Potential for Ground Water Bores to meet Lower Hutt's Emergency Water Needs after Large Earthquakes

J.G. Beban
K.M. Mason
W.J. Cousins
A. Parnell

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J. G. Beban, Cuttriss Consultants Limited, PO Box 30429, Lower Hutt 5040, New Zealand

W. J. Cousins, GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand

K. M. Mason, Centre for Public Health Research, Massey University, PO Box 756, Wellington 6140, New Zealand

A. Parnell, Centre for Public Health Research, Massey University, PO Box 756, Wellington 6140, New Zealand

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ABSTRACT

Large earthquakes in central New Zealand are expected to cause extensive damage to buildings and infrastructure, and to result in many deaths and injuries. Cities most affected include Wellington, Lower Hutt, Upper Hutt and Porirua. It is expected that all major transport routes (air, sea, rail, and road) out of the main urban area, and many within the area will be affected, and that there will be extended loss of bulk and reticulated water.

Prior research has considered the impacts on Wellington of a prolonged loss of bulk water. Wellington was studied because is uniquely vulnerable due to:

- The large distances to its bulk water sources; and
- The lack of alternative sources within the city.

The water situation in Lower Hutt has now been investigated. Lower Hutt is much less vulnerable than Wellington because one of the bulk water sources, the Waiwhetu artesian field, lies within its boundaries. There are many water bores in the valley floor part of the city, a major river, (the Hutt River), flows through the City, as do several small streams, and there are several reservoirs in the hills either side of the valley floor.

The river, streams and reservoirs are not ideal sources of post-earthquake emergency water, the river and streams because of contamination risks, and the reservoirs because of the large distances between them and most of the valley-floor residents. For this reason we have evaluated the potential for the existing artesian bores, supplemented by additional emergency-only bores, to provide the necessary emergency water for the valley-floor people.

Our first finding is that most of the residents of the valley floor live more than 1 km from their nearest existing large source of emergency water, be it a reservoir or a council-owned artesian bore. The distance of 1 km is important because larger distances make it very difficult for people to carry water from source to home. Our second finding is that an additional 16 new bores, strategically located in large open areas of the city, would ensure that the vast majority of the residents will be within 1 km of a suitable emergency-water source.

KEYWORDS

Earthquakes, infrastructure, lifelines, water supply, artesian water, emergency water, Hutt Valley, Wellington Fault.

1.0 INTRODUCTION

This report investigates the potential role that ground water bores could make towards meeting the emergency water needs of Lower Hutt following a Wellington Fault earthquake. Lower Hutt is located in one of New Zealand's most seismically active regions (CAE, 1991; Van Dissen et al., 2010; WRCDEM, 2011), and is especially susceptible to large earthquakes. Of particular concern is the risk associated with a rupture of the Wellington Fault, which is expected to result in a magnitude 7.5 earthquake (Stirling et al., 2012). The direct and indirect impacts (fault rupture, ground shaking, liquefaction and landslides) of a Wellington Fault event are expected to cause extensive damage to buildings, infrastructure and lifelines (CAE, 1991; Kestrel, 2010), and to result in major loss of life and injuries (Cousins, et al., 2009a; Cousins et al., 2014). It is expected that all major transport routes (air, sea, rail, and road) out of the region and many within the region will be affected (WRCDEM, 2005), and that there will be extended loss of bulk and reticulated water (Cousins, et al., 2009b, 2010) and disruption of food, power and fuel supplies (Kestrel, 2010).

A number of studies have been undertaken that investigate the potential water loss scenarios as a result of a 7.5 magnitude Wellington Fault earthquake. The current bulk water supply pipelines cross the Wellington Fault in several places. Damage assessments have concluded that there will be an extended period of time for which bulk water and reticulated water are unavailable to households, due to the extensive damage to the water supply network (Cousins et al., 2009b, 2010; Beban et al., 2012; WeLG, 2012; Cousins, 2013).

In New Zealand, it is generally recommended that in case of an emergency or disaster, people should store 3 litres per person per day (l/p/d) for drinking and an extra 15-20 l/p/d for cooking and hygiene (MCDEM, 2007; GWRC, 2010; WRCDEM, 2010). Beban et al. (2013) suggested that the minimum amount of water that will be required for consumption and hygiene, in the short term, following an earthquake is 6-7.5 litres per person per day and in the mid-long term is at least 15-20 litres per person per day. Water for pets would be extra.

The amount of water people will collect from emergency sources following a Wellington Fault earthquake is likely to reflect the patterns that have emerged from water use research in developing countries. This literature suggests that within 1 km of a water source, people will collect approximately 15 litres per person per day. This is less than the 20 l/p/d recommended as a minimum functional level of water supply. However, the precise amount households will collect following an earthquake will be influenced by a number of factors, including the distances they have to travel, the time it takes to collect water (there may be queues), the types of containers they have to use for collection, the modes of transport available to collect water (vehicular vs. pedestrian access) and, most importantly, the availability of the water.

Prior work has concentrated on Wellington City because of its unique vulnerabilities, as follows:

- Bulk water supply comes from three sources 20-50 km distant from the city;
- All bulk supply pipelines cross the active Wellington Fault at least twice;
- The estimated restoration times for emergency-level supply are between 3 weeks to 3 months, depending on how far a suburb is from its water source;
- Reservoir and personal stored water will be depleted within a few weeks; and
- Finally, if nothing is done to mitigate the problem, tens of thousands of people could be totally without water for weeks to months.

The Lower Hutt situation is much less dire, largely because the estimated times of 20-25 days for restoration of a survival level of supply to collection points, like reservoirs, are much shorter than for Wellington (WeLG, 2012). There could, however, be a serious problem with accessibility, because most people in Lower Hutt are more than one kilometre from their nearest reservoir. For example, if people from the valley floor needed to access reservoirs in the western hills, they would first have to travel to the western edge of valley floor, and from there most reservoirs would involve a trip (each way) of more than 2 km, including a climb then descent of more than 200 m, essentially making those reservoirs inaccessible to most valley floor residents. An added complication for people in central and northern parts of the valley floor would be finding a place to cross a major river, the Hutt River. Hence there is a need to examine the Lower Hutt situation more closely, in particular to investigate alternative sources of potable water for people living on the valley floor. The report is divided into the following sections:

- Section 1 introduces the water supply challenges facing Lower Hutt following a Wellington Fault earthquake and provides information on the Hutt Valley and its aquifer;
- Section 2 summarises the water restoration work that has been undertaken to date;
- Section 3 outlines the methodology that has been undertaken to identify the potential locations of the bores;
- Section 4 identifies the potential positions of the groundwater bores and the potential barriers and challenges associated with their installation;
- Section 5 discusses the implications of the results; and
- Section 6 provides a summary of the findings.

1.1 THE SETTING

Wellington Region is located at the south west tip of the North Island of New Zealand (Inset, Figure 1.1), and has a population of 471,300 as at 2013 (Statistics New Zealand, 2013). This population is dispersed throughout four cities (Wellington, Lower Hutt, Upper Hutt and Porirua) and four districts (Kapiti, South Wairarapa, Carterton and Masterton). The largest city is Wellington with a population of approximately 191,000; the smallest district is Carterton with a population of 8,200 (Statistics New Zealand 2013). Lower Hutt, which is situated 15 km to the north east of Wellington, has a population of 98,000 people.

1.2 TECTONIC SETTING OF THE HUTT VALLEY

Located along the western edge of the Hutt Valley, is the active Wellington Fault (Figure 1.1), with many engineered lifelines (e.g. water, electricity, roads, telecommunications) crossing this fault. Surface fault rupture and a large earthquake (approximately magnitude 7.5) on the Wellington Fault is regarded as New Zealand's probable maximum earthquake loss event (Cousins, et al., 2009b, 2014), with a 10% likelihood of such an event occurring within the next 100 years (Rhoades et al., 2011). Parts of the region are also vulnerable to associated earthquake hazards such as strong ground shaking, surface fault rupture, liquefaction, landslide, and tsunami.

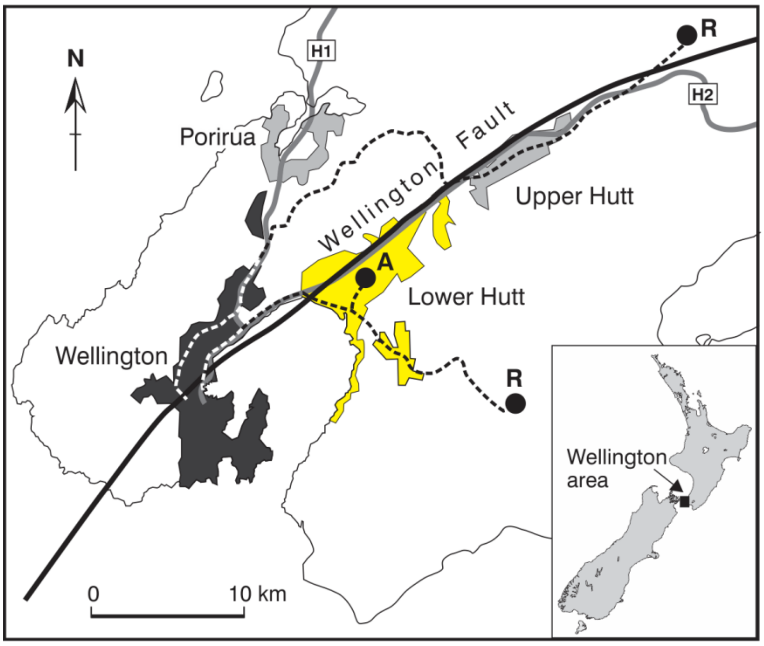

Figure 1.1 Urban Wellington Region: Wellington City (black), Lower Hutt (yellow), other cities (grey) and the Wellington Fault (black line). Nearly all of the surrounding land is rugged hill country. There are only two highways into Wellington (H1 and H2). Both are likely to be blocked by landslides following a Wellington Fault earthquake with the risk that Wellington could be isolated for weeks to months. There are three bulk water sources, two from rivers (R) and one from an artesian field (A).

People living in Wellington region will be significantly affected by a magnitude 7.5 Wellington Fault Earthquake. The earthquake is likely to result in:

- Many deaths and injuries (Cousins et al., 2008, 2014);
- Extensive damage to buildings (Cousins et al., 2014);
- Disruptions to lifelines (water, sewage, electricity and communications) for extended periods of time (CAE, 1991; Cousins et al., 2009b; Beban et al., 2013; WeLG, 2012; Cousins, 2013); and
- Disruptions to all major transport routes (CAE, 1991; WeLG, 2012).

Extensive damage to buildings and infrastructure, particularly on/in soft soils, is expected throughout the region. Most lifelines including water, sewage, electricity and communications will be disrupted for extended periods of time (Table 1.1, from adapted from Wright & Cousins, 2014). All major transport routes including air, sea, rail and road are likely to be affected, hampering efforts to locate and rescue survivors, restore lifelines, and transport emergency and relief supplies. (WRCDEM, 2005). Disruption of the transport infrastructure will also limit evacuation within, and out of, the region.

This report focuses on the potential water needs of the Hutt Valley and explores the role that ground water bores can play in addressing the emergency water needs of the Hutt Valley residents following a Wellington Fault Earthquake. Of particular interest is the valley floor area (Figure 1.2), where people could realistically be expected to walk up to about 1 km to collect water from distribution points. About 63% of Lower Hutt's residents are on the valley floor (Table 1.2, based on data from Statistics New Zealand, 2013).

Table 1.1 Expected Wellington area impacts of a Wellington Fault Earthquake.

Consequences of a Wellington Fault Earthquake
Extended loss of bulk and reticulated water (1-3 months, 2-6 months respectively).
Food, power and fuel supplies disrupted (2-3 months).
People in survival mode until water and food readily available (2-6 months).
Medium and high rise (4+ storey) blocks of apartments unusable until services restored.
Planning hiatus of 6 to 12 (or more) months before major repairs to dwellings and many other buildings can be started.
Heavy competition for resources during reconstruction.

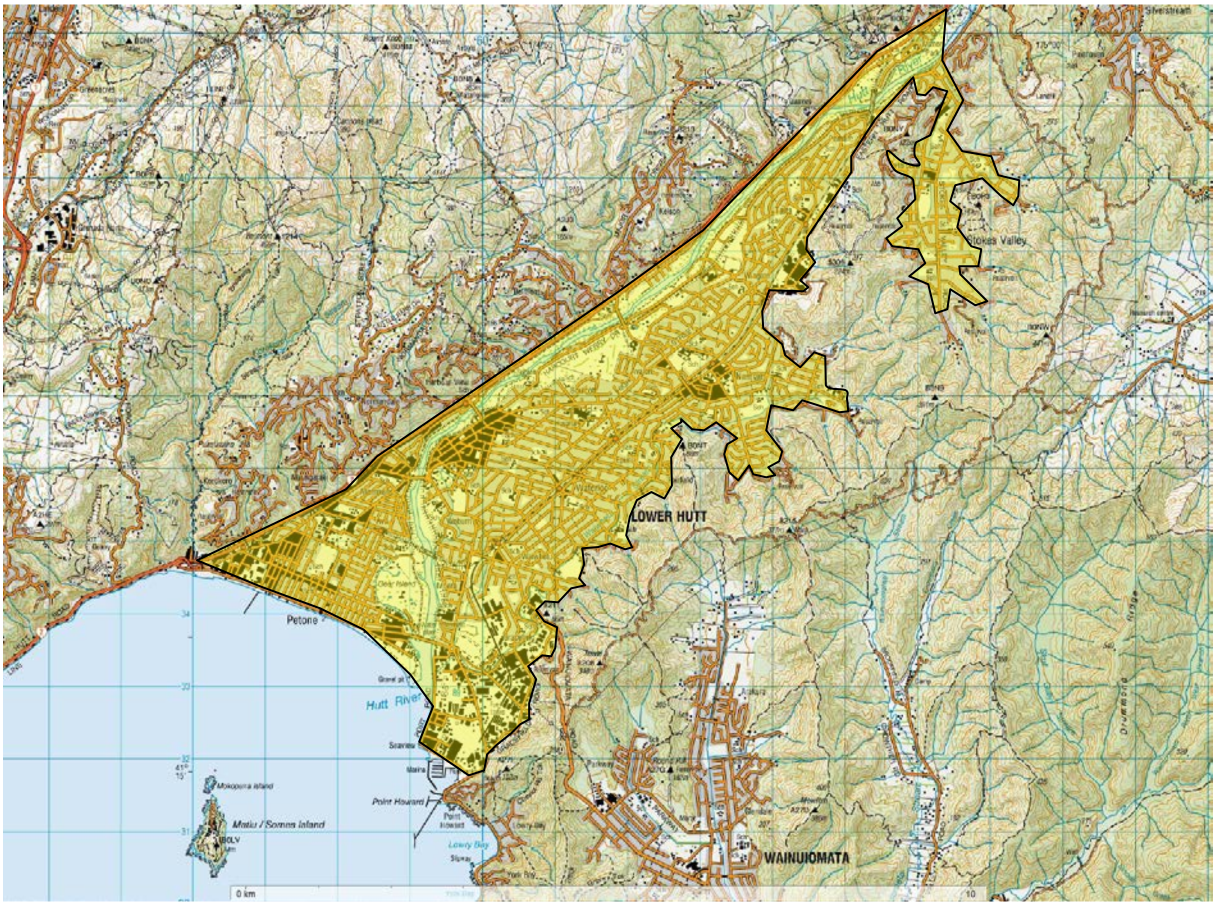

Figure 1.2 Topographic map of Lower Hutt City showing the valley floor area that potentially could be supplied with artesian water in an emergency situation (yellow shaded area). The western hills lie to the north-west of the valley floor, Wainuiomata is in a separate valley to the south-east (labelled), and part of Eastbourne is visible at the southern extremity of the valley floor.

Table 1.2 Census populations of the four main geographic areas of Lower Hutt.

Study Zone	Populations	Percent
Valley Floor	62,200	63
Western Hills	14,100	14
Wainuiomata	17,300	18
Eastbourne	4,700	5
Lower Hutt	98,200	100

1.3 WATER NEEDS AFTER A NATURAL HAZARD

Water is essential for life, and so restoring a basic water supply is a high priority following a disaster. An adequate quantity of water needs to be supplied to the affected population, and the water source protected from contamination (Wisner et al., 2002). The *Sphere Humanitarian Charter and Minimum Standards in Disaster Response* states that "all people should have safe and equitable access to a sufficient quantity of water for drinking, cooking and person and domestic hygiene". Additionally, public water points need to be "sufficiently close to households to enable use of the minimum water requirement" (Sphere 2011, p97).

A staged approach may be needed for restoring water supplies, with gradual improvements made over time. After an emergency, the priority is to get adequate water for survival needs, and in time, improving the quantity, quality and accessibility of water supplies.

1.3.1 Amount of water needed

In New Zealand, it is generally recommended that in case of an emergency or disaster, people should store 3 l/p/d for drinking and an extra 15-20 l/p/d for cooking and hygiene (GWRC, 2010; MCDEM, 2007; WRCDEM, 2010). Beban et al. (2013) suggested that the minimum amounts of water that will be required for consumption and hygiene following an earthquake are:

- 6–7.5 litres per person per day in the short term; and
- 15–20 litres per person per day (minimum) in the mid- to long-term.

These recommendations are relatively consistent with the World Health Organization (Wisner et al., 2002) and SPHERE (2011) recommendations.

As well as domestic water use, water may also be needed for other services provided in emergencies. Fire-fighting generally has a much increased need for water following a natural hazard (Wisner et al., 2002). Hospitals and health centres are also likely to need increased amounts of water, with Sphere guidelines suggesting 40-60 litres per in-patient and 5 litres per out-patient per day (WHO/WEDC, 2011).

1.3.2 Accessibility

Drinking water needs to be accessible to everyone. It has been estimated that after a Wellington earthquake, bulk water supplies will be lost in Lower Hutt for 3 to 4 weeks, and reticulated water supplies for 4 to 6 weeks (WeLG, 2012). Emergency water supplies will be required to supply adequate water to the affected population over this time period. After such an emergency, most, if not all, of the affected population could be without transport, and could need to carry a large volume of water by hand. The precise amount households will collect following an earthquake will be influenced by a number of factors including:

- Distances they have to travel;
- Waiting time it takes to collect water (there may be queues);
- Types of containers they have to use for collection;
- Modes of transport available to collect water (vehicular vs. pedestrian access); and
- Availability of water.

The World Health Organization (Sphere, 2011) suggests a maximum distance of 1 kilometre from shelters to water points for the first three months after an emergency, and 500 metres in the longer term (3 to 6 months post emergency) (Table 1.3). The amount of water people will collect following a Wellington Fault earthquake is likely to also reflect the patterns that have emerged from water use research in developing countries. This literature suggests that within 1 km of a water source people will collect approximately 15 litres per person per day (Beban et al., 2013).

Table 1.3 Suggested quantities of water, and distances of water points from shelters at different stages of an emergency response.

Time – from initial intervention	Quantity of water (litres/person/day)	Maximum distance from shelters to water points (km)
2 weeks to 1 month	5	1.0
1 to 3 months	10	1.0
3 to 6 months	15 (+)	0.5

Making water sources accessible can allow people to stay in their own homes. The framework of the alternative water sources decision tree (Beban et al., 2013, p24) suggests that people are likely to stay home (if it is structurally stable) if they can access water through any of the following: piped water, rainwater tank, stored water, hot water cylinder, CDEM supplied water, non-potable water, able/willing to walk to a reservoir. Only after these possibilities are exhausted, will people consider moving to stay with friends, family or neighbours, at a motel, or at a public shelter.

There is a public health benefit to people staying in their own homes. After a natural hazard, outbreaks of disease are more common in crowded areas of displaced people. Allowing people to remain living in their own homes can decrease crowding and the risk of infectious diseases spreading within relief camps (Wisner et al., 2002).

1.3.3 Water quality

After a natural hazard, water needs to be safe for people to drink and cook with. If water supplies for drinking and cooking are contaminated, it can lead to hospitals and health services quickly becoming overloaded with cases of water-related illnesses. The main water-borne risks to human health following emergencies are from water-related diseases due to contaminated water, and insufficient water for hygiene (Wisner et al 2002).

If water is contaminated with faecal pathogens, it can cause water-related diseases, particularly diarrhoeal diseases. Other water-related risks include typhoid, cholera, dysentery and infectious hepatitis, although these are not common diseases in New Zealand. Bacteriological testing can determine the quality of water, with the indicator bacterium E. coli, according to the following levels:

- Zero E. coli /100 ml: guideline compliant;
- 1–10 E. coli / 100 ml: tolerable;
- 10–100 E. coli /100 ml: requires treatment; and
- Greater than 100 E. coli / 100 ml: unsuitable for consumption without proper treatment (Wisner et al., 2002).

If water needs to be treated, a range of options exist, including disinfection (chlorination for example). Generally, treatment to kill pathogens is recommended unless water sources are known to be safe. The World Health Organization endorses disinfecting drinking-water in emergency situations, when the population size and concentration, lack of sanitary facilities, or health information suggest a significant risk of water-borne diseases (Wisner et al., 2002).

Sufficient water is also required for personal hygiene needs, such as hand-washing. 'Water-washed' diseases are caused by poor personal hygiene due to insufficient water, or skin or eye contact with contaminated water. These diseases include diarrhoea and skin and eye infections, and can be transmitted more easily when water is scarce. If the quantity of available water is restricted, non-potable water can be used for hygiene purposes.

1.4 Potential Sources of Emergency Water in the Hutt Valley

A number of potential emergency water supply options have been suggested for Lower Hutt (Hutchinson and O'Meara, 2013; MWH, 2012; Beban et al., 2013). These options include reservoirs, surface water, groundwater, rainwater, desalination and stored water.

1.4.1 Reservoirs

Currently it is assumed that emergency water will be supplied to Lower Hutt mainly by reservoirs. However, the reservoirs are vulnerable to damage in a strong earthquake, and may lose water through shaking (sloshing) and/or damage.

Cousins (2013) investigated the potential role of reservoirs for providing emergency water supply for Wellington City. Assuming a minimum consumption rate of 20 l/p/d, and assuming that half of the reservoir water was lost as a result of shaking and other damage to the reservoirs, the gap between depletion of stored water and restoration of emergency supply from the bulk supply system was as follows:

- A peak shortfall, at day 20 from the earthquake, of 3 million litres/day, needed to supply 150,000 people;
- 2 million or more litres/day from days 14 to 34 (20 days duration) needed to supply 100,000 or more people; and
- 1 million or more litres/day from days 10 to 45 (35 days) for 50,000 or more people.

If consumption rates were reduced to 6 l/p/d then the following shortfalls would arise for Wellington City:

- A peak of nearly 300,000 litres/day, at day 39, needed to supply almost 50,000 people;
- 180,000 or more litres/day from days 27 to 53 (26 days) needed to supply 30,000 or more people; and
- 90,000 or more litres/day from days 23 to 69 (46 days) for 15,000 or more people.

The Lower Hutt situation is much less dire. Water stored in reservoirs (Figure 1.3) could be sufficient for about 20 to 50 days (MWH, 2012), assuming (MWH, 2012):

- A consumption rate of 20 l/p/d;
- That reservoirs are 80% full at the time of the earthquake; and
- That there is no significant loss of water due to earthquake damage to the reservoirs.

Estimated restoration times for water are approximately 20-25 days for a survival level of supply (i.e. bulk supply to collection points like reservoirs), and approximately 25-40 days for operational (reticulated to houses) supply (WeLG, 2012). The above times for consumption of the stored water and restoration of supply are compared in Table 1.4.

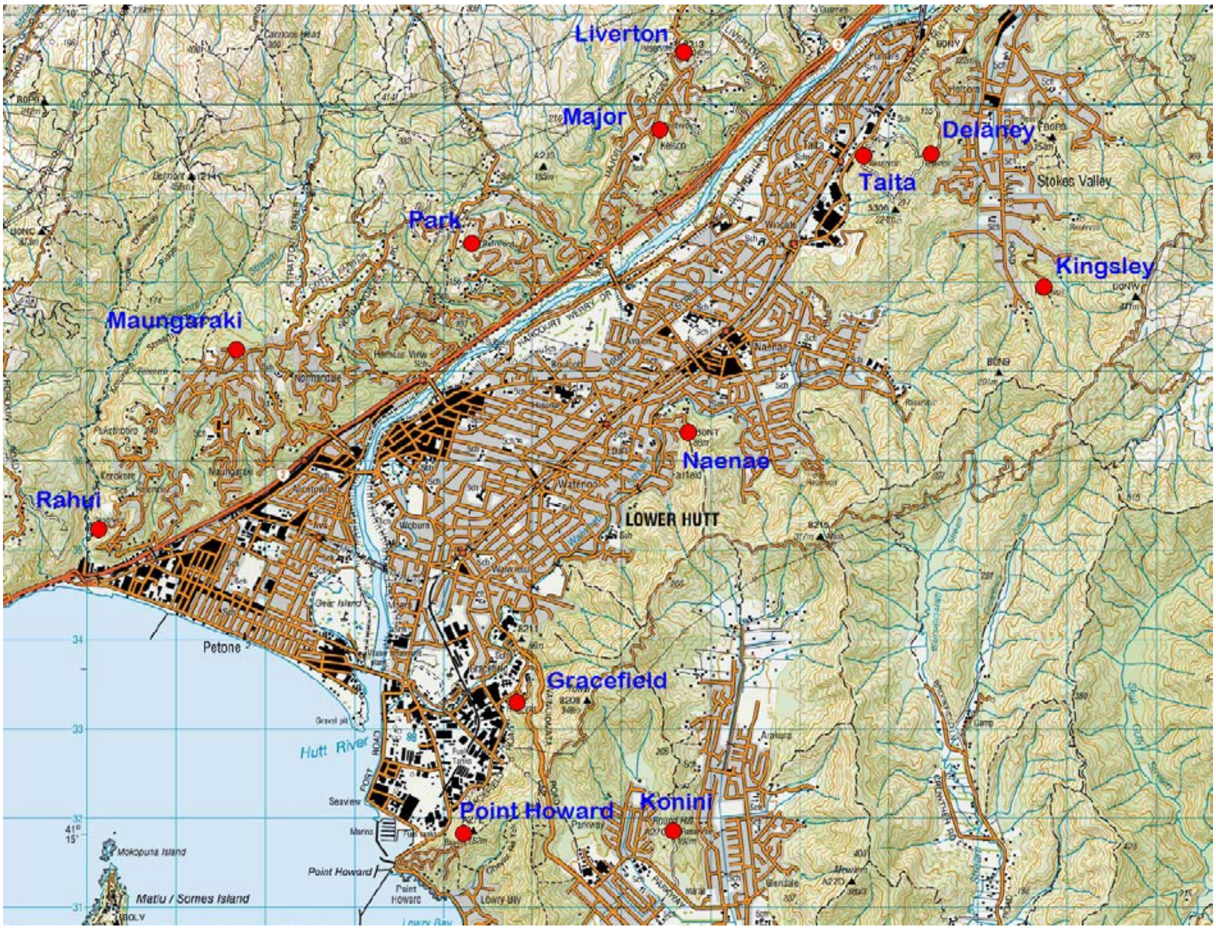

Figure 1.3 Locations of Lower Hutt's main reservoirs. Points to note are (a) most of the reservoirs in the western hills are more than 2 km (by road) from the valley floor, and at elevations of 200 m or more, and (b) while three of the reservoirs in the eastern hills are relatively close to the main valley floor, most people living on the valley floor would have to travel much more than 1 km to their nearest one. The map grid-line spacing is 1 km.

Table 1.4 Comparison of times taken to deplete water stored in the main reservoirs with times to restore survival and operational levels of supply, for various zones of Lower Hutt. Note that these are averages over quite large areas. See Appendix 1 and Appendix 2 for the population and volume data used in the modelling.

Study Zone	Reservoir Depletion (days)	Restoration to Survival Level (days)	Restoration to Operational Level (days)	Accessible Reservoirs
Valley Floor	c. 24	20 – 25	25 – 40	Delaney, Kingsley, Taita, Naenae, Gracefield, Rahui (part),
Western Hills	50+	25+	40+	Liverton, Major, Park, Maungaraki, Rahui (part)
Wainuiomata	23	20	35	Konini, Homedale
Eastbourne	16	25	40	Point Howard

The results in Table 1.4 suggest that a survival level of water supply could be restored to collection points (assumed to be the reservoirs) before the reservoirs are depleted, for most areas, and that reticulated water would be restored within 10 to 20 days of survival level restoration. However, the estimates in Table 1.4 are gross averages over quite large areas, and collection of sufficient water from the reservoirs will not be practicable for many of the valley floor people, for the following three reasons:

- First, most of the reservoirs in the western hills are more than 2 km (by road) from the valley floor, at elevations of 200 m or more, and there is a major barrier, the Hutt River, between them and most valley floor residences.
- Second, while the three reservoirs in the eastern hills are relatively close to the valley floor, most people living on the valley floor would have to travel much more than 1 km to their nearest one.
- Third, the assumption that no water is lost from the reservoirs during the earthquake is, in our opinion, over-optimistic. Loss of up to half of the stored water should be considered (Cousins, 2013), in which case the reservoir depletion times of Table 1.4 would be halved, and in some areas there would then be about a ten-day gap between the depletion of the stored water and the restoration of emergency supply. A very important to note here, however, is that the 50% loss of water could be countered by lowering the consumption rate to 10 l/p/d, which is well above the minimum of 6 l/p/d.

1.4.2 Surface water

Surface water is one source of emergency water, through rivers and streams, although it is generally susceptible to contamination. For example, landslides can lead to sediment and silt in the water, and the water can be contaminated with faecal matter and chemicals.

There are a several sources of surface water in the Hutt Valley, including the Hutt River and small streams like the Korokoro and Waiwhetu. Hillside streams could meet the needs of a small number of communities. However, it is likely the Hutt River and streams on the valley floor (e.g. Waiwhetu) will be contaminated with sewage, chemicals and runoff, and would not be fit for consumption. Even in the current state, water from the Waiwhetu Stream would need to be treated in order to be potable, given the current E. coli levels (Morar & Perrie, 2013). After an earthquake, all surface water to be used for drinking-water would need to be treated (for example with chlorine compounds) before being able to be consumed.

The World Health Organization recommends to initially assume that all surface water will be contaminated after a natural hazard event, and to use groundwater in preference if possible (Wisner et al., 2002).

1.4.3 Groundwater

Groundwater is generally the preferred option for providing emergency water, as it is less susceptible to contamination, and less likely to need treating than other sources of water (Wisner et al., 2002). Boreholes, deep wells and protected springs consistently yield the safest water from a bacteriological point of view (Wisner et al., 2002).

The Hutt Valley has a significant number of groundwater bores which could be used to provide emergency water following an earthquake. These bores are supplied by the confined Waiwhetu artesian aquifer that is present under the Hutt Valley. Water in the aquifer takes about 12 months to filter down from inflow to extraction zones, which means that when extracted it is free of pathogens and requires no treatment. Currently, boreholes for public supply are located along Waterloo Road (eight locations), at Gear Island (three locations), Hutt Hospital (to service the hospital in emergency situations), Buick Street, and the Dowse Museum (Figure 1.4).

The Waterloo Road bores currently provide bulk water supply for Lower Hutt and Wellington, while the Gear Island bores comprise a standby bulk source. The Buick Street and Dowse bores are relatively low-capacity sources that are freely accessible to the general public. These boreholes could potentially be used as post-earthquake emergency supply points, though the Gear Island and Buick Street bores could be inactive due to damage from the earthquake or compromised by salt water intrusion.

In Figure 1.4 we also show the water treatment plant at Waterloo as a potential supply point for artesian water. This is because of its proximity to suburbs east of it, and because the modern steel pipelines between it and the closest bores are unlikely to be ruptured in strong shaking.

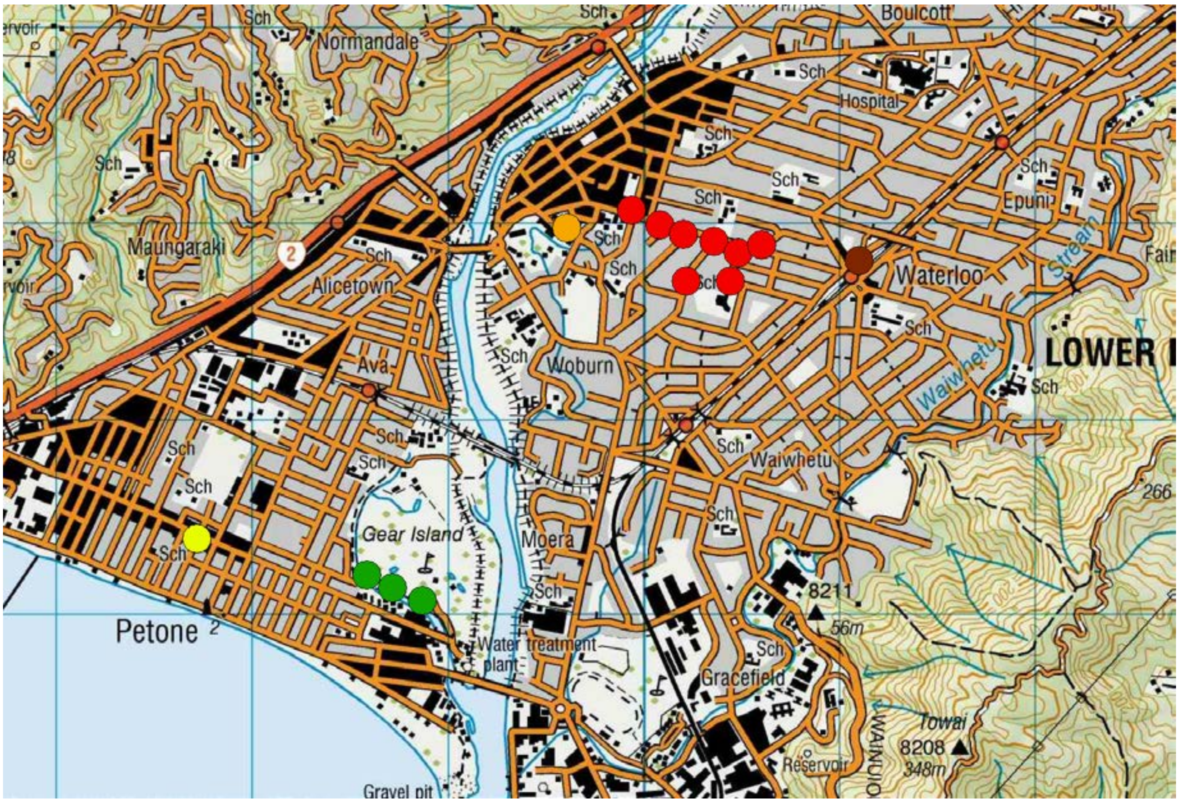

Figure 1.4 Existing local authority owned artesian boreholes in Lower Hutt: Waterloo Road (red), Gear Island (green), Buick Street (yellow) and Dowse Museum (orange). The Waterloo treatment plant is also indicated (brown symbol) as a potential supply point. The grid-line spacing is 1 km.

There are also many privately-owned bores in Lower Hutt (Figure 1.5). Five of them are consented to provide 1000 m^3 (one million litres) or more per day, and in total could provide sufficient water for 480,000 people at the emergency consumption rate of 20 l/p/d. This is assuming:

- That all continue to function after a large earthquake;
- The distribution problem can be overcome;
- The water is potable (not all are currently rated as suitable for potable supply (MWH, 2012), possibly because the current uses of the water, irrigation for example, do not require the water to certified as safe for drinking); and
- That access to the water will be permitted by the owners (or mandated by civil defence authorities).

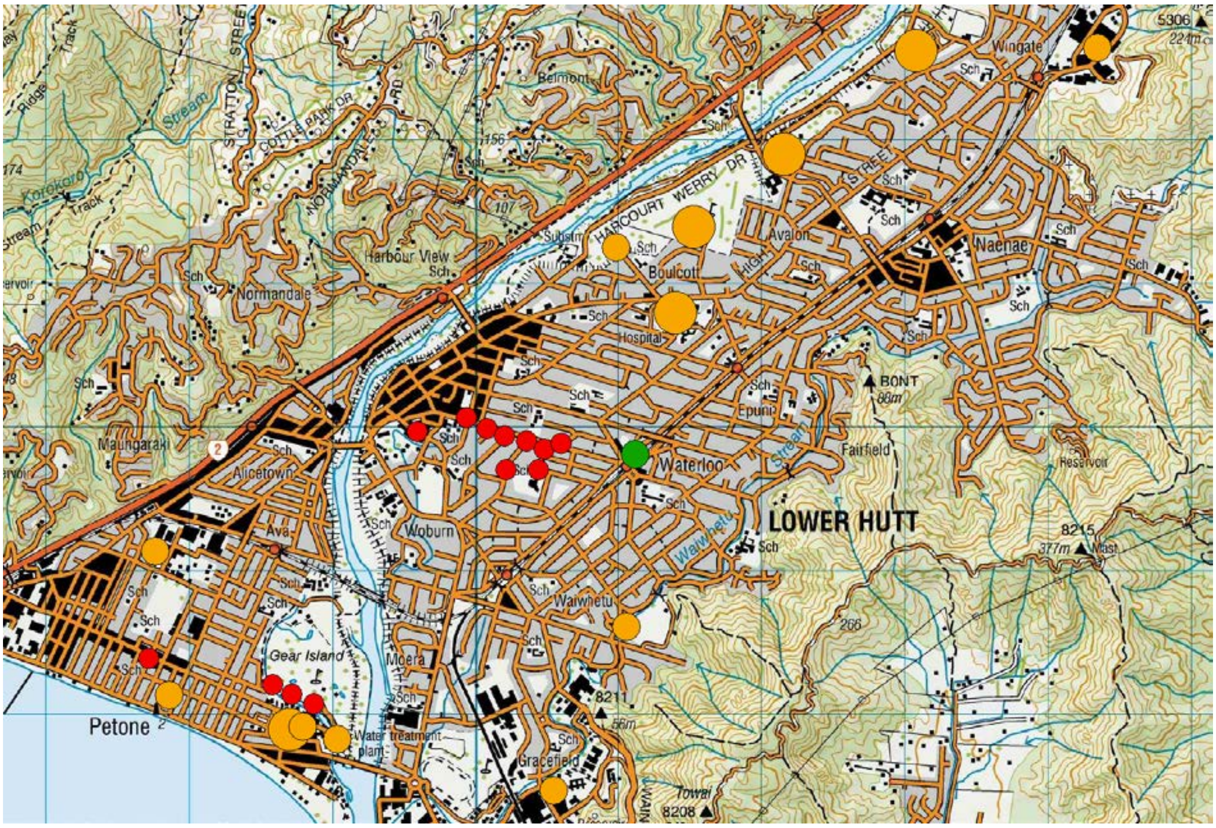

Figure 1.5 Existing private boreholes in Lower Hutt (orange), a potential supply point at the waterloo treatment plant (green), and the publically-owned boreholes from Figure 1.5 (red). Five of the privately-owned bores are consented to supply 1000 m^3 (one million litres) or more per day (large orange symbols).

For the purposes of this report, no significant weight has been given to using the private bores. This is due to the issues identified above as well as the locations of the bores. A number of them are not located in public areas, and so there is limited ability for them to collocate with other services that will be required following a large earthquake (such as emergency housing). Because of this, we have assumed that new bores will be required to provide emergency water to the residents of valley floor. If the above issues could be addressed with the owner of private bores, there would be the potential for the number of new bores as identified in this report to be reduced.

1.4.4 Seawater and desalination

Desalination plants could potentially provide fresh water from sea water. Assuming power can be found to run it, a single desalination plant producing 1 million litres/day, would probably suffice. Disadvantages include cost (about $2 million), power requirements (about 200 kW), distribution of the water, and, most serious, procurement time (about 3 months).

Seawater could, however, be used for non-drinking water (e.g. for laundry, washing dishes), but realistically only by people living within about 1 km of the shore.

1.4.5 Household supplies

Household water supplies include stored water and hot water cylinder water. Beban et al. (2013) showed that on average, households had available 9-11 days of water at the emergency level (6 l/p/d) and 2-5 days at the functional level (20 l/p/d). The bulk of this water would be available within the hot water cylinder, which for many households would not be accessible due to damage, unawareness of how to access this resource, or due to inaccessibility issues (for example the hot water cylinder may be located in an area of the house that is hard to access). The scenario findings highlighted that most of the population (85%) could potentially become dependent on reservoir water in the first 3 days following an earthquake event. This study also found that if people are unwilling or unable to collect and carry water from reservoirs to their homes over an extended period of time, greater demand may be placed on evacuation centres.

1.4.6 Rainwater

Household rainwater tanks can provide an emergency source of water, for houses that have them. A 2000 litre rainwater tank should provide sufficient water for a family of four, even in a dry summer, and a 1000 litre rainwater tank might also do so, depending on season and rainfall.

The summer rainfall in Wellington, in a dry year, is about 60 mm/month (Brown, 2011). Hence an average-sized house, with a roof area 125 m^2 and assumed collection efficiency of 80%, could collect about 200 litres/day, enough for 10 people at 20 l/p/d (litres per person per day). For a family of four, a 1000 litre storage tank would last 12.5 days between refills, and a 2000 litre tank 25 days. Hence a 2000 litre tank seems definitely large enough to store water for a family of four, in a dry year, and a 1000 litre one probably large enough. The potential impacts of rainwater have also been considered by Abbott et al. (2012) and Shaw (2012). Rainwater would likely need to be decontaminated with chlorine or another disinfectant, which could be done at the home.

Beban et al (in prep.) are currently undertaking a one year study that investigates the water quality of rainwater tanks in a Wellington and Lower Hutt urban setting. This project involves fortnightly water quality analysis of a number of rainwater tanks. Based on the findings, recommendations will be made regarding the use of rain water tanks (and the treatment of the stored water) in a Wellington context. Early evidence suggests that the quality of water in the rain water tanks varies significantly across the region, and it is important that households have measures available to treat the water to make it suitable for consumption.

1.5 PROPOSAL FOR NEW BOREHOLES TO ACCESS LOWER HUTT GROUNDWATER

The above discussion suggests that there is unlikely to be a serious water shortage after a Wellington Fault earthquake, but rather difficulties in distribution and/or quality. While helping to fill the gap, household supplies and rainwater are unlikely to provide emergency water supplies for the significant proportion of the Hutt Valley people who are more than 1 km from their closest reservoir or council-owned artesian bore. However, more boreholes could potentially be drilled to give better redundancy and better coverage in an emergency.

The groundwater available in the aquifer below the Lower Hutt is potentially a viable source of emergency water. The water provided out of the boreholes is likely to be free of pathogens and safe to drink untreated (MWH, 2012). We now examine whether a number of additional bores could be installed in the Hutt Valley, to provide a source of emergency water after an earthquake or other natural hazard. The benefits of these additional bores include:

- Able to provide large quantities of safe drinking-water;
- Could be capped when not in use to reduce the likelihood of contamination; and
- Accessible to a large proportion of the Hutt valley population.

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2.0 METHODOLOGY

This section outlines the methodology that was undertaken to identify the appropriate positions of the proposed bores within Lower Hutt. While this was largely a desktop exercise, all potential locations were visited to validate their appropriateness to provide emergency water to local communities.

2.1 SITE IDENTIFICATION

The first component of this research project involved identifying sites that could be suitable for emergency groundwater bores within the Lower Hutt. Sites were identified based on the following features:

- Proximity to population: designed to maximise the number of people within close walking distance of a borehole. The aim was to try to ensure that most households on the valley floor were within 1 km walking distance of a potential bore site. This 1 km distance is based on the recommendations of The World Health Organization, which suggests a maximum distance of 1 km from shelters to water points for the first three months after an emergency, and 500 metres in the longer term (3 to 6 months post emergency) (WHO/WEDC, 2011).
- Ownership: A strong preference was given to identifying sites that are publicly owned, such as parks. This was to ensure that there would be minimal ownership and access issues associated with both the installation of the bores and the distribution of emergency water when required. Furthermore, the locations of parks are well known in local communities, thereby making it easier to educate local residents on the positions of the bores (if they were to be installed).
- Land size: A strong preference was also given to the size of the site, with bias towards larger parks. There is the potential for dwellings and buildings to be rendered structurally unsound following a large earthquake. This could result in the need for evacuation centres to be established, which might include emergency housing. It is likely that such centres would be established in parks where there are often large and flat areas of land in public ownership. It was therefore considered appropriate to ensure that sites that could be potentially used for emergency housing also contained bores, thereby allowing for the collocation of emergency services.
- Multiple bores or access points at parks: On large parks (such as Hutt Park and Te Whiti Park) two bores were proposed. This was to improve accessibility, minimise waiting time, and to allow for larger areas of the Lower Hutt to be reached. Locating the bores at the edges of parks would make them sufficiently accessible that they could be used for other purposes (such as the filling of water tankers to allow for water deliveries or to allow for fire-fighting).
- Not too close to salt water: Care must be taken not to draw too much water from bores close to the sea, to minimise the risk of salt-water intrusion into the aquifer. Particular areas where this could occur are southern Petone and Moera.
- Ground conditions: We have used the subsoil work by Boon et al. (2011) as a guide to help determine the potential position of ground bores in the Lower Hutt. These maps have been considered alongside the liquefaction potential maps generated for the Lower Hutt by Dellow et al. (2014). Based on the findings of the maps, it is recognised

that several of the suggested bore sites might be significantly damaged as a result of liquefaction caused by strong shaking, in a Wellington Fault earthquake.

- Exclusions: We have not included the existing bore at Hutt Hospital as part of the analysis. The hospital is likely to need the bore-water for its own purposes. Studies show that water needs for health services are much higher than 15 litres per person per day – more like 60 litres per person per day (WHO/WEDC, 2011). Additionally, there are likely to be many injured people at the hospital, and they too will need water.

2.2 NETWORK ANALYSIS

The second component of the research project was to assess the geographic locations of all potential sites identified, and to determine the preferred locations for new water bores so as to maximise the population within walking distance of each bore site. To help with this, accessibility to existing and potential water bore sites in Lower Hutt City was calculated using network analysis software within a Geographic Information System (GIS).

2.2.1 Data sources

Potential sites for water bores were determined using the selection criteria described in Section 2.1, then digitized and mapped. The locations of existing water bores also were digitised and mapped. For parks with proposed new bore sites, two or three sites were digitised on opposite sides of the parks, close to roads for ease of access. In reality the same ease of access could be achieved by piping water from one main borehole in a park to multiple outlet points along the park boundary.

A road network was constructed for the Lower Hutt area from OpenStreetMap.org data (© OpenStreetMap contributors).

2.2.2 Analyses

Straight-line (Euclidean) distance was initially used to determine sites that would maximise the population within walking distance (1000 m) from the site. This process helped to identify likely areas that would benefit from having water bores installed.

However, the Euclidean distance can overestimate the population within a catchment, since the road network is not straight line. For a better estimate of the area within walking distance of the bore sites, network analysis was used.

2.2.3 Network analysis

For each water bore, existing and proposed, the travel distance along the road network was calculated, and a service area created to cover 1000 metres walking distance from a bore. Service area polygons were created from the route found along the network to the designated distance, with an offset of 75m either side of the road to create an area. Maps were produced showing all service areas. We used the Network Analysis tool in ArcGIS 10.1.

Sensitivity analyses were carried out (a) by excluding water bores that would be vulnerable to damage in large earthquakes, and (b) with varying travel distances (500 metres, 1000 metres and 1200 metres). These sensitivity analyses allow for assessing the likely effects of changing parameters.

3.0 RESULTS

3.1 IDENTIFYING POTENTIAL NEW BORE SITES

We found the most beneficial types of sites for new bores to be:

- Located in public parks, to be close to emergency shelter sites;
- At multiple sites throughout the Lower Hutt, to maximise the population close to the bore sites; and
- Not in vulnerable zones, including Seaview and Petone, due to the risks of salt water intrusion and damage from earthquake-induced liquefaction and/or tsunami.

Table 3.1 presents the existing sites, and potential new sites identified by our analyses.

Table 3.1 Locations of existing and potential new sites for artesian bores in Lower Hutt.

Existing Council Bores	Existing Private Bores [3]	Potential New Bores
Buick Street, Petone	*Unilever Australasia* [2]	Hutt Recreational Ground (2 bores)
Dowse Art Museum	Avalon Studios	Naenae Park (3 bores)
Bloomfield Terrace	Hutt Valley Health (2 bores) [4]	Mitchell Park
Colin Grove	HCC (Avalon Duck Pond)	Fraser Park (2 bores)
Penrose Street (2 bores)	Hutt Golf Club	Te Whiti Park (2 bores)
Hautana Street	Manor Park Golf Club	Avalon Park (2 bores)
Willoughy Street (2 bores)	*Shandon Golf Club* [2]	Delaney Park
Mahoe Street	*Feltex Carpets Ltd.* [2]	Walter Nash Park
Waterloo Water Treatment Plant [1]	Boulcott Golf Club	*Petone Recreational Ground* [2]
Gear Island (3 bores) [2]	Woolyarns Ltd.	*Hutt Park Raceway* [2]
	NZTS Services Ltd [2]	
	Exide NZ Ltd. site [2,5]	
	Imperial Tobacco NZ [2]	
	Teri Puketapu [6]	

Note:

[1] *The treatment plant is assumed to remain connected to its closest wells and so is able serve as a water supply point for eastern suburbs of the valley floor.*

[2] *The sites in italics are likely to be damaged in a Wellington Fault earthquake and may not be useable.*

[3] *We have not used any of the private bores in the network analysis as access arrangements to these bores following a large earthquake are uncertain.*

[4] *We have assumed that the Hutt Valley Health bores will not be available for public use as they will be needed to meet the operational needs of the hospital.*

[5] *Exide NZ Ltd. closed its Petone plant in 2012.*

[6] *Location unknown, assumed to be in Waiwhetu.*

3.2 AREAS COVERED BY POTENTIAL NEW BORE SITES

3.2.1 Residents within 1 km walking distance of an existing or proposed bore

Figure 3.1 shows the residential areas within 1000 metres walking distance of existing council-owned water bores (in green) and potential new water bores (in blue).

This analysis shows that existing water bores (in green) will only cover the main CBD area of Lower Hutt, and some of Petone, leaving many areas a long travel distance from water bores. However, by adding in several new water bores, particularly north of the CBD, it is possible to cover a much larger area.

By adding new water bores, better coverage is seen in large areas of the valley floor, and particularly in Taita, Naenae, Avalon and Stokes Valley. These areas currently have higher proportions of more vulnerable populations (particularly low income).

This map highlights that some areas that would remain un-serviced, including Alicetown, Moera, Fairfield, Boulcott and Avalon. However, the area of valley floor un-serviced is much smaller than is the case when relying on the existing bore network alone.

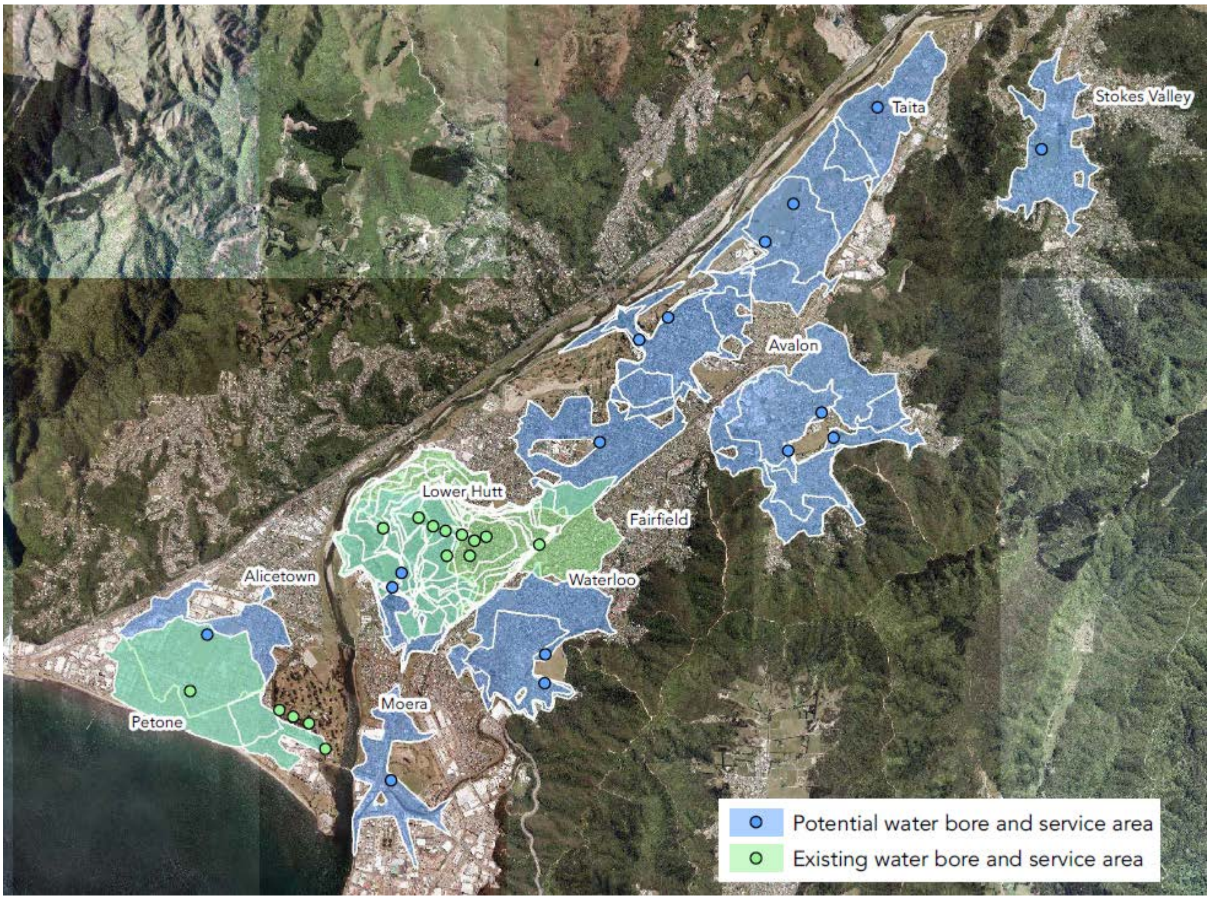

Figure 3.1 1000 m service areas for existing and potential water bores (including vulnerable sites).

Note that when there are several bores close together, as below the label "Lower Hutt", there is much overlap of the serviced areas and hence a plethora of white boundary lines. Where bores are adjacent to large blocks of non-residential land, as for the four bores midway between the labels "Petone" and "Moera", the serviced areas can be highly unsymmetrical and/or irregular in shape.

Some of the existing and proposed water bore sites in southern Lower Hutt are especially vulnerable to damage in large earthquakes, (a) from liquefaction, because they are in deep, soft ground, and (b) from tsunami, because they are close to the shore. Figure 3.2 shows a conservative approach where the vulnerable water bore sites in Petone and Seaview have been excluded from the modelling. This analysis suggests that if the current and proposed bore sites in Petone and Seaview were damaged and unable to be used, then all residents of Petone, Alicetown, Moera and southern Woburn, would be greater than 1 km walking distance from a water source.

If the bores in southern Lower Hutt were to be rendered unusable due to liquefaction and tsunami, then it is likely that many residential dwellings in the area also would be substantially damaged. Depending on the level of damage, the dwellings might not be able to be habited and so many residents of southern Lower Hutt might need to be moved to temporary housing or they could move in with family or friends in less damaged portions of Lower Hutt. If residents from the southern Lower Hutt were evacuated, then there would be less need for bores to be located in these areas.

In a Wellington Fault earthquake, there is potential for co-seismic subsidence of much of the southern Lower Hutt valley floor (Begg et al., 2002). That could result in many residences becoming uninhabitable through inundation, again reducing the need for bores in the southern part of the valley.

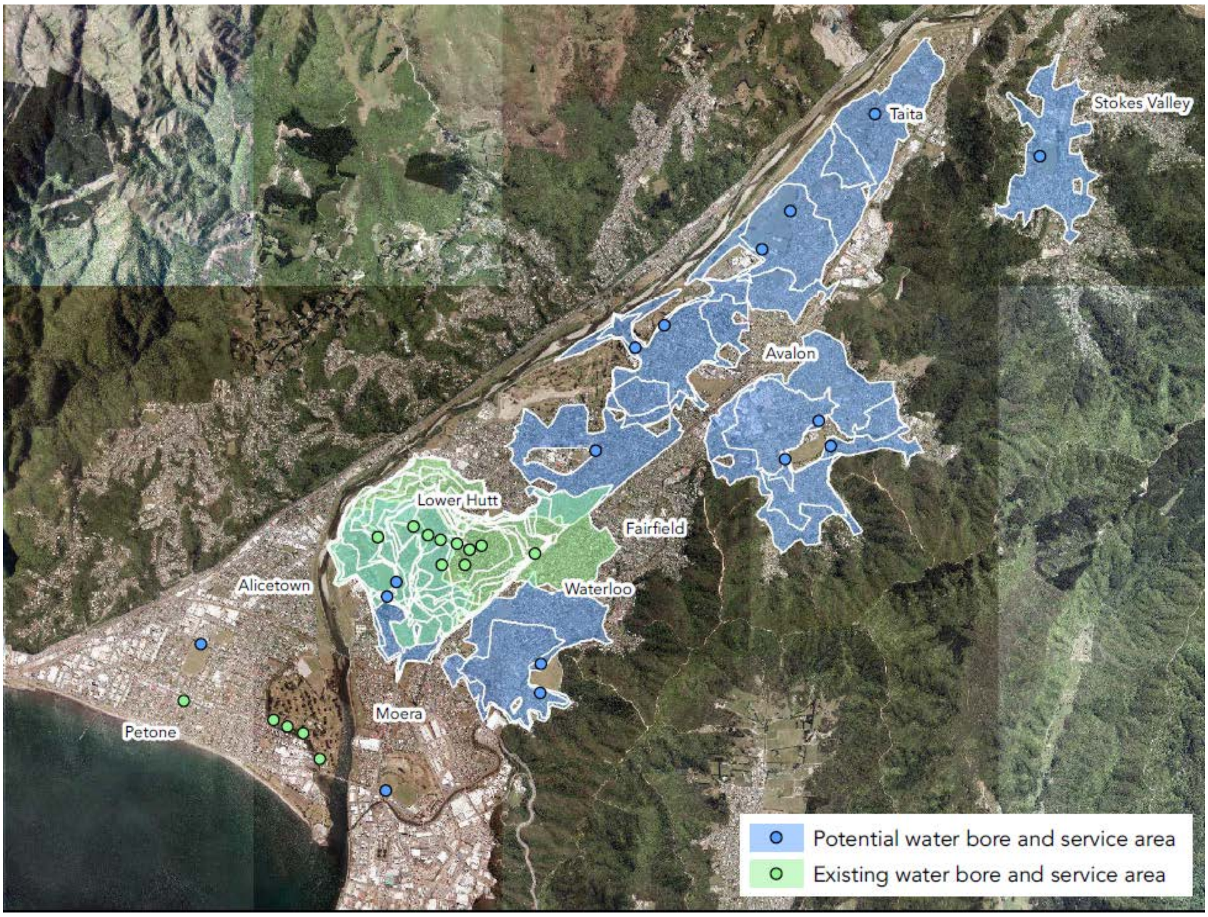

Figure 3.2 1000 m service areas for existing and potential water bores (vulnerable sites not included).

3.2.2 Residents within 500 m walking distance of an existing or proposed bore

The World Health Organization (2011) suggests a maximum distance of 500 m to collect water 3 to 6 months post emergency. Figure 3.3 shows the areas within 500m walking distance of existing water bores (in green) and potential new water bores (in blue).

This analysis shows that existing water bores (in green) would cover only the main CBD area of Lower Hutt, plus a small area of Petone, while the proposed bores would service only small areas elsewhere in the valley. The majority of the residents on the valley floor would not be within 500 m walking distance of any of the bores.

With these results it should be noted that, in the Lower Hutt context, water reticulation is expected to be restored within 3 months of a Wellington Fault Earthquake, and so it is unlikely that groundwater bores would be the sole source of drinking water after this time.

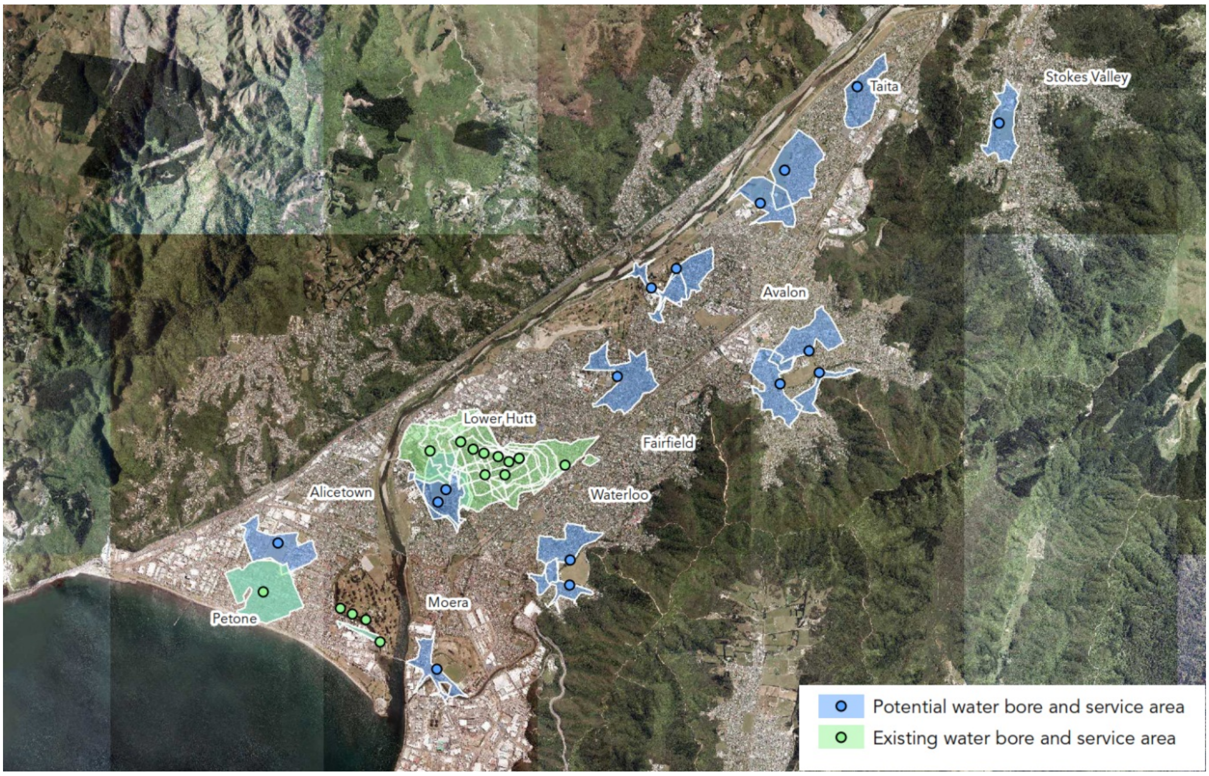

Figure 3.3 500 m service areas for existing and potential water bores (including vulnerable sites).

Figure 3.4 shows the number of properties that are within 500 m walking distance of a ground water bore, after allowing for removal of the bores that are vulnerable to liquefaction and tsunami damage. The removal of these bores shows that none of the southern Hutt Valley would be within 500m walking distance of a ground water source.

Figure 3.4 500 m service areas for existing and potential water bores (vulnerable sites not included).

3.2.3 Residents within 1.2 km walking distance of an existing or proposed bore

For the purposes of this report, we also estimated how many residents would be within 1.2 km walking distance of an existing or proposed water bore. This distance represents a 20% increase over the recommended distance by the World Health Organisation. However, fit healthy people should be capable of walking this distance to obtain water, particularly given that the valley floor is flat.

Figure 3.5 shows the water bores within 1.2 km metres walking distance of existing water bores and potential new water bores.

This analysis shows that existing water bores (in green) will only cover the main CBD area of Lower Hutt and the surrounding suburbs, and the majority of Petone. When the proposed bores are included, the majority of the residents of the valley floor are within 1.2 km walking distance of a water bore. The main areas that are not in walking distances are parts of Alicetown, Moera, Fairfield and Stokes Valley.

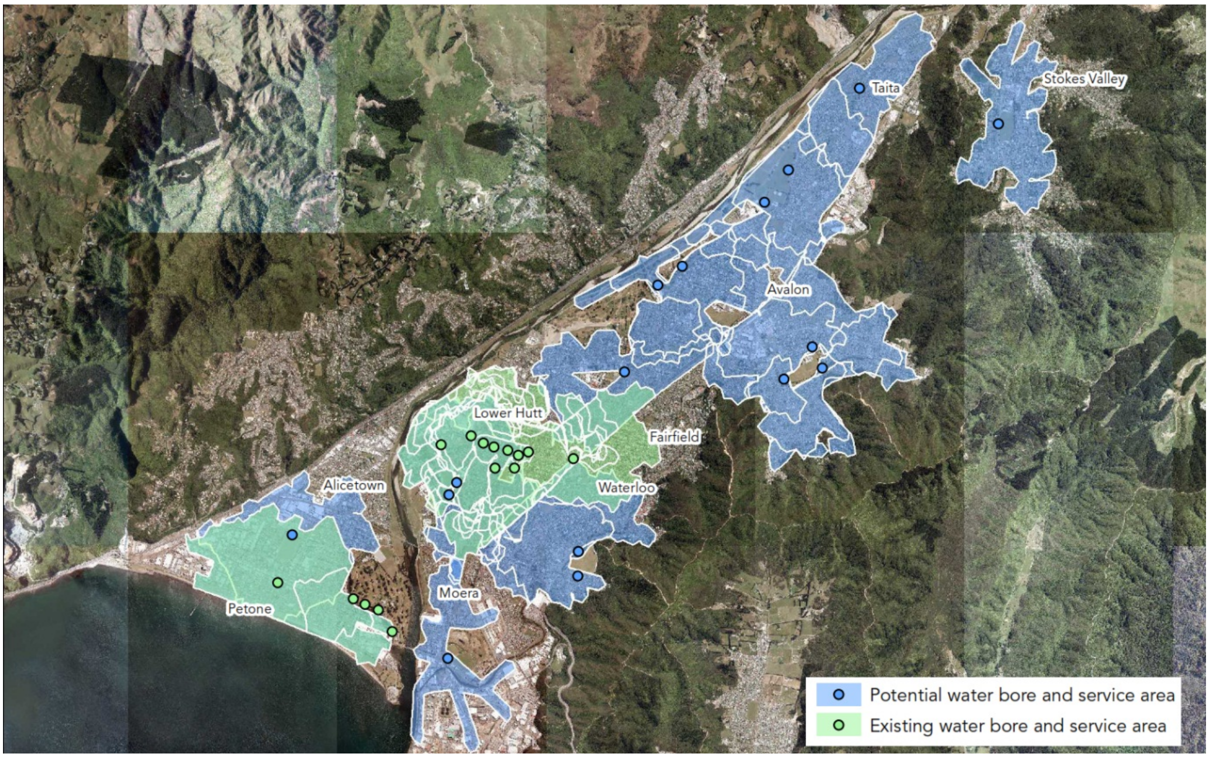

Figure 3.5 1200 m service areas for existing and potential water bores (including vulnerable sites).

Figure 3.6 shows where water bore sites in Petone and Seaview have been excluded. As with the other travel distance scenarios, residents of Petone, Alicetown and Moera would not be within 1.2 km walking distance of a groundwater bore. However, the majority of the remainder of the valley floor would be within 1.2 km walking distance with the exception of those areas as identified in the description of Figure 3.5.

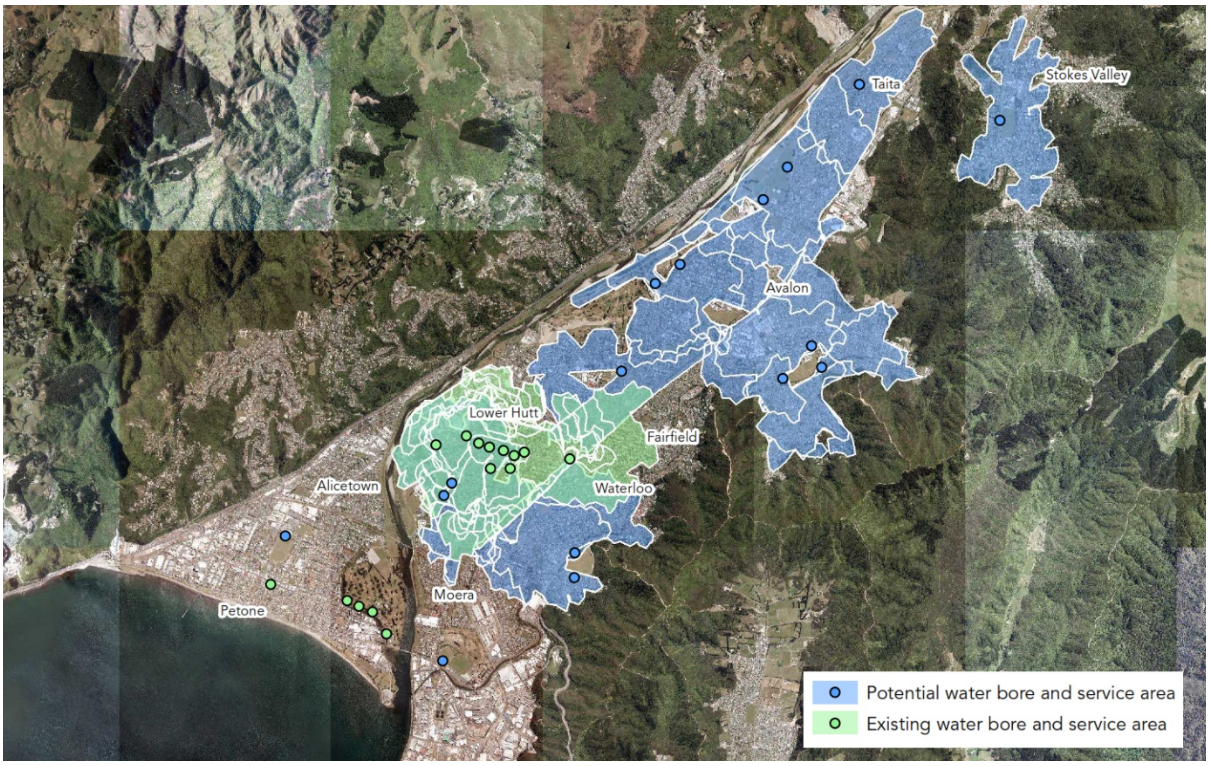

Figure 3.6 1200 m service areas for existing and potential water bores (vulnerable sites not included).

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4.0 DISCUSSION

The above results show that there is potential for the emergency water needs of the majority of the residents of the Lower Hutt valley floor, to be provided from artesian sources within 1 km walking distance of their homes. A combination of existing publically-owned bores, of which there are fourteen, and up to sixteen new emergency-only bores, would be sufficient (Figure 4.1). There are also fifteen privately-owned bores in Lower Hutt, five of which are consented to supply 1000 m^3 or more per day. Some are for potable water supply, but most are for irrigation (of golf courses) or industrial purposes. If arrangements could be made to use some of them for emergency supply, then fewer than sixteen new bores would be needed.

While parts of the parts of the valley floor are not within the recommended 1 km walking distance of a bore site, the areas are small in size and would contain a relatively small proportion of the valley floor residents. However, their needs could be met through new bores at suitably-located schools in Naenae, Alicetown and Waiwhetu, plus access to the large reservoirs in the hills immediately east of the valley floor (Figure 4.1).

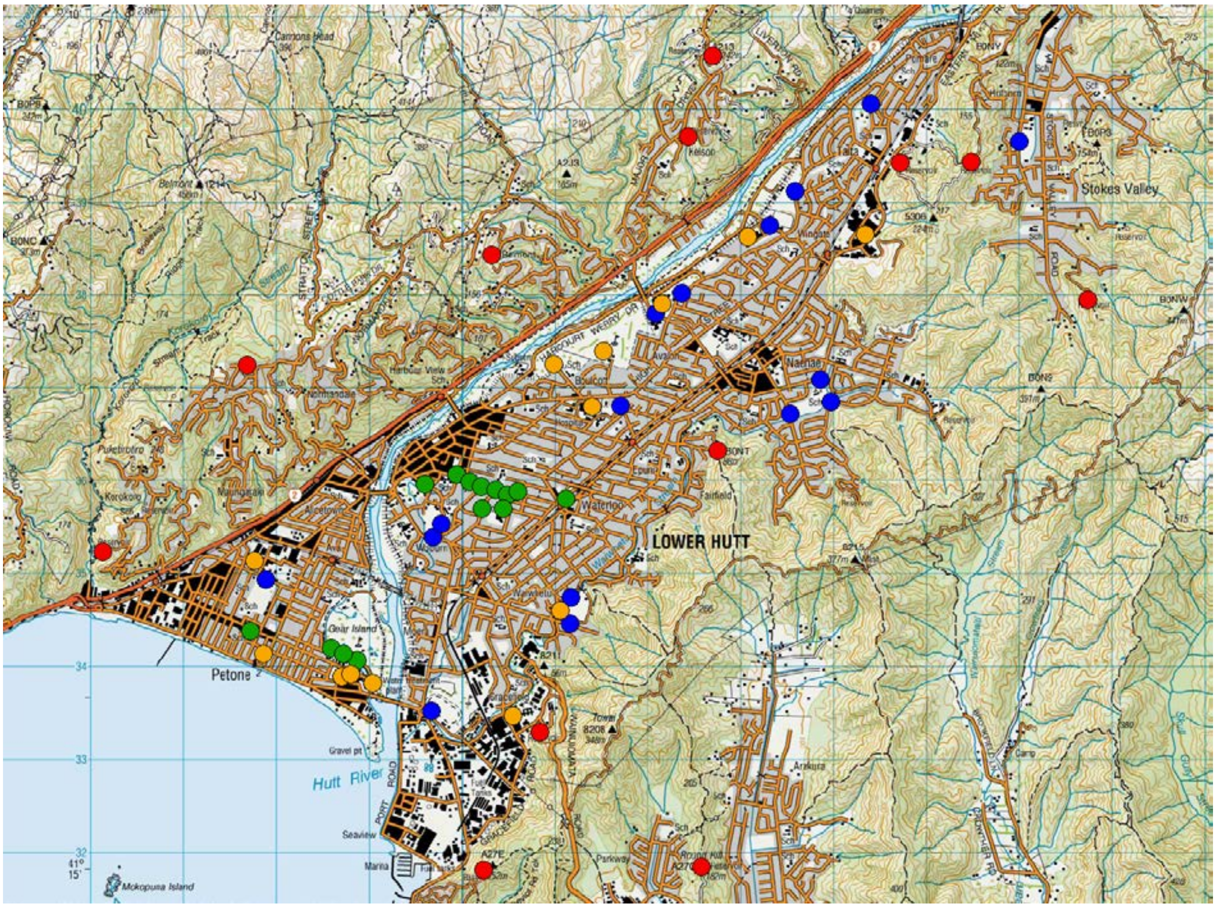

Figure 4.1 Locations of major reservoirs (red symbols), existing council-owned bores (green), existing private bores (orange), and the proposed new emergency-only bores (blue).

Wright and Johnston (2010) (Figure 4.2) developed a decision tree to determine whether people would evacuate or remain in their homes following a Wellington fault earthquake. Wright and Johnston (2010) showed that the key decision regarding whether people stay in their house or evacuate is the structural integrity of the dwelling. If the dwelling is structurally sound, then the next key decision pertaining to evacuation is whether the building is functionally uninhabitable. A contributing factor to whether a whether a building is functionally uninhabitable is the loss of services, which can include water supply.

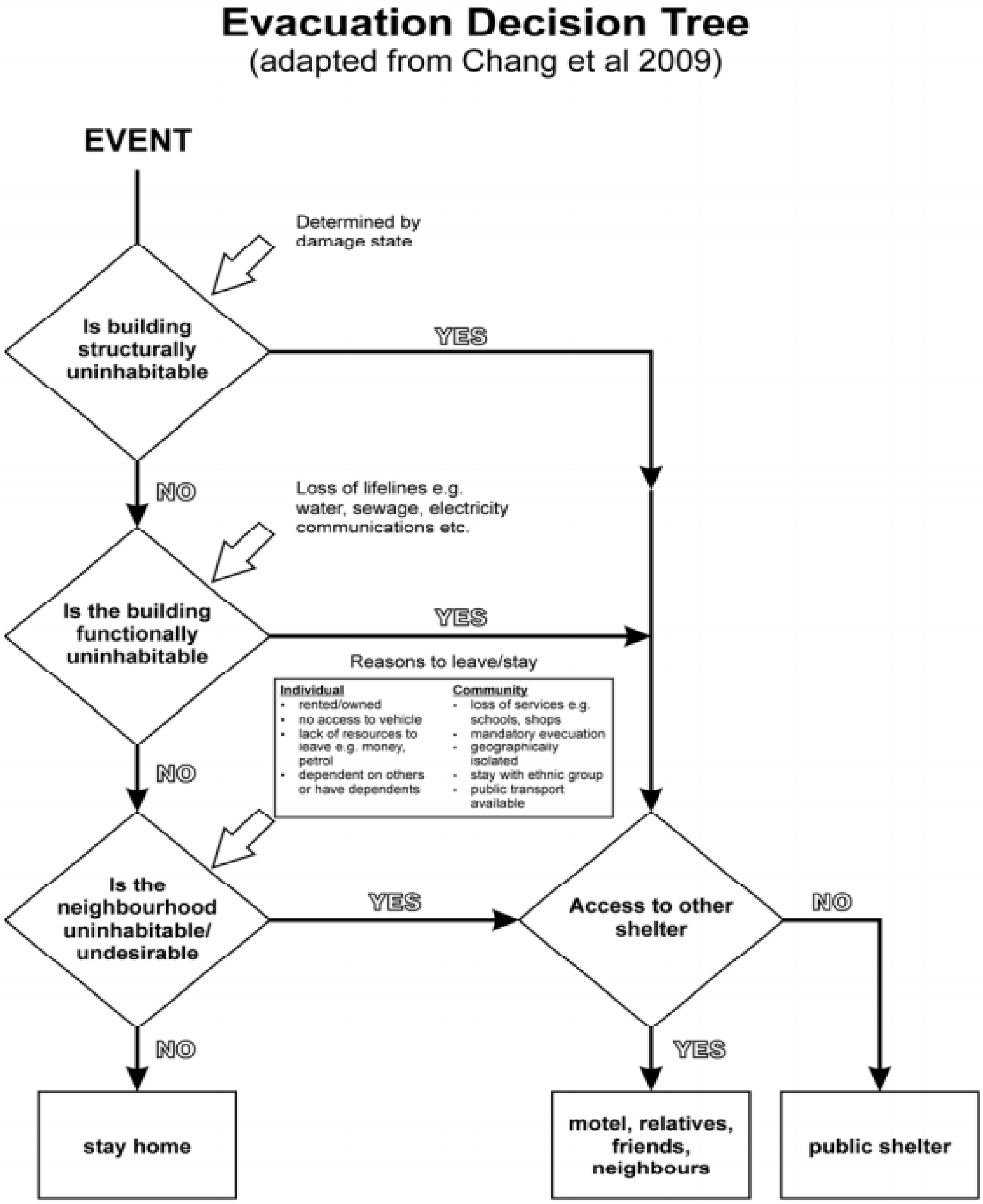

Figure 4.2 Evacuation decision tree (Wright and Johnston, 2010).

Beban et al. (2013) adapted the evacuation decision tree presented in Wright and Johnston (2010) to consider the availability of a water supply as a determinant as to whether to stay within a dwelling or to evacuate (Figure 4.3). This decision tree shows that if people are able to access water (including from civil defence and emergency management sources, such as the bores proposed in this report), then they are likely to stay in their home (providing it is structurally sound). It should be noted that the steps of the decision making process presented in this decision tree are yet to be weighted. The restoration of lifeline and community services following a major earthquake could potentially take weeks or months. Consequently, peoples' attitudes towards sheltering in place may change over time as it is possible their willingness to remain in their house will decrease the longer they are without essential services (Wright and Johnston 2010).

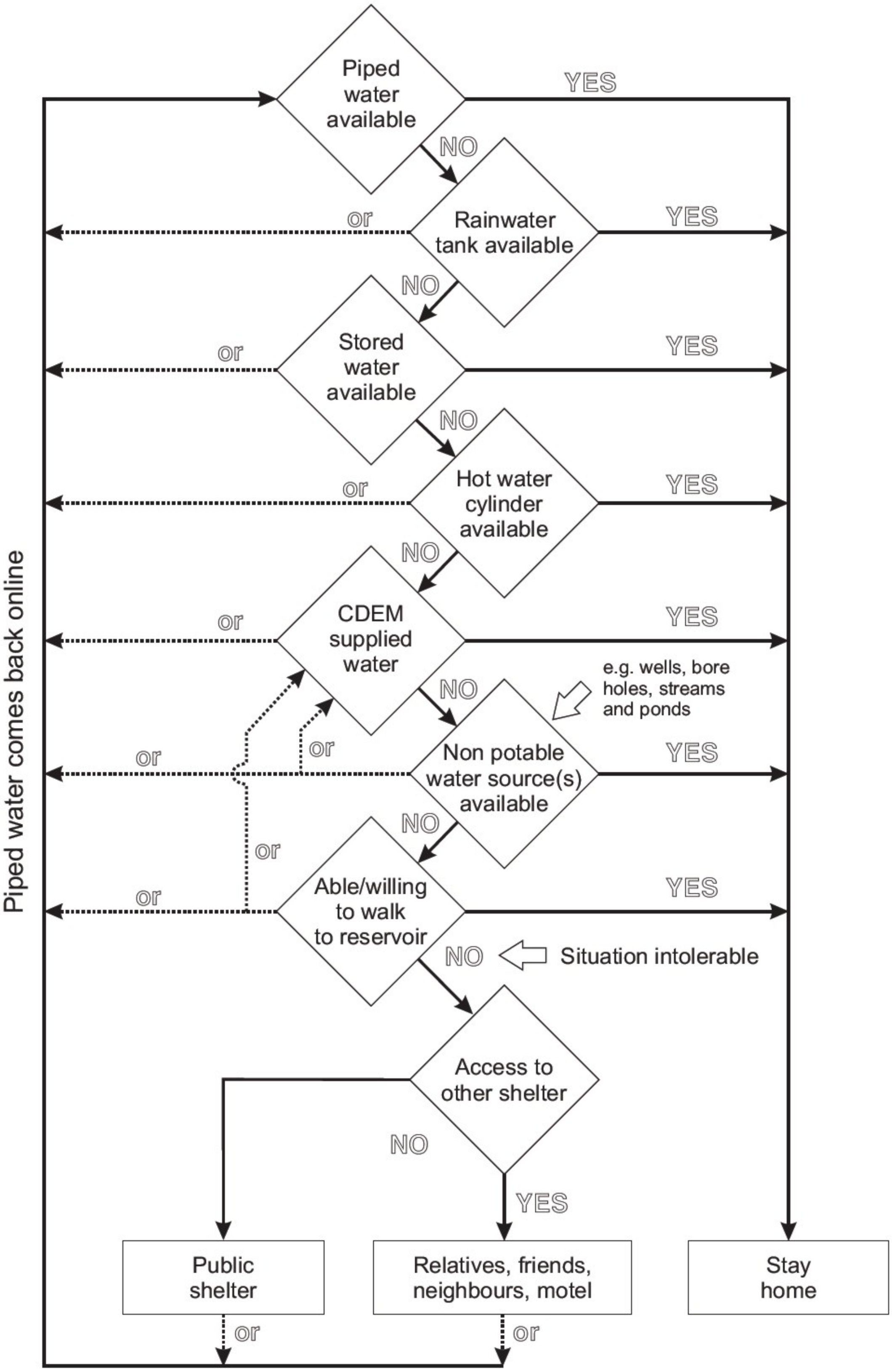

Figure 4.3 Decision tree for evacuation based on the availability of water (Beban et al., 2013).

If people have access to water, they are less likely to evacuate from their home and place additional demands on emergency evacuation shelters. The groundwater bores identified in this study have the potential to provide emergency water to a significant percentage of the valley floor residents of Lower Hutt. This has the potential to reduce the number of people who need to evacuate following a large earthquake, thereby reducing the potential demand for emergency shelter, and ultimately reducing the strain on the emergency response.

4.1 KEY CONSIDERATIONS FOR THE PROPOSED WATER BORES

There are a number of key considerations for the proposed water bores. These include:

- Number of bores;
- Water quality;
- Funding;
- Statutory limitations; and
- Access and education.

These are explored in more detail below.

4.1.1 Numbers of Bores

In this study, 16 potential bore sites were identified in addition to 14 existing council-owned bores. The results suggest that some of the proposed bore sites may not be needed (for example those at the Hutt Recreational Ground), due to the ability for the surrounding residential properties to be able to be serviced by existing groundwater bores. However, the existing groundwater bores are not located on large areas of public land, and given the size of Hutt Recreational Ground, it has the potential to be able to accommodate emergency housing. It is for this reason that the potential bore sites on the Hutt Recreational Ground have been retained.

As discussed in the results section, the ground conditions, and tsunami risk for the Petone Recreational Ground and Hutt Park, may result in these areas being unsuitable to contain groundwater bores. If groundwater bores for emergency supply were considered for these two parks, it is recommended that more detailed site specific hazard analysis is undertaken. This analysis would assist considerably with determining the suitability of these areas for groundwater bores. It is the authors' opinion, based on existing research, that it is unlikely that Hutt Park will be a suitable site.

The number of bores could be reduced further if access arrangements could be obtained to the private bores that already exist. However, as previously discussed, this study has not relied on access to these bores, as there is no certainty at the time of undertaking this study that these bores could be accessed, or that all will deliver potable water.

4.1.2 Water quality

One of the advantages of groundwater is the lack of disease-causing organisms. Towards the northern end of the valley, where water enters the aquifer, however, the water becomes progressively younger and more likely to contain residual viable pathogens. Hence water from the northern boreholes would need to be checked and, if necessary, treated, before being consumed.

4.1.3 Funding

A key factor associated with the installation of groundwater bores is cost. Based on discussions with the Chief Operating Officer of Capacity Infrastructure Services Ltd., the cost of installing a bore would be approximately $250,000. If all sixteen of the proposed bores were to be constructed then the total cost would be about $4 million. This cost would reduce to approximately $3 million if the Hutt Park, Petone Recreational Ground and Hutt Recreational Ground bores were not constructed. These costs may be reduced further if access could be secured to a number of the private bores identified (but not included in the network analysis included in this project).

If the emergency groundwater bores were to be constructed, they would need to form part of the Long Term Plan process of Hutt City Council, and provision for the funding would need to be made. As this process is political and involves decisions regarding the spending of public money, a strong case would need to be made regarding why these bores should be funded over other projects.

4.1.4 Statutory Limitations

Under the Greater Wellington Regional Council's Regional Plan for Water, resource consent would be required to construct the proposed bores. As with any resource consent process, there is a degree of uncertainty as to whether the proposed bores could be constructed. Any resource consent application would need to demonstrate that environmental effects associated with the construction of the proposed bores would be minor and that the proposal was consistent with the objectives and policies of the Regional Policy Statement and the Regional Plan for Water. As part of the resource consent process, mitigation measures would be required to be identified to reduce any environmental effects associated with the proposed bores.

4.1.5 Access and Education

Installation of the proposed water bores would still mean that a significant percentage of the valley floor residents would need to walk up to 1 km to access water (for a small percentage of the population, this distance would be greater). There is an expectation that people will have access to water at their home, and so people would need to be educated, prior to an event, of the need for them to travel up to 1 km to obtain water. While the Hutt Valley is flat, and therefore a 1 km walk would not normally be arduous, this would change once the transportation of water was included in the equation. For example, 20 l/p/d for a family of three equates to 60 kg of water that needs to be transported per day. This will mean that people may need to make multiple trips daily to collect water. Wheelbarrows, trolleys or trikes will be needed.

For some people, being able to travel this distance would not be practicable (especially if they are elderly, unwell, or have a disability that prevents them from travelling). As such, they need to be aware that water may not be accessible and that they may need to leave their homes and live with family or friends, who can collect water for them. Alternatively, these people may be able to stay in their homes, if they have someone who can collect and deliver water to their property.

Related to access is the ability to draw water from the bores. In the days following a large earthquake, it is likely that power supplies may be out or disrupted. Depending on the damage, these interruptions may continue for some time. It is therefore important that water can be pumped from the bores, where the natural flow rate is too low, using pumps powered by petrol generators. To assist with this issue, the bores would need to be constructed in a manner that would allow for petrol generators to easily connect into them to ensure that water can be pumped (note this will require generators and fuel to be stored close to the proposed bores). Consideration should also be given to having connections that allow the fire service easy access to the bores. This would allow the fire service to use the bore-water for fire-fighting purposes following an earthquake, rather than relying on potable water from, for example reservoirs. These connections could also enable the fire service to collect and distribute water to areas that are less well serviced (this could only be undertaken once the immediate threat to life and property from fire or earthquake damage had passed).

5.0 CONCLUSIONS

Lower Hutt has a high likelihood of experiencing a major earthquake on the Wellington Fault within the next 100 years (Rhoades et al., 2011), and there are several other potential sources of large, damaging, earthquakes nearby (Cousins et al 2014). Recent research has shown that water shortages are likely to occur after such earthquakes, due to the time needed to reinstate bulk and reticulated supplies of water. In Wellington, for example, the potential gap between depletion of stored water and the restoration of emergency-level supply could result in tens of thousands of people being without any water for weeks to months (Cousins, 2013).

For Lower Hutt, we have shown that the gap between the depletion of reservoir stored water and the restoration of emergency-level supply is likely to be between zero and about ten days, depending (a) on the proportion of reservoir water lost due to earthquake damage to the reservoirs, and (b) the rate at which the stored water is consumed. Hence, in broad terms, the water-supply gap appears to be much less of a problem for Lower Hutt than for Wellington. Note that only the main storage reservoirs have been used in the modelling, with several small reservoirs being ignored.

There is, however, a significant problem of accessibility, because many Lower Hutt people live much more than 1 km from their closest reservoir. For this reason we have investigated the potential for other sources, like surface (river) water and groundwater, to meet the emergency needs.

In emergency situations, groundwater is preferable to surface water for drinking, as it is less likely to be contaminated. The Lower Hutt valley floor is relatively unique in that it sits on top of a high quality artesian field, the Waiwhetu Aquifer. The water is of sufficient quality that it currently requires no treatment to make it potable. Groundwater would be a good alternative option for emergency water, and would be preferable to using surface water from the Hutt River or local streams. Personal and household stored water is unlikely to provide sufficient water to cover the time it will take to get the reticulated supplies working.

Existing bores are likely to provide water to the Lower Hutt CBD and some of Petone, but would not be very accessible to other parts of the valley floor because of the distances involved. While water could be piped or transported to other parts of the valley, the sheer quantity of water, and the likely poor condition of the road network after a major earthquake, makes this a less than ideal situation.

Our analyses show that there are a number of new sites that could have bores installed to access the Waiwhetu Aquifer. These bores would be located in public parks and would ensure that a significant percentage of the residents of the Valley floor would be within 1 km walking distance of an emergency water supply following a large earthquake. The 1 km distance is based on the recommendations of the World Health Organization, who suggest a maximum distance of 1 km from shelters to water points for the first three months after an emergency, and 500 metres in the longer term (3-6 months post emergency) (WHO/WEDC, 2011).

There are a number of benefits associated with the proposed water bores including:

- The proposed water bores would largely address the issue of the residents on the valley floor of Lower Hutt not being within close walking distance (1 km) of an emergency water source;
- The aquifer water is expected to be potable with no further treatment required;
- If residents have access to potable water, it reduces the likelihood of them leaving their homes after a large earthquake (particularly if the dwelling is structurally sound), thereby reducing the demand on evacuation centres:
- The bores could be accessed by other service providers (such as the fire service for fire-fighting purposes) following a large earthquake, as a water source; and
- The cost of the bores is relatively modest (approximately $3-4 million depending on the number of bores); and could be spread over successive financial years.

There are a number of potential factors that need to be considered to allow for the implementation of the bores. These include obtaining funding and the required resource consent approvals. One of the key issues would be the education of the residents of the valley floor so that they are aware that following a large earthquake they would need to travel to collect water. It is important that residents understand where the bores are located and that travel distances of up to 1 km may be required for them to collect water. This education would ensure that people are acclimatised to the concept of collecting water, so that when an event occurs, the bores are fully utilised and demands on the emergency response are reduced.

The scale and quality of the aquifer underlying Hutt Valley provides a great opportunity to implement a robust emergency water-supply system through the use of purpose-built groundwater bores. While there are several factors that need to be considered and addressed prior to the construction of the bores, the potential benefits for the residents of Lower Hutt, and for the emergency management response following a large earthquake, would be significant.

6.0 ACKNOWLEDGEMENTS

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APPENDICES

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APPENDIX 1: POPULATION DATA USED IN THE MODELLING

Area Unit	Area Unit Name	Residents 2013	Closest Reservoir	Study Zone
568101	Tawhai	3345	Delaney	Valley Floor
568102	Holborn	2067	Delaney	Valley Floor
568103	Delaney	2412	Delaney	Valley Floor
568104	Manuka	1707	Kingsley	Valley Floor
568201	Taita North	2610	Taita	Valley Floor
568202	Taita South	2925	Taita	Valley Floor
568301	Avalon East	2337	Naenae	Valley Floor
568302	Naenae North	4659	Naenae	Valley Floor
568303	Naenae South	3528	Naenae	Valley Floor
568401	Avalon West	2469	Naenae	Valley Floor
568402	Boulcott	2487	Naenae	Valley Floor
568501	Epuni West	3015	Naenae	Valley Floor
568502	Epuni East	2874	Naenae	Valley Floor
568601	Waterloo West	882	Gracefield	Valley Floor
568602	Waterloo East	4245	Naenae	Valley Floor
568701	Waiwhetu North	1359	Gracefield	Valley Floor
568702	Waiwhetu South	2598	Gracefield	Valley Floor
568800	Gracefield	60	Point Howard	Valley Floor
568900	Moera	1533	Gracefield	Valley Floor
569001	Woburn North	1299	Gracefield	Valley Floor
569002	Woburn South	390	Gracefield	Valley Floor
569100	Hutt Central	3954	Gracefield	Valley Floor
569201	Melling	645	Maungaraki	Valley Floor
569202	Alicetown	1971	Maungaraki	Valley Floor
569900	Petone Central	906	Rahui	Valley Floor
570000	Esplanade	2487	Rahui	Valley Floor
570100	Wilford	3363	Rahui	Valley Floor

Area Unit	Area Unit Name	Residents 2013	Closest Reservoir	Study Zone
569301	Normandale	2052	Maungaraki	Western Hills
569302	Maungaraki	3777	Maungaraki	Western Hills
569401	Tirohanga	1164	Park	Western Hills
569402	Belmont	2697	Park	Western Hills
569500	Kelson	2697	Liverton	Western Hills
569600	Haywards-Manor Park	390	Manor Park	Western Hills
569800	Korokoro	1332	Rahui	Western Hills
564800	Glendale	3804	Konini	Wainuiomata
564900	Parkway	3141	Konini	Wainuiomata
565000	Fernlea	1971	Konini	Wainuiomata
565100	Arakura	2448	Konini	Wainuiomata
565200	Homedale West	2460	Homedale	Wainuiomata
565300	Homedale East	2928	Homedale	Wainuiomata
565400	Pencarrow	546	Homedale	Wainuiomata
570300	Eastbourne	4665	Point Howard	Eastbourne
622102	Seaview Marina	42	Point Howard	Eastbourne

APPENDIX 2: RESERVOIR DATA USED IN THE MODELLING

Reservoir Name	Capacity (m^3)
Delaney	5,659
Kingsley	1,917
Taita	5,532
Liverton	4,635
Manor Park	231
Major	2,301
Maungaraki	5,447
Park	3,962
Gracefield	5,643
Naenae	11,343
Rahui	8,960
Point Howard	1,937
Konini	5,100
Homedale	4,900

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