Assessment of the Waimarino Plains Water Supply

A. Lovett
N. Deligne
K. Clark
R. van der Raaij
Z. Rawlinson

GNS Science Consultancy Report 2014/99
July 2014

DISCLAIMER

This report has been prepared by the Institute of Geological and Nuclear Sciences Limited (GNS Science) exclusively for and under contract to Ruapehu District Council. Unless otherwise agreed in writing by GNS Science, GNS Science accepts no responsibility for any use of, or reliance on any contents of this Report by any person other than Ruapehu District Council and shall not be liable to any person other than Ruapehu District Council, on any ground, for any loss, damage or expense arising from such use or reliance.

The data presented in this Report are available to GNS Science for other use from September 2014.

BIBLIOGRAPHIC REFERENCE

Lovett, A.; Deligne, N.; Clark, K.; van der Raaij, R.; Rawlinson, Z. 2014. Assessment of the Waimarino Plains Water Supply, *GNS Science Consultancy Report* 2014/99. 62 p

CONTENTS

FIGURES

TABLES

APPENDICES

APPENDIX FIGURES

APPENDIX TABLES

EXECUTIVE SUMMARY

Ruapehu District Council (RDC) is considering long term options for municipal water supplies to Raetihi and Ohakune. Issues with the current Raetihi supply include an aging pipeline network, a decline in water quality from diesel contamination, and increased suspended sediment. In comparison, there are no known issues with the current Ohakune supply. RDC want to comprehensively consider the best option for maintaining or developing the water supply, particularly as the area is prone to geological events (e.g. volcanic and seismic) and associated risks. RDC are seeking information on water quality, water quantity, supply security, and risk of source and infrastructure to volcanic and seismic hazards upon which to make an informed decision.

Present water supplies for Raetihi and Ohakune townships are obtained from surface water intakes in the Makotuku River and Serpentine (Tutara) Stream, respectively. Water from each intake is piped to water treatment plants (WTP) and onwards to the towns. Previous reports evaluated long term water supply options in the Waimarino Plains, but paid little attention to potential groundwater well sources, or to the potential risks to these supplies (Opus, 2001; United Water, 2010). Therefore, RDC engaged GNS Science to: 1) assess the feasibility and security of surface-, spring-, and ground- water for municipal supply to Raetihi and Ohakune townships; 2) identify the volcanic and seismic risks associated with each water resource option; and, 3) provide recommendations for additional work associated with Tasks 1 and 2 including estimated cost and timeframe.

Surface-, spring-, and ground- water supply sources are all viable options for RDC to consider. Surface water supplies obtained from catchments on Mt Ruapehu are currently of sufficient quantity to meet demand. Water quality issues with the Raetihi supply include hydrocarbon contamination and increased suspended sediment concentration, whereas there are no known water quality issues with the Ohakune supply. For the Raetihi supply, further work on tracing of sediment to identify source, and mitigation measures to minimise sediment and hydrocarbon pollutant sources are required.

Springs located on the lower south-west slopes of Mt Ruapehu are likely to provide sufficient water quantity (3,326 m^3 day^{-1}); however flow rates require verification to determine long-term and seasonal viability. The spring source is distant from the townships, which necessitates extensive infrastructure (piping networks) over or around active faults. Appropriate engineered solutions (e.g. flexible piping) at faults should be considered. If the spring source option is to be pursued a monitoring program of spring water quality and age is essential to determine the suitability and security of this supply.

Knowledge of groundwater resources in the Waimarino Plains is still very limited; however, a local aquifer has been identified that may be of sufficient water quality and quantity for the Raetihi township. Existing information about the aquifer and its groundwater is restricted to one-off testing at one well (733003). Additional monitoring of water quality and age at this well is required to provide more certainty of groundwater suitability and supply. If results of the monitoring are favourable, drilling of an exploratory groundwater well is recommended. Appropriate sampling for geology, groundwater chemistry and age, and hydraulic testing is strongly recommended during the drilling of the exploratory well. Based on the finding from the exploratory well, a decision can be made on the viability for installation of a municipal supply well for Raetihi.

The Waimarino Plains is located in a geologically active region, and is therefore prone to volcanic hazards from the local Taupo Volcanic Zone and seismic hazards from three sets of

active faults. Surface water sources (rivers, streams and springs) are the most at risk, as supply sources are located on or close to an active volcano and within drainage channels in which re-mobilised ash may travel. In addition, streams and associated water treatment plants are vulnerable to ash fall hazards. Of additional concern is that the current Raetihi and Ohakune WTP’s are located on, or within the 150 m buffer zone of active faults.

A groundwater supply source for the Waimarino Plains is recommended to be the most secure, and at least risk from volcanic and seismic events. Key advantages of a groundwater source are that the supply can be located close to the townships, which minimises infrastructure requirements. Also, treatment of the groundwater may not be required if the source aquifer is deemed to be secure from land surface derived contamination and has appropriate water chemistry. However, a seismic event can damage well casing and infrastructure; although these effects can be considerably reduced by appropriate well location and construction.

For each of the potential supply options, particularly spring- and ground- water, more detailed work is required to gain a better understanding of water quality and/or quantity. This understanding is required to make an informed decision on which supply is likely to be the most suitable in terms of chemistry, treatment requirements, security from land surface activities and processes. Also further consideration needs to be given to the location of active faults with particular focus on the location of current infrastructure (e.g. WTP’s) and the location of planned infrastructure and mitigation measures (e.g. pipeline networks, well locations).

1.0 INTRODUCTION

Ruapehu District Council (RDC) has a statutory requirement to maintain provision of water services to the local community. Currently, RDC are considering long term options for upgrading town water supplies to Raetihi and Ohakune townships in the Waimarino Plains. One of the key reasons for assessing potential future water supply options is associated with the security of the current surface water supply. The present water supply for Raetihi is obtained via a gravity intake in the Makotuku River at Tohunga Junction, approximately 10 km north-east of Raetihi. The water supply for Ohakune is obtained from Serpentine (Tutara) Stream, a tributary of the Mangawhero River, located 4 km north of Ohakune. Water from each intake source is piped to respective water treatment plants (WTP) and onwards to the town supply.

At present, there are three primary issues associated with the current Waimarino Plains water supply, all of which could lead to potential supply interruption or failure. Firstly, the existing Raetihi AC piping network, installed in the 1970's, has experienced several breakages and therefore leaks. If the current supply source is the preferred long term option, it may require replacement at a high capital cost to RDC. Secondly, source security issues were raised in October 2013 when a diesel spill (15,000 – 19,000 L) at Turoa ski field infiltrated into the Makotuku Stream. The spill forced a shutdown of the Raetihi water supply for 21 days. The effects of the spill were still evident in January 2014, including elevated hydrocarbon levels following rainfall events. Furthermore, the current raw water quality is reported to be variable, with increased turbidity after rainfall events. It is possible that landuse in the catchment is influencing the water quality. Finally, the Waimarino Plains is located within a geologically active region, with primary hazards originating from volcanic eruptions and earthquakes. Both of these hazards can pose threats to the security of the water resources, and need to be considered when selecting long term supply options.

RDC has previously contracted consultants including Opus (2001) and United Water (2010) to evaluate long term water supply options in the Waimarino Plains. The reports reviewed raw source water options, current and future water demand, legislative requirements, water treatment and supply networks. These reports focused on raw sources from surface- and spring- water sources, but paid little attention to potential groundwater well sources. Therefore, RDC are seeking a comprehensive preliminary assessment by GNS Science on the feasibility and security of surface-, spring-, or ground- water for municipal supply to Raetihi and Ohakune townships. In addition, RDC have requested an assessment of the risks (e.g. volcanic and seismic risks) associated with each water resource. The assessment is a desktop study that reviews all relevant information, and provides recommendations and costs for additional work.

The findings of this assessment are presented in this report in three primary sections. The first task was to provide a summary of available information on water quality and water quantity regarding potential spring-, surface- and ground- water resources. All potential information sources were searched and the findings have been presented in Section 2. The second task was to identify the potential volcanic and seismic risks to the respective water sources, with consideration of the suitability of each water source as a long term supply (Section 3). The findings of the final task are presented in Section 4, including identification of information gaps and recommendation of future work. A summary of approximate costs and time frames for completion of work is also provided.

1.1 STUDY AREA

The Waimarino Plains are located at the south-western base of Mt Ruapehu between elevations of approximately 500 – 800 metres above sea level (ASL) (Figure 1.1). The two primary townships on the plains are Ohakune and Raetihi, with several smaller settlements including Rangataua and Horipito. Historically, the economy in the region was driven by railway line construction, timber milling and small scale market gardening. Currently, the economy in the region is driven by tourism (particularly during the winter) and larger scale farming on the plains. Ohakune and Raetihi towns have a usual resident population (URP) of approximately 1,100 each, and over time it is expected that these numbers will remain static or slowly decline (United Water, 2010). Due to the proximity to Mt. Ruapehu ski fields, population numbers in the region can increase considerably during the winter season. Therefore, peak daily populations for Ohakune and Raetihi are considerably higher than the URP, and have been estimated to be 4,700 and 1,500 respectively (United Water, 2010). However, in contrast to the URP, these numbers are predicted to rise in the future to 6,900 and 2,200, respectively (United Water, 2010). RDC currently own and operate two main water supplies in the Waimarino Plains region, which serve the towns of Ohakune and Raetihi (Figure 1.1).

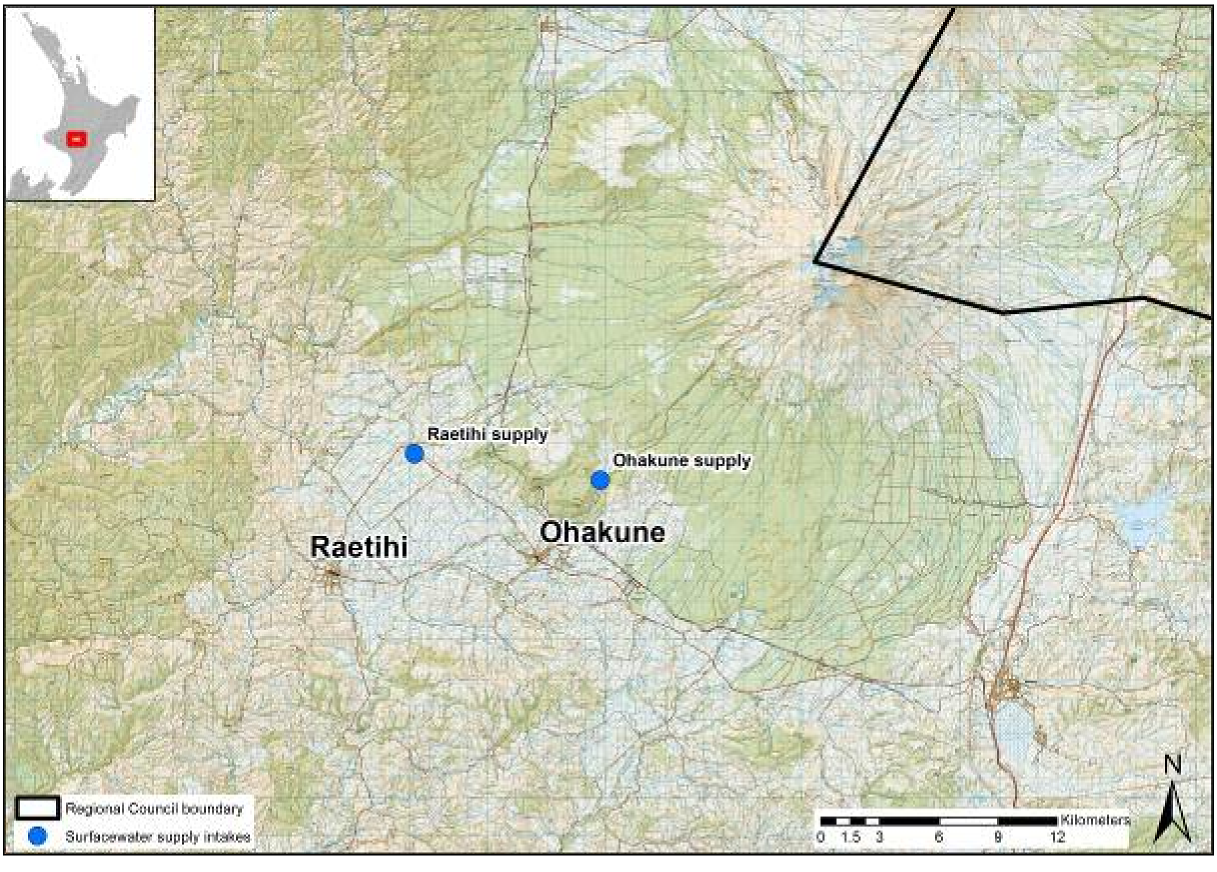


Figure 1.1: Location map of the Waimarino Plains including the towns of Raetihi and Ohakune, and location of the respective surface water supply intakes.

1.1.1 Ohakune supply

The current water supply to Ohakune township is sourced from the Serpentine (Tutara) Stream, a tributary of the Mangawhero River (Figure 1.1). RDC abstracts up to 2,500 m^3 day^{-1} at a rate no greater than 29 L sec^{-1} (104 m^3 hr^{-1}) under water permit 101266 from Horizons Regional Council (United Water, 2010). Raw water is sourced from a weir, equipped with a debris trap, and piped through a gravity fed system of 200 – 225 mm diameter HDPE, PVC or AC water mains to the Ohakune Water Treatment Plant (WTP). Two 1,500 m^3 reservoirs are located at the WTP for the purpose of treated water storage. A comprehensive description of the WTP process following an upgrade in 2010 is presented in United Water (2010).

1.1.2 Raetihi supply

The current water supply to Raetihi is sourced from the Makotuku Stream near the SH49 bridge between Tahonga Junction and Ohakune (Figure 1.1). RDC abstracts up to 1,685 m^3 day^{-1} at streamflows >115 L sec^{-1}, and up to 820 m^3 day^{-1} at stream flows < 115 L sec^{-1}. Water is abstracted under permit 102068 from Horizons Regional Council (United Water, 2010, Horizons, 2014). The water supply intake is gravity fed and consists of a concrete weir and intake chamber from which water is piped 460 m to a grit trap and two settling ponds located 1 km south of the SH49 bridge. The settling ponds act in parallel to reduce turbidity from suspended sediment in the intake water. From the settling ponds, raw water is piped 6.9 km to the Raetihi WTP and Raetihi reservoir (900 m^3) located near Raetihi township. Rural water users are able to obtain settled, but untreated water from along this pipeline. A schematic and description of the current WTP process for Raetihi is provided in United Water (2010).

1.2 EXISTING INFORMATION

The following reports were supplied by Ruapehu District Council:

- Opus, 2001. Raetihi Water Supply. Opus International Consultants Limited, Hamilton
- United Water, 2010. Waimarino Water Supply Options Study. United Water International Pty Ltd, Papakura, 103 p.

A request was sent to Horizons Regional Council for surface water and groundwater information in the region. The following datasets were provided by Horizons (2014):

- Groundwater: locations of wells, bore logs, water quality and water quantity;
- Surface water: stream gauging and water quality;
- Terra Aqua Consultants Limited (TACL) 2013, Assessment of Environmental Effects of Taking Groundwater at 98 Harris Road, Raetihi.

GNS Science information sources were searched as part of this project:

- Tritium and Water Dating Laboratory database (no results);
- Active Faults database;
- New Zealand Petroleum and Minerals Database (Ministry of Economic development, 2014).

2.0 GEOLOGY AND HYDROLOGY

2.1 GEOLOGY

The Ruapehu area has been recently geologically mapped as part of two 1:250,000 scale QMAP sheets (Townsend *et al*., 2008; Lee *et al*., 2011). A simplified representation of this geological map is shown in Figure 2.1. The Waimarino Plains lie at the south-western termination of the Taupo Volcanic Zone (TVZ), an active volcanic arc. Around Ruapehu Volcano, the TVZ forms a NNE-SSW trending graben structure, with associated NNE-SSW trending faults. At the TVZ termination, the faulting regime changes to that of WNW-ESE to E-W trending faults, known as the Ohakune-Raetihi fault set (Villamor and Berryman, 2006). These faults exhibit normal faulting, a predominant dip to the south, and a lack of significant strike-slip motion (Villamor and Berryman, 2006a). To the north and east of Raetihi, the landscape is dominated by Quaternary (last 2 million years) volcanic deposits associated with active andesite volcanism at Ruapehu, Ngauruhoe and Tongariro Volcano's. To the south and west of Raetihi, marine sediments from the Tertiary period, particularly the Neogene Period (2 – 23 million years old), dominate. These marine sediments are associated with the South Wanganui Basin.

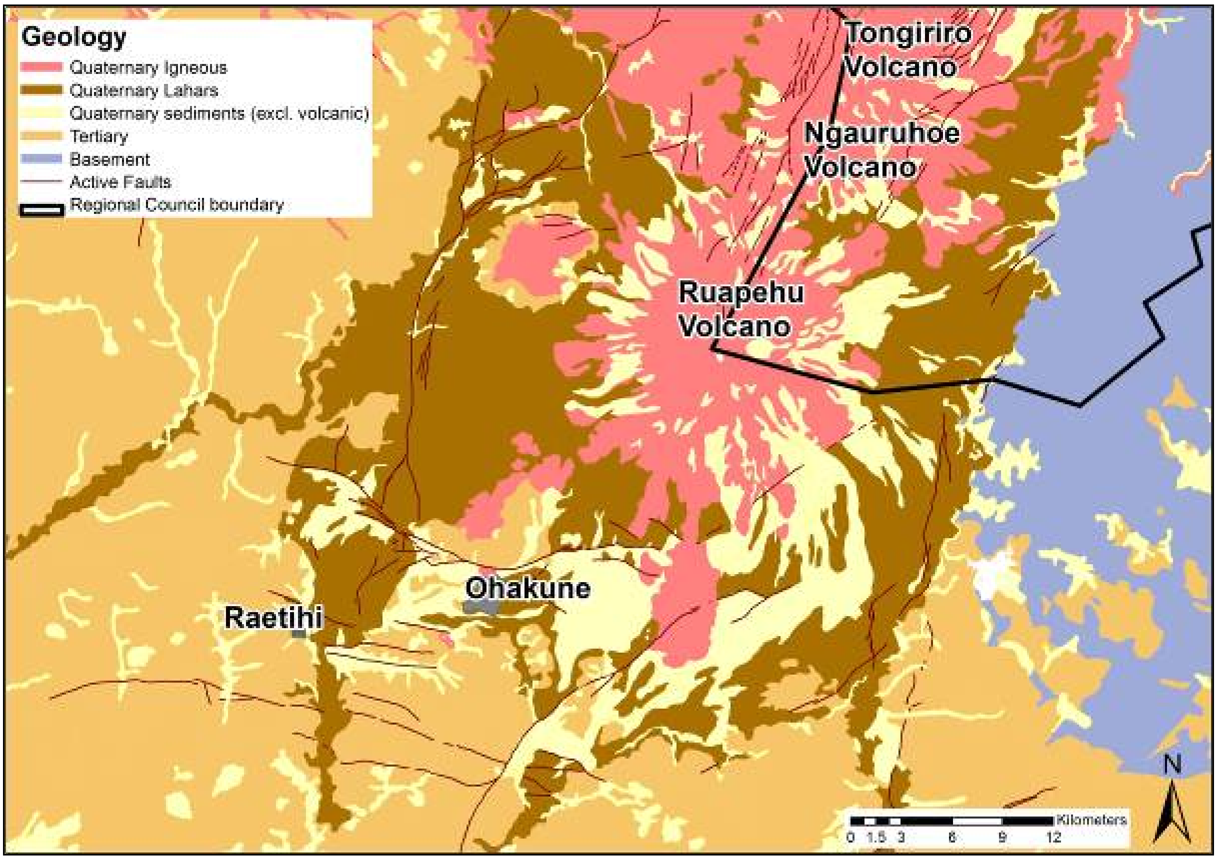


Figure 2.1: A simplified geological map of the Waimarino Plains. Active faults are from the GNS Science active fault database (http://data.gns.cri.nz/af/).

2.2 HYDROLOGY

A general overview of the hydrologic cycle operating in the area is useful to understand the availability and quality of water in the area. Precipitation (rainfall or snowfall) falls on Mt Ruapehu and the surrounding mountains. A proportion of this precipitation infiltrates the volcanic material through the forces of gravity to become groundwater. Another proportion of precipitation does not infiltrate the material, and flows into creeks, streams and rivers as surface water. The remaining proportion evaporates back into the atmosphere. If the geologic material is impervious or has a low porosity, the majority of rainfall will runoff this material and become surface water. However, in situations where materials have a higher porosity and are permeable, more of that water will infiltrate through the geology to the aquifer to form groundwater.

Surface water resources in the Waimarino Plains area are reasonably well documented, with comprehensive records of flow rate and water quality datasets maintained by Ruapehu District Council and Horizons Regional Council. In comparison, information held by local authorities on groundwater resources is more limited. The majority of information on springs in the area is maintained as local knowledge, and supplied by RDC.

2.2.1 Surface water

The primary surface water catchments considered for water supply by Opus (2001) are the Makotuku, Taonui and Mangawhero catchments. These catchments are located on the south-western slopes of Mount Ruapehu and are defined by a dendritic drainage system. These catchments are the closest in proximity to Raetihi and Ohakune, and are the current source of town supplies.

The Makotuku River catchment extends 19 km downslope from the Turoa ski-field carpark (1,800 m ASL) and covers an area of approximately 22 km^2 (Opus, 2001). Water is primarily sourced from rainfall. Land form and land use within the catchment includes scoria slopes, native forest and arable farmland. The Taonui Stream catchment is located immediately south and adjacent to the Makotuku Stream, and covers an area of 16 km^2 (Opus, 2001). Baseflow is predominantly from springs which emerge from approximately 760 – 780 m ASL, with additional surface water flow following precipitation events. The third primary surface water catchment in the area is the Mangawhero River which is located adjacent and immediately south of the Makotuku and Taonui stream catchments. The catchment covers an area of 67 km^2 and extends from above the Turoa skifield carpark (2,200 m ASL) downslope 16 km to SH49 (570 m ASL). Water for the Mangawhero Stream originates from spring and surface water sources.

2.2.1.1 Surface water quality

Water quality measurements have been made by RDC on two stream sites at Tahonga Junction over the period 4 October 2013 to 14 October 2013 (Table 2.1 and Table 2.2). The sites include Makara Stream and Taonui Stream, both of which have been identified as potential water supply sources for Raetihi and/or Ohakune (United Water, 2010). While these data sets are inadequate to properly assess either long-term or seasonal variability in water quality that might be expected for surface waters, the results are in general agreement with those reported earlier (United Water, 2010). All measured determinants except E.Coli are below the Maximum Acceptable Values (MAV’s) as specified in the Drinking Water Standards for New Zealand (DWSNZ:2005) by the Ministry of Health, 2008. Only iron and aluminium exceed Guideline Values (GV’s) for the DWSNZ (2005) in some instances. The iron and aluminium concentrations are not excessively high, and are likely to be reduced sufficiently by the recommended treatment processes.

Table 2.1: Water quality results for Makara Stream at Tohunga Junction 4/10/2013 – 14/10/2013

Test	Units	No. analysed	No. exceeded	Median	Minimum	Maximum	DWSNZ MAV or (GV)
E.coli enumerated	MPN/100 ml	7	7	36	15	2000	1
Total coliforms	MPN/100 ml	7	-	985	400	2400	-
Fluoride		2	0	-	<0.02	0.04	1.5
Ammoniacal-nitrogen	mg/L	5	0	<0.5	-	-	1.5
Chloride	mg/L	5	0	5.8	5.1	6	(250)
Conductivity	mS/m	7	-	8.7	6.3	11.1	-
Nitrate	mg/L as NO_3	5	0	2.3	1.2	2.5	50
Nitrite	mg/L as NO_2	5	0	<0.002	-	-	3
pH	pH unit	5	0	7.9	7.5	8.2	(7.0 – 8.5)
Sulphate	mg/L	5	0	7	4.6	7.7	(250)
Aluminium	mg/L	5	3	0.12	0.072	0.19	(0.1)
Antimony	mg/L	5	0	<0.001	-	-	0.02
Arsenic	mg/L	5	0	0.00019	0.00012	0.00021	0.01
Barium	mg/L	5	0	0.007	0.0048	0.01	0.7
Boron	mg/L	5	0	0.015	0.012	0.017	1.4
Cadmium	mg/L	5	0	<0.00005	-	-	0.004
Chromium	mg/L	5	0	0.00032	0.00026	0.00058	0.05
Copper	mg/L	5	0	0.00062	0.00028	0.0011	2 (1)
Iron	mg/L	7	3	0.15	0.071	0.96	(0.2)
Lead	mg/L	5	0	<0.0001	-	-	0.01
Manganese	mg/L	7	0	0.0094	0.0037	0.051	0.4 (0.04)
Mercury	mg/L	5	0	<0.00005	-	-	0.007
Molybdenum	mg/L	5	0	<0.0003	-	-	0.07
Nickel	mg/L	5	0	0.000185	0.00016	0.00021	0.08
Selenium	mg/L	5	0	<0.0005	-	-	0.01
Sodium	mg/L	5	0	5.8	4.9	7.1	(200)
Total Hardness as $CaCO_3$	mg/L	5	0	28	22	35	(200)
Uranium	mg/L	5	0	0.000013	0.000011	0.000016	0.02
Zinc	mg/L	5	0	<0.001	<0.001	0.0027	(1.5)

Table 2.2: Water quality results for Taonui Stream at Tohunga Junction, 4/10/2013 – 8/10/2013

Test	Units	No. analysed	No. exceeded	Median	Minimum	Maximum	DWSNZ MAV or (GV)
E.coli enumerated	MPN/100 ml	4	4	11.8	6.3	44	1
Total coliforms	MPN/100 ml	4	-	1035	720	2400	-
Ammoniacal nitrogen	mg/L	4	0	<0.4			1.5
Chloride	mg/L	4	0	5	4.9	6.1	(250)
Conductivity	mS/m	4	-	8.1	8	11	-
Nitrate	mg/L as NO_3	4	0	0.255	0.24	0.58	50
Nitrite	mg/L as NO_2	4	0	<0.002			3
pH	pH unit	4	0	7.85	7.8	8.2	(7.0 – 8.5)
Sulphate	mg/L	4	0	4.45	4.4	7.7	(250)
Aluminium	mg/L	4	1	0.0905	0.085	0.16	(0.1)
Antimony	mg/L	4	0	<0.001			0.02
Arsenic	mg/L	4	0	0.00026	0.00011	0.00032	0.01
Barium	mg/L	4	0	0.0051	0.0049	0.0067	0.7
Boron	mg/L	4	0	0.016	0.013	0.017	1.4
Cadmium	mg/L	4	0	<0.00005			0.004
Chromium	mg/L	4	0	0.000675	0.00027	0.0011	0.05
Copper	mg/L	4	0	0.00036	0.00034	0.00045	2 (1)
Iron	mg/L	4	0	0.074	0.069	0.16	(0.2)
Lead	mg/L	4	0	<0.0001			0.01
Manganese	mg/L	4	0	0.0038	0.0035	0.0082	0.4 (0.04)
Mercury	mg/L	4	0	<0.00005			0.007
Molybdenum	mg/L	4	0	<0.0003			0.07
Nickel	mg/L	4	0	<0.0001			0.08
Selenium	mg/L	4	0	<0.0005			0.01
Sodium	mg/L	4	0	6	5.5	6.7	(200)
Total Hardness (as $CaCO_3$)	mg/L	4	0	23.5	20	32	(200)
Uranium	mg/L	4	0	0.0000115	0.00001	0.000014	0.02
Zinc	mg/L	4	0	<0.001	<0.001	0.0011	(1.5)

Horizons Regional Council maintains a substantial number of surface water quality and quantity measurements within the study area (Watson, pers. comm, 2014). An initial request was placed with Horizons to obtain all these datasets for inclusion in this report. However, in conjunction with Horizons, a decision was made not to proceed with this request as: the time taken to extract the required information was substantial; and that further interpretation of these datasets was beyond to scope of this report. It was therefore decided that supplying these full datasets was not a good use of Horizons time. Datasets for water quality for Makotuku Stream and Mangawhero Stream were delivered. These datasets are not audited, and further interpretation was not undertaken.

2.2.2 Springs

Spring water can flow where groundwater appears at the surface, either as a gravity spring, artesian spring or depression spring (Brown, 1990). Water flow in a gravity spring occurs through cracks, fissures and porous material. In comparison, water from an artesian spring is forced under pressure from the aquifer through the geology to the surface. In comparison, depression springs emerge at points where the ground surface dips below the water table (Brown, 1990). It is well documented that spring flow rates can be highly variable both seasonally and annually, particularly in gravity and depression springs (Brown, 1990). In comparison, springs can maintain a relatively constant rate of flow, and constant rate springs are most often artesian. Artesian springs are often recharged from distant sources and maintained within confined aquifers.

Known springs within the study area have been located based on information supplied by RDC (Figure 2.2) (Westcott, pers. comm. 2014). Springs have been named in this report based on the primary tributary in which they flow into. For clarification, any previous documentation of the spring naming has been provided (Table 2.3).

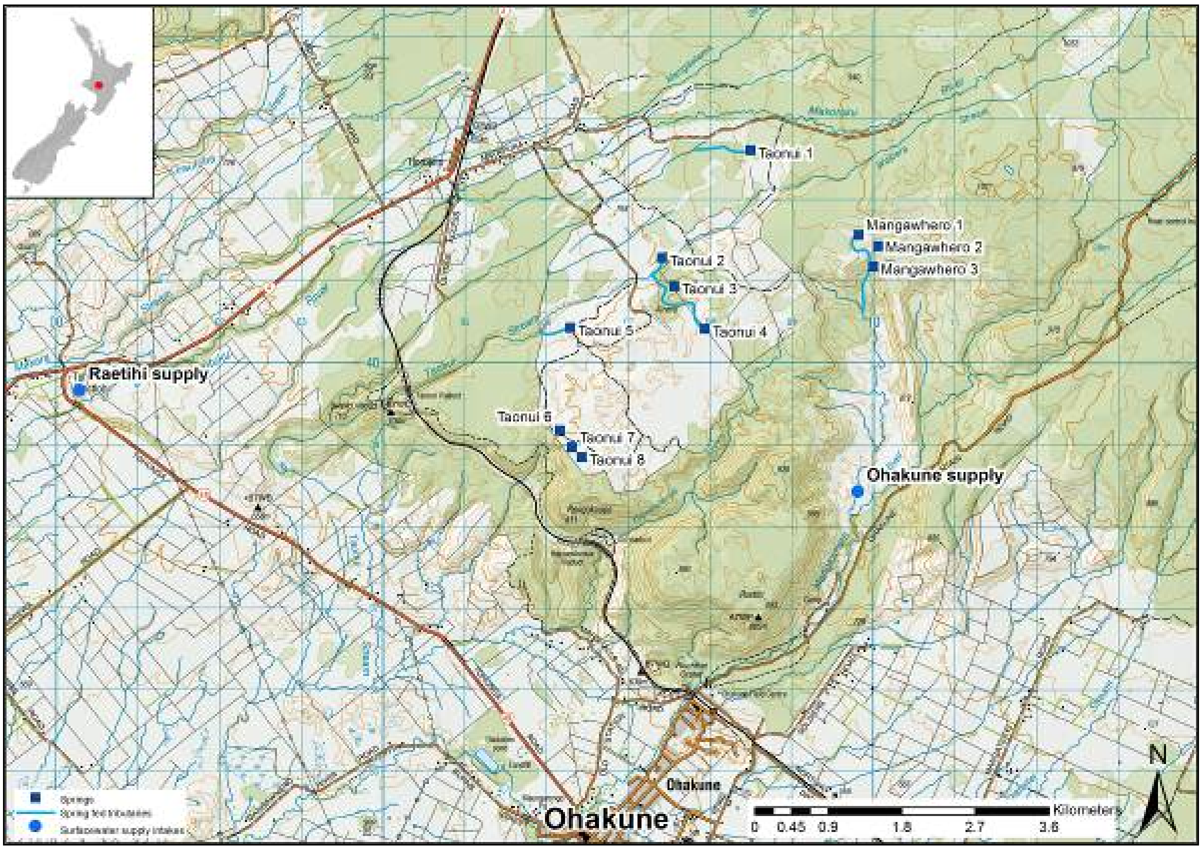


Figure 2.2: Location of documented springs in the upper catchments of the Taonui and Mangawhero Streams. (Westcott, personal communication 2014).

The Mangawhero River has three documented springs which emerge from the north of the stream and contribute to stream flow (Mangewhero 1, 2, and 3). There are no known datasets of spring flow rates or chemistry for these springs. There are 8 documented springs that occur within the upper Taonui Stream catchment. Several of these springs (Taonui 1, 2, 3, and 4) have previously been reported as Bishop's Spring, or variations of Bishop's Spring. These springs have been estimated to contribute 10,000 L day^{-1} to the Taonui Stream (Opus, 2001), although it is unknown how this value was generated. Two gauging measurements of Bishops Spring (Taonui 1) were conducted concurrently on the 25.06.1999, from 11:00 – 11:20 am, and from 11:30 – 11:50 am. Results indicated a measured flow rate of 38 L sec^{-1}

and 39 L sec^{-1} respectively (Opus, 2001), which is equivalent to 3,280 – 3,370 m^3 day^{-1}. There are no other known measurements of spring volume.

Table 2.3: Previously used names and available datasets for springs in the Taonui and Mangawhero catchment (Opus, 2001).

Spring name	Previous naming	Data
Taonui 1	Bishop’s Spring (Hariemarie Spring)	flow rate and chemistry
Taonui 2	Bishop’s Spring north of Waipara Stream	-
Taonui 3	Bishop’s Spring north of new lake	-
Taonui 4	Bishop’s Spring new lake	-

Water quality measurements of Bishops Spring were undertaken in 1991 and 1989, and are reported in Opus (2001). The analyses are limited to microorganism counts and basic chemistry (pH, alkalinity, major anions and major cations). No official laboratory report was presented, and the only results are documented on a communication record from Brent Bishop (Opus, 2001; Appendix 1). A more recent and official sample of the spring water is required to comment any further on suitability of the water quality.

2.2.3 Groundwater

The ability of volcanic material to store and transmit groundwater can vary considerably; however, many units of volcanic material have high water bearing potential (Fetter, 2001; Brown, 1990). Volcanic rocks are deposited in layers of materials based on the eruptive sequences of the region, and each layer represents the conditions of that eruptive episode. For example, deposits can include molten lava, semi-cooled rubble, air fall debris and water transported debris (Brown, 1990). Intrusions of volcanic rocks can also occur, when molten rock is forced upwards to the surface through existing volcanic and fluvial layers of sediment. Due to the variability of volcanic rocks, wells located within volcanic formations can screen a variety of different conditions. Water bearing conditions can include fractured and jointed zones or alternatively volcanic rubble with large pore spaces or porous rock. Therefore, there can be considerable variability in the productivity of well which penetrate volcanic aquifers. In areas which are more remote from the eruptive source, volcanic deposits such as lahars, ash, pumice and fluvial deposits can form river and floodplain aquifers. Overall, young volcanic rocks (deposited within the last 1 million years) such as those located within the Central North island region generally have the highest yielding aquifers (Brown, 1990).

2.2.3.1 Well locations

A search of the Horizons Regional Council database returned 19 wells within a 35 km radius of the Raetihi and Ohakune towns (Figure 2.3). These wells are generally grouped in three main clusters, situated around the National Park, Waimarino Plains and Tangiwai areas (Figure 2.3). Overall, 15 of the 19 wells in the database had associated lithology information from drilling bore logs. There are four wells in the National Park area, with total depths from 6 – 145 m BGL. One of these wells is used for industrial spring water supply (713002), whereas the others are used for stock and domestic supply. Five wells are located in the Waimarino Plains area, with total depths from 7 – 102 m BGL. One of these wells (733003) is used for irrigation, whereas the rest are used for domestic and stock supply. In the Tangiwai area, there are ten wells that range from 10 – 100 m BGL. These wells are used for industrial supply (pulp and paper mill), farm supply and domestic use. An additional deep well has been drilled on Park Ave, Ohakune (Westcott, personal communication, 2014), however, as yet no further information on this well has been obtained. It is understood that the well was drilled with the aim to find thermal water. Any further information (e.g. bore log) from this site would be beneficial to understand the hydrogeology in the area.

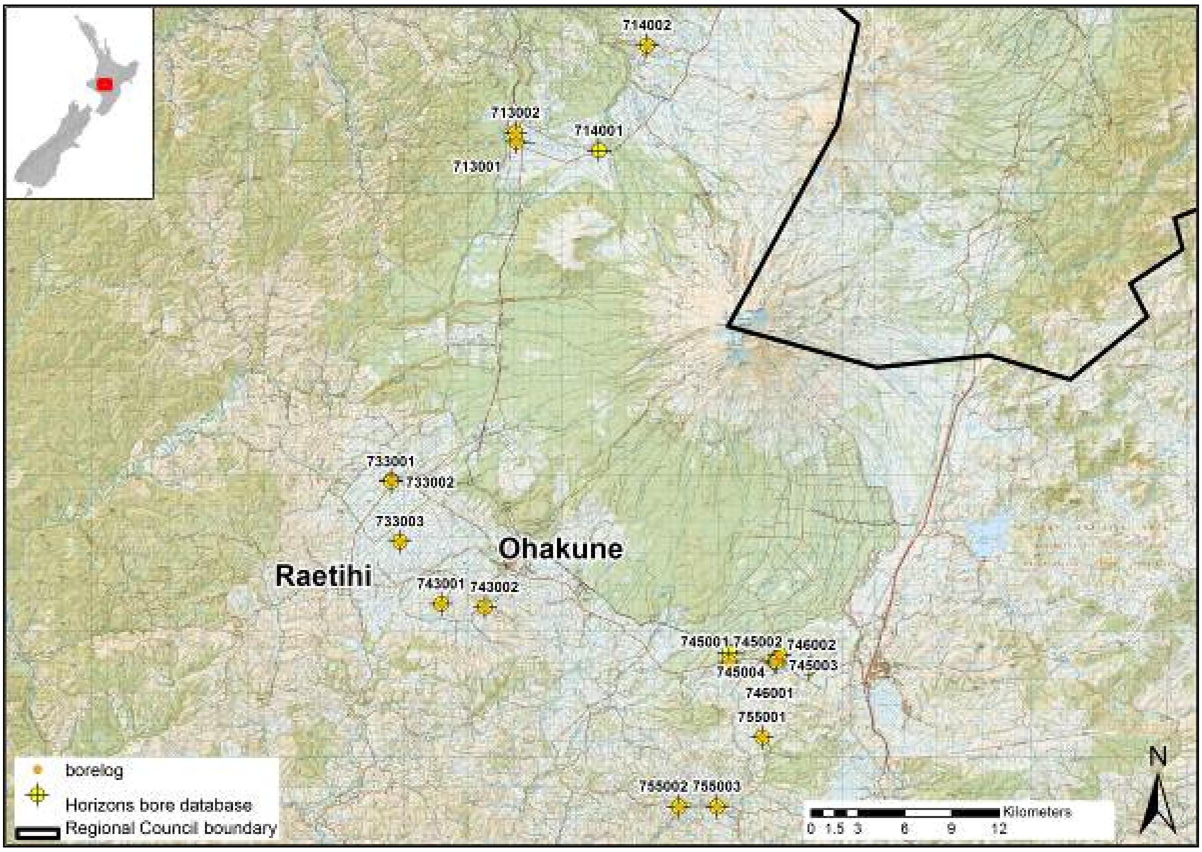


Figure 2.3: Location of wells within 30 km of Raetihi and Ohakune showing well numbers and wells with available bore logs (Horizons Regional Council, 2014). Some wells in the Tangawai area are partially obscured in this image due to the close proximal locations of the wells.

2.2.3.2 Waimarino Plains wells: Geology and lithology

The five wells in the Waimarino Plains area are emplaced on three different surficial geological deposits, including Quaternary alluvium, Matemateaonga Formation, and Waimarino Formation (Figure 2.4). The local distributions of these three deposits, along with important faults in the area, are shown in Figure 2.4. Of the wells in the Waimarino Plains, two are relatively shallow and are located 7 km north north-west of Raetihi, near the supply intake at Tahonga Junction (733001 and 733002). Three are comparably deeper wells, and are located in the region between the towns. One well is located approximately 4 km north-west of Raetihi (733003), and the other two wells are located 3 km south south-west (743002), and 5 km south west (743001) of Ohakune, respectively. These five wells are likely to provide the most useful information on the groundwater system in the Waimarino Plains area.

Table 2.4: Summary of selected well information from Horizons Regional Council database (Matthews, 2014).

Well No.	Altitude (m)	Depth (m)	Depth to Water (m BGL)	GWL (masl)	Surface geology
733002	593	7.70	3.1	589.9	Quaternary alluvium
733001	592	17.50	2.8	589.2	Quaternary alluvium
733003	562	101.60	15.9	546.5	Waimarino Formation
743002	569	78.60	-	-	Matemateaonga Formation
743001	522	79.10	22	500	Quaternary alluvium

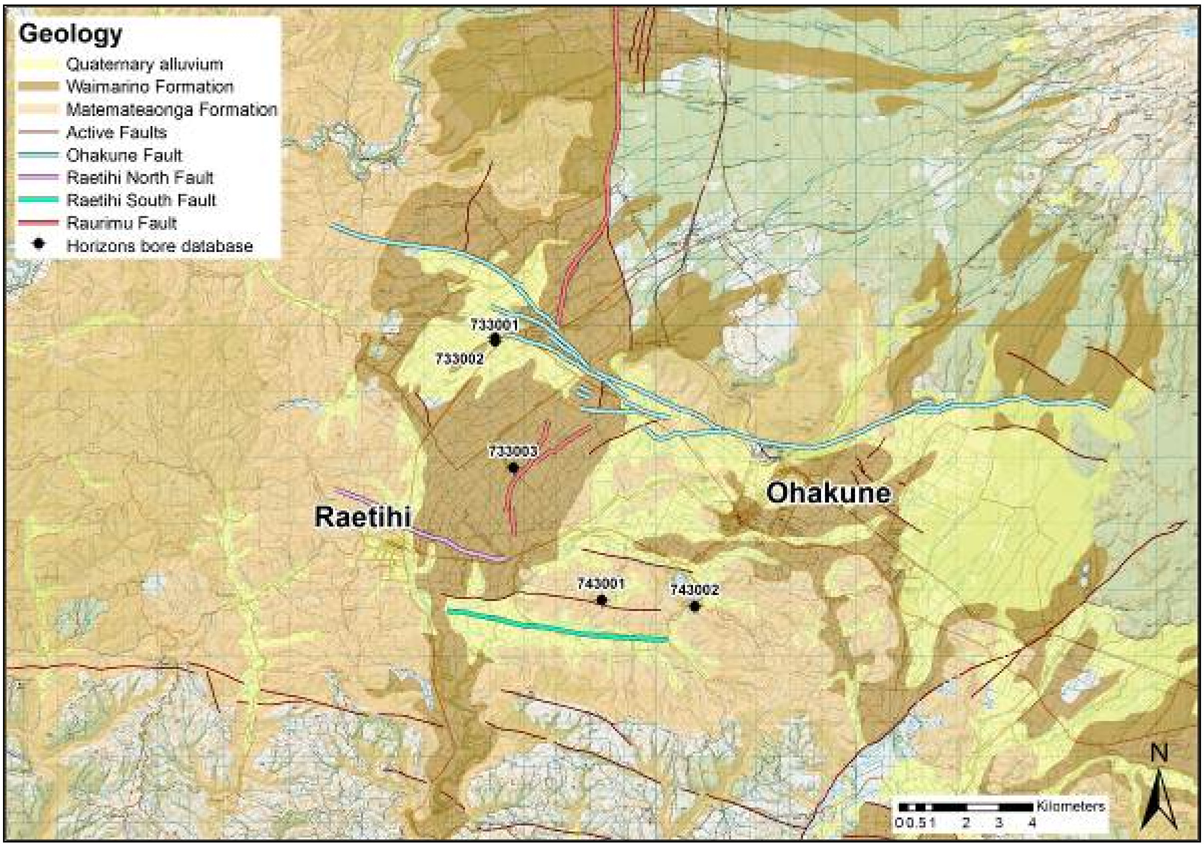


Figure 2.4: Surficial distribution of the three geological units currently used for groundwater by five wells between Ohakune and Raetihi.

Wells 733001 and 733002 are located on Mid–Late Pleistocene river sediment that is dominated by undifferentiated fan gravel ('Quarternary alluvium' in Figure 2.4). The wells are located immediately to the south of the Ohakune Fault. This places them on the downthrown side of the fault, where the throw has been estimated at 55–65 m (Villamor and Berryman, 2006a). These wells are relatively shallow, and were drilled to a total depth of 17.5 m below ground level (BGL) and 7.7 m BGL, respectively (Appendix 2). Subsurface materials were water bearing from 12.5 m BGL and 6.7 m BGL. Following drilling, pumping flow rates were sustainable at 1.3 L sec^{-1} (109 m^3 day^{-1}) and 0.5 L sec^{-1} (44 m^3 day^{-1}), respectively. The static water level (SWL) for well 733001 was 2.8 m BGL. These wells are interpreted to have a relatively low flow volume, and to be located in a shallow, unconfined aquifer.

Well 733003 is located on gravel dominated late Pleistocene lahar deposit of the Waimarino Formation. The Waimarino Formation is often composed of poorly sorted massive, bouldery gravel and coarse sandy fluvial gravels (Townsend *et al*., 2008). It has been dated at 64,000 – 80,000 years old (Villamor and Berryman, 2006a). Well 733003 is located immediately to the west of the Raurimu Fault, which places it on the upthrown side of the fault (Villamor and Berryman, 2006a). This is the deepest known well in the area, and was drilled on Balle Bros. property, 98 Harris Road to 101 m BGL in November, 2012. The bore log indicates alternating layers of volcanic clays, boulders, silts, gravels and pumice to 89 m BGL. Below this depth occurs a layer of cemented pumice and gravels from 89 – 100 m BGL, before a layer of siltstone (papa) is encountered at 100 – 101 m BGL. From the bore log, it is interpreted that the most productive layer encountered during drilling was the cemented volcanic pumice and gravels. This layer was then screened from 86.4 – 100.1 m BGL. It is likely that the siltstone (papa) had much lower water bearing properties, and this is the reason for cessation of drilling at this point. From the bore log, it is difficult to interpret whether the aquifer is confined or unconfined, however, TACL (2013) identify the aquifer as being unconfined.

A comprehensive report on the assessment of environmental effects for groundwater abstraction from well 733003 was conducted (TACL, 2013). The 150 mm diameter bore is screened in stainless steel from 86 – 100 m BGL, with 0.75 mm slots, within cemented volcanic pumice and gravel material. Aquifer testing was completed on the bore including airlift measurements during development, and on the well including a variable rate pumping test and a single 24 hour constant rate pumping test. Test results indicate that the aquifer targeted by the well had a transmissivity of 791 – 205 m^2 day^{-1}, which is consistent with literature values for similar materials (Freeze and Cherry, 1979). It was estimated that the well is capable producing a maximum volume of 1,200 m^3 day^{-1}. This volume is primarily limited by the size of the pump and the diameter of the casing. It was determined that the effects of extracting 1,200 m^3 day^{-1} for a long duration were nil on surrounding wells and surface water in the area.

Wells 743001 and 743002 are located on sandstone dominated early Pliocene Matemateaonga Formation. Matemateaonga Formation is comprised of predominantly muddy sandstone, with siltstone, mudstone, limestone or shellbeds, coal and conglomerate. Shellbeds are typically in a coarse sandy matrix. The formation is found in South Taranaki and near New Plymouth, where it has groundwater yields of between 72 and 1,560 m^3 day^{-1} at depths between 100–800 m. In Taranaki, the Matemateaonga Formation is approximately 1 km thick, whilst in the Waimarino Plains it is expected to be up to 2 km thick (Townsend *et al*., 2008). There is a small graben structure defined by the Raetihi North and Raetihi South Faults (Villamor and Berryman, 2006a) that is likely to influence the subsurface at wells 743001 and 743002.

The two wells sited between Raetihi and Ohakune (743001 and 743002) were drilled to 79.1 m BGL and 78.6 m BGL, respectively. The drilling bore log for well 743001 indicates alternating layers of relatively thicker siltstone (papa) and thinner sandstone throughout the sequence. There is no information in which layer the well is screened, but a SWL of 22 m BGL is reported. Similarly, the bore log for well 743002 also indicates layers of alternating sand and silt throughout the sequence. There is no information in which layer the well is screened, or a SWL. For each of these wells there are no pumping rates or volumes provided. Although difficult to interpret from the bore log, it is possible that these wells also intercept an unconfined aquifer.

2.2.3.3 Groundwater quality and age

A combination of datasets from RDC and Horizons were used to examine information on groundwater quality in the region. A total of five wells (713002, 714001, 733001, 733003, and 725001) had available water quality information available (Figure 2.5). Two of the five wells located on the Waimarino Plains (733001 and 733003) contained groundwater quality information, which will be further interpreted in this section. Based on the large distance of the additional three water quality sites to the townships, these datasets have been included in Appendix 3, but are not further interpreted. Unfortunately there are no known analyses and results for groundwater age interpretation at any of the locations.

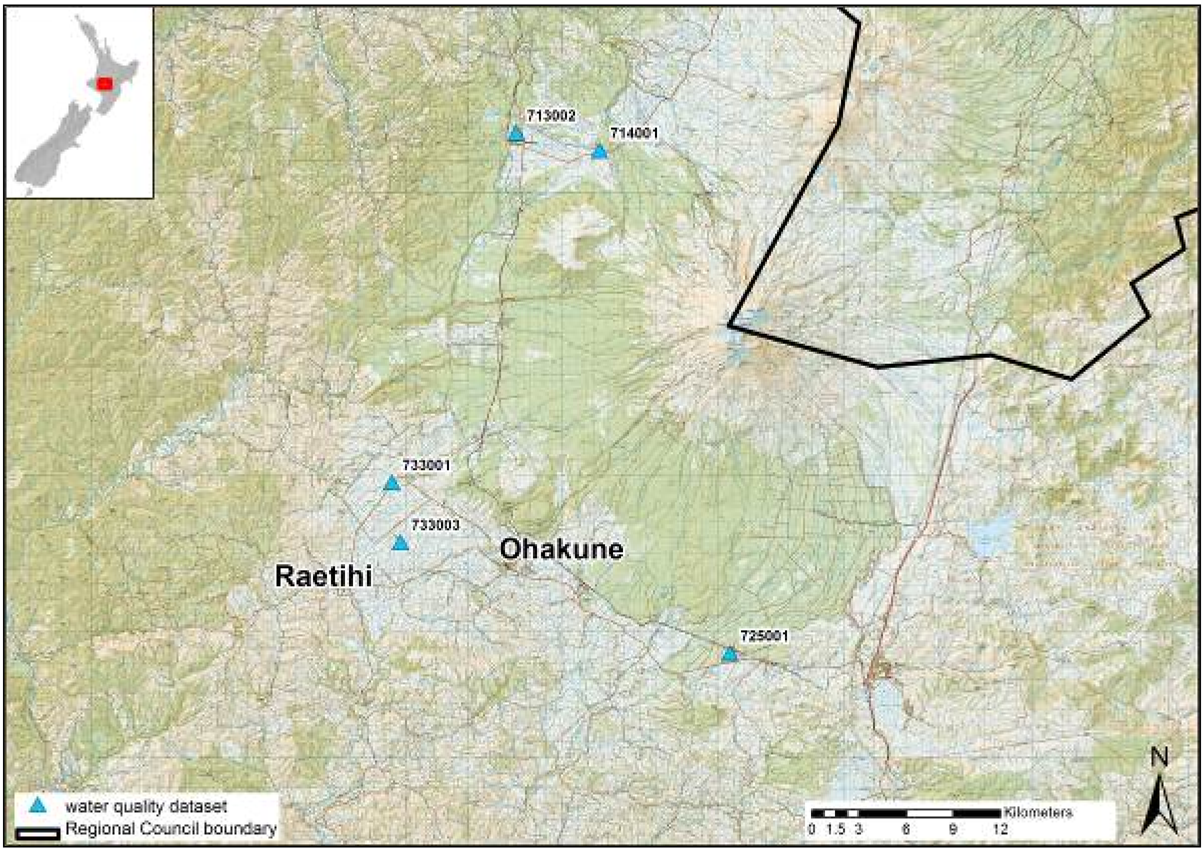


Figure 2.5: Location of five groundwater locations where water quality data exists.

Groundwater quality data is available for two wells (733001 and 733003). Well 733003 is a relatively deep well of 102 m. The water from this well appears to be of good quality, under the proviso that there is only one data point for each determinant. With the exception of E.Coli, which is discussed further below, no determinant exceeds the maximum allowable value (MAV) given in the DWSNZ:2005 (Table 2.5). Concentrations of determinants such as nitrate and nitrite that might not be removed by the treatment process are low and are unlikely to be considered as Priority 2b determinants.

Only one determinant (iron) exceeds a guideline value (GV) set by the DWSNZ:2005. Above this value staining of laundry and sanitary ware may occur (Ministry of Health, 2008). It is not specified whether the test conducted was for dissolved iron or total (unfiltered iron). Iron can be removed from the water during treatment, commonly by aeration followed by filtration. However, the iron concentration observed is only just above the guideline value and further monitoring could indicate whether iron levels will be of concern in the long-term. Water from well 733003 was tested for a range of pesticides and organic determinants. All were below detection limits. The substances tested for, and detection limits are presented in Appendix 3. The presence of E.Coli in the water from well 733003 could indicate that the water from this well is not secure. However, given the depth below ground that the well is drawing water from, this possibility is unlikely. Wells of this depth are regularly observed to draw “old” groundwater which satisfies the residence time criterion (Section 4.5.2.1) of the DWSNZ:2005 (Ministry of Health 2008; van der Raaij and Morgenstern 2007). Contamination by E.Coli can occur by direct leakage around the well casing, in which case the groundwater from this well could not be considered secure until adequate repairs had been made. Alternatively, the presence of E.Coli may be caused by contamination during water sampling, or from drilling muds, and may clear after prolonged use of the well. Further monitoring of this groundwater is required.

Table 2.5: Water quality results for selected wells in the Waimarino Plains.

Test	Units	Well 733003	Well 733001 16/05/96	Well 733001 13/07/99	DWSNZ MAV or (GV)
E.coli enumerated	MPN/100 ml	2	-	-	1
Total coliforms	MPN/100 ml	190	-	-	-
Ammoniacal nitrogen	mg/L	<0.5	-	-	1.5
Chloride	mg/L	5	-	-	(250)
Conductivity	mS/m	16.4	17.3	15.4	-
Nitrate	mg/L as NO_3	0.11	45.17	11.51	50
Nitrite	mg/L as NO_2	<0.002	-	-	3
pH	pH unit	7.8	5.7	-	(7.0 – 8.5)
Sulphate	mg/L	6.2	-	-	(250)
Aluminium	mg/L	0.042	-	-	(0.1)
Antimony	mg/L	<0.001	-	-	0.02
Arsenic	mg/L	0.00093	-	-	0.01
Barium	mg/L	0.0021	-	-	0.7
Bicarbonate	mg/L	-	23.16	-	-
Boron	mg/L	0.021	-	-	1.4
Cadmium	mg/L	<0.00005	-	-	0.004
Chromium	mg/L	0.00057	-	-	0.05
Copper	mg/L	0.061	-	-	2 (1)
Iron	mg/L	0.22	0.29	-	(0.2)
Lead	mg/L	0.0016	-	-	0.01
Manganese	mg/L	0.0097	0.06	-	0.4 (0.04)
Mercury	mg/L	<0.00005	-	-	0.007
Molybdenum	mg/L	0.00046	-	-	0.07
Nickel	mg/L	0.00072	-	-	0.08
Selenium	mg/L	<0.0005	-	-	0.01
Sodium	mg/L	12	-	-	(200)
Total Hardness (as $CaCO_3$)	mg/L	54	-	-	(200)
Uranium	mg/L	0.000056	-	-	0.02
Zinc	mg/L	0.0062	-	-	(1.5)

Well 733001 is a shallow well of 17.5 m. At this depth it is less likely the groundwater would be of sufficient age to satisfy the residence time criterion (Section 4.5.2.1) of the DWSNZ:2005 (Ministry of Health 2008; van der Raaij and Morgenstern 2007). The limited data available for this well indicate an elevated and variable nitrate concentration which, while not exceeding the MAV, is likely to be considered a Priority 2b determinant. Additionally both iron and manganese exceed the guideline values set by the DWSNZ:2005, while pH is below the guideline range of 7.0 – 8.5.

3.0 VOLCANIC AND SEISMIC RISKS TO WATER SUPPLY SOURCES

3.1 VOLCANIC RISKS AND EFFECTS

3.1.1 Volcanic Context of Waimarino Plains

The Waimarino Plains are situated at southwestern end of the Taupo Volcanic Zone (TVZ), and immediately south of Ruapehu Volcano. Ruapehu is the southern-most volcanic system within the TVZ. In addition, the Waimarino Plains are located ~100 km east of Taranaki Volcano, which is not part of the TVZ. A brief overview of Ruapehu and Taranaki Volcanoes is provided, as these volcanoes are the most likely to impact the Waimarino Plains in the future.

Ruapehu is the largest active volcano in New Zealand. It is an andesitic stratovolcano (composed of layers of volcanic ash and lava, also referred to as a composite cone volcano) that began erupting over 250,000 years ago. It is surrounded by ring plains (including the Waimarino Plains), made of lava flows and landslide, lahar and ash deposits. Ruapehu has three summit craters which have been active in the last 10,000 years; current activity is centred under the crater lake of the southern crater. Historically major eruptions have occurred every 50 years (1895, 1945, 1995 AD), although this trend does not provide a forecast for future activity. Minor eruptions happen more frequently, and over 60 have occurred since 1945, with the last eruption in 2007. Volcanic phenomena associated with Ruapehu volcanic activity include ash fall, pyroclastic density currents (also called pyroclastic flows or surges; rare at Ruapehu), lahars, lava flows, and ballistics. As ballistics tend to affect an area within a few kilometres of the vent, and the Waimarino Plains are considerably further, they are not discussed further in this report; the other hazards have reached the Waimarino Plains over geologic time (not necessarily historically) and so will be discussed.

Taranaki is also an andesitic stratovolcano, and began erupting 130,000 years ago. Taranaki has had a large eruption roughly every 500 years (the last one was in 1655 AD) and small eruptions every 90 years (last one in the 1800s). As with Ruapehu, these time intervals do not provide a forecast for future activity. Taranaki is presently volcanically quiet, but is likely to erupt again in the future. Ash fall is the only volcanic phenomena that will potentially reach the Waimarino Plains from Taranaki.

3.1.2 Review of volcanic impacts to water supplies

Volcanic activity can adversely impact water supplies either by reducing functionality of, or destroying water supply infrastructure, or by causing water chemistry changes. In Section 3.1.1, a short literature review of volcanic impacts to water supplies is presented, and in Section 3.1.2, an overview of volcanic hazards in the Waimarino Plains based on existing volcanic hazard maps is presented.

3.1.2.1 Physical impacts to water supply infrastructure

Volcanic hazards can destroy, damage, or temporarily reduce the functionality of water supply infrastructure in a number of ways. Lava flows, lahars, pyroclastic density currents, earthquakes, and ground deformation can destroy, damage, or bury pipes and other infrastructure, although there are a limited number of documented examples of these impacts (all these examples lead to replacement or abandonment of the infrastructure). For these flow hazards, the best mitigation measure is to locate infrastructure away from likely flow paths, although given that flows generally follow drainages, this may be difficult to do.

Furthermore, if these hazards have a low likelihood of happening over the lifespan of the infrastructure, some providers may decide the cost of relocating existing infrastructure is greater than the potential risk from volcanic flows for the projected lifespan of the infrastructure. Damage from volcanic ash infiltration is much more common, and discussed below.

Volcanic ash can cause the following problems to water supply infrastructure:

a. Ash can reduce water intake by blocking water intake and blocking filters in the treatment process. This can reduce pumping rates; for example, the 1945 Ruapehu eruption reduced water supply pumping rates for Taumaranui's plant from 90,000 L/hr to just 31,500 L/hr (Johnston, 1997). Filters exposed to volcanic ash are often damaged or experience a much-reduced lifespan (Wilson *et al*., 2012). A mitigation measure would be to have an initial flocculation/coagulation (sedimentation) trap where ash could settle out prior to water treatment (Stewart, pers. comm. 2014).

b. Ash can clog pipes and reduce the short and long term capacity of the network; the same effect can be observed in open irrigation channels (Wilson *et al*., 2012). As it is costly and time-intensive to remove ash, the best mitigation measure is to prevent ash ingress in the first place.

c. Ash can damage the electrical systems and motors that run the water supply infrastructure (Wilson *et al*., 2012). As such, a plant may be offline until these components are fixed or replaced, stopping the production of drinking water until that time. This happened in Argentina following the July 2000 eruption of Copahue Volcano (Stewart *et al*., 2006). A mitigation measure would be to have back-up power generation and prevent ash ingress.

d. Ash can damage intake structures and cause increase wear on infrastructure components due to its highly abrasive and corrosive nature (corrosive in part due to ash leachate, discussed in the water chemistry section). The best mitigation measure is to prevent ash ingress or to shut off treatment plants once a certain turbidity level is reached.

As these are all physical impacts, these potential impacts (particularly points a, b, and d) are of concern both during the ashfall event and subsequent remobilisation events (e.g., ash being remobilised by wind at intervals of days, weeks, months, or years after the eruption, depending on whether ash deposits have been stabilised). Vulnerable points in the system are exposed supply waterways (such as rivers, lakes, or channels) and exposed parts of the treatment plant (such as ponds). The best mitigation measure is to prevent ash ingress into the system. Systems reliant solely on groundwater supplies tend to be more resilient at least until the treatment step. In some cases asset protection, such as temporarily shutting down a plant, might be the best course of action to minimise ash ingress and associated long term costly and time-intensive cleaning, repair, and replacement. Appendix 4 is a poster, commissioned by the Auckland Engineering Lifelines Group, providing advice for water supply managers dealing with volcanic ash.

A note on turbidity is warranted. Ash is well documented to greatly increase turbidity, which can not only damage infrastructure (see points a) and d) above) but also compromise the water treatment processes. For example, heavy rainfall in the months after the Mt St Helens eruption caused ash to enter water supply systems, increasing turbidity, and compromised the treatment process, as evidenced by waterborne *Giardiasis* being reported up to 100's of kilometres away (Stewart *et al*., 2006); this is an example of remobilised ash causing problems long after the eruption. A recent New Zealand example of turbidity is the 6 August 2012 Tongariro eruption increasing turbidity at the Rangipo prison water supply to over 20 NTU, at which point the plant automatically shut down (Stewart, pers. comm. 2014).

3.1.2.2 Impacts to water chemistry

There are two main ways volcanic products can impact water chemistry: through volcanic gases dissolving into the water supply (rare), or from surface coatings on volcanic particles leaching into water after particles fall into water (common given explosive activity).

Volcanic gases migrating upwards from a several-km deep intrusion at South Sister volcano, Oregon, USA, caused changes in water chemistry at a low temperature local spring-fed creek (Separation Creek; see Evans *et al*., 2004). Specifically, there were elevated levels of chloride (up to 20 mg/L) and magmatic carbon ($CO_2 + HCO_3^- + CO_3^{2-}$). These changes in the water chemistry were detected years before deformation was picked up at the volcano which confirmed an intrusion. What is unusual about this event is that this change in water chemistry occurred in a low temperature system; had this been a higher population area, it could have feasibly been a water supply source. There are other examples of water chemistry changing, but all in high temperature systems such as fumaroles that are highly unlikely to be drinking water sources. Additionally, no eruption was associated with this event – it resulted from activity several km's below the surface. At the moment this is an isolated example globally, but illustrates the possibility of low temperature groundwater systems being infiltrated by volcanic gases.

Following an explosive volcanic eruption (i.e., volcanic tephra is produced) there is high chance of contamination of surface water supply sources if any fresh tephra falls into the water. When ash particles are in the volcanic plume, they interact with volcanic gases including water, HCl, SO_2, H_2S, CO_2, and HF and acquire a soluble coating (Figure 3.1). If tephra then falls into surface water, this soluble coating will dissolve and water contamination will occur. Acidification is almost always a problem, there are over 55 possible dissolved ions, and fluoride contamination can be a major concern (Witham *et al*., 2005, Stewart *et al*., 2006, Wilson *et al*., 2012). Of the 55+ possible leachates, the most common are sulphate, Cl, Na, Ca, Mg, and F, and the most common minor leachate components are Mn, Zn, Ba, Se, Br, B, Al, Si, Cd, Pb, As, Cu, and Fe (Stewart *et al*., 2006). Table 3.1 provides an overview of possible and documented water chemistry impacts from around the world, drawn heavily from Stewart *et al*., (2006). The most common documented impact on water chemistry is that the water tastes metallic/funny, but is still within legal safety limits to drink. These impacts are often short-lived (Stewart, pers. comm. 2014). However, due to taste and possible colour changes, most people will most likely not want to drink it and may not consider it safe to drink despite being told otherwise by authorities.

Unlike physical impacts, chemical impacts tend to be shorter lived, as rainfall after ash is deposited tends to dissolve the soluble coating on ash particles, and so generally remobilised ash has already been stripped of chemical leachates (physical impacts, however, can persist for some time). The Ministry of Health is currently developing a protocol for testing water chemistry following a volcanic eruption (Stewart, pers. comm., 2014). It is suggested that to prevent contamination in the first place, the simplest mitigation measure is to cover all surface water supplies prior to an eruption to prevent ash infiltration and consequent dissolution of ash particle soluble coatings.

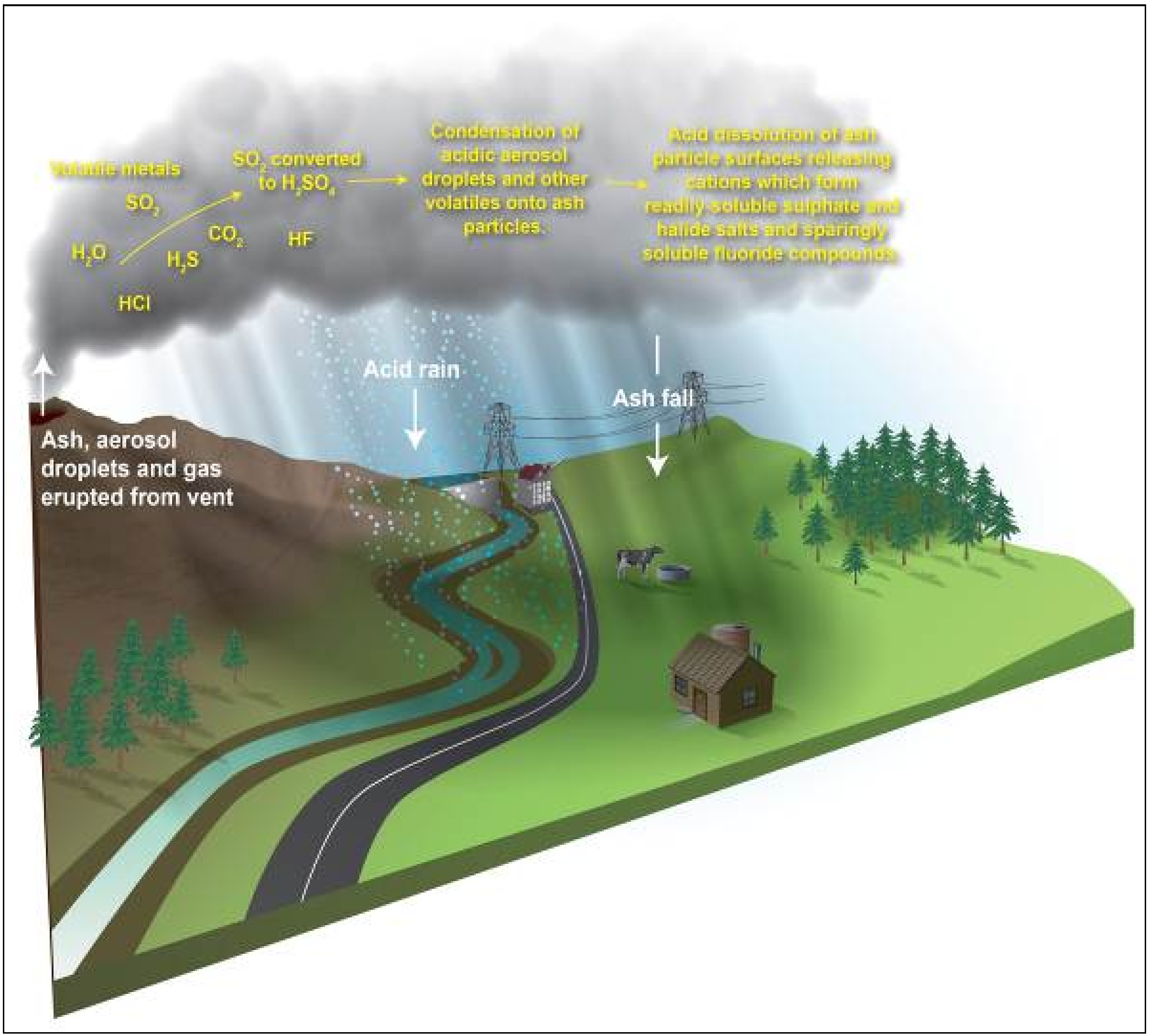


Figure 3.1: Volcanic plume processes causing water contamination.

Table 3.1: Representative water chemistry impacts from volcanic eruptions around the world, after Stewart *et al*., (2006).

Impact type	Eruption	Impact
Acidification	Mt Spurr volcano, Alaska, 1953	Anchorage, Alaska public water supply dropped to pH 4.5 for a few hours after receiving 3 – 6 mm of ashfall (Blong 1984)
	Copahue volcano, Argentina, 2000	pH 2.1 in nearby Lake Caviahue, pH 2.5 in streams 60 km away
Fluoride contamination	Lopevi volcano, Vanuatu, 2003	10 mg/L fluoride in rainwater-fed tanks
	Hekla volcano, Iceland, 1947 – 1948	9.5 mg/L fluoride in nearby Markjá stream
Other contamination	Copahue volcano, Argentina, 2000	Increased iron, fluoride, and sulphate in water supplies
	Soufrière Hills volcano, Montserrat, 1997	Increased sulphate, chloride, and fluoride in water supplies

3.1.2.3 Volcanic impacts to source water supply volume

Volcanic activity can impact the volume of available water for water supply, although often these changes are temporary, as the overall rate of water flow is rarely changed and water must go somewhere.

Surface water can be dammed by lava flows, lahars, and ash and pyroclastic density current deposits. Recently-emplaced dams can severely reduce available water downstream as water fills behind the dam; one of the earliest documented cases is that of the Skafta River temporarily drying up during the 1783 Laki eruption in Iceland; here the river ceased to flow until water was able to overtop the dam (Steingrímsson 1788). The further upstream the dam is, the less the overall water supply will be impacted. Lava flow dams can be stable for millennia (e.g., Hamblin 1994, Deligne 2012, van Gorp *et al*., in press), while loose sediment dams (lahars, ash, and pyroclastic density current deposits) are inherently unstable; these latter can cause severe problems in the case of catastrophic failure. We note a site-specific evaluation of Ruapehu for was not undertaken to evaluate chance of catastrophic failure of the lava dam which contains the summit crater lake.

Groundwater flow patterns can change when there is an intrusion or when magma ascends towards the surface, changing the thermal structure of the subsurface and thus influencing water flow. This is commonly associated with signs of unrest at the volcano, so can happen before an eruption or not be associated with a subsequent eruption at all. A recent example is of springs drying up at Mayon Volcano in the Philippines during a period of heightened unrest in June 2013 (Amo 2013). Very large volcanic eruptions depositing huge amounts of material can completely modify the groundwater system, but if this were to happen in New Zealand this would be the least of our concerns.

3.1.3 Volcanic hazard occurrence frequency in the Waimarino Plains

No new volcanic hazard modelling was undertaken for this report; however a literature review was completed. We begin with discussion of the volcanic ash hazard as this is the hazard of greatest concern for the Waimarino Plains, and then briefly touch on other volcanic hazards.

Existing New Zealand-wide probabilistic volcanic ash modelling by Hurst and Smith (2010) suggests that the Waimarino Plains can expect, on average, ~8 mm of volcanic ash every 500 years or ~64 mm of volcanic ash every 10,000 years (Figure 3.2). Note that this depth is for cumulative volcanic activity – it is unlikely (but possible) to get 8 mm at once. Large eruptions from the Taupo or Okataina centres are modelled by Hurst and Smith (2010) to deposit approximately 10 meters of volcanic ash on the Waimarino Plains over a million years; this is likewise the cumulative effect of several discrete eruptions.

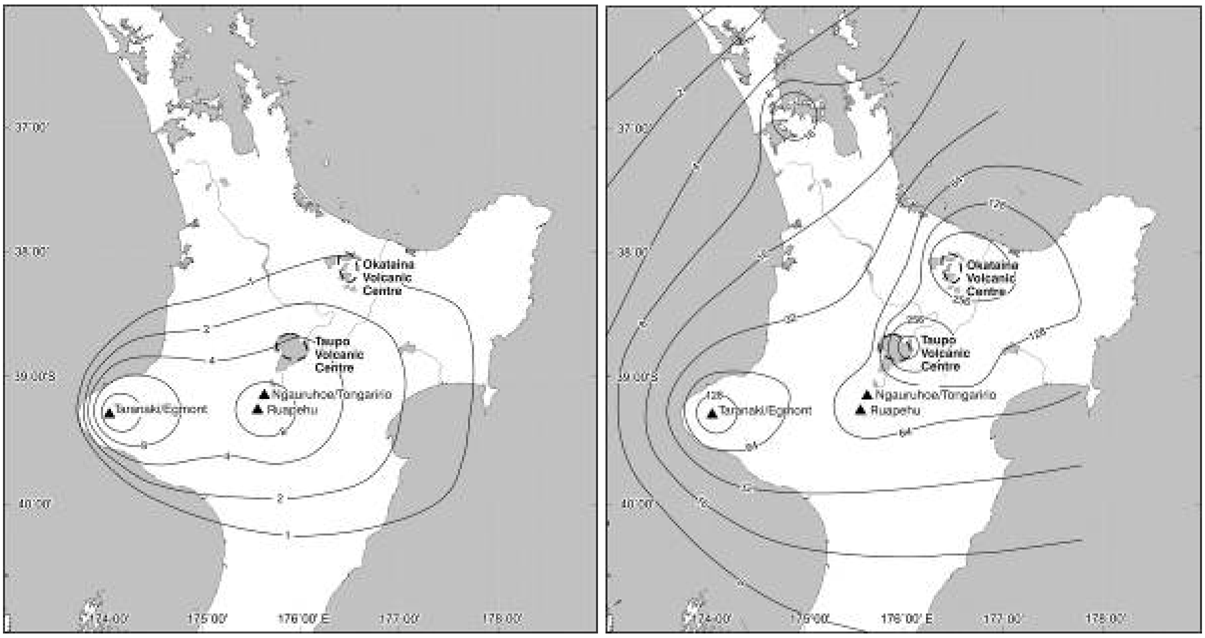


Figure 3.2: Probabilistic volcanic ash modelling for all sources in New Zealand, from Hurst and Smith (2010); contours show volcanic ash deposition in mm over (left) 500 years and (right) 10,000 years.

Volcanic ash deposition is highly dependent on wind conditions. The Waimarino Plains are typically upwind of the closest volcanic centres in Tongariro National Park and so are generally shielded from high volcanic ash impacts. However, if an eruption were to happen during a northerly, the plains could receive the bulk of the tephra deposit. An eruption from Taranaki is potentially more likely to be problematic for the Waimarino Plains than an eruption Tongariro National Park. A very large eruption from either the Taupo or Okataina centres could also be problematic, particularly (from the Waimarino Plains perspective) due to possible widespread electricity transmission line failures and road disruptions. However, a large Taupo or Okataina eruption is less likely to occur than a Taranaki eruption.

Lava flows and lahars are topographically controlled, as are pyroclastic density currents to some extent, and so not influenced by atmospheric conditions like volcanic ash. For these hazards, Ruapehu is the only volcanic source of concern for the Waimarino Plains. Below we discuss these hazards in the Waimarino context in more detail, drawing on reports by Neall *et al.,* (1999) and Neall *et al.,* (2001).

Lahars are the most likely hazard to impact the Waimarino Plains (Figure 3.3), although the majority of the plains are mapped by Neall *et al.,* (1999) as a low lahar risk zone (i.e., recurrence interval between 12,000 and 25,000 years). Neall *et al.,* (1999) identify the Mangawhero River as moderate to low risk (6000 – 12,000 year recurrence interval) and the Mangaturuturu River and as extreme to very high risk lahar zones (under 1000 year recurrence interval). There are no known historic events.

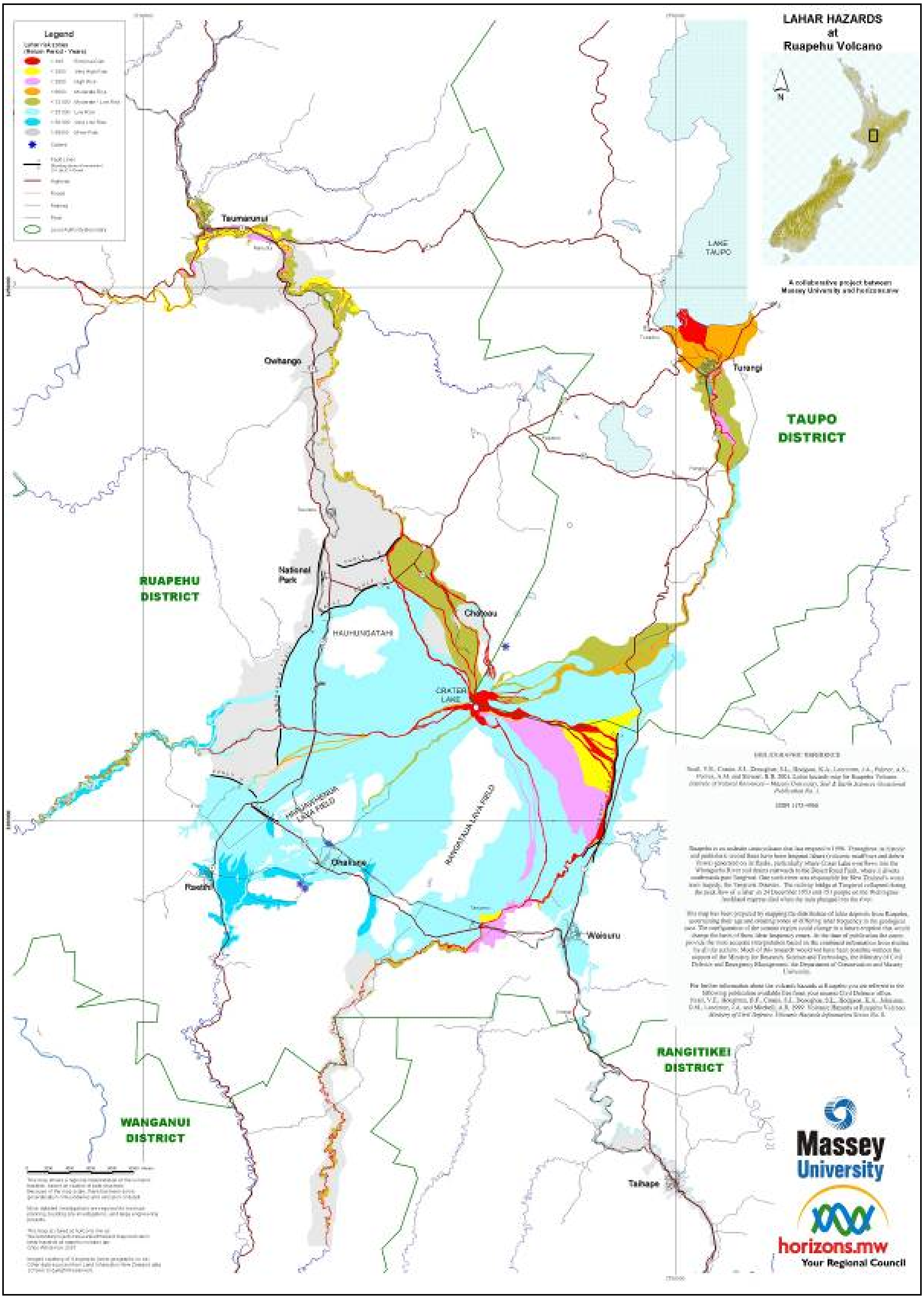


Figure 3.3: Lahar hazard map for Ruapehu by Neall *et al.,* (1999).

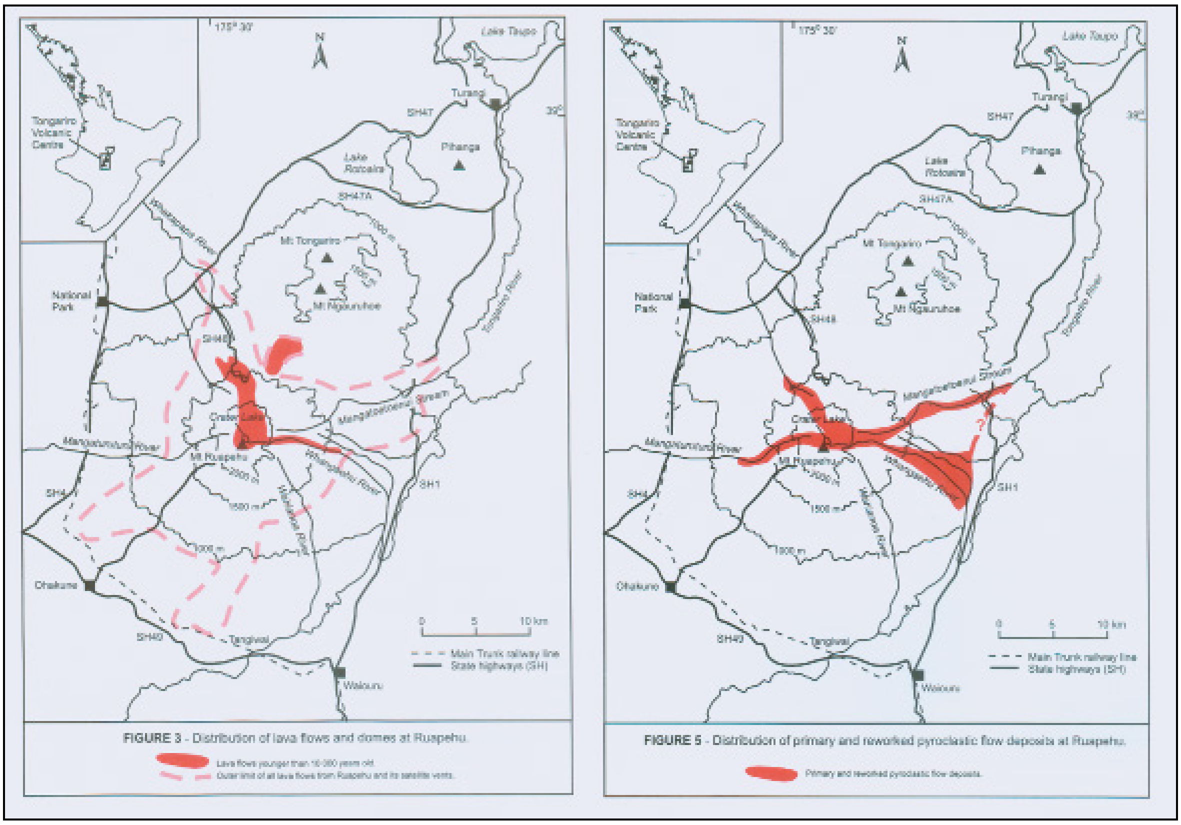


Figure 3.4: (Left) Lava flow and dome map for Ruapehu, from Neall *et al.,* (2001). In red are lava flows emplaced in the last 10,000 years, and the red dashed line indicates the extent of all Ruapehu lava flows over geologic time. (Right) Pyroclastic density current map for Ruapehu from Neall *et al.,* (2001), showing the distribution of primary and reworked deposits.

Ruapehu lava flows have reached the Waimarino Plains over geologic time (Figure 3.4) and so theoretically could be a concern, particular for infrastructure located in drainages. No lava flows have reached the Waimarino Plains in the past 10,000 years. Pyroclastic density currents do not appear to be a concern for the Waimarino Plains (Figure 3.4).

Overall, the Waimarino Plains are most likely to be impacted by ash (Ruapehu or Taranaki) or lahars (Ruapehu) and possibly lava flows (Ruapehu). However, eruptions that could impact the Waimarino Plains are infrequent by human timescales.

3.2 SEISMIC RISKS AND EFFECTS

The Waimarino Plains are located at the southwestern end of the Taupo Volcanic Zone (TVZ), within a region undergoing tectonic extension related to backarc rifting of the Hikurangi Subduction Zone (Villamor and Berryman, 2006). In general terms, the Waimarino Plains, and southern region bounding Mt Ruapehu is being pulled apart by extensional tectonic forces, the earth’s crust in this area is thinning as the rifting-apart motion of the TVZ propagates southward. The geologic extension rate across the region is 2.3 +/- 1.2 mm/yr (Villamor and Berryman, 2006). This extension rate is accommodated by earthquakes on active faults across the region. There have been no significant (damaging) historic earthquakes in the region of the Waimarino Plains. The primary sources of seismic hazard to the Waimarino Plains are: (1) local active faults that traverse the Plains and have a surface expression; (2) ground shaking caused by regional and distal earthquakes. To address the first seismic hazard source a summary of the known active faults on the Waimarino Plains is presented, and to address ground shaking information from the most recent National Seismic Hazard Model is presented (Stirling *et al*., 2012).

Seismic activity can adversely impact water supplies by causing short- to long-term changes in spring discharge, stream flow, and groundwater levels, causing direct blockage or diversion of surface water due to ground surface rupture, and by reducing functionality of, or destroying water supply infrastructure. An overview of seismic hazards in the Waimarino Plains based on existing data is presented in Section 3.2.1. Following this, a short literature review of seismic impacts to water supplies is presented with particular emphasis on the 2010-2011 Canterbury earthquake sequence is presented in Section 3.2.2.

3.2.1 Waimarino Plains Seismic setting

At the southern end of the TVZ there are three main active fault sets, each of these sets has an expression on the Waimarino Plains (Table 3.2; Figure 3.5):

- The NNE-trending Mt Ruapehu Graben
- The E-W and ESE-WNW-trending Ohakune and Raetihi Fault set
- The NE-trending Karioi fault set.

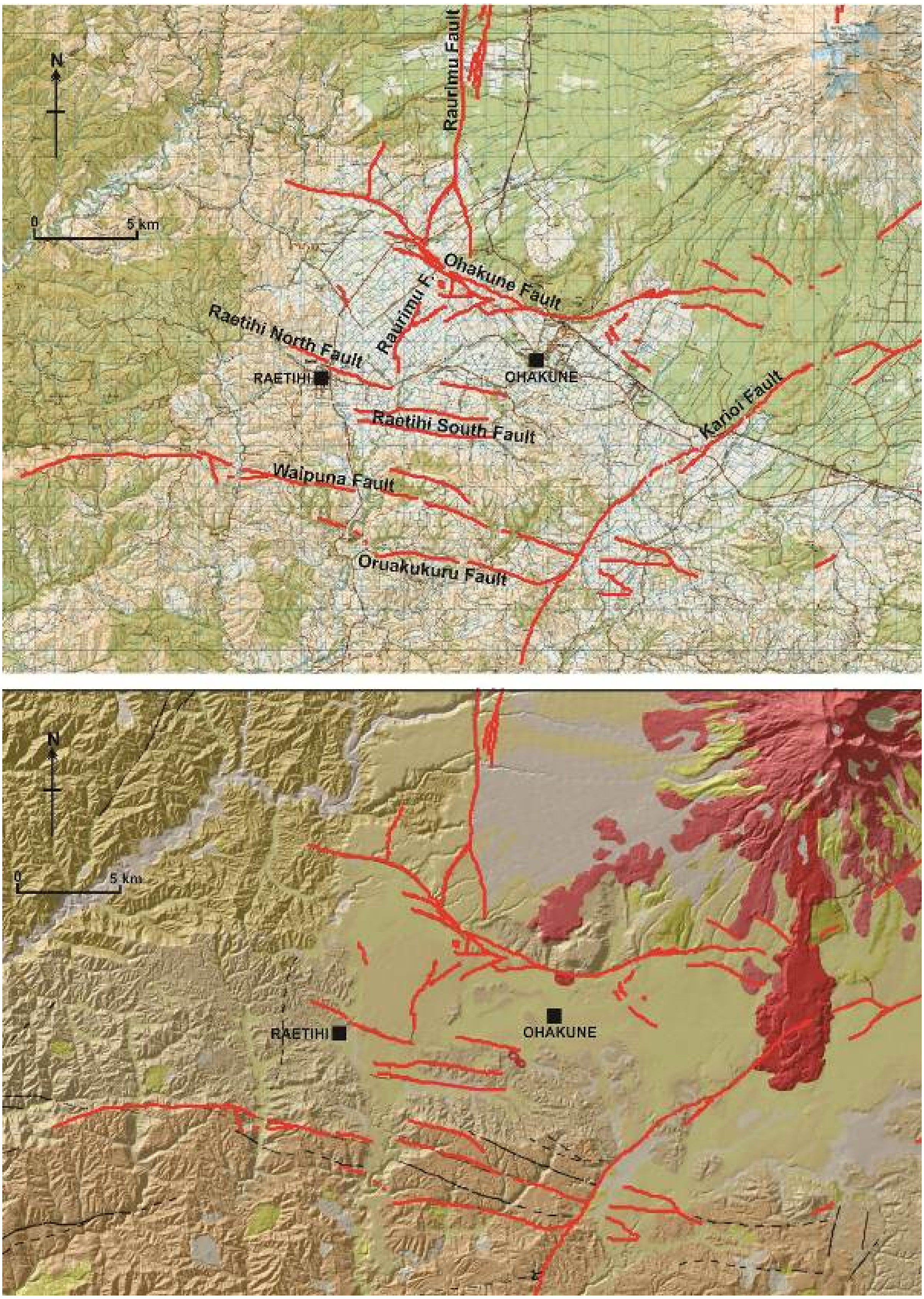


Figure 3.5: Active faults (red lines) of the Waimarino Plains region. Upper map shows the faults overlain on a 1:50000 topographic map. Lower map shows the faults overlain on a shaded DTM with geological units. The red active fault traces are from the New Zealand Active Faults Database (http://data.gns.cri.nz/af/, accessed March 2014). The geological units are from Townsend *et al*., 2008. Light yellow and beige units are Quaternary volcaniclastic and alluvial units, and Miocene to Plio-Pleistocene sedimentary units. The pink and red units are Quaternary igneous units. Also see Figure 2.1 for geology.

Table 3.2: Active faults of the Waimarino Plains. Data sourced from the New Zealand Active Faults Database (accessed March, 2014). *these fault sets contain other faults but they do not traverse the Waimarino Plains region. **Slip rate data sourced from Villamor and Berryman, 2006. + The single event displacement values are sourced from the NSHM (Stirling *et al*., 2012) and are derived from formulas than estimate single event displacement from the parameters of fault dimensions (length, width) and the slip rate, these do not represent primary, ground-truthed data. ++ Raetihi North and Raetihi South faults are combined into a single fault source in the NSHM, 0.6 m represents the combined displacement on these two faults.

Fault set	**Fault name**	**Type**	**Down-dropping quadrant**	**Dip**	**Dip direction**	**Slip rate (mm/yr)****	**Single event displacement (m)$^{+}$**	**Recurrence interval**
Mt Ruapehu Graben*	Raurimu Fault	normal	E	c. 60°	c. 104°	1.5 ± 0.2	1.1	< 2000 years
Ohakune-Raetihi fault set	Ohakune Fault	normal	SW	60° ± 10°	c. 206°	3.5 ± 1.2	1.2	< 2000 years
	Raetihi North Fault	normal	SW	60° ± 10°	c. 205°	0.5 ± 0.2	0.6^{++}	c. 2000 - 3500 years
	Raetihi South Fault	normal	N	60° ± 10°	c. 10°	0.4 ± 0.1	0.6^{++}	c. 2000 - 3500 years
	Waipuna Fault	normal	SW	60° ± 10°	c. 193°	0.4 ± 0.3	1.1	c. 2000 - 3500 years
	Oruakukuru Fault	normal	S	60° ± 10°	c. 200°	0.7 ± 0.4	0.4	< 2000 years
Karioi fault set*	Karioi Fault	normal	SE	60° ± 10°	c. 152°	0.4 ± 0.1	1	c. 2000 - 3500 years

Table 3.2 shows the characteristics of each active fault, this information is sourced from Villamor and Berryman, 2006 and the National Seismic Hazard Model (NSHM, Stirling *et al*., 2012). The active fault surface traces were mapped using aerial photos from 1948, 1959 and 1968 at a scale of 1:16500 and 1:25000 (e.g. Figure 3.6). Only a few sites along each fault have had the location ground-truthed, and located to a higher degree of accuracy (Villamor and Berryman, 2006). Given the fault traces were mapped from aerial photos and then transferred into a GIS, the location of each fault has a conservatively estimated uncertainty of ± 150 m. However, where fault lines traverse highly erodible terrain such as mudstone hill country, the fault scarp expression become more difficult to trace and fault locations may be higher, up to ± 250 m (e.g. left hand side of Figure 3.6). Fault location uncertainties could be considerably reduced by using a higher resolution digital terrain model if available (e.g. LiDAR), or by undertaking field work to ground truth the fault location. An example of the Ohakune Fault scarp expression in an air photo is shown in Figure 3.6.

All the mapped faults have a normal-sense of slip (Figure 3.6) and have slip rates ranging from 3.5 ± 1.2 mm/yr (Ohakune Fault) to 1.5 ± 0.2 mm/yr (Raurimu Fault). In the context of New Zealand active faults, these are all considered to be “medium” slip-rate faults. The paleoseismology (prehistoric earthquake history) of the faults has not been extensively investigated; Villamor *et al.,* (2006a, 2006b) excavated a number of trenches across many of the active faults but the primary purpose of the trenches was to obtain slip rates, rather than earthquake histories. The slip rate has been used to estimate the earthquake recurrence interval, which is <2,000 years or 2,000 – 35,000 years (Table 3.2). The single event displacement values are derived from formulas that use fault dimensions (length, width) and the slip rate to estimate the single event displacement. There is potential for better constraining single events displacements and recurrence intervals by targeted trenching of faults of particular interest.

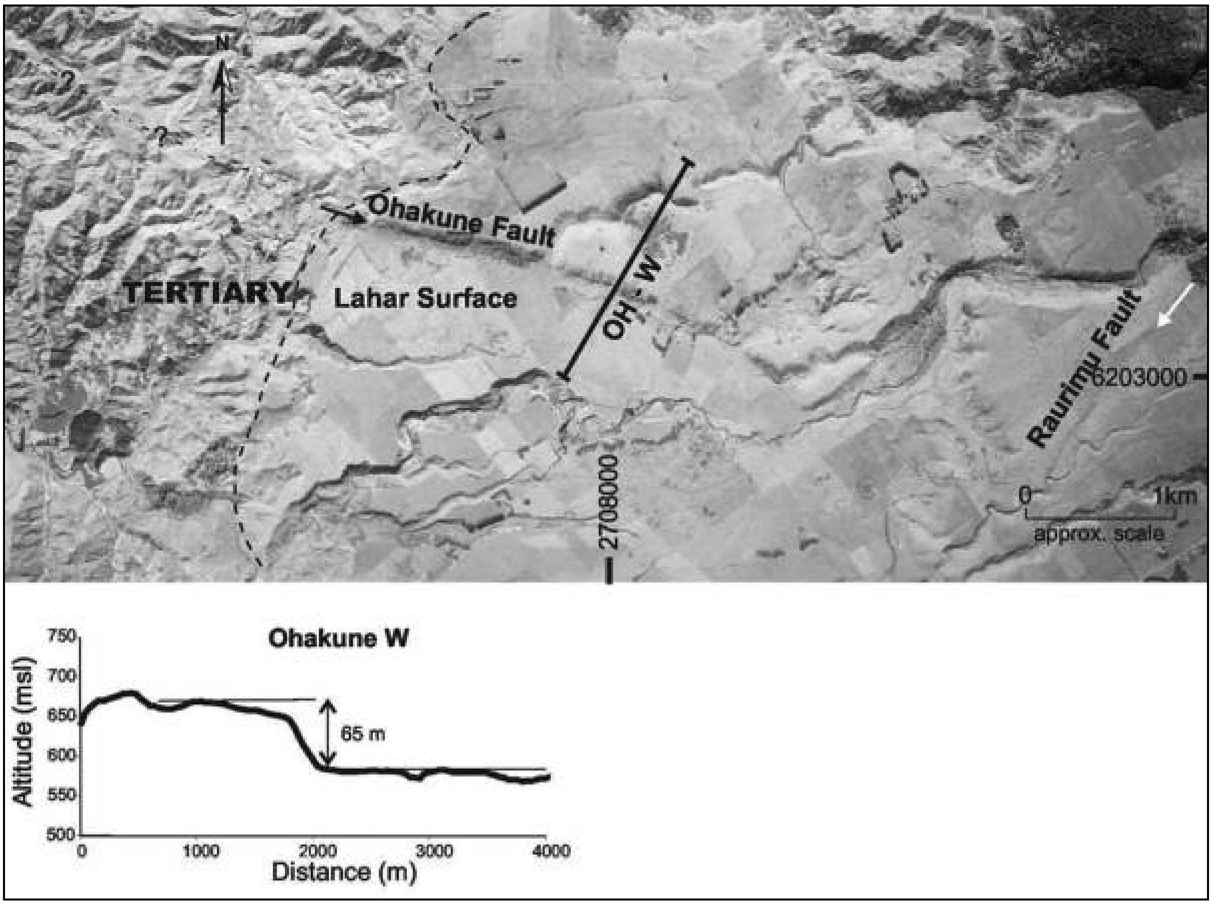


Figure 3.6: The Ohakune Fault scarp on an air photo. The topographic profile along line Oh-W is shown below (topography measured by altimeter and 1:50000 topographic map). The surface on the northside of the fault has an age of c. 64000-26500 years and on the downthrown side the surface age is 26500-10000 years. The fault slip rate of 3.5 ± 1.2 mm/yr was calculated from an offset not shown in this photograph. Figure from Villlamor and Berryman (2006).

The Ministry for the Environment (MfE) provides guidelines for planning for development of land on or close to active faults (Kerr *et al*., 2004). According to the categories developed in the guidelines, the active faults of the Waimarino Plains are in Recurrence Interval (RI) Class I (≤2000 years), RI Class II (>2000 – ≤3500 years). Water treatment facilities are categorised as Building Importance Category (BIC) 3 (water treatment facilities being a structure of high value to the community). Following the risk-based approach of the guidelines, water facilities of BIC 3 should not be sited on faults of RI Class I, II or III. The MfE guidelines were developed for buildings, and do not extend to other infrastructure such as pipelines, bore holes and reservoirs, although logically such infrastructure should not be sited on active faults either.

3.2.1.1 Location of Ruapehu District Council water treatment plants and water pipe lines in relation to active faults

The main water pipelines supplying surface water to the water treatment plants in Raetihi and Ohakune both cross active faults, and the water treatment plants are sited close to, or possibly on active faults (Figure 3.8). The water pipeline supplying Raetihi crosses the Ohakune Fault at the northern end of the pipeline; it also enters the zone of the Raetihi North

Fault. The water treatment plant at Raetihi does appear to be located directly on the Raetihi North Fault scarp. The water pipeline supplying Ohakune crosses the Ohakune Fault, and the Ohakune water treatment plant is located ~50 m from the zone of uncertainty surrounding the location of the Ohakune Fault. It should be noted that the active faults in these areas have not been mapped in detail and our estimates of the fault locations have an uncertainty of ± 150 m. The Ohakune Fault is in RI Class I (≤2000 years), and the Raetihi North Fault is in RI Class II (>2000 – ≤3500 years) according to the MfE guidelines.

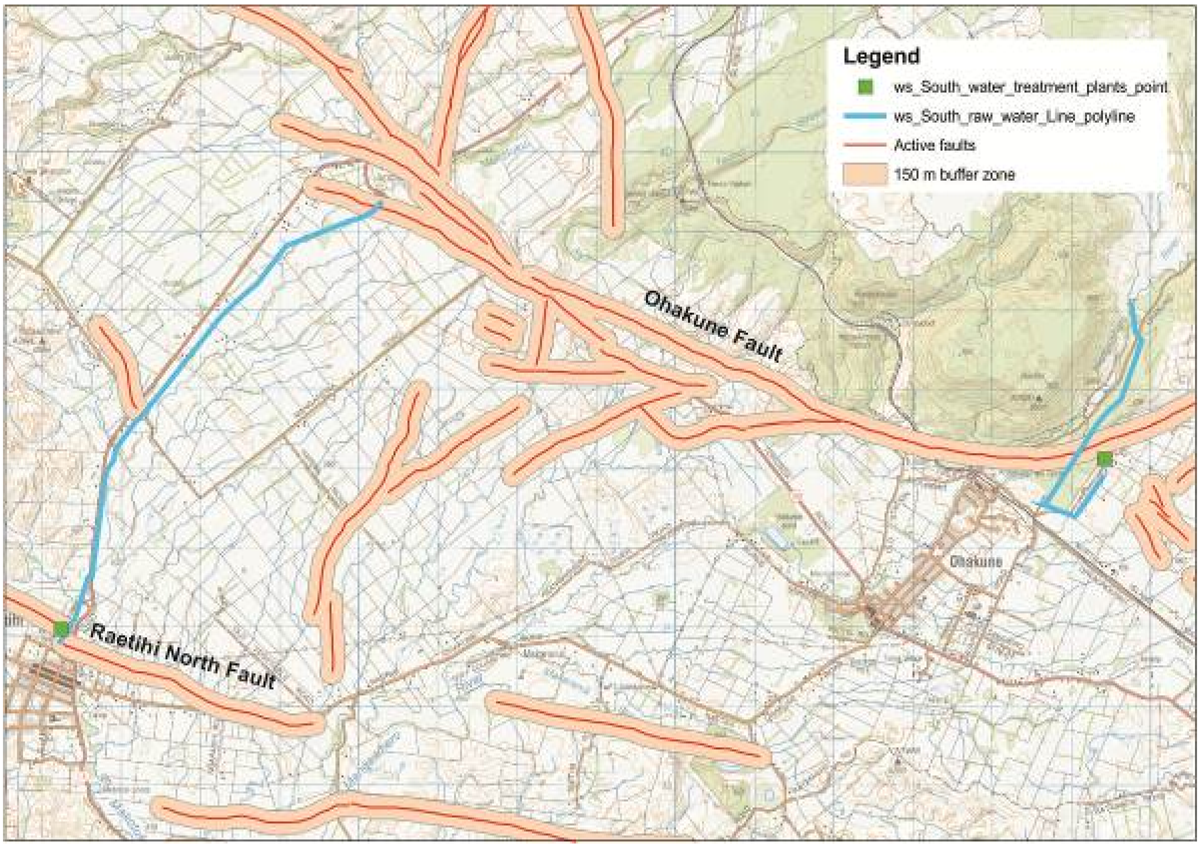


Figure 3.7: Map of the main water pipelines and water treatment facilities in the Raetihi and Ohakune area in relation to mapped active faults. The active faults have a buffer of ± 150 m around them to represent the fault location uncertainty zone.

3.2.1.2 Ground shaking hazard to the Waimarino Plains

The New Zealand National Seismic Hazard model (NSHM) provides estimates of the level (strength) of earthquake ground shaking throughout the country for various return times (Stirling *et al*., 2012, Figure 3.8). These ground motion estimates are used to derive earthquake loadings for the design and construction (or retrofit) of buildings and other structures (e.g. dams, bridges) so that they comply, or exceed, specified performance objectives. The NSHM uses geologic data and the historical earthquake record to define the locations of earthquake sources and the likely magnitudes and frequencies of earthquakes that may be produced by each source, and then estimates the ground motions that the sources will produce at a grid of sites that covers the country. The geologic data component includes the dimensions and slip rates of mapped fault sources, and includes all the faults known on the Waimarino Plains as listed in Table 3.2 above.

The peak ground acceleration (PGA) seismic hazard maps are presented in Figure 3.8 for return periods of 475 and 2,500 years based on subsoil class C (shallow soil) site conditions. These maps are provide an indication of the strength and probability of ground shaking that the Waimarino Plains will experience, they are useful because they take into account not just the proximal active faults but also distributed seismicity (earthquakes not on mapped faults) and the ground shaking effect that distant faults will have on the Waimarino Plains. For the design of specific structures, more detailed study should be undertaken in to the geologic site conditions and specific queries made of ground shaking return times for those site conditions.

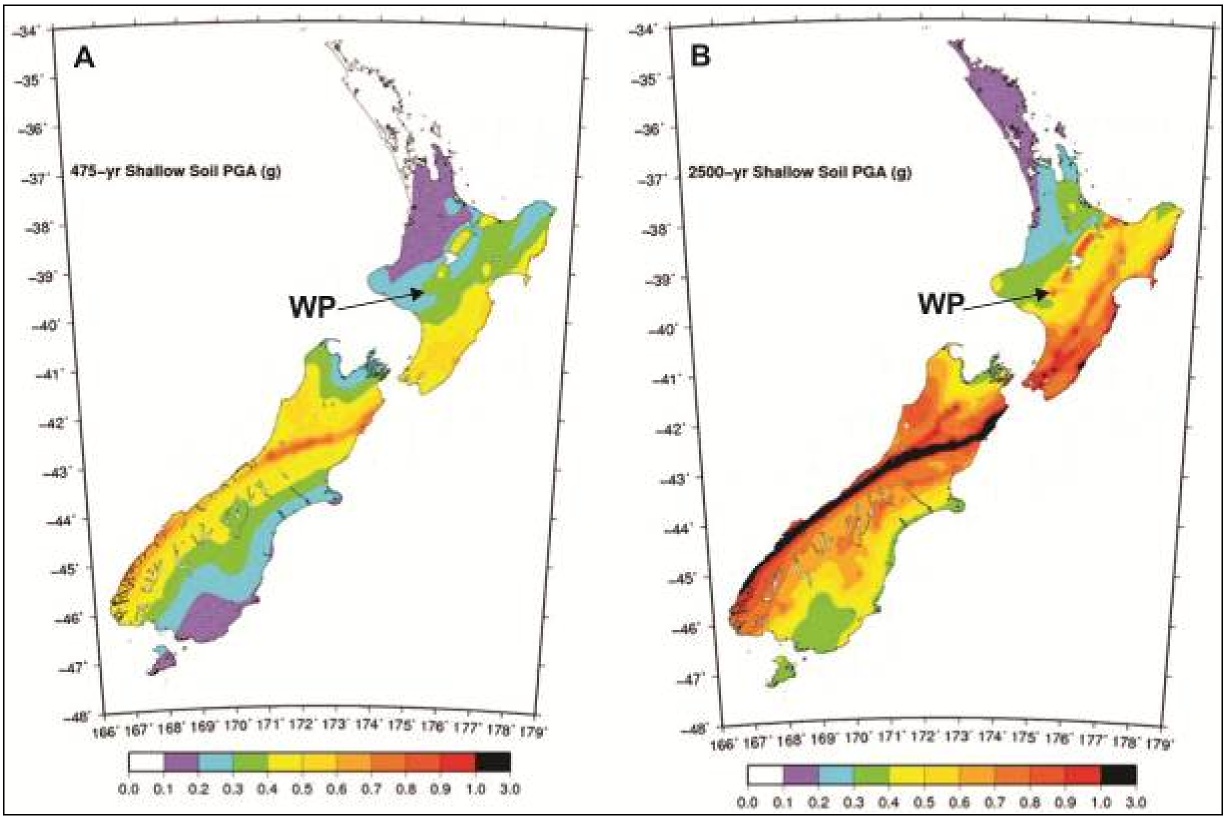


Figure 3.8: Seismic hazard maps of New Zealand (Stirling *et al*., 2012). A: PGA for 475 year return period (i.e., 10% probability of exceedance in the next 50 years) for subsoil class C (shallow soil) site conditions. B: PGA for 2500 year return period (i.e., 2% probability of exceedance in next 50 years) for subsoil class C (shallow soil) site conditions. WP: Waimarino Plains.

3.2.2 Review of seismic impacts to water supplies

The primary effects of seismic activity (earthquakes) are ground shaking, ground surface rupture, and crustal stresses in the vicinity of the earthquake epicentre. Secondary impacts can include landsliding, liquefaction, and seiches/tsunami. In this report we focus on the effects that ground shaking, crustal stresses and surface rupture can have upon water supplies, but follow-up studies on the secondary impacts landslides and liquefaction are recommended. The 2010-2011 Canterbury earthquake sequence provides a recent and well documented case study in how earthquakes impact water supplies; the effects on groundwater are particularly well studied (Cox *et al*., 2012; Gulley *et al*., 2013) therefore we will heavily draw upon examples from the Canterbury earthquake sequence in the following section.

3.2.2.1 Seismic impacts to source water supply volume

Hydrologic responses to earthquakes have been observed and documented for thousands of years (Montgomery and Manga, 2003; Wang and Manga, 2010). Commonly observed hydrologic responses are changes in stream and spring flow and changes in groundwater levels, other impacts include liquefaction, mud volcano eruptions and changes in water chemistry, temperature and turbidity (see Table 1 of Wang and Manga, 2010, for a list of examples of earthquake triggered hydrologic phenomena). Figure 3.9 shows simplified interactions between earthquakes and hydrologic processes. Changes to stream and spring flow and changes in groundwater levels due to earthquakes range from transient, with normal conditions resuming within hours to days of the earthquake, to sustained with changes lasting years, to permanent.

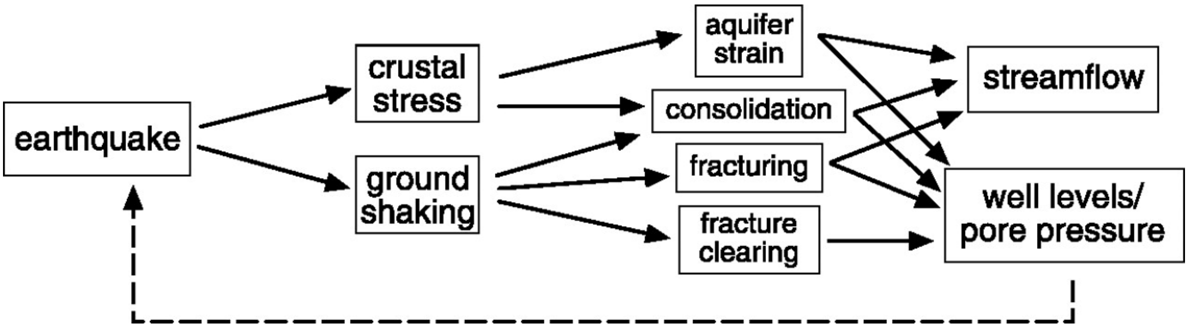


Figure 3.9: Interactions between earthquakes and hydrological processes, image from Montgomery and Manga, 2003.

Changes in stream and spring flows following earthquakes have been quantatively documented in a number of case studies. For examples, the 2001 M_w6.8 Nisqually earthquake near Seattle in which 67 out of 161 stream gauges within 115 km of the epicentre showed a streamflow change (Montgomery *et al*., 2003), and the 1983 M_w7.0 Borah Peak earthquake in Idaho which doubled the flow rates of some rivers for several months after the event (Muir-Wood and King, 1993). Typically, changes in stream and spring flow are seen within tens to hundreds of kilometres of the earthquake epicentre and most commonly an increase in stream discharge is observed, rather than a decrease (Montgomery and Manga, 2003). Likewise, observations of new springs appearing after earthquakes seem to be more common than drying up of existing springs. The cause of increased surface and spring water flow is not fully understood and probably varies with geologic setting and earthquake mechanism, but it is often attributed to increased permeability: the earthquake produces dynamic strain that can dislodge blockages from fractures thus enhancing permeability (Wang and Manga, 2010). Transient changes in stream flow have also been attributed to coseismic aquifer deformation and expulsion of water due to consolidation of surficial deposits (Montgomery and Manga, 2003). Following the September 2010 M_W7.1 Darfield earthquake new springs appeared in the south and east of Christchurch (Cox *et al*., 2012). Cox *et al.,* suggested the cause of new springs on the Plains was fracturing or liquefaction vents that breached of confining layers of artesian aquifers, and springs that appeared adjacent to the Port Hills they attributed to increased permeability due to fracturing of volcanic rocks. Cox *et al.,* (2012) noted that most new springs were relatively small seeps that formed a minor portion of the total groundwater flow in Christchurch.

Changes in ground water levels are widely observed phenomena following earthquakes, with a remarkable feature being the distance from the earthquake epicentre at which effects are seen. For example, the 2010 M_W7.1 Darfield earthquake in Canterbury caused a short-term 65 mm increase in groundwater level at a bore hole in Whangarei, ~900 km from the epicentre (Cox *et al*., 2012), and the 2002 M_W7.9 Denali Fault earthquake in Alaska caused a 0.6 m water-level rise in a well in Wisconsin, more than a 1600 km from the epicentre (Sneed *et al*., accessed 2014), the even larger 1964 M_W9.2 Alaska earthquake was recorded in wells across the mainland USA and in other countries as far afield as England, South Africa and Australia (Vorhis, 1967).

Groundwater responses to earthquakes are most often manifest as an instantaneous water level offset, or step-change, as recorded by bore hole monitors (Figure 3.10A). In some cases, depending on sampling rate, high frequency oscillations of groundwater are recorded, such oscillations may reflect the passage of seismic waves (Figure 3.10B). There have been a number of detailed case studies of groundwater responses to earthquakes, one of the most detailed studies comes from Taiwan where a dense network of wells recorded the effects of the 1999 M_W7.5 Chichi earthquake (Chia *et al*., 2008; Lee *et al*., 2002). The M_W7.5 Chichi earthquake caused groundwater rises up to 7.4 m at 27 km from the fault, and water level falls up 11 m at 2 km from the fault (Chia *et al*., 2008).

A notable case study, due to its effect on household water supplies, was the 1998 M_W5.2 Pymatuning earthquake in north-western Pennsylvania, USA, which caused about 120 local household-supply water wells to go dry within three months following the earthquake (Fleeger *et al*., 1999). Wells on a ridgeline saw groundwater decreases of up to 30 m, while groundwater level in an adjacent valley rose, it was suggested that the earthquake caused an increase in vertical hydraulic conductivity of the bedrock beneath the ridge, which allowed ground water to drain from the hilltops and into the valley (Fleeger *et al*., 1999). This severe impact on household water wells does appear to be an extreme example, as most groundwater changes are more moderate and largely transient, as is demonstrated by the 2010 Darfield earthquake.

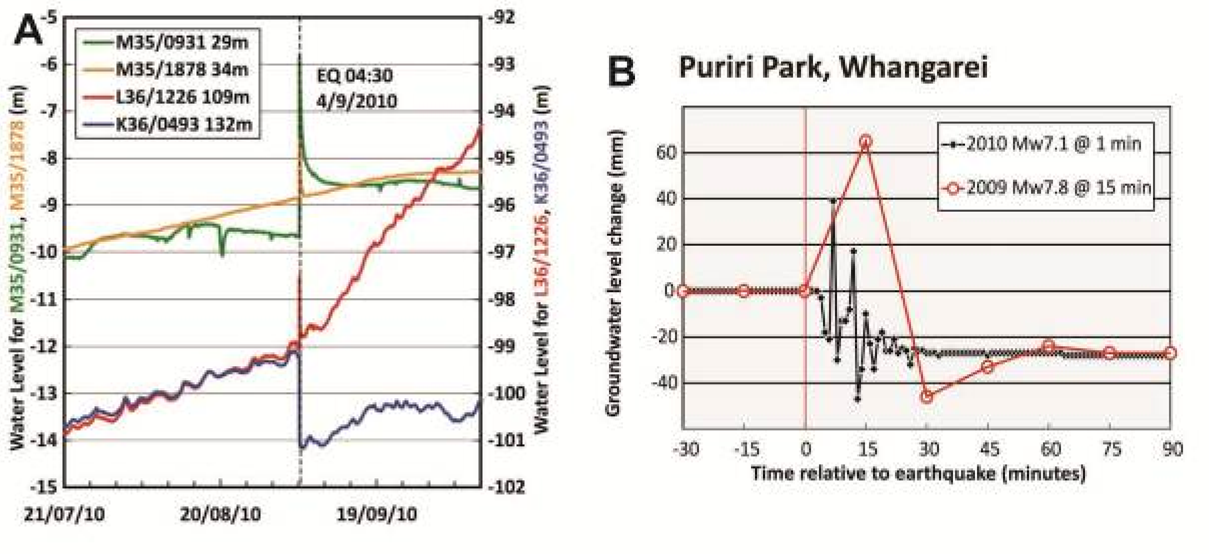


Figure 3.10: Examples of groundwater responses to the Darfield earthquake. (A) Responses from wells at intermediate (M35/0931, M34/1878) and deep (L36/1126, K36/0493). Note the coseismic spikes and the slope changes. (B) Groundwater oscillations recorded in a Whangarei bore hole, the Darfield earthquake response was recorded at 1 minute intervals (black line), and the 2009 Dusky Sound earthquake response was recorded at a 15 minute interval (red line). Figures from Cox *et al*., 2012.

The Darfield earthquake, on the Greendale Fault, caused short term (minutes-hours), short term (days), and long-term (>1 year) changes in groundwater levels in the Canterbury region (Cox *et al*., 2012; Gulley *et al*., 2013). The Canterbury plains are underlain by alluvial and (towards the coast) fine-grained estuarine sediments; unconfined, semi-confined and confined aquifers underlie the region and are an important water resource for drinking water and agriculture. Of the 257 wells in the Canterbury region, 161 wells recorded the groundwater response to the earthquake. Groundwater responses included local groundwater level increases of >20 m around the Greendale Fault, particularly in deep aquifers (>80 m), whereas decreases occurred in coastal confined aquifers beneath

Christchurch city. Increases of up to 5 m persisted within 20 km of the fault 12 h after the earthquake (Cox *et al*., 2012). Figure 3.11 summarises the distribution and type of hydrologic responses to the Darfield earthquake. The most common groundwater response to the earthquake was a short coseismic spike (positive or negative) followed by a return to pre-earthquake levels within 30 – 60 minutes of the earthquake; a coseismic spike followed a post-seismic shift to a new higher or lower level was also common. In many cases, there was a change in the slope of the hydrograph at the time of the earthquake, with the slope changes potentially reflecting permanent changes to the recharge and discharge rate of the aquifer (Cox *et al*., 2012). Studies are currently on-going to determine the long-term effects of the earthquakes on groundwater levels and aquifer functioning. The impact of the Canterbury earthquake sequence on water supply infrastructure and water quality will be discussed below.

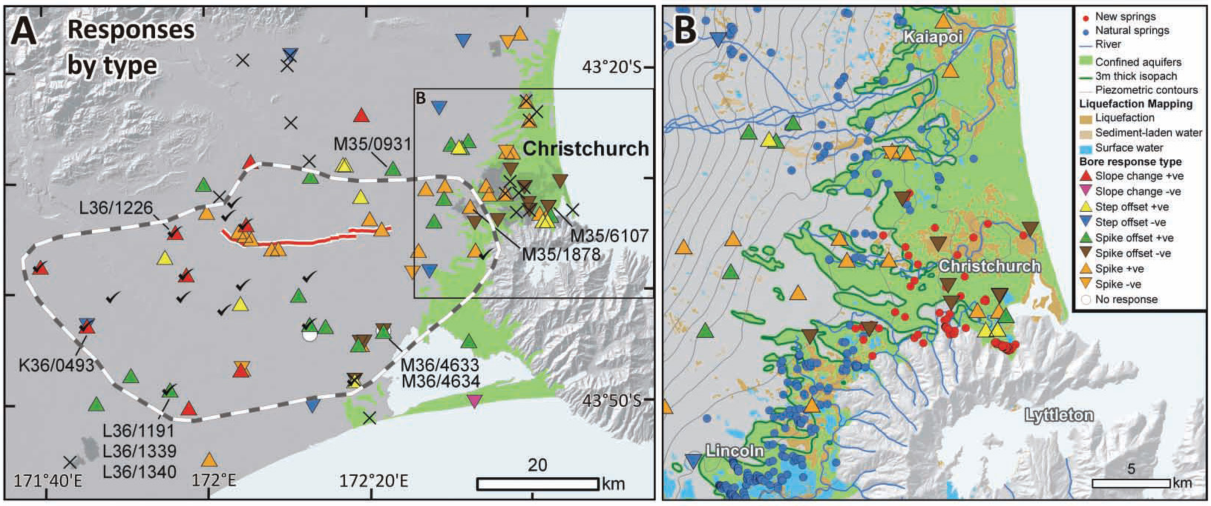


Figure 3.11: Near-field hydrologic responses to the M_W7.1 Darfield earthquake on the Greendale fault (red line on A). (A) Map of bore hole groundwater responses over the Canterbury region. Symbols are colour-coded according to different response types. Coastal confined aquifers are shown by the light green area. Ticks represent bore holes (some measured monthly) where abnormally high groundwater levels were still present in October 2011, with the region highlighted by a dashed white/dark grey line. Crosses show where groundwater levels returned to normal. (B) Enlargement of the Christchurch urban area, also showing bore hole responses, isopiezometric contours and new springs (red circles) that emerged following the M_W7.1 Darfield earthquake, compared with the location of seasonally influenced 'natural' springs (blue circles) documented by Environment Canterbury to be present prior to (and presumably after) the earthquake. Mapping of liquefaction, sediment-laden water and ponded surface water following the earthquake is from aerial and satellite images, but with limited ground truthing (Unpublished work carried out by GNS Science, Canterbury University and Tonkin and Taylor. Dougal Townsend, pers. comm.). Image and figure caption from Cox *et al*., 2012.

The causes of groundwater changes induced by earthquakes are varied and complex, but useful reviews on this topic are provided by Wang and Manga (2010) and Montgomery and Manga (2003). In general, Wang and Manga (2010) suggest that the dominant mechanisms of near-field changes in groundwater are un-drained consolidation or dilatation (i.e., ground shaking causes loose, sediments to consolidate and expel water, or fractures/pathways open up in the rock formations) while intermediate-field changes are due to earthquake-enhanced permeability. Furthermore, Wang and Manga (2010) discuss how near-field effects tend to be step-like and while intermediate-field effects tend to be gradual and sustained. Some studies have also noted that the pattern of groundwater rises and falls can mimic the strain pattern of the earthquake (e.g. Jonsson *et al*., 2003) and that the type of faulting can have an impact on the magnitude of hydrologic responses. Of note is a study by Muir-Wood and King (1993) that suggests major normal fault earthquakes produce the most significant hydrologic changes; normal faulting events are the most likely type of earthquake to occur in the locality of the Waimarino Plains.

A further way in which seismic activity can affect water supply is through direct, physical disruption of the stream bed. Earthquakes that rupture the ground surface can disrupt, divert or block surface water flow; an example of this is the September 2010 M_W7.1 Darfield earthquake on the Greendale fault. Rupture of the Greendale fault temporarily diverted the course of the Horarata River (Figure 3.12, Barrell *et al*., 2011), however, the river was relatively quickly restored to its former course by earthworks undertaken by the landowners. Permanent diversion of rivers and streams due to fault rupture is not known to be a widespread and common effect of earthquakes, most effects are temporary, but the Darfield example shows it can cause significant short term problems, which would be amplified if the stream affected was used as a water source. Earthquake-induced landslides (or landslides of any cause, such as rainfall-induced) can also block rivers and streams, and/or deliver large pulses of sediment to rivers; the sediment pulse could be a potential problem if there was a water intake downstream of the landslide.

Figure 3.12: The sinuous course of the Hororata River, flowing from upper right to upper left, is crossed by the fault in this westward view, taken 4 September. A significant portion of the river's flow is diverted towards the lower left, along the downthrown side of the fault. Photo and caption source: Barrell *et al*., 2011.

Fault rupture could also feasibly disrupt water supplies by fracturing or offsetting the confining layer of an aquifer, leading to a loss of confining layer integrity. This does not appear to be a common phenomenon and no examples have been found where this has been attributed to adversely affected water supplies. As mentioned above, some new springs in Christchurch that appeared after the Darfield earthquake may have been the result of breaching of aquifer confining layers (Cox *et al*., 2012) but the volume of water expelled in proportion to aquifer volume was not significant.

3.2.2.2 Physical impacts to water supply infrastructure

Ground shaking and ground surface rupture caused by an earthquake have the potential to damage water supply infrastructure, particularly if the infrastructure was proximal to, or crossing over a surface rupture. The most relevant example of damage to water supply infrastructure is from the 2010-2011 Canterbury earthquake sequence. Christchurch's water supply systems were badly damaged, particularly by the 22 February M_W6.3 earthquake. Figure 3.13 shows examples of damage to wells and Table 3.3 shows a summary of the damage to the fresh water supply system.

Figure 3.13: Examples of damage to wells caused by the M_W7.1 earthqauke. Some well heads rose out of the ground, while others were affected by settling/subsidence around the annulus (photos supplied by H. Rutter, Aqualinc, via Zemansky *et al*., 2012).

Table 3.3: A summary of ways in which the fresh water supply system of Christchurch city was damaged by the 2010-2011 Canterbury earthquake sequence (http://strongerchristchurch.govt.nz/work/fresh-water/damage) (accessed 28 March 2014).

Cracks	The earthquakes cracked pipe walls, reducing delivery pressure and spraying water into the surrounding ground area. This wasted water and sometimes destabilised the ground and/or utility conduits.
Breaks	Some fresh water pipe sections completely broke, particularly older pipes. Because of the potential to destabilise the ground, these pipes need to be switched off urgently before they are rebuilt.
Joint breakage	Where some pipes have been joined together, the shaking has separated the two parts again, so the pipe is essentially broken.
Contamination	Thankfully there was very little contamination from wastewater, storm water, or ground water because the water supply pipes are pressurised. However, there was some minor contamination and the risk remains in large future events. After damaging earthquakes, Christchurch City Council asks residents to boil tap water before use as a precaution until they have checked for contamination.
Reservoir damage	Some reservoirs were structurally affected but remain usable. In the long term, they will need to be restored. Huntsbury reservoir, our city's biggest, has been seriously damaged, which places significant pressure on the water supply.
Pump station damage	Pump station buildings suffered similar non-critical damage as many reservoirs. Most are operating but will need to be fixed properly in the future. One station needs a complete rebuild at a new site.
Well damage	Well casings were distorted deep under the surface in September 2010 by the horizontal movement at interfaces between the layers of earth (strata). That effect is known as lateral shear. In February and June 2011 – where the movement profile was much more vertical – well casings lifted, which brought many of the wells out of alignment with the water pipes.

Impacts that are potentially of greatest concern are with regards to water supply on the Waimarino Plains are: (1) bore hole collapse or shearing off of well headworks due to ground shaking, (2) severe damage to pipelines and other infrastructure due to active fault surface rupture.

Bore hole collapse may occur due to ground shaking reaching such a level that the sediments and rock formations around the bore collapse inwards; shearing or dislocation of the headworks from the bore hole can be produced when lateral or vertical ground motions exceed the flexibility of the couplings between the well and the headworks. These effects can be mitigated against, for example, Christchurch City Council is strengthening their well network by: (1) using an exterior casing down to 50 m and grouting the bore hole casing within the bore hole, thereby strengthening the bore hole, and (2) redesigning well heads with heavy articulated flexible bellow couplings to allow differential movement (Zemansky *et al*., 2012).

Where a water supply pipeline crosses an active fault, it is possible that an earthquake on that fault will cause permanent rupture of the ground surface, therefore rupturing or severely damaging the pipeline. The amount and direction of ground movement in an earthquake varies with earthquake magnitude and faulting style. In the Waimarino Plains area, all known active faults are normal faults meaning that one side of the fault will drop down relative to the other, in an extensional style (see Figure 3.14 for the fault styles). Damage to pipelines can be partially to fully mitigated, firstly by locating as accurately as possible where the active fault scarps are in the pipe network, and then designing a flexible pipe system that can accommodate the amount and direction of movement that may be expected should the active fault rupture. In addition, extra shut off valves either side of the fault can be added to the piping network to allow for a quicker rebuild in the case of any damage from seismic events. Critical infrastructure in the water supply network such as pumping stations and bore holes should not be sited upon active fault scarps.

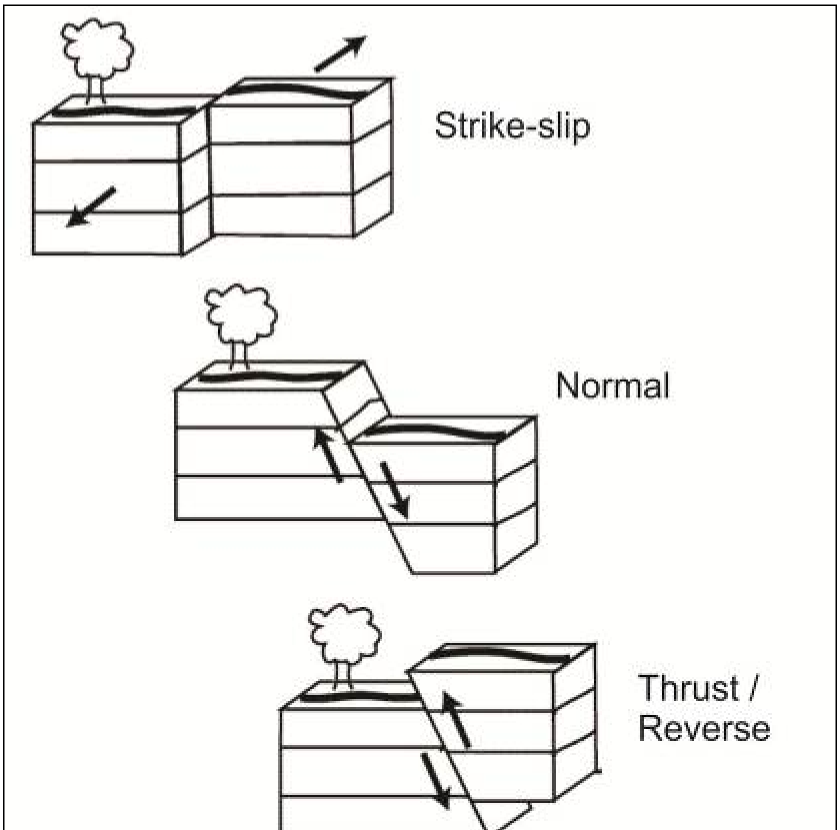


Figure 3.14: Styles of active fault movement. The most typical type of fault in the Taupo Volcanic Zone, including the Waimarino Plains, is a normal fault. Note that there can be variations on the above three basic styles, with normal and thrust faults having a strike-slip component. Figure source: adapted from USGS.

Damage to water supply infrastructure could also occur due to liquefaction, landslides and seiches/tsunami. Tsunami damage is not of concern for the inland Waimarino Plains, but if a large water reservoir was to be built then the hazard of earthquake-induced seiching should be considered. Liquefaction was responsible for a very large amount of damage to water supply infrastructure in the Canterbury earthquake sequence. Liquefaction typically occurs in uniform (single-grain size), loose, water saturated, silty or sandy ground. Areas that are particularly vulnerable to liquefaction include abandoned river channels that have been infilled by fine-grained flood sediments, young (>20,000 years) flood plains, estuaries, manmade hydraulic fills and mine tailings in ponds. The above substrates are either not present or not significant in the Waimarino Plains and liquefaction may not be a significant risk to water supply infrastructure on the Waimarino Plains. However, site-specific studies should be carried out to better understand liquefaction hazard, particularly if infrastructure is sited on, or traverses, young, alluvial sediments. Landslides are commonly triggered by earthquakes (also note that landslides can be triggered by a number of mechanisms, including rainfall), and they could present a hazard to water supply infrastructure. Large landslides are unlikely to occur on the relatively gentle topography of the Waimarino Plains but other types of mass movement such as debris flows, slumps, creeps, and lateral spread can also severely disrupt water supply infrastructure, particularly underground pipes. Water supply infrastructure should not be located on sites of active or recently active mass movement, or in locations vulnerable to mass movement. Site specific studies can be carried out to assess landslide hazards, particularly if the water supply infrastructure in on steep topography, or in an area of highly erodible sedimentary rocks.

3.2.2.3 Impacts to water quality

Earthquakes can have an impact on water quality. There are examples where water chemistry, turbidity and temperature have been altered (usually adversely) by earthquakes, however in most case studies it appears the effects for short-term. Following the Darfield earthquake and the 22 February 2011 M_W6.3 earthquake there was significant concern in Christchurch about the effect of earthquakes on drinking water quality for the following reasons: (1) potential for mixing of water between aquifers; (2) influx of water from different areas; (3) changes in dissolved gas concentrations; (4) re-dissolving of precipitated minerals; and (5) infiltration of pollutants from soil or ground surface (ECAN, 2011). A testing programme was carried out on public water supply wells in Christchurch and results were compared with pre-earthquake data; there was some increase in water turbidity and iron concentrations but overall it was concluded that no significant change in water quality that would pose a risk to water users (ECAN, 2011). In this case study, all of the drinking water for Christchurch is sourced from wells; should a water supply rely on surface water the infiltration of pollutants would be of greater hazard.

Increases in turbidity and changes in temperature are commonly recorded impacts of earthquakes but this is not as systematically studied as the changes in stream flow and ground water levels. One example of an adverse effect on water supply is from the 1992 M_W7.3 Landers earthquake (California) where gas bubbles appeared in several water supply wells, leading to clogging and disabling of the filtration system (Roeloffs *et al.*, 1995).

3.3 INFORMATION GAPS AND POTENTIAL FUTURE WORK

A number of information gaps relating to knowledge of water resources and hazards in the Waimarino Plains have been identified as a result of this literature review. These knowledge gaps can be separated into three main sections: hydrology, seismic hazard and volcanic hazard. In each of these sections, the information gaps are presented and recommendations for further work are identified.

3.3.1 Hydrology

Water quality datasets are limited. There is only one groundwater quality sample from well 733003, and there are no officially documented spring water quality samples. Although several datasets for surface water quality exist, these need to be collated into a single dataset to allow for spatial and temporal comparisons to be made. It is recommended that RDC conduct additional sampling of the water source quality which will be pursued for future town supply (e.g. groundwater, surface water or spring water). In the case of spring water and groundwater, it is also recommended that RDC conduct age dating of the water to gain an understanding of the source and security.

Water quantity datasets on the volumes of groundwater and spring flow exist, but are limited. The study by TACL (2013) on well 733003 is comprehensive in estimating aquifer properties and is a good source of information. No other groundwater quantity datasets exist in the area. Two official gauging's are documented for Taonui Spring 1 (Bishops Spring), however no indication of seasonal or annual variability in spring flow rate can be gained from this. It is recommended that RDC conduct sampling of temporal spring water flow if it will be pursued for future town supply.

It is known that a well has been drilled at Park Ave, Ohakune (Westcott, personal communication 2014). Unfortunately, no further details as to the drilling company, depth, lithology, owner or purpose of the well are known at this stage. It is recommended that additional work be undertaken to track down any drilling records for this site to interpret the geology and aquifer properties. This information would be particularly useful if RDC are to consider a groundwater source for Ohakune.

Based on the information presented in the TACL (2013) report, and what is known about volcanic geology in the region, a groundwater supply source is a potential option that RDC should consider. In the first instance, it is recommended to further sample water quality from well 733003. If the results are comparable (or better) than those presented in this report, then the water quality could be sufficient for town supply. In this case, RDC are recommended to drill an exploratory well near Raetihi, at a site that could be developed into a pumping station. Based on the findings of the exploratory well, RDC have the option of water sampling for quality and age dating, pump testing to determine aquifer properties and yields. If the findings of this study and reporting are favourable for a groundwater supply option, then RDC can pursue with drilling of the town supply at this location.

Suspended sediment concentration appears to be an issue for surface water quality, particularly at the Tahonga Junction intake. A study into the composition and type of sediment entering the settling ponds could allow for determination of the sediment origin. This would then allow for preventative measures to be put in place to reduce natural or human induced erosion within the upper catchment.

3.3.2 Volcanic

This report does not constitute an exhaustive list of all possible volcanic impacts to water supplies in the Waimarino Plains area, but does discuss the most likely impacts. Interdependencies and cascading impacts with other sections, notably power and transportation (for access to infrastructure), have not been addressed, although they too are vulnerable to volcanic activity.

The frequency and quantity of ash deposited on the Waimarino Plains based historic and geologic records of activity can be assessed probabilistically on a site or region specific scale. At the moment Figure 3.2 is the best indicator of total accumulated ash over 500 and 10,000 years, but it does not provide information on how many ashfall events the region might expect over that period nor the accumulation of ash from individual events.

Interdependencies with other sectors might be worth investigating to assist planning and assessment of capabilities if power or other critical infrastructure is unavailable due to a volcanic event.

3.3.3 Seismic

The information presented here is not an exhaustive list of all possible geologic hazards to water supplies in the Waimarino Plains area. Depending on the water source selected, its location, and location of related infrastructure other geologic hazards may deserve particular attention, including landslides and liquefaction. Landslides and liquefaction have been briefly discussed above in relation to seismically-triggered hazards, but they have not been reviewed in any detail for this report.

Active faults should be avoided when locating water supply infrastructure. The locations of active faults could be better constrained by undertaking higher level of active fault mapping, this could be done using a higher resolution digital terrain model (e.g. LiDAR) or by field work to capture the fault locations using precise global positioning systems (GPS).

Where pipelines cross active faults, studies should be undertaken to better estimate the amount of fault scarp displacement expected during a future earthquake and to constrain the frequency (recurrence interval) of such earthquakes. Knowing the expected single event displacement may allow the infrastructure to be designed to accommodate that amount of movement.

The Raetihi water treatment plant is located close to or atop of the Raetihi North Fault, and the Ohakune water treatment plant is located within 50 m of the zone of uncertainty around the location of the Ohakune Fault. Mapping of the Raetihi North Fault and Ohakune Faults in the vicinity of the water treatment plants would decrease the uncertainty on the location of the active fault. Trenching the fault scarps near the water treatment plants may yield a better estimate of the fault slip rate and single event displacement.

The level and frequency of ground shaking at any particular site on the Waimarino Plains could be better understood by doing a site-specific study. The NSHM presents an overview of ground shaking hazard in New Zealand but for the design of any critical infrastructure, a site-specific study of ground shaking needs to be undertaken.

Liquefaction and landslide hazards have only briefly been addresses in this report and may need to be investigated in future.

3.4 ESTIMATED COSTS AND TIMEFRAME

A summary of potential tasks which could be carried out to further understand the hydrology and geological hazards in the Waimarino Plains area has been provided in Table 3.4. This table provides an indicative cost and timeframe to undertake the work. If required, specific projects can be developed to address certain information gaps to align with RDC's budget and requirements.

Table 3.4: Estimated timeframe and estimated costing for potential tasks that could be undertaken to better understand the hydrology and geological risks within the Waimarino Plains area.

Task description	Timeframe	Estimated cost
Establishment of a sampling plan, collection, analysis and interpretation of water samples for chemistry and selected samples for age dating	Field sampling 1 – 2 days Chemistry analysis: 1 – 2 weeks Age Dating analysis: 2 – 3 months	$6,500 + age dating analysis @ $1,300 / sample
Flow measurement of spring volumes	1 week	$6,000
Information on location of non-registered bores / wells in the RDC region (e.g., Park Ave)	unknown	most cost effective for RDC to follow up
Comprehensive exploratory drilling of bore hole including: geological logging, water sampling for chemistry and age dating, aquifer testing and reporting	1 – 2 months	$50,000 – $60,000 for 6" diameter, air rotary drilling, casing to c. 100 m and 6 m stainless steel screen Plus: $30,000 - $40,000 hydrogeological services
Study into the origin of suspended sediment within the source catchment	1 – 2 months including field work and analysis	$20,000
Risk assessment of volcanic hazard on infrastructure in the region	2 – 3 months	$20,000 (to be verified)
Site specific study of ground shaking on proposed new infrastructure	1 month	$ 7 – 5,000 (per site)
Site specific investigations of active faults near existing water pipelines and water treatment plants	4 – 6 months	$25,000 - $60,000 (depends on whether fault trenching is required)
Mapping of active faults in the vicinity of proposed new water infrastructure. Project could vary from desktop study to report on locations of active faults to site visits and detailed fault surveying.	2 months	$5,000 – 40,000
Investigation into the potential effects of liquefaction and landslides on infrastructure	3 - 4 months	$50,000

4.0 SUMMARY

RDC is considering long term options for upgrading town water supplies to Raetihi and Ohakune townships. Issues include an aging pipeline network, and water quality degradation of the Raetihi supply from diesel contamination and an increase in suspended sediment content. RDC wish to comprehensively consider the best option for maintaining or developing the water supply, particularly in a region prone to volcanic and seismic events and associated hazards. Key features to consider for the supply source to each town include: water quality, water quantity, supply security, and risk of the supply source and infrastructure to volcanic and seismic events.

The following key findings have been determined based on a review of water source supply options (surface-, spring-, and ground- water) and geological hazards for the Waimarino Plains. Consideration of these risks and knowledge gaps, which are described in detail in Section 3 of this report, need to be considered when identifying appropriate long-term water supply sources and associated infrastructure development. A summary of the review for each of the supply options is provided in the following sections:

4.1 SURFACE WATER

1. The source of surface water in rivers and streams originates from precipitation that falls on Ruapehu and does not infiltrate the shallow geology, and from groundwater that emerges as springs (particularly in the Taonui catchment).
2. There are no known water quality issues affecting the current Ohakune surface water supply from Serpentine (Tutara) Stream.
3. Hydrocarbon contamination from a diesel spill at Turoa ski-field in 2013 continues to affect the Raetihi supply. It is unknown how long it will take to flush the diesel from the Makotuku catchment. Although monitoring equipment has been installed to measure hydrocarbon levels in the stream, this does not remove the risk of future contamination from a diesel spill at the ski field. Infrastructure or procedures associated with ski-field operations should be put into place to minimise this risk.
4. Visual observations indicate that the suspended sediment concentration in Makotuku Stream has increased. Prior to initiating remediation measures, the hydrological processes contributing to the increase in sediment, and the source of sediment, need to be identified. For example, it is unknown if baseflow sediment levels have increased or if sediment mobilisation occurs during rainfall events. Options for determining the source/s include development of a spatial and temporal suspended sediment monitoring program. In addition, sampling of surface water and reservoir sediment using tracing methods such as x-ray diffraction (XRD) could identify if the source is land use (e.g. native forest, agriculture) related. Following identification of sediment sources, mitigation measures (e.g. riparian planting, sediment traps, diverting flow, farming management practices, slope stabilisation) could be initiated to reduce volumes of sediment in the surface water; or an alternative supply source may need to be found.
5. Surface water supplies to Raetihi and Ohakune are currently of a sufficient quantity to supply the townships in the future. This is based on predicted static or declining permanent populations. The ability of each WTP to process and store enough water to meet the predicted increased demand during the peak tourist season (winter) is an infrastructure consideration, and beyond the scope of this report.

6. In the case of a volcanic eruption, it is highly likely that volcanic ashfall will contaminate surface water. Ash particles can react with volcanic gases including water, HCl, SO_2, H_2S, CO_2 and HF which dissolve into surface water. In addition, acidification can occur as up to 55 dissolved ions and fluoride can enter the surface water supply. The most common major leachates from volcanic ash are Cl, Na, Ca, Mg, and F, and the most common minor leachates are Mn, Zn, Ba, Se, Br, B, Al, Si, Cd, Pb, As, Cu, and Fe.

   Ash can cause major issues for water supply infrastructure, and in general the best mitigation measure is to stop ash ingress occurring. Ash can block the intake, filters, pipes, damage electrical systems and increase wear on infrastructure components. Prevention of ash ingress to the plant can be reduced by use of an initial flocculation (sedimentation) trap, or to temporarily shut down the plant. Another issue is that increased turbidity from ash can compromise the water treatment process.

   The simplest mitigation measures are to cover all surface water supplies (reservoirs) prior to an eruption to prevent ash fall, and to shut down the supply intake as soon as an eruption occurs. Covering the reservoirs could be difficult and/or costly to employ in protecting the Waimarino Plains surface water supply. Alternative storage (e.g. concrete tanks) capable of holding large volumes (e.g. 2 – 3 days of treated water supply) should be considered as an option.

7. Surface water supply sources can be dammed by lava flows, lahars and pyroclastic density current deposits. Although these events are possible, there is a low likelihood of occurrence in the Waimarino Plains.

8. During seismic events the stream bed can be physically disrupted, and flow diverted or blocked. Although permanent disruption to stream bed and flow can occur, most effects are temporary. Given that the stream catchments are confined within valleys, and follow dendritic drainage systems aligned with the mountain side, is unlikely. Stream bed disruption is slightly more likely on the plains where the gradient reduces.

9. Landslides (potentially induced by, but not limited to, seismic or volcanic activity) can block rivers and streams, or deliver pulses of sediment to rivers. These impacts would cause problems to water supplies and require temporary sources to be arranged while remediation measures are implemented.

4.2 SPRING WATER

10. Springs that emerge on the western slopes of Mt. Ruapehu are formed when precipitation that has fallen at higher altitude infiltrates the volcanic sediments, flows down gradient and emerges as a spring.

    Spring flow rate for Bishops Spring (Taonui 1) was measured to be 38 – 39 L s^{-1}, the average of which is 3,326 m^3 day^{-1}. No other spring flow rate information was obtained for this review.

    Additional flow rate measurements of any supply springs and surrounding springs are required to determine any seasonal flow rate change. If the spring water option is pursued, an understanding of temporal flow rates are required to ensure water quantity is sufficient throughout the year, especially during critical dry periods.

11. No official laboratory results for water quality of the springs have been identified. If springs are to be pursued as a supply option, water quality sampling and evaluation with the NZDWS:2005 are required to ensure the supply is suitable for domestic water supply.

12. Springs provide a more secure supply than surface water because they have a source that is protected from the atmosphere. Water that emerges from springs has travelled through local geology (e.g. lava flows), which provides a natural filter from volcanic eruptive sediments that occur on the land surface.

13. So long as a spring head is constructed and secured appropriately, then the security of the supply will generally increase with greater distance from the recharge source.

14. The springs currently supply a substantial proportion of baseflow to the Taonui Stream. Therefore, the influence of abstracting spring water on the downstream environment would need to be considered for environmental, cultural and economic effects (e.g. Assessment of Environmental Effects).

15. Spring water supply sources are: at a moderate risk from ash fall contamination to the catchment and storage ponds; very low risk of damage to infrastructure by lahar or lava flows; and possible damage to infrastructure through seismic events.

16. Although there are examples of springs drying up following a volcanic event, it is more common for new springs to appear, or for discharge to increase. Seismic events can also change spring flow rates and locations. It is not known what influence volcanic eruptions and seismic events have historically had, or will potentially have, on spring water quality, quantity and distribution on Mt Ruapehu, and whether the impacts are short, or long term. Increases in spring water flow resulting from a seismic event are not properly understood, but are thought to be associated with increased permeability of the aquifer unit.

4.3 GROUNDWATER

17. Of the 19 bores within the greater Waimarino Plains, five bores are located in close proximity to Raetihi and Ohakune. These bores are at a depth of 7.7 – 101.6 m BGL. The deepest bore (Balle Bros., 733003) is located 4km north-west of Raetihi.

18. Bore 733003 is 150 mm in diameter, has been drilled to a depth of 101.6 m BGL, and is screened in volcanic sediments from 86.4 – 100.0 m BGL. The static water level is 15.9 m BGL and the bore is capable of being pumped at a rate equivalent to, or greater than 50 m^3 hr^{-1} (1,200 m^3 day^{-1}). The bore is screened in an unconfined aquifer.

19. A similar supply bore would likely be sufficient to meet the current water demand for Raetihi (812 m^3 day^{-1}) and the estimated peak demand for 2030 of 986 m^3 day^{-1}. If required, additional volume can be obtained from the aquifer through a greater diameter well, or through multiple wells.

20. Although results are limited, all water quality values bores in the Waimarino Plains fall within MAV New Zealand National Drinking Water Standards (Ministry of Health, 2008).

21. Based on two samples, nitrate contamination is evident in the shallow (7.7 m BGL) groundwater well (733001). Nitrate concentration in this well is inconsistent, and varied from 45 mg/L (1996) to 11 mg/L (1999). Both these values are below the NZDWS MAV of 50 mg/L; however these elevated values indicate land use impact. Based on a single sample, elevated nitrate concentrations do not occur in well 733003, reflecting the more secure deeper supply source that is free from land use impacts.

22. Iron concentration (0.29 mg/L) for well 733003 exceeded the GV for NZDWS (2005) of 0.20 mg/L. However, this is based on only one sample, and requires verification through additional water quality testing. Elevated levels of iron can cause negative aesthetic effects (e.g. taste, discolouration).

23. Water quality sampling of well 733003 is required to indicate the suitability of groundwater from this aquifer for town supply. Potential treatment methods (e.g decreasing Fe concentration) would then be required based on these results.

24. The limited available data indicate that groundwater is present up to a maximum depth of approximately 100 m BGL in the vicinity of Raetihi. Information obtained from geological log (TACL, 2013) indicates permeable volcanic sediments to 100 m BGL, below which an impermeable layer of sandstone (papa) occurs.

25. If a groundwater supply is pursued, drilling of an exploratory well to approximately 100 m BGL is strongly recommended. Appropriate hydrogeological sampling including geological logging, water quality, age approximation and water quantity of the exploratory well should be undertaken during drilling. Based on the findings of exploratory well water quality and quantity, a decision can be made on the installation of a production well (e.g. depth, casing size, screen depth placement).

26. Shallow groundwater is at high risk from being affected from land use and land surface processes (e.g. increased nutrients from agriculture; and fluoride, iron and sulphate contamination from ash fall events), in comparison to deeper groundwater.

27. A local seismic event could damage the well casing which would require that the well be re-drilled, or remediated to allow well casings to be replaced. The best mitigation measure is to ensure the well and pumping stations are not constructed on a fault.

28. A well is likely to negate the need for extensive pipe networks across the plains, which minimises the seismic risk due to localisation of infrastructure. Mitigation measures for groundwater can also include strengthening the borehole (e.g. placing additional exterior casing and grouting), and redesigning well heads to allow for flexible differential movement.

29. Groundwater flow patterns can be changed when there is a volcanic intrusion or when magma ascends towards the land surface, however this impact is not common. In addition, the style of volcanism at Ruapehu suggests that this is very unlikely.

30. Groundwater responses to earthquakes are most commonly an instantaneous water level offset, however most groundwater changes are moderate and largely transient. Water quality can be affected if water is mixed between different aquifers, or when pollutants from the ground surface infiltrate sediments. Both these issues are unlikely to be relevant in the Waimarino Plains as the aquifer is reported to be unconfined, and the water is sourced from depth (80 – 100 m BGL).

4.4 GEOLOGICAL HAZARDS RELATING TO ALL SUPPLY SOURCES

31. Three active fault sets occur in the Waimarino Plains area including the: NNE-trending Mt Ruapehu Graben; the E-W and ESE-WNW-trending Ohakune and Raetihi Fault set; and the NE-trending Karioi fault set. Active faults are at RI class I and II, indicating recurrence intervals of ≤2,000 years, and >2,000 to ≤3,500 years, respectively.

32. Water treatment facilities are considered to be a structure of high value to the community, and guidelines indicate they should not be placed on, or in close proximity to, RI I, II or II faults. Currently, both the Raetihi and Ohakune WTP's are located on, or in close proximity (±150 m) to active faults. This is an issue that should be addressed in future water supply infrastructure development in the Waimarino Plains.

33. Currently, the faults have an uncertainty of ±150 m which can be reduced with additional research (e.g. through field verification).

34. The majority of the plains are mapped as a low lahar risk zone (reoccurrence 12,000 – 25,000 years). Although Ruapehu flows have reached the plains over geologic time, none have occurred in the past 10,000 years.

35. Ground shaking and ground surface rupture can potentially damage water supply infrastructure, particularly when in close proximity to, or overlying a fault. One of the primary concerns for the Waimarino Plains is severe damage to pipelines. Pipeline

damage can be partially to fully mitigated, by locating pipe networks away from active faults / scarps, or by designing flexible pipe systems to accommodate the direction and intensity of movement expected from a fault rupture. In addition, valves can be fitted either side of active faults to allow for quicker remediation of there are damaging events.

36. Flow events (e.g. lava flows, lahars, and pyroclastic density currents) have a very low potential to affect the Waimarino Plains water supply options. The best mitigation measure to prevent damage to water supply infrastructure from flow events is to locate infrastructure away from likely flow paths. Given that flows generally follow drainages, this may be difficult to do in the case of surface water supply.
37. The Waimarino Plains can expect approximately 8 mm of ash accumulation over a 500 year period, although it is highly unlikely that 8 mm of ash fall would occur in a single event. As the plains are located upwind of the predominant volcanic centres, the region is generally shielded from high volcanic ash impacts. In the case of a northerly wind direction, the plains could receive the bulk of the tephra deposit. In any case, 8-10 mm of ashfall should not cause significant damage to the supply infrastructure if the suggested operational and mitigation measures are followed.
38. In each case of water supply, the cost of infrastructure required for the water sources needs to be weighed up or assessed against the potential risk to the infrastructure from seismic events. (For example, the risk of contamination of the supply from an eruptive event for surface water supply is high, and for spring and groundwater supply is low).
39. Seismic activity can cause short to long-term changes in spring discharge, stream flow and groundwater levels. Changes in these aspects can be transient (resuming to normal within hours), sustained (lasting years), or permanent.
40. Water supply infrastructure can also be damaged by liquefaction. Liquefaction is most likely to affect abandoned river channels that have been infilled by fine-grained flood sediments. There is likely to be low risk from liquefaction in the Waimarino Plains, however studies can be undertaken to understand the hazard on young, alluvial sediments.

No information obtained in this study has indicated that any of the potential supply sources should be eliminated. Therefore, surface-, spring-, and ground- water supply sources are all still viable options for RDC to pursue for town supplies. In each case, it is recommended that additional information as detailed in Section 3.3 (e.g. water quality, water quantity, identification of sediment source, verification of active faults), be obtained in order to gain a better understanding of the supply characteristics. In particular, sustained water quality and water quantity are important factors to understand and consider. Each supply option has an associated risk from geological hazards, and further work needs to be instigated to assess the risk.

Based on the findings in this review, it is recommended that a groundwater supply source, assuming it is off appropriate quality and quantity, would provide the most secure continued supply for the future. Surface water sources (streams, rivers and springs) are the most ‘at risk’ from volcanic and seismic hazards due to a combination of their source location on Mt. Ruapehu, and infrastructure requirements (e.g. distances required for piping networks; reservoir storage; continued supply issues during and following seismic and volcanic events).

5.0 REFERENCES

Amo, C. 2013. http://www.philstar.com/headlines/2013/06/05/950297/springs-around-mayon-drying-phivolcs.

Barrell, D. J. A.; Litchfield, N. J.; Townsend, D. B.; Quigley, M.; Van Dissen, R. J.; Cosgrove, R.; Cox, S. C.; Furlong, K.; Villamor, P.; Begg, J. G.; Hemmings-Sykes, S.; Jongens, R.; Mackenzie, H.; Noble, D.; Stahl, T.; Bilderback, E.; Duffy, B.; Henham, H.; Klahn, A.; Lang, E. M. W.; Moody, L.; Nicol, R.; Pedley, K.; and Smith, A. 2011; Strike-slip ground-surface rupture (Greendale Fault) associated with the 4 September 2010 Darfield earthquake, Canterbury, New Zealand: Quarterly Journal of Engineering Geology and Hydrogeology, v. 44, no. 3, p. 283-291.

Blong, R.J. 1984. Volcanic hazards – a sourcebook on the effects of eruptions. Academic Press, Sydney 424 pp.

Brown, L.J. 1990. New Zealand Water Well Drillers' guide to logging water wells. New Zealand Geological Survey Report 145, Lower Hutt.

Chia, Y.; Chiu, J. J.; Chiang, Y.-H.; Lee, T.-P.; Wu, Y.-M.; Horng, M.-J. 2008. Implications of coseismic groundwater level changes observed at multiple-well monitoring stations: Geophysical Journal International, v. 172, no. 1, p. 293-301.

Cox, S. C.; Rutter, H. K.; Sims, A.; Manga, M.; Weir, J. J.; Ezzy, T.; White, P. A.; Horton, T. W.; and Scott, D. 2012. Hydrological effects of the M W 7.1 Darfield (Canterbury) earthquake, 4 September 2010, New Zealand: New Zealand Journal of Geology and Geophysics, v. 55, no. 3, p. 231-247.

Deligne, N.I. 2012. After the flow: landscape response to the emplacement of Holocene lava flows, Central Oregon Cascades, USA. PhD thesis, University of Oregon. 217 p.

ECAN. 2011. Earthquake impacts on groundwater. Update Report #3. http://ecan.govt.nz/publications/General/earthquake-impacts-groundwater-update-3-010911.pdf. Accessed March, 2014.

Evans, W.C.; van Soest, M.C.; Mariner, R.H.; Hurwitz, S.; Ingebritsen, S.E.; Wicks Jr. C.W.; Schmidt, M.W. 2004. Magmatic intrusion west of Three Sisters, central Oregon, USA: The perspective from spring geochemistry. Geology v. 32; no.1; p.69–72; DOI 10.1130/G19974.1.

Fetter, C.W., 2001. Applied Hydrogeology (4th ed.). Prentice-Hall, Upper Saddle River, New Jersey, 598 p.

Freeze, R.A., Cherry, J.A., 1979. Groundwater. Prentice-Hall, 604 p.

Fleeger, G. M.; Goode, D. J.; Buckwalter, T. F.; Risser, D. W. 1999. Hydrologic effects of the Pymatuning Earthquake of September 25, 1998, in Northwestern Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 99-4170, p. 8 p.

Gulley, A. K.; Dudley Ward, N. F.; Cox, S. C.; Kaipio, J. P. 2013. Groundwater responses to the recent Canterbury earthquakes: a comparison: Journal of Hydrology, v. 504, no. 0, p. 171-181.

Hamblin, W.K. 1994. Late Cenozoic lava dams in the western Grand Canyon: Boulder, Colorado, Geological Society of America Memoir 183, 139 p.

Horizons Regional Council, 2014. Dataset request for all groundwater information available within 35 km of the Waimarino Plains. Dataset requested on 21.02.14, dataset obtained on 17.03.14.

Hurst, T., Smith, W. 2010. Volcanic ashfall in new Zealand – probabilistic hazard modelling for multiple sources. New Zealand Journal of Geology and Geophysics, v. 53 no. 1, p 1-14.

Johnston, D.M. 1997. Physical and social impacts of past and future volcanic eruptions in New Zealand. Unpublished PhD thesis, Massey, 423 p.

Jonsson, S.; Segall, P.; Pedersen, R.; Bjornsson, G. 2003. Post-earthquake ground movements correlated to pore-pressure transients: Nature, v. 424, no. 6945, p. 179-183.

Kerr, J.; Nathan, S.; Van Dissen, R.; Webb, P.; Brunsdon, D.; King, A. 2004. Planning for Development of Land on or Close to Active Faults: A guideline to assist resource management planners in New Zealand Ministry for the Environment, Wellington., v. http://www.mfe.govt.nz/publications/rma/planning-development-active-faults-dec04/planning-development-active-faults-dec04.pdf, p. 68 p.

Lee, J.; Bland, K.; Townsend, D.; Kamp, P. 2011. Geology of the Hawke's Bay area. Institute of Geological and Nuclear Sciences 1:250 000 Geological Map.

Lee, M.; Liu, T.-K.; Ma, K.-F.; Chang, Y.-M. 2002. Coseismic hydrological changes associated with dislocation of the September 21, 1999 Chichi earthquake, Taiwan: Geophysical Research Letters, v. 29, no. 17, p. 1824.

Ministry Of Economic Development. (2014). New Zealand Petroleum & Minerals online exploration database, https://data.nzpam.govt.nz/GOLD/system/mainframe.asp, last accessed March 2014.

Ministry of Health. 2008. Drinking-water Standards for New Zealand 2005 (Revised, 2008). Ministry of Health, Wellington, New Zealand. 163 p. Available online at: http://www.moh.govt.nz.

Montgomery, D. R.; Manga, M. 2003. Streamflow and Water Well Responses to Earthquakes: Science, v. 300, no. 5628, p. 2047-2049.

Montgomery, D. R.; Greenberg, H. M.; Smith, D. T. 2003. Streamflow response to the Nisqually earthquake: Earth and Planetary Science Letters, v. 209, no. 1–2, p. 19-28.

Muir-Wood, R.; King, G. C. P. 1993. Hydrological signatures of earthquake strain: Journal of Geophysical Research: Solid Earth, v. 98, no. B12, p. 22035-22068.

Neall, V.E.; Cronin, S.J.; Donoghue, S.L.; Hodgson, K.A.; Lecointre, J.A.; Palmer, A.S.; Purves, A.M.; Stewart, R.B. 2001. Lahar Hazards Map for Ruapehu Volcano. Institute of Natural Resources – Massey University, Soil and Earth Sciences Occasional Publication No. 1.

Neall, V.E.; Houghton B.F.; Cronin, S.J.; Donoghue, S.L.; Hodgson, K.A.; Johnston, D.M.; Lecointre, J.A.; Mitchell, A.R. 1999. Volcanic hazards at Ruapehu volcano. Volcanic hazard information series 8. Ministry of Civil Defence, Wellington, Volcanic hazards information series, No. 8.

Opus International Consultants Limited (Opus), 2001. Raetihi Water Supply, Ruapehu District Council. Opus International Consultants Limited, Hamilton. p. 16 + Appendices.

Roeloffs, E.; Danskin, W. R.; Farrarr, C. D.; Galloway, D. L.; Hamlin, S. N.; Quilty, E. G.; Quinn, H. M.; Schaefer, D. H.; Sorey, M. L.; Woodcock, D. E. 1995. Hydrologic effects of the June 28, 1992 Landers earthquake: U. S. Geological Survey Open File report 95-42.

Sneed, M.; Galloway, D. L.; Cunningham, W. L. accessed 2014. Earthquakes - Rattling the Earth's Plumbing System: U.S. Geological Survey Fact Sheet 096-03 http://pubs.usgs.gov/fs/fs-096-03/#pdf.

Steingrímsson, J. 1788. Fires of the Earth: The Laki eruption 1783 – 1784: Reykjavik, Iceland, Nordic Volcanological Institute and the University of Iceland Press, 93 p. (English translation of the original 1788 text).

Stewart, C. 2014. Carol Stewart, Research Affiliate, Joint Centre for Disaster Research, GNS Science / Massey University. Personal communication, February – March, 2014. stewart.carol@xtra.co.nz.

Stewart, C.; Johnston, D.M.; Leonard, G.S.; Horwell, C.J.; Thordarson, T.; Cronin, S.J. 2006. Contamination of water supplies by volcanic ashfall: A literature review and simple impact modelling. Journal of Volcanology and Geothermal Research Volume 158, Issue 3-4, 15 November 2006, Pages 296-306 DOI 10.1016/j.jvolgeores.2006.07.002.

Stirling, M.; McVerry, G.; Gerstenberger, M.; Litchfield, N.; Van Dissen, R.; Berryman, K.; Barnes, P.; Wallace, L.; Bradley, B.; Villamor, P.; Langridge, R.; Lamarche, G.; Nodder, S.; Reyners, M.; Rhoades, D. A.; Smith, W.; Nicol, A.; Pettinga, J. R.; Clark, K.; Jacobs, K. 2012. National Seismic Hazard Model for New Zealand: 2010 Update: Bulletin of Seismological Society of America, v. 102, no. 4, p. 1514-1542; doi: 1510.1785/0120110170.

Terra Aqua Consultants Limited (TACL), 2013. Assessment of Environmental Effects of Taking Groundwater at 98 Harris Road, Raetihi. Terra Aqua Consultants Limited, Hamilton, p. 21.

Townsend, D.; Vonk, A.; Kamp, P. J. J.; and (compilers). 2008. Geology of the Taranaki area: scale 1:250,000. : GNS Science. Institute of Geological and Nuclear Sciences, Lower Hutt., v. 1:250,000 geological map 7. 77 p. + 1 folded map.

Townsend, D.; Vonk, A.; Kamp, P.J.J. 2008. Geology of the Taranaki Area. Institute of Geological and Nuclear Sciences 1:250 000 Geological Map.

United Water, 2010. Waimarino Water Supply Options Study (Draft Report – Issued for Comment). United Water International Pty Ltd, Papakura, 103 p

van der Raaij, R.W.; Morgenstern, U. 2007. Demonstrating security of groundwater for the New Zealand Drinking Water Standards by groundwater age-dating. 8 p. (paper 248P) IN: Trefry, M.G. (ed.) Groundwater quality 2007 : securing groundwater quality in urban and industrial environments, Fremantle, Western Australia, 2-7 December 2007 : program and proceedings. Wembley, WA: CSIRO.

van Gorp, W.A.; Temme, J.A.M.; Jantiene, E.M.; Schoorl, B and J.M. (in press) Landscape Evolution Modelling of naturally dammed rivers. Earth Surface Processes And Landforms.

Villamor, P.; Berryman, K.R. 2006a. Late Quaternary geometry and kinematics of faults at the southern termination of the Taupo Volcanic Zone, New Zealand. New Zealand Journal of Geology and Geophysics 49, 1–21.

Villamor, P.; Berryman, K.R. 2006b. Evolution of the southern termination of the Taupo Rift, New Zealand. New Zealand Journal of Geology and Geophysics 49, 23–37.

Vorhis, R. C. 1967. Hydrologic effects of the earthquake of March 27, 1964, outside Alaska : U.S. Geological Survey Professional Paper 544-C, p. C1-C53.

Wang, C.-Y.; Manga, M. 2010. Hydrologic responses to earthquakes and a general metric: Geofluids, v. 10, no. 1-2, p. 206-216.

Watson, B. 2014. Brent Watson, Senior Co-ordinator (Data Delivery) – Catchment data, Horizons Regional Council, Palmerston North, 21.02.14 - 18.06.14

Westcott, A-M., 2014. Anne-Marie Westcott, Environmental Manager, Ruapehu District Council, Taumaranui. Interview, email and phone communication between 24.01.14 – 12.06.2014

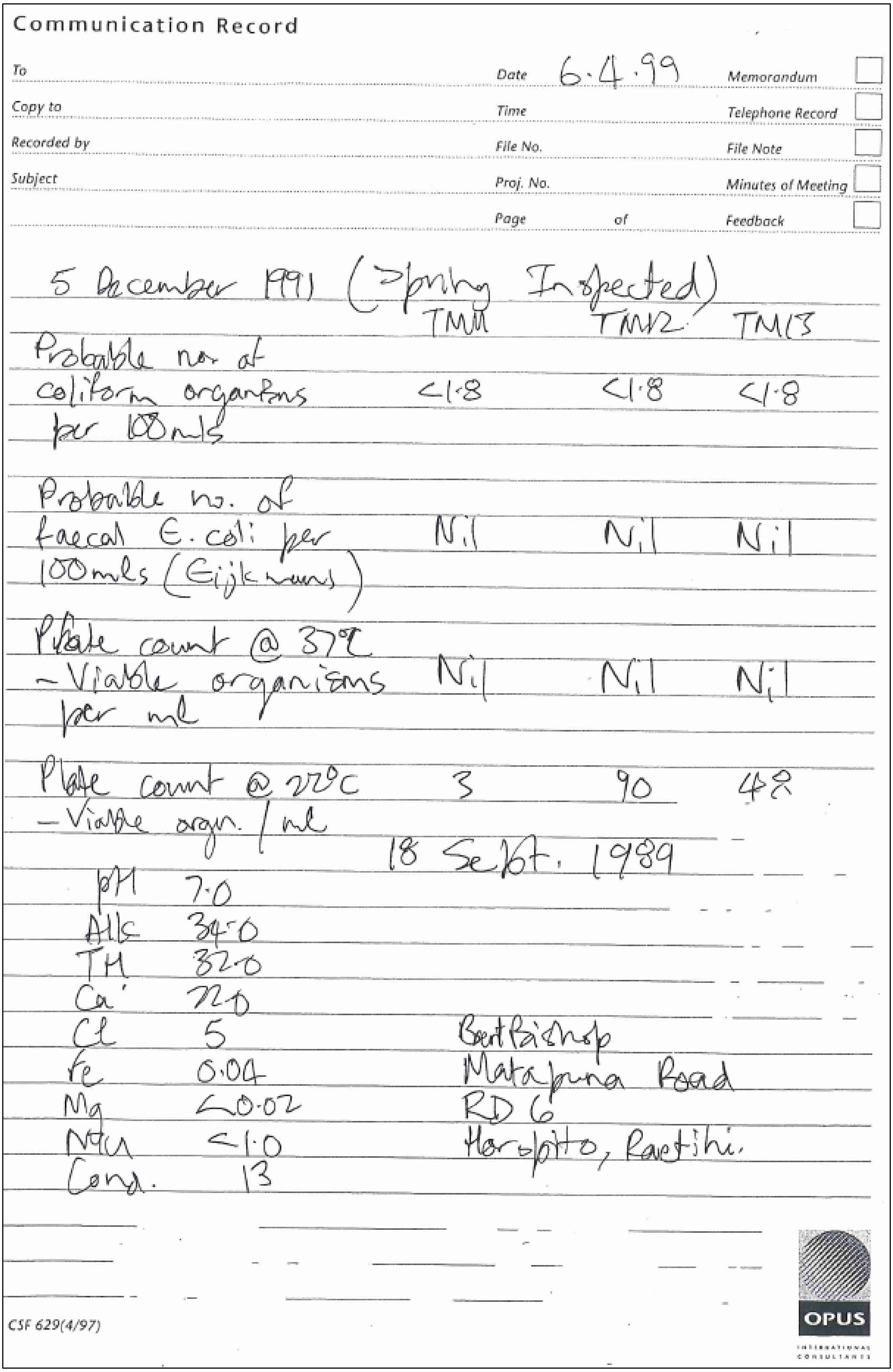
Wilson, T.M.; Stewart, C.; Sword-Daniels, V.; Leonard, G.SW.; Johnston, D.M.; Cole, J.W.; Wardman, J.; Wilson, G.; Barnard, S.T. 2012. Volcanic ash impacts on critical infrastructure. Physics and Chemistry of the Earth, Parts A/B/C Volumes 45–46, Pages 5–23 DOI 10.1016/j.pce.2011.06.006.

Witham, C.S.; Oppenheimer, C.; Horwell, C.J. 2005. Volcanic ash-leachates: a review and recommendations for sampling methods. Journal of Volcanology and Geothermal Research Volume 141, Issues 3–4, 15 March 2005, Pages 299–326 DOI 10.1016/j.jvolgeores.2004.11.010.

Zemansky, G.; Van Dissen, R.; Cox, S.; Gusyev, M. 2012. Potential impact of a Wellington Fault movement on the Waiwhetu Aquifer: GNS Science consultancy report 2012-204 (confidential report for the Greater Wellington Regional Council), p. 76 p.

APPENDICES

APPENDIX 1: WATER QUALITY RESULTS (OPUS, 2001)



Communication Record

To
Date 6·4·99
Memorandum ☐
Copy to
Time
Telephone Record ☐
Recorded by
File No.
File Note ☐
Subject
Proj. No.
Minutes of Meeting ☐
Page of
Feedback ☐

5 December 1991 (Spring Inspected)

	TM1	TM2	TM3
Probable no. of coliform organisms per 100mls	<1·8	<1·8	<1·8
Probable no. of faecal E. coli per 100mls (Eijkmans)	Nil	Nil	Nil
Plate count @ 37°C - Viable organisms per ml	Nil	Nil	Nil
Plate count @ 22°C - Viable orgn./ml	3	90	48

18 Sept. 1989

pH	7·0
Alk	34·0
TH	32·0
Ca	12·0
Cl	5
Fe	0·04
Mg	<0·02
Na	<1·0
Cond.	13

Bert Bishop
Matapuna Road
RD 6
Horopito, Raetihi.

CSF 629(4/97)

OPUS
INTERNATIONAL CONSULTANTS

APPENDIX 2: BORE LOGS

Table A1.1: Bore log for Horizons well number 733001.

Well No.	Easting	Northing	From	To	Lithology	Driller's Description
733001	2709200	6201200	0	0.5	Top Soil	Top soil
733001	2709200	6201200	0.5	3.5	Clay	Brown clay
733001	2709200	6201200	3.5	6	Silt	Black silt and hard formation rock
733001	2709200	6201200	6	12.5	Silt	Black silt and angular gravels, starting to produce small amounts of water
733001	2709200	6201200	12.5	17.5	Silt	Black silt and gravel with brown clay content, w/b

Table A1.2: Bore log for Horizons well number 733002.

Well No.	Easting	Northing	From	To	Lithology	Driller's Description
733002	2709200	6201300	0	0.5	Top Soil	Top soil
733002	2709200	6201300	0.5	6.7	Clay	Brown clay and silt
733002	2709200	6201300	6.7	7.7	Gravel	Black angular gravels, large grey stones, w/b

Table A1.3: Bore log for Horizons well number 733003.

Well No.	Easting	Northing	From	To	Lithology	Driller's Description
733003	2709753	6197381	0	0.8	Clay	Volcanic Clay
733003	2709753	6197381	0.8	9	Volcanic	Volcanic Boulders
733003	2709753	6197381	9	15.3	Silt	Volcanic silts with Basalt gravel and pumice
733003	2709753	6197381	15.3	17	Rock	Boulders
733003	2709753	6197381	17	26	Silt	Volcanic silts, pumice, gravel with boulders
733003	2709753	6197381	26	36.5	Silt	Volcanic silts, sand, gravel
733003	2709753	6197381	36.5	38	Silt	Silts brown
733003	2709753	6197381	38	39	Rock	Boulders
733003	2709753	6197381	39	55	Silt	Volcanic silts,sand, gravel
733003	2709753	6197381	55	56.5	Rock	Boulders
733003	2709753	6197381	56.5	89	Sand	Volcanic sand, gravels with silt layers
733003	2709753	6197381	89	100	Volcanic	Volcanic pumice, gravels cemented
733003	2709753	6197381	100	101	Papa	Papa

Table A1.4: Bore log for Horizons well number 743001.

Well No.	Easting	Northing	From	To	Lithology	Driller's Description
743001	2712400	6193400	0	0.3	Top Soil	Top soil
743001	2712400	6193400	0.3	1.2	Volcanic	Volcanic loam
743001	2712400	6193400	1.2	4.9	Clay	Clay
743001	2712400	6193400	4.9	5.2	Sand	Sand, small grip
743001	2712400	6193400	5.2	23.2	Silt	Papa
743001	2712400	6193400	23.2	24.1	Sand	Sand
743001	2712400	6193400	24.1	36.9	Silt	Papa
743001	2712400	6193400	36.9	37.8	Sand	Sand, some small shells
743001	2712400	6193400	37.8	40.9	Silt	Papa
743001	2712400	6193400	40.9	41.2	Sand	Sandstone, hard
743001	2712400	6193400	41.2	41.5	Sand	Sand
743001	2712400	6193400	41.5	42.1	Silt	Papa
743001	2712400	6193400	42.1	45.4	Sand	Sandstone
743001	2712400	6193400	45.4	47.6	Silt	Papa
743001	2712400	6193400	47.6	48.5	Sand	Sandstone
743001	2712400	6193400	48.5	56.1	Silt	Papa
743001	2712400	6193400	56.1	56.4	Sand	Sandstone
743001	2712400	6193400	56.4	57.6	Silt	Papa
743001	2712400	6193400	57.6	58	Sand	Sandstone
743001	2712400	6193400	58	73.8	Silt	Papa
743001	2712400	6193400	73.8	74.4	Sand	Sand
743001	2712400	6193400	74.4	78.1	Sand	Sandstone, bands of sand
743001	2712400	6193400	78.1	79.1	Silt	Papa, hard

Table A1.5: Bore log for Horizons well number 743002.

Well No.	Easting	Northing	From	To	Lithology	Driller's Description
743002	2715200	6193200	0	0.6	Top Soil	Top soil
743002	2715200	6193200	0.6	1.5	Volcanic	Volcanic loam (ash)
743002	2715200	6193200	1.5	2.1	Clay	Clay (yellow)
743002	2715200	6193200	2.1	3	Gravel	Grit (loose) (few pebbles)
743002	2715200	6193200	3	3.7	Sand	Coarse cemented sand
743002	2715200	6193200	3.7	4	Clay	Clay (yellow)
743002	2715200	6193200	4	5.5	Gravel	Grit and small stone
743002	2715200	6193200	5.5	5.8	Clay	Clay (firm)
743002	2715200	6193200	5.8	8.8	Gravel	Grit (loose) (few pebbles)
743002	2715200	6193200	8.8	9.8	Clay	Clay (firm)
743002	2715200	6193200	9.8	11.3	Gravel	Small stone (loose and jumpy)
743002	2715200	6193200	11.3	11.6	Silt	Silt (papa)
743002	2715200	6193200	11.6	15.2	Sand	Grey sand (very firm)
743002	2715200	6193200	15.2	15.5	Silt	Silt (papa)
743002	2715200	6193200	15.5	19.5	Sand	Grey sand (very fine)
743002	2715200	6193200	19.5	21.9	Silt	Silt (papa)
743002	2715200	6193200	21.9	26.2	Sand	Grey sand (very fine)
743002	2715200	6193200	26.2	32	Silt	Shaily papa (hard)
743002	2715200	6193200	32	32.3	Silt	Shaily papa (jumpy loose)
743002	2715200	6193200	32.3	36	Silt	Shaily papa
743002	2715200	6193200	36	41.5	Silt	Firm papa (steady)
743002	2715200	6193200	41.5	45.1	Silt	Shaily papa (jumpy and firm)
743002	2715200	6193200	45.1	45.7	Silt	Firm papa (steady)
743002	2715200	6193200	45.7	47.5	Silt	Shaily papa
743002	2715200	6193200	47.5	51.2	Silt	Firm papa
743002	2715200	6193200	51.2	52.4	Silt	Shaily papa
743002	2715200	6193200	52.4	57.9	Silt	Shaily papa
743002	2715200	6193200	57.9	61	Sand	Very fine sand (grey firm)
743002	2715200	6193200	61	76.2	Unspecified	Unknown
743002	2715200	6193200	76.2	78.6	Silt	Shaily papa (hard)

APPENDIX 3: ORGANIC DETERMINANDS AND PESTICIDES

Test type	Determinand	Detection limit	MAV	Units
phenols	2,4,6-trichlorophenol	<0.004	0.2	mg/L
phenols	Pentachlorophenol	<0.001	0.009	mg/L
pesticides	Alachlor	<0.1	20	µg/L
pesticides	Atrazine	<0.1	2	µg/L
pesticides	Bromacil	<0.1	400	µg/L
pesticides	Carbofuran	<0.1	8	µg/L
pesticides	Cyanazine	<0.1	0.7	µg/L
pesticides	Dimethoate	<0.5	8	µg/L
pesticides	Diuron	<0.1	20	µg/L
pesticides	Hexazinone	<0.1	400	µg/L
pesticides	Metalaxyl	<0.1	100	µg/L
pesticides	Metolachlor	<0.1	10	µg/L
pesticides	Metribuzin	<0.1	70	µg/L
pesticides	Molinate	<0.1	7	µg/L
pesticides	Oxadiazon	<0.1	200	µg/L
pesticides	Pendimethalin	<0.1	20	µg/L
pesticides	Pirimiphos methyl	<0.1	100	µg/L
pesticides	Procymidone	<0.1	700	µg/L
pesticides	Propazine	<0.1	70	µg/L
pesticides	Pyriproxifen	<0.1	400	µg/L
pesticides	Simazine	<0.1	2	µg/L
pesticides	Terbacil	<0.1	40	µg/L
pesticides	Terbuthylazine	<0.1	8	µg/L
pesticides	Thiabendazole	<1.0	400	µg/L
pesticides	Trifluralin	<0.1	30	µg/L
SVOC	Alachlor	<0.2	20	µg/L
SVOC	Atrazine	<0.1	2	µg/L
SVOC	Azinphosmethyl	<0.8	4	µg/L
SVOC	Bromacil	<0.4	400	µg/L
SVOC	Chlorpyriphos	<0.2	40	µg/L
SVOC	Cyanazine	<0.1	0.7	µg/L
SVOC	Di(2-ethylhexyl)phthalate	<2.0	9	µg/L
SVOC	Endrin	<0.1	1	µg/L
SVOC	Lindane	<0.01	2	µg/L
SVOC	Hexazinone	<0.1	400	µg/L
SVOC	Metalaxyl	<0.1	100	µg/L
SVOC	Methoxychlor	<0.2	20	µg/L
SVOC	Metolachlor	<0.1	10	µg/L
SVOC	Metribuzin	<0.1	70	µg/L
SVOC	Molinate	<0.1	7	µg/L
SVOC	Oryzalin	<10	400	µg/L
SVOC	Oxadiazon	<0.1	200	µg/L
SVOC	Pendimethalin	<0.2	20	µg/L
SVOC	Procymidone	<0.2	700	µg/L
SVOC	Propazine	<0.1	70	µg/L
SVOC	Simazine	<0.1	2	µg/L
SVOC	Terbuthylazine	<0.2	8	µg/L
SVOC	Trifluralin	<0.2	30	µg/L
VOC	Benzene	<0.0001	0.01	mg/L
VOC	Bromodichloromethane	<0.0001	0.06	mg/L
VOC	Bromoform	<0.0001	0.1	mg/L
VOC	Carbon tetrachloride	<0.0001	0.005	mg/L
VOC	Chloroform	<0.0001	0.4	mg/L
VOC	Dibromochloromethane	<0.0001	0.15	mg/L
VOC	Ethylbenzene	<0.0001	0.3	mg/L
VOC	Hexachlorobutadiene	<0.0001	0.0007	mg/L
VOC	Styrene	<0.0001	0.03	mg/L
VOC	Toluene	<0.0001	0.8	mg/L
VOC	Vinyl chloride	<0.0001	0.0003	mg/L

APPENDIX 4: POSTER PROVIDING ADVICE FOR WATER SUPPLY MANAGERS IN CASE OF VOLCANIC ASHFALL

VOLCANIC ASH

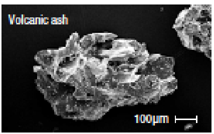
ADVICE FOR WATER SUPPLY MANAGERS

VOLCANIC ASH IS: HARD, HIGHLY ABRASIVE, MILDLY CORROSIVE AND CONDUCTIVE WHEN WET.

ASH IMPACTS ON DRINKING WATER TREATMENT

A VOLCANIC ASHFALL CAN:

- Increase turbidity in raw water sources
- Create high water demand during the cleanup phase.
- Cause operational problems for water treatment plants



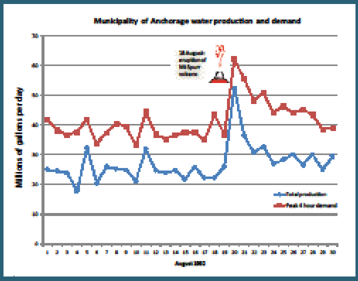
EFFECTS ON RAW WATER SOURCES

IN GENERAL, THE MAJOR EFFECT OF ASHFALL ON RAW WATER SOURCES IS LIKELY TO BE INCREASED TURBIDITY RATHER THAN CHANGES IN CHEMICAL COMPOSITION.

EFFECTS OF ASHFALL ON RAW WATER QUALITY	
Turbidity	Ash suspended in water will increase turbidity in raw water sources. Very fine ash may settle slowly and residual turbidity may remain in standing water bodies. In streams, ash may continue to be remobilised by rainfall events, and lahars may be a hazard in some regions.
Acidity	Fresh ashfall commonly has a strongly acidic surface coating. This may cause a slight depression of pH (not usually beyond pH 6.5) in low-alkalinity surface waters.
Potentially toxic elements	Fresh ash has a surface coating of soluble salts that are rapidly released on contact with water. The most abundant soluble elements are typically Ca, Na, S and Cl, followed by Mg, K, Al, Si, Fe and F. Compositional changes depend on the ash surface chemistry, the amount of ashfall and the dilution volume. • In streams, there will be a short-lived pulse of dissolved constituents. • In lakes and reservoirs, the volume of dilution is usually large enough that compositional changes are not discernible. The constituents most likely to be elevated above background levels are Fe, Mn and Al. Thus water is likely to become unpalatable due to discolouration or a metallic taste before it becomes a health hazard.

WATER DEMAND

HIGH DEMAND FOR WATER TYPICALLY OCCURS AFTER AN ASHFALL DURING THE CLEANUP PHASE.
Demand may remain high for months afterwards if water is needed to dampen down wind-remobilised ash.



The 18 August 1992 eruption of Mt Spurr volcano, Alaska, deposited around 3 mm of sand-sized volcanic ash on the city of Anchorage. The population used mostly wet methods to clean up the ash, creating a peak water demand which resulted in water shortages and loss of pressure in some parts of the city due to bottlenecks in the distribution system. This incident prompted a major upgrade of the city's distribution network

EFFECTS ON TREATMENT PLANTS

VOLCANIC ASH CAN CAUSE A RANGE OF OPERATIONAL PROBLEMS FOR WATER TREATMENT PLANTS.

- Turbidity may be satisfactorily removed by normal coag/floc treatment
- If turbidity exceeds normal operating range of plant for flood flows, suspended ash may penetrate further into plant and block filtration equipment.
- Ash is highly abrasive and likely to cause accelerated wear on pump impellers
- Ash can penetrate bearings and seals and overload motors

An ashfall is unlikely to cause service interruptions for water treatment plants, but a great deal of increased maintenance can be expected. Ash-induced electricity outages are the most common cause of disruptions to water production after an eruption.

Ash can enter sand filter beds both from direct fallout, and through the intake. Cleaning of filter beds creates heavy additional labour demands, such as at Bariloche WTP following the June 2011 Puyehue Cordon- Caulle eruption (below)

RECOMMENDED ACTIONS

WHERE TO FIND WARNING INFORMATION

See www.geonet.org.nz for ashfall forecasts in the event of an explosive eruption.

HOW TO PREPARE

PLANNING

At-risk water treatment plant should ensure that their PHRMPs include provision for ashfall events, including site cleanup. The plan should have procedures for incorporating up-to-date information from GeoNet into operational decisions.

Anticipate increased water demand following an ashfall. Where possible, use alternative, non-potable sources of water for cleanup and firefighting. Do not use recycled wastewater (e.g. treated effluent) for these purposes. Encourage cleanup using brooms and shovels rather than hoses.

Anticipate increased maintenance schedule: review stocks of essential items.

Ensure access to back-up power generation.

HOW TO RESPOND

Take precautions to exclude ash:

- Close intake before turbidity levels become excessive
- If necessary adjust coagulation/flocculation dosage to remove excess turbidity
- Consider covering open filter beds and clarifiers
- Protect other exposed equipment such as electrical control panels
- Maintain a clean site to reduce contamination.

Ensure regular monitoring of turbidity, pH, chlorine residuals and indicator bacteria in distribution network.

Be aware of the possibility of pH depression in low-alkalinity water sources and adjust any pH-sensitive treatment steps as required. For treatment processes that do not include pH adjustment, remind consumers of the need to flush their taps briefly before drawing water.

Public anxiety about contamination of water supplies is common after a volcanic eruption. Refer concerns to the Drinking-Water Assessor at the Public Health Unit of your local DHB.

THE FOLLOWING RESOURCES PROVIDE FURTHER INFORMATION ON VOLCANIC HAZARDS:
http://www.geonet.org.nz
http://www.gns.cri.nz
http://volcanoes.usgs.gov/ash/index.html
http://www.ivhhn.org

DRAFTED BY CAROL STEWART & TOM WILSON.
30 January 2013

UC University of Canterbury
Auckland Engineering Lifelines
Massey University

Figure A.1 Poster commissioned by Auckland Engineering Lifelines Group providing advice to water supply managers in the case of ashfall. Available at http://www.aelg.org.nz/document-library/volcanic-ash-impacts/.

APPENDIX 5: GLOSSARY OF VOLCANIC TERMS

Ash: Fine particles of pulverised rock blown from an explosion vent < 2 mm in diameter.

Ashfall: Volcanic ash that has fallen through the air from an eruption cloud. A deposit so formed is usually well sorted and layered. Also known as airfall.

Ash flow: A turbulent mixture of gas and rock fragments, most of which are ash-sized particles, ejected violently from a crater or fissure. The mass of pyroclastics is normally of very high temperature and moves rapidly down the slopes or even along a level surface.

Eruption: The process by which solid, liquid, and gaseous materials are ejected into the earth's atmosphere and onto the earth's surface by volcanic activity. Eruptions range from the quiet overflow of liquid rock to the tremendously violent expulsion of pyroclastics.

Eruption cloud: The column of gases, ash, and larger rock fragments rising from a crater or other vent. If it is of sufficient volume and velocity, this gaseous column may reach many miles into the stratosphere, where high winds will carry it long distances. Also known as an eruption plume or a volcanic plume.

Lahar: A torrential flow of water-saturated volcanic debris down the slope of a volcano in response to gravity. A type of debris flow.

Lava: Magma which has reached the surface through a volcanic eruption. The term is most commonly applied to streams of liquid rock that flow from a crater or fissure. It also refers to cooled and solidified rock.

Lava dome: Mass of lava, created by many individual flows, that has built a dome-shaped pile of lava.

Lava flow: An outpouring of lava onto the land surface from a vent or fissure. Also, a solidified tongue like or sheet-like body formed by outpouring lava.

Pyroclastic: Pertaining to fragmented (clastic) rock material formed by a volcanic explosion or ejection from a volcanic vent.

Pyroclastic density current: General term for turbulent mixture of gas and rock fragments which moves rapidly down slopes or even on level surfaces; often very hot. Types of pyroclastic density currents include ash flows, pyroclastic flows, block-and-ash flows, pumice-and-ash flows, pyroclastic surges, and nuees ardentes.

Tephra: Materials of all types and sizes that are erupted from a crater or volcanic vent and deposited from the air. Volcanic ash is tephra < 2 mm diameter.

www.gns.cri.nz

Principal Location

1 Fairway Drive
Avalon
PO Box 30368
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4600

Other Locations

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
T +64-3-477 4050
F +64-3-477 5232

Wairakei Research Centre
114 Karetoto Road
Wairakei
Private Bag 2000, Taupo
New Zealand
T +64-7-374 8211
F +64-7-374 8199

National Isotope Centre
30 Gracefield Road
PO Box 31312
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4657