-estuarine muds to more permeable sands and gravels. The assessment of well depths suggests that a considerable number of wells terminate in these marine units, indicating that these are probably a source of water, at least locally. However, where they are composed primarily of less permeable sediments with higher clay contents, they probably form poor aquifers and may restrict groundwater flow between the over- and underlying more permeable sediments of the terrestrial Holocene and Pleistocene units.

5.4.3.3 Q2-Q4 and Q6-Q8 model units

Extensive gravel deposits occur at depth within the Q2-Q4 and Q6-Q8 model units. Both the Q2-Q4 and Q6-Q8 model units are recharged by downwards leakage from the overlying Q1 non-marine units. This downwards leakage is probably considerably higher near the outer limits of the plains and beyond, due to the absence of marine layers which probably act as confining units. In addition to seepage from overlying layers, groundwater recharge to the Q2-Q4 and Q6-Q8 model units also occurs from other units where these terminate or abut along faults (Figure 5.26).

To the east of the Edgecumbe Fault, these gravels are probably dominated by greywacke clasts, whereas their composition appears to be more variable with a higher portion of volcanoclastic (e.g. pumiceous) material to the west of this important structural element due to the proximity of outcropping volcanic units here.

Thickness of the Q2-Q4 and Q6-Q8 model units is generally greater in geographic zone 1 west of the Edgecumbe Fault than in geographic zone 3, due to ongoing subsidence. East of the Edgecumbe Fault, the top of the Matahina Ignimbrite, which is probably present at depths of c. 200 m, provides a limit for the maximum thickness of the gravels. Where Q1 marine and Q5 marine model units are present within the plains (Figures 5.13 and 5.15), they probably restrict groundwater flow between units, and therefore vertically separate different gravel deposits. However, the property model of gravel (Figure 5.21) indicates that gravels are abundant within the Q2-Q4 and Q6-Q8 model units in geographic zone 3, and may be vertically continuous. Therefore, these units may represent major aquifers.

To the west of the Edgecumbe Fault, the Matahina Ignimbrite and other units are down-faulted within the Whakatane Graben, and the top of the Matahina Ignimbrite, which constrains the maximum thickness of the Q1-Q8, typically occurs at depths of more than 800 m throughout much of the central and western plains (Figure 5.21). The maximum bore depth in this area is approximately 300 m (Figure 4.1), and the property model (Figure 5.21) therefore only represents the occurrence of gravels to this depth; however, gravels are probably present below this depth as a result of subsidence and deposition. Such depths are likely to be too great for economic development as a groundwater resource, at least in the short term. On the gravel property model (Figure 5.21), gravels are less continuous both vertically and laterally west than to the east of the Edgecumbe Fault. This probably partly reflects the presence of other lithologies such as organic sediments or pumice in this subsiding depocentre. However, it may also reflects a relative lack of deep wells especially near the coast and in the north-west (Figure 4.1); further drilling is required to test the lateral and vertical continuity of gravels across geographic area 1.

5.4.3.4 Volcanics undifferentiated

This model unit incorporates volcanoclastic sediments and volcanic rocks of highly variable age, composition and hydraulic properties. The volcanic sediments and rocks in this unit form extensive surface outcrop areas in the southern part of the geological model area (geographic zones 2, 9, 10 and 11; Figure 5.1). Where they are unconsolidated volcanoclastic materials, recharge rates are likely to be considerable. In addition, volcanic rocks can also form primary recharge areas if they are highly fractured, so there may be significant groundwater recharge at Mt. Edgecumbe. Some of the components of this unit with varying ages probably continue laterally into the Rangitaiki Plains. However, in places groundwater outflow to streams, or groundwater recharge of other units (particularly Q1 non-marine, Q2-Q4 or Q6-Q8; Figure 5.26), may occur where they interface in the subsurface.

5.4.3.5 Matahina Ignimbrite

Matahina Ignimbrite is present in much of the Whakatane Graben at depths below those presently feasible for groundwater resource development (Figure 5.21). Compounding this economic uncertainty, the hydraulic properties of the Matahina Ignimbrite are variable throughout the geological model area. Recharge to the Matahina Ignimbrite occurs through its extensive surface outcrop areas in geographic zones 2, 4, 5, 9, 10 and 11 (Figures 5.1 and 5.21). Because the Matahina Ignimbrite is strongly welded, a high fraction of the excess rainfall (defined as precipitation minus evaporation) probably generates surface runoff from these areas.

Inferences of the significance of the Matahina Ignimbrite as a groundwater resource in different parts of the geological model area include:

- In the south-western Rangitaiki Plains near Otakiri (Figure 5.1), BOPRC (2002) estimated transmissivities of between 6,000 and 12,000 m^2/day for fractured Matahina Ignimbrite near Otakiri. Artesian pressure has been reported from wells in this area (BOPRC 1991), suggesting that the ignimbrite here is a significant aquifer.
- In the central and near coastal part of Rangitaiki Plains west of the Edgecumbe Fault (geographic zone 1; Figure 5.1), the Matahina Ignimbrite is down-faulted within the Whakatane Graben and the top of the unit is typically at depths greater than 800 m (e.g. Figure 5.21). Groundwater stored within the Matahina Ignimbrite in this area probably originates from rainfall recharge through the surface outcrops of this unit outside the plains in geographical zones 2, 9, 10 and 11 (Figures 5.1 and 5.25). Seismic profiles show that the top of the Matahina Ignimbrite is a strong reflector, suggesting that it is strongly welded. The high density contrast with overlying Q8 or younger units suggests the top of the Matahina Ignimbrite may form a relatively impervious surface across a wide area and that hydraulic connection with the overlying Quarternary sediments is small; faults in the area (e.g. Figure 5.21) may provide conduits for upwards or downwards groundwater flow. The Matahina Ignimbrite continues laterally beyond the present day coastline, and groundwater outflow from this unit probably occurs north of the coast.
- In geographic zone 3 in the eastern Rangitaiki Plains (Figure 5.1), the Matahina Ignimbrite does not form a strong reflector in seismic profiles, suggesting that it is not as strongly welded as west of the Edgecumbe Fault. In contrast to the area to the west of the Edgecumbe Fault, the Matahina Ignimbrite of geographic zone 3 is not hydraulically linked to any significant outcrop area of Matahina Ignimbrite, as the surface outcrops are dominated by (greywacke) basement in this area. Here, recharge to the Matahina Ignimbrite therefore probably results primarily through seepage from the overlying Quaternary sediments (Figures 5.26 and 5.27). Groundwater flow from the Matahina Ignimbrite into Pleistocene sediments may occur at its western truncation against the Edgecumbe Fault (Figures 5.26 and 5.27).
- In geographic zone 5 and 6 (Figure 5.1), the Matahina Ignimbrite is present at the surface and in the subsurface. Groundwater recharge to the Matahina Ignimbrite here therefore probably occurs directly through rainfall recharge on surface outcrops. The depth of the Matahina Ignimbrite is poorly constrained due to paucity of drill hole information, but the geometry of the valley, with its very narrow outlet, suggests that groundwater may flow from the Matahina Ignimbrite into overlying Quaternary units (Figure 5.27) in this area.

5.4.3.6 Basement undifferentiated

Greywacke basement typically forms poor aquifers, and it is therefore assumed that a large fraction of rainfall on the greywacke outcrops generates surface runoff, and no significant groundwater recharge occurs. Where the basement is down-faulted along faults (e.g. Edgecumbe Fault), there is the potential for some transfer of water towards Pleistocene sediments, but any such transfer is likely to be relatively minor.

5.5 Uncertainty of the 3D geological model

All three-dimensional geological models are associated with uncertainties, which can result for example from (but are not limited to) the following factors (e.g. Lelliot *et al.* 2009):

- **Data density:** Data density is typically low if the layer structure is based on lithological records from a few wells, whereas it is high where the top of a layer is based on the DTM.
- **Data quality:** This factor refers to inaccurate well location, lithological descriptions or lack of descriptive detail (as discussed in Chapter 4.1.3).
- **Geological complexity:** Where geological complexity is low, there are few possible 3D solutions; but where geological complexity is high (as particularly in the plains part of the study area), many solutions are available to explain available data. However, geological models developed in other parts of New Zealand give some clues to the distribution of some geological units. For example the Holocene marine incursion is common to many coastal areas e.g.: Christchurch (White 2009), Marlborough (White *et al.* 2009a) and Horowhenua (White *et al.* 2010).

While a detailed uncertainty analysis is beyond the scope of this project, it is important to be aware of data uncertainties and limitations, and that these may vary across the model domain. For example, the lack of drill hole data may have a significant impact where the model aims to differentiate between different Quaternary model units in the plains part of the model, but the lack of drill records does not impact where “Basement undifferentiated” forms surface outcrops, because the data from the DTM can be used here.

Table 5.1 gives an estimate of the variation of the model uncertainties throughout the different geographic zones, and gives recommendations on how to further reduce these uncertainties.

Table 5.1 Distribution of uncertainty in different geographic zones of the geological model domain.

Geographic zone (Figure 5.1)	Data density	Data quality	Geological complexity		Overall uncertainty	Priority for model improvement	Options for model improvements
			Structural	Depositional			
1	variable[1]	variable[1]	high	high	high	high	drill additional stratigraphic wells, radiocarbon dating of sediments
2	high	high[1]	low	low	medium	low	N/A
3	variable[1]	variable[1]	medium	high	high	high	drill additional stratigraphic wells, radiocarbon dating of sediments
4	high	high[2]	low	low	low	low	N/A
5	low	low	medium	medium	high	high	drill stratigraphic (deep) wells to basement in alluvial sediments of Whakatane river valley, radiocarbon dating of sediments
6	medium	low (mostly shallow wells)	low	low	medium	high	drill stratigraphic (deep) wells to basement in alluvial sediments of Whakatane river valley, radiocarbon dating of sediments
7	high[2]	high[2]	low	low	low	low	N/A
8	low	low	low	low	high	high	drill stratigraphic (deep) wells to basement in sedimentary basin, radiocarbon dating of sediments
9	variable[3]	variable[3]	low	low	medium	medium	drill stratigraphic well(s) to basement in north-western part of the plains, radiocarbon dating of sediments
10	low	low	high	medium	high	high	drill stratigraphic wells in alluvial sediments of Tarawera River valley (currently underway)
11	variable[3]	variable[3]	low	low	low	low	drill stratigraphic well(s) in alluvial sediments of Rangitaiki River valley

[1] = abundant shallow wells, but only few deep wells, high-quality geophysical data

[2] = top of layers mostly based on DTM data and geological mapping

[3] = most layers based on DTM data, but some layers require lithological descriptions from wells

6.0 GROUNDWATER BUDGET

Groundwater catchments are identified in the study area for the Rangitaiki Plains, the Tarawera River catchment, part of the Rangitaiki River catchment and part of the Whakatane River catchment south of Rangitaiki Plains (Section 6.1).

A groundwater budget is developed for individual groundwater catchments and also for the study area as a whole (Section 6.2). These groundwater budgets are used to estimate steady-state inflows and outflows. These groundwater budgets are also used to estimate groundwater available for allocation (Section 7).

6.1 Groundwater catchment boundaries

Major groundwater catchments are identified on the Rangitaiki Plains and the Tarawera River and Whakatane River catchments above Rangitaiki Plains (Figure 6.1). Groundwater catchment boundaries on the Rangitaiki Plains are identified with an analysis of surface water flows, including drainage scheme flows, and groundwater flow directions (see Section 6.1.1). Surface water flows are relevant to identification of groundwater catchment boundaries on the Rangitaiki Plains because:

- surface drainage catchments have measurements of surface water inflow and outflow that are used for groundwater budget calculations;
- surface drainage catchments are relatively large on the Plains and groundwater budget calculations are made in a relatively small number of catchments;
- surface drainage catchments may receive groundwater flow from adjacent groundwater catchments (groundwater budgets are used to assess these flows); and
- surface flow in drains comes from groundwater, therefore groundwater use may impact on drain flow within a groundwater catchment.

Boundaries of groundwater catchments the Tarawera River and Whakatane River catchments above Rangitaiki Plains are assumed as surface catchment boundaries (see Section 6.1.2).

6.1.1 Rangitaiki Plains surface catchment boundaries and pumped catchment boundaries

Groundwater catchments in the Rangitaiki Plains are identified using a combination of GIS techniques and field verification by Bay of Plenty Regional Council’s drain extents and Rivers and Drainage staff.

The surface hydrology of the Rangitaiki Plains has been considerably altered over the last 100 years by drainage schemes and by realignment of natural waterways (Gibbons 1990). These schemes developed pastoral land from the once vast Rangitaiki Plains wetland system. Thus, the present-day drainage on the Rangitaiki Plains does not reflect the original drainage characteristics of the Plains; the natural drainage patterns have been considerably altered.

Identification of groundwater catchments typically includes assessment of groundwater levels (Figure 6.2, Appendix 3). The potentiometric surface, and groundwater flow directions, indicates two shallow groundwater catchments in the Rangitaiki Plains:

- groundwater in the Whakatane area flows from the general direction of Awakeri and the Whakatane River towards Whakatane township and the coast; and
- groundwater in the Tarawera and Rangitaiki surface catchments flows from the upper Plains towards the coast.

However, Rangitaiki Plains groundwater catchments are difficult to identify from groundwater levels and flow directions alone. This is because because groundwater levels are very similar in most wells across the Rangitaiki Plains, particularly in the lower Plains. Therefore, surface catchment boundaries are developed (Figure 6.3). These surface catchment boundaries are delineated with the use of ArcGIS 9.3.1 and the extension Arc hydro v1.3 (GISWR 2009) as follows:

i. The Arc hydro Terrain Processing toolset is used to generate topographically correct catchments based on elevation data at a resolution of one square kilometre, for the Rangitaiki Plains. Major streams, drains and rivers are ‘burned’ into the elevation surface to force drainage to these systems. Surface catchments on most of the Rangitaiki Plains are delineated using LIDAR data; the vertical accuracy of LIDAR is 0.25 m. Hill catchments that feed Rangitaiki Plains drainage systems, and are outside the extent of LIDAR data, are digitised from the 20 m contour data and Bay of Plenty Regional Council's 1:50 000 River Line dataset. Note that topographically-correct catchments do not always correspond to hydrological catchments because drain systems alter the natural drainage.
ii. Hydrological catchment areas corresponding to major drain systems are identified by the Arc Hydro Terrain Processing toolset. The Stream Definition function uses a flow accumulation grid as input and creates a Stream Grid for a user-defined threshold (1 km^2) to estimate surface flow direction. Drain catchments are grouped according to their contributing stream grid.
iii. Data verification was undertaken by Bay of Plenty Regional Council’s Rivers and Drainage field staff because of the highly modified nature of the Rangitaiki Plains and the presence of hydrologic structures such as culverts. This process ensures that baseflow discharge, which may be intercepted by culverts and other engineered structures, is modelled as discharging to the correct drainage system.
iv. Surface catchments represent aggregated hydrological catchment areas that are named according to Bay of Plenty Regional Council’s drainage schemes and described according to the river catchment (Rangitaiki, Whakatane or Tarawera) into which they discharge (Figure 6.3). ArcGIS attribute descriptors of surface catchments are listed in Appendix 4.

Pumped catchment boundaries on the Rangitaiki Plains, shown in Figure 6.4, are then delineated to represent drained areas by the following process:

i. Bay of Plenty Regional Council’s pump catchment area data for the Rangitaiki Plains are overlain with surface catchments (Figure 6.4). The pumped catchment boundaries are cropped and adjusted to align with surface catchment boundaries. Pumped catchment boundaries may differ slightly from surface catchment boundaries because a coarse resolution was used in their original delineation. The accuracy with which the original pumped catchments were captured is unknown.

ii. ArcGIS attribute descriptors include pump name and Bay of Plenty Regional Council drainage scheme, as provided by Bay of Plenty Regional Council Rivers and Drainage staff (Appendix 4 and Appendix 5).

6.1.2 Tarawera and Whakatane river catchments above Rangitaiki Plains

Tarawera and Whakatane river catchment boundaries above the Rangitaiki Plains are identified by BOPRC. These catchment boundaries are based on topographic analysis.

6.2 Groundwater budget components

The groundwater budget for the study area identifies inflows and out flows from the groundwater system. Inflows to groundwater are: 1) the net of rainfall (P) minus actual evapotranspiration (AET); 2) surface water inflows from adjacent groundwater catchments (IS); and 3) groundwater inflows from adjacent groundwater catchments (IG). Groundwater outflows are: 1) groundwater outflow to surface water as baseflow, including streams and drains (OS); 2) groundwater outflow across the coastal boundary (OC); and 3) groundwater outflow to adjacent groundwater catchments (OG).

The groundwater budget equation assumes steady-state conditions, i.e.:

$$\text{water inflow} = \text{water outflow, or}$$

$$P + IS + IG = AET + OS + OC + OG$$

The groundwater budget represents some surface water flow components. For example, surface water inflow to the study area from Lake Tarawera is relevant to the groundwater budget because the Tarawera River is shown to gain flow from groundwater in the upper catchment (Section 6.2.3.1).

The groundwater budget does not aim to represent all surface water components of flow. For example, surface water inflows and out flows on the Rangitaiki Plains in the major rivers (Rangitaiki, Whakatane and Tarawera) have not been included in this groundwater budget. This is because good estimates of surface flow are not available at points of inflow to Rangitaiki Plains and outflow from the Rangitaiki Plains, and on the Rangitaiki Plains, in the major rivers. Therefore estimates of losses or gains in river flow, as a result of the interaction of groundwater and surface water in the major rivers, are unknown and not considered in this groundwater budget. The groundwater budget for Rangitaiki Plains groundwater catchments makes conservative assumptions of groundwater flow in Rangitaiki Plains groundwater catchments by discounting potential inflow to groundwater from major rivers, and potential groundwater outflow to major rivers. These conservative assumptions result in assessments of groundwater available for allocation (Section 7) in Rangitaiki Plains groundwater catchments that are appropriately conservative. Correct assessment of all surface water flow components is beyond the scope of this report.

This approach is the same as that used to estimate groundwater budgets in the Western Bay of Plenty (White *et al.* 2009b) and the Paengaroa-Matata area (White *et al.* 2008). However, the estimation of rainfall recharge to groundwater in this report differs from that in White *et al.* (2009b) and White *et al.* (2008). In this report rainfall to groundwater is estimated as P – AET. The approach of White *et al.* (2009b) and White *et al.* (2008) was to estimate rainfall recharge, because a model of actual evapotranspiration was not available to these projects, as:

- approximately 50% rainfall recharge on hill catchments which is the maximum measured in two lysimeters located at Kaharoa, near Lake Rotorua, in volcanic lithologies (White *et al*. 2007) and approximately 50% rainfall recharge is measured for the Mamaku Plateau discharge through springs and streams around Putaruru (White *et al*., 2004);
- approximately 30% rainfall recharge over coastal plains because 30% rainfall recharge through sedimentary deposits is measured by White *et al*. (2003) in Canterbury and rainfall minus potential evapotranspiration is 30% of rainfall at Tauranga (Bay of Plenty Regional Council 1990).

Estimates of groundwater recharge from rainfall in the Rangitaiki study area emphasise that rainfall recharge on hill catchments is greater than rainfall recharge in plains catchments. For example rainfall recharge, as rainfall – AET (from Table 6.1), in the study area is approximately:

- 52% of rainfall on hill catchments;
- 38% of rainfall on plains catchments.

Estimates of groundwater recharge from rainfall in the Rangitaiki study area also indicate that rainfall recharge estimates used by White *et al.* (2009b) and White *et al.* (2008) are conservative with regard to rainfall recharge.

6.2.1 Groundwater inflow

Rainfall and AET on the Rangitaiki Plains are controlled, somewhat, by the topography. For example, rainfall tends to decrease across the plains and increase along the hills catchments while the inverse is true for AET (Figure 6.5 and Figure 6.6).

Mean rainfall and mean AET are estimated in mm/year for each groundwater catchments using the statistics tool available from the ArcGIS Spatial Analyst toolset (Table 6.1). Mean rainfall and AET are estimated as 83.4 million m^3/year and 42.5 million m^3/year, respectively, by multiplying the groundwater catchment area with mean rainfall and mean AET calculated using the GIS map.

Groundwater inflows from adjacent groundwater catchments are assessed with a groudwater budget in Section 6.3.

6.2.2 Groundwater outflow to surface water baseflow on the Rangitaiki Plains

Low flow estimates for surface water in the Rangitaiki Plains are required to calculate baseflow, i.e. groundwater outflow to surface water. Three methods are used to calculate groundwater outflow to surface water from the Rangitaiki Plains catchments:

- calculate baseflow using historic gaugings recorded in Bay of Plenty Regional Council's surface gauging dataset;
- calculate baseflow using gaugings measured in March 2010; and
- estimate groundwater outflow using pumping data available from actively-pumped drain catchments.

Generally, baseflow is calculated as the median of gauged flows. The median calculation is made because this calculation represents central tendancy, where the distribution of the values is skewed i.e. observations include some low flows and small numbers of high flows, better than the average calculation. Further, some measurements of high flows are removed from the data set in highly skewed distributions of gauging measurements before calculation of median flow values.

All the groundwater catchments on the Rangitaiki Plains are considered as closed catchments, i.e. rainfall is assumed to be the only inflow to the groundwater system.

6.2.2.1 Baseflow discharge with historic low flow gaugings

Bay of Plenty Regional Council's database of historic surface flow gaugings (Glen Ellery, BOPRC pers. comm.) includes 219 measurements collected at a range of flows (Appendix 6, Table A6.1). A total of 155 low flow gauging sites, identified with a long term record and multiple gaugings, are used to estimate baseflow in the Rangitaiki Plains. No continuous flow measurement data is available.

Baseflow discharge is calculated with historic gaugings in Rangitaiki Plains drain catchments (Appendix 7) as follows:

i. groundwater catchments (Figure 6.1) and Rangitaiki Plains drain catchments (Figure 6.4) are identified to estimate baseflow (Figure 6.7);

ii. median discharge is calculated for drain catchments ('Measured Discharge, Median Historic Gaugings', Appendix 7) with available data suitable to estimating low flows from the BOPRC gauging data (Appendix 6, Table A6.1), i.e. flood flows are removed from the dataset;

iii. median specific discharge is calculated for groundwater catchments and Rangitaiki Plains drain catchments ('Specific Discharge, Median Of Historic Gaugings', Appendix 7); and

iv. median discharge in Rangitaiki Plains drain catchments ('Estimated Discharge', Appendix 7) is estimated in catchments without any historic gauging data by transposition from catchments with median flows using a mean specific discharge of 14.08 l/s/km^2 (i.e. the mean specific discharge of all Rangitaiki Plains gauged catchments, Appendix 7).

6.2.2.2 Baseflow discharge with March 2010 low flow gaugings

Surface flows were measured at ten sites in March 2010 ('Measured Discharge, March 2010 Gaugings' in Appendix 7) for the purposes of recording flow in some catchments without historic gauging measurements and recording flows in a period of known low rainfall (Table 6.2). Low rainfall conditions are indicated by total rainfalls in the year to 15 March 2010 at Rangitaiki Plains recorders (Rangitaiki at Thornton, Rangitaiki at Te Teko and Tarawera at Awakaponga) that were between 61% and 77% of average rainfall.

Surface flows measured in March 2010 are generally dissimilar to the median of historic gaugings. However, mean specific discharge estimated with March 2010 gaugings (8.94 l/s/km^2, Appendix 7) is less than mean specific discharge estimated with historic gaugings (14.08 l/s/km^2, Appendix 7). An extensive analysis of baseflow in drains on the Rangitaiki Plains is required to confirm estimates of baseflow in all Rangitaiki Plains drains and such an investigation is beyond the scope of this report.

Table 6.1 Groundwater catchment name, catchment area, mean annual rainfall and mean annual AET.

Groundwater catchment ID	Groundwater catchment name	Groundwater catchment area (km^2)	Average annual rainfall and AET (actual evapotranspiration)				Average annual groundwater recharge (Rainfall - AET) (l/s)
			Rainfall (inflow)		AET (outflow)		
			mm/year	l/s	mm/year	l/s	
1	Awaiti Canal	92.3	1559.6	4564	936.0	2739	1825
2	Awakaponga	36.3	1707.7	1967	927.6	1068	899
3	Edgecumbe Catchwater	31.1	1679.3	1658	927.6	916	742
4	Kope Orini 1	21.6	1381.3	944	928.2	635	309
5	Kope Orini 2	1.5	1194.7	58	896.7	44	14
6	Kope Orini 3	16.0	1260.3	641	910.2	463	178
7	Mangamako area	14.3	1584.8	717	891.1	403	314
8	Mangaone Stream	43.5	2114.0	2918	906.9	1252	1666
9	Mangate	27.5	1928.2	1680	884.4	771	909
10	Mangawhio	52.1	1974.0	3261	866.7	1432	1829
11	Matata	6.7	1450.7	309	900.0	192	117
12	Ngakauroa Stream	28.5	1477.2	1336	908.0	821	515
13	Nursery Drain	5.1	1456.9	234	927.5	149	85
14	Old Rangitaiki Canal	24.5	1318.4	1023	915.1	710	313
15	Oromoeroa Flats	40.1	1529.4	1944	920.1	1169	775
16	Oromoeroa Hills	119.8	1667.4	6333	867.7	3296	3037
17	Rangitaiki Dunes	7.5	1215.4	288	899.8	213	75
18	Reids Central Canal	46.4	1317.0	1938	914.9	1346	592
19	Rotoroa	15.3	1943.1	944	935.0	454	490

Groundwater catchment ID	Groundwater catchment name	Groundwater catchment area (km^2)	Average annual rainfall and AET (actual evapotranspiration)				Average annual groundwater recharge (Rainfall - AET) (l/s)
			Rainfall (inflow)		AET (outflow)		
			mm/year	l/s	mm/year	l/s	
20	Tarawera Dunes	0.2	1215.4	7	899.8	5	2
21	Te Rahu 1	20.4	1457.5	943	903.3	584	359
22	Te Rahu 2	18.0	1455.3	833	929.9	532	301
23	Tumarau	8.7	1911.4	525	946.2	260	265
24	Tumurenui	6.8	1916.0	416	951.9	207	209
25	Upper Tarawera	173.8	2104.9	11600	875.7	4826	6774
26	Waiaute	114.6	2156.8	7836	856.5	3112	4724
27	Waikamihi Stream	20.9	2067.2	1368	892.6	591	777
28	Waikanapiti	40.3	2048.4	2619	901.7	1153	1466
29	Waikowhewhe area	20.3	1645.8	1062	915.2	591	471
30	Waimana East Flats	37.7	1723.4	2062	925.0	1107	955
31	Waimana Hills	144.4	1889.5	8652	874.7	4005	4647
32	Waimana West Flats	8.2	1565.2	407	928.9	241	166
33	Waioho Canal	112.0	1561.5	5548	918.6	3264	2284
34	Whakatane Dunes	3.3	1223.2	127	900.3	94	33
35	Whakatane East	54.0	1512.7	2591	918.6	1574	1017
36	Whakatane West Hills	80.5	1575.1	4018	895.6	2285	1733
Total		**1494.2**		**83370**		**42501**	**40869**

Table 6.2 Rainfall summary report for 15 March 2010 from Bay of Plenty Regional Council's website (Bay of Plenty Regional Council 2010).

Site	Most recent sample	Intensity (mm/hr)	Today (mm)	Yesterday (mm)	Last 5 days (mm)	This month (mm)	Last month total (mm)	Last month, % of mean	Year to date (mm)	Year to date, % of mean
Tuapiro at Woodlands	12/05/2010 09:54					15	52	28%	325	54%
Waipapa at Goodalls	18/05/2010 06:30		0	0	28	96	75.5	37%	333	53%
Tauranga Harbour at Omokoroa	18/05/2010 08:05	0	0	0	18.5	51.5	29.5	20%	167	39%
Rapurapu at Kaimai Summit	18/05/2010 06:35	0	0	0	18	151.5	63	29%	391.5	60%
Kaituna at Te Matai	18/05/2010 06:30		0	0	36.5	66.5	55.5	39%	186.5	46%
Rotorua at Whakarewarewa	18/05/2010 08:00		0	3	55	122	36.5	31%	257.5	59%
Rotorua at Kaharoa	18/05/2010 06:00	0.5	0.5	0	51.5	150	62.5	40%	282.5	53%
Mangorewa at Saunders	18/05/2010 06:30		0	0	33	84.5	23	14%	182.5	36%
Pongakawa	18/05/2010 06:00		0	0	49	81	60.5	47%	192	47%
Ohinekoao at Herepuru Road	18/05/2010 08:00		0	0	27.5	56	78.5	59%	358	81%
Tarawera at Awakaponga	18/05/2010 08:00		0	0	26.5	51.5	76	67%	248	70%
Rangitaiki at Thornton	18/05/2010 08:05	0	0.5	0	34.5	57	96	77%	280	77%
Rangitaiki at Te Teko	18/05/2010 08:00		0	0.5	27	49.5	56.5	45%	229	61%
Rangitaiki at Waihua	18/05/2010 05:31	0	0	4.5	67.5	166.5	71	45%	326.5	74%
Whirinaki at Galatea	18/05/2010 07:15	0	0	0	55.5	85.5	35	32%	347.4	95%
Rangitaiki at Kokomoka	18/05/2010 06:30		0	0.5	21.5	48	58.5	62%	348	89%
Whakatane at Huiarau Summit	18/05/2010 06:00		0	2.5	54.5	109	64.5	33%	546.5	79%
Whakatane at Huitieke	18/05/2010 06:00		0	0.5	85.5	143.5	92.5	85%	321.5	75%
Waimana at Ranger Station	18/05/2010 08:00		0	1	126	212.5	117	74%	344	64%
Whakatane at Kopeopeo	18/05/2010 08:02	0	0	8.4	46.1	59.9	69.5	75%	206.5	58%
Waioeka at Koranga	18/05/2010 06:00		0	2	83.5	131	71	50%	406.5	70%
Waioeka at Cableway	18/05/2010 08:00		0	9.5	129	221	130	71%	453.5	71%
Waioeka at Mouth of Gorge	18/05/2010 08:08	0	0	24.5	54	114	80	62%	337.5	76%
Otara at Tutaetoko	18/05/2010 06:00		0	29	87	148	113.5	68%	418	63%
Otara at Browns Bridge	18/05/2010 08:00		0.5	50	143	206.5	62	44%	308.5	67%
Otara at Opotiki Town Wharf	18/05/2010 08:00		0	30.5	77	140	54.5	66%	331	97%
Pakihi at Pakihi Station	18/05/2010 06:00		0.5	40	151.5	212	109	57%	404	61%
Pakihi at Rakanui	18/05/2010 06:00		0.5	25.5	120	168	85	62%	421.5	81%
Haparapara at East Cape	18/05/2010 06:00		0.5	2.5	64	213	233.5	78%	903.5	92%

6.2.2.3 Baseflow discharge with pumping schemes

Bay of Plenty Regional Council maintains pumped drainage schemes on the Rangitaiki Plains to remove water from the Plains. The pumping schemes predominantly target high flow events. Some drains are pumped more regularly than others and flow from these drains may represent baseflow. Most low flows are discharged via culvert and flap gate structures and drains are not necessarily pumped at times of low flow.

Baseflow from pumping schemes is estimated, using normalised monthly electricity use (kWh/month), in the period March 2006 to February 2010 (Chris Power, Bay of Plenty Electricity pers. comm.) as follows:

i. Normalised monthly electricity use is converted to median monthly use (KWh/month), from which estimated hours of operation are calculated with:

KW x Hrs = KWh or Hrs = KWh/KW

KW = Individual pump motor KW operational usage

Hrs = Hours

KWh = Kilowatt hours

ii. Water volume pumped during hours of operation is calculated with rating curves relating pump operating power (KW) to water discharge (m^3). The average of the minimum and maximum discharge provided by the rating curve is applied. However, the upstream head varies during pumping and power use is variable during the month. Relevant pump station information is summarised in Appendix 5.

iii. Mean monthly and annual discharge from individual drainage schemes is estimated as follows:

Mean monthly pumped hours x 12 months x Mean discharge rate

iv. Pump catchment area is calculated from polygons representing catchment area of each drainage scheme pump. Catchment areas are cross-checked with topography, on a 2 m DEM produced from LIDAR data, and corrected to suit the topographic catchment area. Mean discharge is calculated as follows:

Mean Discharge (l/s) / Area Drained (km^2)

v. See Appendix 8 (Table A8.1) for estimates of specific discharge from pump schemes.

6.2.2.4 Comparison of methods

Estimates of groundwater outflow to surface water based on pumping schemes are discounted from further analysis because:

- estimates of groundwater outflow to surface water with pumped data, approximately 142 m^3/s, are much greater than the difference between rainfall and AET, approximately 17.5 m^3/s, Appendix 8 (Table A8.2); and
- estimates are much greater than the other two methods (Table 6.3).

Estimates of groundwater outflow to surface water using historic gauging data (Table 6.3) are greater than estimates using March 2010 gauging data (Table 6.3). This is because historic gaugings typically record higher flows than the March 2010 gauging data. For example comparisons of median flows for historic gaugings and March 2010 gaugings can be made in six drain catchments (Appendix 7). For this set, the mean (of median) flow is approximately 469 l/s (historic gaugings) and 279 l/s (March 2010 gaugings).

Groundwater outflow estimates based on medians of historic gaugings are preferred, over March 2010 gaugings, for water budget components in following sections. This is because:

- historic gaugings measure flows in more catchments than the March 2010 gaugings; and
- median flows estimated from historic gaugings are typically greater than flows recorded by March 2010 gaugings. Therefore estimates of groundwater available for allocation (Section 7) are more conservative with mean flows estimated from historic gaugings.

6.2.3 Groundwater outflow to surface water baseflow in the Tarawera, Rangitaiki, and Whakatane river catchments above the Rangitaiki Plains

Groundwater outflow for each groundwater catchment is estimated in this section for the groundwater catchments in the Tarawera, Rangitaiki, and Whakatane river catchments above the Rangitaiki Plains. Groundwater outflow is estimated by with the calculated values of groundwater recharge for each groundwater catchment (assumed as P – AET, Table 6.1) and estimates of surface water flow.

Surface water flow is estimated from flow observations held in BOPRC's database of continuous flow measurement sites and gauging sites. All BOPRC flow sites located within the boundaries of the study area are assigned to a groundwater catchment. Median flow is calculated for each flow site. Appendix 6 (Table A6.2) includes the flow gauging site locations, names, site numbers, and median flow values calculated for each flow site.

Gauging sites are selected from the BOPRC database to represent the surface water inflow and outflow within each groundwater catchment (Table 6.4, Figure 6.7). Gauging sites are selected in the upper Tarawera and Whakatane catchment areas based on:

- proximity to the inflow and the outflow boundary of groundwater catchments;
- gauging sites measured in the main surface water feature within the groundwater catchment;
- gauging sites with multiple measurements, over a long time period, where possible; and
- gauging sites that are probably not representative of flood flows.

Some of the gauging sites only have a single measurement recorded, which may result inaccurate estimates of runoff. Some of the groundwater catchments contain no surface water gauging sites that are representative of the total discharge from the catchment.

Table 6.3 Estimates of outflow from groundwater catchments on the Rangitaiki Plains with historic gauging data and with March 2010 gauging data.

Major river catchment	Groundwater catchment ID	Groundwater catchment	Area km^2	Specific discharge, historic gaugings or default (l/s/km^2)	Discharge, historic gaugings or default calculation (million m^3/yr)	Specific discharge, March 2010 gaugings or default (l/s/km^2)	Discharge, March 2010 gaugings or default calculation (million m^3/yr)
		Specific discharge default value (mean of median, Appendix 7)		**14.08**		**8.94**	
Dunes	20, 17, 34	Dunes*	10.92	14.08	4.85	8.94	3.08
Tarawera	1	Awaiti Canal	92.3	11.5	33.47	8.94	26.02
Tarawera	2	Awakaponga	36.3	14.08	16.13	8.94	10.24
Tarawera	8	Mangaone Stream	43.5	49.43	67.86	37.23	51.11
Tarawera	11	Matata	6.7	14.08	2.98	8.94	1.89
Tarawera	23	Tumarau	8.7	14.08	3.84	8.94	2.44
Tarawera	24	Tumurenui	6.8	14.08	3.04	8.94	1.93
Tarawera	27	Waikamihi Stream	20.9	14.08	9.27	8.94	5.88
Tarawera	14	Old Rangitaiki Canal	24.5	14.08	10.86	8.94	6.90
Rangitaiki	3	Edgecumbe Catchwater	31.1	14.08	13.82	2.2	2.16
Rangitaiki	12	Ngakauroa Stream	28.5	2.66	2.39	2.53	2.27
Rangitaiki	13	Nursery Drain	5.1	14.08	2.25	8.94	1.43
Rangitaiki	18	Reids Central Canal	46.4	1.53	2.24	0.9	1.32
Whakatane	4	Kope Orini 1	21.6	15.04	10.23	8.94	6.08
Whakatane	5	Kope Orini 2	1.5	15.04	0.73	8.94	0.43
Whakatane	6	Kope Orini 3	16.0	15.04	7.61	8.94	4.52
Whakatane	21	Te Rahu 1	20.4	2.59	1.67	7.65	4.92
Whakatane	22	Te Rahu 2	18.0	2.59	1.47	7.65	4.35
Whakatane	33	Waioho Canal	112.0	14.22	50.25	3.13	11.06
Whakatane	35	Whakatane East	54.0	14.08	23.99	8.94	15.23
Whakatane	36	Whakatane West Hills	80.5	14.08	35.73	8.94	22.68
Total (million m^3/year)					**304.66**		**185.96**
Total (m^3/s)					**9.66**		**5.90**

* Tarawera, Rangitaiki, and Whakatane dunes

Table 6.4 Selected flow sites in catchments above the Rangitaiki Plains.

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Number of gaugings	Median flow (l/s)
Tarawera	Mangawhio	Mangawhio	U/S Tarawera Confluence	15364	2830110	6333900	3	1979
Tarawera	Mangate	Mangate	U/S Tarawera Confluence	15336	2830840	6335360	1	126
Tarawera	Waiaute	Waiaute	Below Waiwhakapu Confluence	15367	2825660	6332810	1	5427
Tarawera	Upper Tarawera	Tarawera	D/S Lake Tarawera	NIWA	2817400	6330300	1972-2005	6546
Tarawera	Upper Tarawera	Tarawera	Kawerau Bridge	15316	2835670	6340360	174	22486
Tarawera	Upper Tarawera	Tarawera	Edwards Road	15373	2825950	6333670	1	15347
Tarawera	Waikanapiti	Ruruanga	U/S Tarawera Confluence	1015344	2836110	6341680	11	1139
Whakatane	Oromoeroa Flats	Whakatane	Limeworks	15547	2860090	6325990	32	15179
Whakatane	Waimana Hills	Waimana	Waimana Gorge	15511	2864210	6336580	36	7127
Whakatane	Waimana Hills	Waimana	Taneatua Bridge	NSN2054	2861579	6340248	16	7091

6.2.3.1 *Tarawera River catchment above Rangitaiki Plains*

The Tarawera River catchment above the Rangitaiki Plains includes six groundwater catchments (Figure 6.1):

- Upper Tarawera;
- Waikanapiti;
- Mangate;
- Mangawhio;
- Waiaute; and
- Rotoroa.

Surface water inflows are assumed as zero for the Rotoroa, Waiaute, Waikanapiti, Mangate, and Mangawhio groundwater catchments. Surface water gauging information near the outflow boundary of the groundwater catchments is available for these groundwater catchments.

Surface water flow gauging values estimate median discharge from the Waiaute (5,427 l/s), Waikanapiti (median 1,139 l/s), and Mangawhio (median 1,979 l/s) groundwater catchments that are similar to the annual groundwater recharge (estimated as P – AET, Table 6.1). This indicates that the entire groundwater outflow from the Waiaute, Waikanapiti, and Mangawhio groundwater catchments probably flows into the Tarawera River as surface water. Likewise, all groundwater outflow from the Mangate and Rotoroa groundwater catchments probably flows into the Tarawera River.

The Tarawera River flows out of Lake Tarawera through the Upper Tarawera groundwater catchment. There are three key flow gauging sites in the Tarawera River within the Upper Tarawera groundwater catchment:

- Tarawera River below the Lake Tarawera outlet, where median flow recorded between 1972 and 2005 is 6,546 l/s (Ellery, 2010);
- Tarawera River at Edwards Road (site 15373), where flow is measured only once at approximately 15,347 l/s; and
- Tarawera River at Kawerau Bridge (site 15316), where median flow calculated to be 22,486 l/s based on a derived relationship with a downstream recorder (Ellery, 2010).

The Upper Tarawera groundwater catchment upstream of gauging site 15373 is further assessed to estimate the groundwater outflow from Lake Tarawera (Figure 6.8). The groundwater inflow (P – AET) is estimated for the Upper Tarawera groundwater catchment upstream of gauging site 15373 as 4,219 l/s (Table 6.5). This value is less than the difference in flow (8,801 l/s) between the surface water gauging site 15373 and the NIWA site below the Lake Tarawera outlet. Therefore the Tarawera River probably gains flow from Lake Tarawera through the groundwater system. Based on the calculations in Table 6.5, groundwater is discharging from Lake Tarawera at 4,582 l/s to balance the water budget.

Table 6.5 Water budget for area upstream of gauging site 15373 in Upper Tarawera groundwater catchment.

Groundwater catchment name	Area upstream of site gauging 15373 (km^2)	Average annual rainfall and AET (actual evapotranspiration)				Average annual groundwater recharge (Rainfall - AET) (l/s)	Median surface water inflow from Lake Tarawera (l/s)	Median surface water discharge at site 15373 (l/s)	Annual groundwater inflow from Lake Tarawera (l/s)	Annual water balance (l/s)
		Rainfall (inflow)		AET (outflow)						
		Mm/year	l/s	mm/year	l/s					
Upper Tarawera	95.1	2252	6791	853	2571	4219	6546	15347	-4582	0

Surface water flow at flow gauging site 15316 (Tarawera River at Kawerau Bridge) measures a median flow of 22486 l/s (Table 6.4) from the Upper Tarawera, Mangate, Mangawhio and Waiaute groundwater catchments. Therefore surface water baseflow from the Upper Tarawera catchment at site 15316 is estimated as 14954 l/s (Table 6.6) i.e. the difference of 22486 l/s and 7532 l/s (i.e. the sum of estimated median flow from the Mangate, Mangawhio and Waiaute groundwater catchments, Table 6.4).

Flow from the Waikanapiti groundwater catchment is measured at flow gauging site 1015344, which is located downstream of gauging site 15316.

6.2.3.2 Rangitaiki River catchment above Rangitaiki Plains

The Rangitaiki River catchment above the Rangitaiki Plains consists of two groundwater catchments:

- Waikowhewhe area; and
- Mangamako area.

The Rangitaiki River makes up the boundary between these two groundwater catchments (Figure 6.1). Groundwater in each catchment may flow to the Rangitaiki River. However, groundwater inflows from the river, or groundwater outflows to the river, cannot be assessed from surface gaugings. This is because: no flow gauging information is available for the Rangitaiki River at the upstream and downstream boundaries of these catchments; and a single flow gauging site is located in each catchment but only one measurement has been recorded at each site (Appendix 6, Table A6.2) so measurements are probably not representative of flows in these groundwater catchments. Groundwater in each catchment may also flow to down-gradient groundwater catchments.

6.2.3.3 Whakatane River catchment above Rangitaiki Plains

The Whakatane River catchment above the Rangitaiki Plains is divided into five groundwater catchments based on the geology and topography of the area:

- Oromoeroa Hills;
- Oromoeroa Flats;
- Waimana Hills;
- Waimana East Flats; and
- Waimana West Flats.

The Whakatane River flows through the Oromoeroa Hills and Oromoeroa Flats groundwater catchments. No surface water flow gauging data are available for the Whakatane River at the inflow boundary of the Oromoeroa Hills. One gauging site (site 15547) estimates flow at the outflow boundary of the Oromoeroa Hills groundwater catchment and the inflow boundary of the Oromoeroa Flats groundwater catchment. No representative flow gauging data are available for the outflow of the Oromoeroa Flats groundwater catchment where the Whakatane River meets the Waimana River.

Two surface flow gauging sites (sites 15511 and NSN2054) record flow in the Waimana River near the outflow boundary of the Waimana Hills and the Waimana East Flats groundwater catchments. Surface flow gauging records are available for other flow sites within these groundwater catchments. However estimates of surface flows at other flow sites are not used in groundwater budget calculations because only one or two measurements of flow are recorded atr each gauging site and the distribution of measurements is not sufficient to estimate flows in the many streams in the area (Appendix A6.2).

No flow gauging data (e.g. in Waiwherowhero Stream) are recorded in the Waimana West Flats groundwater catchment. Waiwherowhero Stream enters Waimana River below gauging site NSN2054 and therefore the measured flow at this site is not relevant to flow in the stream.

6.3 Groundwater budget

Groundwater budgets for groundwater catchments in the study area are presented in Table 6.6. These groundwater budgets are estimated using:

- the groundwater budget equation from Section 6.2;
- estimates of groundwater budget components from Section 6.2; and
- estimates of groundwater outflow to adjacent groundwater catchments (Table 6.7), based on likely groundwater flow directions (Figure 6.2).

The groundwater catchments in Table 6.6 are listed by major groundwater catchment (Figure 6.1). The following sections summarise assumptions in the groundwater budget components, development of the groundwater budget, and some implications of the calculations on groundwater allocation.

6.3.1 Rangitaiki major groundwater catchment

A summary of groundwater flow budget components for the Rangitaiki major groundwater catchment has approximately:

- inflow from rainfall of 14.8 m^3/s;
- outflow from AET of 9.2 m^3/s;
- groundwater inflow from the Upper Tarawera groundwater catchment of 2.9 m^3/s:
- groundwater outflow to surface water of 3.7 m^3/s, including the Rangitaiki River and the Tarawera River catchment (Figure 6.3);
- groundwater outflow to the Whakatane major groundwater catchment of 0.05 m^3/s; and
- groundwater outflow to the coast of 5.4 m^3/s.

Groundwater inflow to the Rangitaiki major groundwater catchment (Edgecumbe catchment groundwater catchment) is an important component of the groundwater budget of the Rangitaiki major groundwater catchment. This inflow comes from the Upper Tarawera groundwater catchment. Groundwater outflow from the Waikowhewhe and Mangamako groundwater catchments is assumed to flow to the Rangitaiki River (Table 6.7).

6.3.2 Tarawera major groundwater catchment

A summary of groundwater flow budget components for the Tarawera major groundwater catchment has approximately:

- inflow from rainfall of 35.4 m^3/s;
- outflow from AET of 15.3 m^3/s;
- surface water inflow from Lake Tarawera of 6.5 m^3/s:
- groundwater inflow from Lake Tarawera of 4.6 m^3/s:
- groundwater outflow to surface water, mostly to the Tarawera River, of 26.9 m^3/s;
- groundwater outflow to the Rangitaiki major groundwater catchment of 2.9 m^3/s; and
- groundwater outflow to the coast of 0.02 m^3/s.

A good quality estimate of groundwater outflow from Lake Tarawera is important because this number is relevant to the water budget of the Tarawera major groundwater catchment and the Rangitaiki major groundwater catchment. Therefore more work, including gaugings, in the Upper Tarawera River is recommended to assess this component of the water budget (Section 8).

Groundwater outflow of three groundwater catchments (Mangaone, Mangawhio and Waiaute) is estimated to be a negative number, which is then adjusted to balance the groundwater budget. Negative groundwater outflow is an artefact of the data and most unlikely, in reality, in these catchments. The quality of the estimate of surface water flow in these catchments is unknown. Therefore it is recommended that more gaugings are measured in these catchments to assess the groundwater budget (Section 8).

6.3.3 Whakatane major groundwater catchment

A summary of groundwater flow budget components for the Whakatane major groundwater catchment has approximately:

- inflow from rainfall of 33.1 m^3/s;
- outflow from AET of 18.0 m^3/s;
- surface water inflow in the Whakatane catchment of 33.3 m^3/s;
- groundwater inflow from the Rangitaiki major groundwater catchment of 0.05 m^3/s;
- groundwater outflow to surface water, to the Whakatane River and the Waimana River, of 48.3 m^3/s; and
- groundwater outflow to the coast of 0.2 m^3/s.

Groundwater inflow from the Rangitaiki major groundwater catchment to the Kope Orini 3 groundwater catchment is estimated.

The distribution of gauging measurements in the upper Whakatane River and Waimana catchment generally does not allow estimates of groundwater inflows to streams. Therefore, stream flow estimates are generally made with rainfall and AET measurements. For example:

1. Surface water inflow to the Oromoeroa Hills groundwater catchment is estimated as 12142 l/s (Table 6.6) with:
   - net inflow from rainfall, i.e. rainfall minus AET from values in Table 6.6, of 3037 l/s for the catchment; and
   - surface water inflow to the catchment is surface water discharge minus inflow from rainfall of 15179 l/s – 3037 l/s. This assumes all net inflow from rainfall travels to streams.
2. Surface water discharge from the Oromoeroa Flats groundwater catchment is estimated as 15954 l/s with:
   - surface water inflow to the Oromoeroa Flats groundwater catchment of 15179 l/s;
   - net inflow from rainfall, i.e. rainfall minus AET from values in Table 6.6, of 775 l/s; and
   - surface water discharge from the Oromoeroa Flats groundwater catchment of 15179 l/s + 775 l/s.
3. Surface water discharge from the Waimana West Flats groundwater catchment is estimated as rainfall minus AET as there are no gauging measurements in this catchment;
4. Surface water inflow to the Waimana East Flats groundwater catchment is estimated as 6145 l/s (Table 6.6) with:
   - net inflow from rainfall, i.e. rainfall minus AET from values in Table 6.6, of 955 l/s for the catchment; and
   - surface water inflow to the catchment is surface water discharge minus inflow from rainfall of 7100 l/s – 955 l/s. This assumes all net inflow from rainfall travels to streams.
5. Surface water inflow to the Waimana Hills groundwater catchment is estimated as C l/s with:
   - surface water discharge to the Waimana East Flats groundwater catchment of 1498 l/s;
   - net inflow from rainfall, i.e. rainfall minus AET from values in Table 6.6, of 4647 l/s; and
   - surface water discharge from the Oromoeroa Flats groundwater catchment of 6145 l/s – 4647 l/s.
6. Surface water discharge from the Whakatane West Hills groundwater catchment is estimated as 1733 l/s (Table 6.6) with net inflow from rainfall, i.e. rainfall minus AET from values in Table 6.6 for the catchment.

Table 6.6 Groundwater budgets for groundwater catchments.

Major groundwater catchment	Groundwater catchment ID	Groundwater catchment	Area (km^2)	Average rainfall (l/s)	Average AET (l/s)	Groundwater inflow (l/s)	Surface water median inflow to catchment (l/s)	Rangitaiki Plains specific discharge (l/s/km^2)	Surface water baseflow discharge from catchment (l/s)	Groundwater outflow to another catchment (l/s)	Groundwater outflow to coast (l/s)	Groundwater balance (l/s)
				P	**AET**	**IG**	**IS**		**OS**	**OG**	**OC**	
Rangitaiki	1	Awaiti Canal	92.3	4564	2739	3464	N/A	11.50	1061	4479	N/A	0
Rangitaiki	3	Edgecumbe Catchwater	31.1	1658	916	3054	N/A	14.08	438	3483	N/A	0
Rangitaiki	4	Kope Orini 1	21.6	944	635	108	N/A	15.04	325	137	N/A	0
Rangitaiki	5	Kope Orini 2	1.5	58	44	384	N/A	15.04	23	472	N/A	0
Rangitaiki	7	Mangamako area	14.3	717	403	0	N/A	N/A	314	0	N/A	0
Rangitaiki	12	Ngakauroa Stream	28.5	1336	821	0	0	2.66	76	439	N/A	0
Rangitaiki	13	Nursery Drain	5.1	234	149	95	N/A	14.08	72	233	N/A	0
Rangitaiki	14	Old Rangitaiki Canal	24.5	1023	710	4233	N/A	14.08	345	4447	N/A	0
Rangitaiki	17	Rangitaiki Dunes	7.5	288	213	4960	N/A	14.08	106	0	5369	0
Rangitaiki	18	Reids Central Canal	46.4	1938	1346	248	N/A	1.53	71	962	N/A	0
Rangitaiki	21	Te Rahu 1	20.4	943	584	0	0	2.59	53	306	N/A	0
Rangitaiki	29	Waikowhewhe area	20.3	1062	591	0	N/A	N/A	471	0	N/A	0
Tarawera	2	Awakaponga	36.3	1967	1068	0	0	14.08	511	388	N/A	0
Tarawera	8	Mangaone Stream	43.5	2918	1252	0	0	49.43	2150	-484	N/A	0
Tarawera	9	Mangate	27.5	1680	771	0	0	N/A	126	783	N/A	0
Tarawera	10	Mangawhio	52.1	3261	1432	0	0	N/A	1979	-150	N/A	0
Tarawera	11	Matata	6.7	309	192	0	0	14.08	94	23	N/A	0
Tarawera	19	Rotoroa	15.3	944	454	0	0	0	117	373	N/A	0
Tarawera	20	Tarawera Dunes	0.2	7	5	22	0	14.08	3	0	22	0
Tarawera	23	Tumarau	8.7	525	260	0	0	14.08	122	143	N/A	0
Tarawera	24	Tumurenui	6.8	416	207	0	0	14.08	96	113	N/A	0
Tarawera	25	Upper Tarawera	173.8	11600	4826	4580	6546	N/A	14954	2946	N/A	0
Tarawera	26	Waiaute	114.6	7836	3112	0	0	N/A	5427	-703	N/A	0
Tarawera	27	Waikamihi Stream	20.9	1368	591	0	0	14.08	294	483	N/A	0
Tarawera	28	Waikanapiti	40.3	2619	1153	0	0	N/A	1139	327	N/A	0
Whakatane	6	Kope Orini 3	16	641	463	375	N/A	15.04	241	380	N/A	0
Whakatane	15	Oromoeroa Flats	40.1	1944	1169	0	15179	N/A	15954	0	N/A	0
Whakatane	16	Oromoeroa Hills	119.8	6333	3296	0	12142	N/A	15179	0	N/A	0
Whakatane	22	Te Rahu 2	18	833	532	484	N/A	2.59	47	749	N/A	0
Whakatane	30	Waimana East Flats	37.7	2062	1107	0	6145	N/A	7100	0	N/A	0
Whakatane	31	Waimana Hills	144.4	8652	4005	0	1498	N/A	6145	0	N/A	0
Whakatane	32	Waimana West Flats	8.2	407	241	0	0	N/A	166	0	N/A	0
Whakatane	33	Waioho Canal	112	5548	3264	0	0	14.22	1577	707	N/A	0
Whakatane	34	Whakatane Dunes	3.3	127	94	218	0	14.08	46	0	253	0
Whakatane	35	Whakatane East	54	2591	1574	0	0	14.08	760	257	N/A	0
Whakatane	36	Whakatane West Hills	80.5	4018	2285	0	0	N/A	1733	0	N/A	0

Table 6.7 Destination of groundwater outflow.

Major groundwater catchment	Groundwater catchment ID	Groundwater catchment name	Destination of groundwater outflow
Rangitaiki	1	Awaiti Canal	Old Rangitaiki Canal
Rangitaiki	3	Edgecumbe Catchwater	Awaiti Canal
Rangitaiki	4	Kope Orini 1	Reids Central Canal (50%), Kope Orini 3(50%)
Rangitaiki	5	Kope Orini 2	Rangitaiki Dunes
Rangitaiki	7	Mangamako area	Rangitaiki River
Rangitaiki	12	Ngakauroa Stream	Nursery Drain (50%), Reid Central Canal (50%)
Rangitaiki	13	Nursery Drain	Awaiti Canal
Rangitaiki	14	Old Rangitaiki Canal	Rangitaiki Dunes
Rangitaiki	17	Rangitaiki Dunes	Coast
Rangitaiki	18	Reids Central Canal	Rangitaiki Dunes (50%) Kope Orini2 (50%)
Rangitaiki	21	Te Rahu 1	Reids Central Canal (50%), Kope Orini 1(50%)
Rangitaiki	29	Waikowhewhe area	Rangitaiki River
Tarawera	2	Awakaponga	Tarawera River
Tarawera	8	Mangaone Stream	Tarawera River
Tarawera	9	Mangate	Tarawera River
Tarawera	10	Mangawhio	Tarawera River
Tarawera	11	Matata	Tarawera Dunes
Tarawera	19	Rotoroa	Tarawera River
Tarawera	20	Tarawera Dunes	Coast
Tarawera	23	Tumarau	Tarawera River
Tarawera	24	Tumurenui	Tarawera River
Tarawera	25	Upper Tarawera	Edgecumbe Catchwater
Tarawera	26	Waiaute	Tarawera River
Tarawera	27	Waikamihi Stream	Tarawera River
Tarawera	28	Waikanapiti	Tarawera River
Whakatane	6	Kope Orini 3	Whakatane Dunes (70%), Whakatane River (30%)
Whakatane	15	Oromoeroa Flats	Whakatane River
Whakatane	16	Oromoeroa Hills	Whakatane River
Whakatane	22	Te Rahu 2	Kope Orini 3 (50%), Whakatane River (50%)
Whakatane	30	Waimana East Flats	Waimana River
Whakatane	31	Waimana Hills	Waimana River, Whakatane East
Whakatane	32	Waimana West Flats	Waimana River
Whakatane	33	Waioho Canal	Te Rahu 2 (70%), Whakatane River (30%)
Whakatane	34	Whakatane Dunes	Coast
Whakatane	35	Whakatane East	Whakatane River
Whakatane	36	Whakatane West Hills	Whakatane River

6.3.4 Uncertainty in the groundwater budget

All components of the groundwater budget are associated with an uncertainty, which can be the result of: natural variability of the hydrologic cycle, errors associated with measurement techniques, and assumptions made for the estimation of parameters (Healy *et al.* 2007). For example, uncertainties associated with rainfall or evaporation can result from errors of the actual measurements at climate stations or from the techniques used to interpolate the widely-spaced data over large areas. Due to the limitations associated with the estimation of the different components of the water budget, uncertainty cannot be eliminated completely from water budget studies even in ideal circumstances.

An assessment of the uncertainty of all components of the groundwater budget is beyond the scope of this project. However, uncertainty is considered in a conservative approach to estimation of groundwater parameters (Section 6.2) in relation to the calculation of groundwater available for allocation (Section 7). For example conservative assumptions of groundwater flow in Rangitaiki Plains groundwater catchments (Section 6.2) has surface water baseflow of 9.66 m^3/s, using historic gaugings, and not 5.9 m^3/s, with March 2010 gaugings (Table 6.3). This assumption has the effect of reducing the estimate of groundwater outflow (i.e. outflow to other groundwater catchments and to the coast) from the Rangitaiki Plains by approximately 3.8 m^3/s (i.e. the difference of 9.66 m^3/s and 5.9 m^3/s, rounded). Therefore less groundwater is available for allocation on the Rangitaiki Plains with the conservative assumption because estimates of groundwater outflow are used to estimate groundwater available for allocation (Section 7).

Assessment of the uncertainty in groundwater budget components is recommended (Section 8.10), particulary for groundwater catchments where estimated groundwater outflow is low, or negative (Table 6.6).

7.0 GROUNDWATER ALLOCATION

Groundwater allocation is best managed with groundwater allocation zones, limits and policies that ensure the sustainability of the groundwater resource. This section suggests groundwater allocation zones and uses the groundwater budgets developed in Section 6 to estimate groundwater available for allocation. Identification of groundwater allocation limits requires policy decisions by Bay of Plenty Regional Council that are beyond the scope of this report. BOPRC is responsible for making decisions on priorities and this report seeks to inform the decision-making process with water budget estimates. However, this report summarises, for consideration by Bay of Plenty Regional Council, elements of allocation policies that would be desirable to maintain the sustainability of groundwater systems in the study area.

Groundwater available for allocation, estimated in this report, is compared with groundwater allocation and estimated groundwater use. This allows an assessment of the sustainability of current allocation and estimates of groundwater that may be available for allocation in the future.

7.1 Groundwater allocation zones

Groundwater allocation zones are suggested for the purposes of managing groundwater allocation and use. Three major groundwater allocation zones are suggested (Rangitaiki, Tarawera and Whakatane) that include groundwater catchments (Figure 6.1). Groundwater catchment boundaries are developed with an aim of identifying hydrological and hydrogeological areas that are rational for groundwater management. In particular, the groundwater catchment boundaries aim to include land that provides groundwater recharge to surface water bodies. For example, a groundwater catchment may include a surface water feature such as a spring; management of the groundwater use in the catchment of the surface feature may aim to maintain baseflow in the surface water feature.

The major groundwater allocation zones are broadly associated with the three major rivers in the area. Groundwater catchment boundary identification is discussed in Section 6.

7.2 Groundwater available for allocation

Groundwater available for allocation is estimated from the groundwater budget (Table 6.6). Water budget components are generally taken as estimated in Section 6. Groundwater available for allocation (GAA) in each allocation zone, i.e. each groundwater catchment, is generally estimated as:

GAA = rainfall – AET – groundwater outflow to surface water i.e. baseflow

This approach is the same as that used to estimate GAA for BOPRC in the Western Bay of Plenty (White *et al.* 2009b) and the Paengaroa-Matata area (White *et al.* 2008). Generally, groundwater outflow to surface water is not available for allocation. This assumption aims to protect surface water features from over-abstraction of groundwater. Surface water features in the Rangitaiki Plains include drains; baseflow in these drains may be worthy of protection; for example, maintenance of baseflow may protect the water budgets of important wetland areas. However, the intended purpose of the drains is to make land suitable for farming and therefore protection of baseflow in drains may not be a priority for BOPRC.

Some conservative estimates of water budget components are made in the translation of water budget components given in Table 6.6 to the estimates of groundwater available for allocation given in Table 7.1. For example:

- GAA is assumed as zero where a groundwater catchment has an estimate of groundwater outflow that is less than zero (Table 7.1). In this circumstance, the water balance estimate is typically dependent on estimates of surface flow, and these estimates are generally of unknown quality. Hence assignment of zero GAA is a conservative approach that accounts for uncertainty in the estimates of the water budget components;
- surface baseflow estimates in groundwater budgets are either median flow values from historic gaugings or calculated with catchment area and specific discharge estimated from historic gaugings (Table 6.6). Surface baseflow estimates for Rangitaiki Plains based on historic gaugings that are used in the water budget are typically greater than the flow measured in March 2010 (Section 6.2.2.4). Thus, the calculated GAA is less, i.e. a conservative approach, when based on estimates of surface flow calculated with historic gaugings;

- groundwater inflows are not included in the GAA estimation. Therefore groundwater allocation in one catchment is not dependent on groundwater outflow from another catchment. Estimates of groundwater outflow from catchments (Table 7.1) are calculated with a water budget and each of the components of the water budget will have errors; these errors are compounded in the estimates of groundwater outflow. Therefore the conservative approach here is not to allocate this groundwater flow.

The use of median flows in calculating surface baseflow is also a conservative assumption in relation to the GAA calculation. For example BOPRC use 'Q_5 7-day' flow as an estimate of minimum flow in streams (Wilding 2003). GAA estimates given in Table 7.1 are conservative because they are less than would be calculated with Q_5 7-day minimum flow. This is because median surface flow is typically greater than the Q_5 7-day minimum flow. For example, White *et al.* (2009) show that median surface flow is greater than Q_5 7-day minimum flow estimates of Wilding (2003), e.g. median flow in the Whatakao Stream is 266 l/s (White *et al.* 2009b) and Q_5 7-day flow is 150 l/s (Wilding 2003). Median flow estimates were also preferred for estimates of GAA in the study area because Q_5 7-day flows are generally not available for the study area.

Groundwater available for allocation is summarised by major groundwater allocation zones in the following text.

A summary of estimates of groundwater available for allocation for the Rangitaiki major groundwater catchment has approximately:

- 2.3 m^3/s of groundwater available for allocation; and
- the following allocation zones have zero GAA: Kope Orini 1, Kope Orini 2, Mangamako area, Old Rangitaiki Canal, Rangitaiki Dunes and Waikowhewhe area. This is because estimated baseflow in these allocation zones is greater than the difference between rainfall and AET.

A summary of estimates of groundwater available for allocation for the Tarawera major groundwater catchment has approximately:

- 5.6 m^3/s of groundwater available for allocation and much (2.9 m^3/s) of this groundwater available for allocation is in the Upper Tarawera groundwater allocation zone; and
- the following allocation zones have zero GAA: Mangaone Stream, Mangawhio, Tarawera Dunes and Waiaute. This is because estimated baseflow in these allocation zones is greater than the difference between rainfall and AET.

A summary of estimates of groundwater available for allocation for the Whakatane major groundwater catchment has approximately:

- 1.2 m^3/s of groundwater available for allocation and of this (0.7 m^3/s) groundwater available for allocation is in the Te Rahu 2 groundwater allocation zone; and
- eight allocation zones have zero GAA and most of these are in the upper catchment. This is few estimates of baseflow from groundwater catchments are provided by surface gaugings and therefore baseflow in these allocation zones is estimated as rainfall minus AET.

The coastal zones of the three major groundwater allocation zones all have zero GAA. This is because the GAA calculation includes only recharge associated with land within the zone. However, the groundwater budget indicates that groundwater outflow across the coastal boundary is approximately 5.1 m^3/s (Section 6.3), and this groundwater may available for allocation.

7.3 Water allocation and water use in the study area

Water allocation in the study area is consented from groundwater and surface water sources (Figure 7.1, Appendix 9). Bay of Plenty Regional Council supplied allocation records as at December 2009 (Janine Barber BOPRC pers. comm.). The method used to calculate water allocation is as follows:

i. identify the source of water recorded in the BOPRC consents database as groundwater (UNC), geothermal (UNG) or surface water (SUC) (Appendix 9);
ii. identify the type of use, i.e. irrigation, frost or other (Appendix 9);
iii. identify groundwater allocation by groundwater catchment (Figure 6.1);
iv. identify geothermal allocation by groundwater catchment (Figure 6.1); and
v. identify surface water allocation by surface catchment (Figure 6.3).

Annual water use by groundwater and surface water consents is estimated as the sum of:

- daily frost allocation × 30 days/year; plus
- daily irrigation allocation × 155 days/year; plus
- daily municipal allocation × 365 days/year; plus
- daily industry allocation × 365 days/year; plus
- other use × 365 days/year.

Calculated consented use is as follows:

- total groundwater allocation is 62.3 million m^3/annum, or approximately 1.97 m^3/s (Table 7.2);
- total geothermal allocation is 22.4 million m^3/annum, or approximately 0.7 m^3/s (Table 7.3); and
- total surface water allocation is 269.6 million m^3/annum, or approximately 8.6 m^3/s (Table 7.4).

Annual water use by geothermal consents is estimated as daily allocation × 365 days/year. One geothermal consent is not considered in the total in Table 7.3. This consent relates to geothermal drilling, therefore use of this water will not be continuous, so the consent is not relevant to water budget estimates.

Table 7.1 Estimates of groundwater available for allocation (GAA).

Major groundwater catchment	Groundwater catchment ID	Groundwater catchment	Area (km^2)	Average rainfall (l/s)	Average AET (l/s)	Surface water baseflow (l/s)		Groundwater available for allocation (l/s)
Groundwater budget symbol				**P**	**AET**	**OS**	**P-AET-OS**	**GAA**
Rangitaiki	1	Awaiti Canal	92.3	4564	2739	1061	764	764
Rangitaiki	3	Edgecumbe Catchwater	31.1	1658	916	438	304	304
Rangitaiki	4	Kope Orini 1	21.6	944	635	325	-16	0
Rangitaiki	5	Kope Orini 2	1.5	58	44	23	-9	0
Rangitaiki	7	Mangamako area	14.3	717	403	314	0	0
Rangitaiki	12	Ngakauroa Stream	28.5	1336	821	76	439	439
Rangitaiki	13	Nursery Drain	5.1	234	149	72	13	13
Rangitaiki	14	Old Rangitaiki Canal	24.5	1023	710	345	-32	0
Rangitaiki	17	Rangitaiki Dunes	7.5	288	213	106	-31	0
Rangitaiki	18	Reids Central Canal	46.4	1938	1346	71	521	521
Rangitaiki	21	Te Rahu 1	20.4	943	584	53	306	306
Rangitaiki	29	Waikowhewhe area	20.3	1062	591	471	0	0
Tarawera	2	Awakaponga	36.3	1967	1068	511	388	388
Tarawera	8	Mangaone Stream	43.5	2918	1252	2150	-484	0
Tarawera	9	Mangate	27.5	1680	771	126	783	783
Tarawera	10	Mangawhio	52.1	3261	1432	1979	-150	0
Tarawera	11	Matata	6.7	309	192	94	23	23
Tarawera	19	Rotoroa	15.3	944	454	117	373	373
Tarawera	20	Tarawera Dunes	0.2	7	5	3	-1	0
Tarawera	23	Tumarau	8.7	525	260	122	143	143
Tarawera	24	Tumurenui	6.8	416	207	96	113	113

Major groundwater catchment	Groundwater catchment ID	Groundwater catchment	Area (km^2)	Average rainfall (l/s)	Average AET (l/s)	Surface water baseflow (l/s)		Groundwater available for allocation (l/s)
Groundwater budget symbol				**P**	**AET**	**OS**	**P-AET-OS**	**GAA**
Tarawera	25	Upper Tarawera	173.8	11600	4826	3828[1]	2946	2946
Tarawera	26	Waiaute	114.6	7836	3112	5427	-703	0
Tarawera	27	Waikamihi Stream	20.9	1368	591	294	483	483
Tarawera	28	Waikanapiti	40.3	2619	1153	1139	327	327
Whakatane	6	Kope Orini 3	16	641	463	241	-63	0
Whakatane	15	Oromoeroa Flats	40.1	1944	1169	775[2]	0	0
Whakatane	16	Oromoeroa Hills	119.8	6333	3296	3037[2]	0	0
Whakatane	22	Te Rahu 2	18	833	532	47	254	254
Whakatane	30	Waimana East Flats	37.7	2062	1107	955[3]	0	0
Whakatane	31	Waimana Hills	144.4	8652	4005	4647[3]	0	0
Whakatane	32	Waimana West Flats	8.2	407	241	166	0	0
Whakatane	33	Waioho Canal	112	5548	3264	1577	707	707
Whakatane	34	Whakatane Dunes	3.3	127	94	46	-13	0
Whakatane	35	Whakatane East	54	2591	1574	760	257	257
Whakatane	36	Whakatane West Hills	80.5	4018	2285	1733	0	0

[1] Net of inflows to the Upper Tarawera groundwater catchment from Lake Tarawera, i.e. 14954 l/s baseflow (Table 6.6) minus Lake Tarawera surface inflow and groundwater inflow (6546 l/s and 4580 l/s, respectively, Table 6.6).

[2] Net inflows to the Whakatane River estimated as rainfall – AET.

[3] Net inflows to the Waimana River estimated as rainfall – AET.

Table 7.2 Estimated annual groundwater use and annual groundwater allocation in the study area.

Major groundwater zone	Groundwater catchment ID	Groundwater allocation zone	Number of consents	Estimated groundwater use (m^3/year)	Groundwater allocation	
					m^3/year	l/s
Rangitaiki	1	Awaiti Canal	34	8019569	21337827	677
Rangitaiki	3	Edgecumbe Catchwater	2	826770	1946910	62
Rangitaiki	4	Kope Orini 1	11	2014747	5706447	181
Rangitaiki	5	Kope Orini 2	0	0	0	0
Rangitaiki	7	Mangamako area	1	18250	18250	1
Rangitaiki	12	Ngakauroa Stream	20	1884005	7344165	233
Rangitaiki	13	Nursery Drain	4	1165415	3848195	122
Rangitaiki	14	Old Rangitaiki Canal	1	26645	26645	1
Rangitaiki	17	Rangitaiki Dunes	1	116250	273750	9
Rangitaiki	18	Reids Central Canal	21	3700488	10085498	320
Rangitaiki	21	Te Rahu 1	0	0	0	0
Rangitaiki	29	Waikowhewhe area	1	700800	700800	22
Tarawera	2	Awakaponga	4	559255	755185	24
Tarawera	8	Mangaone Stream	0	0	0	0
Tarawera	9	Mangate	0	0	0	0
Tarawera	10	Mangawhio	0	0	0	0
Tarawera	11	Matata	0	0	0	0
Tarawera	19	Rotoroa	0	0	0	0
Tarawera	20	Tarawera Dunes	0	0	0	0
Tarawera	23	Tumarau	0	0	0	0
Tarawera	24	Tumurenui	2	59520	140160	4
Tarawera	25	Upper Tarawera	3	4381054	4382482	139
Tarawera	26	Waiaute	0	0	0	0
Tarawera	27	Waikamihi Stream	2	3858050	3858050	122
Tarawera	28	Waikanapiti	2	2790	6570	0
Whakatane	6	Kope Orini 3	2	51630	81030	3
Whakatane	15	Oromoeroa Flats	3	196340	201590	6
Whakatane	16	Oromoeroa Hills	0	0	0	0
Whakatane	22	Te Rahu 2	6	305310	540930	17
Whakatane	30	Waimana East Flats	0	0	0	0
Whakatane	31	Waimana Hills	4	374873	385776	12
Whakatane	32	Waimana West Flats	0	0	0	0
Whakatane	33	Waioho Canal	3	33604	79132	3
Whakatane	34	Whakatane Dunes	0	0	0	0
Whakatane	35	Whakatane East	5	441226	485158	15
Whakatane	36	Whakatane West Hills	1	55115	55115	2
		Total	**133**	**28791705**	**62259664**	**1974**

Table 7.3 Estimated annual geothermal water use and annual geothermal allocation in the study area.

Major groundwater zone	Groundwater catchment ID	Groundwater allocation zone	Number of consents	Estimated geothermal use (m^3/year)	Geothermal allocation	
					m^3/year	**l/s**
Rangitaiki	1	Awaiti Canal	0	0	0	0
Rangitaiki	3	Edgecumbe Catchwater	0	0	0	0
Rangitaiki	4	Kope Orini 1	0	0	0	0
Rangitaiki	5	Kope Orini 2	0	0	0	0
Rangitaiki	7	Mangamako area	0	0	0	0
Rangitaiki	12	Ngakauroa Stream	0	0	0	0
Rangitaiki	13	Nursery Drain	0	0	0	0
Rangitaiki	14	Old Rangitaiki Canal	0	0	0	0
Rangitaiki	17	Rangitaiki Dunes	0	0	0	0
Rangitaiki	18	Reids Central Canal	0	0	0	0
Rangitaiki	21	Te Rahu 1	1	160600	160600	5
Rangitaiki	29	Waikowhewhe area	0	0	0	0
Tarawera	2	Awakaponga	0	0	0	0
Tarawera	8	Mangaone Stream	0	0	0	0
Tarawera	9	Mangate	0	0	0	0
Tarawera	10	Mangawhio	0	0	0	0
Tarawera	11	Matata	0	0	0	0
Tarawera	19	Rotoroa	8	2392210	2392210	76
Tarawera	20	Tarawera Dunes	0	0	0	0
Tarawera	23	Tumarau	0	0	0	0
Tarawera	24	Tumurenui	0	0	0	0
Tarawera	25	Upper Tarawera	1	19447200	19447200	617
Tarawera	26	Waiaute	0	0	0	0
Tarawera	27	Waikamihi Stream	0	0	0	0
Tarawera	28	Waikanapiti	3	358430	358430	11
Whakatane	6	Kope Orini 3	0	0	0	0
Whakatane	15	Oromoeroa Flats	0	0	0	0
Whakatane	16	Oromoeroa Hills	0	0	0	0
Whakatane	22	Te Rahu 2	0	0	0	0
Whakatane	30	Waimana East Flats	0	0	0	0
Whakatane	31	Waimana Hills	0	0	0	0
Whakatane	32	Waimana West Flats	0	0	0	0
Whakatane	33	Waioho Canal	0	0	0	0
Whakatane	34	Whakatane Dunes	0	0	0	0
Whakatane	35	Whakatane East	0	0	0	0
Whakatane	36	Whakatane West Hills	0	0	0	0
		Total	**13**	**22358440**	**22358440**	**709**

Table 7.4 Estimated annual surface water use and annual surface water allocation in the study area.

Major groundwater zone	Groundwater catchment ID	Groundwater allocation zone	Number of consents	Estimated surface water use (m^3/year)	Surface water allocation	
					m^3/year	**l/s**
Rangitaiki	1	Awaiti Canal	18	7271845	18072610	573
Rangitaiki	3	Edgecumbe Catchwater	0	0	0	0
Rangitaiki	4	Kope Orini 1	0	0	0	0
Rangitaiki	5	Kope Orini 2	0	0	0	0
Rangitaiki	7	Mangamako area	0	0	0	0
Rangitaiki	12	Ngakauroa Stream	4	624870	2319210	74
Rangitaiki	13	Nursery Drain	2	233095	784385	25
Rangitaiki	14	Old Rangitaiki Canal	3	2105720	3197400	101
Rangitaiki	17	Rangitaiki Dunes	0	0	0	0
Rangitaiki	18	Reids Central Canal	6	6502250	15311750	486
Rangitaiki	21	Te Rahu 1	2	60912.5	132312.5	4
Rangitaiki	29	Waikowhewhe area	0	0	0	0
Tarawera	2	Awakaponga	7	848376	1389336	44
Tarawera	8	Mangaone Stream	8	25833230	28196360	894
Tarawera	9	Mangate	0	0	0	0
Tarawera	10	Mangawhio	0	0	0	0
Tarawera	11	Matata	0	0	0	0
Tarawera	19	Rotoroa	0	0	0	0
Tarawera	20	Tarawera Dunes	0	0	0	0
Tarawera	23	Tumarau	2	1519000	3577000	113
Tarawera	24	Tumurenui	1	992000	2336000	74
Tarawera	25	Upper Tarawera	6	81694776	83200728	2638
Tarawera	26	Waiaute	0	0	0	0
Tarawera	27	Waikamihi Stream	0	0	0	0
Tarawera	28	Waikanapiti	4	76973585	77857055	2469
Whakatane	6	Kope Orini 3	1	20605710	20605710	653
Whakatane	15	Oromoeroa Flats	1	331785	331785	11
Whakatane	16	Oromoeroa Hills	0	0	0	0
Whakatane	22	Te Rahu 2	0	0	0	0
Whakatane	30	Waimana East Flats	0	0	0	0
Whakatane	31	Waimana Hills	0	0	0	0
Whakatane	32	Waimana West Flats	0	0	0	0
Whakatane	33	Waioho Canal	3	360195	2543685	81
Whakatane	34	Whakatane Dunes	0	0	0	0
Whakatane	35	Whakatane East	2	7625560	9782730	310
Whakatane	36	Whakatane West Hills	0	0	0	0
		Total	**70**	**233582909**	**269638056**	**8550**

7.4 Comparison of groundwater allocation, water use and groundwater available for allocation

Current groundwater allocation and geothermal allocation are summarised in Table 7.2 and Table 7.3, respectively. Current groundwater allocation and net geothermal allocation are compared to estimates of GAA in Table 7.5. Estimated groundwater use and net geothermal use are compared to estimates of GAA in Table 7.6. Net geothermal use is used here to represent the difference between geothermal abstraction and geothermal reinjection. Two geothermal consent holders reinject geothermal fluid and it is assumed that these consent holders reinject all geothermal abstraction. Groundwater catchment budgets are not impacted by the use of geothermal fluid where all fluid is reinjected.

Some groundwater catchments have current groundwater allocation that exceeds the estimated groundwater available for allocation (Table 7.5). For example:

- Nursery Drain: current groundwater allocation is 122 l/s, whereas estimated GAA is 13 l/s; and
- six groundwater catchments have allocation that is greater than zero, but GAA is zero (‘excess’) in Table 7.5. Note however that allocation generally exceeds GAA by a small amount.

Some groundwater catchments have estimated groundwater use that exceeds the estimated groundwater available for allocation (Table 7.6). For example:

- Nursery Drain: estimated groundwater use is 37 l/s, whereas estimated GAA is 13 l/s; and
- six groundwater catchments have estimated groundwater use that is greater than zero, but GAA is zero (‘excess’) in Table 7.6. Note however that estimated groundwater use generally exceeds GAA by a small amount.

Generally, allocation rates and estimated use are low in groundwater catchments where GAA is zero. For example, groundwater allocation and groundwater use, both estimated as 1 l/s, represent a small allocation in the Mangamako area groundwater catchment.

7.5 Uncertainty and GAA estimates

Uncertainty in groundwater budget components (Section 6.3.4) and assumptions associated with GAA estimates (Section 7.2) combine to give uncertainty in GAA estimates. Rigourous assessment of the uncertainty of groundwater budget components and GAA estimates is beyond the scope of this project. However, uncertainty is considered in a conservative approach to estimation of groundwater available for allocation. For example GAA is estimated as zero where the equation for GAA (i.e. rainfall – AET – groundwater outflow to surface water) calculates a value less than zero. In these examples uncertainty in hydrological characterisation and groundwater budget components have an important influence on GAA. Therefore improvement in understanding of the groundwater system, through better characterisation and better estimation of groundwater budget components may result in non-zero estimates of GAA and groundwater becoming available for allocation.

Therefore, assessment of the uncertainty in groundwater available for allocation, and groundwater budget components, is recommended (Section 8.10).

Table 7.5 GAA and annual allocation for groundwater and net geothermal uses.

Major groundwater zone	Groundwater catchment ID	Groundwater allocation zone	GAA, Table 7.1 (l/s)	Groundwater allocation, Table 7.2 (l/s)	Geothermal allocation, Table 7.3 (l/s)	Total allocation (l/s)	Allocation as a percentage of GAA
Rangitaiki	1	Awaiti Canal	764	677	0	677	89%
Rangitaiki	3	Edgecumbe Catchwater	304	62	0	62	20%
Rangitaiki	4	Kope Orini 1	0	181	0	181	excess
Rangitaiki	5	Kope Orini 2	0	0	0	0	N/A
Rangitaiki	7	Mangamako area	0	1	0	1	excess
Rangitaiki	12	Ngakauroa Stream	439	233	0	233	53%
Rangitaiki	13	Nursery Drain	13	122	0	122	938%
Rangitaiki	14	Old Rangitaiki Canal	0	1	0	1	excess
Rangitaiki	17	Rangitaiki Dunes	0	9	0	9	excess
Rangitaiki	18	Reids Central Canal	521	320	0	320	61%
Rangitaiki	21	Te Rahu 1	306	0	5	5	2%
Rangitaiki	29	Waikowhewhe area	0	22	0	22	excess
Tarawera	2	Awakaponga	388	24	0	24	6%
Tarawera	8	Mangaone Stream	0	0	0	0	N/A
Tarawera	9	Mangate	783	0	0	0	0%
Tarawera	10	Mangawhio	0	0	0	0	N/A
Tarawera	11	Matata	23	0	0	0	0%
Tarawera	19	Rotoroa	373	0	15	15	4%
Tarawera	20	Tarawera Dunes	0	0	0	0	N/A
Tarawera	23	Tumarau	143	0	0	0	0%
Tarawera	24	Tumurenui	113	4	0	4	4%
Tarawera	25	Upper Tarawera	2946	139	0	139	5%

Major groundwater zone	Groundwater catchment ID	Groundwater allocation zone	GAA, Table 7.1 (l/s)	Groundwater allocation, Table 7.2 (l/s)	Geothermal allocation, Table 7.3 (l/s)	Total allocation (l/s)	Allocation as a percentage of GAA
Tarawera	26	Waiaute	0	0	0	0	N/A
Tarawera	27	Waikamihi Stream	483	122	0	122	25%
Tarawera	28	Waikanapiti	327	0	11	11	3%
Whakatane	6	Kope Orini 3	0	3	0	3	excess
Whakatane	15	Oromoeroa Flats	0	6	0	6	excess
Whakatane	16	Oromoeroa Hills	0	0	0	0	0%
Whakatane	22	Te Rahu 2	254	17	0	17	7%
Whakatane	30	Waimana East Flats	0	0	0	0	0%
Whakatane	31	Waimana Hills	0	12	0	12	excess
Whakatane	32	Waimana West Flats	0	0	0	0	0%
Whakatane	33	Waioho Canal	707	3	0	3	0%
Whakatane	34	Whakatane Dunes	0	0	0	0	N/A
Whakatane	35	Whakatane East	257	15	0	15	6%
Whakatane	36	Whakatane West Hills	0	2	0	2	excess

Table 7.6 GAA and estimated annual use by groundwater and net geothermal uses.

Major groundwater zone	Groundwater catchment ID	Groundwater allocation zone	GAA, Table 7.1 (l/s)	Groundwater estimated use, Table 7.2 (l/s)	Geothermal estimated net use[1], Table 7.3 (l/s)	Total allocation (l/s)	Allocation as a percentage of GAA
Rangitaiki	1	Awaiti Canal	764	254	0	254	33%
Rangitaiki	3	Edgecumbe Catchwater	304	26	0	26	9%
Rangitaiki	4	Kope Orini 1	0	64	0	64	excess
Rangitaiki	5	Kope Orini 2	0	0	0	0	N/A
Rangitaiki	7	Mangamako area	0	1	0	1	excess
Rangitaiki	12	Ngakauroa Stream	439	60	0	60	14%
Rangitaiki	13	Nursery Drain	13	37	0	37	285%
Rangitaiki	14	Old Rangitaiki Canal	0	1	0	1	excess
Rangitaiki	17	Rangitaiki Dunes	0	4	0	4	excess
Rangitaiki	18	Reids Central Canal	521	117	0	117	22%
Rangitaiki	21	Te Rahu 1	306	0	0	0	0%
Rangitaiki	29	Waikowhewhe area	0	22	0	22	excess
Tarawera	2	Awakaponga	388	18	0	18	5%
Tarawera	8	Mangaone Stream	0	0	0	0	N/A
Tarawera	9	Mangate	783	0	0	0	0%
Tarawera	10	Mangawhio	0	0	0	0	N/A
Tarawera	11	Matata	23	0	0	0	0%
Tarawera	19	Rotoroa	373	0	15	15	4%
Tarawera	20	Tarawera Dunes	0	0	0	0	N/A
Tarawera	23	Tumarau	143	0	0	0	0%
Tarawera	24	Tumurenui	113	2	0	2	2%

Major groundwater zone	Groundwater catchment ID	Groundwater allocation zone	GAA, Table 7.1 (l/s)	Groundwater estimated use, Table 7.2 (l/s)	Geothermal estimated net use[1], Table 7.3 (l/s)	Total allocation (l/s)	Allocation as a percentage of GAA
Tarawera	25	Upper Tarawera	2946	139	0	139	5%
Tarawera	26	Waiaute	0	0	0	0	N/A
Tarawera	27	Waikamihi Stream	483	122	0	122	25%
Tarawera	28	Waikanapiti	327	0	11	11	3%
Whakatane	6	Kope Orini 3	0	2	0	2	excess
Whakatane	15	Oromoeroa Flats	0	6	0	6	excess
Whakatane	16	Oromoeroa Hills	0	0	0	0	0%
Whakatane	22	Te Rahu 2	254	10	0	10	4%
Whakatane	30	Waimana East Flats	0	0	0	0	0%
Whakatane	31	Waimana Hills	0	12	0	12	excess
Whakatane	32	Waimana West Flats	0	0	0	0	0%
Whakatane	33	Waioho Canal	707	1	0	1	0%
Whakatane	34	Whakatane Dunes	0	0	0	0	N/A
Whakatane	35	Whakatane East	257	14	0	14	5%
Whakatane	36	Whakatane West Hills	0	2	0	2	excess
		Total	**23152**	**914**	**26**	**940**	

[1] These calculations exclude consents where geothermal fluid is reinjected.

8.0 RECOMMENDATIONS

This report brings together available information on the geology, groundwater level and surface water flows relevant to the groundwater resource in the Rangitaiki Plains and surrounding catchments to estimate groundwater budgets and groundwater available for allocation. This section summarises recommendations to improve environmental data for future refinements of the geological model, provide more robust estimates of groundwater allocation, and inform allocation policies on the Rangitaiki Plains.

The preliminary assessment of groundwater available for allocation in this report notes various gaps in available information that partly result in the use of conservative estimates of groundwater available for allocation (Section 7). Better environmental information will result in a less conservative approach to estimation of groundwater available for allocation and thus allow Bay of Plenty Regional Council greater confidence in allocation, particularly within the groundwater catchments under greater stress in the area.

The Rangitaiki Plains is a focus of this project. This report provides important improvements of our knowledge of the hydrology of the Plains with identification of surface water catchments, groundwater catchments and groundwater budgets. However further work is required in the Plains to improve our knowledge of the area’s hydrology and hydrogeology.

8.1 Geological data

The geological model of the Rangitaiki Plains has been developed with available surface geological information and driller’s log records held by BOPRC. Lithological data collected from future drill holes will be used to refine this model and the following recommendations aim to assist future model revisions:

- BOPRC hold a workshop for drillers active in the Rangitaiki Plains, and other interested parties, to explain:
  - the importance of good lithological data;
  - the use of driller’s logs in development of the geological model; and
  - key features of the geology of the Rangitaiki Plains in relation to groundwater supply, e.g. depth to Pleistocene Last Glaciation terrestrial sediments, which may be an important aquifer.
- BOPRC interpret drill hole logs, as they are lodged by drillers, in relation to chronology (e.g. Holocene (Q1), Pleistocene Last Glacial (Q2-Q4), Pleistocene Last Interglacial (Q5), Matahina Ignimbrite) developed in the geological model and record interpreted chronololgy with the well data.

8.2 Low-flow measurement programme

Bay of Plenty Regional Council holds records of low flow for many streams and drains in the study area. However some low flow measurement sites are not located in the ideal position to measure baseflow discharge and many streams and drains have only one, or few, flow measurements. Baseflow discharge is used to estimate groundwater available for allocation (Section 7). However the historical record includes flow measurements that are typically not targeted at the measurement of baseflow. Groundwater – surface water interaction on the

Rangitaiki Plains associated with the Rangitaiki, Whakatane and Tarawera rivers is not considered in the groundwater budgets (Section 6.2) yet these interactions could be important components of the groundwater budget.

Generally, targeted measurements of baseflow, with a programme of low-flow gaugings, will improve our knowledge of outflow from the groundwater system. Therefore it is recommended that Bay of Plenty Regional Council review its low-flow measurement programme in the Rangitaiki Plains and other catchments in the study area, with regard to:

- the location of flow gauging sites to measure baseflow discharge from groundwater catchments identified in this report, i.e. gauging sites would be ideally located at the bottom of groundwater catchments;
- the location of sites that could indicate surface water discharge to groundwater;
- groundwater – surface water interaction on the Rangitaiki Plains associated with the Rangitaiki, Whakatane and Tarawera rivers;
- prioritisation for measurement; and
- frequency of measurement.

It is also recommended that Bay of Plenty Regional Council incorporate low-flow measurements in Rangitaiki Plains streams and drains, and other groundwater catchments in the study area, at priority sites in its summer gauging programme for the purpose of measuring baseflow discharge (Section 8.3).

8.3 Surface baseflow discharge estimates

The following recommendations for baseflow measurement in the study area assume the following priorities, in order of priority from high to low:

- groundwater catchments where groundwater allocation is greater than groundwater available for allocation (Section 7), i.e. where existing groundwater allocation may exceed sustainable limits;
- groundwater catchments where estimated baseflow is similar to the difference between rainfall and AET, i.e. where groundwater available for allocation is low, or zero;
- groundwater catchments with no measurements of baseflow; and
- groundwater catchments where existing gauging data provide poor characterisation of baseflow.

Groundwater allocation exceeds groundwater available for allocation in the Nursery Drain groundwater catchment and the Ngakauroa Stream groundwater catchment (Section 7). The Nursery Drain groundwater catchment receives groundwater recharge from the Ngakauroa Stream groundwater catchment and, taken together, the groundwater allocation in these catchments is greater than groundwater available for allocation. These are the groundwater catchments under greatest use pressure in the study area and therefore some further study is warranted to ensure groundwater use remains sustainable.

The following are recommended:

- improve the estimates of stream baseflow with low-flow gaugings of streams in the area;
- spring-fed streams and drains are observed in these catchments and therefore simultaneous low-flow gaugings would be useful in identifying the locations of groundwater inflow.

Groundwater catchments where estimated baseflow is similar to the difference between rainfall and AET include six groundwater catchments where groundwater available for allocation is zero and allocation for groundwater use is greater than zero (i.e. 'excess' in Table 7.6) including: Kope Orini 1, Waikowhewhe area, Rangitaiki Dunes, Kope Orini 3, Mangamako area and Old Rangitaiki Canal.

Groundwater allocation in these catchments is low. For example, groundwater allocation in these six catchments is greatest in Kope Orini 1, with an allocation equivalent of 64 l/s (Table 7.6); allocation is less than 4 l/s in four of these catchments. Therefore current allocation is most unlikely to be a problem to the sustainability of the groundwater resource. However the estimated groundwater available for allocation is zero (Table 7.6), which indicates that groundwater use may impact on baseflow. This points to the need for improved estimates of specific discharge in these groundwater catchments by measuring baseflow at suitable sites.

Baseflow in the Rangitaiki Plains includes discharge from drains. Problems with the use of drain flows to measure baseflow discharge include:

- low, or zero, surface gradients in the lower Plains giving rise to low, or zero, flow in drains at times of low flow;
- pumped drains with unusually large estimates of baseflow (Section 6);
- drains with flap valves that only open when the drain level is greater than the receiving water body; and
- areas of the lower Plains that are below sea level.

This report identifies a wide range in estimates of baseflow discharge from drains and the following are recommended:

- annual summer gaugings at suitable sites to estimate baseflow discharge from groundwater catchments; and
- installation of a stage recorder at a site that is possibly representative of baseflow discharge from the Plains but is not influenced by tidal effects. The Te Rahu Drain is suggested as a suitable feature for these measurements.

Surface baseflow measurements would be useful in groundwater catchments where existing gauging data provide poor characterisation of baseflow. These catchments include those above the Rangitaiki Plains. A general aim is to identify surface baseflow above a groundwater catchment and below a groundwater catchment so that any gain in surface flow from the groundwater catchment could be measured. The following are recommended and a justification for each recommended measurement site is noted:

- Upper Tarawera River: measure flow at Edwards Road, site 15373 (Figure 6.9). Only one flow measurement has been made at this site, and this measurement indicates a significant groundwater inflow from Lake Tarawera (Section 6.2.3). An improved estimate of groundwater outflow from Lake Tarawera is relevant to assessment of the water budget and water quality of Lake Tarawera;

- Oromoeroa Flats groundwater catchment: measure baseflow in the Whakatane River above and below this catchment. Baseflow gain from this catchment by the Whakatane River is unknown because suitable surface gauging measurements above and below the catchment are not available;
- Waimana East Flats groundwater catchment: measure baseflow in the Waimana River above this catchment. Baseflow gain from this catchment by the Waimana River can be assessed by comparison of low flow measurements at an upstream site with flow measurements at the existing Waimana Gorge site;
- Waimana West Hills groundwater catchment: measure baseflow in the Waimana River above and below this catchment. Baseflow gain from this catchment by the Waimana River is unknown because suitable surface gauging measurements above and below the catchment are not available; and
- Whakatane River gaugings to assess any groundwater outflows from Whakatane West Hills and Whakatane east groundwater catchments.

8.4 Groundwater level

Many BOPRC groundwater level records are influenced by pumping (Section 6). These level records cannot be used in the groundwater level map. Therefore it is recommended that BOPRC review their groundwater level data to identify wells that would be suitable for groundwater level measurement, in order to develop an improved groundwater level map, i.e. wells with access for measurement of the groundwater level and wells that are evenly distributed over the Rangitaiki Plains. A programme of groundwater level measurement in these wells is recommended for the middle – end of summer period with the aim of improving the piezometric map.

Ground level is below sea level near the coast between Matata and the Rangitaki River. Hence groundwater level may be below sea level near the coast. Therefore sea water intrusion is a risk to groundwater on the Rangitaiki Plains between Matata and the Rangitaki River. Collection of groundwater elevation data, pumping data and relevant aquifer properties (e.g., hydraulic conductivity) would be helpful to assess the risks of salt water intrusion in this area.

It is recommended that:

- wells between Matata and the Rangitaki River near the coast are located on the ground;
- ground elevations at the wells, and groundwater depths in the wells, are surveyed and static groundwater elevation is calculated;
- wells where groundwater level is at, or below, sea level are considered at risk from salt water intrusion;
- drawdowns during pumping and groundwater levels after pumping should be considered in this analysis;

- Bay of Plenty Regional Council consult with well owners and discuss possible future actions; and
- Bay of Plenty Regional Council review estimates of groundwater available for allocation in the groundwater catchments if static groundwater levels are shown to be below sea level.

8.5 Groundwater chemistry

Groundwater chemistry data in the study area have not been reviewed in this report. Therefore it is recommended that groundwater chemistry data are reviewed including consideration of the potential for salt water intrusion and of the relatively high iron concentrations in groundwater on the Rangitaiki Plains as identified by Gordon (2001).

8.6 Possible groundwater outflow from Lake Rotoma

An assessment of groundwater budgets in the Paeangaroa-Matata area (White *et al.* 2008) identifies that Lake Rotoehu and Lake Rotoma may be discharging water to groundwater; this water may provide baseflow to streams flowing to the coast north of the lakes. Lake Rotoma may provide baseflow to the Mangaone Stream groundwater catchment in the study area, which may explain the unusually large specific discharge from this catchment (Table 6.7). Groundwater available for allocation is zero in this catchment, assuming groundwater inflow is zero (Table 7.6). However, groundwater inflow may come from Lake Rotoma. Therefore further investigation of the water budget components in this catchment is recommended, including measurement of baseflow in the Mangaone Stream catchment near the Lake Rotoma catchment boundary.

8.7 Groundwater and surface water allocation policy

It is recommended that Bay of Plenty Regional Council consider allocation policies for:

- groundwater allocation based on GAA estimates in this report (Table 7.1);
- surface water flow in drains in the Rangitaiki Plains. This is because drains are important features of the hydrology of the Rangitaiki Plains. Groundwater commonly flows to drains and estimated flow to drains is a component of the water budget used to estimate groundwater available for allocation. Baseflow in drains may be crucial to the maintenance of important wetlands. Therefore maintenance of baseflow in drains, through limits on groundwater allocation, may be of environmental importance.

  However, maintenance of baseflow in drains, or streams, may not be a priority for BOPRC. Groundwater available for allocation will be larger than estimates in Table 7.5 should there be no provision for maintenance of baseflow in drains. For example, current groundwater allocation is greater than groundwater available for allocation in the Nursery Drain catchment (Table 7.5). Should the policy not aim to protect surface water flow in the Nursery Drain catchment (72 l/s, Table 6.7), then groundwater available for allocation will increase by 72 l/s.
- salt water intrusion with definition of a ‘set-back’ distance for wells taking water from coastal aquifers and from aquifers where static groundwater level is at, or near, sea level. This policy could aim to reduce the potential for salt water intrusion to groundwater;
- allocation of groundwater from storage. Allocation of groundwater from storage (as

opposed to groundwater flux) is not good practice as this can lead to mining of the groundwater resource. However allocation of groundwater from storage may be reasonable in emergency situations (e.g., fire or failure of drinking water supplies in natural disasters). Therefore stringent rules around allocation of groundwater from storage in emergency situations, and rules that identify an emergency situation, could be considered by Bay of Plenty Regional Council.

8.8 Current groundwater allocation and estimated use

Potential stress on the groundwater resource is indicated by:

- groundwater allocation, and groundwater use, that are relatively large proportions of estimated groundwater available for allocation; and
- groundwater level measurements that indicate the risk of salt water intrusion (Section 8.4 and Section 8.5).

Current groundwater allocation is generally less than estimated groundwater available for allocation in the study area (Section 7). Groundwater allocation is greater than groundwater available for allocation in the Nursery Drain groundwater catchment and the Ngakauroa Stream groundwater catchment.

Bay of Plenty Regional Council could consider further groundwater investigations in catchments that have potential stress from groundwater use to improve knowledge of groundwater recharge and groundwater use. These investigations would aim to assess, for example:

- estimates of baseflow in streams and drains (Section 8.3);
- hydrological properties e.g. hydraulic conductivity;
- effects of groundwater use on groundwater levels at the catchment scale;
- effects of pumping on groundwater level in neighbouring wells; and
- effects of groundwater pumping on stream flow.

8.9 Groundwater and surface water allocation and availability

Groundwater allocation and surface water allocation are linked where groundwaters and surface waters are linked. For example, Section 6.2.3.1, a surface water flow gauging in Waiaute Stream (Table 6.4) estimates surface baseflow from the Waiaute groundwater catchment (5,427 l/s) that is similar to estimated annual groundwater recharge (4724 l/s, Table 6.1). This indicates that the entire groundwater outflow from the Waiaute groundwater catchment probably flows into Waiaute Stream and GAA is set at zero (Table 7.1) to protect this baseflow.

Groundwater allocation limits and surface water allocation limits are not compared in this report. However, groundwater allocation limits and surface water allocation limits are both important where groundwaters and surface waters are linked. For example use of groundwater may reduce surface flow below a surface allocation limit.

Therefore this report recommends that groundwater allocation limits derived by BOPRC (Section 8.7) from GAA estimates (Table 7.1) are compared with surface water allocation limits. This is to ensure that estimates of GAA are consistent with surface water allocation limits. For example GAA in a groundwater catchment should not be greater than the surface water allocation limit in a stream that gains groundwater.

It is also recommended that the use of surface water allocation limits (e.g. 'Q_5 7-day' flow, Wilding 2003) is investigated in determining GAA estimates, i.e. as an alternative to using surface baseflow in Table 7.1.

This report also recommends that datasets are developed in a GIS format to allow convenient access to information on: groundwater flow, surface water flow, goundwater allocation (when determind by BOPRC from GAA estimates), surface water allocation and water availablity (i.e. the difference between water allocation limits, when determined by BOPRC, and water allocation). BOPRC could also provide a convenient information system on water allocation, and linked groundwater – surface water allocation, by integrating data on groundwater allocation with data on surface water allocation within common geographic units (i.e. groundwater catchments).

8.10 Assessment of uncertainty

Uncertainties in groundwater budget components and GAA estimates have not been rigoursly assessed in this project. Therefore this report uses a conservative approach to estimate GAA (sections 6.3.4 and 7.5).

A rigourous approach to estimating uncertainty in groundwater budget components and GAA is recommended. Ideally, this would come after improvements in estimations of groundwater budget components (e.g. sections 8.2 and 8.3). Uncertainty in groundwater budget components and GAA could be expressed in GIS maps.

The uncertainty assessment could be piecemeal or include the whole project area. A piecemeal approach could focus on groundwater catchments where use is a large proportion of GAA, or use is great than zero but GAA is assessed as zero (e.g. Table 7.5). This could follow targetted hyroglogical (e.g. sections 8.2 and 8.3), and hydrogeological, investigations in these catchments (e.g. Section 8.8).

8.11 Geothermal allocation

Geothermall allocation is large in some groundwater catchments (Table 7.3). However geothermal use (i.e. net use) is mostly assumed as zero i.e. it is assumed that most geothermal water is reinjected to the ground. The assumption that most geothermal water is reinjected is untested in this report. Geothermal production water that is 'lost' from groundwater catchments, e.g. through evaporation, could be a significant portion of groundwater catchment budgets.

Therefore any losses of geothermal fluid between abstraction and reinjection could be assessed by BOPRC and any effects on groundwater catchment budgets and GAA could be identified.

8.12 Model of groundwater recharge and flow

The model of groundwater recharge and outflow used in this report is quite simple but is appropriate as a first cut at estimating groundwater availability for allocation in the Rangitaiki Plains. Further analysis by groundwater catchment could provide more detailed information on groundwater flows and availability for allocation.

It is recommended that Bay of Plenty Regional Council consider a more sophisticated model to improve the confidence of groundwater allocation estimates on the Rangitaiki Plains. A MODFLOW or FEFLOW groundwater model would be the next logical step to assess groundwater resources in the area. This model could consider rainfall recharge, groundwater flow, groundwater recharge from streams, groundwater outflow to streams and drains and groundwater outflow off shore. Conceptual models of geological layers and groundwater flows described in this report are sufficient to commence development of a steady-state model.

9.0 SUMMARY

Groundwater in the Rangitaiki Plains, Bay of Plenty, and surrounding catchments is taken by municipal, agricultural and commercial users. Municipal users, for example Whakatane District Council and Kawerau District Council, take groundwater from bores and springs (White 2005). Use of groundwater by agriculture and commercial users in the Rangitaiki Plains is predicted to increase in the future (White 2005). However, past development of groundwater resources has been without estimates of groundwater availability. To avoid inadvertent over-allocation of groundwater, Bay of Plenty Regional Council (BOPRC) commissioned GNS Science to complete a preliminary assessment of groundwater availability in the Rangitaiki Plains and surrounding catchments.

The area of this assessment (Figure 1.1) includes the surface catchments of the Tarawera River, the Rangitaiki River north of Matahina Dam and Whakatane River catchments (including the catchment of the Waimana River) north of the foothills. This assessment is completed with a synthesis of geological information, hydrological data and hydrogeological information to identify geological structure suitable for aquifers, calculate groundwater budgets and estimate groundwater available for allocation (GAA).

The geology of Rangitaiki Plains area is summarised in this report in terms of:

- Jurassic to Early Cretaceous basement rocks;
- Quaternary volcanic and sedimentary deposits; and
- structure of the Whakatane Graben.

Basement rocks are characterised geologically by their complex deformation. Sedimentary rocks of Torlesse (composite) terrane crop out in the east of the area and range in age from Jurassic to Early Cretaceous. These are principally comprised of greywacke, i.e. indurated, poorly sorted, mostly lithic sandstone and siltstone.

Quaternary deposits in the study area are represented by lavas and pyroclastics of the Taupo Volcanic Zone (TVZ) and sediments of the Tauranga Group. Quaternary lavas and ignimbrites with a large extent in the area include: Okataina Group rhyolitic lava outcrop between Lake Rotoma and Kawerau; Whakamaru Ignimbrite exposed south of the Tarawera River and Kawerau; and Matahina Ignimbrite which underlies the Rangitaiki Plains and a large part of the hills surrounding the Rangitaiki Plains.

Tauranga Group sediments are predominantly volcaniclastic, derived by reworking of TVZ eruption deposits. The major sedimentary events within the area are commonly responses to pulses of volcanic activity, rather than climatic fluctuations. Materials are dominated by loose, pumiceous sandstone, but also contain minor mudstone.

Marine fossils of Quaternary Holocene age are identified in Quaternary sediments below Rangitaiki Plains. Subsequent to deposition of the Matahina Ignimbrite and prior to the Holocene period, there were two periods of high sea level when sea level elevation was similar to today. In the intervening periods, Rangitaiki Plains sediments were deposited in a terrestrial environment because sea levels were low and shorelines retreated to the edge of the continental shelf.

Holocene deposits from eruptions are common on the Rangitaiki Plains, including: Taupo Pumice Alluvium, interpreted as an outwash deposit that followed soon after the c. 1.72 kyr Taupo eruption, that is widely distributed around the course of the Rangitaiki River across the plains; Kaharoa Pumice Alluvium, mapped extensively from Kawerau across the eastern side of the Tarawera River almost as far as Matata; and 1886 Tarawera Eruption deposits including scoria, sand, silt and mud thinly covering most of the Rangitaiki Plains.

The present Holocene period, with a relatively warm climate, commenced about 12 kyr. Sea level rose, invading the Rangitaiki Plains as far as Awakeri and almost to Te Teko. Holocene alluvium and swamp deposits are widely distributed across the Rangitaiki Plains, the former particularly around the courses of the Whakatane and Rangitaiki rivers, the latter particularly behind dune and marginal marine materials in the coastal strip.

The Whakatane Graben is a key structural feature of the study area which includes the Taupo Rift and associated faults of the North Island Fault System. Four important Taupo Rift faults are the Edgecumbe, Otakiri, Awaiti and Braemar/Matata faults; most faults strike approximately northeast and dip either to the northwest or the southeast, probably at or about 60°. The Edgecumbe Fault was the locus of the principal rupture plane in the M6.3 1987 Edgecumbe Earthquake. The rupture associated with the earthquake had a maximum displacement of c. 2.5 m. Gravity and seismic data across the Rangitaiki Plains near the coast identifies the Edgecumbe Fault as carrying the major displacement of the Whakatane Graben with an approximate vertical throw on greywacke basement of up to 2300 m.

Faults of the North Island Fault System are dominantly strike-slip and strike about north-south in the Rangitaiki Plains area. These faults include the Waiohau Fault and the Whakatane Fault that form the eastern margin of the Whakatan Graben.

The Okataina Volcanic Centre is an important structural feature in the south of the study area. Late Quaternary rhyolitic eruptions from the Okataina calderas have each produced large quantities of loose airfall that was re-deposited as alluvial pumiceous outwash materials across the study area.

Stratigraphic marker horizons represented in a geological model of the Rangitaiki Plains area include: Holocene terrestrial and marine sediments; the top of Last Glacial terrestrial deposits; the top of Last Interglacial marine deposits; the top of Matahina Ignimbrite; and top of basement. Marine incursions to the Rangitaiki Plains are represented in the model, including the Holocene (Q1) and the last Pleistocene marine incursion (Q5) identified by shell deposits. The surface at the end of the Last Glaciation (Q2) is represented over the Rangitaiki Plains by sediments deposited in a terrestrial environment that are about 40 m deep at the coast.

Potential aquifers identified in the geological model include:

- gravels associated with Whakatane River at the end of the Pleistocene, approximately 25 m deep west of Whakatane township;
- gravels associated with Whakatane River in the Whakatane River valley upstream of Taneatua;
- gravels associated with the Rangitaiki River in the Holocene period;
- pumice associated with the Rangitaiki River and Tarawera River south of about Edgecumbe; and
- Matahina Ignimbrite under the Rangitaiki Plains particularly where the ignimrite is relatively thick near the western hills.

The geological model also represents key structural features, including faults. The importance of the Edgecumbe Fault to the structure of the Whakatane Graben is demonstrated in the model:

- basement east of this fault is relatively shallow and Quaternary sediments are relatively thin; and
- basement west of this fault is relatively deep and Quaternary sediments are relatively thick.

Three major groundwater and surface water catchments are identified in the study area associated with the Tarawera, Rangitaiki and Whakatane rivers. Within these major groundwater catchments, the boundaries of 36 groundwater catchments are estimated in the study area based on an analysis ground topography, surface water flows (including drainage scheme flows), geology and groundwater flow directions. Surface water flows are relevant to identification of groundwater catchment boundaries on the Rangitaiki Plains because:

- surface drainage catchments have measurements of surface water flow that are used for groundwater budget calculations;
- surface drainage catchments may receive groundwater flow from adjacent groundwater catchments and groundwater budgets are used to assess these flows; and
- surface flow in drains comes from groundwater, therefore groundwater use may impact on drain flow within a groundwater catchment.

Groundwater budgets of groundwater catchments are calculated using estimates of: rainfall, actual evaporation, surface water baseflow in streams (calculated from historical gaugings) and drains (using historical gaugings and estimates of specific discharge), and groundwater flow. For example, a summary of major groundwater flow budget components for the Rangitaiki major groundwater catchment has:

- inflow from rainfall of 14.8 m^3/s and outflow from AET of 9.2 m^3/s;
- groundwater inflow from the Tarawera major groundwater catchment of 2.9 m^3/s:
- groundwater outflow to surface water of 3.7 m^3/s, including the Rangitaiki River and the Tarawera River catchment; and
- groundwater outflow to the coast of 4.9 m^3/s.

Groundwater flow budgets are used to estimate groundwater available for allocation (GAA) in each allocation zone, i.e. each groundwater catchment, generally with:

GAA = rainfall – AET – groundwater outflow to surface water i.e. baseflow

This approach assumes that groundwater outflow to surface water is not available for allocation, thereby protecting surface water features from over-abstraction of groundwater. Some conservative estimates of water budget components aiming to protect groundwater from over-abstraction, and consider the uncertainty of estimates, are made in the translation of groundwater budget components to estimates of GAA, for example:

- GAA is assumed as zero where a groundwater catchment has an estimate of groundwater outflow that is greater than the difference between rainfall and AET;
- estimates of specific discharge on the Rangitaiki Plains that are used in the water budget typically yield a calculated surface flow that is greater than the flow measured in March 2010 following a period of low rainfall;
- groundwater inflows to groundwater catchments are not included in the GAA estimation; and
- median flows are used in estimating surface baseflow.

An example of the calculation of GAA for the Rangitaiki major groundwater catchment gives:

- GAA approximately 2 m^3/s; and
- zero GAA in the following allocation zones: Kope Orini 1, Kope Orini 2, Mangamako area, Old Rangitaiki Canal, Rangitaiki Dunes and Waikowhewhe area.

Annual allocation and estimated groundwater use are compared with GAA to assess the sustainability of current groundwater allocation in the study area. For example, in the Rangitaiki major groundwater catchment:

- total annual groundwater allocation is approximately 1.6 m^3/s and total estimated use is approximately 0.6 m^3/s;
- current groundwater allocation in the Nursery Drain groundwater catchment is 122 l/s, while estimated GAA is 13 l/s;
- current groundwater allocation in the Ngakauroa Stream groundwater catchment is 233 l/s, while estimated GAA is 189 l/s; and
- allocation is greater than zero but GAA is zero in six groundwater catchments. Note however that allocation generally exceeds GAA by a small amount in these groundwater catchments.

Some groundwater catchments have estimated groundwater use that exceeds the estimated GAA. For example:

- estimated groundwater use in the Nursery Drain groundwater catchment is 37 l/s, while estimated GAA is 13 l/s;
- groundwater use is greater than zero but assigned GAA is zero in six groundwater catchments. Note however that groundwater use generally exceeds GAA by a small amount in these groundwater catchments.

This report makes recommendations to improve environmental data for future refinements of the geological model, to provide more robust estimates of groundwater allocation and to consider allocation policies on the Rangitaiki Plains. These recommendations include:

- run a workshop for local drillers informing them of the results of the geological model;
- conduct a summer low-flow measurement programme in Rangitaiki Plains streams and drains for the purpose of measuring baseflow discharge;
- measure baseflow discharge estimates in:
    - groundwater catchments where groundwater allocation is greater than GAA, i.e. where existing groundwater allocation may exceed sustainable limits;
    - groundwater catchments where estimated baseflow is similar to the difference in rainfall and AET, i.e. where GAA is low, or zero; and
    - groundwater catchments with no, or very few, measurements of baseflow.
- measure groundwater level near the coast between Matata and the Rangitaiki River because groundwater level may be below sea level in this area and so the aquifer may be at risk from salt water intrusion;
- consider surface water allocation policy for drains in the Rangitaiki Plains. This is because drains are important features of the hydrology of the Rangitaiki Plains. Baseflow in drains may be crucial to the maintenance of important wetlands. Therefore maintenance of baseflow in drains, through limits on groundwater allocation, may be of environmental importance. However, the intended purpose of the drains is to make land suitable for farming and therefore protection of baseflow in drains may not be a priority for BOPRC. GAA will be larger than estimates in this report, in groundwater catchments with drains, should there be no provision for maintenance of drain baseflow.

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FIGURES

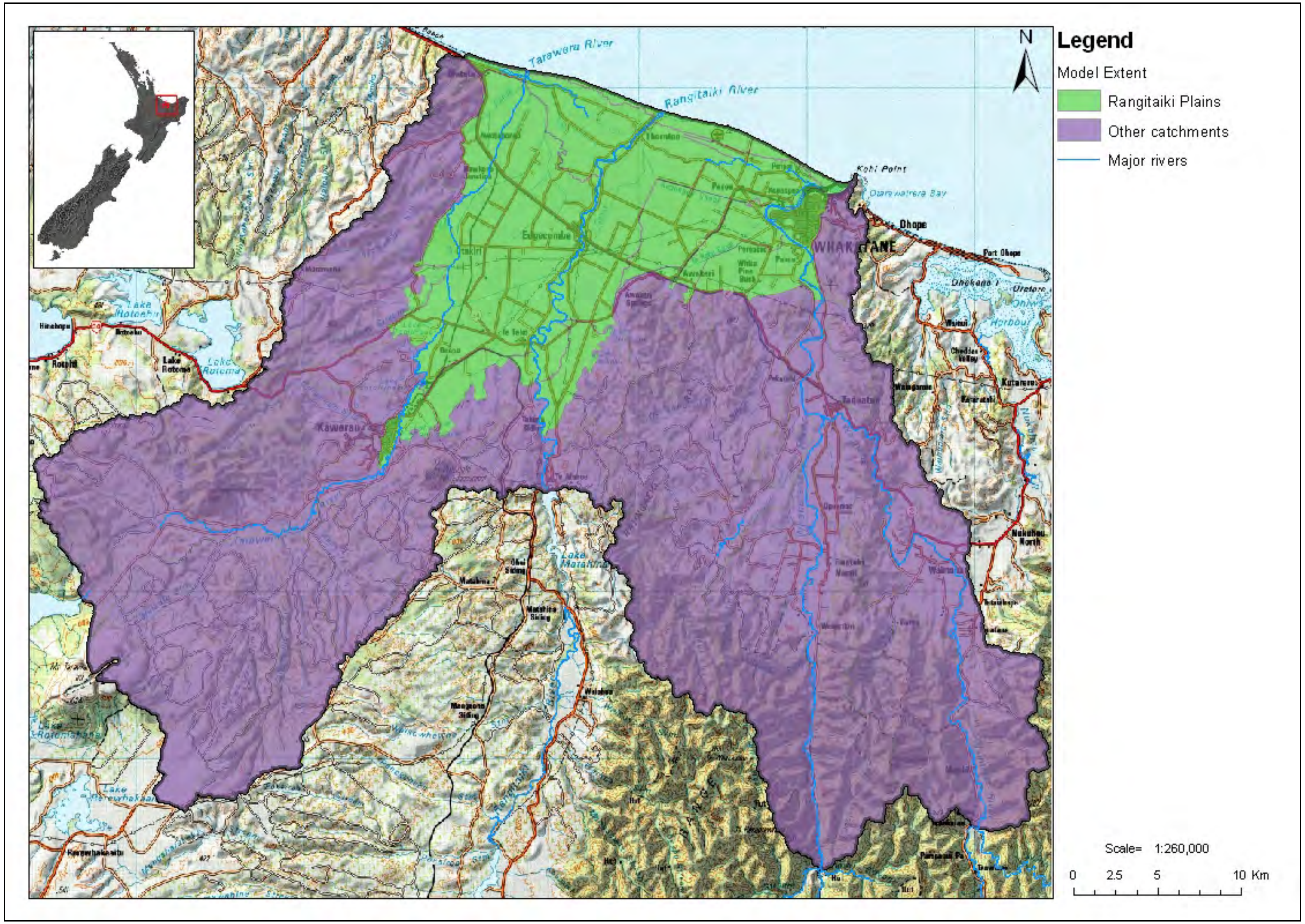


Figure 1.1 Rangitaiki Plains area.

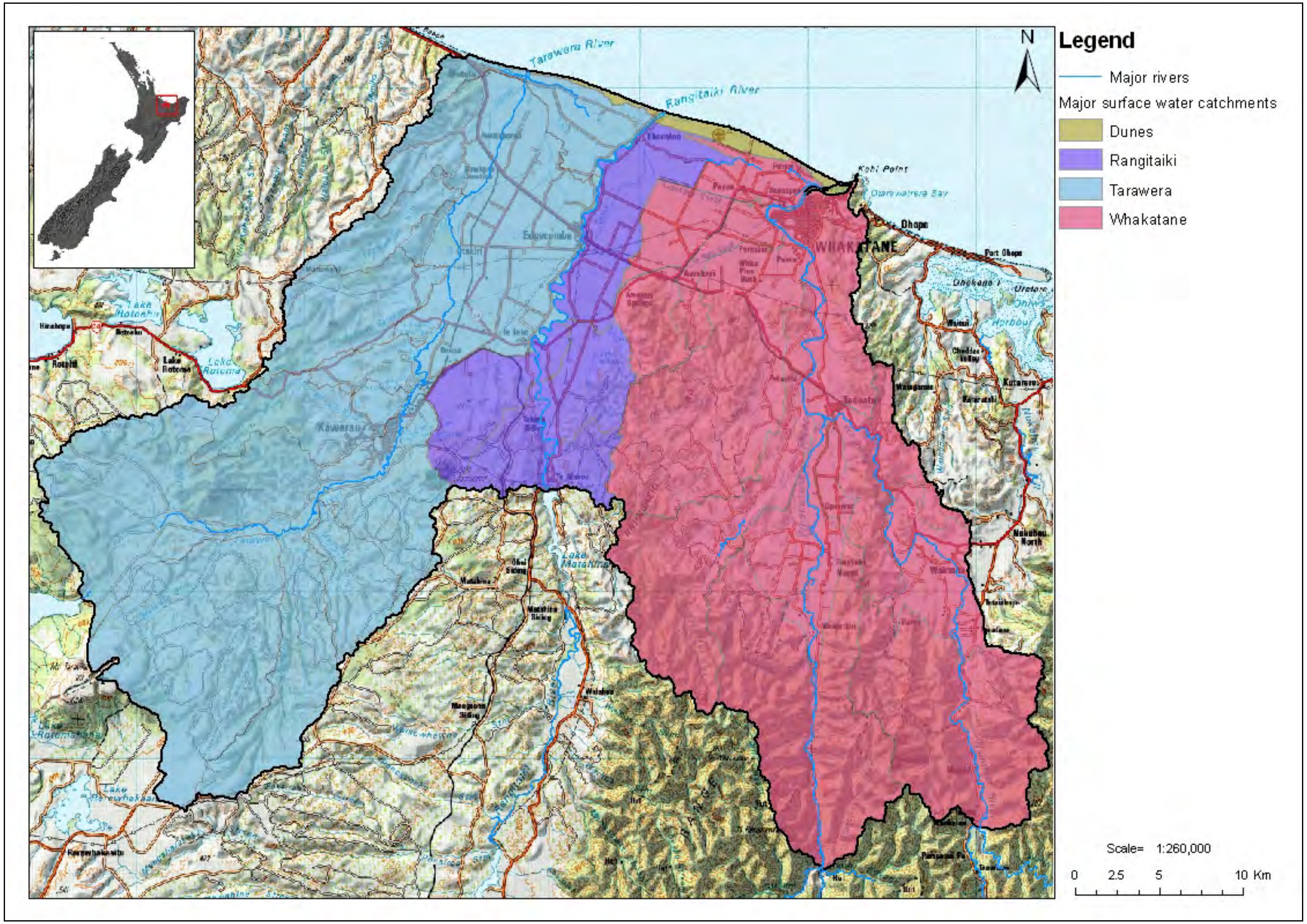


Figure 1.2 Major surface water catchments in the Rangitaiki Plains area.

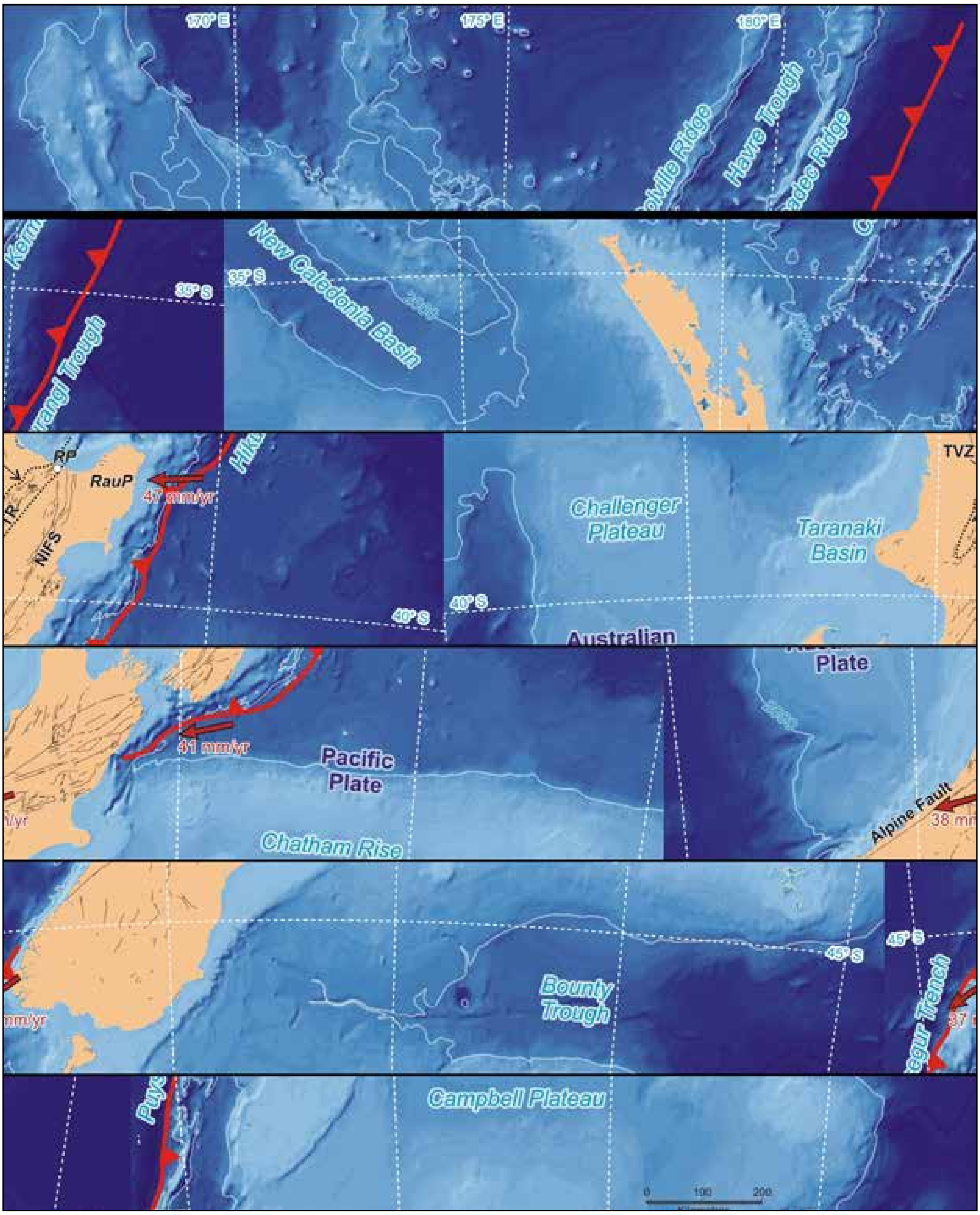


Figure 2.1 New Zealand's regional tectonic setting, showing the location of the Hikurangi Trough, the Raukumara Peninsula (RauP), North Island Fault System strike-slip faults, Taupo Volcanic Zone (TVZ) and active faults of the Taupo Rift (TR; normal faults). Major onshore active faults are marked as fine black lines. Offshore features (including the Kermadec and Colville ridges, the Havre Trough and the 2000 m isobath) are annotated. The Rangitaiki Plains area (RP) lies on the Australian Plate and the red arrows indicate the direction and relative rate of convergence with the Pacific Plate (after Anderson and Webb 1994).

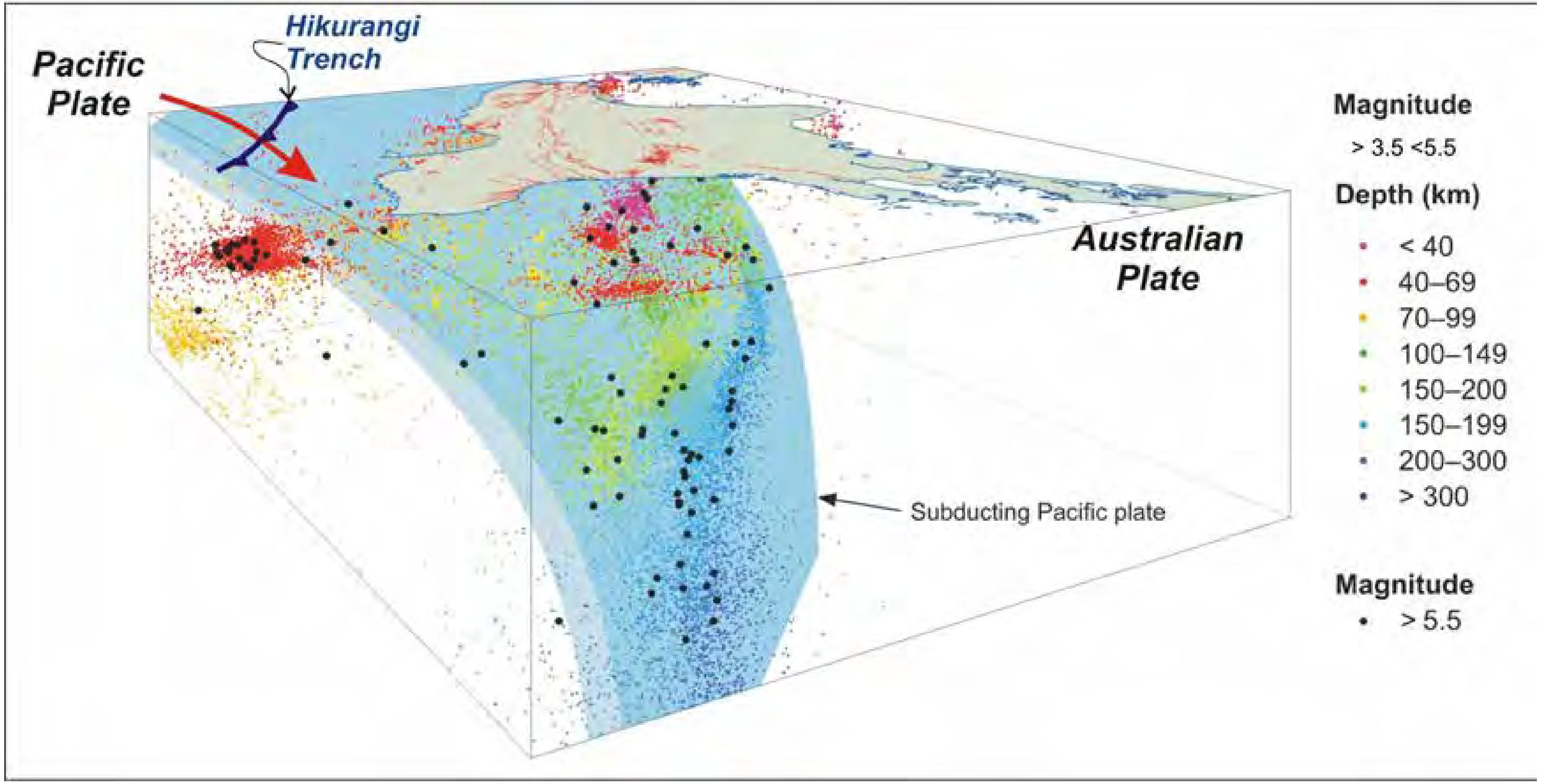


Figure 2.2 A cross section through the Hikurangi Margin. The Pacific Plate, in the process of subduction along the convergent Hikurangi Trench, dips down beneath the leading edge of the Australian Plate (beneath the North Island). The fault between the subducting Pacific and overlying Australian Plate is known as the subduction interface. The subduction interface and the underlying cool, brittle and flexing Pacific Plate is a significant source of earthquakes. Here, the epicentres of all earthquakes recorded between 1990 and 2009 are plotted by location. Smaller earthquakes between M3.5 and M5.5 are colour-coded according to depth. Note that the depth of the Pacific Plate beneath the Taupo Volcanic Zone is c. 120 to 170 km, where microearthquakes are coloured green. Note also the density of microearthquakes at shallow depth (< 60 km; pink and red) beneath the TVZ. The locations of earthquakes > M5.5 are plotted as black balls. Relative convergence between the Pacific and Australian plates is represented by the red arrow. Onshore active faults are shown as red lines. Note that the horizontal scale is the same as the vertical scale in this diagram.

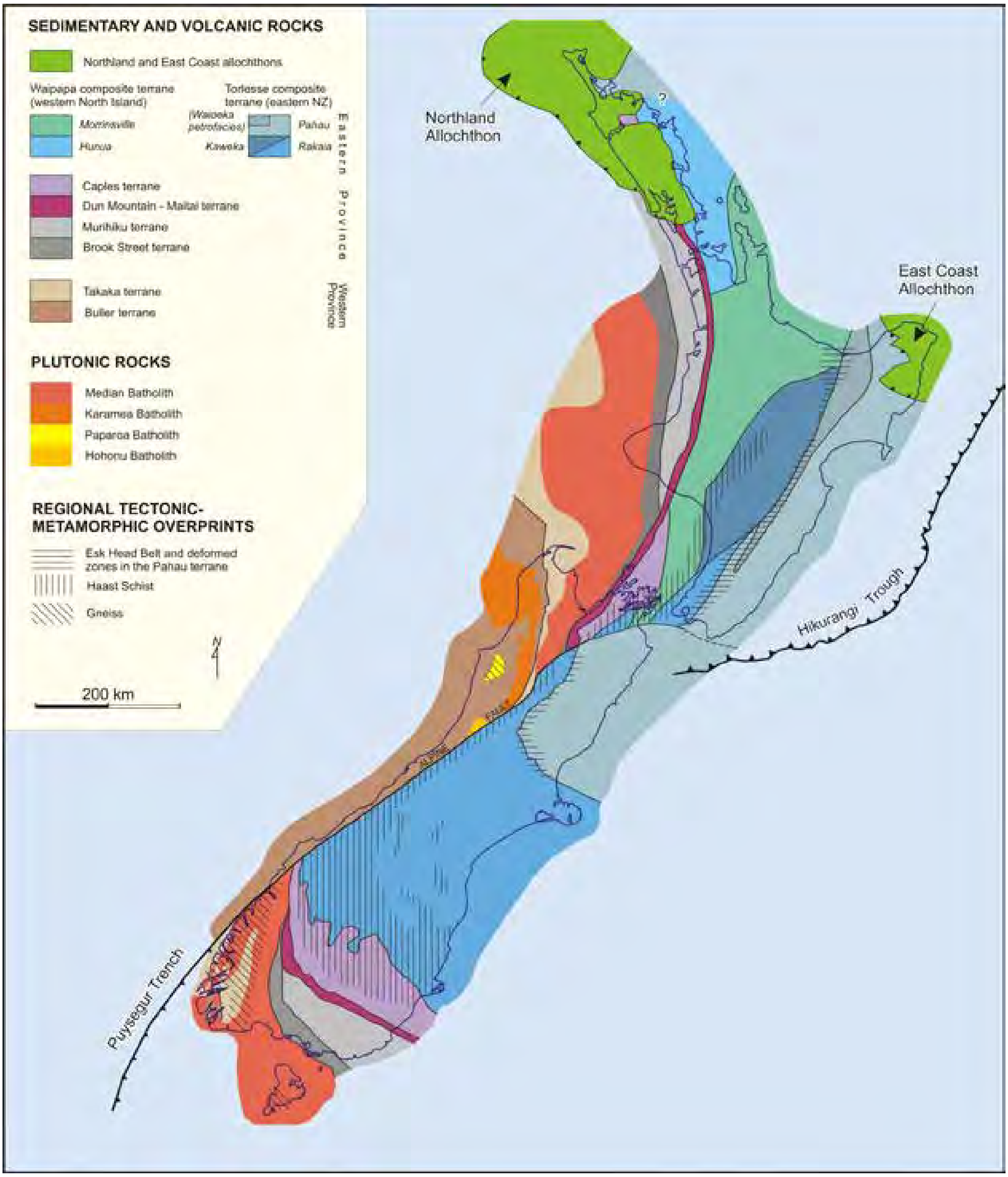


Figure 2.3 Basement rocks of New Zealand. The distribution of pre-Cenozoic rocks subdivided into tectonostratigraphic terranes and batholiths (after Mortimer 2004; Adams *et al.* 2007). Nomenclature and boundaries of North Island terranes are controversial; parts of Murihiku terrane, and Morrinsville and Pahau units may be correlative, Late Jurassic to Early Cretaceous terrane overlap assemblages, provisionally assigned to the Waipa Supergroup (Kear and Mortimer 2003). The extent of the Northland and East Coast allochthons, emplaced in the Early Miocene, is also shown; all other units were in mutual juxtaposition by the Late Cretaceous. Basement terranes underlie the Northland and East Coast allochthons, and although not shown, to the northwest of the North Island landmass.

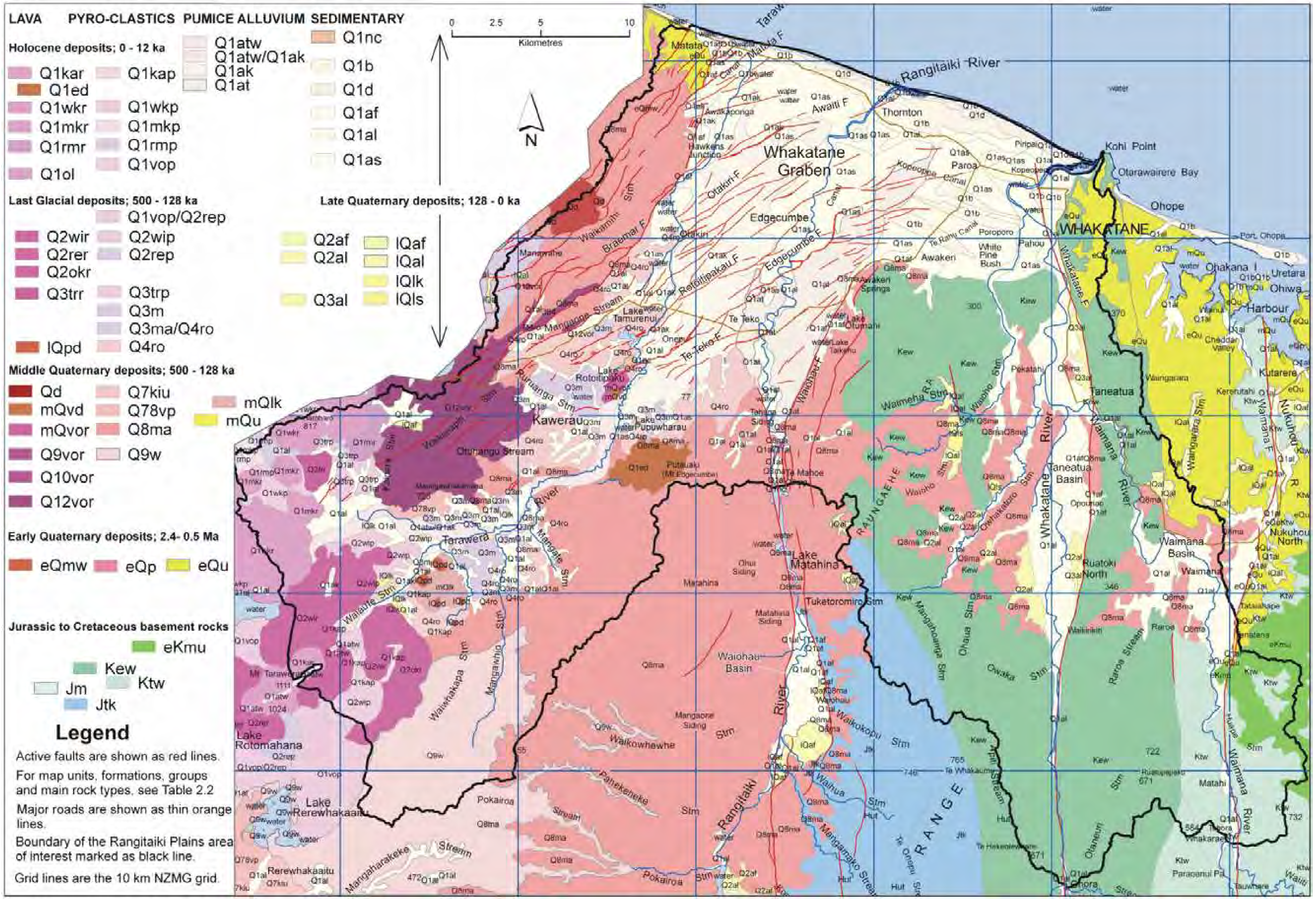


Figure 2.4 Geological map of the Rangitaiki Plains. Geological units are marked with a unit code; unit codes are arranged in the legend approximately in stratigraphic order, with lavas on the left, pyroclastics in the middle and sediments on the right. Unit code prefixes (e.g. Q2) refer to the oxygen isotope stage age of the unit (see Table 2.3 for absolute ages). A summary of lithologies found in each unit is provided in Table 2.2.

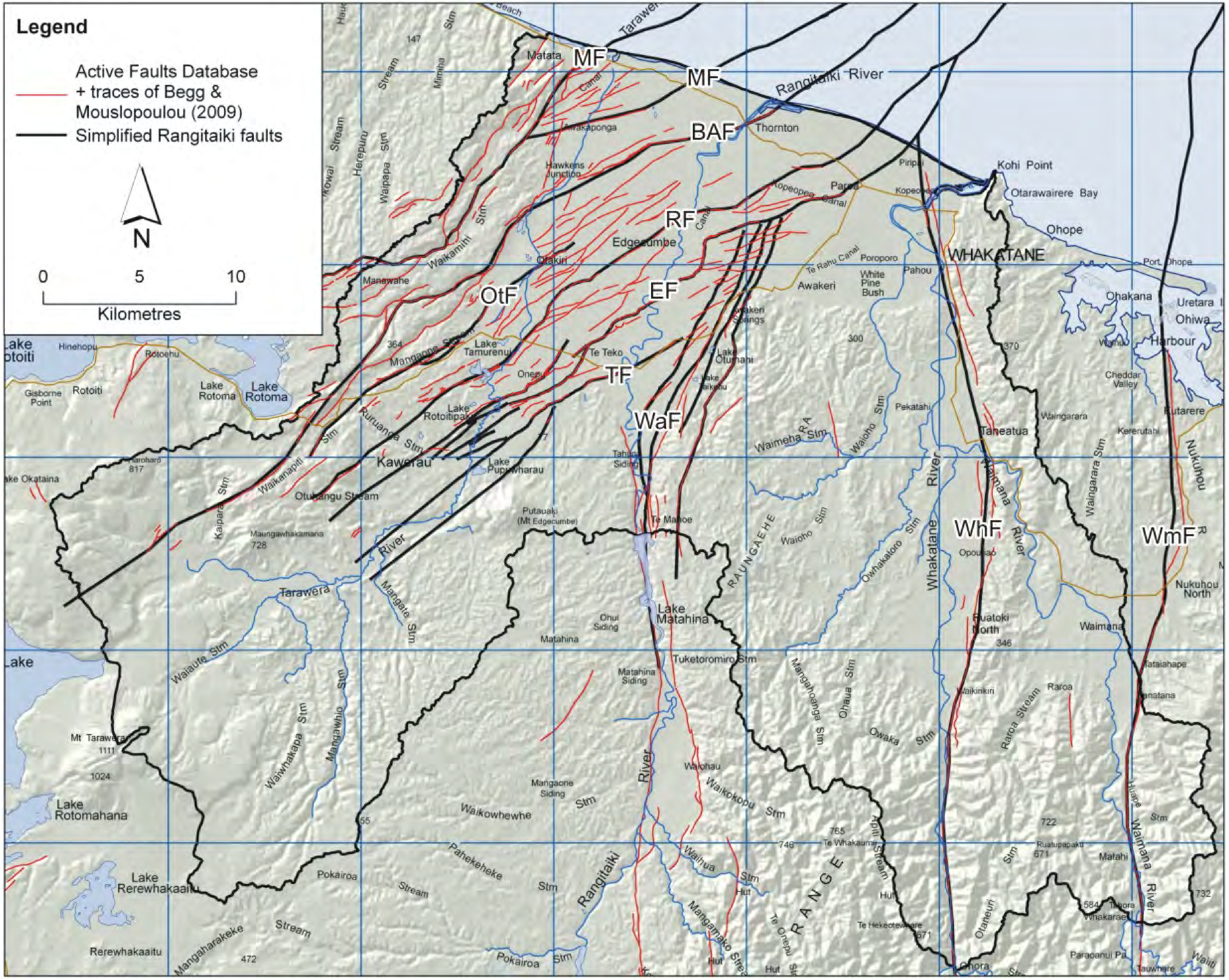


Figure 3.1 Faults of the Rangitaiki Plains area. Many active faults of the North Island Fault System and Taupo Rift traverse the Rangitaiki Plains. They are here shown in red. For the purposes of the modelling, they have been reduced in number to those with the major displacements, and simplified in form. Modelled faults are shown as heavy black lines. MF = Matata Fault; BAF = Braemar-Awaiti Fault; OtF = Otakiri Fault; RF = Rotoitipaku Fault; EF = Edgecumbe Fault; WaF = Waiohau Fault; WhF = Whakatane Fault; WmF = Waimana Fault.

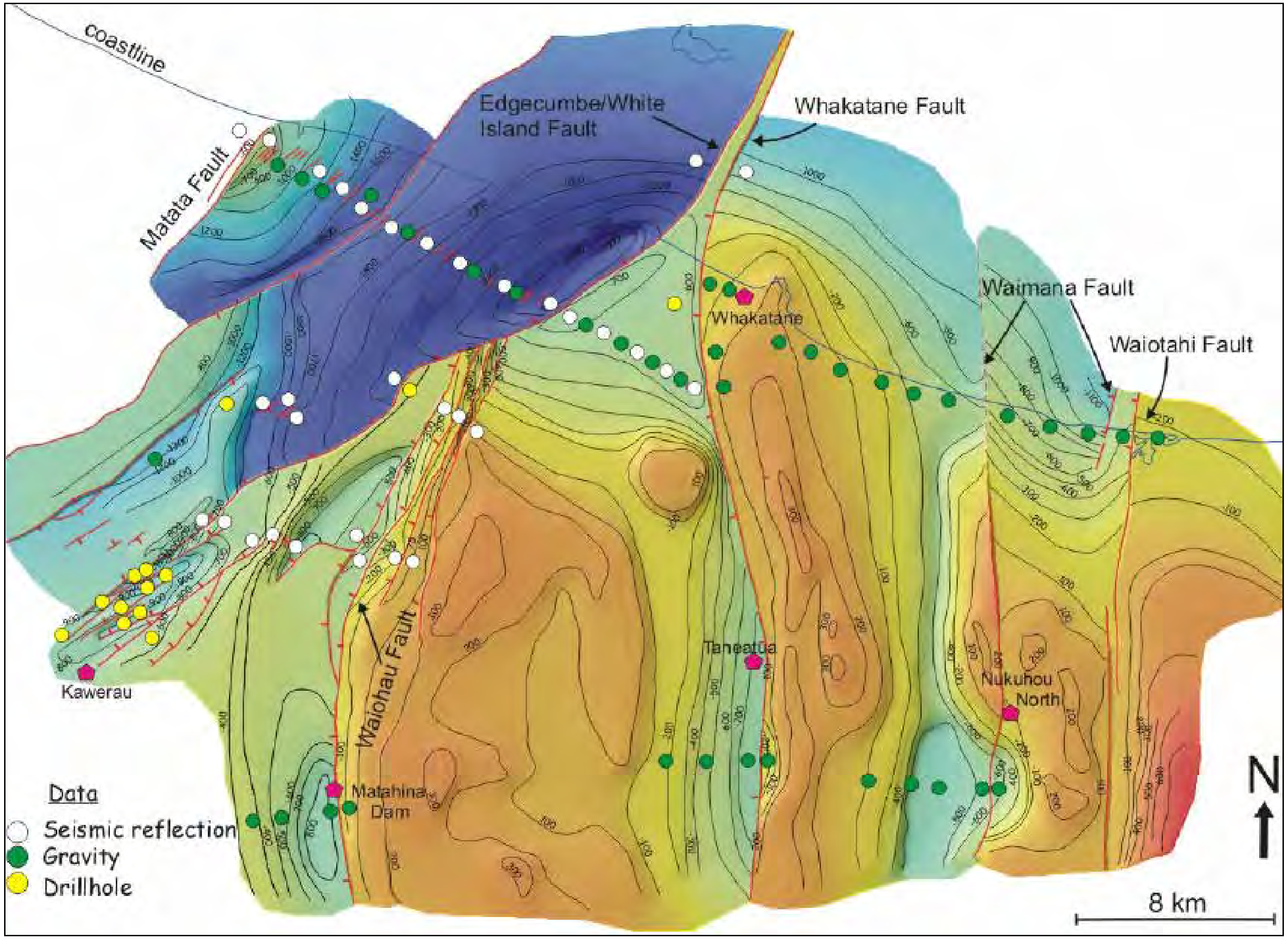


Figure 3.2 Elevation of the top of basement (Mouslopoulou 2006, Mouslopoulou *et al.* 2008) derived from seismic reflection profiles, interpretation of gravity surveys and some published drillhole information in the Rangitaki Plains area. Active faults (known at the time) are shown as red lines, with ticks on the downthrown side. Structure contours are in metres above and below sea level. The coastline and major townships are indicated. Note that the model of Mouslopoulou (2006) and Mouslopoulou *et al.* (2008) has been slightly refined in the course of this work.

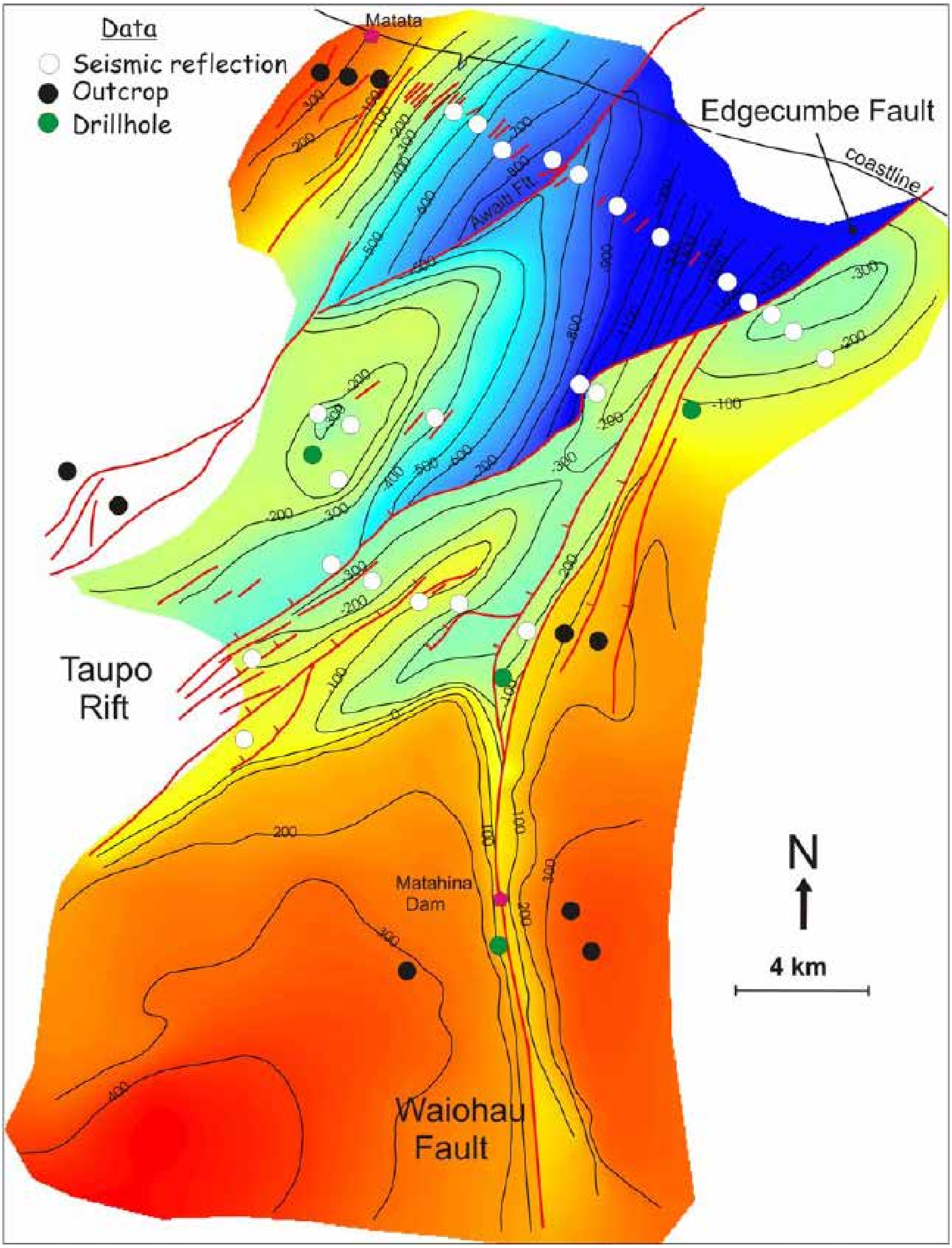


Figure 3.3 Elevation of the top of Matahina Ignimbrite (Mouslopoulou 2006, Mouslopoulou *et al.* 2008) compiled from seismic reflection profiles, drillholes and outcrop geology on the top of the Matahina Ignimbrite. Black lines are structure contours marked as positive above sea level and negative below sea level. Note that the model of Mouslopoulou (2006) and Mouslopoulou *et al.* (2008) has been slightly refined in the course of this work.

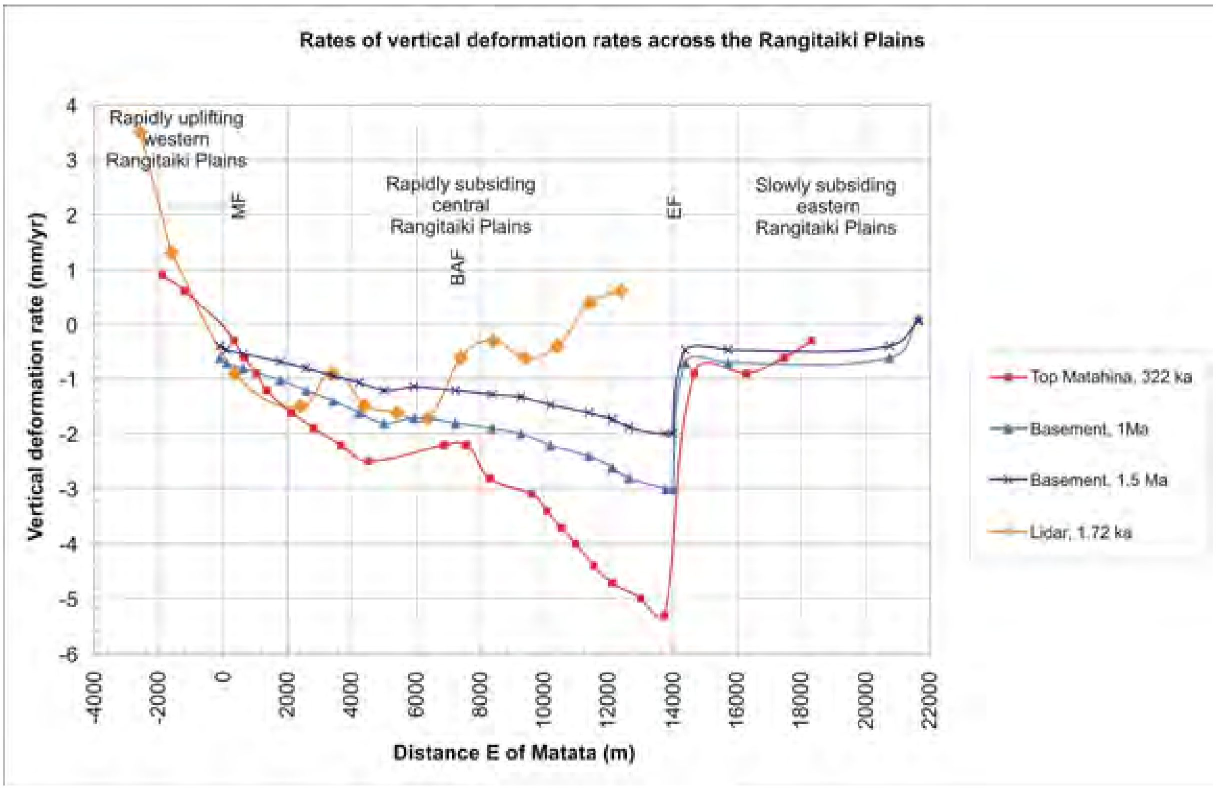


Figure 3.4 Estimates of deformation rates across the Rangitaiki Plains. The overall pattern of vertical deformation rates across the Rangitaiki Plains is remarkably similar over a wide range of time scales. Matata is located at the zero point on the horizontal axis. The coloured lines illustrate deformation rates across the Rangitaiki Plains near the coast over differing time periods. The two blue lines show possible deformation of the basement surface beneath the plains and is cumulative since the ages shown. The red line illustrates the deformation rate across the Rangitaiki Plains on the top of the Matahina Ignimbrite (c. 322 kyr); the rate is cumulative from the time of deposition to the present day. The orange line is derived from LIDAR data and represents the deformation rate based on the current elevation of the 1.72 kyr beach ridge compared with the elevation of its present day analogue. Even though the Edgecumbe Fault (EF) ruptured in 1987, there is little indication of deformation at the coast (downthrown west of 14 000 m for the 1.72 kyr line). Instead, the 1.72 kyr deformation signal is dominated by very young displacements of the Otakiri (c. 10 000 - 11 000 m east of Matata; BAF) and Matata faults (c.1 000 – 2 000 m east of Matata; MF). Note also that rates of deformation derived from the period between the Matahina eruption and the present day are significantly higher than those for the time between the basement surface and the present day, and for the period between 1.72 kyr and the present day. Note that positive numbers on the vertical axis represent uplift and negative numbers on the vertical axis subsidence.

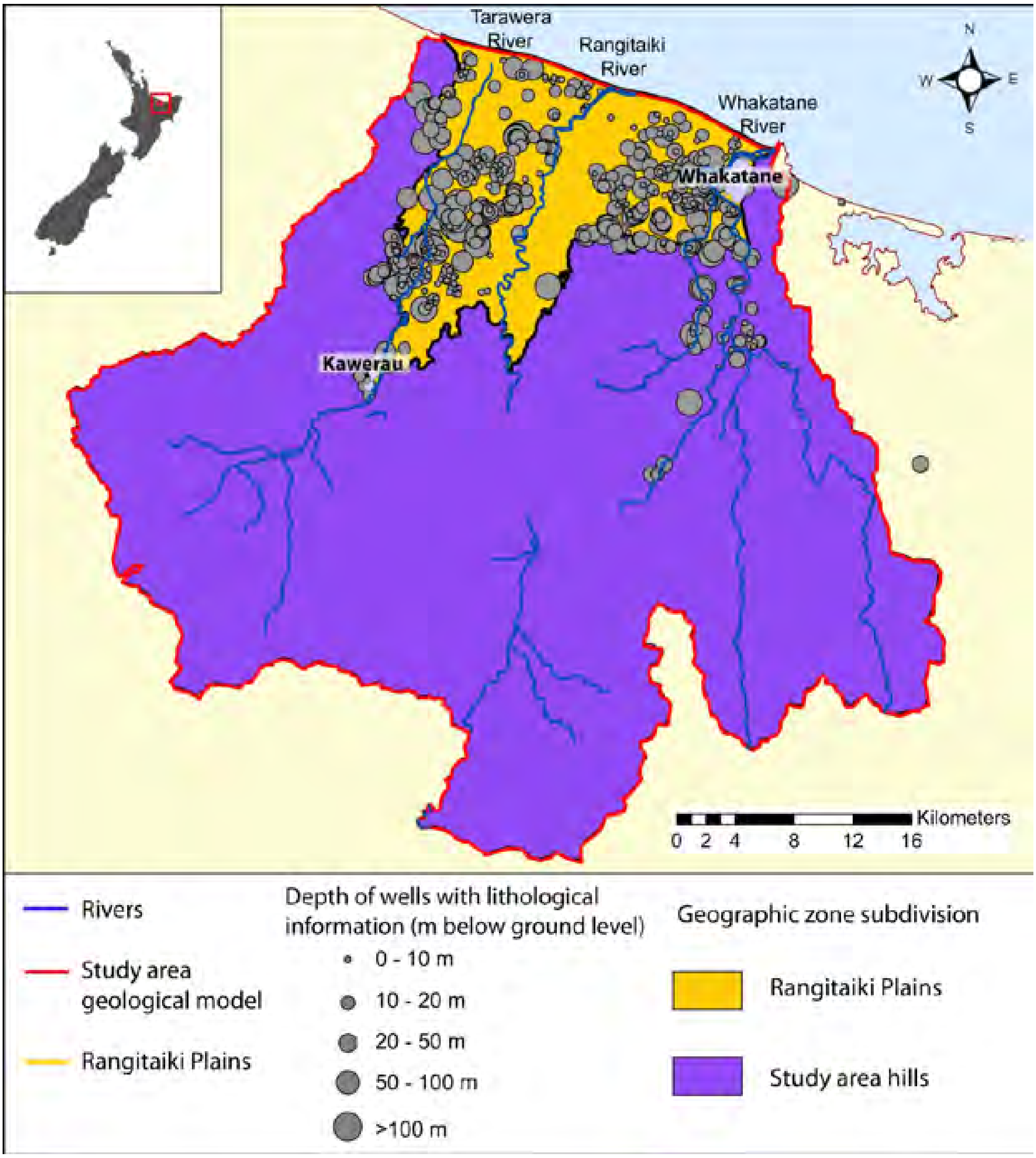


Figure 4.1 Location and depths of wells used in the Rangitaiki Plains geological model.

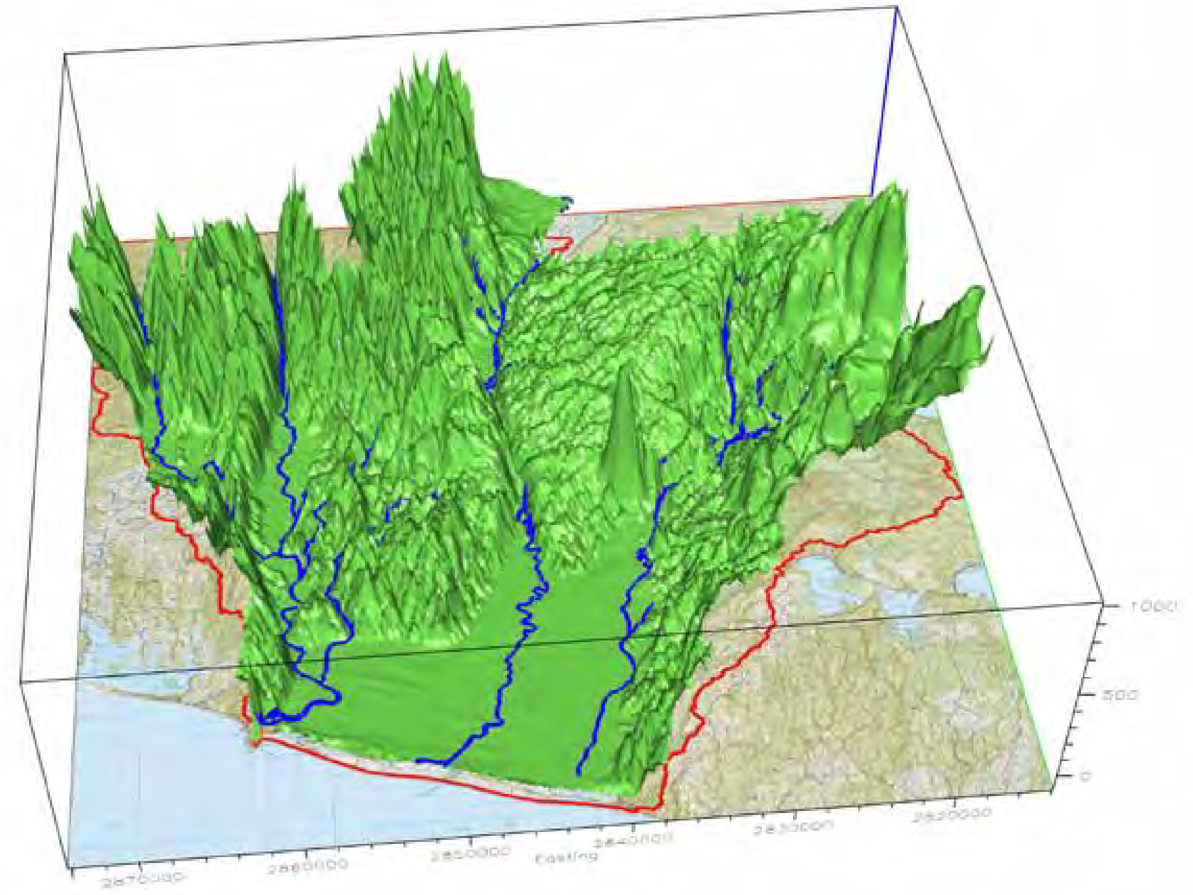
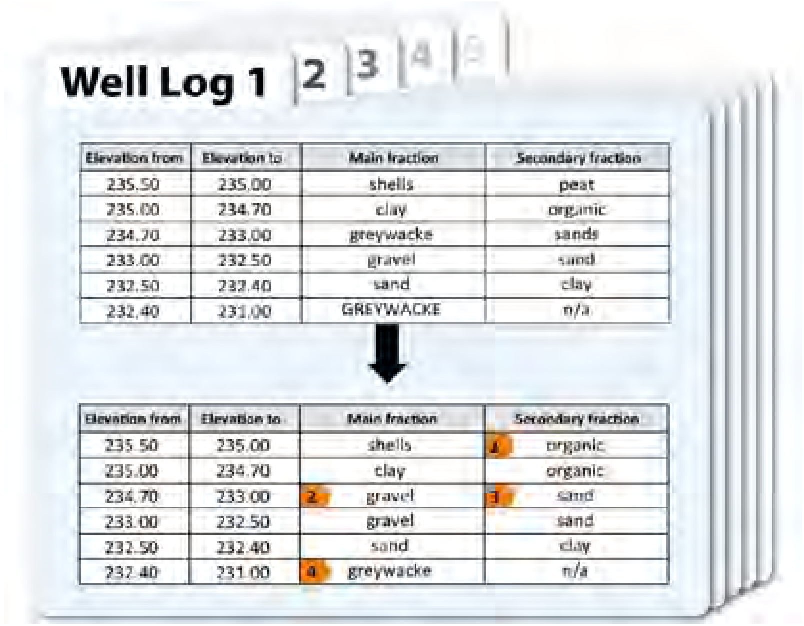


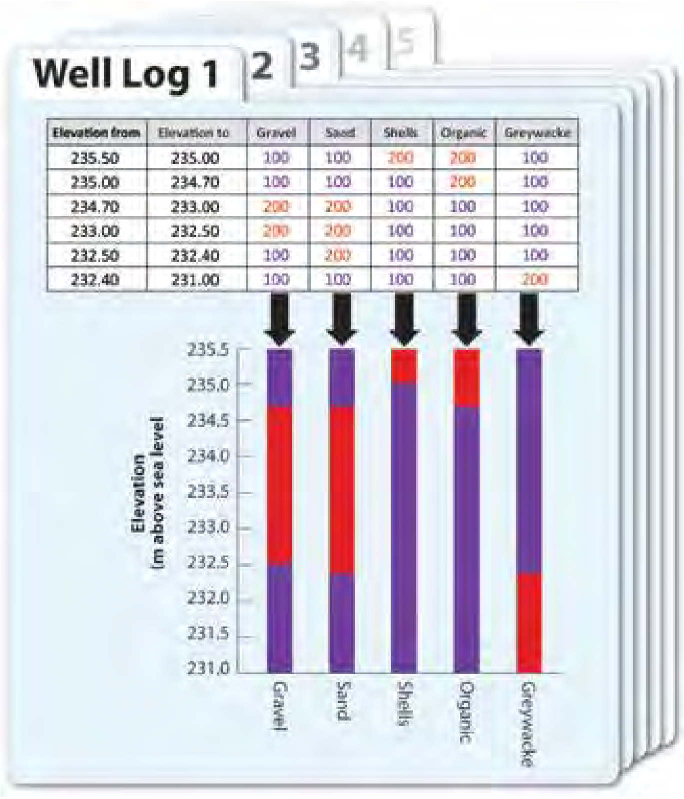
Figure 4.2 Digital terrain model (DTM) of the area of the Rangitaiki Plains geological model. The red line on the topographic map below the DTM shows the study area boundary.



Elevation from	Elevation to	Main fraction	Secondary fraction
235.50	235.00	shells	peat
235.00	234.70	clay	organic
234.70	233.00	greywacke	sands
233.00	232.50	gravel	sand
232.50	232.40	sand	clay
232.40	231.00	GREYWACKE	n/a

Elevation from	Elevation to	Main fraction	Secondary fraction
235.50	235.00	shells	1 organic
235.00	234.70	clay	organic
234.70	233.00	2 gravel	3 sand
233.00	232.50	gravel	sand
232.50	232.40	sand	clay
232.40	231.00	4 greywacke	n/a

Figure 4.3 Examples of edits and corrections made during checking of hypothetical well log data. Highlighted numbers show examples, including: 1) edits to ensure consistency of terminology, e.g. universal use of the term "organic" instead of a term like "peat"; 2) corrections to probable geological errors, e.g. greywacke occurring above gravel; 3) consistent use of singular vs. plural descriptors, e.g. "sand" instead of "sands" and 4) consistent use of lower case text.



Elevation from	Elevation to	Gravel	Sand	Shells	Organic	Greywacke
235.50	235.00	100	100	200	200	100
235.00	234.70	100	100	100	200	100
234.70	233.00	200	200	100	100	100
233.00	232.50	200	200	100	100	100
232.50	232.40	100	200	100	100	100
232.40	231.00	100	100	100	100	200

Figure 4.4 Assignment of lithological property codes and creation of pseudo-logs for a hypothetical well log. Throughout this report, the lithological property code value of 200 is used to indicate the presence of certain lithology or marker, whereas a value of 100 is used to indicate its absence (the actual values used are arbitrary). Pseudo-log plots show the presence or absence of lithological properties using red or purple, respectively.

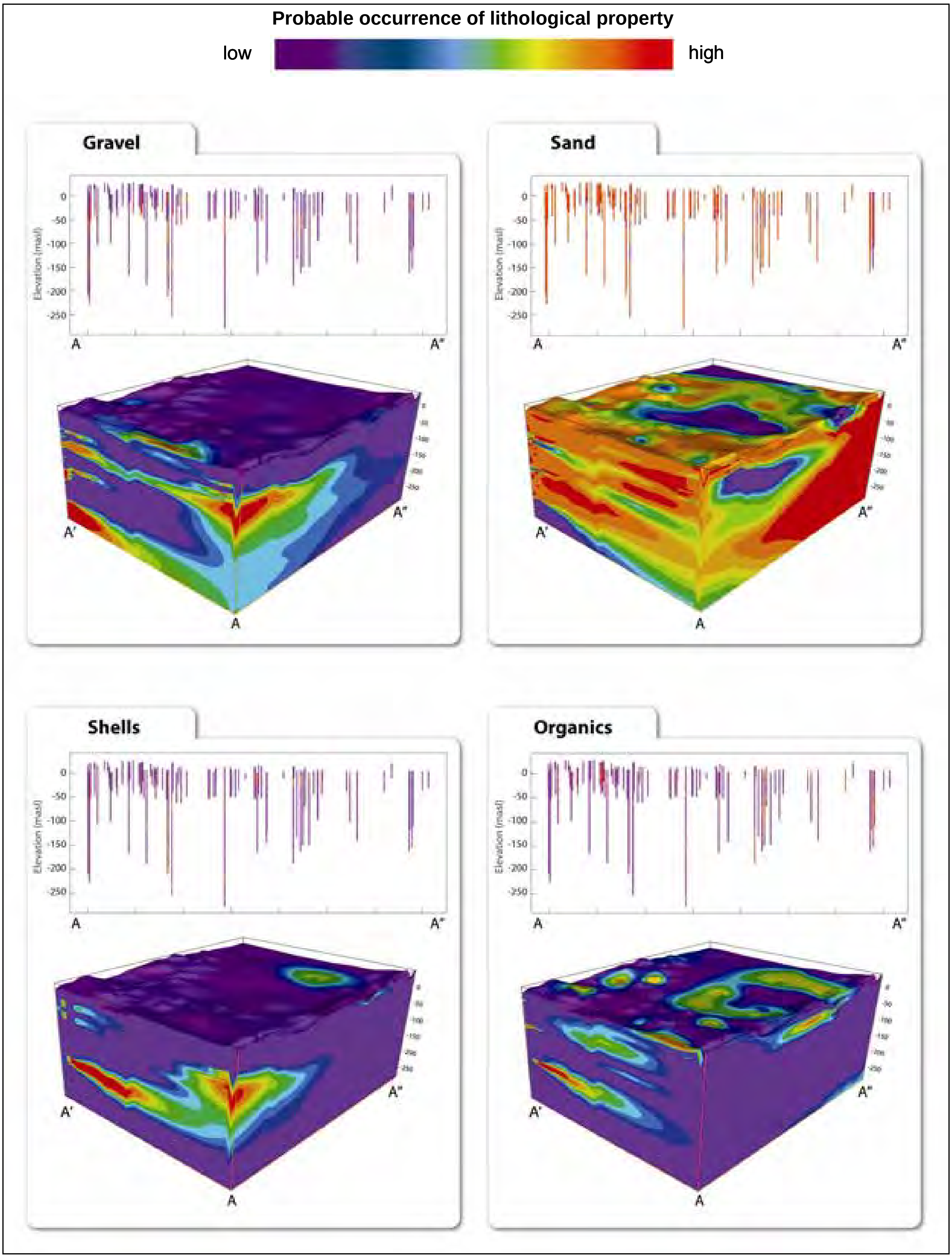


Figure 4.5 Pseudo-logs and lithological property models generated for a hypothetical geological scenario.

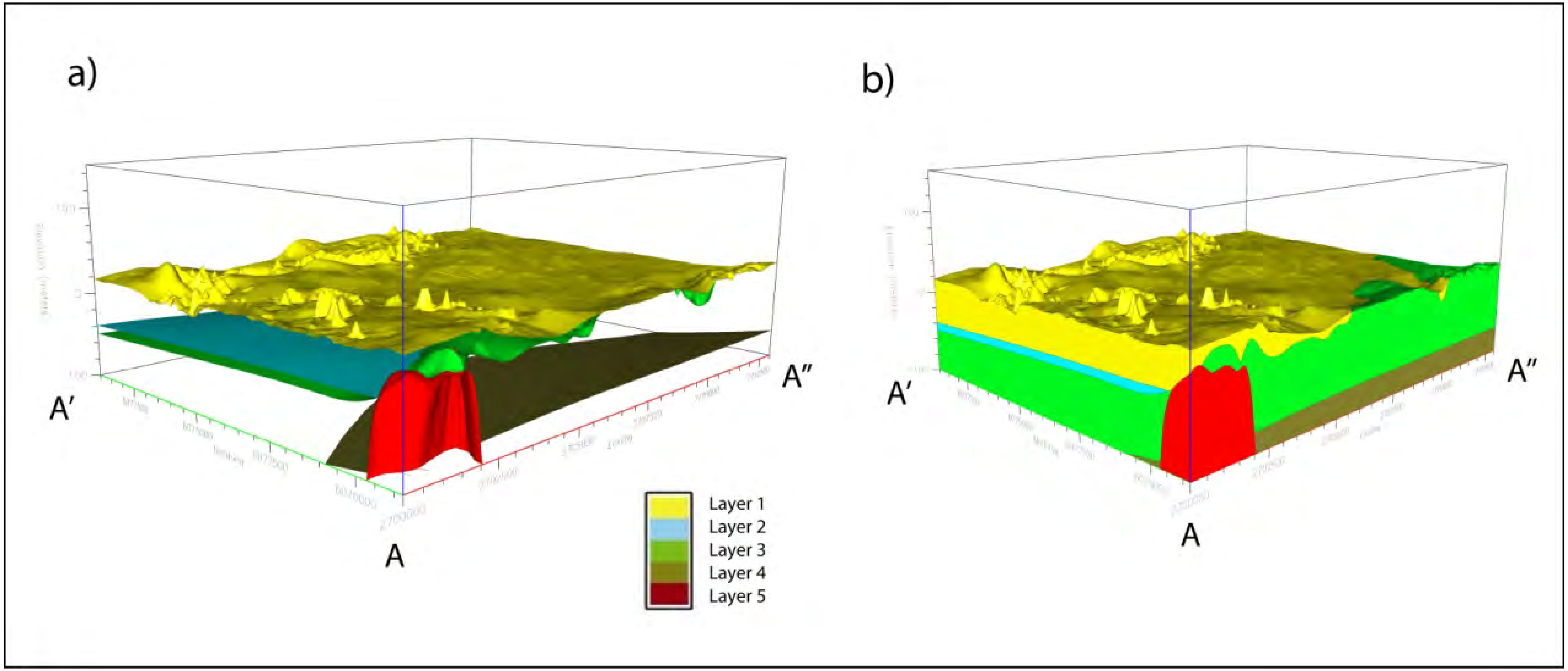


Figure 4.6 Development of geological layers including: a) surfaces representing the tops of geological units, b) assembly of layers into a complete 3D geological model.

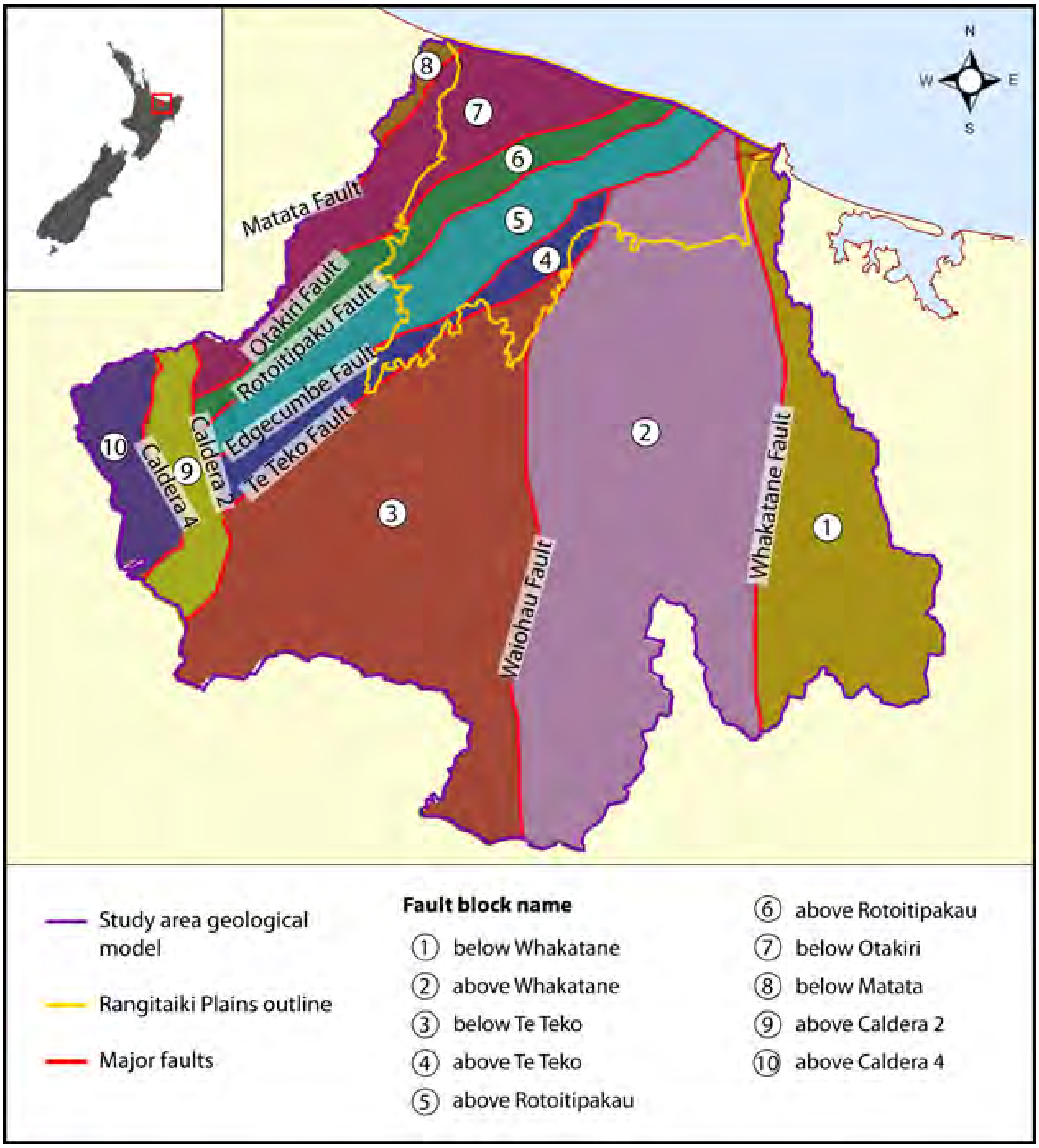


Figure 4.7 Plain view of the faults included in the Rangitaiki geological model, and fault blocks used in the model.

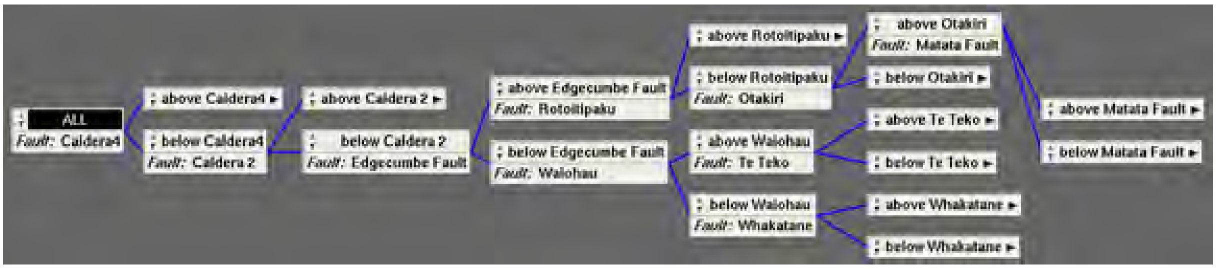
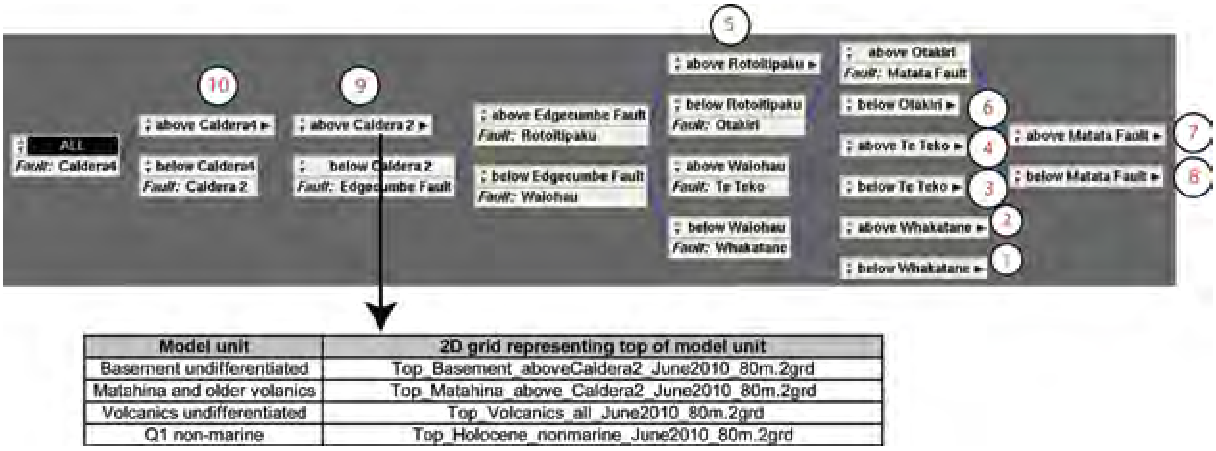


Figure 4.8 Fault tree of the Rangitaiki geological model, starting with the youngest fault (Caldera 4 Fault).



Model unit	2D grid representing top of model unit
Basement undifferentiated	Top_Basement_aboveCaldera2_June2010_80m.2grd
Matahina and older volanics	Top_Matahina_above_Caldera2_June2010_80m.2grd
Volcanics undifferentiated	Top_Volcanics_all_June2010_80m.2grd
Q1 non-marine	Top_Holocene_nonmarine_June2010_80m.2grd

Figure 4.9 Fault tree of the Rangitaiki geological model and corresponding fault blocks (Figure 4.7). Integration of faults with horizons is shown using fault block 9 as an example.

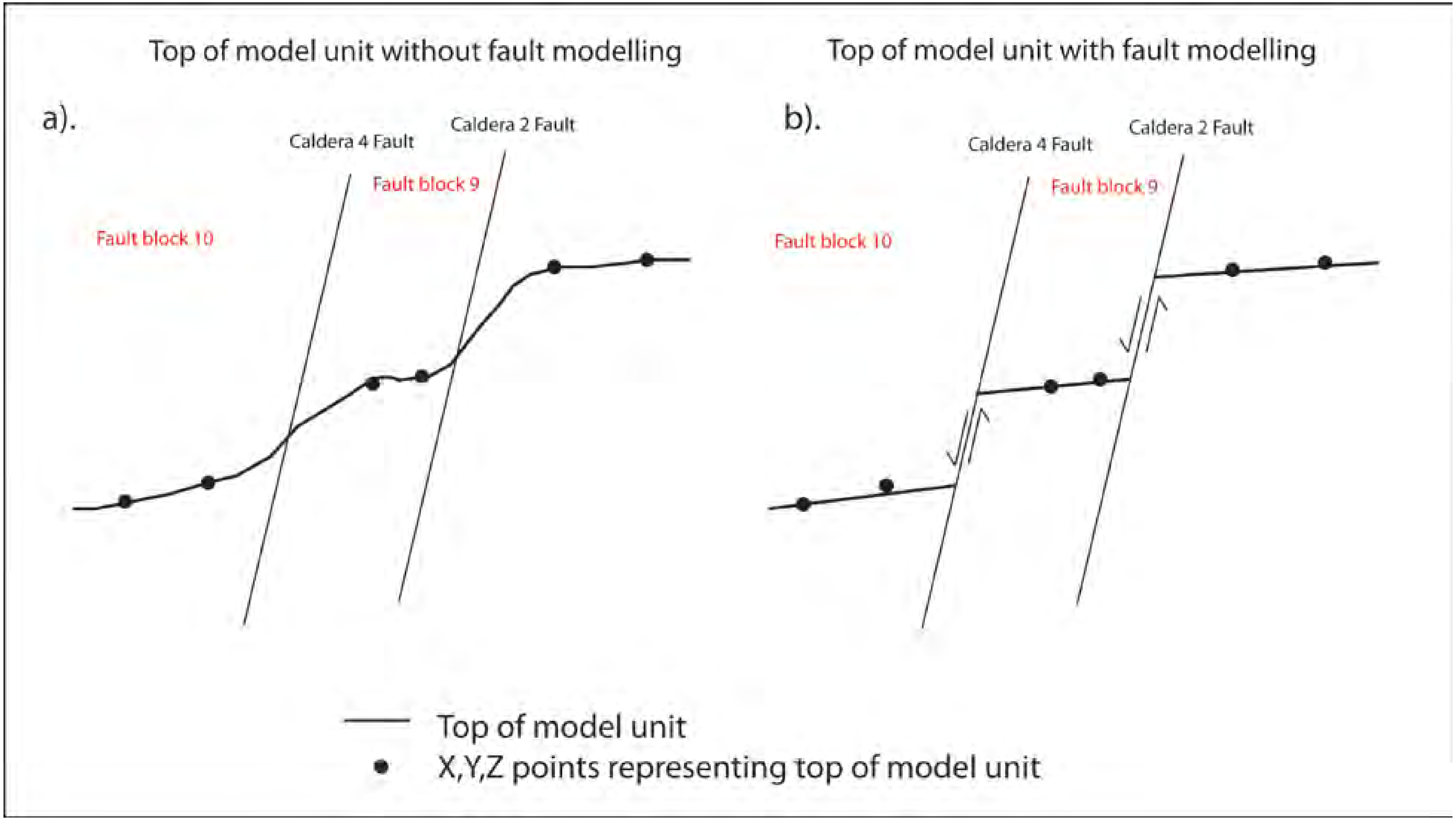


Figure 4.10 Example showing the top of a layer modelled from the same set of points a) faults are not included and only one surface is developed for all fault blocks; and b) faults are included and separate 2D grids are developed for the top of a model unit in different fault blocks.

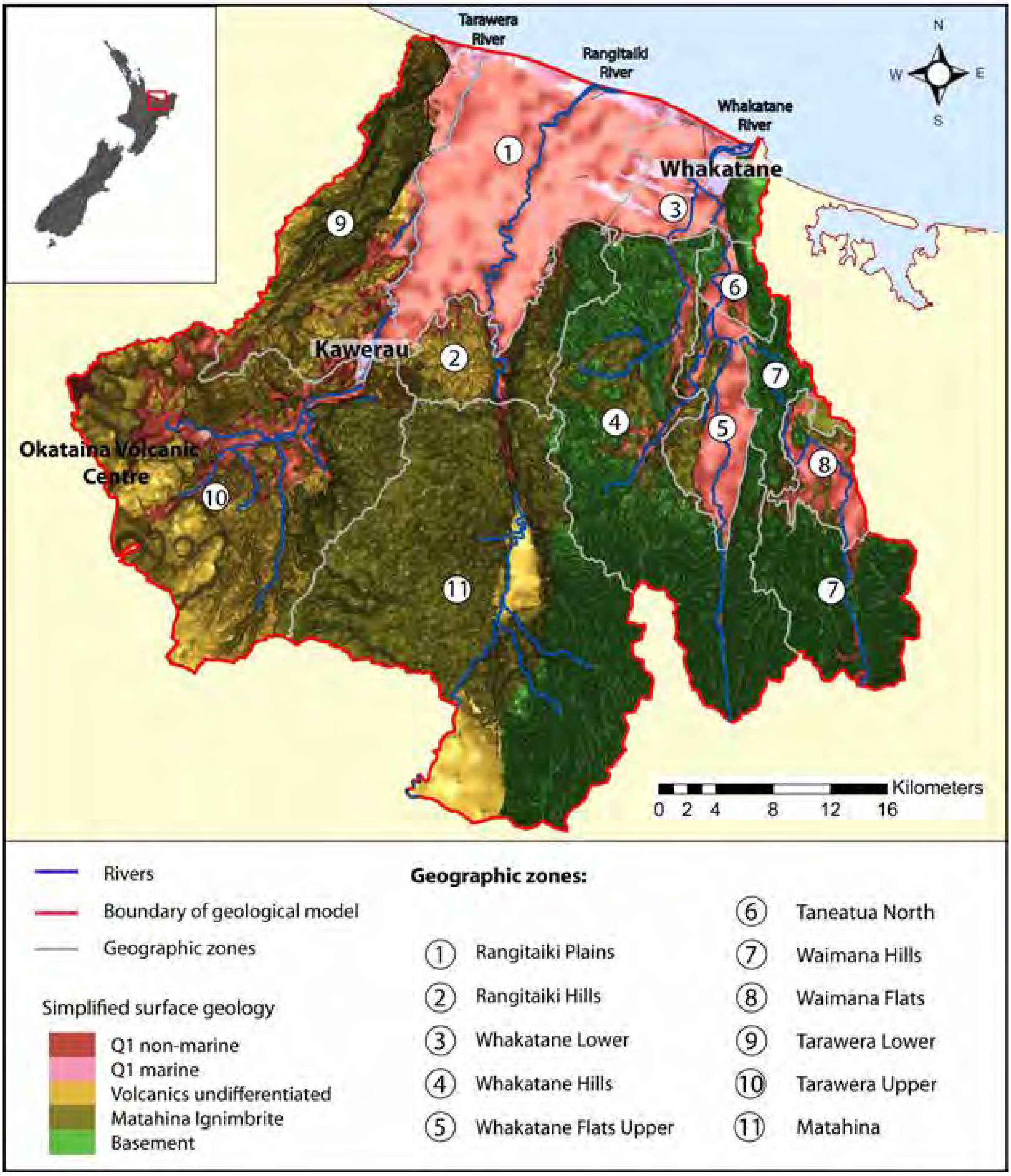


Figure 5.1 Geographic zones, simplified surface geology and topography of the Rangitaiki Plains model domain.

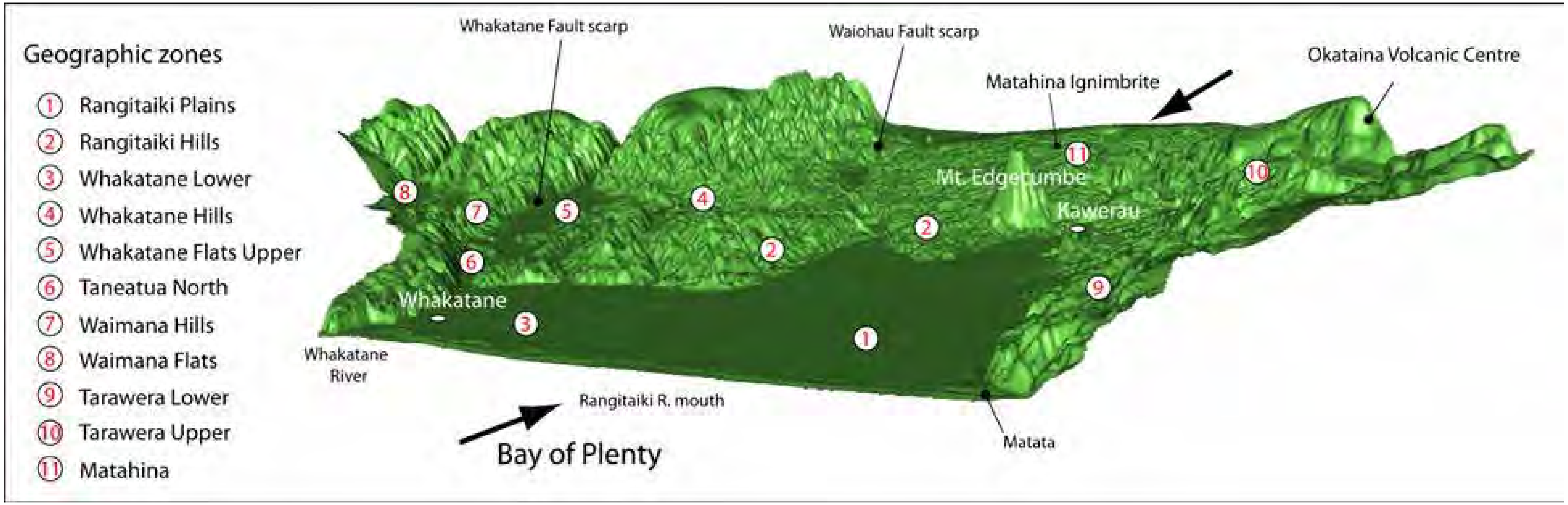


Figure 5.2 Digital elevation model (LIDAR for Rangitaiki Plains and shuttle radar DTM for the hills, Appendix 1) showing important geological and geomorphological features and subdivision into different geographic zones.

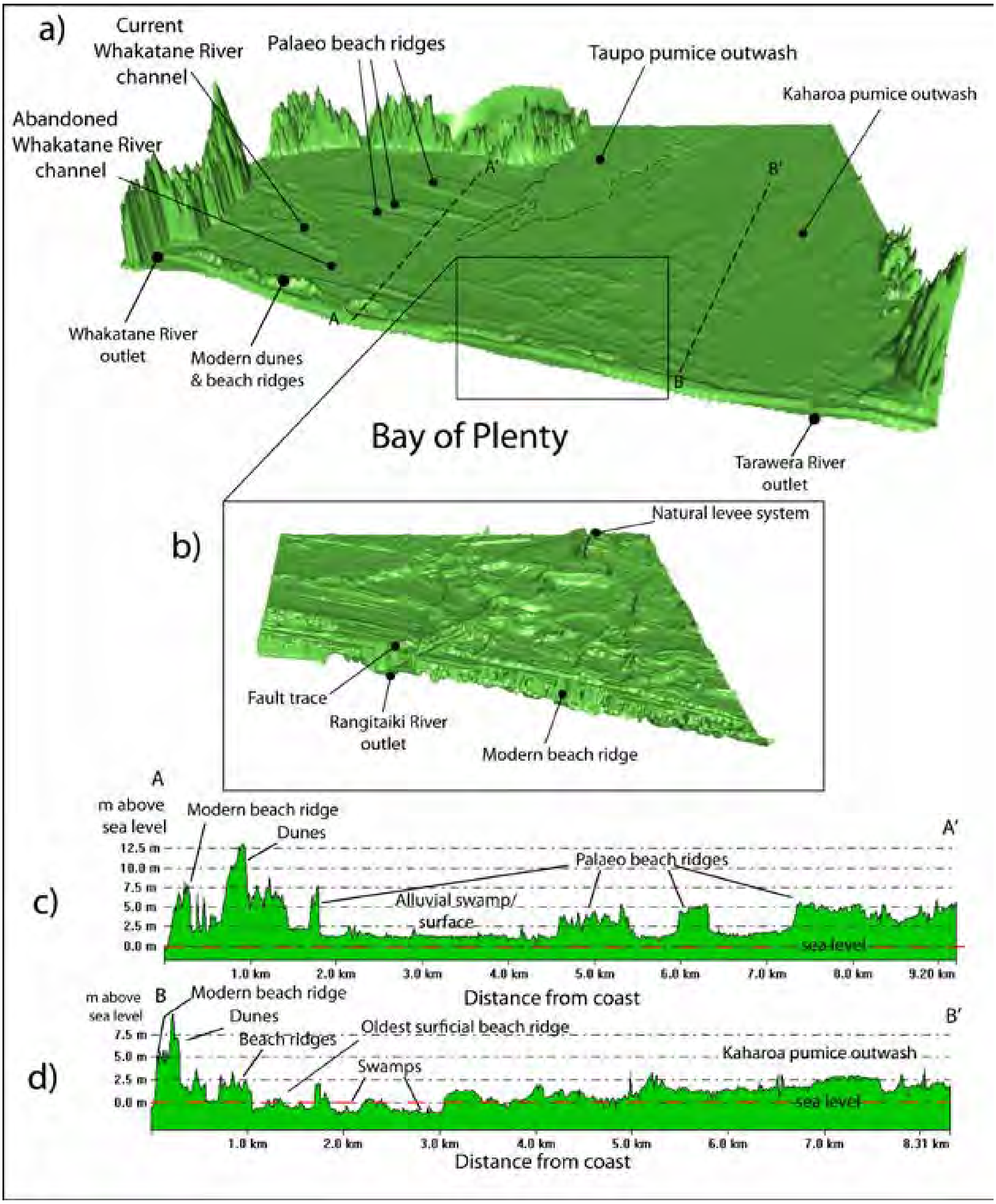


Figure 5.3 Digital elevation model (LIDAR) of the coastal plain of the Rangitaiki Plains model domain, showing significant geomorphological features.

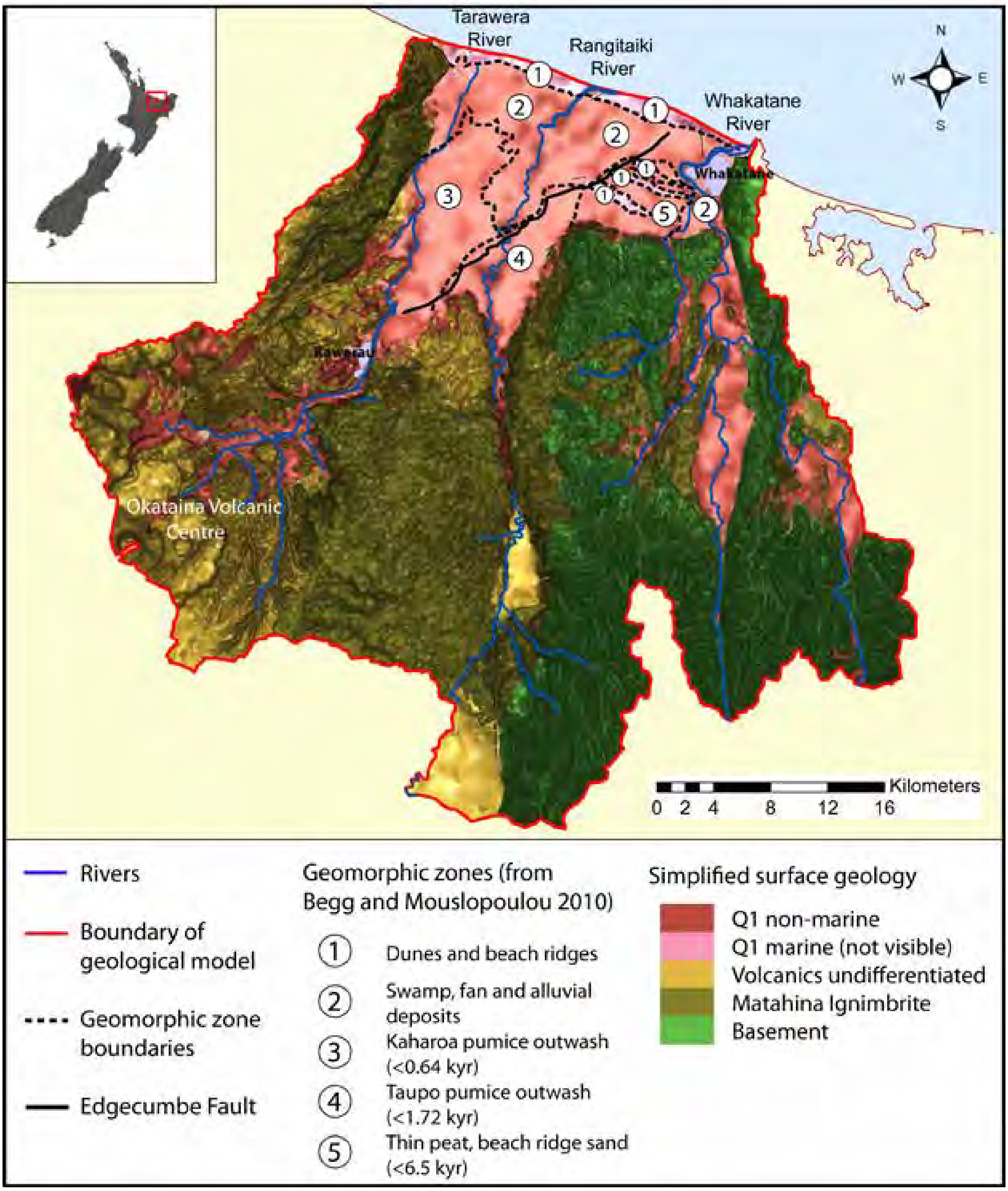


Figure 5.4 Geomorphic zones in geographic zones 1 and 3 of the Rangitaiki Plains geological model domain based on interpretation of LIDAR data and surface mapping (from Begg and Mouslopoulou 2009).

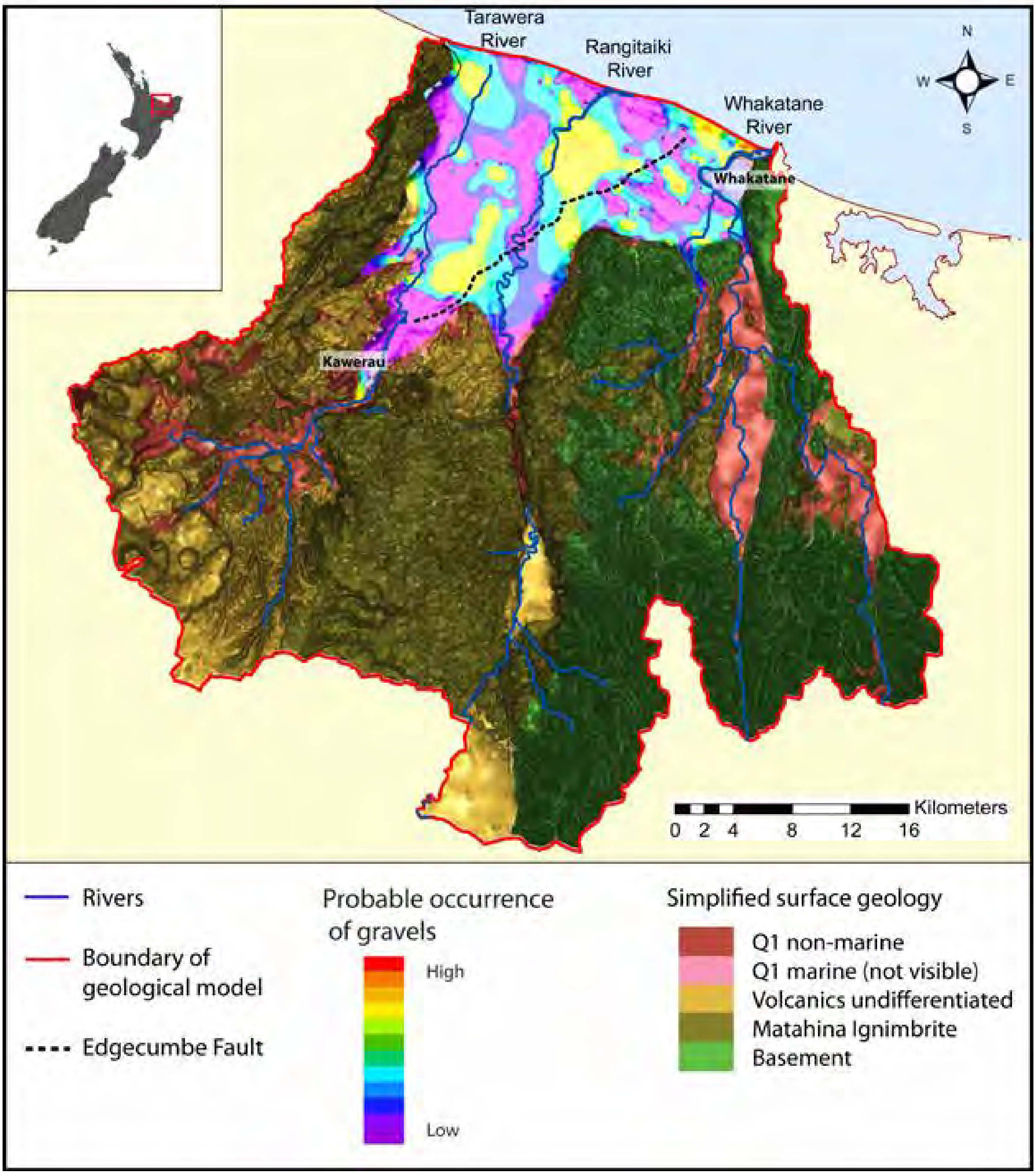


Figure 5.5 Probable occurrence of gravels in shallow layers (inferred from three-dimensional property models) in geographic zones 1 and 3 (Figure 5.1).

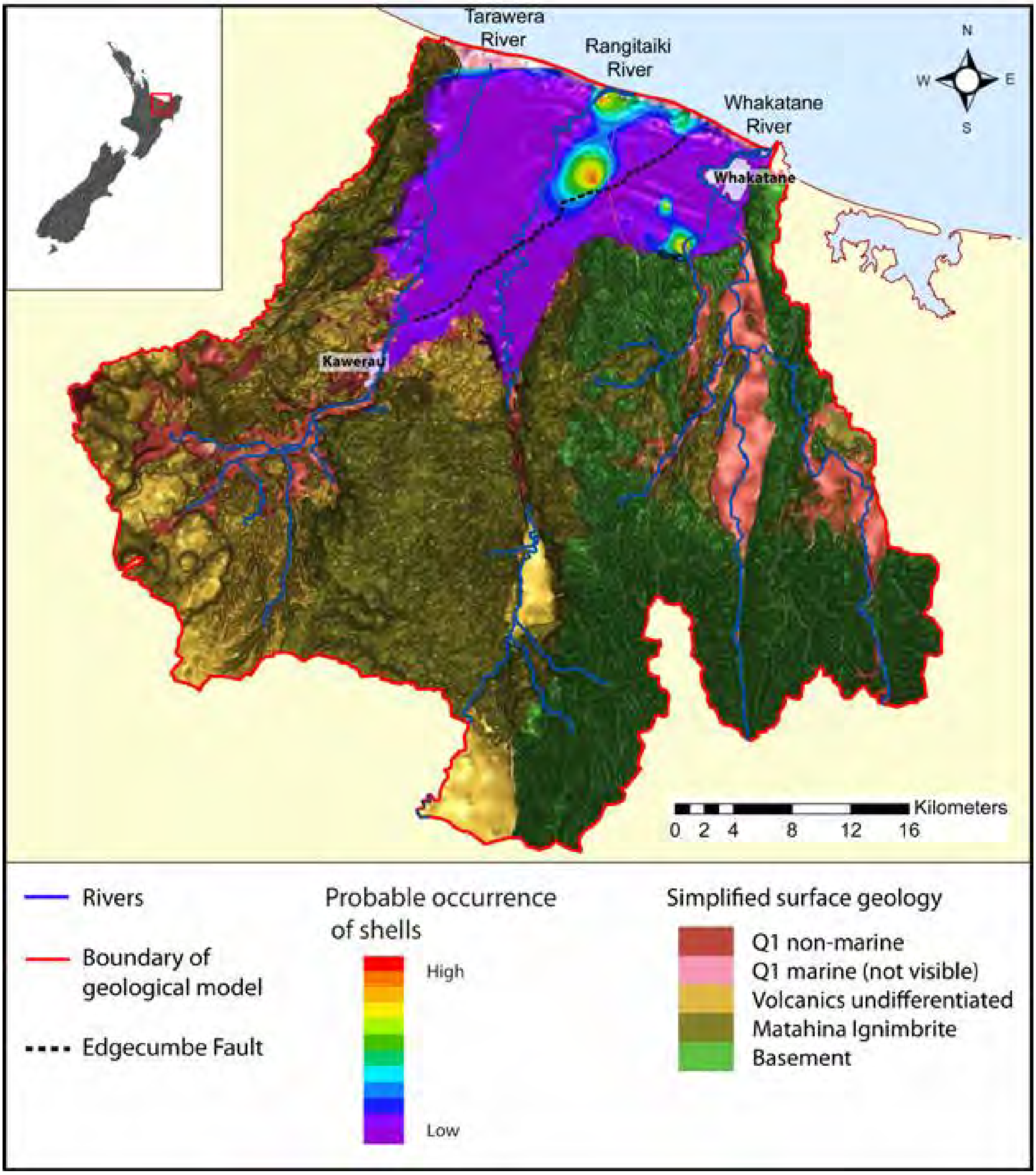


Figure 5.6 Probable occurrence of shells in shallow layers (inferred from three-dimensional property models) in geographic zones 1 and 3 of the Rangitaiki Plains geological model domain (Figure 5.1).

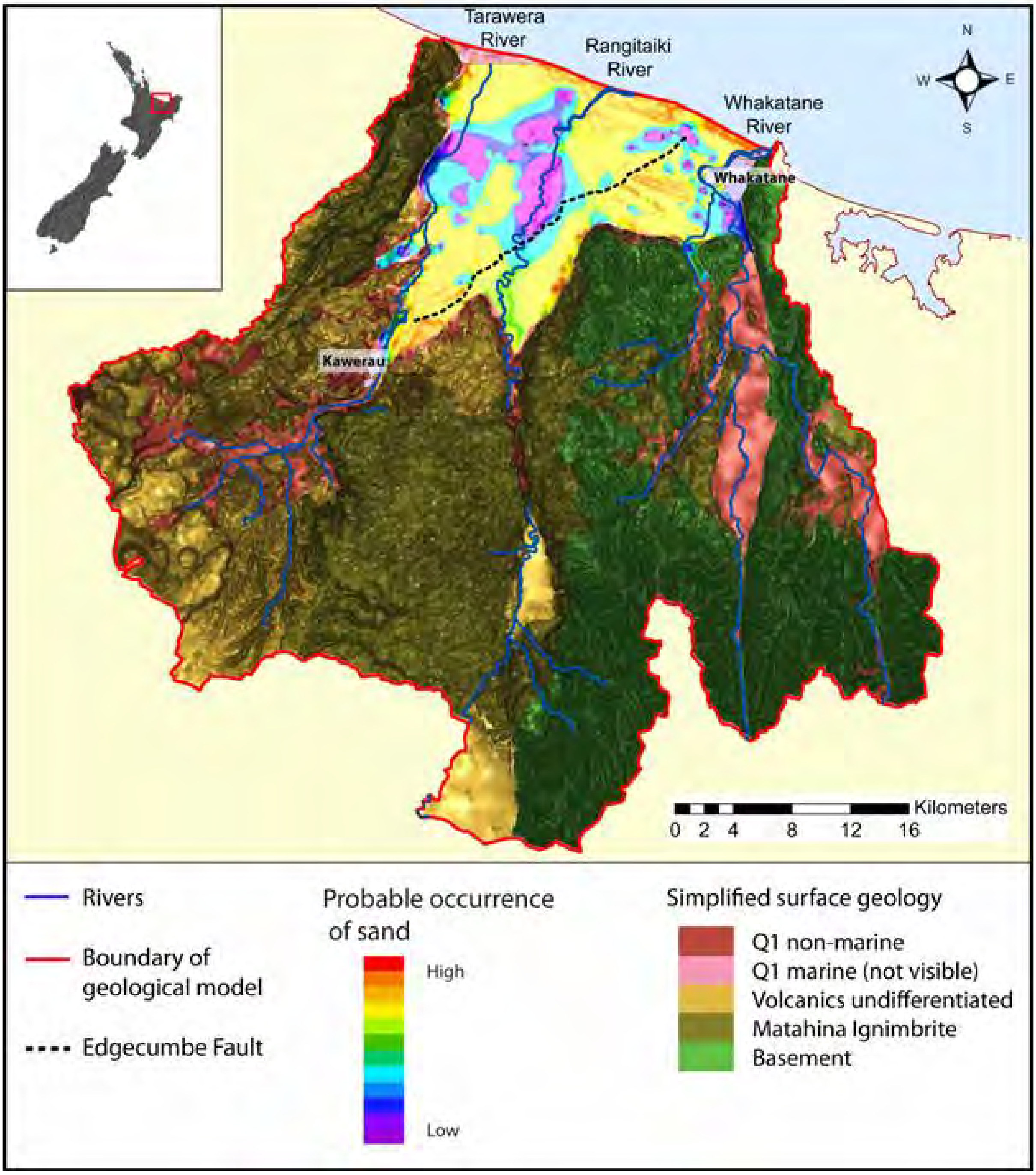


Figure 5.7 Probable occurrence of sand in shallow layers (inferred from three-dimensional property models) in geographic zones 1 and 3 (Figure 5.1).

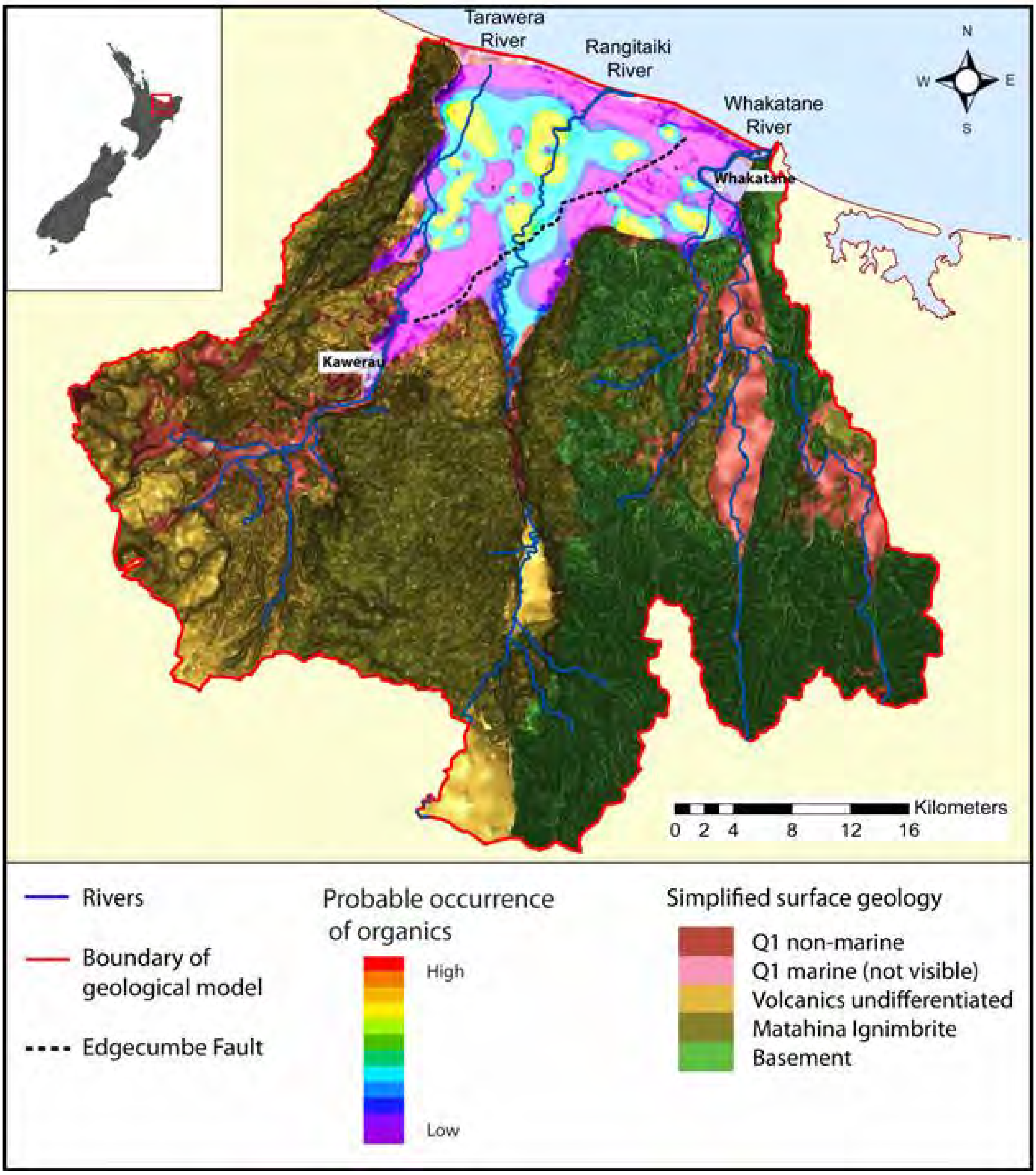


Figure 5.8 Probable occurrence of organics in shallow layers (inferred from three-dimensional property models) in geographic zones 1 and 3 (Figure 5.1).

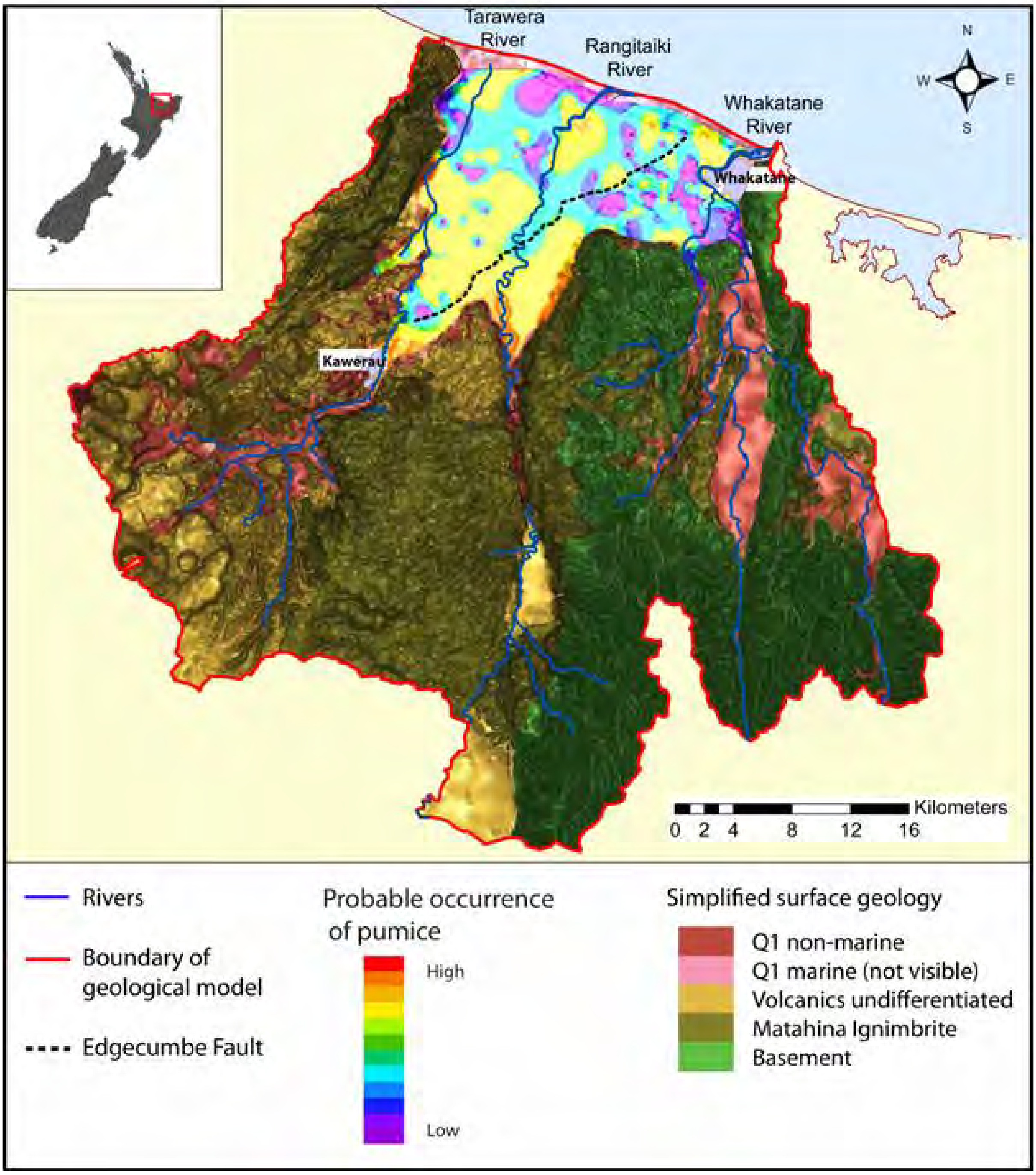


Figure 5.9 Probable occurrence of pumice in shallow layers (inferred from three-dimensional property models) in geographic zones 1 and 3 (Figure 5.1).

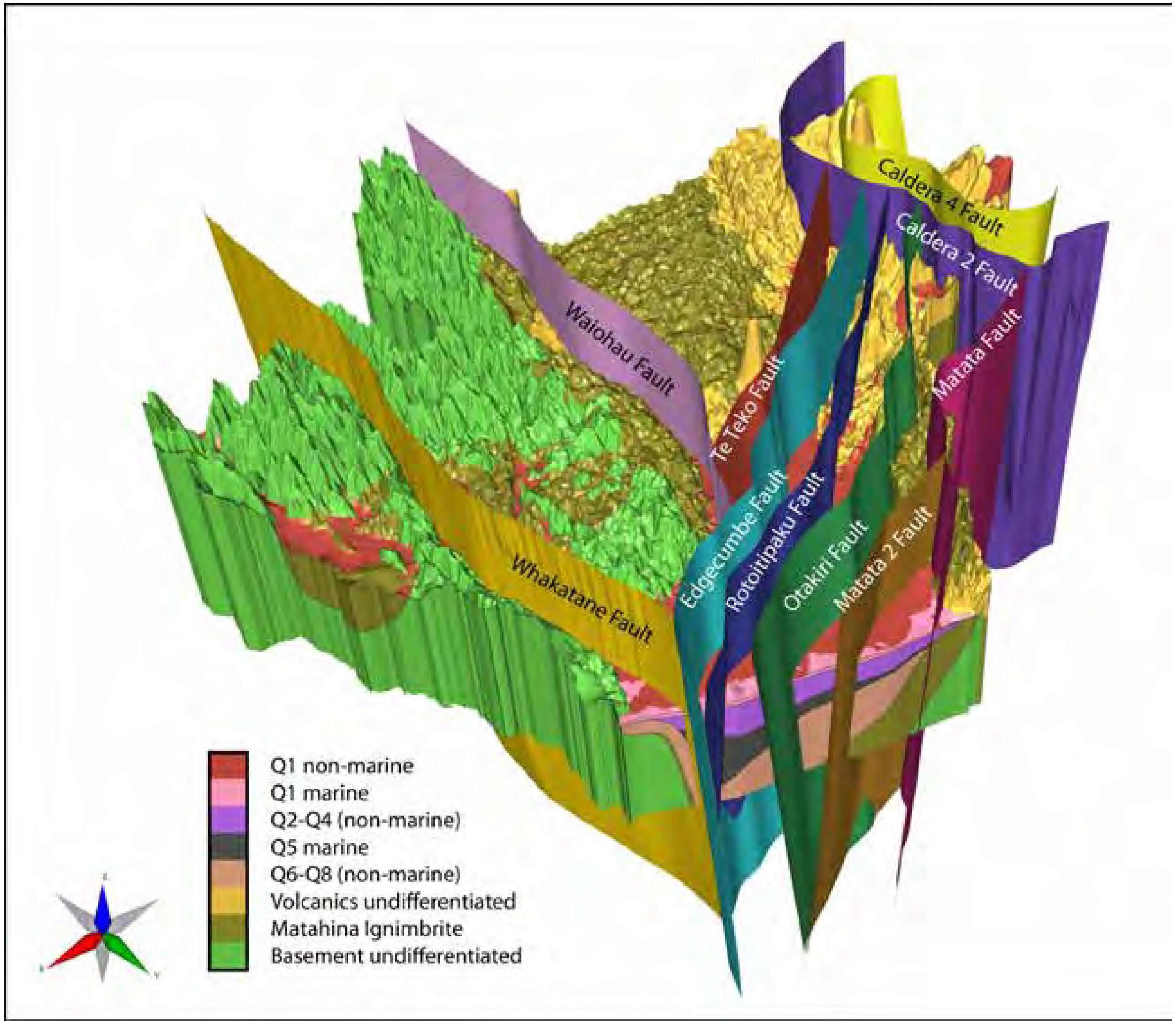


Figure 5.10 Unfaulted three-dimensional model of the Rangitaiki Plains and location of faults.

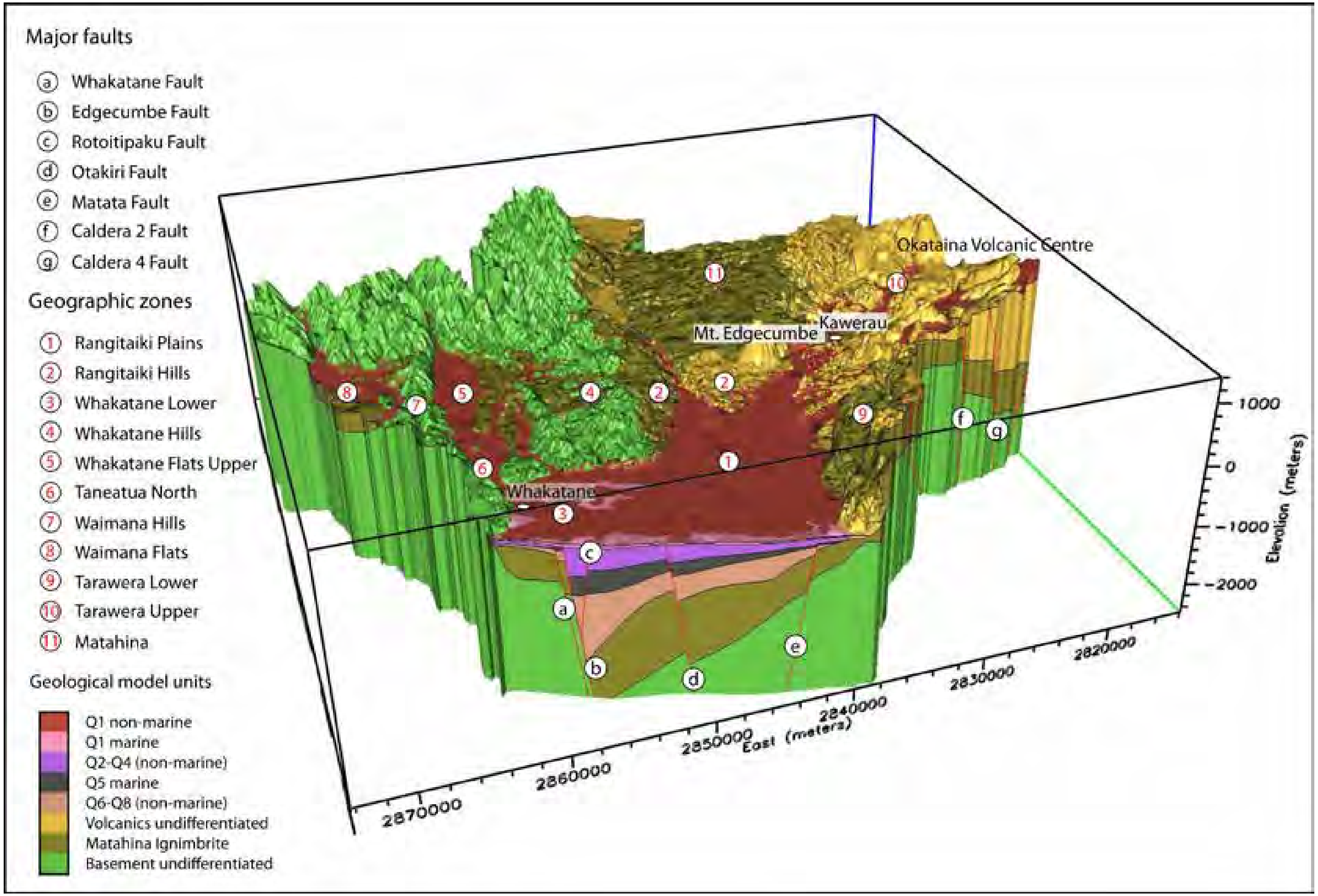


Figure 5.11 Three-dimensional model of the Rangitaiki Plains showing all geological model units and the dimension of the model as reference for the following figures.

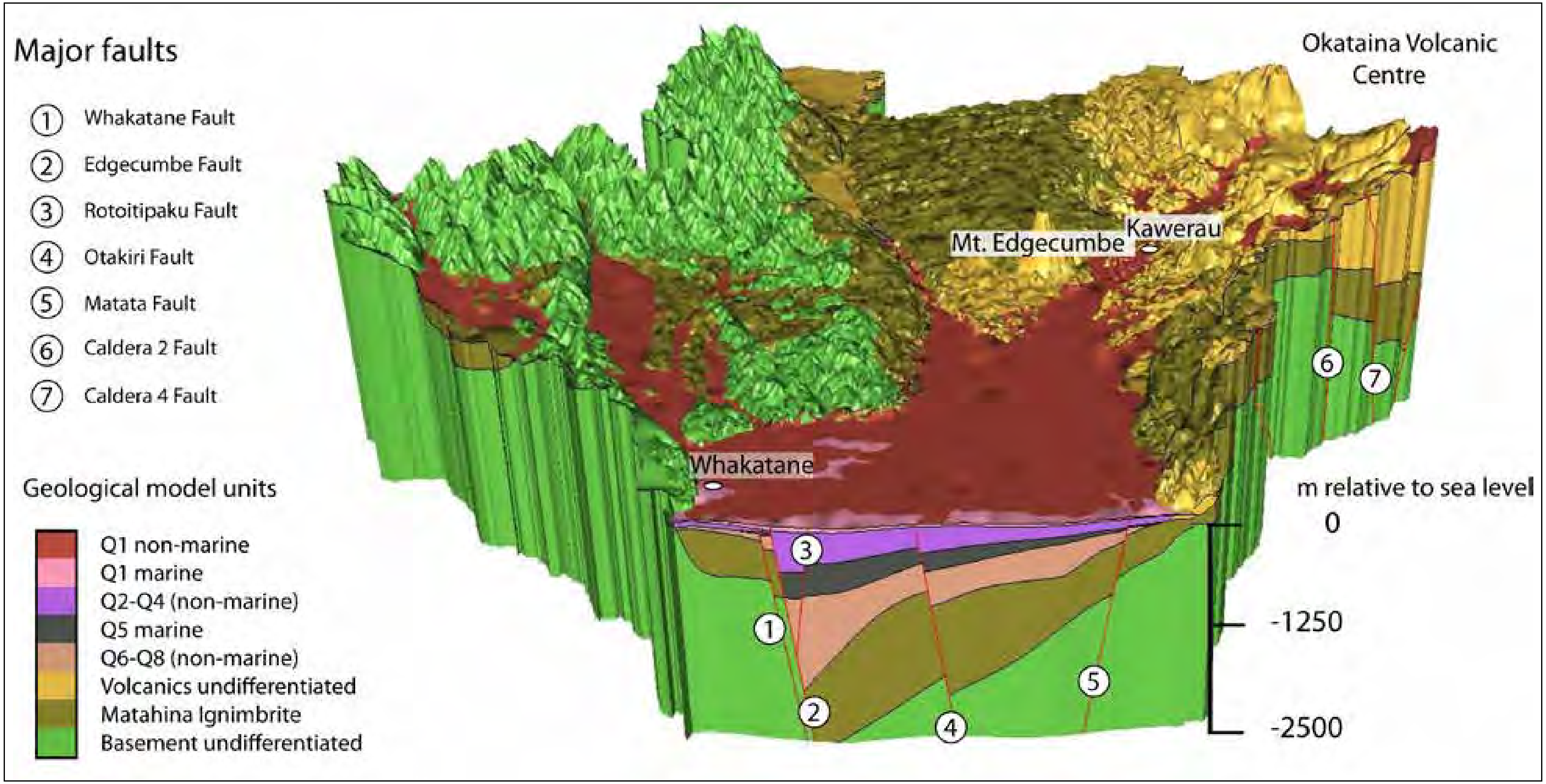


Figure 5.12 Three-dimensional model of the Rangitaiki Plains showing all model units and faults.

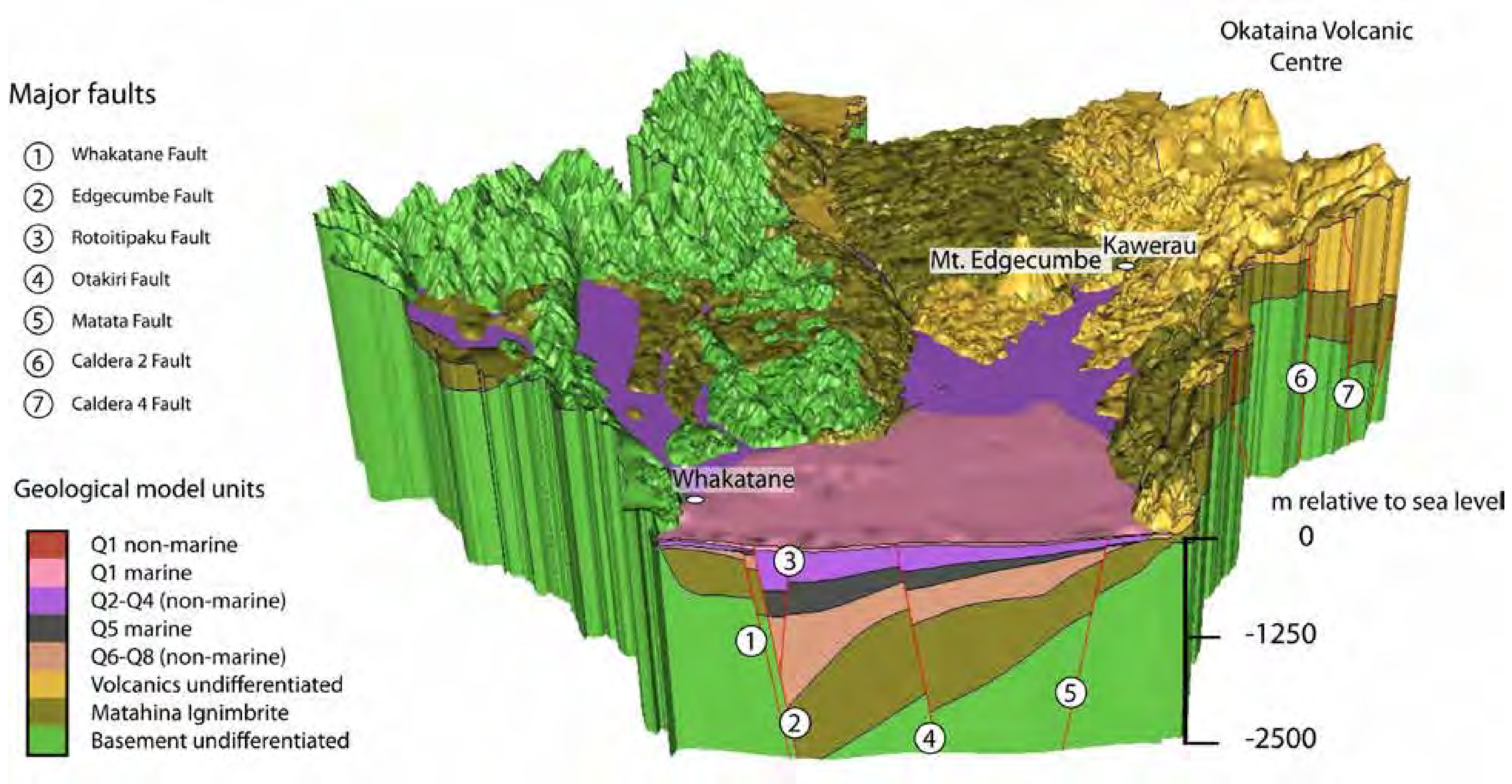


Figure 5.13 Three-dimensional model of the Rangitaiki Plains without the Q1 non-marine model unit.

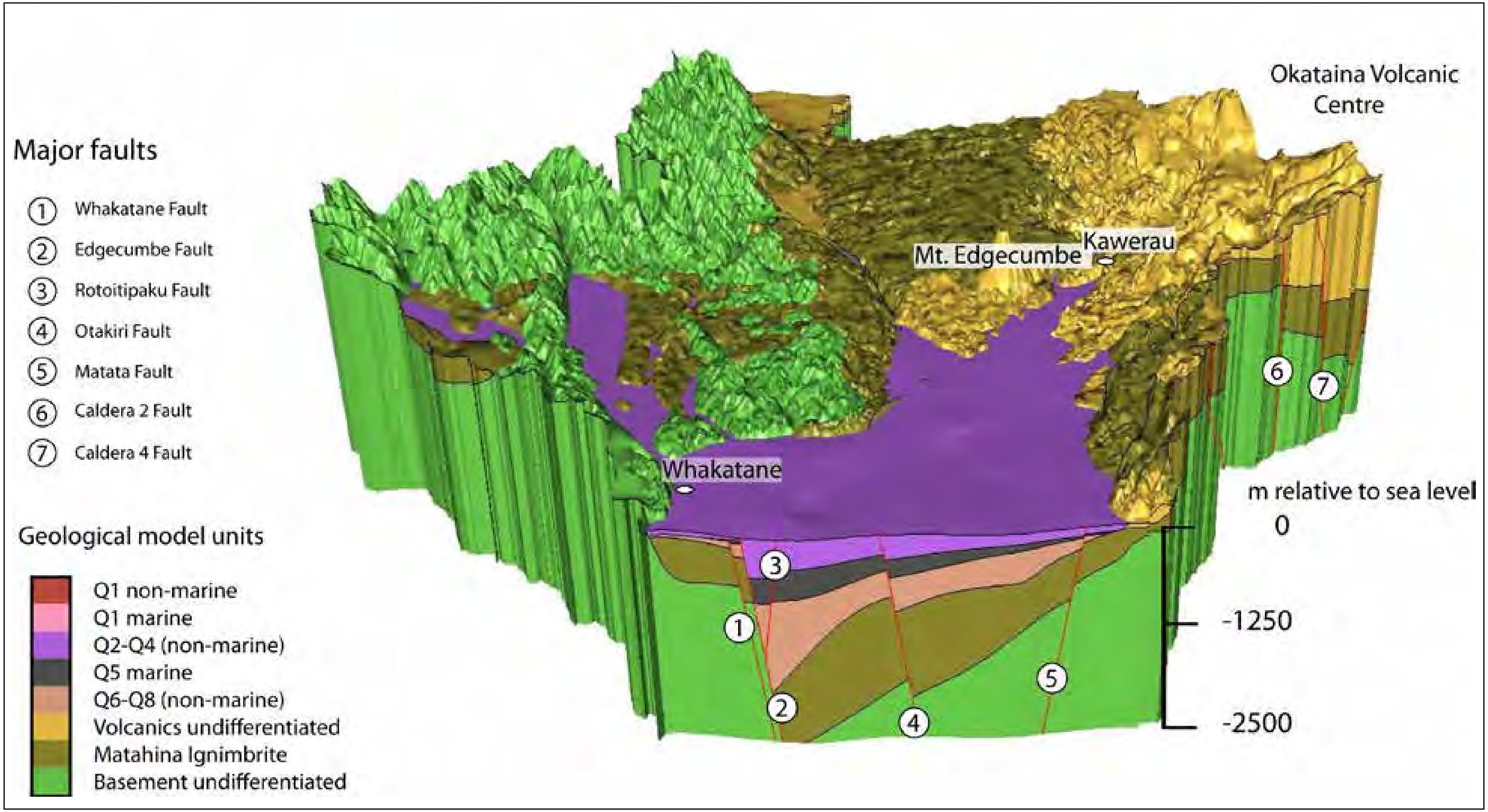


Figure 5.14 Three-dimensional model of the Rangitaiki Plains without the Q1 non-marine and Q1 marine model units.

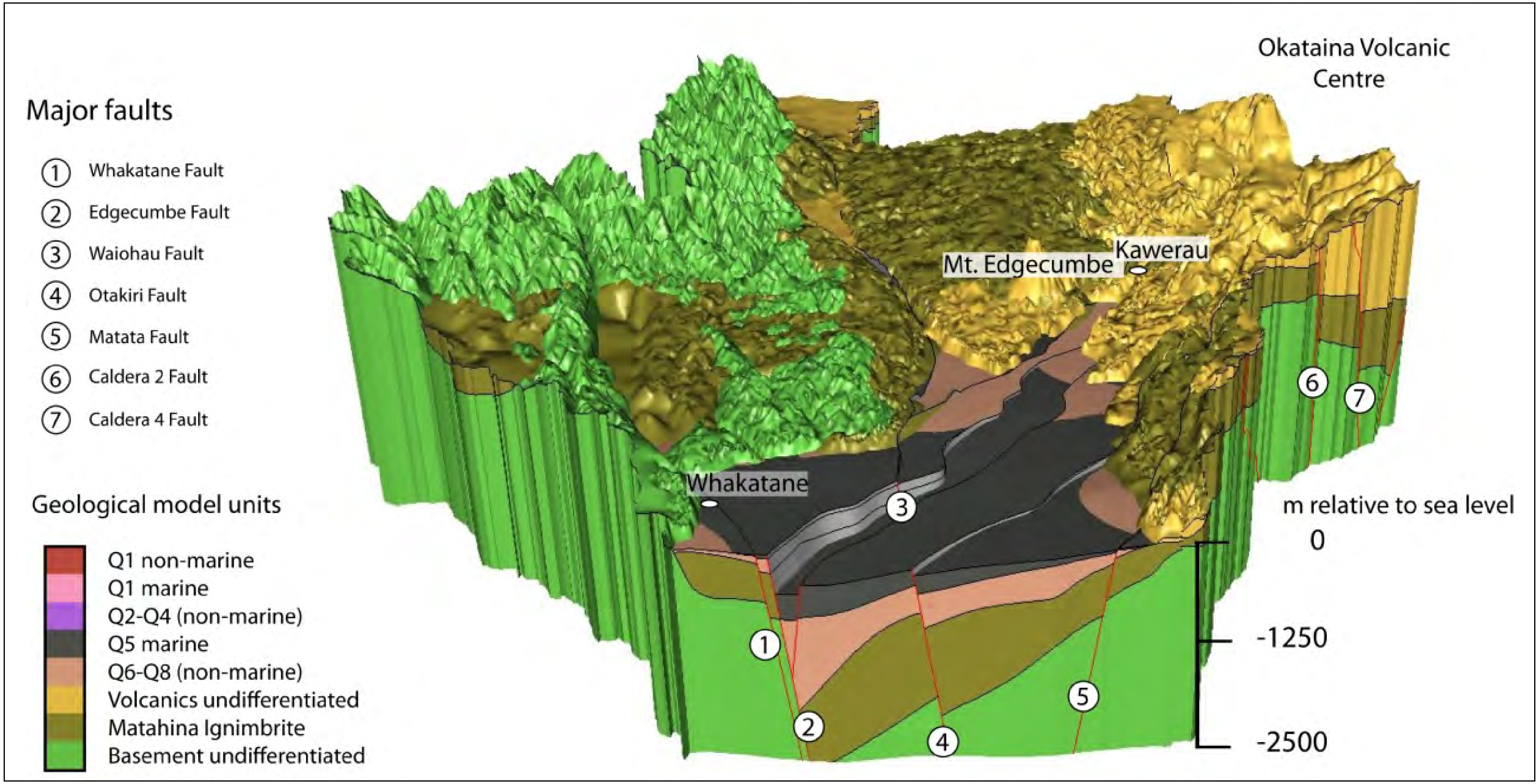


Figure 5.15 Three-dimensional model of the Rangitaiki Plains without the Q1 non-marine, Q1 marine and Q2-Q4 model units.

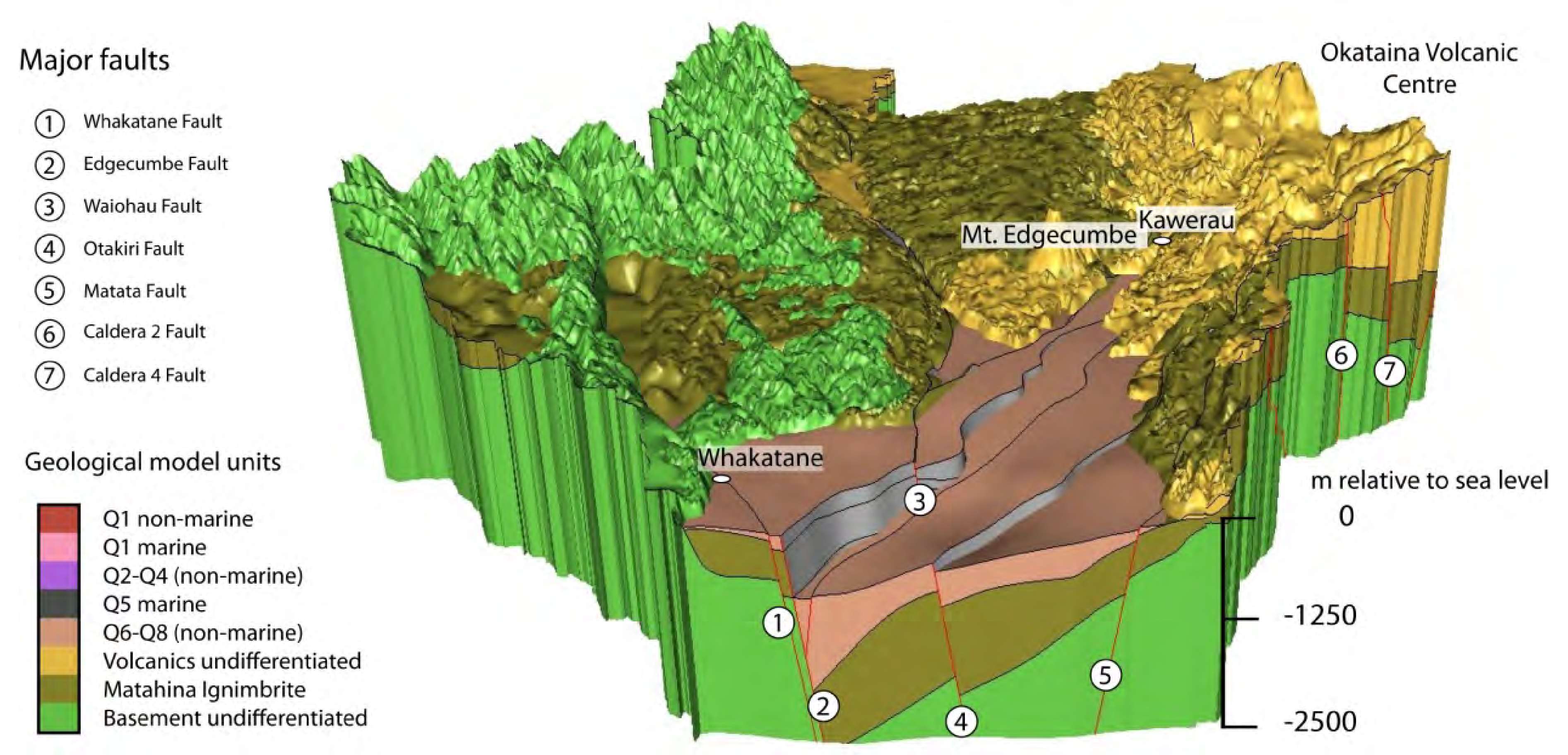


Figure 5.16 Three-dimensional model of the Rangitaiki Plains without the Q1 non-marine, Q1 marine, Q2-Q4 and Q5 marine model units.

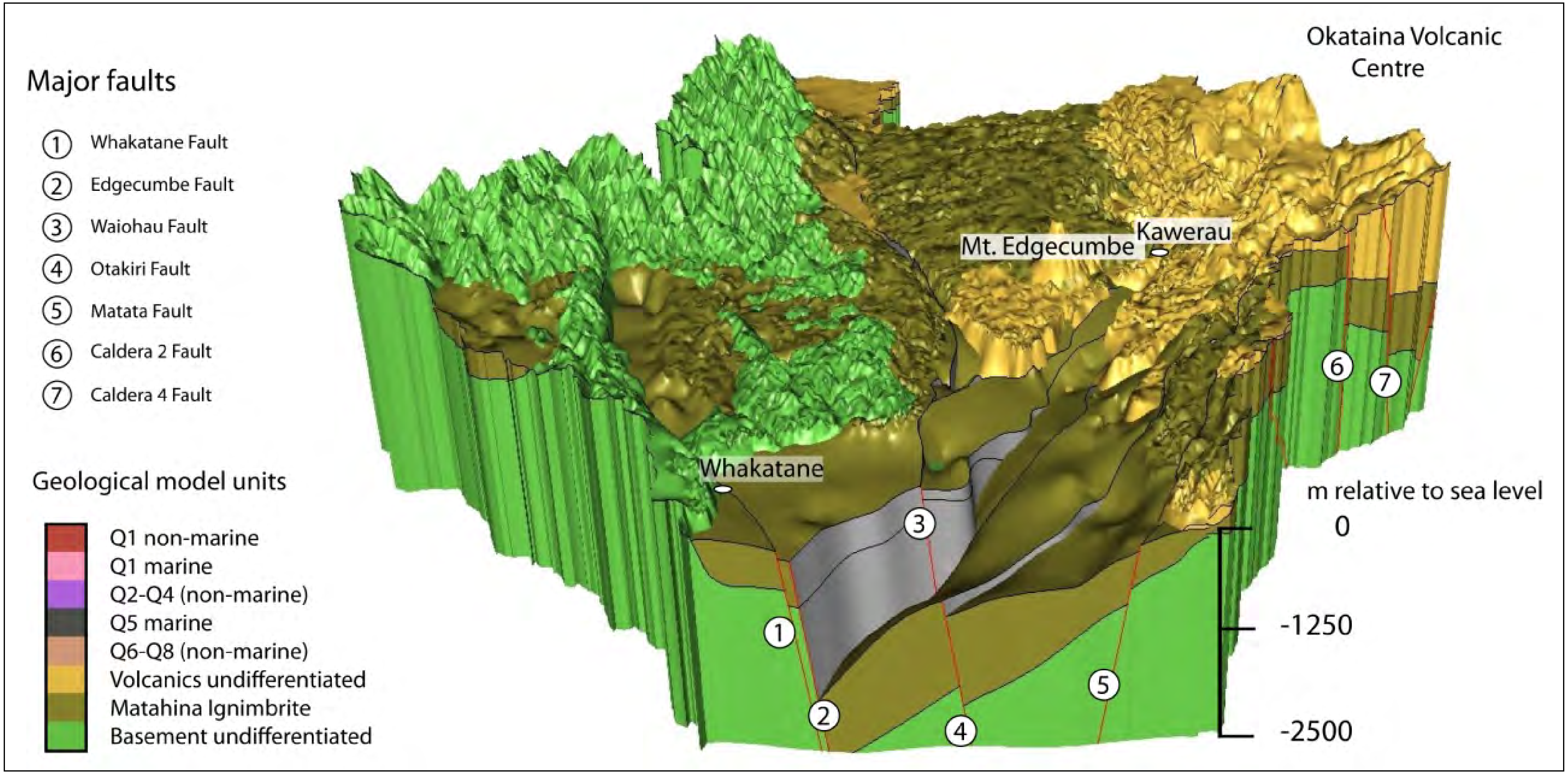


Figure 5.17 Three-dimensional model of the Rangitaiki Plains showing the undifferentiated basement, Matahina Ignimbrite and undifferentiated volcanics (all other model units not displayed).

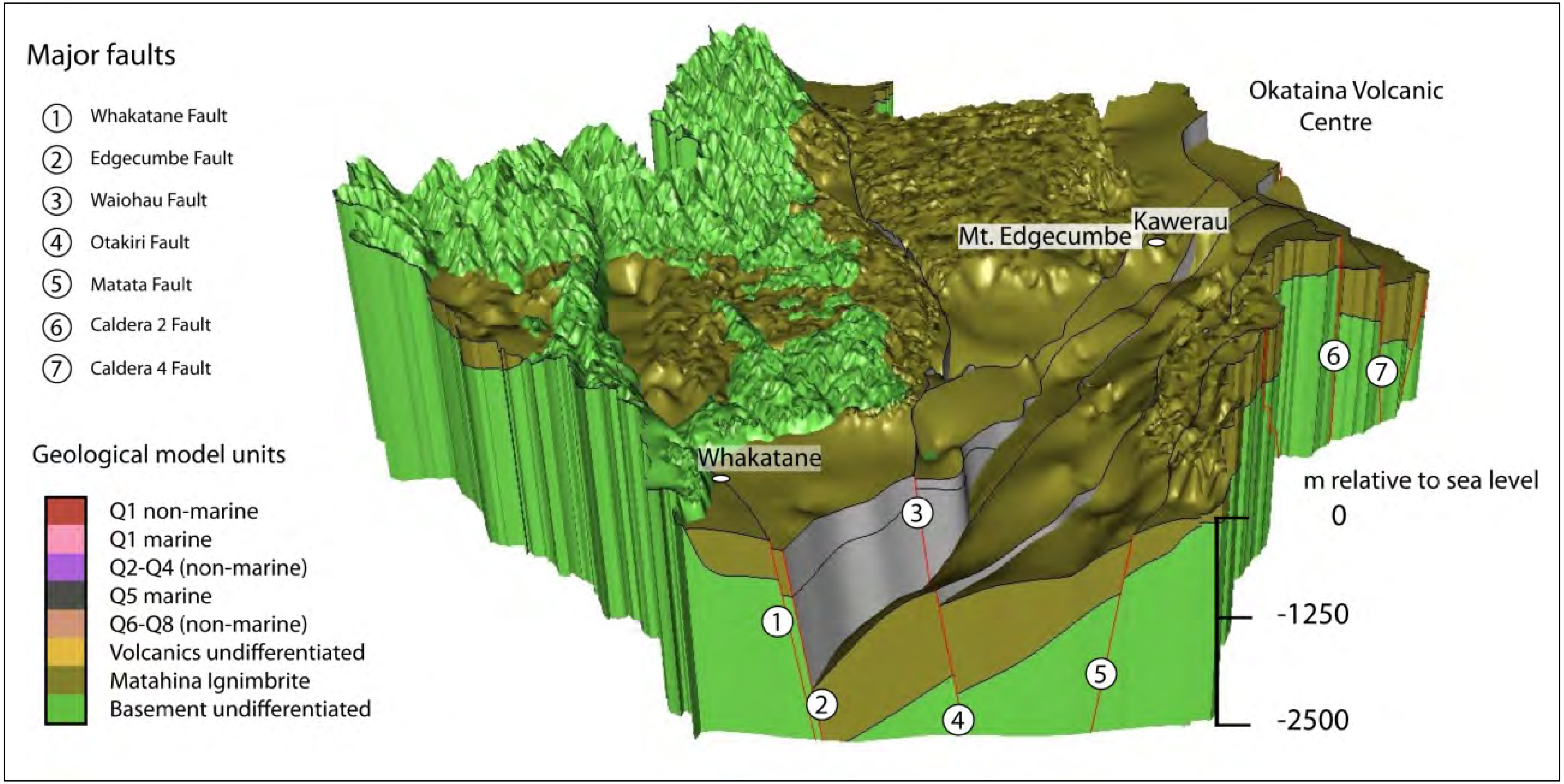


Figure 5.18 Three-dimensional model of the Rangitaiki Plains showing the undifferentiated basement and the Matahina Ignimbrite (all other model units not displayed).

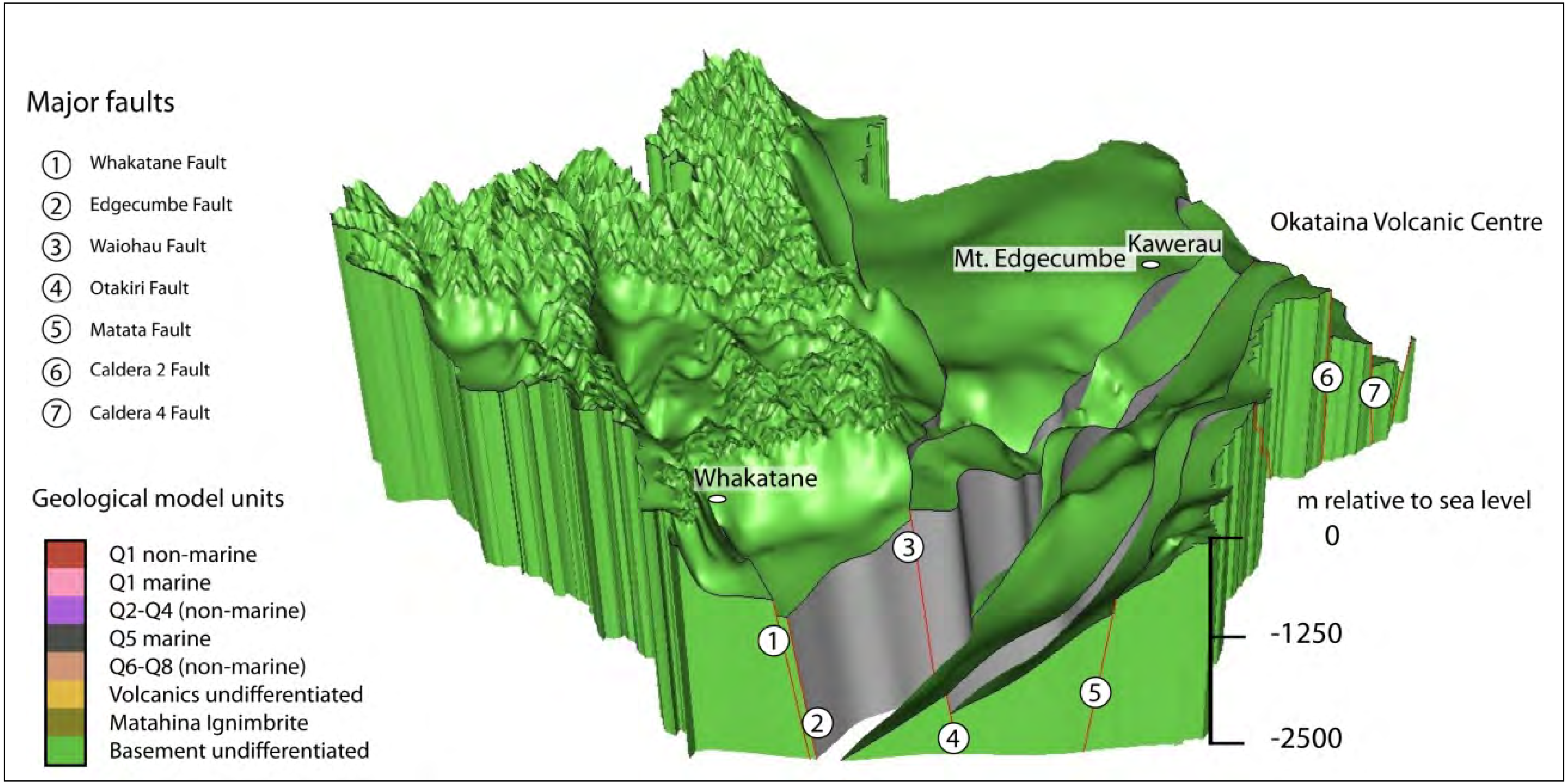


Figure 5.19 Three-dimensional model of the Rangitaiki Plains showing the undifferentiated basement model unit (all other model units not displayed).

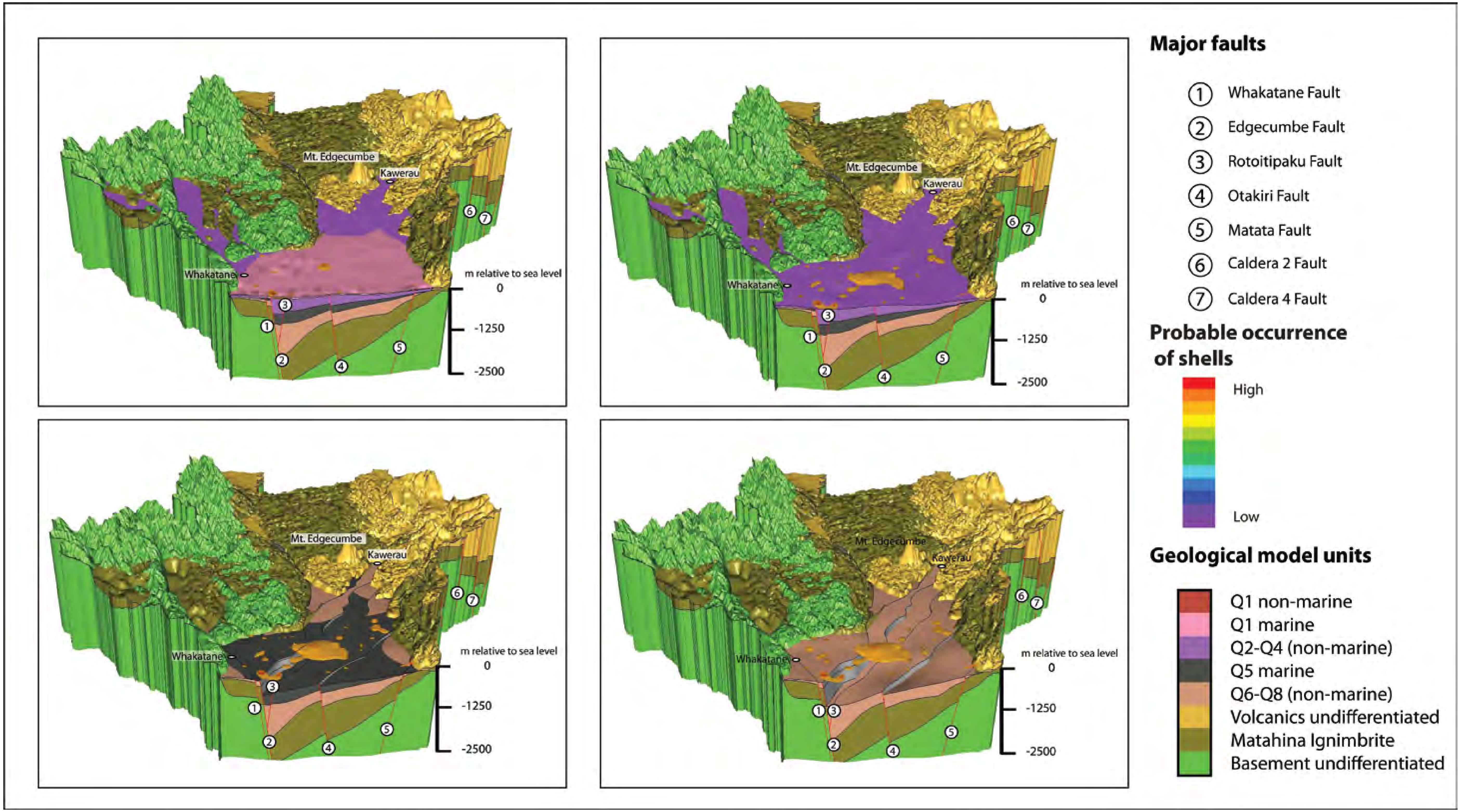


Figure 5.20 Distribution of shells within geological model units in the Rangitaiki Plains geographic areas one and three (Figure 5.1) (displaying only the higher range, i.e. where it is very likely that shells are present).

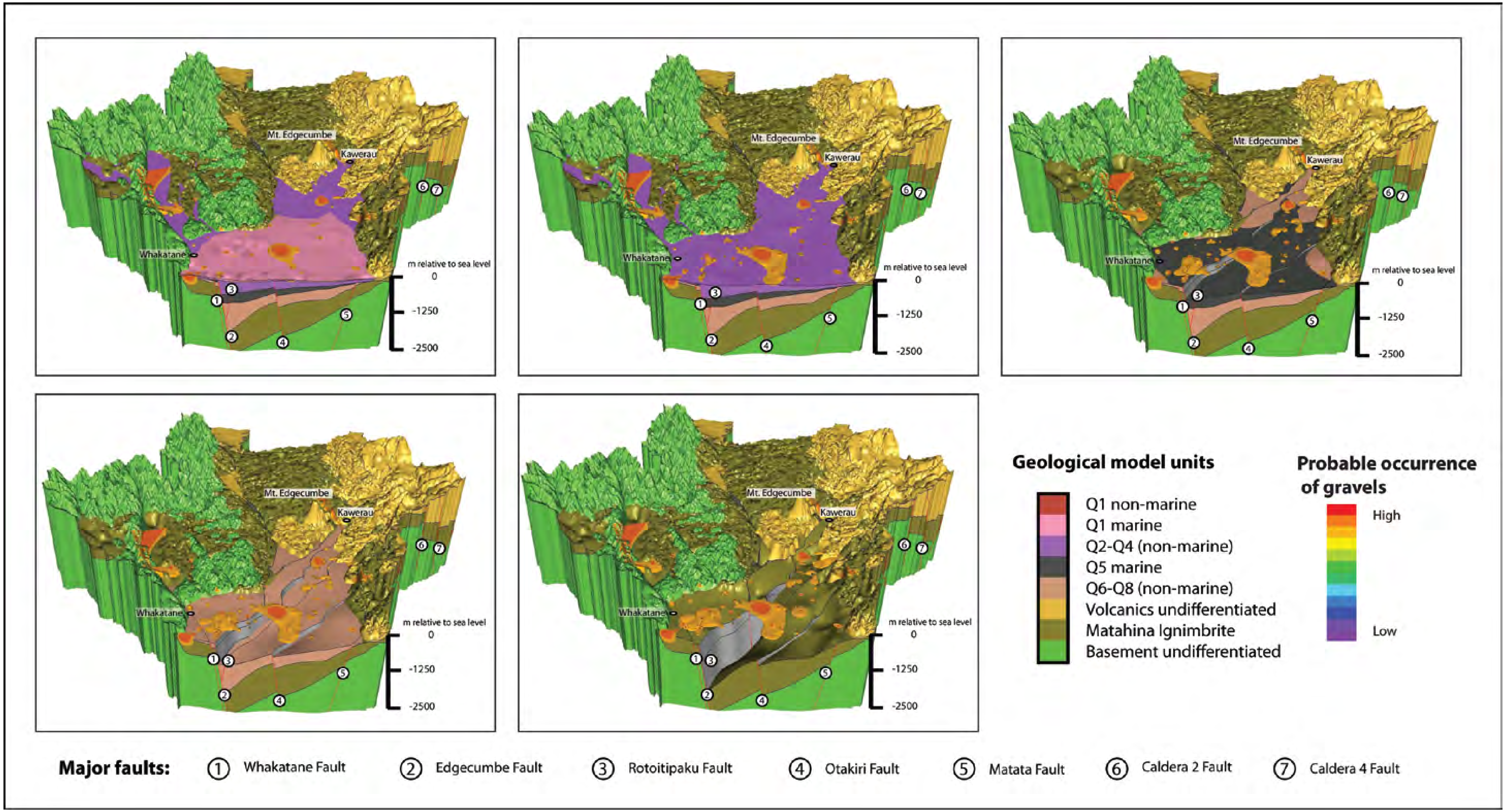


Figure 5.21 Distribution of gravels within the geological model units of the Rangitaiki Plains geographic zones one and three (Figure 5.1) (displaying only the higher range, i.e. where it is very likely that gravels are present).

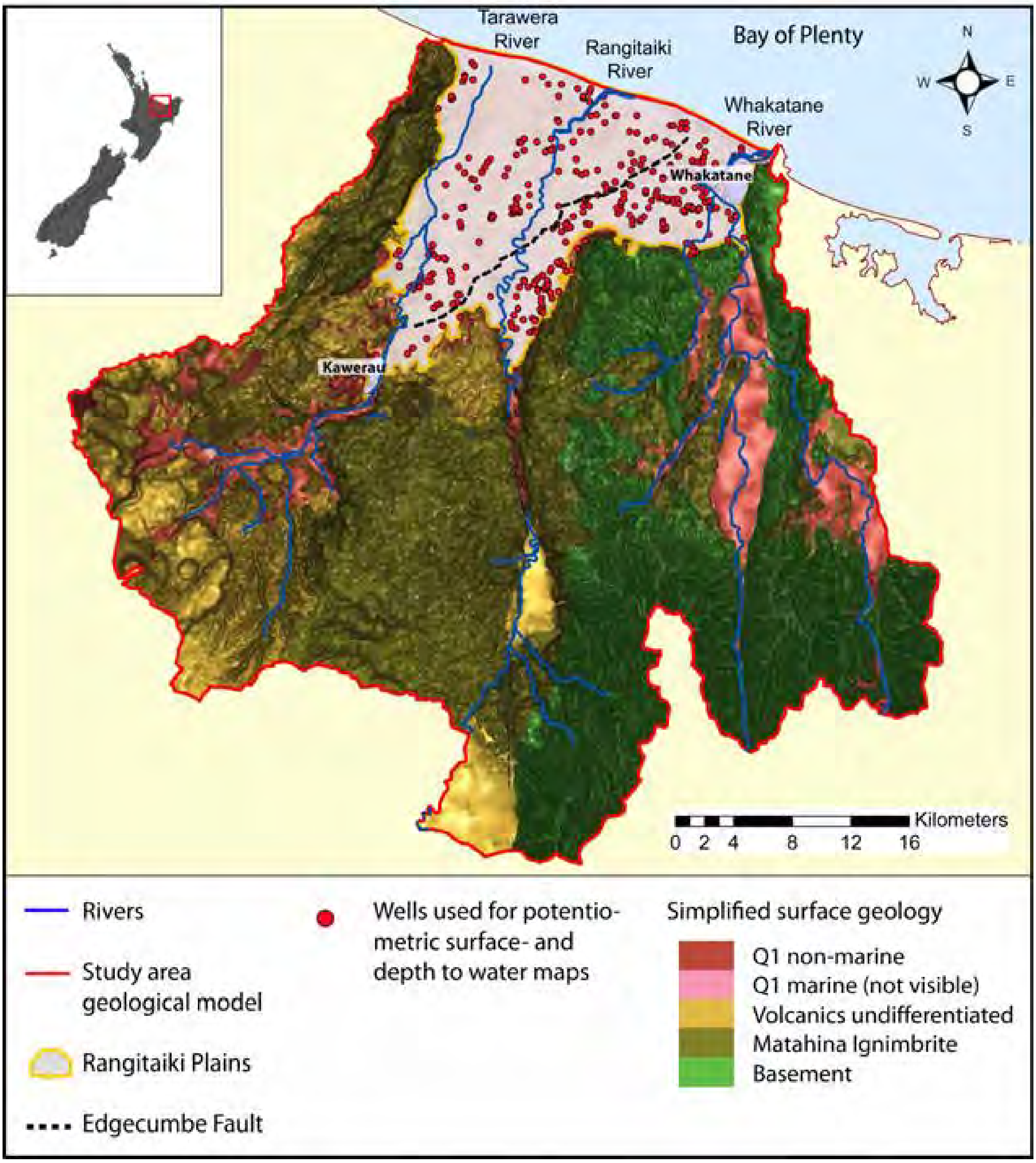


Figure 5.22 Locations of wells used to construct the potentiometric surface- and depth to water map.

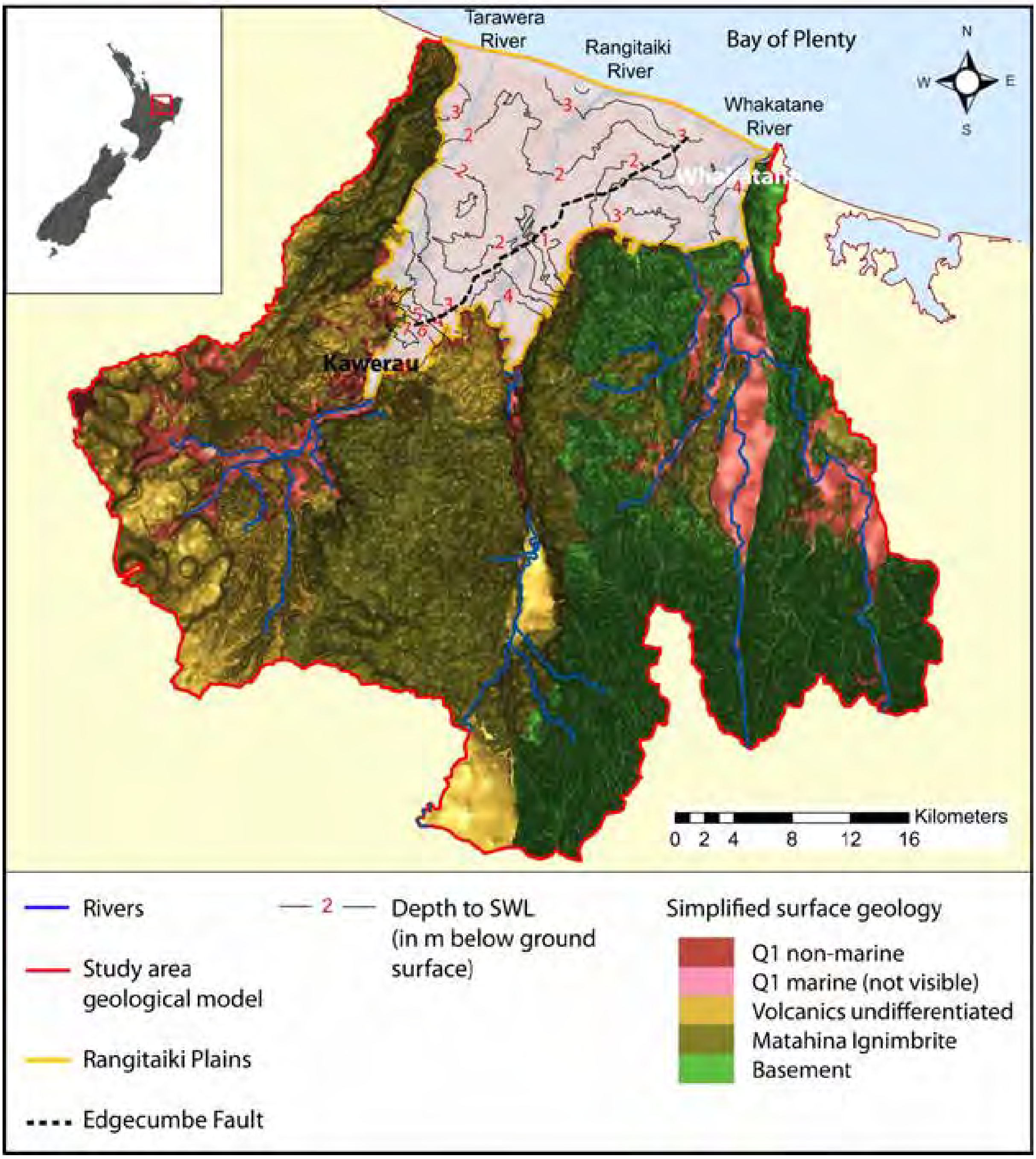


Figure 5.23 Depth to static water level in the "Rangitaiki Plains" and "Whakatane Lower" geographic zones.

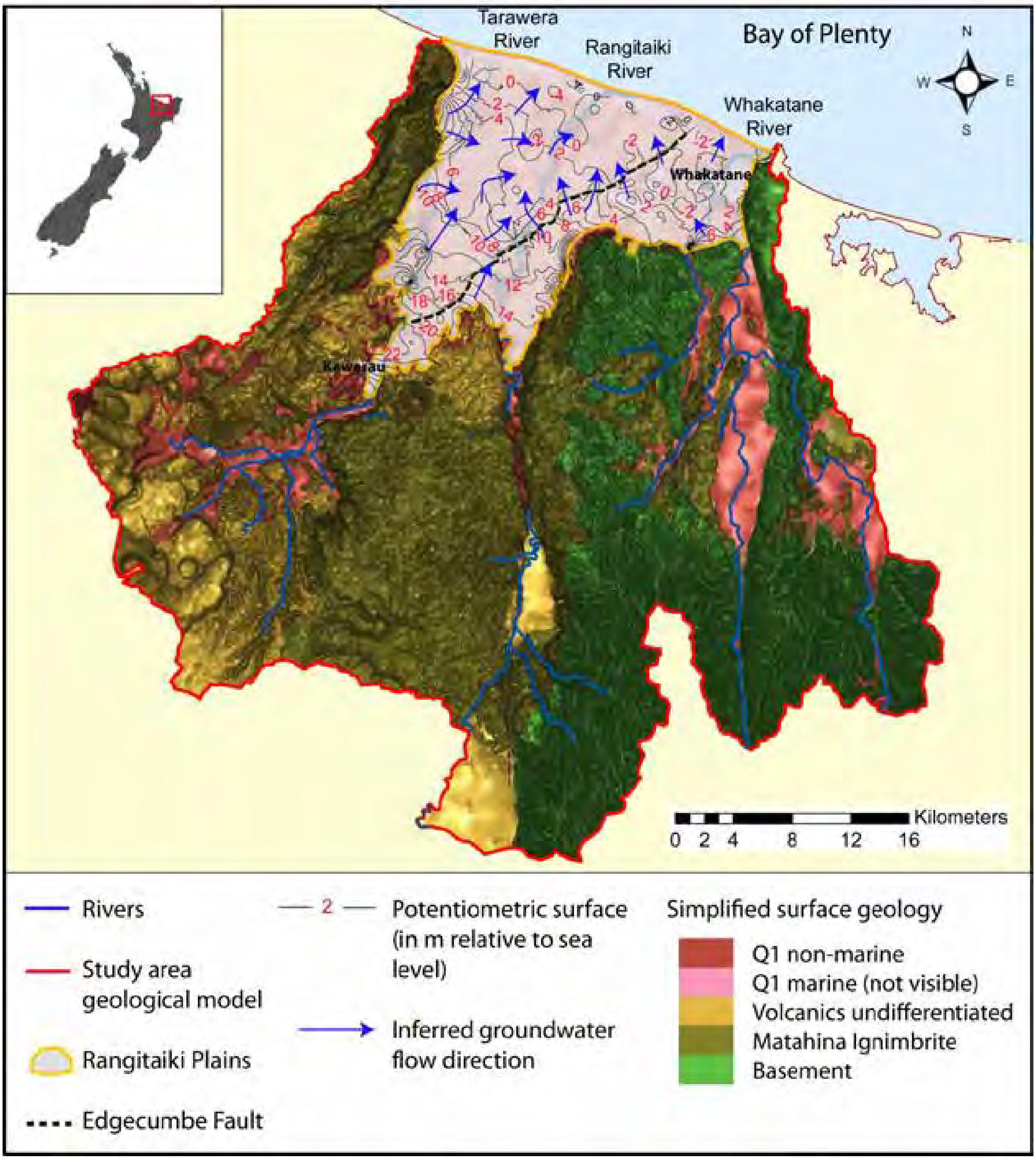


Figure 5.24 Potentiometric surface map showing the inferred direction of groundwater flow in the “Rangitaiki Plains” and “Whakatane Lower” geographic zones.

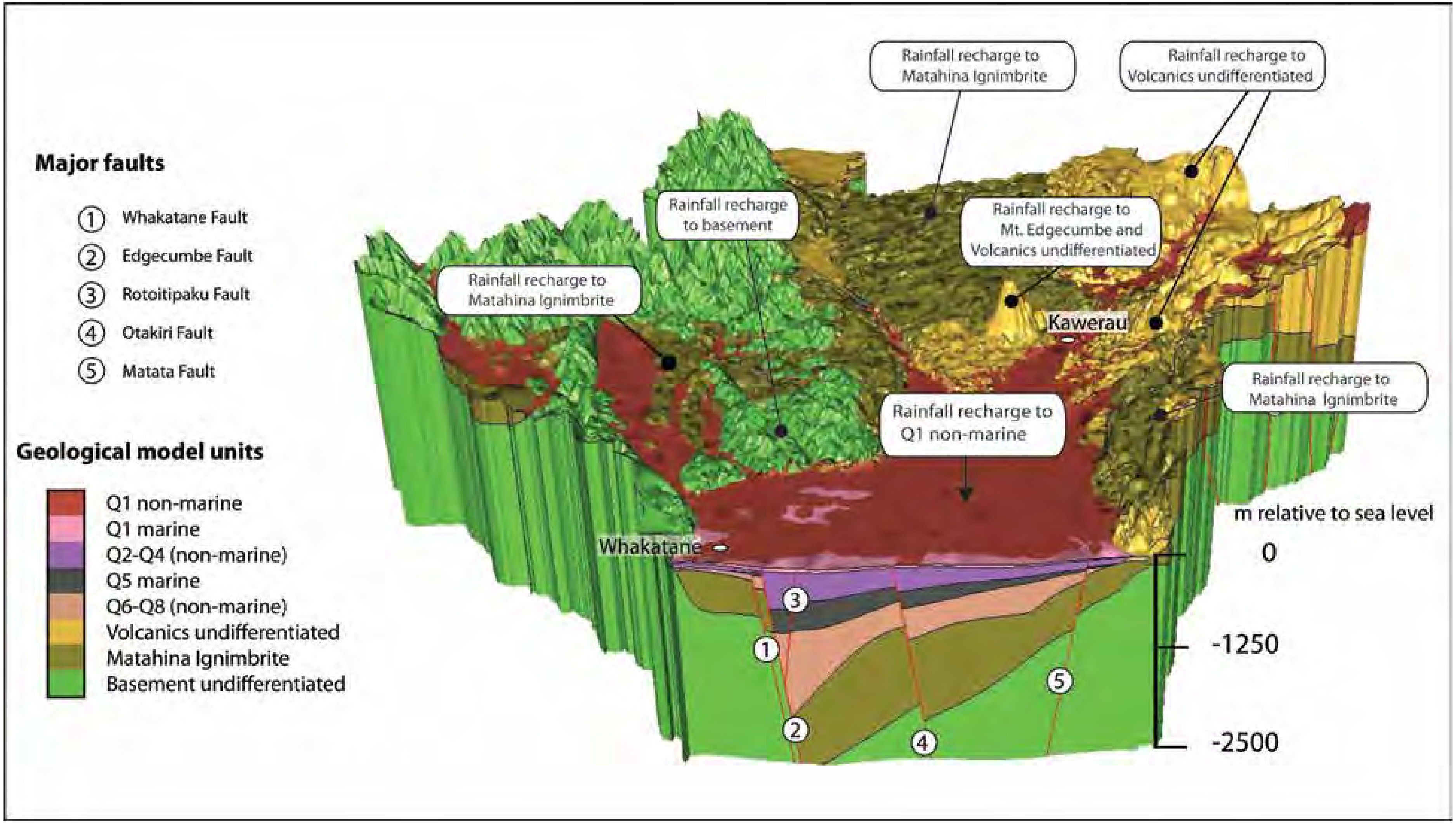


Figure 5.25 Preferential areas of rainfall recharge to different model units.

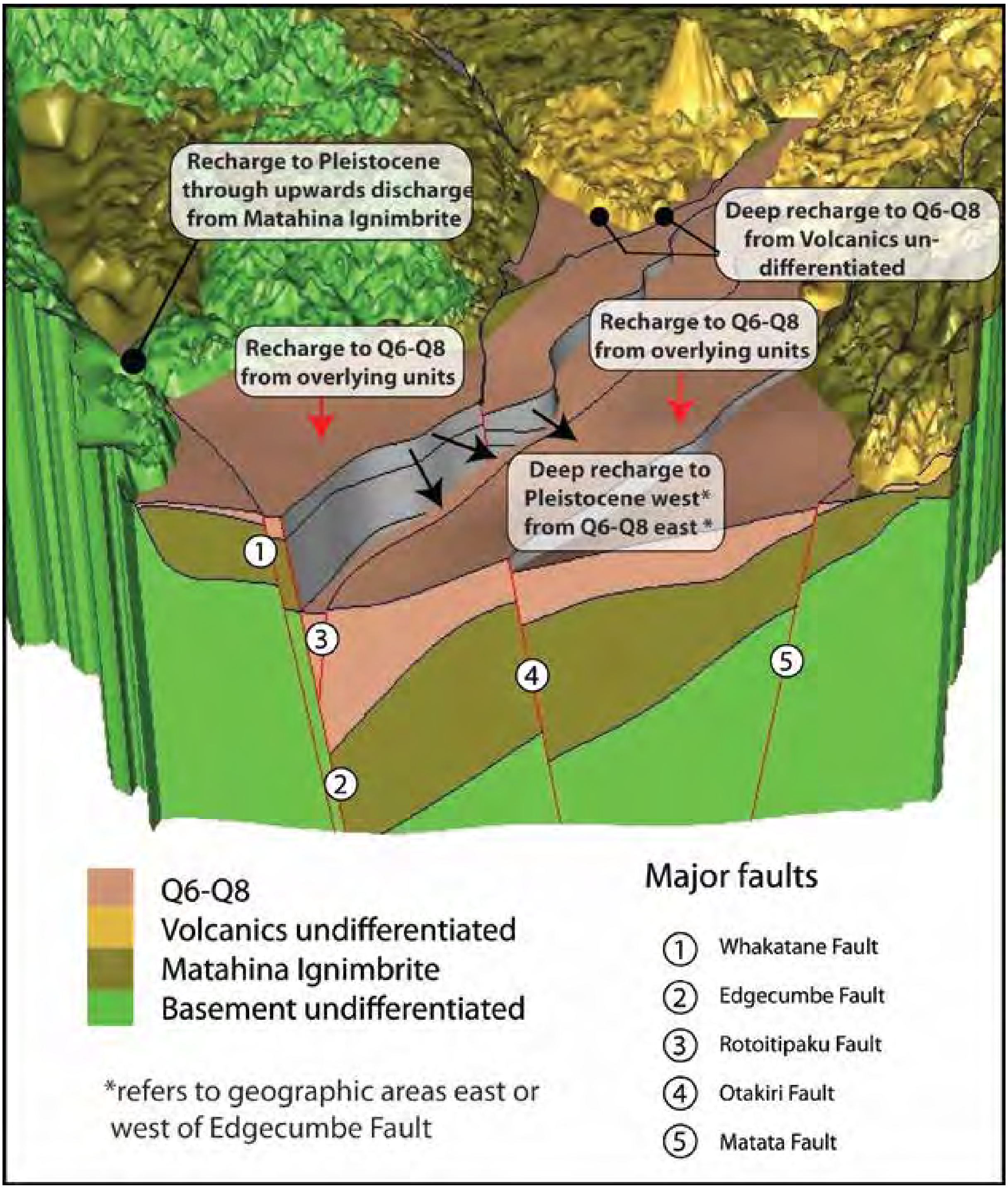


Figure 5.26 Conceptual model of recharge mechanisms to Pleistocene Q6-Q8 unit. Recharge mechanisms to Q2-Q4 are likely to follow the same principle.

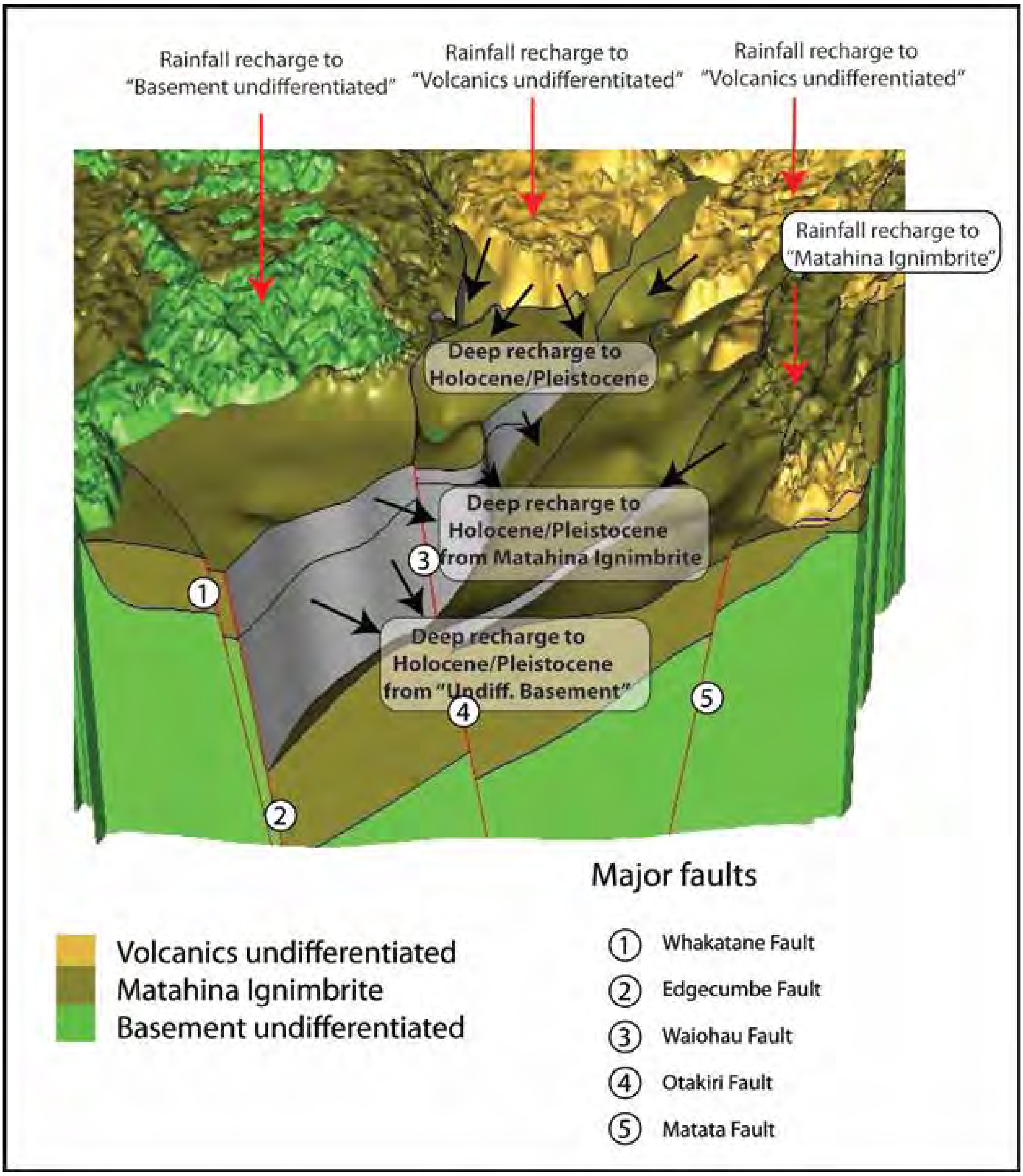


Figure 5.27 Conceptual model of recharge to, and outflow from, the "Matahina Ignimbrite", "Volcanics undifferentiated" and "Basement undifferentiated" model units.

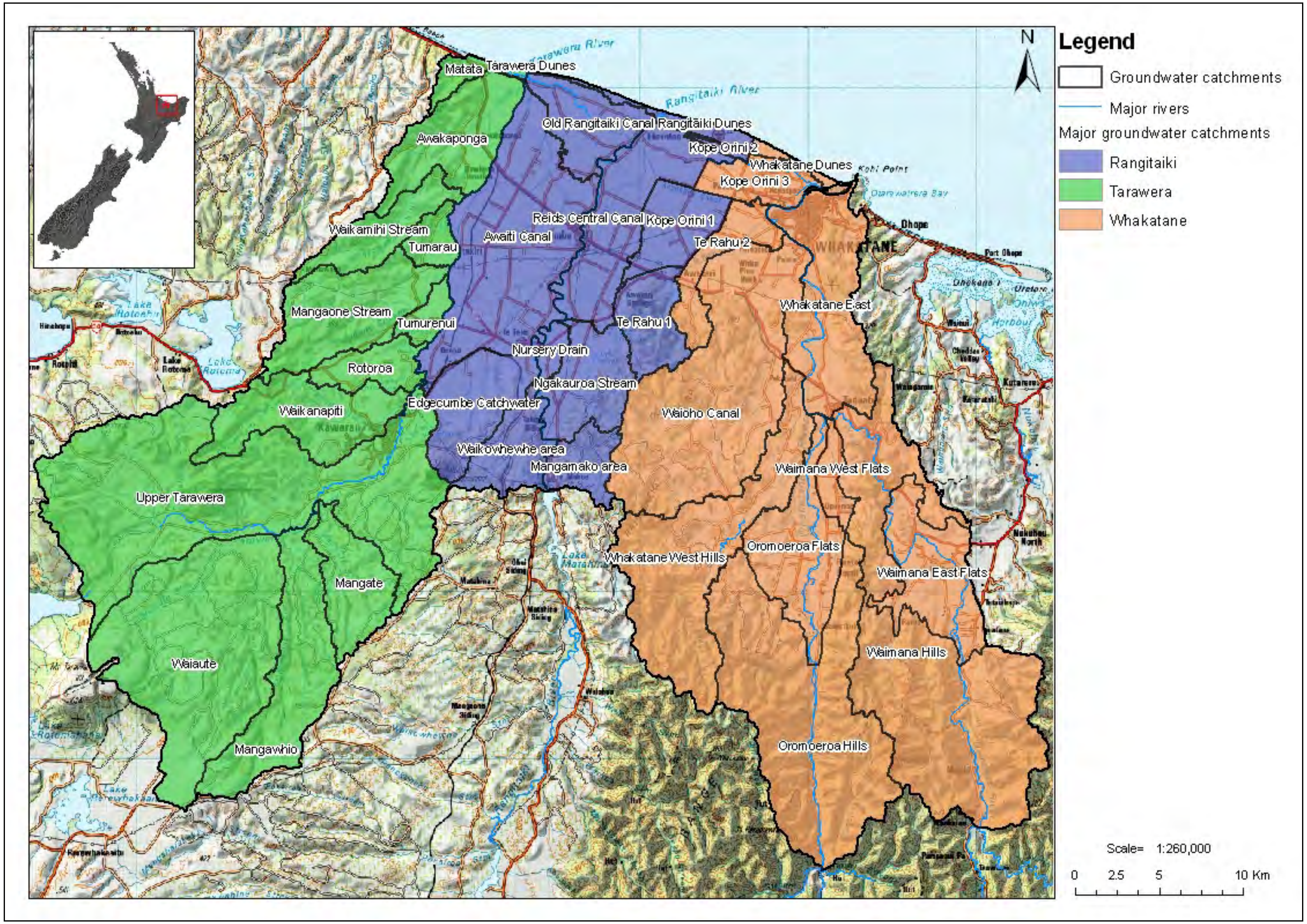


Figure 6.1 Major groundwater catchments and groundwater catchment boundaries in the study area.

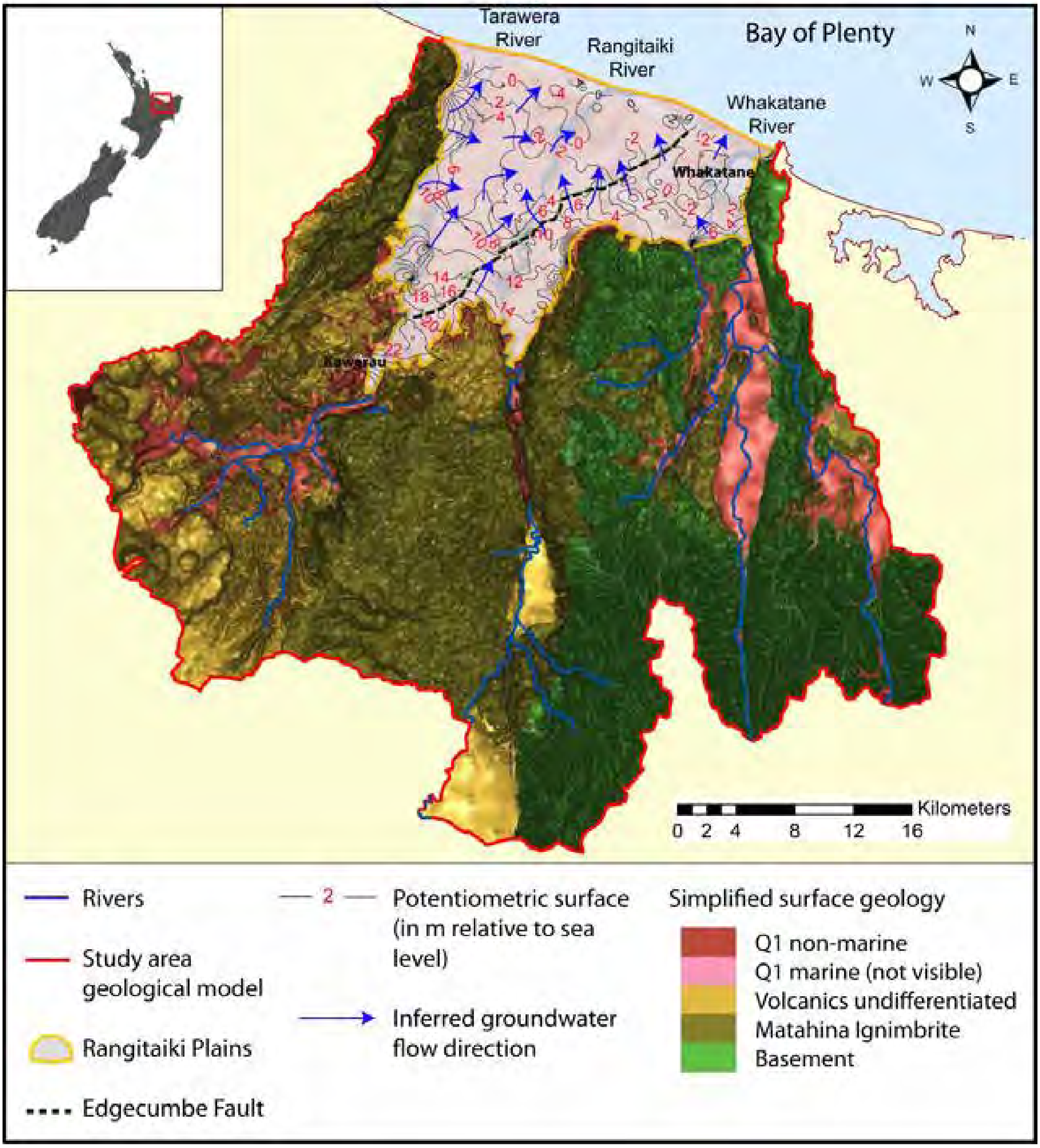


Figure 6.2 Groundwater level and groundwater flow directions in the study area (Appendix 3).

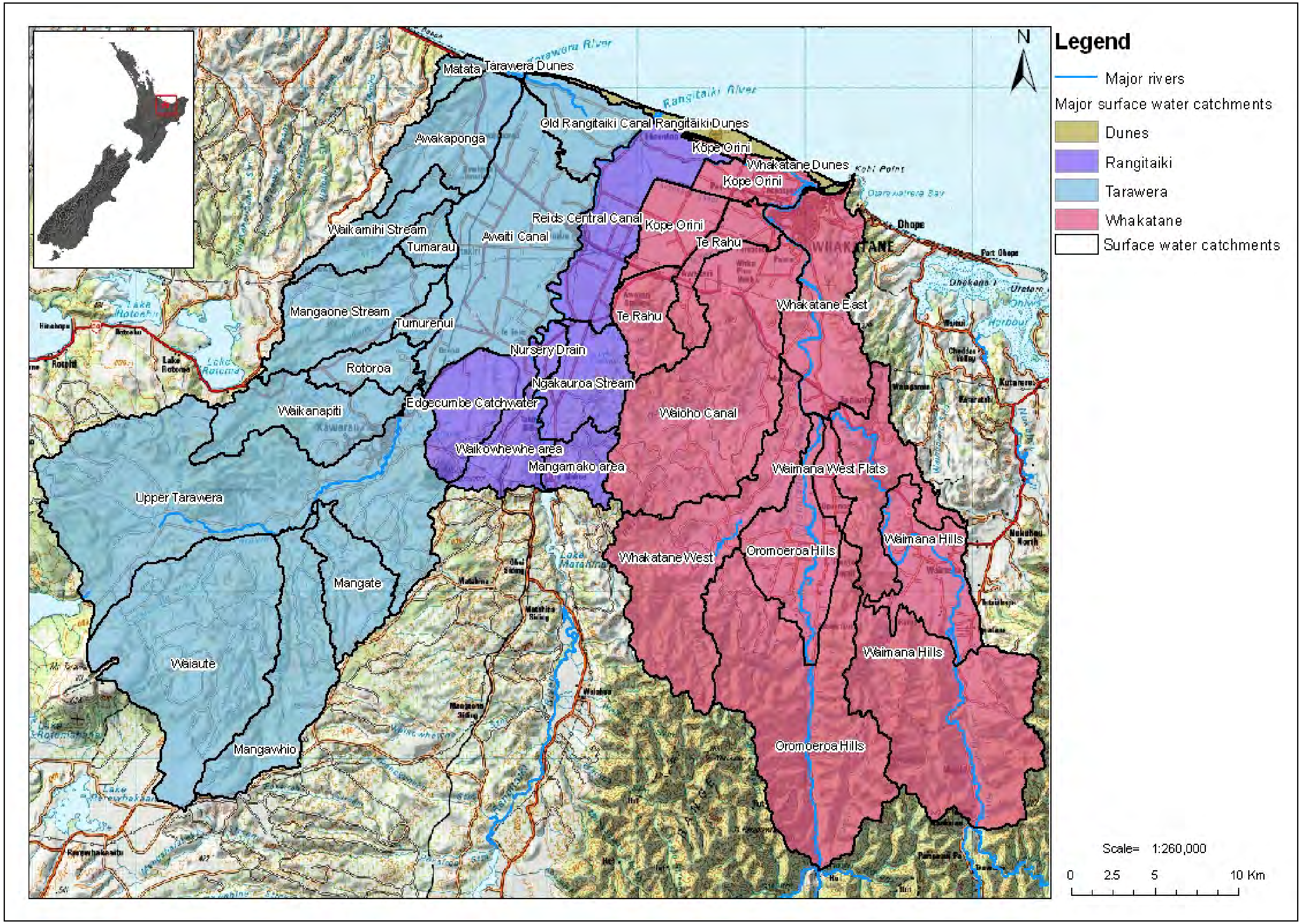


Figure 6.3 Surface catchment boundaries and waterways in the study area.

Figure 6.4 Pumped drainage catchments on the Rangitaiki Plains.

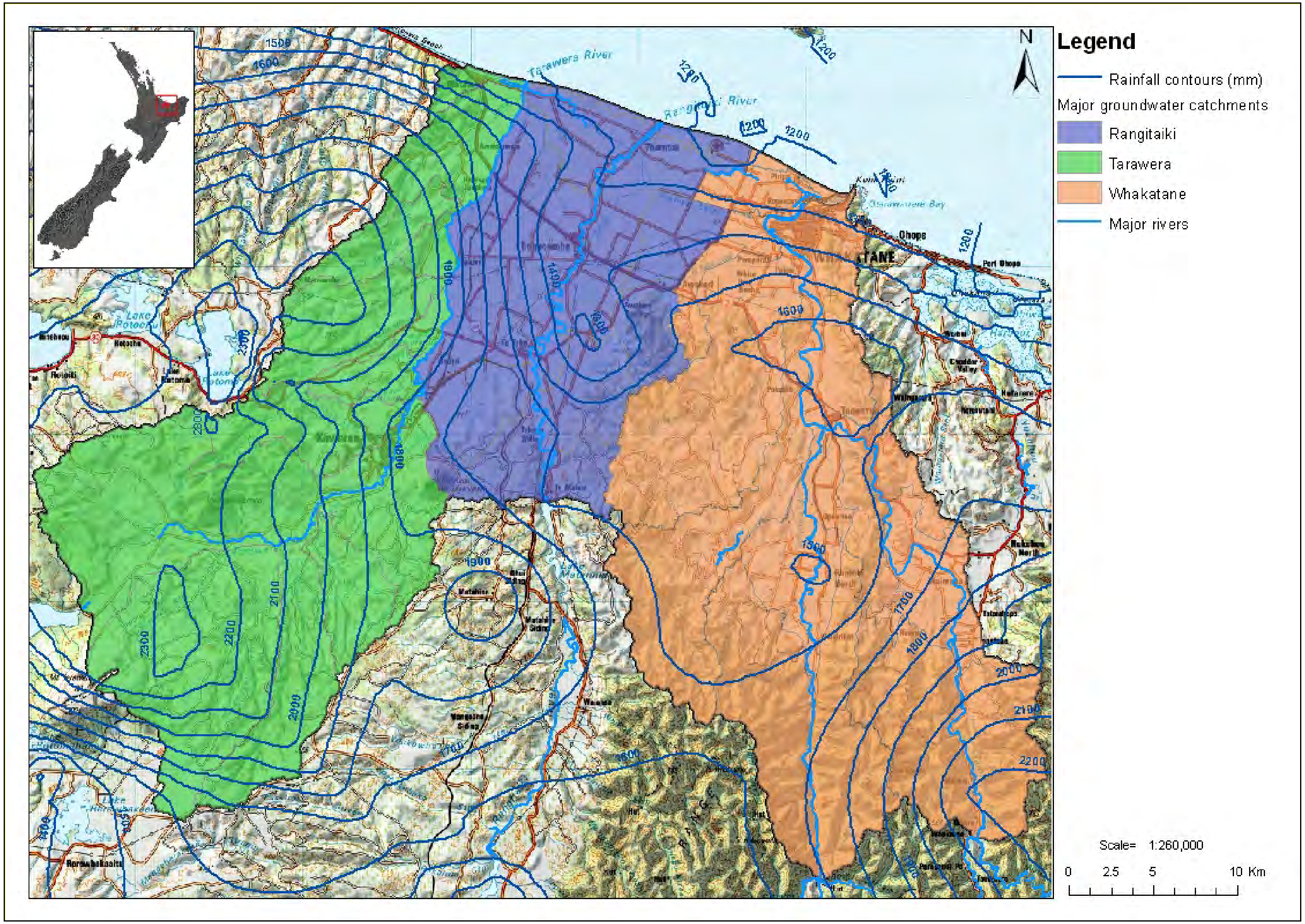


Figure 6.5 Annual rainfall in the study area.

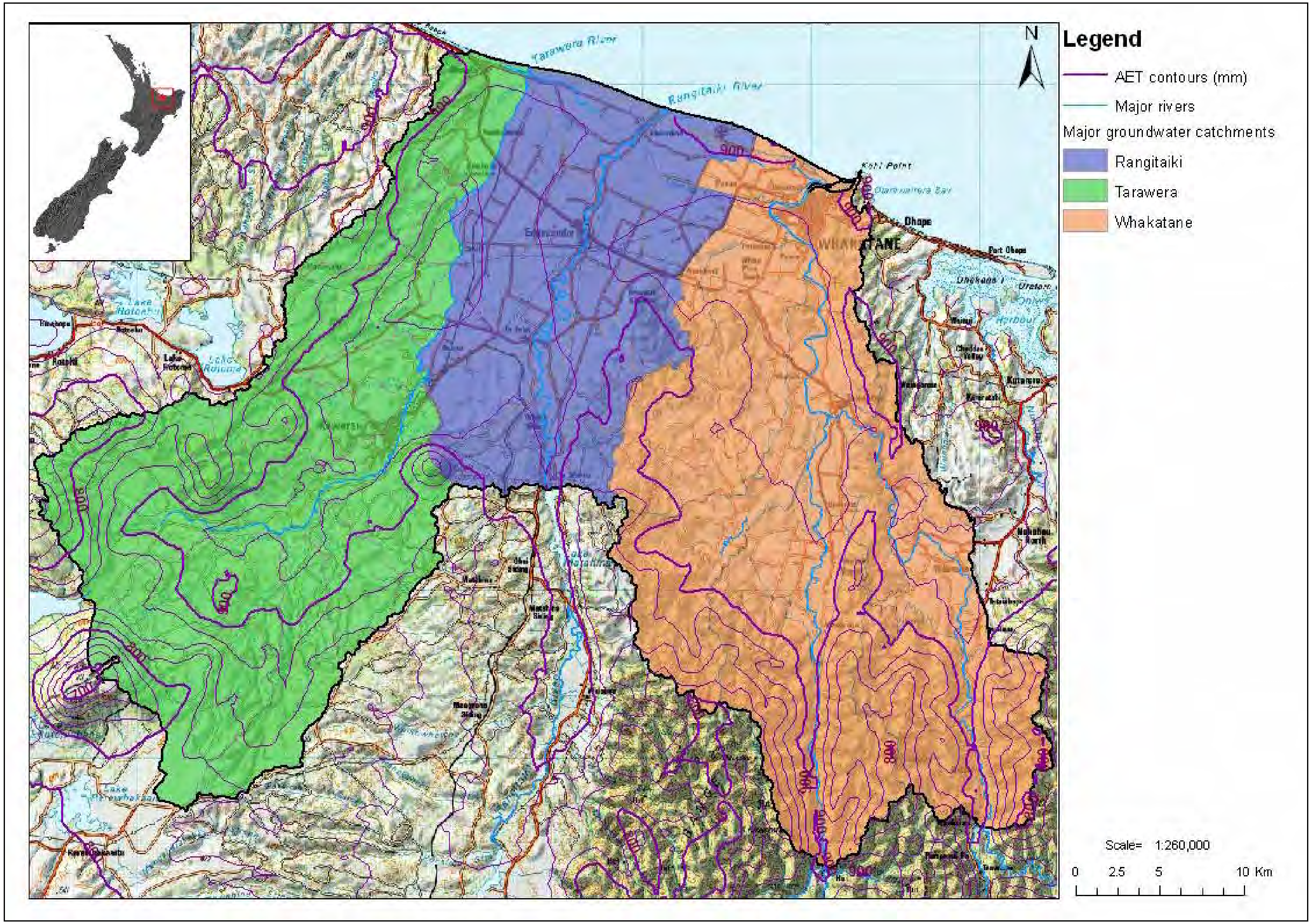


Figure 6.6 Annual AET (actual evapotranspiration) in the study area.

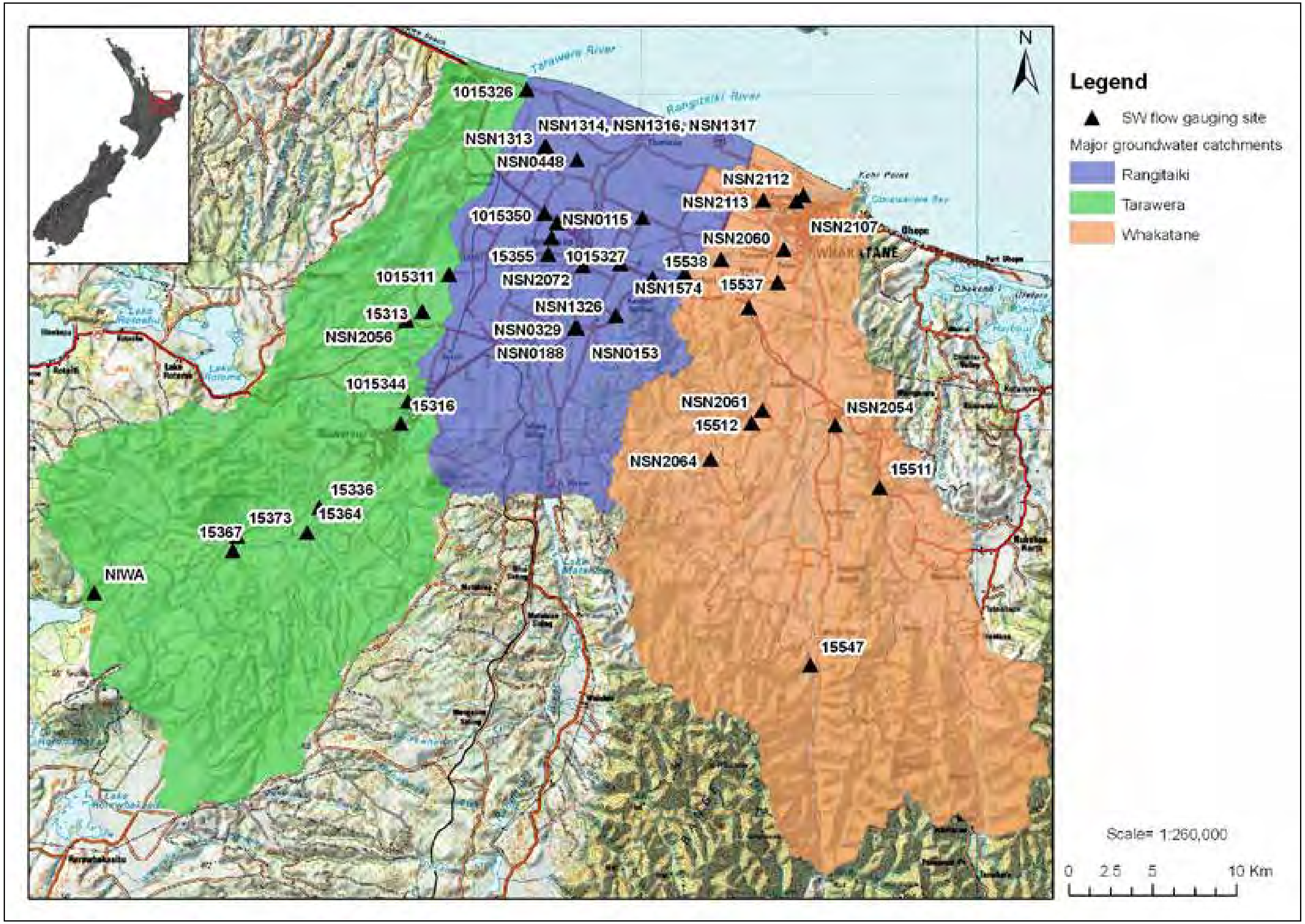


Figure 6.7 Groundwater catchments and location of flow gauging sites used to estimate baseflow in the study area.

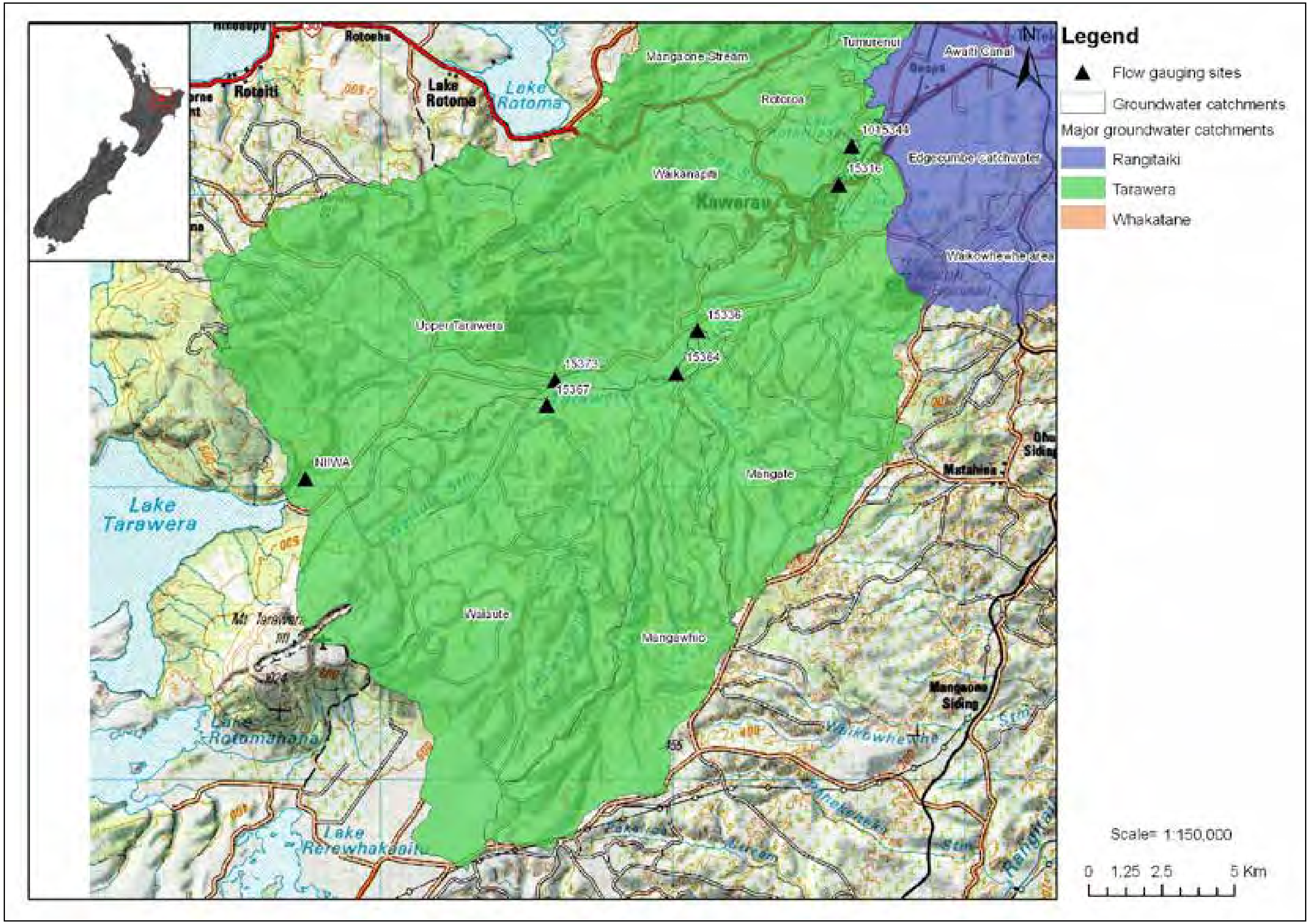


Figure 6.8 Flow gaugings used to estimate baseflow in the Tarawera groundwater catchments above the Rangitaiki Plains.

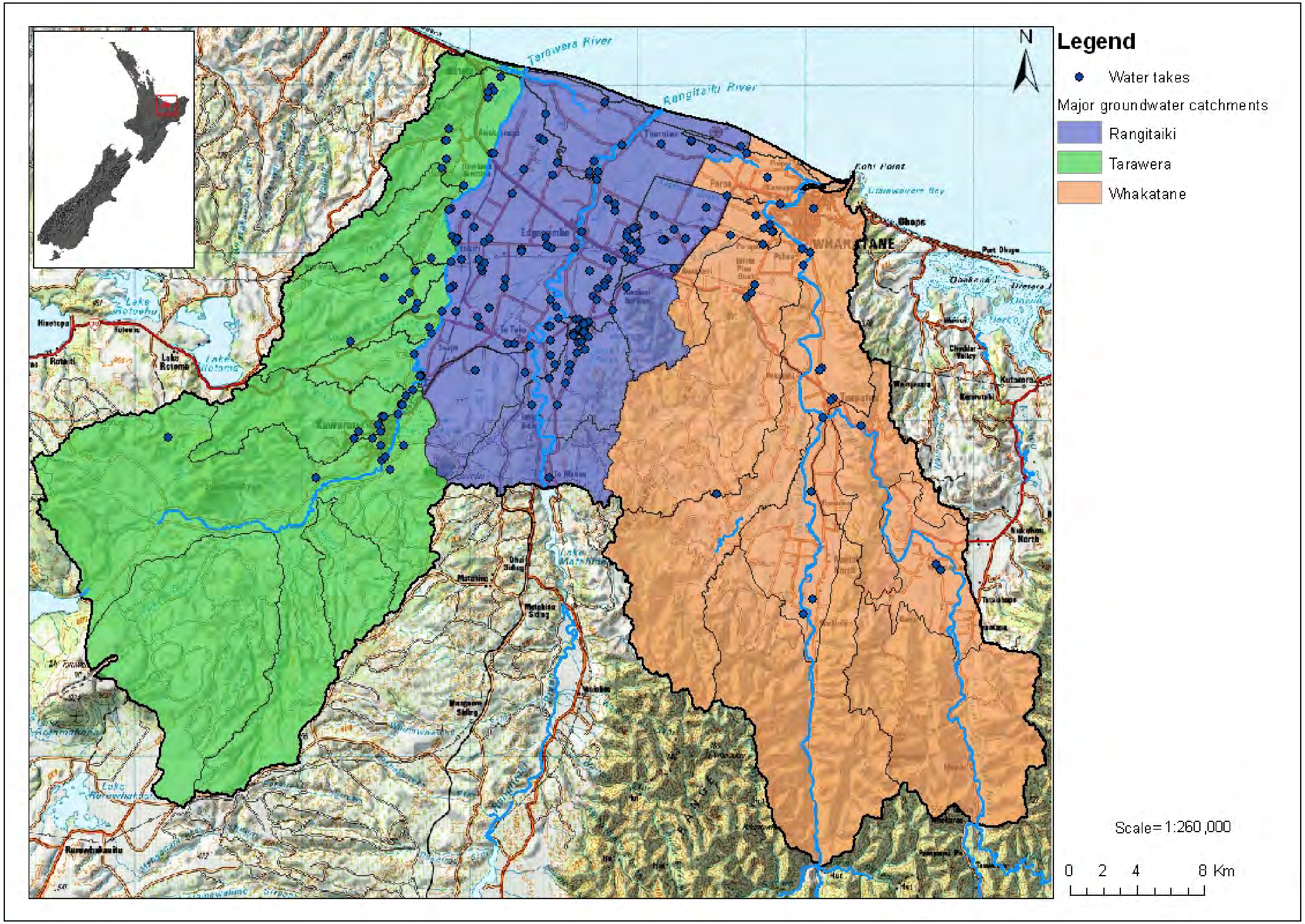


Figure 7.1 Location of groundwater, surface water and geothermal allocation in the study area.

APPENDICES

APPENDIX 1 GROUND ELEVATION IN THE STUDY AREA

Topographic data for this study are obtained from different sources:

- DTM developed by GNS Science based on Land Information New Zealand (LINZ) 20 m elevation contours mapped at a scale of 1:50,000;
- NASA's Shuttle Radar Topography Mission (SRTM) data, Farr *et al.* (2007), with an absolute vertical accuracy better than 9 m (Farr *et al.* 2007);
- BOPRC Terralink DTM; and
- LIDAR data collected by AAMHatch for Bay of Plenty Regional Council in late 2006 for Rangitaiki Plains, with a vertical and hor izontal accuracy of ~0.15 and < 0.55 m, respectively.

For the 3D geological model, a DTM (DEM__Rangitaiki_for_report.2grd) is developed using a combination of data from the SRTM DTM (for the hills area outside the actual Rangitaiki Plains; Figure 1.1) and the LIDAR data set (for the Rangitaiki Plains; Figure 1.1). Data were extracted as scattered xyz datasets with a 20 m x 20 m resolution from the LIDAR data set and with a 45 m x 45 m resolution from the SRTM DTM.

The integrated DTM from the different data sources is developed using EarthVision® software by interpolation of the available topographic data over the area 6305000 to 6366000 m north and 2811540 to 2891140 east (all coordinates used in this report pertain to the New Zealand map grid). In this study, all interpolation is performed within EarthVision® using the in-built minimum tension (minimum curvature) technique. Other interpolation techniques exist and may produce different results, but their comparison to the minimum tension technique is beyond the scope of this study. DTMs are developed in this project with a range of horizontal and vertical scales during the modelling process. This means that many different interpolation models may be created and compared before the final model is selected.

APPENDIX 2 WELL LOG DATA AND DATA QUALITY CHECKS

Well log data were provided by BOPRC in an Excel spreadsheet. The data include but are not limited to: well number, well location (easting and nor thing), well depth, depths of lithology (top and bottom) and lithological descriptions provided by drillers. In summary, this data set includes:

- 500 wells;
- 2243 lithology descriptions;
- total logged length across all wells: 17,274.93 metres.

A2.1 Processing of well log data

The driller's description column 'GLG_description' has been copied in an Excel column named 'GLG_description _processed' for editing. The text in the 'GLG_description' is edited to correct spelling mistakes and to ensure consistent descriptions of lithologies, with revised descriptions in the column 'GLG_description _proc' (Table A2.1).

Table A2.1 Edits to lithological descriptions in the study area.

Driller's description	GLG_description _proc	Occurrences
SS	sandstone	39
course	coarse	13
S/S	sandstone	14
&	and	126
metal	gravel	1
wb	water bearing	15
w/b	water bearing	4
shelly	shell	1
pumic	pumice	1
pumicee	pumice	1
shingle	gravel	7
cobbles	gravel	7
gravels	gravel	373
sands	sand	595
silts	silt	95
clays	clay	29
shell	shell	106
logs	organic	1
timber	organic	43
rhyolite	ignimbrite	42
wood-logs	organic	89
log	organic	3
wood	organic	36
peat	organic	222
vegetation	organic	15
boulders	boulder	8
top soil	topsoil	49
organics	organic	30
organe	organic	1
ignambrites	ignimbrite	1
ignambrite	ignimbrite	3
papa	mudstone	10
ignimbrites	ignimbrites	1

All text is edited to lower case.

A2.2 Statistics of lithological descriptions

Occurrences of major lithologies (gravel, sand, silt, clay, shells, organic, etc.), and lithology colour, in 2243 descriptions of lithology have been sorted and listed as follows:

- ‘gravel’ occurs 511 times;
- ‘sand’ occurs 383 times;
- ‘silt’ occurs 147 times;
- ‘clay’ occurs 66 plus 9 (clayey) times;
- ‘shell’ occurs 125 times;
- ‘organic’ occurs 354 times;
- ‘greywacke’ (as hard rock) occurs 8 times;
- ‘ignimbrite’ occurs 91 times;
- ‘pumice/pumiceous’ occurs 906 times;
- ‘pumice’ occurs 379 times;
- ‘greywacke’ gravel occurs 36 times;
- ‘blue gravel’ occurs 28 times;
- ‘brown gravel’ occurs 11 times;
- ‘grey’ occurs 218 times;
- ‘blue’ occurs 117 times;
- ‘brown’ occurs 318 times;
- ‘black’ occurs 11 times;
- ‘white’ occurs 61 times;
- ‘yellow’ occurs 21 times.

Gravel is the most common lithological description in the area (Figure A2.1).

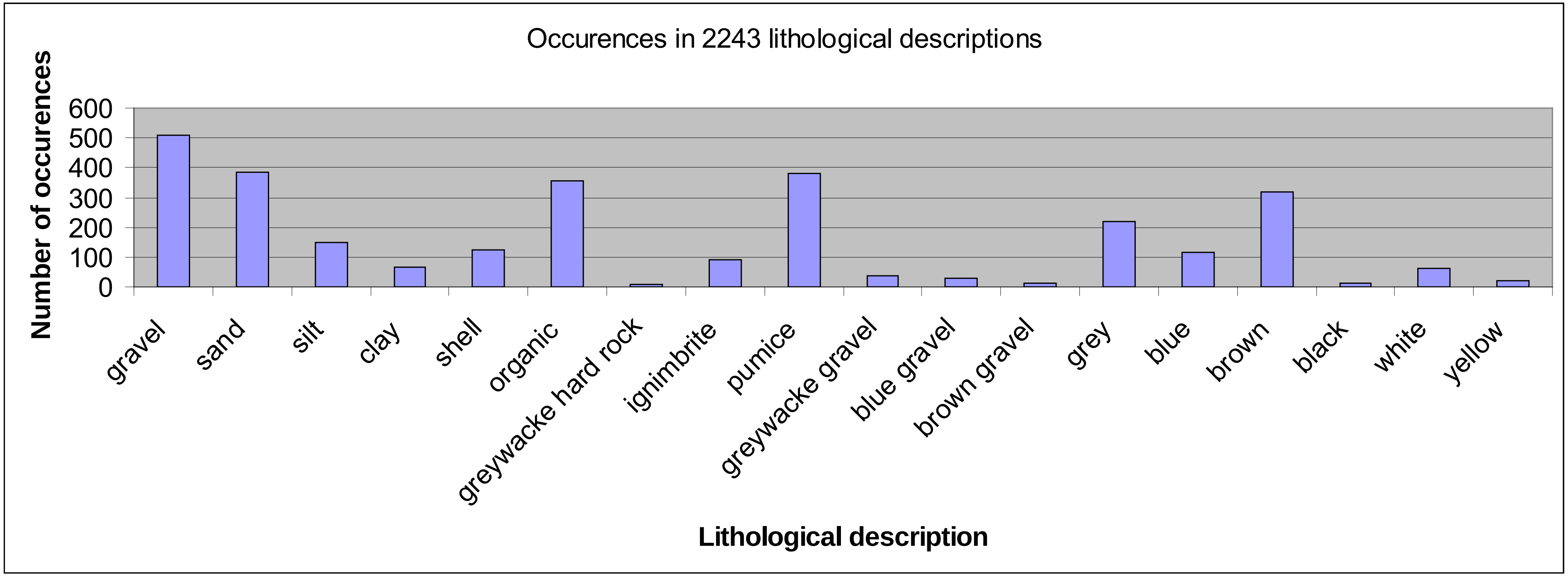


Figure A2.1 Occurrences of text descriptions in Rangitaiki Plains well log lithological descriptions.

A2.3 Quality checks of well locations, well elevations and lithological descriptions

The process geological modelling includes quality checks on well locations and well elevations. These quality checks can result in corrections to errors in the database including revisions to the well data and corrections are noted in the following text. The assistance of Jonathan Freeman (BOPRC pers. comm.) is gratefully acknowledged in assisting with identification of poor quality well location information.

A2.3.1 Well location information

After calculating the New Zealand Map Grid coordinates from the map references stored in the lithological database it was shown that some wells had been recorded with the wrong map references. The easting and northing coordinates of wells (Table A2.2) were changed in the database of lithological logs after consulting Jonathan Freeman at BOPRC.

Table A2.2 Corrected locations for wells.

Well number	Easting	Northing
822	2863260	6339650
4872	2851400	6356500
4914	2836648	6347391
10508	2857091	6341719
10374	2848898	6358798
4929	2840571	6345588
392	2861842	6354326
4885	2836653	6347520
10187	2846301	6352403
10454	2846501	6359601
4898	2843803	6352301

A2.3.2 Well removed from database

Well 2997 (Table A2.3) is removed from the lithology data because the well has the wrong coordinates.

Table A2.3 Lithological log of well 2997.

Top of unit	Bottom of unit	GLC_description
0	6.5	Topsoil, brown peaty silts and sand
6.5	18	Grey mudstone
18	30	Various brown silts
30	83	Hard dark grey mudstone
83	118	Harder dark grey mudstone (greywacke)

A2.4 Well added to database

Well 11692 (drilled at Paul Road) was completed after the BOPRC database was generated by BOPRC. The lithology in this well is added to the lithology database.

APPENDIX 3 GENERATION OF POTENTIOMETRIC SURFACE FOR THE RANGITAIKI PLAINS AQUIFER SYSTEM

A map of groundwater elevation (potentiometric surface) in the study area is estimated using groundwater depth information from wells in the BOPRC database (Figure A3.1). The elevation of groundwater, relative to sea level, in a well is calculated by subtracting groundwater depth from the general ground surface; LIDAR (Appendix 1) and photogrammetric elevation data are used to represent the ground surface.

The potentiometric surface typically estimates groundwater level within the elevation range of the BOPRC database, which includes groundwater depth data, but does not generally record the elevation of the reference point for groundwater depth measurement. Therefore it is unknown whether the depth to groundwater in a well is measured from the top of a well casing or from ground level. The potential error in groundwater level elevation could be typically 0.5 m but may be up to several meters. However, the contoured surface of groundwater elevation is probably not affected by errors in elevations of reference points for groundwater depth measurement where the density of well data is relatively high. Errors in elevations of reference points could become significant to the contoured groundwater level surface where the density of wells is low. This is because greater importance is placed on individual observations by the contouring procedure in areas where the density of observations is low.

The map of groundwater elevation aims to represent static groundwater levels, i.e. levels in absence of groundwater pumping. Groundwater level data that are probably representative of pumped groundwater level is assessed. Wells are removed from the dataset where the groundwater level is very different from the average groundwater level, e.g. where groundwater levels are quite away below sea level. Figure A3.2 shows the depth to groundwater estimated in the selected wells.

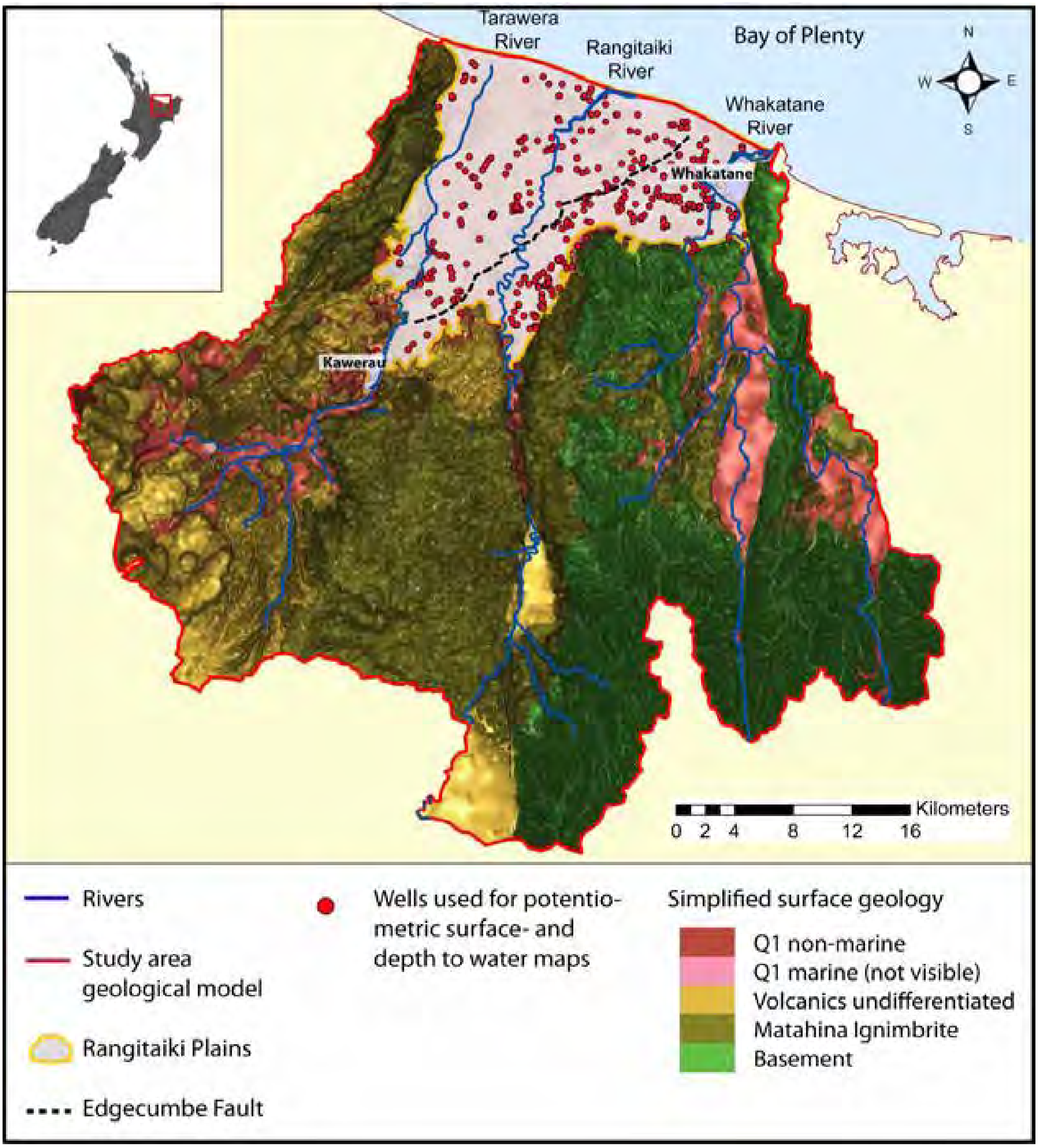


Figure A3.1 Location of wells used to contour groundwater level.

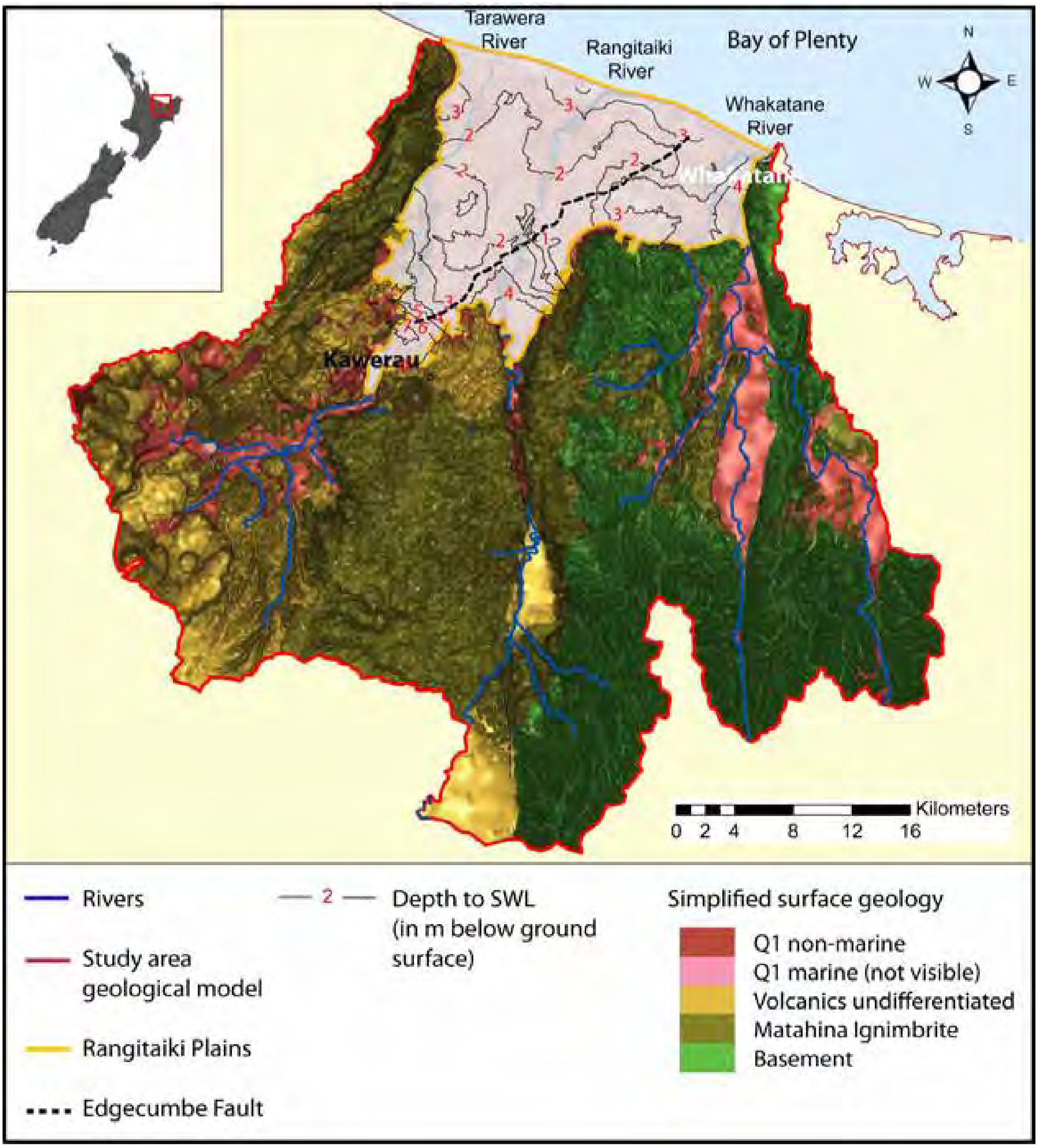


Figure A3.2 Depth to groundwater in wells used to contour groundwater level.

APPENDIX 4 CATCHMENT CLASSIFICATION, ATTRIBUTE DESCRIPTION

Table A4.1 Attributes associated with the shapefile of Rangitaiki Plains drain and pumped catchments.

Rangitaiki Plains low flow catchments	
Attribute title	**Description**
MajRivCatc	Major river catchment to which the greater catchment discharges e.g. Rangitaiki
Greater_Ca	Major drain catchment as according to Bay of Plenty Regional Council's Rivers and Drainage Scheme data.
Topo_Class	Topographic classification of the drain catchment
MinorCatch	Minor drain catchments as identified by Bay of Plenty Regional Council’s Rivers and Drainage Scheme data.
Catchment_	A random numeric identifier that is unique to each individual (minor catchment) catchment
Shape_Area	The catchment area square kilometres
No Measures	The number of measures used to estimate low flows
Gauge_ID	The unique gauging number idnetified in Bay of Plenty Regional Council's gaugebase dataset and corresponding to the low flow data used.
Rangitaiki Plains pumped catchments	
Attribute title	**Description**
PumpNo	The unique pump no relating to the pump station information provided by the Rivers and Drainage section and Illustrated in Appendix 4
SchemeName	The rivers and drainage or common name, applied to each pump scheme.
KWh_Month	The mean monthly KWh March 2006 to February 2010 supplied by Horizons energy

APPENDIX 5 RIVER AND DRAINAGE PUMP STATION INFORMATION

Table A5.1 Communal pump schemes.

Scheme No.	Scheme name	No. of pumps	Pump type	Pump No.	Size of pump	Impeller	Motor (kW)	Pole	Rpm	Previously overhauled, serviced, or new	Repairer	Motor rewound or new	Years since overhauled or serviced	Year station constructed	Comments
M10	Angle Road	2	MacEwans	1	18/22	B+4	22	8	715	Jun-94	BOPRC	-	16	1981	
				2	18/22	B+4	22	8	715	Aug-98	Ross Eng.	-	12	1981	
M11	Awaiti West	2	MacEwans	1	24/30	C+2	59.6	8	725	Feb-2002	Ross Eng.	Jan-97	8	1971	Service + reconditioned deflector ('BC')
				2	24/30	C-2	59.6	8	725	Apr-98	Ross Eng.	-	12	1971	Shaft balance and repairs
M44	Awaiti East	2	Warman	1	AF400		22	6	915	Sep-2003	Craig Arnett	Oct-03	7	1990	Motor by Whak. Contractors
				2	AF400		22	6	915	Mar-98	Ross Eng.	-	12	1990	Serviced 3/98
M12	Awakeri Farms (West)	2	MacEwans	1	18/22	B-2	18.6	8	715	Oct-2003	Ross Eng.	Apr-00	7	1967	
				2	18/22	B-2	18.6	8	715	Aug-97	Ross Eng.	Jun-78	13	1967	
	Awakeri Farms (East)	1	MacEwans	1	SFP 2		3.75	4	1450	Jan-53			57	1953	Scheme declined service
M13	Baird-Miller	2	MacEwans	1	24/30	B-0	18.5	10	580	Jan-86	-	-	24	1986	Lifted June 97 - OK
				2	15/18	A+4	11	10	570	May-2004	Ross Eng.	-	6	1986	
M14	Foubister	1	MacEwans	1	18/22	B-2	22	8	720	Aug-2003	Ross Eng.	Feb-97	7	1970	
M15	Gordon	2	MacEwans	1	15/18	B+2	15	8	730	Oct-2004	MacEwans	Apr-06	6	1970	
				2	SFP 2	B+2	-	-	-	Jun-2002	Ross Eng.	-	8	1970	
M16	Greig Road	2	MacEwans	1	24/30	C-2	74.5	8	730	Mar-98	Ross Eng.	Oct-84	12	1962	
M16	Greig Road			2	24/30	C-2	74.5	8	730	Sep-2005	Ross Eng.	Jun-95	5	1962	
M17	Halls	2	MacEwans	1	15/18	C+4	22	6	970	May-2004	Ross Eng.	Jun 96	6	1964	Additional bearing fitted 5/97
				2	15/18	C+4	22	6	970	May-2004	Ross Eng.	Dec-91	6	1964	Additional bearing fitted 3/98
M18	Hyland-Baillie (Vierboom)	2	MacEwans	1	15/18	B+2	15	8	710	Aug-2003	Ross Eng.	Oct-87	7	1969	
				2	15/18	B+2	15	8	710	Apr-2002	Ross Eng.	-	8	1969	
M18	Hyland-Baillie (Mexted)	1	MacEwans	1	12/14	C-4	11	4	1220	Nov-2004	Ross Eng.	Apr-85	6	1969	
M20	Kuhanui (Martin)	2	MacEwans	1	12/14 Mk2	C+2	15	4	1450	Apr-2001	Ross Eng.	Apr-01	9	1963	New motor and pump recondition. Pump lowered 300mnm.
				2	12/14 Mk2	C+2	15	4	1450	Jan-2004	Ross Eng.	-	6	1963	Scheme declined service
M21	Lawrence	2	Flygt	1	LL3152	610	8.8	6	950	Apr-2002	Aspec'd	Apr-02	8	1984	pump + motor overhaul (4/2002)
				2	LL3152	610	8.8	6	950	Apr-2000	Whak. Cont.	Apr-00	10	1984	pump + motor overhaul (4/2000)
M22	Longview-Richlands A	1	MacEwans	1	12/14	C+4	9.3	4	1440	Sep-2001	Ross Eng.	-	9	1959	
M22	Longview-Richlands B	1	MacEwans	1	15/18	C-4	18.6	6	960	Sep-2005	Ross Eng.	-	5	1965	
M23	Luxton Valley	2	Flygt	1	LL3300		44	6	970	Aug-99	Fuller	-	11	1981	
				2	LL3300		44	6	970	Jan-2005	Opotiki Pumps	Jan-02	5	1981	
M24	Martins	1	Flygt	1	LL3300	614	44	6	970	Aug-99	Fuller	-	11	1981	
M25	Massey Drain (Fox)	1	Flygt	1	LL3201		22	6	950	Apr-2005	New (Trimate)		5	1964	
M25	Massey Drain (McFarland)	1	MacEwans	1	18/22	B-2	18.6	8	720	Mar-2002	Ross Eng.	Jul-99	8	1964	
M25	Massey Drain (Vierboom)	2	MacEwans	1	18/22	B+2	18.6	8	720	Dec-2003	Ross Eng	May-96	7	1964	
				2	18/22	B+2	15	8	720	Dec-2003	Ross Eng	May-99	7	1964	

Scheme No.	Scheme name	No. of pumps	Pump type	Pump No.	Size of pump	Impeller	Motor (kW)	Pole	Rpm	Previously overhauled, serviced, or new	Repairer	Motor rewound or new	Years since overhauled or serviced	Year station constructed	Comments
M26	Mexted-Withy	2	MacEwans	1	18/22	B-0	22.3	8	715	Apr-2003	Ross Eng	May-97	7	1968	
				2	18/22	B-0	22.3	8	715	May-99	Ross Eng	-	11	1968	
M27	Murray (Webb)	2	Weirs	1	350AF		22	4	1450	Mar-2000	New	Mar-2000	10	1994	New Weir Pump Mar-2000 @ 2653hrs
				2	350AF		22	4	1450	Mar-2000	New	Mar-2000	10	1994	New Weir Pump Mar-2000 @ 2852hrs
M27	Murray (Pratt)	1	MacEwans	1	18/22	C+4	30	8	715	Feb-2003	Ross Eng.	Aug-00	7	1965	Motor by Whak. Contractors
M28	Nicholas (Wainani)	2	MacEwans	1	12/14	B-0	19	4	1440	Aug-2003	Ross Eng.	-	7	1960	New pump supports fitted 2/98
M28	Nicholas (Wainani)			2	18/22	B+4	30	8	715	Apr-2000	J Two Eng.	Apr-00	10	1960	pump + motor overhaul (4/2000)
M29	Noord-Vierboom	2	MacEwans	1	18/22	B-0	18.6	8	720	Apr-96	MacEwans	-	14	1956	400 l/s
				2	Flygt	-	8.8	-	750	Sep-2005	Trimate	Sep-05	5	1956	
M30	Omeheu East	2	MacEwans	1	18/22	B+4	22.3	8	720	Apr-2004	Ross Eng	-	6	1974	
				2	24/30	C-0	44.7	8	725	Feb-2000	Ross Eng	-	10	1974	pump only overhauled (2/2000)
M43	Omeheu West	1	EIM	1	MSA3515	-	11	8	-	May-2004	Opotiki Pumps	-	6	1988	
M42	Omeheu Adjunct	2	KSB	1	PWT500A	-	30	8	720	Apr-2003	Jayar Opotiki	-	7	1988	New seals, O rings and bearings
				2	PWT500A	-	30	8	720	Jun-2005	Opotiki Pumps	-	5	1988	
M32	Pedersen - Van den Top	2	MacEwans	1	12/14	C+4	18.6	4	1460	Sep-2005	Ross Eng.	Aug-04	5	1966	
				2	12/14	C+4	18.6	4	1460	Jul-02	Ross Eng.	Aug-04	8	1966	Additional bearing installed *
M33	Platts (West)	2	MacEwans	1	15/18	B+4	15	8	730	May-2000	Ross Eng	May-00	10	1966	pump + motor overhaul (5/2000)
				2	18/22	B-4	22	8	740	May-2000	J Two Eng.	May-00	10	1966	pump + motor overhaul (5/2000)
M33	Platts (Powers)	2	Flygt	1	PL7050	17o	27		725	Aug-99	Fuller		11	1956	Model 7050.680-5249
M33	Platts (Powers)			2	PL7050	17o	27		725	Apr-2004	Whak. Cont.	-	6	1956	Model 7050.680-5249
M34	Reynolds	3	MacEwans	1	15/18	B+4	22	6	970	Sep-2005	Ross Eng.	Sep-05	5	1966	
				2	12/14 Mk4	B+4	15	-	1440	Sep-2005	Ross Eng.	Jan-88	5	1966	
				3	12/14 Mk2	B+4	15	-	710	Sep-2005	Ross Eng.	Jul-04	5	1966	
M41	Poplar Lane	2	Flygt	1	LL3152LT	-	8.8	6	950	Aug-99	Fuller	Nov-91	11	1987	
M41	Poplar Lane			2	LL3102LT.410	180	3.1	4	1450	May-2006	Trimate	-	4	1987	
M19	Riverslea Road	1	Flygt	1	PL3127LT	-	5.9?	4	1450	May-2006	Fuller	-	4	1987	
M35	Robins Road	1	MacEwans	1	18/22	D+4	56	6	985	Jul-2004	Ross Eng.	Oct-89	6	1970	
M36	Robinson's	2	Flygt	1	LL3152	-	8.8	6	950	Aug-2003	East Bay Marine	Oct-97	7	1984	New impellor fitted 2003
				2	LL3152	-	8.8	6	950	Aug-2003	East Bay Marine	-	7	1984	New impellor fitted 2003
M37	Thompson-Ernest	2	MacEwans	1	24/30	B-4	37.2	10	580	Nov-98	Ross Eng.	Jul-84	12	1968	
M37	Thompson-Ernest			2	24/30	B-2	37.2	10	580	Apr-2006	Ross Eng.	-	4	1968	
M38	Travurzas	2	MacEwans	1	15/18	C+2	18.6	6	955	Mar-98	Ross Eng.	-	12	1975	Service/shaft balance 3/98
				2	15/18	C+2	18.6	6	955	Mar-84	RDB	-	26	1975	
M39	Withys	2	MacEwans	1	15/18	B+2	18.6	8	720	May-96	MacEwans	-	14	1975	
				2	15/18	B+2	18.6	8	720	May-2002	Ross Eng.	-	8	1975	
M40	Wyld	2	Flygt	1	LL3300	616	44	6	970	Aug-99	BOPRC	-	11	1980	Screens and pump seats replaced
				2	LL3300	616	44	6	970	Aug-99	BOPRC	-	11	1980	

APPENDIX 6 SURFACE GAUGING MEASUREMENTS IN THE STUDY AREA

Table A6.1 Selected surface gauging measurements used for estimating specific discharge, Rangitaiki Plains.

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Date	Discharge (l/s)	Median Q all (l/s)	Median discharge excluding high flows (l/s)
Whakatane	Kope Orini 3	Kope Canal	Hokowhitu Marae	NSN2112	2859670	6353980	6/06/2006	2480	379	
Whakatane	Kope Orini 3	Kope Canal	Hokowhitu Marae	NSN2112	2859670	6353980	6/06/2006	350	379	
Whakatane	Kope Orini 3	Kope Canal	Hokowhitu Marae	NSN2112	2859670	6353980	6/06/2006	315	379	
Whakatane	Kope Orini 3	Kope Canal	Hokowhitu Marae	NSN2112	2859670	6353980	28/04/2007	501	379	
Whakatane	Kope Orini 3	Kope Canal	Keepa Road Bridge	NSN2107	2859270	6353610	28/04/2006	369	379	
Whakatane	Kope Orini 3	Kope Canal	Keepa Road Bridge	NSN2107	2859270	6353610	6/06/2006	2494	379	
Whakatane	Kope Orini 3	Kope Canal	Keepa Road Bridge	NSN2107	2859270	6353610	6/06/2006	192	379	
Whakatane	Kope Orini 3	Kope Canal	Keepa Road Bridge	NSN2107	2859270	6353610	6/06/2006	180	379	
Whakatane	Waioho Canal		Poroporo Marae	NSN2060	2858500	6350720	29/04/2004	659	1848	
Whakatane	Waioho Canal		Poroporo Marae	NSN2060	2858500	6350720	28/05/2004	3036	1848	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	7/06/1968	1230	263	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	22/07/1969	279	263	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	12/03/1973	268	263	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	12/04/1973	263	263	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	18/05/1973	258	263	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	19/06/1973	244	263	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	12/07/1973	253	263	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	7/02/1974	240	263	
Whakatane	Waioho Canal		Te Toki Road	15537	2858130	6348790	18/02/1980	476	263	
Whakatane	Kope Orini 3	Kope Canal	Shaw Road	NSN2113	2857270	6353660	28/04/2006	389	379	
Whakatane	Kope Orini 3	Kope Canal	Shaw Road	NSN2113	2857270	6353660	6/06/2006	1784	379	
Whakatane	Kope Orini 3	Kope Canal	Shaw Road	NSN2113	2857270	6353660	6/06/2006	490	379	
Whakatane	Kope Orini 3	Kope Canal	Shaw Road	NSN2113	2857270	6353660	6/06/2006	340	379	
Whakatane	Waioho Canal		Foster Road	NSN2061	2857200	6341170	29/04/2004	620	1274	1273
Whakatane	Waioho Canal		Foster Road	NSN2061	2857200	6341170	28/05/2004	1555	1274	1273
Whakatane	Waioho Canal		Foster Road	NSN2061	2857200	6341170	10/08/2004	2811	1274	1273
Whakatane	Waioho Canal		Foster Road	NSN2061	2857200	6341170	1/10/2004	1275	1274	1273
Whakatane	Waioho Canal		Foster Road	NSN2061	2857200	6341170	1/11/2004	1521	1274	1273
Whakatane	Waioho Canal		Foster Road	NSN2061	2857200	6341170	25/11/2004	1273	1274	1273
Whakatane	Waioho Canal		Foster Road	NSN2061	2857200	6341170	28/01/2005	773	1274	1273
Whakatane	Waioho Canal		Foster Road	NSN2061	2857200	6341170	22/04/2005	355	1274	1273
Whakatane	Waioho Canal	Waioho	Proposed Regional Site	15514	2856590	6340390	29/04/2004	649	1134	1060
Whakatane	Waioho Canal	Waioho	Proposed Regional Site	15514	2856590	6340390	28/05/2004	1396	1134	1060
Whakatane	Waioho Canal	Waioho	Proposed Regional Site	15514	2856590	6340390	10/08/2004	2507	1134	1060

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Date	Discharge (l/s)	Median Q all (l/s)	Median discharge excluding high flows (l/s)
Whakatane	Waioho Canal	Waioho	Proposed Regional Site	15514	2856590	6340390	1/10/2004	1207	1134	1060
Whakatane	Waioho Canal	Waioho	Proposed Regional Site	15514	2856590	6340390	1/11/2004	1385	1134	1060
Whakatane	Waioho Canal	Waioho	Proposed Regional Site	15514	2856590	6340390	25/11/2004	1060	1134	1060
Whakatane	Waioho Canal	Waioho	Proposed Regional Site	15514	2856590	6340390	28/01/2005	758	1134	1060
Whakatane	Waioho Canal	Waioho	Proposed Regional Site	15514	2856590	6340390	22/04/2005	288	1134	1060
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	22/11/1967	4633	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	29/02/1968	437	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	1/03/1968	419	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	29/03/1969	688	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	1/04/1969	673	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	9/04/1969	622	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	24/02/1970	474	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	22/02/1978	378	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	26/01/1979	267	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	15/02/1982	434	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	9/11/2003	521	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	10/11/2003	1354	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	10/11/2003	1380	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	10/11/2003	1193	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	10/11/2003	1332	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	11/11/2003	1230	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	11/11/2003	1162	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	2/12/2003	941	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	19/12/2003	667	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	16/04/2004	488	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	29/04/2004	655	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	28/05/2004	2148	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	22/07/2004	11624	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	10/08/2004	3535	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	1/10/2004	1551	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	1/11/2004	1663	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	25/11/2004	1362	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	23/12/2004	1295	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	28/01/2005	885	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	25/02/2005	941	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	22/04/2005	381	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	24/06/2005	3356	941	881.5

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Date	Discharge (l/s)	Median Q all (l/s)	Median discharge excluding high flows (l/s)
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	20/07/2005	4604	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	29/08/2005	2302	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	25/11/2005	878	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	16/12/2005	749	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	24/01/2006	371	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	24/03/2006	1384	941	881.5
Whakatane	Waioho Canal	Waioho	S.H. 2 Bridge (White Pine Bush Road)	15512	2856420	6347250	26/05/2006	4261	941	881.5
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	16/12/1967	1079	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	1/03/1968	137	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	11/04/1969	150	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	14/04/1969	142	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	24/02/1970	131	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	16/12/1967	1079	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	1/03/1968	137	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	11/04/1969	150	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	14/04/1969	142	142	
Whakatane	Te Rahu 2	Te Rahu Canal	Baker's Farm	15538	2854770	6350140	24/02/1970	131	142	
Whakatane	Waioho Canal		Sissams Farm	NSN2064	2854140	6338240	29/04/2004	119	183	
Whakatane	Waioho Canal		Sissams Farm	NSN2064	2854140	6338240	28/05/2004	203	183	
Whakatane	Waioho Canal		Sissams Farm	NSN2064	2854140	6338240	1/10/2004	217	183	
Whakatane	Waioho Canal		Sissams Farm	NSN2064	2854140	6338240	1/11/2004	236	183	
Whakatane	Waioho Canal		Sissams Farm	NSN2064	2854140	6338240	25/11/2004	183	183	
Whakatane	Waioho Canal		Sissams Farm	NSN2064	2854140	6338240	28/01/2005	145	183	
Whakatane	Waioho Canal		Sissams Farm	NSN2064	2854140	6338240	22/04/2005	69	183	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	31/01/1974	19	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	30/10/1975	154	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	20/01/1977	107	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	8/01/1978	36	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	22/02/1978	34	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	17/10/1978	91	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	25/01/1979	22	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	8/02/1980	69	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	12/02/1982	47	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	4/02/1983	10	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	20/01/1987	38	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	19/02/1993	48	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	31/01/1974	19	43	

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Date	Discharge (l/s)	Median Q all (l/s)	Median discharge excluding high flows (l/s)
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	30/10/1975	154	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	20/01/1977	107	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	8/01/1978	36	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	22/02/1978	34	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	17/10/1978	91	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	25/01/1979	22	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	8/02/1980	69	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	12/02/1982	47	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	4/02/1983	10	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	20/01/1987	38	43	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge	NSN0025	2852600	6349300	19/02/1993	48	43	
Whakatane	Te Rahu 1	Te Rahu Canal	Edgecumbe - Awakeri Road	NSN0465	2850660	6349050	17/10/1978	53	13	
Whakatane	Te Rahu 1	Te Rahu Canal	Edgecumbe - Awakeri Road	NSN0465	2850660	6349050	8/01/1979	13	13	
Whakatane	Te Rahu 1	Te Rahu Canal	Edgecumbe - Awakeri Road	NSN0465	2850660	6349050	29/10/1984	7	13	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge (Watchorn's)	NSN1326	2848510	6346790	22/02/1978	14	18	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge (Watchorn's)	NSN1326	2848510	6346790	17/10/1978	46	18	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge (Watchorn's)	NSN1326	2848510	6346790	12/02/1982	22	18	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge (Watchorn's)	NSN1326	2848510	6346790	4/02/1983	5	18	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge (Watchorn's)	NSN1326	2848510	6346790	29/10/1984	25	18	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge (Watchorn's)	NSN1326	2848510	6346790	21/01/1987	14	18	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge (Watchorn's)	NSN1326	2848510	6346790	4/02/1988	16	18	
Whakatane	Te Rahu 1	Te Rahu Canal	S.H. 30 Bridge (Watchorn's)	NSN1326	2848510	6346790	19/02/1993	19	18	
Tarawera	Awaiti Canal	Omeheu Canal	Edgecumbe - Matata Road	1015343	2845000	6352350	16/03/1993	148	284	
Tarawera	Awaiti Canal	Omeheu Canal	Edgecumbe - Matata Road	1015343	2845000	6352350	20/06/1996	284	284	
Tarawera	Awaiti Canal	Omeheu Canal	Edgecumbe - Matata Road	1015343	2845000	6352350	20/06/1996	302	284	
Tarawera	Awaiti Canal	Omeheu Canal	Poplar Lane	1015327	2844650	6351430	11/09/1987	544	2820	544
Tarawera	Awaiti Canal	Omeheu Canal	Poplar Lane	1015327	2844650	6351430	15/02/1988	9494	2820	544
Tarawera	Awaiti Canal	Omeheu Canal	Poplar Lane	1015327	2844650	6351430	15/02/1988	7928	2820	544
Tarawera	Awaiti Canal	Omeheu Canal	Poplar Lane	1015327	2844650	6351430	16/02/1988	2820	2820	544
Tarawera	Awaiti Canal	Omeheu Canal	Poplar Lane	1015327	2844650	6351430	16/02/1988	1412	2820	544
Tarawera	Awaiti Canal	Omeheu Canal	Otariki Road	15355	2844460	6350460	21/10/1974	635	346	
Tarawera	Awaiti Canal	Omeheu Canal	Otariki Road	15355	2844460	6350460	26/01/1979	57	346	
Tarawera	Awaiti Canal	Omeheu Canal	Awaiti Confluence	NSN1313	2844340	6356880	11/09/1987	6084	5569	
Tarawera	Awaiti Canal	Omeheu Canal	Awaiti Confluence	NSN1313	2844340	6356880	11/09/1987	5053	5569	
Tarawera	Awaiti Canal	Awaiti Canal	Omeheu Confluence	NSN1314, NSN1316, NSN1317	2844260	6356880	11/09/1987	1439	358	
Tarawera	Awaiti Canal	Awaiti Canal	Omeheu Confluence	NSN1314, NSN1316, NSN1317	2844260	6356880	11/09/1987	358	358	
Tarawera	Awaiti Canal	Awaiti Canal	Omeheu Confluence	NSN1314, NSN1316, NSN1317	2844260	6356880	11/09/1987	97	358	

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Date	Discharge (l/s)	Median Q all (l/s)	Median discharge excluding high flows (l/s)
Tarawera	Awaiti Canal	Omeheu Drain	Edgecumbe - Matata Road	1015350	2844250	6352900	26/01/1979	12	111	68
Tarawera	Awaiti Canal	Omeheu Drain	Edgecumbe - Matata Road	1015350	2844250	6352900	11/09/1987	120	111	68
Tarawera	Awaiti Canal	Omeheu Drain	Edgecumbe - Matata Road	1015350	2844250	6352900	15/02/1988	3927	111	68
Tarawera	Awaiti Canal	Omeheu Drain	Edgecumbe - Matata Road	1015350	2844250	6352900	15/02/1988	3509	111	68
Tarawera	Awaiti Canal	Omeheu Drain	Edgecumbe - Matata Road	1015350	2844250	6352900	16/03/1993	35	111	68
Tarawera	Awaiti Canal	Omeheu Drain	Edgecumbe - Matata Road	1015350	2844250	6352900	20/06/1996	101	111	68
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	5/12/1967	4709	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	5/12/1967	5219	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	5/12/1967	5965	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	5/12/1967	7102	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	5/12/1967	742	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	5/12/1967	8711	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	5/12/1967	9174	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	5/12/1967	5193	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	1813	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	62	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	461	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	426	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	319	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	741	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	531	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	1634	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	1648	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	1314	1634	469
Tarawera	Awaiti Canal	Awaiti Canal	Tide Gates	1015326	2843180	6360250	16/03/1993	188	1634	469
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	28/10/1976	2427	1630	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	20/05/1983	1086	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	30/11/1983	2189	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	26/09/1986	2451	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	6/11/1991	2016	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	15/01/1992	1570	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	11/03/1992	1753	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	22/04/1992	1302	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	3/06/1992	1272	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	14/07/1992	1435	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	16/09/1992	1822	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	18/11/1992	1690	0	

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Date	Discharge (l/s)	Median Q all (l/s)	Median discharge excluding high flows (l/s)
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	10/02/1993	1464	0	
Tarawera	Mangaone Stream	Mangaone	U/S Tarawera Confluence	1015311	2838550	6349250	14/04/1993	1352	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	25/09/1974	2381	1336	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	21/10/1974	2251	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	25/01/1979	1230	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	30/11/1982	1336	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	3/02/1983	1262	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	29/03/1983	1256	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	7/03/1984	1765	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	16/03/1993	1389	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	26/02/1997	1749	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	15/02/2005	1071	0	
Tarawera	Mangaone Stream	Mangaone	Braemar Road Bridge	15313	2836960	6347040	1/03/2005	1054	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	12/11/2003	1033	1018	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	2/12/2003	857	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	1027	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	1027	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	956	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	997	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	1018	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	1020	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	1039	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	885	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	1034	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	852	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	837	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	1127	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	1019	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	979	0	
Tarawera	Mangaone Stream	Mangaone	Above Mangawiki Confluence	NSN2056	2836020	6346520	10/02/2004	867	0	
Rangitaiki	Reids Central Canal	Western Drain	Above McLeans Road	NSN0115	2850080	6352650	29/03/1978	1	1	
Rangitaiki	Reids Central Canal	Western Drain	Railway Bridge	NSN1574	2848750	6349920	29/03/1978	3	3	
Rangitaiki	Reids Central Canal	Reids Central Canal	McCracken Road Bridge	NSN2072	2846540	6349780	16/04/2009	27	27	
Rangitaiki	Ngakauroa Stream	Ngakauroa	S.H. 30	NSN0153	2846200	6346060	26/01/1979	32	72	
Rangitaiki	Ngakauroa Stream	Ngakauroa	S.H. 30 Bridge	NSN0188	2846200	6346060	8/02/1980	99	72	
Rangitaiki	Ngakauroa Stream	Ngakauroa	Tasman Orchard Bridge (S.H. 30)	NSN0448	2846200	6356080	28/02/1984	96	72	
Rangitaiki	Ngakauroa Stream	Ngakauroa	Tasman Orchard	NSN0329	2846050	6346080	21/12/1982	47	72	

Table A6.2 Gauging sites in the upper Tarawera, upper Rangitaiki and upper Whakatane rivers.

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Number of gaugings	Median flow (l/s)
Tarawera	Mangawhio	Mangawhio	Cuming Road	15365	2829040	6330750	2	1705
Tarawera	Mangawhio	Mangawhio	U/S Tarawera Confluence	15364	2830110	6333900	3	1979
Tarawera	Mangate	Mangate	U/S Tarawera Confluence	15336	2830840	6335360	1	126
Tarawera	Mangate	Mangate	Putauaki Road	15363	2831760	6332040	1	3633
Tarawera	Waiaute	Waiaute	Below Waiwhakapu Confluence	15367	2825660	6332810	1	5427
Tarawera	Waiaute	Waiaute	Edwards Road	15368	2823140	6329940	2	779.5
Tarawera	Waiaute	Gold Mine Hill Spring	Tasman, Tarawera	NSN0251	2822261	6329384	1	283
Tarawera	Waiaute	Rusty Creek	Edwards Road	15369	2821890	6329300	2	501.5
Tarawera	Waiaute	Waiwhakapa	Confluence	15370	2826250	6328260	2	1409.5
Tarawera	Waiaute	Pancake Stream	Confluence	15371	2826160	6328180	1	884
Tarawera	Waiaute	Waiwhakapa	American Road	15372	2824850	6323920	1	267
Tarawera	Upper Tarawera	Tarawera	Kawerau Bridge	15316	2835670	6340360	174	22486
Tarawera	Upper Tarawera	Centre Stream	Putauaki Road	15360	2836170	6336140	1	0
Tarawera	Upper Tarawera	Centre Stream	Titri Road	15361	2835810	6332930	1	0
Tarawera	Upper Tarawera	Buddle's Stream	Fenton's Mill Road	15362	2830790	6336550	3	372
Tarawera	Upper Tarawera	Korutu	Homestead Road	15366	2829260	6334220	3	119
Tarawera	Upper Tarawera	Tarawera	Edwards Road	15373	2825950	6333670	1	15347
Tarawera	Upper Tarawera	Wiki's Creek	Tarawera Road	15374	2823981	6333440	1	0
Tarawera	Upper Tarawera	Kaipara Stream	Fenton's Mill Road	15375	2822330	6334780	3	925
Tarawera	Upper Tarawera	Mangakotukutuku	Pukemaire Road	15376	2820970	6334360	2	926
Tarawera	Upper Tarawera	Tarawera	Waterfall Road Bridge	1015319	2821200	6333750	1	286
Tarawera	Upper Tarawera	Fentons Mill Spring	Source, Tarawera Tributary	NSN0250	2816101	6334680	1	258
Tarawera	Upper Tarawera	Hot Water Flow	Cooling Pond Weir	1015332	2836510	6341870	17	109.0
Tarawera	Upper Tarawera	Tarawera	Lake Tarawera	Hamilton *et al.* 2006	2816740	6329560	N/A	7240
Tarawera	Upper Tarawera	Tarawera	D/S Lake Tarawera	NIWA	2817400	6330300	1972-2005	6546
Tarawera	Upper Tarawera	Kaipara Stream	Site 1	14749	2821640	6340000	3	271
Tarawera	Rotoroa	Tasman Ponds	Outlet Flume	1015307	2836480	6343980	49	2383.0
Tarawera	Rotoroa	Tarawera	Tarawera River at Pipe Bridge	1015331	2836600	6343800	53	18015.0
Tarawera	Rotoroa	Tasman Ponds	Inlet to No. 2	1015346	2836280	6344540	5	2180.0
Tarawera	Rotoroa	Tasman Ponds	Outlet From No. 2	1015347	2836550	6344040	5	2210.0
Tarawera	Rotoroa	Hot Water Creek	Savage Greenhouse	1015333	2837100	6342660	9	117.0
Tarawera	Waikanapiti	Ruruanga	U/S Tarawera Confluence	1015344	2836110	6341680	11	1139.0
Tarawera	Waikanapiti	Ruruanga	Tamarangi Drive	15314	2834630	6339920	4	1116.5
Tarawera	Waikanapiti	Ruruanga	Kawerau Loop Road	15359	2834590	6339830	3	1306
Tarawera	Waikanapiti	Waikanapiti	Water race	15340	2827360	6341500	1	305
Rangitaiki	Mangamako area	Kakahatoa	Murupara Road	NSN0330	2845100	6338250	1	42

Major river catchment	Groundwater catchment	Gaugebase stream name	Gauging site name	Gauging site number (BOPRC)	Easting (m)	Northing (m)	Number of gaugings	Median flow (l/s)
Rangitaiki	Waikowhewhe area	Te Teko Spring	Quarry Road Crossing	NSN0331	2844120	6339100	1	23
Whakatane	Oromoeroa Hills	Whakatane	D/S Kanihi and Ohora Confluence	NSN1796	2860850	6313700	1	4682
Whakatane	Oromoeroa Flats	Whakatane	Limeworks	15547	2860090	6325990	32	15178.5
Whakatane	Oromoeroa Flats	Whakatane	500m Below Limeworks	NSN0357	2860040	6326320	1	4704
Whakatane	Oromoeroa Flats	Totara	Ruatoki Bridge	NSN0359	2860950	6332240	1	28
Whakatane	Oromoeroa Flats	Whakatane	Ruatoki	15510	2860900	6332400	7	10451.0
Whakatane	Oromoeroa Flats	Waimana Trib.	Waimana Dairy Company	NSN0034	2861760	6332290	1	161
Whakatane	Oromoeroa Flats	Ohaua	Whakatane Confluence	NSN0360	2859700	6337260	1	60
Whakatane	Oromoeroa Flats	Whakatane	U/S Waimana Confluence	NSN1798	2860800	6340400	1	6020
Whakatane	Waimana Hills	Ureroa	Matahi School	NSN0346	2869790	6318970	1	122
Whakatane	Waimana Hills	Huape Stream	Above Confluence	NSN1309	2869600	6323290	1	759
Whakatane	Waimana Hills	Mangapouri	Matahi Valley Road Bridge	NSN0347	2869550	6323530	1	74
Whakatane	Waimana Hills	Waimana	Waimana Gorge	15511	2864210	6336580	36	7127.0
Whakatane	Waimana Hills	Waimana	Taneatua Bridge	NSN2054	2861579	6340248	16	7091.0
Whakatane	Waimana East Flats	Waimana	Piripari	NSN0348	2869140	6325710	1	1946
Whakatane	Waimana East Flats	Parau	Side Road	NSN0349	2869720	6328400	1	12
Whakatane	Waimana East Flats	Waimana Trib.	Waimana Dairy Company	NSN0147	2866300	6331240	1	273
Whakatane	Waimana East Flats	Matatere	Bells Farm	NSN1753	2868590	6331310	1	18.96
Whakatane	Waimana East Flats	Waimana Trib.	U/S Waimana Confluence	NSN0350	2867080	6333270	1	3
Whakatane	Waimana East Flats	Raroa	Waimana Confluence	NSN0351	2865460	6331590	1	100
Whakatane	Waimana East Flats	Waimana	Whakatane Confluence	NSN0354	2860900	6340480	2	2419.5

APPENDIX 7 BASEFLOW DISCHARGE ESTIMATES CALCULATED WITH HISTORIC GAUGINGS AND MARCH 2010 GAUGINGS, RANGITAIKI PLAINS

Table A7.1 Rangitaiki Plains gaugings.

Major groundwater catchment	Groundwater catchment name	Groundwater catchment ID	Drain catchment	Drain unique ID	Drain area (km^2)	Measured Discharge, Median Historic Gaugings (l/s)	Specific Discharge, Median Of Historic Gaugings ($l/s/km^2$)	Estimated Discharge**** (l/s)	Measured Discharge, March 2010 Gaugings (l/s)	Specific Discharge, March 2010 Gaugings ($l/s/km^2$)
TARAWERA MAJOR SURFACE WATER CATCHMENTS										
Rangitaiki	Awaiti Canal	1	Other	87	54.82	5569*	101.59*	772	No measurable flow	No measurable flow
Rangitaiki	Awaiti Canal	1	Omeheu Canal	13	25.50	544	21.33	359		
Rangitaiki	Awaiti Canal	1	Omeheu Canal	112	25.01	346	13.83	352		
Rangitaiki	Awaiti Canal	1	Omeheu Canal	113	28.49	284	9.97	401		
Rangitaiki	Awaiti Canal	1	Omeheu Canal	86	10.13	68	6.71	143		
Rangitaiki	Awaiti Canal	1	Greater Catchment	95	87.96	496	5.33	1238		
Rangitaiki	Awaiti Canal	1	Section 109	9	4.11	No observation	N/A	58		
Rangitaiki	Awaiti Canal	1	Awaiti Canal	10	6.62	No observation	N/A	93		
Rangitaiki	Awaiti Canal	1	Awaiti Canal	15	21.16	No observation	N/A	298	No measurable flow	No measurable flow
Rangitaiki	Awaiti Canal	1	Other	91	0.89	No observation	N/A	13		
Rangitaiki	Awaiti Canal	1	Other	92	1.06	No observation	N/A	15		
	Mean Subtotals						**11.50**			
Tarawera	Awakaponga	2	Awakaponga	19	1.40	No observation	N/A	20		
Tarawera	Awakaponga	2	Awakaponga	20	9.53	No observation	N/A	134		
Tarawera	Awakaponga	2	Awakaponga	21	0.55	No observation	N/A	8		
Tarawera	Awakaponga	2	Awakaponga	22	2.95	No observation	N/A	42		
Tarawera	Awakaponga	2	Wilson	59	17.05	No observation	N/A	240		
Tarawera	Awakaponga	2	Awakaponga	64	0.08	No observation	N/A	1		
Tarawera	Awakaponga	2	Greater Catchment	104	30.16	No observation	N/A	425		
Tarawera	Awakaponga	2	Awarua	17	5.93	No observation	N/A	83		
	Mean Subtotals						**N/A**			
Tarawera	Mangaone Stream	8	Above Mangawiki Confluence	27	13.52	1018	75.30	190		
Tarawera	Mangaone Stream	8	Greater Catchment	107	43.46	1630	37.51	612		
Tarawera	Mangaone Stream	8	Mangaone above Braemar Bridge	106	37.66	1336	35.47	530	1402	37.2
	Mean Subtotals						**49.43**			
Tarawera	Matata	11	Greater Catchment	18	6.60	No observation	N/A	93		
	Mean Subtotals						**N/A**			
Rangitaiki	Old Rangitaiki Canal	14	Seacombes Canal	2	0.99	No observation	N/A	14		
Rangitaiki	Old Rangitaiki Canal	14	Old Rangitaiki Canal	3	3.06	No observation	N/A	43		
Rangitaiki	Old Rangitaiki Canal	14	Old Rangitaiki Canal	4	0.90	No observation	N/A	13		
Rangitaiki	Old Rangitaiki Canal	14	Old Rangitaiki Canal	5	0.49	No observation	N/A	7		
Rangitaiki	Old Rangitaiki Canal	14	Old Rangitaiki Canal	7	1.68	No observation	N/A	24		
Rangitaiki	Old Rangitaiki Canal	14	Old Rangitaiki Canal	8	3.46	No observation	N/A	49		
Rangitaiki	Old Rangitaiki Canal	14	Old Rangitaiki Canal	51	0.80	No observation	N/A	11		
Rangitaiki	Old Rangitaiki Canal	14	Seacombes Canal	70	2.13	No observation	N/A	30		
Rangitaiki	Old Rangitaiki Canal	14	Robinsons	1	3.06	No observation	N/A	43		

Major groundwater catchment	Groundwater catchment name	Groundwater catchment ID	Drain catchment	Drain unique ID	Drain area (km^2)	Measured Discharge, Median Historic Gaugings (l/s)	Specific Discharge, Median Of Historic Gaugings (l/s/km^2)	Estimated Discharge**** (l/s)	Measured Discharge, March 2010 Gaugings (l/s)	Specific Discharge, March 2010 Gaugings (l/s/km^2)
Rangitaiki	Old Rangitaiki Canal	14	Greig Road Drain	6	7.49	No observation	N/A	105		
Rangitaiki	Old Rangitaiki Canal	14	Greater Catchment	94	24.06	No observation	N/A	339	No measurable flow	No measurable flow
	Mean Subtotals						**N/A**			
Tarawera	Tumarau	23	Greater Catchment	23	6.76	No observation	N/A	95		
	Mean Subtotals						**N/A**			
Tarawera	Tumurenui	24	Greater Catchment	28	5.87	No observation	N/A	83		
	Mean Subtotals						**N/A**			
Tarawera	Waikamihi Stream	27	Greater Catchment	60	20.84	No observation	N/A	293		
	Mean Subtotals						**N/A**			
DUNES MAJOR SURFACE WATER CATCHMENTS										
All Dunes	Tarawera, Whakatane, and Rangitaiki Dunes	20, 34, 17	All Dunes	105	10.31	No observation	N/A	145		
	Mean Subtotals						**N/A**			
RANGITAIKI MAJOR SURFACE WATER CATCHMENTS										
Rangitaiki	Edgecumbe Catchwater	3	Greater Catchment	93	30.92	No observation	N/A	435	67.9	2.2
	Mean Subtotals						**N/A**			
Rangitaiki	Ngakauroa Stream	12	Greater Catchment	68	26.89	71.5	2.66	379	67.9	2.53
	Mean Subtotals						**2.66**			
Rangitaiki	Nursery Drain	13	Greater Catchment	35	3.87	No observation	N/A	54		
	Mean Subtotals						**N/A**			
Rangitaiki	Reids Central Canal	18	Reids Central Canal	32	6.72	27	4.02	95		
Rangitaiki	Reids Central Canal	18	Western Drain	69	5.64	2.7	0.48	79		
Rangitaiki	Reids Central Canal	18	Western Drain	84	7.70	0.7	0.09	108	6.9	0.8957
Rangitaiki	Reids Central Canal	18	Massey Catchment	31	8.52	No observation	N/A	120		
Rangitaiki	Reids Central Canal	18	Reids Central Canal	32	20.28	No observation	N/A	286		
Rangitaiki	Reids Central Canal	18	Reids Central Canal Lower	36	0.99	No observation	N/A	14		
Rangitaiki	Reids Central Canal	18	Kopeopeo Wests Canal	43	1.06	No observation	N/A	15		
Rangitaiki	Reids Central Canal	18	Greater Catchment	97	45.29	No observation	N/A	638		
	Mean Subtotals						**1.53**			
WHAKATANE MAJOR SURFACE WATER CATCHMENTS										
Rangitaiki	Te Rahu 1	21	Te Rahu Canal	111	10.46	13	1.24	147		
Rangitaiki	Te Rahu 1	21	Te Rahu Canal	108	8.29	17.7	2.14	117		
Rangitaiki	Te Rahu 1	21	Te Rahu Canal	89	20.13	42.5	2.11	283		
	Mean Subtotals						**2.59****			
Whakatane	Te Rahu 2	22	Fortunes	48	4.31	No observation	N/A	61		
Whakatane	Te Rahu 2	22	Te Rahu Canal	109	9.02	No observation	N/A	127		
Whakatane	Te Rahu 2	22	Te Rahu Canal	80	4.47	No observation	N/A	63		
			Te Rahu Canal	110	29.14	142	4.87	410	223	7.65
	Mean Subtotals						**2.59****			
Rangitaiki	Kope Orini 1	4	Greater Catchment	83	25.20	379	15.04	355	No measurable flow	No measurable flow

Major groundwater catchment	Groundwater catchment name	Groundwater catchment ID	Drain catchment	Drain unique ID	Drain area (km^2)	Measured Discharge, Median Historic Gaugings (l/s)	Specific Discharge, Median Of Historic Gaugings (l/s/km^2)	Estimated Discharge**** (l/s)	Measured Discharge, March 2010 Gaugings (l/s)	Specific Discharge, March 2010 Gaugings (l/s/km^2)
Rangitaiki	Kope Orini 1	4	Kopeopeo East Canal	44	2.13	No observation	N/A	30		
Rangitaiki	Kope Orini 1	4	Kopeopeo East Canal	45	1.83	No observation	N/A	26		
Rangitaiki	Kope Orini 1	4	Kopeopeo East Canal	47	0.73	No observation	N/A	10		
Rangitaiki	Kope Orini 1	4	Kopeopeo East Canal	49	13.29	No observation	N/A	187		
Rangitaiki	Kope Orini 1	4	Kopeopeo East Canal	56	3.72	No observation	N/A	52		
	Mean Subtotals						**15.04*** **			
Rangitaiki	Kope Orini 2	5	Orini Canal	42	0.20	No observation	N/A	3		
Rangitaiki	Kope Orini 2	5	Orini Canal	53	1.33	No observation	N/A	19		
	Mean Subtotals						**15.04*** **			
Whakatane	Kope Orini 3	6	Kopeopeo East Canal	30	0.17	No observation	N/A	2		
Whakatane	Kope Orini 3	6	Kopeopeo East Canal	33	0.59	No observation	N/A	8		
Whakatane	Kope Orini 3	6	Kopeopeo East Canal	34	0.74	No observation	N/A	10		
Whakatane	Kope Orini 3	6	Kopeopeo East Canal	37	1.48	No observation	N/A	21		
Whakatane	Kope Orini 3	6	Orini Canal	39	6.49	No observation	N/A	91		
Whakatane	Kope Orini 3	6	Orini Canal	40	0.73	No observation	N/A	10		
Whakatane	Kope Orini 3	6	Orini Canal	41	0.57	No observation	N/A	8		
Whakatane	Kope Orini 3	6	Orini Canal	52	4.30	No observation	N/A	61		
Whakatane	Kope Orini 3	6	Kopeopeo East Canal	66	0.57	No observation	N/A	8		
Whakatane	Kope Orini 3	6	Orini Canal	82	13.62	No observation	N/A	192		
	Mean Subtotals						**15.04*** **			
Whakatane	Waioho Canal	33	Government Drain No1 East	76	64.31	1274	19.81	905		
Whakatane	Waioho Canal	33	Government Drain No1 East	75	57.67	1060	18.38	812		
Whakatane	Waioho Canal	33	Government Drain No1 East	38	10.22	183	17.90	144		
Whakatane	Waioho Canal	33	Greater Catchment	74	111.56	1847	16.56	1571		
Whakatane	Waioho Canal	33	Government Drain No1 East	77	89.07	882	9.90	1254	278.8	3.13
Whakatane	Waioho Canal	33	Government Drain No1 East	78	94.47	263	2.78	1330		
Whakatane	Waioho Canal	33	Te Rahu Canal	55	11.80	No observation	N/A	166		
Whakatane	Waioho Canal	33	Pearsons Drain	71	5.29	No observation	N/A	74		
	Mean Subtotals						**14.22**			
Whakatane	Whakatane East	35	Other	99	39.63	No observation	N/A	558		
Whakatane	Whakatane East	35	Wainuitewhara Stream	100	5.89	No observation	N/A	83		
Whakatane	Whakatane East	35	Greater Catchment	101	45.52	No observation	N/A	641		
	Mean Subtotals						**N/A**			
	Mean (l/s/km^2)						**14.08**			**8.94**

* Not used in mean median value calculation.

** Mean median value for all gauging on the entire catchment feeding the Te Rahu Canal system.

*** Mean median value for all gauging on the entire catchment feeding the Kope Orini Canal system.

**** Estimated discharge (l/s) = drain area (km^2) * mean specific discharge (14.08 l/s/km^2).

APPENDIX 8 PUMPED CATCHMENTS, RANGITAIKI PLAINS

Table A8.1 Discharge per catchment area from pumped catchments, Rangitaiki Plains.

Pump number	Scheme name	Groundwater catchment	Pump station	Area km^2	KWH month	Pump operating hrs/month	Estimated operating days	Min discharge rating (m^3/min)	Max discharge rating (m^3/min)	Mean flow l/s	Mean flow m^3/year	Mean specific discharge l/s/km^2
M19	Riverslea Road	Awaiti Canal	Poplar Lane	0.55	430	72.9	3	5.4	6.6	100	314847.5	181.5
M30	Omeheu East	Awaiti Canal	Omeheu East	4.35	1213.5	54.4	2.3	19	35	450	1057867.3	103.5
M37	Thompson-Ernest	Awaiti Canal	Thompson Earnest	6.62	4882.5	131.3	5.5	30	45	625	3543750	94.4
M42	Omeheu Adjunct	Awaiti Canal	Omeheu Adjunct	3.85	2673	89.1	3.7					
M43	Omeheu West	Awaiti Canal	Omeheu West	0.98	512.5	46.6	1.9					
Subtotals		**Awaiti Canal**								**391.7**		**126.5**
M26	Mexted-Withy	Awakaponga	Mexted Withy	2.95	2408.5	108	4.5	16	31	391.7	1827435.9	132.6
M39	Withys	Awakaponga	Withy	1.86	1647.5	88.6	3.7	12	24	300	1147935.5	161.3
Subtotals		**Awakaponga**								**345.8**		**146.9**
M10	Angle Road	Kope Orini 1	Angle Road	2.39	1134	51.5	2.1	18	35	441.7	983487.3	185.0
M14	Foubister	Kope Orini 1	Foubister	2.13	26.5	1.2	0.1	15	29	366.7	19080	172.2
M24	Martins	Kope Orini 1	Martins	0.73	643	14.6	0.6		28.8	480	303028.4	654.7
M28	Nicholas (Wainani)	Kope Orini 1	Nicholas	3.72	2057	108.3	4.5	7	14	175	818469.5	47.0
M40	Wyld	Kope Orini 1	Wylds	1.83	575	13.1	0.5		25.5	425	239931.8	231.7
Subtotals		**Kope Orini 1**								**377.7**		**258.1**
M12a	Awakeri Farms (East)	Kope Orini 3	Awakeri Farms East	2.66	605.5	32.6	1.4	15	29	366.7	515651.6	137.6
M13	Baird-Miller	Kope Orini 3	Baird Miller	1.64	163	8.8	0.4	30	55	708.3	269610.8	432.5
Subtotals		**Kope Orini 3**								**537.5**		**285.1**
M11	Awaiti West	Old Rangitaiki Canal	Awaiti West	4.9	4246.5	71.3	3	50	75	1041.7	3206250	212.5
M15	Gordon	Old Rangitaiki Canal	Gordons	0.9	2182.5	145.5	6.1	12	24	300	1885680	333.3
M16	Greig Road	Old Rangitaiki Canal	Greigs Road	7.49	5259	70.6	2.9	35	60	791.7	2414198.7	105.7
M18a	Hyland-Baillie (Mexted)	Old Rangitaiki Canal	Mexted	0.49				8	14	183.3		
M18b	Hyland-Baillie (Vierboom)	Old Rangitaiki Canal	Vierboom	3.46	3383.5	225.6	9.4	12	24	300	2923344	86.7
M21	Lawrence	Old Rangitaiki Canal	Lawrence	0.78	1812	205.9	8.6					
M35	Robins Road	Old Rangitaiki Canal	Robins Road	1.68	1462.5	26.1	1.1	30	47	641.7	723937.5	381.2
M36	Robinson's	Old Rangitaiki Canal	Robinsons	0.89								
M44	Awaiti East	Old Rangitaiki Canal	Awaiti East	1.37	2971	135	5.6					
Subtotals		**Old Rangitaiki Canal**								**543.1**		**223.9**
M17	Halls	Reids Central Canal	Halls	2.38	1687.5	76.7	3.2	18	31	408.3	1353068.2	171.7
M20	Kuhanui (Martin)	Reids Central Canal	None	0.81	400.5	26.7	1.1	12	18	250	288360	309.8
M25	Massy Drain (All)	Reids Central Canal	FoxMcfarlandVierboom	5.73	1910	102.4	4.3					
M29	Noord-Vierboom	Reids Central Canal	Noord Vierboom	1.16	458	24.6	1	7	14	175	186154.8	150.6
M32	Pedersen - Van den Top	Reids Central Canal	Pedersen Top	1.15	1085	58.3	2.4	13	19.5	270.8	682500	235.6
M33a	Platts (Grants)	Reids Central Canal	Platts Grants	2.79	156	10.4	0.4	13.5	25.5	325	146016	116.3
M33b	Platts (Powers)	Reids Central Canal	Platts Powers	1.06	2153.5	79.8	3.3	22.8	36	490	1688344	460.3
M34	Reynolds	Reids Central Canal	Reynolds	1.28	1126.5	51.2	2.1	13.5	25.5	325	718911.8	254.7
Subtotals		**Reids Central Canal**								**320.6**		**242.7**
M23	Luxton Valley	Te Rahu 1	None	2.13	915	20.8	0.9		28.8	480	431214.5	224.9
Subtotals		**Te Rahu 1**								**480**		**224.9**
M38	Travurzas	Te Rahu 2	Travursas	2.19	658	35.4	1.5	15.5	28.5	366.7	560361.3	167.5
Subtotals		**Te Rahu 2**								**366.7**		**167.5**

Note: Median values have been calculated from data electricity use data captured between March 2006 and February 2010.

Mean discharge (Q) per month has been calculated as follows (Median Pumping Hours x Mean Discharge).

Discharge estimates have only been calculated fro those pumps for which rating curves could be obtained and could be matched with an appropriate location and catchment area.

Table A8.2 Estimates of discharge from major river catchments on the Rangitaiki Plains using pump data and comparison with rainfall and AET.

Major river catchment	Inflow: rainfall million m^3/yr	Outflow: AET million m^3/yr	Inflow: rainfall minus AET million m^3/yr	Discharge from pumped catchments million m^3/yr
Tarawera	322.13	177.97	144.16	1326.54
Rangitaiki	172.79	64.12	108.67	846.43
Whakatane	489.63	193.38	296.25	2238.05
Coastal Dunes	12.56	9.28	3.28	71.53
Total (m^3/s)	**31.62**	**14.1**	**17.52**	**142.14**
Total (million m^3/year)	**997.11**	**444.75**	**552.36**	**4482.54**

APPENDIX 9 CONSENTED ALLOCATION AND ESTIMATES OF ACTUAL USE

Table A9.1 Surface water, groundwater, and geothermal allocation in the study area as at December 2009.

Information from consent database											Allocated water use				Estimated use (m^3/year)
Consent number	Consent status (January 2010)	Issue date	Expiry date	Location		Groundwater catchment	Well consent file	Main purpose	Water resource		Frost (m^3/d)	Irrig (m^3/d)	Other (m^3/d)	Max rate (l/s)	
				Easting	Northing				TYPE_CODE3	Description					
20634-1	C		1/10/2026	2839184	6350818	Awaiti Canal		Domestic	SUC	Surface Water	0	0	130		47450
21703-0	C		1/10/2026	2847524	6354353	Awaiti Canal	3349	Frost	SUC	Surface Water	0	135	0		20925
62039-0	C	21/01/2009	30/04/2013	2839160	6350620	Awaiti Canal		Irrigation	SUC	Surface Water	0	8820	0	130	1367100
65136-0	C	3/06/2008	30/11/2017	2844540	6350880	Awaiti Canal		Irrigation	SUC	Surface Water	0	175			27125
63142-0	C	10/06/2008	31/05/2015	2836637	6343950	Awaiti Canal		Irrigation	SUC	Surface Water	0	5660	0		877300
63324-0	C	10/06/2008	30/09/2015	2838849	6349486	Awaiti Canal		Irrigation	SUC	Surface Water	0	6250	0		968750
21852-0	C		1/10/2026	2847168	6354865	Awaiti Canal		Irrigation	SUC	Surface Water	0	82	0		12710
65076-0	C	15/05/2008	31/03/2018	2844200	6356800	Awaiti Canal		Irrigation	SUC	Surface Water	0	172			26660
65077-0	C	15/05/2008	31/03/2018	2844400	6356700	Awaiti Canal		Irrigation	SUC	Surface Water	0	700			108500
64967-0	C	30/05/2008	31/01/2028	2843580	6344460	Awaiti Canal		Irrigation	SUC	Surface Water	1800	650	0		154750
21923-0	C		1/10/2026	2846252	6350273	Awaiti Canal		Irrigation	SUC	Surface Water	0	164	0		25420
65515-0	C	20/03/2009	28/02/2019	2844800	6347200	Awaiti Canal		Irrigation	SUC	Surface Water	991	238	0		66620
20634-2	C		1/10/2026	2839184	6350818	Awaiti Canal		Irrigation	SUC	Surface Water	0	130	0		20150
65467-0	C	19/08/2008	31/08/2018	2838310	6346470	Awaiti Canal		Irrigation	SUC	Surface Water	0	6653	0		1031215
61975-0	C	27/06/2003	30/04/2023	2843580	6344460	Awaiti Canal		Irrigation	SUC	Surface Water	650	130	0		39650
61410-0	C	7/01/2002	31/10/2012	2841440	6355960	Awaiti Canal		Irrigation & Frost	SUC	Surface Water	0	4320	0		669600
61896-0	C	27/03/2003	31/01/2013	2838870	6352610	Awaiti Canal		Other	SUC	Surface Water	0	4664			722920
62264-0	C	30/01/2004	30/11/2013	2843236	6354988	Awaiti Canal		Other	SUC	Surface Water	0	7000			1085000
20595-2	C		1/10/2026	2838825	6347845	Awaiti Canal	394, 922, 932	Frost	UNC	Ground Water	1580	158	0	44	71890
20983-2	C		1/10/2026	2844879	6350311	Awaiti Canal	1029	Irrigation & Frost	UNC	Ground Water	360	108	0	25	27540
20874-0	C		1/10/2026	2840714	6348896	Awaiti Canal	2509	Frost	UNC	Ground Water	0	400	0	4.6	62000
63380-0	C	19/04/2006	31/03/2016	2839001	6347999	Awaiti Canal	2511, 2510	Irrigation	UNC	Ground Water	0	0	5200	60	1898000
63339-0	C	22/12/2005	31/10/2020	2840649	6349101	Awaiti Canal	10945	Irrigation	UNC	Ground Water	0	720	0	25	111600
62814-0	C	15/11/2005	30/09/2014	2840280	6351531	Awaiti Canal		Frost	UNC	Ground Water	2700	2160	0	75	415800
20595-1	C		1/10/2026	2838822	6347845	Awaiti Canal	394, 922, 932	Frost	UNC	Ground Water	1580	158	0	0	71890
64299-0	C	5/03/2007	31/10/2021	2842060	6347980	Awaiti Canal	2988	Irrigation	UNC	Ground Water	1200	500	0	34	113500
63681-0	C	8/08/2006	31/05/2021	2842626	6344607	Awaiti Canal		Irrigation	UNC	Ground Water	907	302	0	0	74020
63342-0	C	22/02/2006	31/10/2020	2839140	6346523	Awaiti Canal		Irrigation	UNC	Ground Water	778	272	0	18	65500
62892-0	C	31/07/2007	31/10/2014	2842247	6344603	Awaiti Canal		Irrigation	UNC	Ground Water	648	325	0	0	69815
20983-1	C		1/10/2026	2844879	6350311	Awaiti Canal	532	Irrigation	UNC	Ground Water	360	108	0	0	27540
20607-0	C		1/10/2026	2844597	6350437	Awaiti Canal	2715	Frost	UNC	Ground Water	0	136	0	1.58	21080
65399-0	C	23/07/2008	30/06/2018	2842530	6353510	Awaiti Canal	11209	Irrigation	UNC	Ground Water	0	1770	0	0	274350
65514-0	C	10/10/2008	31/08/2018	2841160	6346720	Awaiti Canal	11211	Irrigation	UNC	Ground Water	0	910	0	18	141050
65816-0	C	26/08/2009	31/07/2019	2842100	6348400	Awaiti Canal	11216	Irrigation	UNC	Ground Water	0	8640	0	100	1339200
20358-0	C		1/10/2026	2840571	6345588	Awaiti Canal	1034, 2068, 4929	Irrigation	UNC	Ground Water	0	100	0		15500
61363-0	C	19/10/2001	30/09/2011	2839800	6352300	Awaiti Canal	4991	Irrigation	UNC	Ground Water	0	2787	0		431985
66018-0	C	8/02/2010	30/06/2020	2840840	6349410	Awaiti Canal	4964	Irrigation	UNC	Ground Water	0	2905	0		450275
60515-0	C	17/04/2002	30/06/2010	2840840	6349410	Awaiti Canal	4964	Domestic	UNC	Ground Water	0	0	2905		1060325
21197-0	C		1/10/2026	2847132	6354642	Awaiti Canal	906	Irrigation	UNC	Ground Water	0	117	0		18135
61721-0	C	14/11/2002	30/09/2022	2839300	6350840	Awaiti Canal	2541	Irrigation	UNC	Ground Water	480	790	0		136850
20981-1	C	26/04/2006	1/10/2026	2843102	6350058	Awaiti Canal	528, 527, 3584	Frost	UNC	Ground Water	675	300	0		66750
20984-1	C		1/10/2026	2843079	6350221	Awaiti Canal	529	Irrigation	UNC	Ground Water	286	86.4	0		21972
20984-2	C		1/10/2026	2843079	6350228	Awaiti Canal	4824	Irrigation	UNC	Ground Water	286	86.4	0		21972
62421-0	C	9/10/2006	31/01/2014	2844900	6354650	Awaiti Canal	10572	Irrigation	UNC	Ground Water	280	144	0		30720
62258-0	C	22/10/2003	30/09/2018	2840850	6350630	Awaiti Canal	934	Irrigation	UNC	Ground Water	0	1728	0		267840

Information from consent database											Allocated water use				Estimated use (m^3/year)
Consent number	Consent status (January 2010)	Issue date	Expiry date	Location		Groundwater catchment	Well consent file	Main purpose	Water resource		Frost (m^3/d)	Irrig (m^3/d)	Other (m^3/d)	Max rate (l/s)	
				Easting	Northing				TYPE_CODE3	Description					
21207-0	C		1/10/2026	2840422	6346161	Awaiti Canal	4201	Irrigation	UNC	Ground Water	0	100	0		15500
20981-2	C		1/10/2026	2843106	6350058	Awaiti Canal	527, 528, 3584	Other	UNC	Ground Water	675	300			66750
63212-0	C	5/10/2005	31/07/2020	2845201	6355404	Awaiti Canal	10992	Irrigation	UNC	Ground Water	7200	864	0		349920
20981-1	C	26/04/2006	1/10/2026	2843083	6350079	Awaiti Canal	528, 527, 3584	Frost	UNC	Ground Water	675	300	0		66750
21584-0	C		1/10/2026	2841143	6350832	Awaiti Canal	374	Irrigation	UNC	Ground Water	230	230	0		42550
21620-1	C	30/05/2007	1/10/2026	2839472	6349604	Awaiti Canal	938, 936, 937	Irrigation	UNC	Ground Water	800	150	0		47250
21607-0	C	13/03/1985	1/10/2026	2840551	6349577	Awaiti Canal	935, 2053, 2515	Irrigation	UNC	Ground Water	250	750	0		123750
20280-0	C		1/10/2026	2838509	6356707	Awakaponga		Domestic	SUC	Surface Water	0	0	495		180675
20359-3	C		1/10/2026	2838724	6357412	Awakaponga		Irrigation	SUC	Surface Water	0	182	0		28210
21217-1	C		1/10/2026	2838585	6356711	Awakaponga		Irrigation	SUC	Surface Water	0	0	518.4		189216
20671-0	C		1/10/2026	2838576	6355581	Awakaponga		Irrigation	SUC	Surface Water	0	250	0		38750
20854-1	C		1/10/2026	2841256	6359872	Awakaponga		Irrigation	SUC	Surface Water	0	760	0		117800
20977-1	C	14/02/2007	1/10/2026	2841061	6359239	Awakaponga		Irrigation	SUC	Surface Water	504	580	0		105020
20416-1	C		1/10/2026	2841309	6355907	Awakaponga		Other	SUC	Surface Water	0	0	517		188705
20017-0	C		1/10/2026	2839623	6353978	Awakaponga	38	Domestic	UNC	Ground Water	0	0	1136		414640
20853-0	C		1/10/2026	2841431	6359663	Awakaponga	4370	Irrigation	UNC	Ground Water	0	380	0		58900
20857-0	C		1/10/2026	2841833	6360502	Awakaponga	454, 351	Irrigation	UNC	Ground Water	0	156	0		24180
65486-0	C	6/05/2009	31/08/2018	2841100	6359600	Awakaponga		Irrigation	UNC	Ground Water	0	397	0		61535
65895-0	C	9/12/2009	31/01/2020	2843300	6342840	Edgecumbe Catchwater	10491	Irrigation	UNC	Ground Water	0	150	0		23250
62541-0	C	3/05/2004	28/02/2019	2840290	6343019	Edgecumbe Catchwater		Irrigation	UNC	Ground Water	0	5184	0		803520
20119-1	C		1/10/2026	2855315	6353398	Kope Orini 1	4394	Other	UNC	Ground Water	0	0	14.1	0.61	5146.5
63336-0	C	1/12/2006	31/08/2020	2850174	6350131	Kope Orini 1		Irrigation & Frost	UNC	Ground Water	1872	1872	0	0	346320
63302-0	C	7/11/2005	31/08/2020	2851630	6350740	Kope Orini 1		Irrigation & Frost	UNC	Ground Water	720	240	0	16.7	58800
62831-0	C	13/12/2004	30/09/2014	2849398	6349680	Kope Orini 1	10443, 11688	Irrigation & Frost	UNC	Ground Water	160	432	0		71760
62649-0	C	8/10/2004	31/08/2014	2851480	6350793	Kope Orini 1	11192	Other	UNC	Ground Water	0	6500			1007500
65328-0	C	13/05/2008	31/05/2018	2854090	6352680	Kope Orini 1		Irrigation	UNC	Ground Water	0	250	0		38750
62969-0	C	29/03/2005	31/12/2014	2852824	6350831	Kope Orini 1		Irrigation	UNC	Ground Water	0	2203	0		341465
20803-0	C		1/10/2026	2853991	6351339	Kope Orini 1	2079	Irrigation & Frost	UNC	Ground Water	0	227	0		35185
21242-0	C		1/10/2026	2852169	6351367	Kope Orini 1	901, 550	Irrigation & Frost	UNC	Ground Water	0	114	0		17670
62036-0	C	16/08/2006	31/10/2013	2849728	6349594	Kope Orini 1	11698	Domestic	UNC	Ground Water	540	210	0		48750
21646-0	C		1/10/2026	2850983	6352231	Kope Orini 1	2514	Irrigation	UNC	Ground Water	0	280	0		43400
20015-1	C		1/10/2026	2858488	6352933	Kope Orini 3		Other	SUC	Surface Water	0	0	56454	654	20605710
21961-0	C		1/10/2026	2856484	6355939	Kope Orini 3	1326	Domestic	UNC	Ground Water	0	0	82	3	29930
21953-0	C		1/10/2026	2857758	6354471	Kope Orini 3	4317	Irrigation	UNC	Ground Water	0	140	0		21700
64943-0	C	12/11/2007	31/07/2022	2844735	6336588	Mangamako area		Municipal	UNC	Ground Water			50	4	18250
20914-3	C		1/10/2026	2836400	6347594	Mangaone Stream		Domestic	SUC	Surface Water	1560	156	0		70980
21164-0	C		1/10/2026	2832906	6344703	Mangaone Stream		Irrigation	SUC	Surface Water	0	130	0		20150
62221-0	C	30/09/2003	31/07/2013	2836878	6346960	Mangaone Stream		Irrigation & Frost	SUC	Surface Water	612	225	0	0	53235
20325-4	C		1/10/2026	2836723	6348905	Mangaone Stream		Irrigation & Frost	SUC	Surface Water	0	0	27.3		9964.5
20914-1	C		1/10/2026	2836400	6347594	Mangaone Stream		Irrigation & Frost	SUC	Surface Water	1560	156	0		70980
20914-2	C		1/10/2026	2836400	6347594	Mangaone Stream		Irrigation & Frost	SUC	Surface Water	1560	156	0		70980
60927-0	C	15/01/2001	31/10/2015	2835950	6347190	Mangaone Stream		Irrigation & Frost	SUC	Surface Water	0	1988	0		308140
24434-0	C	22/04/1996	31/03/2016	2834855	6348465	Mangaone Stream		Other	SUC	Surface Water	0	0	69120		25228800
63177-0	C	5/10/2005	30/06/2020	2845296	6346058	Ngakauroa Stream		Irrigation	SUC	Surface Water	2880	2880	0		532800
20597-0	C		1/10/2026	2846324	6346017	Ngakauroa Stream		Irrigation & Frost	SUC	Surface Water	0	364	0	0	56420
20632-0	C		1/10/2026	2846486	6346050	Ngakauroa Stream		Irrigation & Frost	SUC	Surface Water	0	26	0	0	4030
62725-0	C	17/11/2004	30/09/2014	2846375	6344003	Ngakauroa Stream		Irrigation & Frost	SUC	Surface Water	0	204	0		31620
65183-0	C	30/11/2009	31/10/2019	2846670	6345280	Ngakauroa Stream	10762	Irrigation	UNC	Ground Water	3000	620	0	83.3	186100

Information from consent database											Allocated water use				Estimated use (m^3/year)
Consent number	**Consent status (January 2010)**	**Issue date**	**Expiry date**	**Location**		**Groundwater catchment**	**Well consent file**	**Main purpose**	**Water resource**		**Frost (m^3/d)**	**Irrig (m^3/d)**	**Other (m^3/d)**	**Max rate (l/s)**	
				Easting	**Northing**				**TYPE_CODE3**	**Description**					
65525-0	C	4/12/2008	30/11/2018	2846910	6345590	Ngakauroa Stream	11213	Irrigation & Frost	UNC	Ground Water	1800	250	0	42	92750
62848-0	C	13/12/2004	30/09/2014	2846499	6345449	Ngakauroa Stream	11215	Irrigation	UNC	Ground Water	1152	173	0	32	61375
21512-0	C		1/10/2026	2845203	6340938	Ngakauroa Stream	1605	Irrigation	UNC	Ground Water	0	635	0	7.6	98425
21910-0	C		1/10/2026	2845956	6343335	Ngakauroa Stream	492	Irrigation	UNC	Ground Water	0	110	0	1.27	17050
65990-0	C	10/02/2010	31/01/2020	2846150	6345170	Ngakauroa Stream	11690	Irrigation	UNC	Ground Water	225	225	0		41625
65708-0	C	20/04/2009	31/03/2019	2846840	6344260	Ngakauroa Stream		Irrigation	UNC	Ground Water	241	145	0		29705
62079-0	C	14/07/2003	31/07/2013	2845900	6342900	Ngakauroa Stream	2759	Irrigation	UNC	Ground Water	0	550	0		85250
65882-0	C	15/10/2009	30/09/2019	2846790	6345390	Ngakauroa Stream		Irrigation & Frost	UNC	Ground Water	720	200	0		52600
20890-0	C		1/10/2026	2847072	6345855	Ngakauroa Stream	4252	Irrigation & Frost	UNC	Ground Water	0	108	0		16740
21328-0	C		1/10/2026	2846454	6344629	Ngakauroa Stream	2763, 905	Irrigation & Frost	UNC	Ground Water	0	182	0		28210
62520-0	C	5/10/2005	31/07/2015	2846170	6345050	Ngakauroa Stream	10821	Irrigation & Frost	UNC	Ground Water	576	216	0		50760
62755-0	C	11/02/2005	31/07/2014	2846691	6345841	Ngakauroa Stream	10371	Irrigation	UNC	Ground Water	0	240	0		37200
21964-0	C	8/12/2000	1/10/2026	2845677	6342261	Ngakauroa Stream	2711	Irrigation	UNC	Ground Water	0	1128	0		174840
64725-0	C	30/05/2007	30/04/2017	2844711	6342535	Ngakauroa Stream		Irrigation	UNC	Ground Water	0	700	0		108500
62328-0	C	20/11/2003	31/10/2013	2846720	6345280	Ngakauroa Stream	4672	Irrigation	UNC	Ground Water	0	1011	0		156705
21438-0	C		1/10/2026	2846824	6345268	Ngakauroa Stream	2540, 2544	Irrigation & Frost	UNC	Ground Water	0	150	0		23250
21451-0	C		1/10/2026	2847045	6344957	Ngakauroa Stream	939	Irrigation & Frost	UNC	Ground Water	0	1200	0		186000
63201-0	C	5/10/2005	31/05/2015	2846635	6344704	Ngakauroa Stream	10896	Irrigation	UNC	Ground Water	1300	300	0		85500
63316-0	C	16/06/2008	31/10/2020	2846800	6345770	Ngakauroa Stream	11188	Irrigation	UNC	Ground Water	864	2100	0		351420
62566-0	C	5/08/2004	30/06/2014	2844689	6345583	Nursery Drain		Irrigation	SUC	Surface Water	800	600	0		117000
20967-0	C		1/10/2026	2844761	6345627	Nursery Drain		Irrigation & Frost	SUC	Surface Water	0	749	0		116095
65096-0	C	3/06/2008	31/01/2018	2844780	6343870	Nursery Drain		Irrigation	UNC	Ground Water	0	353	0	7	54715
64397-0	C	23/04/2007	31/12/2021	2845050	6343340	Nursery Drain	10763	Irrigation	UNC	Ground Water	3000	2340	0		452700
64397-0	C	23/04/2007	31/12/2021	2845050	6343340	Nursery Drain	10763	Irrigation	UNC	Ground Water	750	600	0		115500
21686-0	C		1/10/2026	2844827	6344806	Nursery Drain	1109	Irrigation & Frost	UNC	Ground Water	0	3500	0		542500
21063-0	C		1/10/2026	2847618	6354814	Old Rangitaiki Canal		Irrigation	SUC	Surface Water	2000	208	0	0	92240
21224-0	C		1/10/2026	2847403	6355432	Old Rangitaiki Canal		Irrigation	SUC	Surface Water	0	1800	0	0	279000
65252-0	C	3/06/2008	30/04/2023	2844500	6358260	Old Rangitaiki Canal		Irrigation	SUC	Surface Water	0	0	4752		1734480
20056-0	C		1/10/2026	2848010	6358993	Old Rangitaiki Canal	2803	Other	UNC	Ground Water	0	0	73		26645
20696-1	C		1/10/2026	2861027	6340150	Oromoeroa Hills		Industry	SUC	Surface Water			909	31.6	331785
20146-0	C		1/10/2026	2860358	6335745	Oromoeroa Hills		Dairy Shed	UNC	Ground Water			27.3	1.29	9965
61412-0	C	7/01/2002	30/11/2011	2860420	6329340	Oromoeroa Hills		Irrigation	UNC	Ground Water				25	3875
62627-0	C	5/08/2004	30/09/2019	2859870	6328470	Oromoeroa Hills		Municipal	UNC	Ground Water			500	8	182500
20069-0	C	29/10/2001	1/10/2026	2856152	6356382	Rangitaiki Dunes	829, 547 , 10873	Irrigation	UNC	Ground Water	0	750	0		116250
62000-0	C	3/11/2003	30/06/2023	2846627	6351230	Reids Central Canal		Irrigation	SUC	Surface Water	0	30000	0	900	4650000
65821-0	C	5/10/2009	31/10/2019	2845160	6346760	Reids Central Canal		Irrigation	SUC	Surface Water	0	6500	0		1007500
21008-0	C		1/10/2026	2849060	6356441	Reids Central Canal		Irrigation	SUC	Surface Water	0	50	0		7750
65632-0	C	27/02/2009	31/01/2019	2848680	6352930	Reids Central Canal		Irrigation	SUC	Surface Water	0	1800	0		279000
65632-0	C	27/02/2009	31/01/2019	2848680	6352500	Reids Central Canal		Irrigation & Frost	SUC	Surface Water	0	1800	0		279000
65632-0	C	27/02/2009	31/01/2019	2848270	6353150	Reids Central Canal		Irrigation & Frost	SUC	Surface Water	0	1800	0		279000
63211-0	C	5/10/2005	31/07/2020	2849903	6351505	Reids Central Canal	10993	Irrigation & Frost	UNC	Ground Water	4104	1197	0	95	308655
21206-1	C		1/10/2026	2847619	6347902	Reids Central Canal	4836	Irrigation & Frost	UNC	Ground Water	2000	208	0	0	92240
63285-0	C	7/11/2005	31/08/2020	2849941	6350597	Reids Central Canal		Irrigation & Frost	UNC	Ground Water	1800	500	0	41	131500
60905-0	C	7/06/2001	30/04/2011	2849550	6350750	Reids Central Canal	10011	Irrigation	UNC	Ground Water	252	252	0		46620
21828-0	C		1/10/2026	2848234	6348441	Reids Central Canal	482	Irrigation & Frost	UNC	Ground Water	0	105	0		16275
20556-1	C		1/10/2026	2849382	6351270	Reids Central Canal	466	Other	UNC	Ground Water	0	136			21080
63416-0	C	19/04/2006	31/12/2020	2848059	6348194	Reids Central Canal		Irrigation & Frost	UNC	Ground Water	0	180	0		27900
21206-2	C		1/10/2026	2847619	6347895	Reids Central Canal	4128	Irrigation & Frost	UNC	Ground Water	2000	208	0		92240

Information from consent database											Allocated water use				Estimated use (m^3/year)
Consent number	Consent status (January 2010)	Issue date	Expiry date	Location		Groundwater catchment	Well consent file	Main purpose	Water resource		Frost (m^3/d)	Irrig (m^3/d)	Other (m^3/d)	Max rate (l/s)	
				Easting	Northing				TYPE_CODE3	Description					
65227-0	C	7/08/2009	31/05/2018	2847330	6347424	Reids Central Canal	1187	Irrigation & Frost	UNC	Ground Water	675	186	0		49080
20709-0	C		1/10/2026	2853175	6356653	Reids Central Canal	3371	Irrigation	UNC	Ground Water	0	54.5	0		8447.5
20880-0	C		1/10/2026	2848500	6349503	Reids Central Canal	503	Irrigation	UNC	Ground Water	0	140	0		21700
21263-0	C		1/10/2026	2849740	6351443	Reids Central Canal	4543	Irrigation	UNC	Ground Water	0	50	0		7750
60590-0	C	30/09/2002	31/12/2012	2849350	6350990	Reids Central Canal		Irrigation	UNC	Ground Water	396	396	0		73260
61679-0	C	10/06/2008	31/08/2017	2847101	6348899	Reids Central Canal		Irrigation	UNC	Ground Water	0	4320	0		669600
20884-0	C		1/10/2026	2848200	6349698	Reids Central Canal	502	Irrigation	UNC	Ground Water	300	180	0		36900
20581-1	C		1/10/2026	2848002	6347993	Reids Central Canal	814	Irrigation	UNC	Ground Water	0	150	0		23250
20950-0	C		1/10/2026	2847567	6347172	Reids Central Canal	538	Irrigation	UNC	Ground Water	0	109	0		16895
61700-0	C	17/04/2003	31/07/2022	2853210	6356690	Reids Central Canal		Irrigation	UNC	Ground Water	0	2400	0		372000
61562-0	C	4/04/2003	31/03/2022	2851400	6356500	Reids Central Canal	4872	Domestic	UNC	Ground Water	0	0	3888		1419120
20068-0	C		1/10/2026	2854426	6356209	Reids Central Canal	4524	Other	UNC	Ground Water	0	0	500		182500
63038-0	C	22/12/2005	30/09/2020	2849219	6350158	Reids Central Canal	10890	Irrigation	UNC	Ground Water	504	441	0		83475
23294-0	C	30/09/1991	29/09/2016	2837096	6342693	Rotoroa		Geothermal	UNG	Geothermal			182	5.31	66430
23294-0	C	30/09/1991	29/09/2016	2837098	6342690	Rotoroa		Geothermal	UNG	Geothermal			182	5.31	66430
23294-0	C	30/09/1991	29/09/2016	2837100	6342692	Rotoroa		Geothermal	UNG	Geothermal			182	5.31	66430
23294-0	C	30/09/1991	29/09/2016	2837114	6342695	Rotoroa		Geothermal	UNG	Geothermal			182	5.31	66430
23294-0	C	30/09/1991	29/09/2016	2837100	6342700	Rotoroa		Geothermal	UNG	Geothermal			182	5.31	66430
23294-0	C	30/09/1991	29/09/2016	2837100	6342692	Rotoroa		Geothermal	UNG	Geothermal			182	5.31	66430
23294-0	C	30/09/1991	29/09/2016	2837100	6342703	Rotoroa		Geothermal	UNG	Geothermal			182	5.31	66430
24710-0	C	4/05/2010	31/10/2012	2837115	6342647	Rotoroa		Geothermal	UNG	Geothermal			5280	61.11	1927200
61645-0	C	20/02/2003	30/06/2022	2849350	6347920	Te Rahu 1		Geothermal	UNG	Geothermal			440	5	160600
21239-0	C		1/10/2026	2852161	6349022	Te Rahu 1		Irrigation & Frost	SUC	Surface Water	0	340	0		52700
20228-1	C		1/10/2026	2848493	6346595	Te Rahu 1		Other	SUC	Surface Water	0	0	22.5		8212.5
21942-0	C	20/04/2001	1/10/2026	2857880	6351690	Te Rahu 2	729	Domestic	UNC	Ground Water	0	0	360	8.33	131400
61082-0	C	8/05/2001	31/03/2011	2857510	6351470	Te Rahu 2	2560	Irrigation	UNC	Ground Water	0	672	0	8	104160
21863-0	C		1/10/2026	2858104	6351287	Te Rahu 2	919	Irrigation	UNC	Ground Water	0	100	0		15500
21862-0	C		1/10/2026	2858047	6351226	Te Rahu 2	921	Irrigation & Frost	UNC	Ground Water	0	100	0		15500
65457-0	C	19/08/2008	31/08/2018	2855560	6351020	Te Rahu 2	10447	Irrigation	UNC	Ground Water	0	115	0		17825
20995-0	C		1/10/2026	2857044	6352224	Te Rahu 2	508	Irrigation	UNC	Ground Water	0	135	0		20925
65023-0	C	1/09/2009	31/07/2019	2837700	6349700	Tumarau		Irrigation	SUC	Surface Water	0	6200	0	72	961000
65196-0	C	3/06/2008	31/01/2018	2838940	6350970	Tumarau		Irrigation	SUC	Surface Water	0	3600	0		558000
64913-0	C	30/05/2008	31/03/2018	2837700	6345200	Tumurenui		Irrigation	SUC	Surface Water	0	6400	0		992000
21124-0	C		1/10/2026	2837597	6345530	Tumurenui	4641	Irrigation	UNC	Ground Water	0	275	0	6.37	42625
21195-0	C		1/10/2026	2836703	6346671	Tumurenui	944, 541	Irrigation	UNC	Ground Water	0	109			16895
20843-1	C		1/10/2026	2836075	6338486	Upper Tarawera		Domestic	SUC	Surface Water			40	2.5	14600
61351-0	C	16/11/2001	30/06/2012	2834950	6337800	Upper Tarawera		Irrigation	SUC	Surface Water				40	535680
65254-0	C	27/05/2009	30/04/2019	2830840	6336570	Upper Tarawera		Irrigation	SUC	Surface Water		3715		43	575856
61344-0	C	31/10/2001	30/04/2012	2835200	6337100	Upper Tarawera		Municipal	SUC	Surface Water			20736	240	7568640
24226-0	C	7/11/2005	31/12/2012	2836000	6340916	Upper Tarawera		Other	SUC	Surface Water			190000	2540	69350000
61328-0	C	4/05/2010	30/09/2011	2835700	6340400	Upper Tarawera		Other	SUC	Surface Water			10000	116	3650000
20237-0	C		1/10/2026	2834212	6338896	Upper Tarawera		Irrigation	UNC	Ground Water				3.8	589
20329-0	C		1/10/2026	2834727	6337610	Upper Tarawera		Municipal	UNC	Ground Water			12000	152	4380000
21821-0	C		1/10/2026	2834639	6338499	Upper Tarawera		Irrigation	UNC	Ground Water				3	465
24598-0	C	18/12/2009	30/09/2030	2836606	6341818	Upper Tarawera		Geothermal	UNG	Geothermal			53280	Unknown	19447200
20094-0	C		1/10/2026	2838752	6352574	Waikamihi Stream	4724	Domestic	UNC	Ground Water	0	0	9730		3551450
65038-0	C	8/02/2008	31/01/2018	2838300	6355020	Waikamihi Stream		Domestic	UNC	Ground Water	0	0	840		306600
20906-0	R			2835900	6341000	Waikanapiti		Industry	SUC	Surface Water			182000	5300	66430000

Information from consent database											Allocated water use				Estimated use (m^3/year)
Consent number	Consent status (January 2010)	Issue date	Expiry date	Location		Groundwater catchment	Well consent file	Main purpose	Water resource		Frost (m^3/d)	Irrig (m^3/d)	Other (m^3/d)	Max rate (l/s)	
				Easting	Northing				TYPE_CODE3	Description					
21989-1	C	14/12/1999	1/10/2026	2835931	6340918	Waikanapiti		Industry	SUC	Surface Water			27100	878	9891500
61352-0	C	16/11/2001	30/06/2012	2834510	6339750	Waikanapiti		Irrigation	SUC	Surface Water				20	267840
65254-0	C	27/05/2009	30/04/2019	2834740	6340210	Waikanapiti		Irrigation	SUC	Surface Water		2479		28.7	384245
20464-0	C		1/10/2026	2833388	6339318	Waikanapiti		Irrigation	UNC	Ground Water				3	465
61350-0	C	19/10/2001	30/06/2012	2833090	6338910	Waikanapiti		Irrigation	UNC	Ground Water		270		15	2325
20340-1	C	26/04/2006	1/10/2026	2834901	6340223	Waikanapiti		Geothermal	UNG	Geothermal			682	(8.34)	248930
23571-0	W			2836200	6341500	Waikanapiti		Geothermal	UNG	Geothermal					0
24953-0	C	25/01/2002	30/11/2011	2834660	6339360	Waikanapiti		Geothermal	UNG	Geothermal			300	(3.47)	109500
65622-0	C	9/03/2009	28/02/2019	2843700	6340900	Waikowhewhe area		Domestic	UNC	Ground Water	0	0	1920		700800
20283-0	C		1/10/2026	2867804	6331422	Waimana Hills		Municipal	UNC	Ground Water			200	3.9	73000
21044-0	C		1/10/2026	2863327	6339684	Waimana Hills		Municipal	UNC	Ground Water			805	12	293825
64869-0	C	30/06/2008	30/04/2018	2868100	6331100	Waimana Hills		Irrigation & Frost	UNC	Ground Water		1280		22.22	3444
65193-0	C	30/05/2008	30/04/2018	2868100	6331100	Waimana Hills		Irrigation	UNC	Ground Water		2568		29.7	4604
21578-0	C		1/10/2026	2856475	6347344	Waioho Canal		Irrigation	SUC	Surface Water	0	109	0		16895
21234-0	C	16/07/2003	1/10/2026	2857009	6348096	Waioho Canal		Irrigation	SUC	Surface Water	2880	550	0		171650
62765-0	C	5/10/2005	31/07/2015	2856978	6348101	Waioho Canal		Other	SUC	Surface Water	2880	550	0		171650
20742-0	C		1/10/2026	2859822	6350209	Waioho Canal	2549, 2080	Irrigation	UNC	Ground Water	0	81.8	0	0	12679
21428-0	C		1/10/2026	2856783	6347581	Waioho Canal	4544	Irrigation	UNC	Ground Water	0	80	0		12400
21517-0	C		1/10/2026	2857437	6350482	Waioho Canal	710	Irrigation	UNC	Ground Water	0	55			8525
20198-1	C	28/01/2010	1/10/2026	2860295	6350004	Whakatane East		Domestic	SUC	Surface Water	0	0	20000		7300000
62744-0	C	4/07/2005	30/04/2020	2859890	6349270	Whakatane East		Irrigation & Frost	SUC	Surface Water	5830	972			325560
20125-1	C	13/02/2004	1/10/2026	2860983	6343155	Whakatane East	4699, 10006	Other	UNC	Ground Water	0	0	120		43800
20223-0	C		1/10/2026	2860476	6352611	Whakatane East	4726	Irrigation	UNC	Ground Water	0	82	0		12710
20691-0	C		1/10/2026	2860830	6342970	Whakatane East	18, 825	Irrigation	UNC	Ground Water		127.2	0		19716
20876-1	C		1/10/2026	2861679	6341335	Whakatane East	4768, 1250	Other	UNC	Ground Water			500		182500
21496-0	C		1/10/2026	2861521	6341217	Whakatane East	4769	Other	UNC	Ground Water			500		182500
65028-0	C	30/05/2008	31/10/2023	2854700	6335600	Whakatane West Hills		Other	UNC	Ground Water			151		55115
														TOTAL	**284733054**

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