A SUSTAINABLE REBUILT CITY USING GEOTHERMAL HEAT PUMPS: THE CHRISTCHURCH STORY

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ABSTRACT

The post-earthquake re-build of Christchurch's inner city has allowed large commercial-scale building owners to design and utilise more efficient building energy systems using aquifer based geothermal heat pump (GHP) technology. The city is located on a series of confined aquifers, ranging in depths from 5 m to greater than 200 m. These aquifers contain water that is consistently between 12-13ºC providing a stable consistent source of heat energy. The systems extract heat from this source and also use it as a sink for cooling. The overall annual energy requirements from a large commercial building will usually require a greater cooling load than heating load. Six years after the earthquakes, there are over fifteen large GHP projects under-development or completed across the city and this paper summarises these GHP developments with a view to showcasing the present use of this technology in New Zealand.

1. INTRODUCTION

Geothermal heat-pumps (also known as ground-source heat pumps or geoexchange systems) harness low-temperature renewable energy stored in shallow near-surface soils, rocks and ground water at a relatively constant temperature for heat supply and also as a heat sink when cooling is required. The heat transferred from the subsurface is upgraded into useable energy using mechanical compression plant that changes the temperature of the energy supplied. In the Christchurch circumstance the aquifer waters are at a temperature such that free cooling is able to be used which enables energy to be transferred to the aquifer water without requiring the use of mechanical compression equipment. These systems are highly effective in using a renewable energy source for heating and cooling larger commercial facilities.

Geothermal heat pump (GHP) systems are used extensively in Europe where they are a common technology (Weber *et al*, 2014; Lind, 2011). The uptake of this technology in New Zealand is more recent, with approximately 150 known installations throughout of the country (Carey *et al*, 2015). Most of these installations are located in the South Island, with only a handful located in the North (GNS Geothermal Use database - 2017). Facilities with greater heating and cooling demand, such as airports, libraries, swimming pools, hospitals, convention centers and larger accommodation facilities (e.g. hotels, lodges, residential care) are adopting aquifer-based GHP technology when the circumstances are right. Christchurch is particularly suitable as is discussed in this paper.

New Zealand's climate is generally temperate, experiencing neither excessive heat nor extreme cold. In the residential home sector this has led to a history of minimal investment in home energy systems with the population generally having lower expectations of indoor comfort than is found in many other nations (Climo *et al*, 2012). This is a barrier to the uptake and utilisation of GHP technology in this sector (Coyle, 2014) where these types of systems are really only being installed in top end residential circumstances.

2. CHRISTCHURCH

Christchurch city, Canterbury, has had the greatest recent growth of GHP technology in New Zealand. The key driver for this has been the rebuilding of a greener more energy efficient city in the wake of the destructive 2010 / 2011 earthquakes where more than 1000 commercial buildings in Christchurch's central business district were destroyed, demolished and many are now being rebuilt.

Following the demolition phase, the city's priority was to rebuild infrastructure and power systems, including underground services. Christchurch City Council opened the recovery planning process to local businesses, property owners, public sector organisations, residents and community groups for ideas and comments on what they wanted in the new city. The guiding principles that emerged (CCC, 2011) were:

- To foster business investment,
- To respect the past,
- To have a long-term view to the future,
- To be easy to get around, and
- To create a vibrant central city.

The opportunity for major infrastructure re-building provided a unique opportunity for installing shared energy systems and improved power, water and sewerage infrastructure. Longer term benefits including more energy efficient resilient infrastructure using renewable lower carbon sources of energy should feature in the rebuild (Sustainable Cities, 2011). Unfortunately, the processes around city energy networks were not set-up quickly enough to enable the implementation of larger coordinated initiatives, and businesses started to rebuild independently, applying for energy consents individually or sometimes in conjunction with near neighbours.

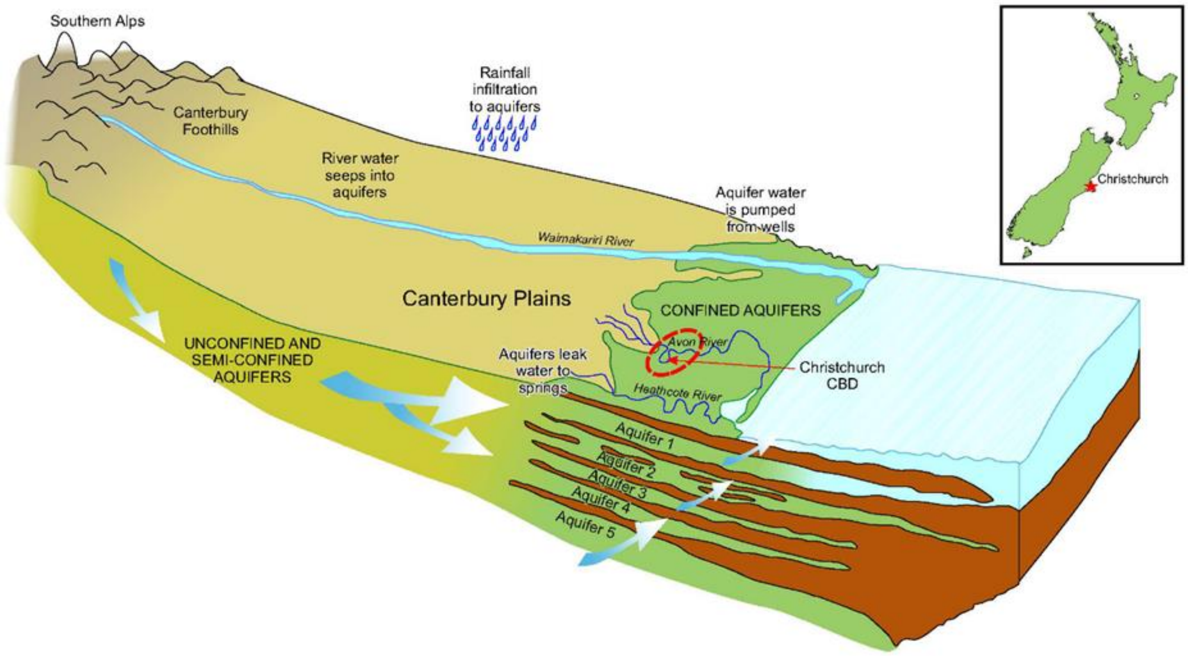

Figure 1: Conceptual diagram showing the groundwater flow from the foothills of the Southern Alps to the confined aquifers under Christchurch. Image redrawn from Weeber (2008).

2.1 Geological and Hydrological setting

Christchurch is located above a series of aquifers, ranging in depths from <13 m (Springston Formation) to depths greater than 150 m (Figure 1). There are six separate aquifer systems over this depth range in gravel alluvium and glacial outwash deposits, confined by marine sediments composed of silt, clay, peat and shelly sands, which act as aquitards (Taylor et al, 1989).

(1) < 13 m Springston Formation (~10 m thick)
(2) 20-40 m Riccarton Gravels (~15 m thick)
(3) 50-85 m Linwood Gravels (variable thickness)
(4) 95-105 m Burwood Gravels (~5 m thick)
(5) 15- >125 m Wainonui Gravels (~5 m thick)
(6) >150 m Aquifer No 5

An artesian system occurs in the coastal area due to the hydraulic gradient and the confining nature of the system with the artesian pressure increasing with depth. The aquifer transmissivities vary between <40 and up to 20,000 m^2/d with the individual aquifer "averages" being between 1200 and 4300 m^2/d (Rutter, 2015) The water temperatures are generally between 11°C and 13°C, with water originating in the Port Hills (south of the city) generally being warmer.

The first artesian wells were drilled in the 1860s in response to a need for uncontaminated water supply (CCL, 2016). The number of wells reached several thousand by the late 1980s, accessing water from up to 200 m deep for agricultural, industrial and domestic water supply.

3. CONSENT REQUIREMENTS AND POLICIES

Prior to the Christchurch earthquakes in 2010 and 2011, GHP schemes were required to obtain consent to extract and discharge to groundwater or surface water. Although the regional plan operative at the time did not allow for new consumptive groundwater takes, GHP schemes that injected 100% of the extracted water back to the aquifer system could be consented. Thermal impacts were managed on an effects basis, with applicants required to assess the potential for effects on any temperature-sensitive wells within influencing distance.

The opportunity to support and encourage development of high efficiency building energy solutions as part of the post-earthquake rebuild was recognised by a number of agencies. The city and central government agencies offered funding grants to support feasibility studies and a contribution towards capital costs of GHP systems (CAfE, 2013; EECA, 2015; 2016). Several issues were identified by developers as potential deterrents to aquifer based energy system. They were:

(1) the additional time required for the consenting process,
(2) the associated uncertainty, and
(3) the additional costs involved in gaining consent.

In 2013 the opportunity was taken by the Geothermal Heat Pump Association of New Zealand and Central Heating New Zealand, to seek revisions to the planning rules in the proposed Canterbury Land and Water Regional Plan. Submissions made (Carey, 2013) sought changes to:

(1) Allow flexibility in the depth and location of the water and heat abstraction and discharge within groundwater allocation zones;
(2) Clearly state that non-consumptive groundwater takes, where the take and discharge are within the same groundwater allocation zone, would not be subject to any groundwater allocation zone limits regardless of the depth and location of the take and discharge;
(3) Ensure that non-consumptive takes and discharges would be managed in the context of the groundwater allocation zone, not the single aquifer context; and
(4) Ensure that further non-consumptive groundwater abstraction within the Christchurch - West Melton groundwater allocation zone was not prohibited.

In 2015 there were rules introduced into the Canterbury Land and Water Plan permitting certain water takes for aquifer thermal energy systems that applied specifically to the central city area. The provisions are included in rule 9.5.15 of the plan (ECan, 2015). Water could be used for energy purposes provided it was taken and then discharged to identified aquifers and that the takes and discharges complied with other prescribed requirements. The water is to be extracted from aquifers between 30 m to 100 m deep, and discharged to the shallower Riccarton aquifer below 20 m deep. Discretionary applications can be made for permits (rule 9.5.16) where the use doesn't meet the requirements of the permitted activity rule.

Almost all of the commercial aquifer energy installations in the central Christchurch city area that have been installed in the last few years or are being planned are based on specific consents for their facilities even though the permitted activity rule has been in place since 2015.

4. GHP INSTALLATIONS

4.1 Pre-Earthquake installations

The Townhall utilised the city water for heating and cooling purposes in the 1970's (Marshall, 2013), however the first purpose-drilled wells for energy purposes were drilled in 1997 on the University of Canterbury's campus. The campus, currently has a series of seven bores ranging in depths from 9 m to 60 m, which extract aquifer water at a maximum rate of 5 L/s in the shallower wells, and a maximum of 30 L/s in the deeper wells (Consent CRC971519; ECan, 2016). The water is discharged to the Avon River or the Okeover Stream at temperatures < 21°C.

In 2011, heat pumps and chillers were installed at Christchurch Airport, located 12 km from the city centre. The heat pump and chiller systems take advantage of the 12°C water in the subsurface aquifers to provide heating and cooling to the airport buildings. Groundwater from six wells at depths between 16 m and 40 m (Consent CRC074115.1; ECan, 2016) pass through the heat plant being discharged through a soak pit back into the ground. The system makes use of a design with the water from the wells used to precool or directly cool some components of the airport facilities. The direct cooling bypasses the chiller systems further enhancing the system energy effectiveness.

The airport system gained both national and international industry recognition. It was awarded the Gold Award of Excellence at the 2014 ACENZ Innovate NZ Awards and the Building and Construction category at the 2014 IPENZ NZ Engineering Excellence Awards. It won the International Project of the Year at the 2015 CIBSE Building Performance Awards in London.

4.2 Post 2011 Installations

The Christchurch rebuild has seen a surge in the installation of GHP systems, unmatched elsewhere in New Zealand. Table 1 has data for commercial facilities including the date of completion. The influence of post 2010/11 earthquake rebuilding on the uptake of the technology is apparent. The table is colour coded with the known fully operational facilities shown in green, the partially operational facilities shown in blue and those under construction in white.

Facility	Floor Area m2	Completion
University of Canterbury		1997 +
Christchurch International Airport		2011
TAIT Technology Centre		Apr-15
Bus Exchange	9500	May-15
ECan office	8000	Mar-16
Art Centre	13000	2016-19
St Georges Hospital		2016-19
Justice Precinct	42000	Aug-17
The Terrace	4000	Oct-17
King Edward Barracks	30000	2017
Town Hall	11000	Jul-18
Central Library	9800	2018
School of Biological Sciences (University of Canterbury)		2019
Convention Centre		2020
Metro Sports Facility	34,000	2020
New Education Building (University of Canterbury)		

Table 1: Commercial facilities using or proposing to use aquifer water energy.

Domestically, at least 30 GHP systems have been installed since 2010 in the Canterbury region (GNS Science, 2017). This is about the same number that had been installed in Canterbury prior to the earthquake. However, it is the larger scale, commercial sector which has experienced significant growth since 2010/11. Seven of the new installations that have been completed or are near-completion in Christchurch are shown in Figure 2.

The paper goes on to discuss a number of these installations. Data has been acquired for one of the smaller installations (ECan offices) and this is discussed in more detail.

4.2.1 Bus Exchange

The Bus Exchange is a purpose built public transport facility located in the core of Christchurch CBD. The design process was relatively rapid as the retail spaces were already under construction when the site became available for the Exchange. The Bus Exchange occupies approximately 5,000m^2 catering for 8.6 million bus passengers per year and approximately 1,850 buses per day (MFE, 2005). It became operational in May 2015.

The building is heated and cooled by an aquifer GHP system, which extracts water from a depth of 85 m (Linwood Gravels) at a rate of up to 189,000 m^3 per year (Consent CRC167902; ECan, 2016) and re-injects a similar quantity of water at a depth of 36 m (Riccarton Gravels) (consent CRC167904; ECan, 2016). The range of temperature change permitted is ±6 °C.

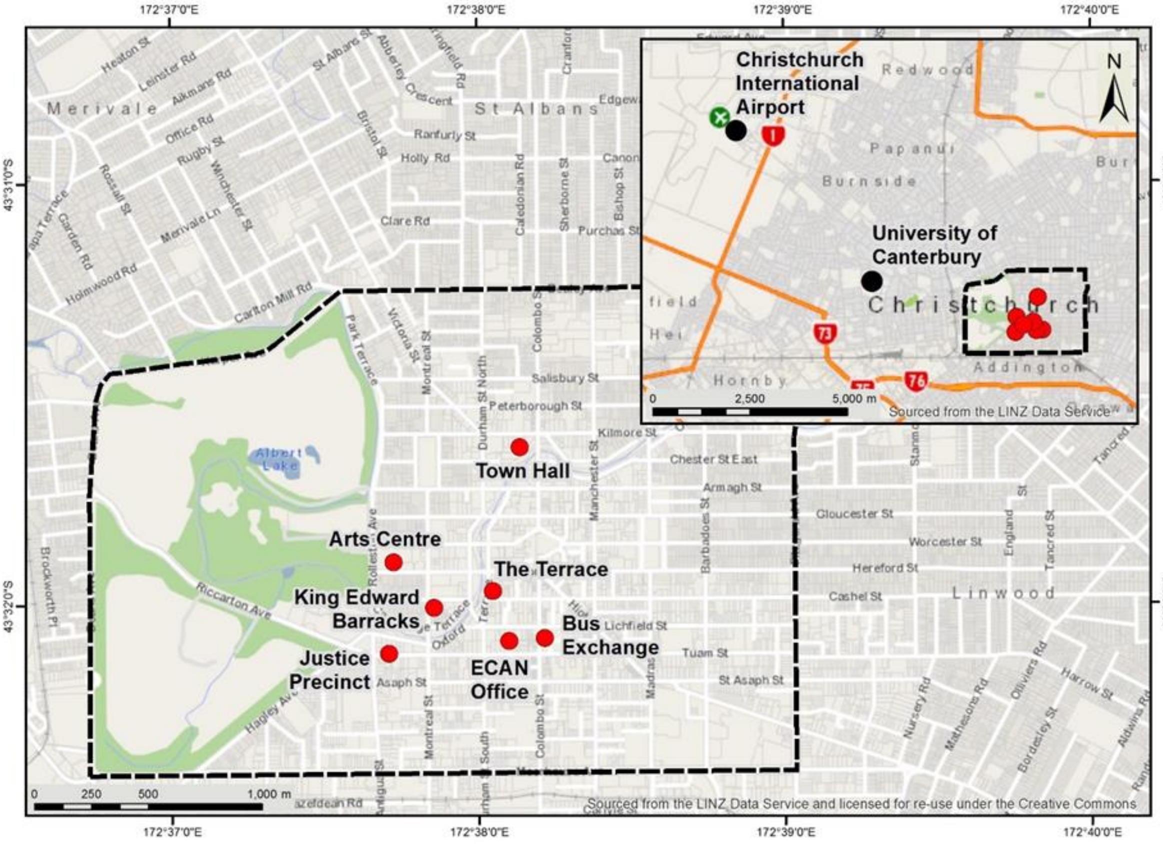

Figure 2. Map showing location of new GHPs in Christchurch's CBD. From Seward et al., 2017

4.2.2 The Arts Centre (The Performing Arts Precinct)

The Art Centre was originally established as a college campus. Construction began with the Clock Tower block in 1877. A Girls' High School opened the following year, followed by the Boys' High School three years later, and other buildings were added as the campus expanded to also include the University. The secondary schools moved away from the site in 1881 and 1926, and by 1978, the University had fully relocated to Ilam. The site's buildings were then transferred to the Arts Centre of Christchurch Trust Board for a Performing Arts Precinct for creative performance, music, drama, and dance.

Due to damage sustained from the earthquakes, an extensive seven-year, $290 million restoration programme is currently underway (CCC, 2015). During this period the site is to be progressively re-opened in stages.

Prior to the earthquakes, the Art Centre Trust had considered a GHP system to heat and cool the buildings. The heating and cooling system for the facilities was reviewed in 2013 and decisions to install an aquifer based GHP system made. Bores were installed in 2014. The Art Centre is consented to take water at rates of not more than 80 L/s (Consent CRC154729; ECan, 2016), and inject the water with a temperature difference range of +/- 6°C (Consent CRC154730; ECan, 2016). Four wells are used, two producing water and two injecting water discharged from the heat plant. There are two plant rooms as part of the site with seven heat pumps installed between them.

4.2.3 ECan Offices

The Environmental Canterbury (ECan) offices opened in early 2016, housing 450 staff over 5 floors, with a total floor area of ~8000 m^2 (Stuff, 2016). It has a 4 Green Star rating and is built to 120% of the current building code for building strength. The building is heated by 0.65 MW heat plant using artesian water. The water is extracted from well BX24/0527 (85 m depth) at a rate no greater than 33 L/s, up to a maximum of 2500 m^3 per day and up to 350,000 m^3 per annum (average 11 L/s) (Consent CRC146483; ECan, 2016). The water is then injected at 35 m, within a temperature range of +/- 8^{o}C of the extraction temperature (Consent CRC146484; ECan, 2016;). Figure 3 is a photo of the submersible extraction pump (black unit suspended from the crane) removed from the well.

Figure 3. ECan submersible extraction pump suspended from crane.

Examples of monitored data from the ECan GHP heat plant are shown in Figure 4 and 5 for February 2017. At a pump rate of 30 L/s, the incoming water temperature is shown in blue (left hand axis) and temperature difference is shown in red (Right hand axis). The pump only operates for part of the day and this is seen in the figure with the pump not operating when the incoming water temperature is plotted below 5°C.

During the month of February the heat plant was operating in cooling mode and Figure 5 is a plot of the calculated daily energy (MJ per day) delivered to the aquifer from the heat plant.

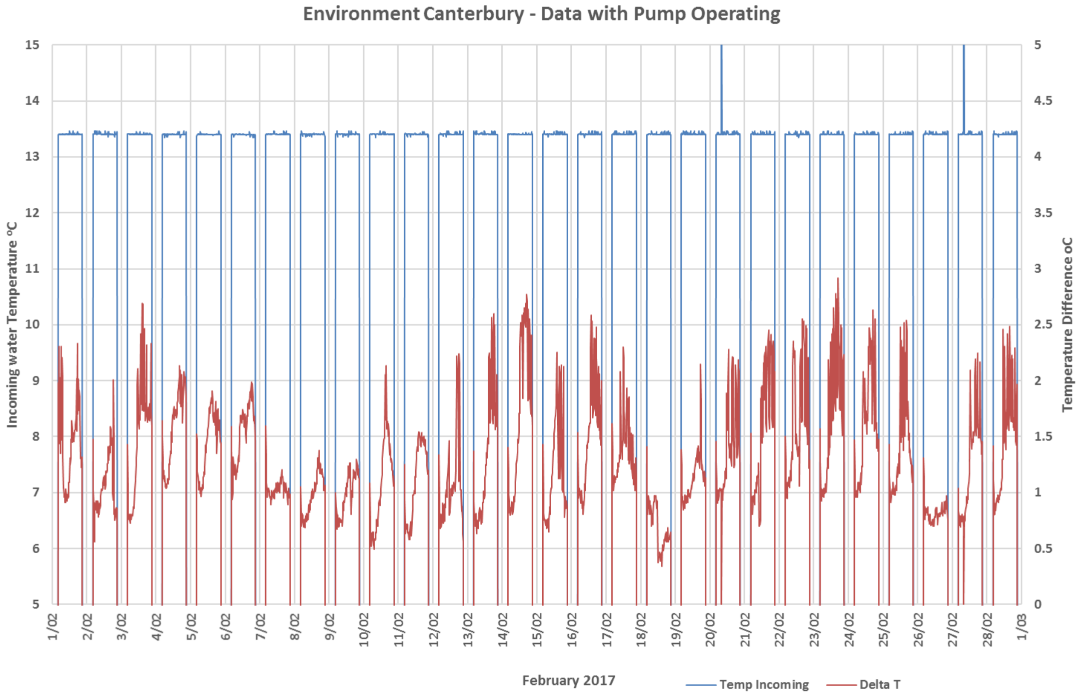

Figure 4. Incoming water temperature from bore BX24/0527 (Blue). Temperature difference of water injected into bore BX24/0528 (Red – right hand vertical axis). Temperature change is positive with heat plant operating in cooling mode

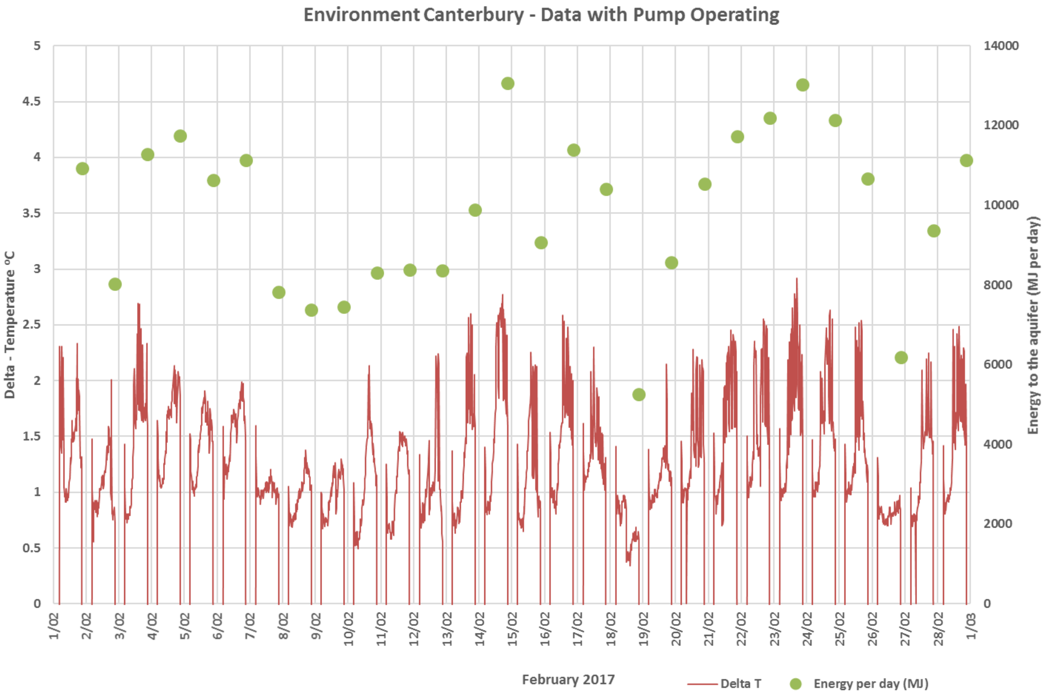

Figure 5. Daily energy delivered to the aquifer (Green dots in MJ per day – right hand vertical axis) into bore BX24/0528 (Red data is temperature change – left hand vertical axis).

4.2.4 Justice Precinct

The Christchurch Justice and Emergency Services Precinct is a $300 million development project that is purpose-built to bring together the justice and emergency services. An estimated 2,000 people will work in or utilise the Precinct (MOJ, 2016).

The construction of the Precinct began in mid-2014, and it is due for occupation in July / August 2017. It will be constructed with advanced seismic design including base isolation. The building has a floor area of approximately 40,000 m^2 over five floors and will utilise aquifer based GHP heat plant. The system installed at the Justice Precinct will extract groundwater through three bores drilled to around 150 m. The water discharged is injected back into the groundwater at less than 90 m depth (Consent CRC165438; ECan, 2016). The heat plant is rated for 3 MW of cooling and 2 MW of heating and the annual energy delivered from the plant is estimated to be 4.2 GWh for cooling and 2.2 GWh for heating.

4.2.5 The Terrace

The Terrace is a $120 million redevelopment of the Christchurch hospitality precinct that will house 16 restaurants and bars, a large 4,000 m^2 office building and a car park building.

Heating and cooling for part of the complex will be through a 500 kW heat pump extracting water from the Linwood Formation (85 m deep) and returning water to the Riccarton Gravel Formation (30 m). The temperature difference between extraction and injection can be up to +/- 8°C. The facility has been approved by the Canterbury Regional Council to abstract groundwater at a rate of up to 47 L/s, to a maximum volume of 830,000 m^3 per annum (averaged take 26.3 L/s) from two bores (Consent CRC156321; ECan, 2016), and to discharge the water to the Riccarton gravel aquifer (Consent CRC156322; ECan, 2016).

4.2.6 King Edward Barracks Site

The King Edward Barracks were built in 1905. It was used for drilling and housing soldiers and later for civic functions and social occasions until 1993. The area is now planned for a combination of commercial, residential and parking buildings (Ngai Tahu, 2015). The piazza and open urban spaces on the site are to be utilised as public space. A 30,000 m^2 building is planned for the area which will house offices and an apartment complex. Up to 1,500 workers will occupy the site.

The King Edward Barracks site has been consented to extract at a maximum rate of 80 L/s from a depth of 128 m, up to a maximum of 1,264,896 m^3 per year (averaged take 40 L/s) (Consent CRC168911; ECan, 2016). Heat is to be extracted from the aquifer water using 1.5-2.5 MW heat plant. The water will then be injected to a depth of 38.5 m (Consent CRC168912; ECan, 2016) at a water temperature in the range +/- 8°C from the extraction temperature.

4.2.7 Christchurch Town Hall

The Christchurch Town Hall suffered significant damage during the 2011 earthquake, mostly due to liquefaction. The main auditorium was able to be saved, but the rest of the building was demolished. The rebuild began in November 2015 to install concrete piles into the ground to support the auditorium and to provide stability in the event of future liquefaction. The rebuild of the Town Hall aims to keep the original charm and characteristics, while making it a state of the art performance venue (CCC, 2015).

The original Town Hall that opened in 1972, was equipped with a heat pump system that was well maintained utilising the council's mains cold water system to provide most of the heating and cooling requirements of the building (Marshall, 2013). Unfortunately, this system suffered damage from the flooding of the Avon River so will be replaced with a more efficient aquifer based GHP heat plant that will extract groundwater from 80 m depth and discharge the water to the Avon River (Marshall, 2013).

5. SUMMARY

Geothermal heating and cooling technology in Christchurch utilises the abundant renewable energy aquifer resource that underlies the city. There has been significant growth in GHP installations in Christchurch following the 2010/11 earthquakes. Fourteen large-scale commercial GHP developments have been completed or are underway in the city as part of the rebuild. These range in size up to 3 MW in capacity serving buildings with floor areas of up to 40,000 m^2.

This opportunity for GHP growth has been supported by government incentives, a permissive rule frame framework, a small network of experienced designers and installers underpinned by a push for renewable and sustainable building energy choices as part of the city rebuild.

The rate of domestic GHP installations in Canterbury has continued to remain steady, at around ten per year.

Christchurch is leading the way in the New Zealand GHP market, and surely stands as an exemplar of the uptake of this technology for the rest of the nation.

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