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Geothermal Heat Pumps Role in Rebuilding Christchurch's Commercial Business District

A. Seward and B. Carey

Wairakei Research Centre, GNS Science, Private Bag 2000, Taupo 3352, New Zealand

a.seward@gns.cri.nz,

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ABSTRACT

In February 2011 Christchurch experienced a destructive earthquake, resulting in the central business district being extensively damaged. Significant rebuilding of the commercial infrastructure has seen megawatt scale geothermal heat pump (GHP) systems installed.

Christchurch city overlies a series of confined groundwater aquifers, ranging in depth from less than 13 m to greater than 150 m. The aquifers are productive, with yields in excess of 100 L/s possible from a single well, with ground water temperatures of about 13°C providing an ideal source for energy for facilities heating and cooling. With these physical characteristics, the installation costs of megawatt sized GHP systems can be paid back in under ten years; this being a key driver to the recent increased uptake of this technology.

This paper discusses the Christchurch aquifers and the aquifer energy systems, analyses the rate of uptake of the technology, discusses four projects in more detail and identifies two projects that are anticipated to be completed before 2022.

1. INTRODUCTION

Christchurch, Canterbury, New Zealand has experienced the greatest growth in GHP technology in New Zealand in recent years with a doubling in capacity since 2014. The background to this growth emerges from the availability of productive groundwater aquifers that are suitable for energy use under the city, and the devastating 2010 / 2011 earthquakes where more than 1000 commercial buildings in the central business district were destroyed. The subsequent rebuilding programme, worth billions of dollars, has seen a number of the major facilities adopting air conditioning systems using aquifer water as the heat energy source and sink. A driver for this has been rebuilding using greener more energy efficient technology, with the aquifer water systems for mid to larger sized commercial buildings paying back in under ten years.

GHP systems are used extensively in Europe and North America (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 - 2019). Use of groundwater to supply energy commenced in Christchurch in 1972 when the cities potable water supply was used as part of the Town Hall facilities energy supply. Subsequently energy wells into the Christchurch aquifers started to be drilled during the late 1980's. When a facility has a reasonable sized heating or cooling demand, such as an airport, university, library, public swimming pool, hospital, and larger accommodation facility (e.g. hotels, lodges, residential care) GHP technology is sound technology to adopt in moving to a more sustainable low carbon energy supply.

Christchurch is situated above a series of confined aquifers, ranging in depth from < 13 m, to depths greater than 150 m (Figure 1). There are six separate aquifer systems over this depth range, located in gravel alluvium and glacial outwash deposits, confined by marine sediments composed of silt, clay, peat and shelly sands (Taylor et al., 1989). An artesian system occurs in the coastal area due to the hydraulic gradient and the confined nature of the system with the artesian pressure increasing with depth, making the city ideally suited to aquifer water open-loop GHP systems.

The open ground-loop designs operate by directly taking ground water and supplying it to heat pump systems, or at certain times cooling can be supplied as free cooling with the water bypassing the chillers / heat pumps, used in the facility and then the water is discharged back underground to a different aquifer or in a few cases to surface water. The water is pumped, transferring heat from the aquifer to the heat pump system, which transfers heat / cool to the facility. There are some facilities where heat supply is the main function whereas for others cooling is the main function required. For example, the Arts Centre is heating dominated, whereas the Justice Precinct is cooling dominated.

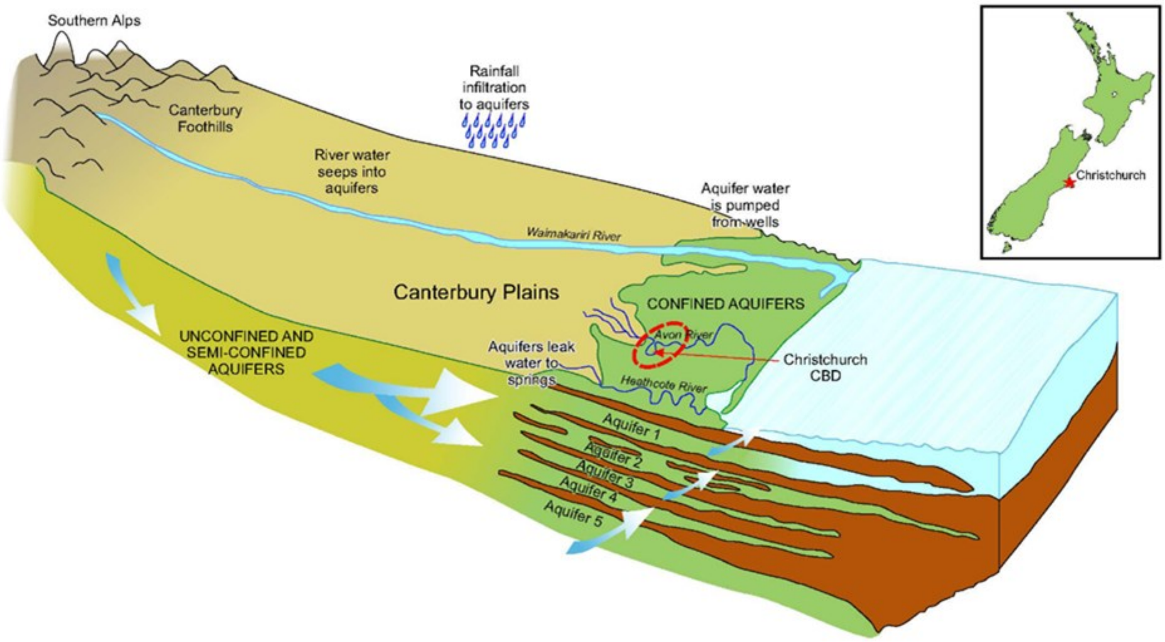

Figure 1: Conceptual diagram showing the groundwater flow from the foothills of the Southern Alps to the confined aquifers under Christchurch. Image redrawn from Weeber (2008).

This paper updates material on the GHP uptake in Christchurch, New Zealand, reported in Seward et al, 2017a and 2017b.

2. UPTAKE OF GEOTHERMAL HEAT PUMPS IN CHRISTCHURCH

GHP systems started to be installed in Christchurch from the 1970's, with the Town Hall being a leading example using the city water supply, from 1972 (Marshall 2013), providing or accepting heat depending on the energy demand of the facility. In 1988 the University of Canterbury drilled a number of dedicated aquifer water energy wells as the energy source for a number of the campus buildings. The wells are shallow, the majority being less than 60m deep and after use, the aquifer water was discharged to a tributary of the Avon river. The Christchurch Airport was the next major user to establish large scale aquifer energy use in 1997.

A photo taken minutes after the 22nd February 2011 earthquake shows the rising dust cloud from the central business district. It was the rebuilding that followed this destructive event, that required more than 1000 commercial buildings (LINZ, per comms 2017) in the central business district to be demolished, that has led to a significant increase in the utilization of aquifer water energy heat pump systems in a number of the rebuilt facilities.

Figure 2: Rising dust cloud from damaged Christchurch central business district – 22nd February 2011. Photo credit: Gillian Needham (www.earthquakephoto.co.nz)

Data from the Canterbury Regional Council database has been used to prepare Figure 3 which is plotted as a time sequence showing consents granted with time since 1988 and in Figure 4 the data is plotted cumulatively along with the September 2010 and February 2011 earthquakes. The vertical axis in both figures is energy per annum (GJ) consented to be added to the aquifer water.

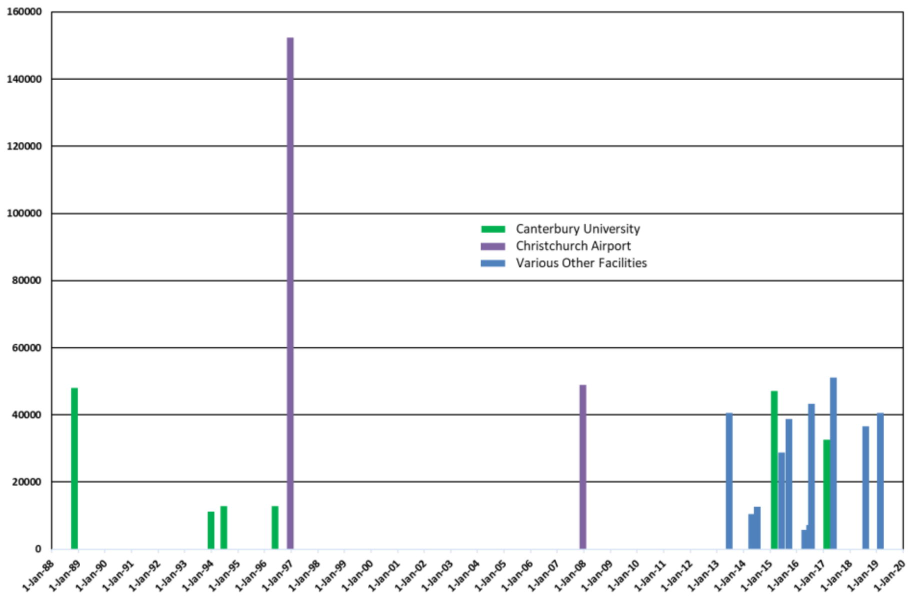

Figure 3: Aquifer water energy consents. GJ of Energy per annum able to be added to the aquifer water shown on the left hand axis

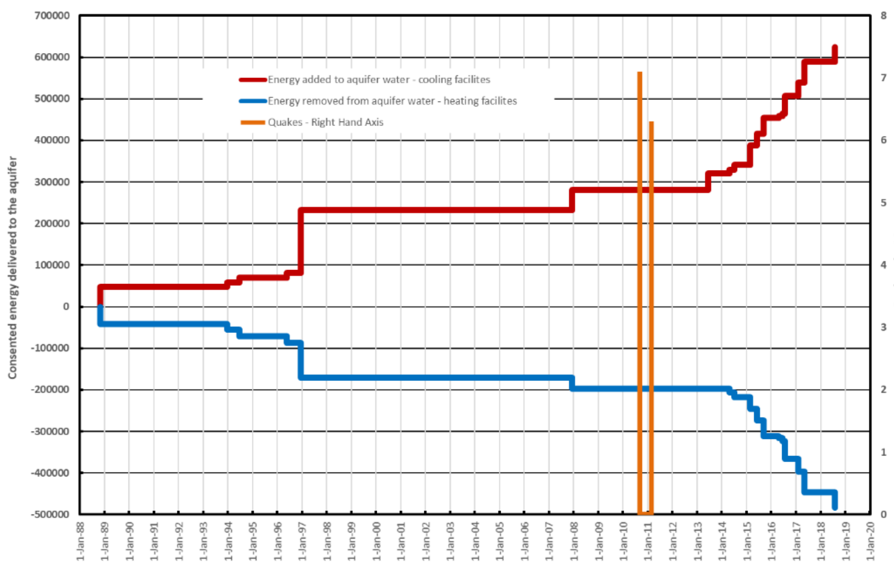

Figure 4: Aquifer water energy consents. Cumulative annual GJ of energy removed (blue) or added (red) to the aquifer water. Two earthquakes (2010 and 2011) shown as orange bars.

The reconstruction programme has prompted the adoption of aquifer water energy systems as shown in Figure 4. The rapid uptake has seen a doubling of the consented energy use from the aquifers in the period 2014 to 2019 compared to the use prior to 2011. The figure also shows a delay of at least 3 years from when the 2011 earthquake occurred to when the first rebuilt buildings became operational. Table 1 is a facility listing for buildings completed since 2015 detailing the cost, the consented annual aquifer energy use (building cooling mode), an estimated capacity of the heat plant and date the facility was opened. Also included is data on two upcoming major projects, the Convention Centre and the Metro Sports complex due for completion in 2020 and 2021 respectively.

Table 1: Facilities data

Facility	Floor Area	Year Operational	Estimated Plant Size	Dollars	Annual Consented Energy to Aquifer
	m^2		MW	Million	GJ
TAIT Technology Centre	6000	2015		57	9628
Bus Exchange	9500	2015	1	53	4748
ECAN office	8000	2016	0.65	52	11724
Art Centre	13000	2016	1.6	250	37924

King Edward Barracks	30000	2017	2	150	42369
Justice Precinct	42000	2017	3	300	50244
The Terrace	4000	2017	0.5	120	27802
Central Library	9800	2018	1.2	92	35651
Town Hall	11000	2019	1.2	167	39612
Convention Centre		2020	3	240	
Metro Sports Facility	34,000	2021	4	300	

Data collated from the Canterbury Regional Council consent database is plotted (Figure 5) as the consented annual average instantaneous energy (MW) able to be added to the aquifer water by a given party. If there are more than one consent for a given party or facility, then the data has been aggregated. It is clear from the figure that Christchurch Airport and Canterbury University are the largest users by a factor of 4 or 5 relative to the next largest user.

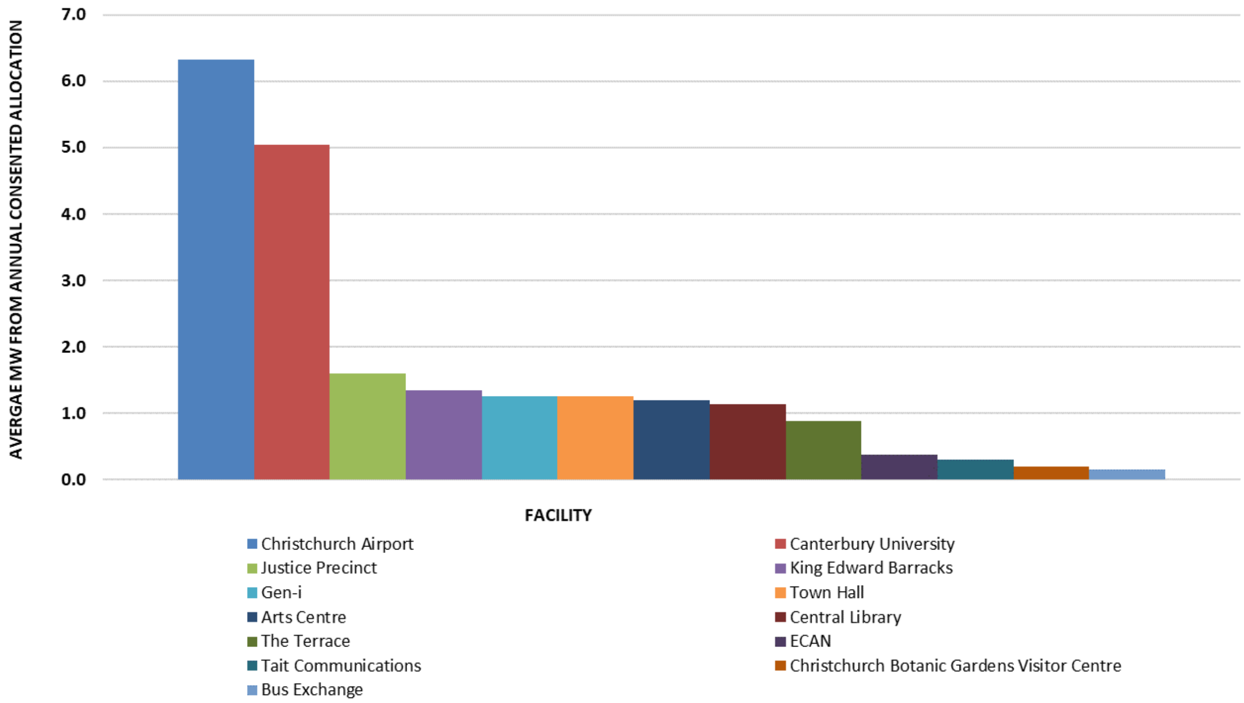

Figure 5: Consented annual average instantaneous power (MW)

2.1 Permitted Activity Rule 9.5.15 Canterbury Land and Water Regional Plan

In 2015 the Canterbury Regional Council (ECan, 2015) adopted a permitted activity rule in the Land and Water Regional Plan for aquifer water energy systems that applied specifically to the area of the central city. The take and discharge has to be located within the area bounded by Moorhouse Avenue, Fitzgerald Avenue, Bealey Avenue, Harper Avenue and Deans Avenue (Black hashed line in Figure 6). The take is from bores screened at a depth of no less than 30 and no more than 100 metres deep, with the discharge to the Riccarton gravel aquifer being the first gravel aquifer encountered below 20 metres. Discretionary applications can be made for permits (under rule 9.5.16) where the use doesn't meet the requirements of the permitted activity rule 9.5.15.

Almost all of the commercial aquifer energy installations in the central Christchurch city area (Figure 6) 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. One facility using the permitted activity rule is the rebuilt Town Hall that reopened in early 2019.

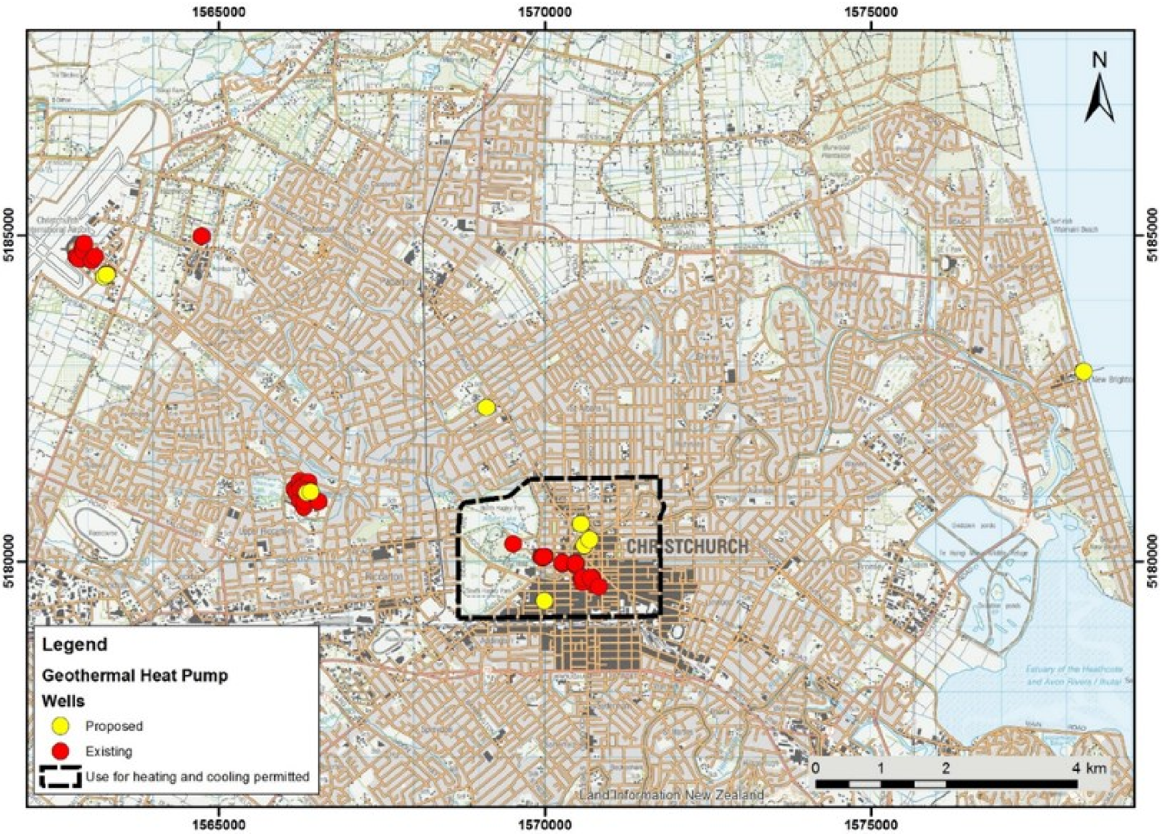

Figure 6: Location of existing (Red) and proposed (Yellow) GHP facilities. The permitted activity rule 9.5.15 applies within the black hashed line.

2.2 Installed systems

In the sections that follow more detail is provided on four of the facilities; The Arts Centre, Environment Canterbury, the Justice Precinct and the Bus Exchange. These were chosen to show an example of one of; the largest operations, the smallest operations, a restoration project and one example for which good monitoring data was able to be supplied.

2.2.1 The Arts Centre

The centre is an outlet for Christchurch for performance, including; music, drama, dance, art, festivals and markets. The buildings, run by a trust, became the Arts Centre in the 1970's.

Figure 7: Arts Centre, Christchurch, post earthquake restoration

The centre comprises a number of buildings which developed over a period of about 45 years, commencing with the construction of the clock tower in 1877. Additional buildings including schools, and university buildings were added, with the buildings forming the largest group of gothic revival style buildings in the Southern Hemisphere (Newshub 2018).

The buildings were significantly damaged during the 22 February 2011 earthquake. An extensive 7 year rebuilding programme saw the reopening of 11 buildings in late 2018 (Newshub 2018). Work is continuing on other buildings that are yet to be repaired and restored. The total cost of the rebuilding work is estimated at $250 Million (Stuff 2019). As part of the work a 2 MW aquifer water heat pump system has been installed. Aquifer water is extracted through 2 bores from a depth of 122 to 125 m, at a maximum combined instantaneous rate of 80 L/s (Consent CRC154729). The water discharge consent (CRC154730) facilitates a +/- 6 °C temperature change from energy use with the water re-injected between 22 and 36 m deep in two wells. Two plant rooms house the heat plant. One plant room is under the existing library building and the other is a purpose-built plant room facility constructed as part of the rebuild. Access constraints for installing equipment into the library plant room necessitated the installation of five 0.215 MW heat pumps whereas in the purpose build plant room two 0.66 MW heat pumps were installed. Plant data and consent data are tabulated in Table 2 and Table 3 respectively.

Table 2: Arts Centre Plant Room Data

Library Plant Room							
Aquifer water heat exchangers				**Plant Room Heat Pumps**			
#	flow / unit l/s	Capacity / unit kw	Cumulative capacity kw	#	flow / unit	Capacity / unit kw
2	20	340	680	5	10.5	215
Mechanical Services Plant Room						
Aquifer water heat exchangers				**Plant Room Heat Pumps**		
#	flow / unit l/s	Capacity / unit kw	Cumulative capacity kw	#	flow / unit	Capacity / unit kw
2	20	512	1024	2	31.6	660
Totals						
	Total aquifer flow l/s		Total aquifer water capacity kw			Total Capacity kw
	80		1704			2395

Table 3: Aquifer Water Consent Data

Consent Data – Take CRC154729 and Discharge CRC154730					
Maximum Flow	Maximum delta T	Calculated instantaneous capacity	Total annual aquifer water take	Calculated annual energy	Calculated annual average capacity
l/s	°C	kW	m^3	MJ	kW
80	+/- 6	2000	1509581	37900000	1200

Of interest is the various ways that the energy capacity of the system can be described, so for instance the granted consents facilitate an instantaneous capacity of 2 MW, but an annual average consented capacity of 1.2 MW being constrained by the capped annual water take. For the heat plant the aquifer water heat exchanger design capacity is 1.7 MW whilst the installed heat pump capacity is 2.4 MW. The approach taken in reporting data such as this in the format to the 2020 World Geothermal Congress (Daysh et al 2020) has been to use 60 percent of the consented annual energy take or discharge from or to the aquifer water which in this case is 22,740,000 MJ in both heating and cooling modes.

Christchurch Bus Exchange

The Bus Exchange is a 3,500 m^2 purpose built public transport facility located in the center of Christchurch's CBD, catering for 8.6 million bus passengers per year. The indoor environment is naturally ventilated and underfloor hydronic systems warms or cools the concourse (Architectus 2016). About 1,850 buses use the facility every day (MFE 2005) with automatic doors preventing passengers from straying onto the bus apron and door air curtains assisting in keeping the concourse area fume free (Architectus 2016). Another part of the facility includes 6000 m^2 of retail space and a covered bike-lock area. The building was completed in 2015, is heated and cooled by a geothermal heat pump system, which extracts water from a depth of 80 m at a rate of up to 12 L/s (Consent CRC155593) and re-injects the water at a similar rate, to a depth of 35 m (consent CRC167904) with a temperature change of the water being no more than +/- 6 °C. The system is one of the smaller commercial systems (refer Table 1) installed as part of the rebuilding.

Figure 8: Christchurch Central City Bus Exchange – Photograph credit Simon Devitt.

Canterbury Regional Council Offices

The Environmental Canterbury (ECAN) offices opened in early 2016, housing 450 staff over 5 floors (Stuff, 2016b). The building has an operating 4.5 Star rating under the National Australian-Built Environment Rating NZ (NABERSNZ) energy use scale (Scale maximum of 6 Star). The facilities are conditioned with 650 kW of heat plant using artesian water. The water is extracted using a downhole pump from 85 m depth at a consented rate no greater than 33 L/s, up to a maximum of 2500 m^3 per day and 350,000 m^3 per annum (Consent CRC146483; ECan, 2019). The water is then returned underground at a depth of 35 m, at a temperature no greater or less than 8°C from its extraction temperature (Consent CRC146484; ECan, 2019). Good data is available for February 2017 and two plots show the performance of the system when the facilities are being cooled near the height of the 2017 summer.

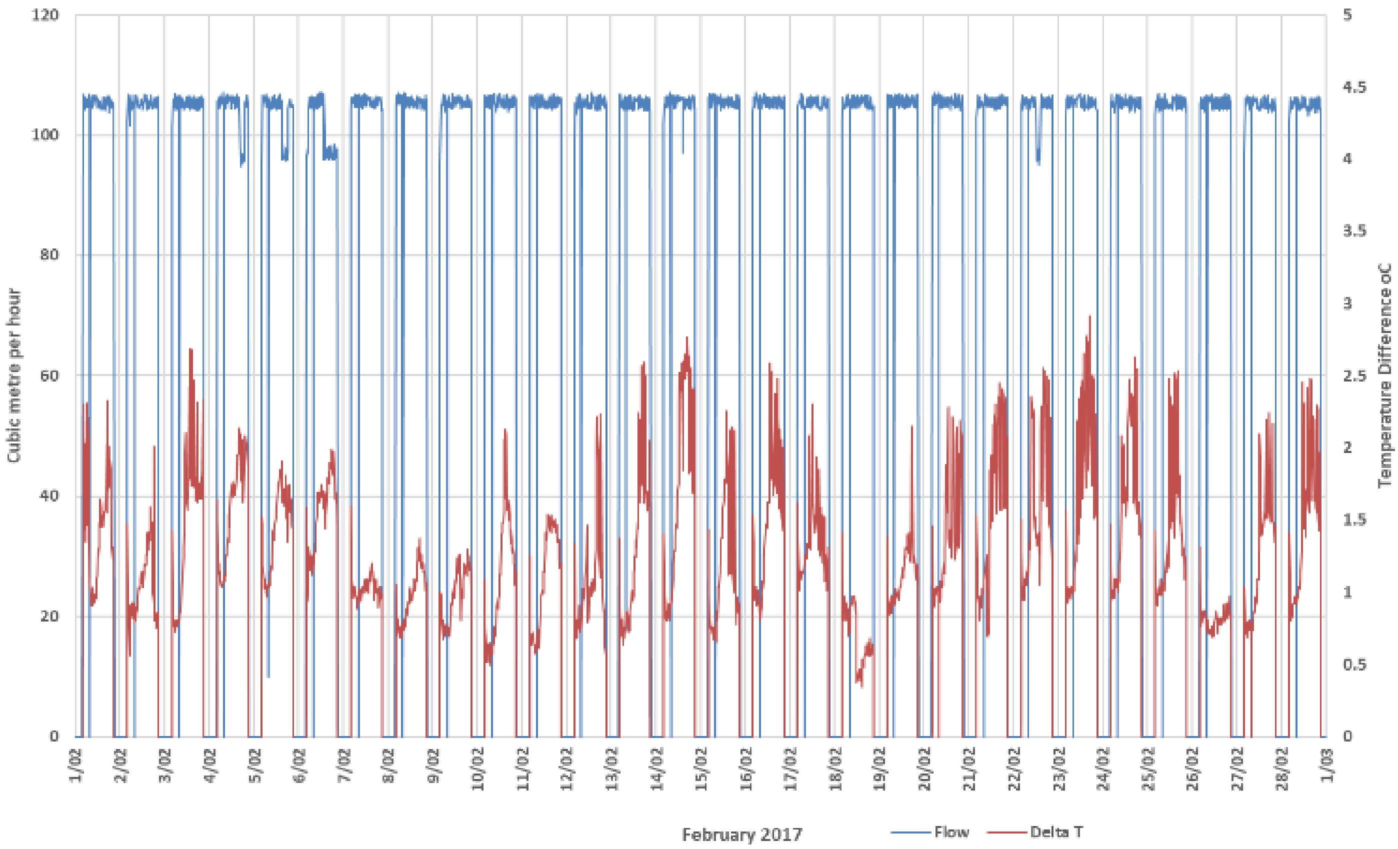

Figure 9: Pump Flow rate (blue – Left hand axis) and aquifer water temperature difference (Red – Right hand axis)

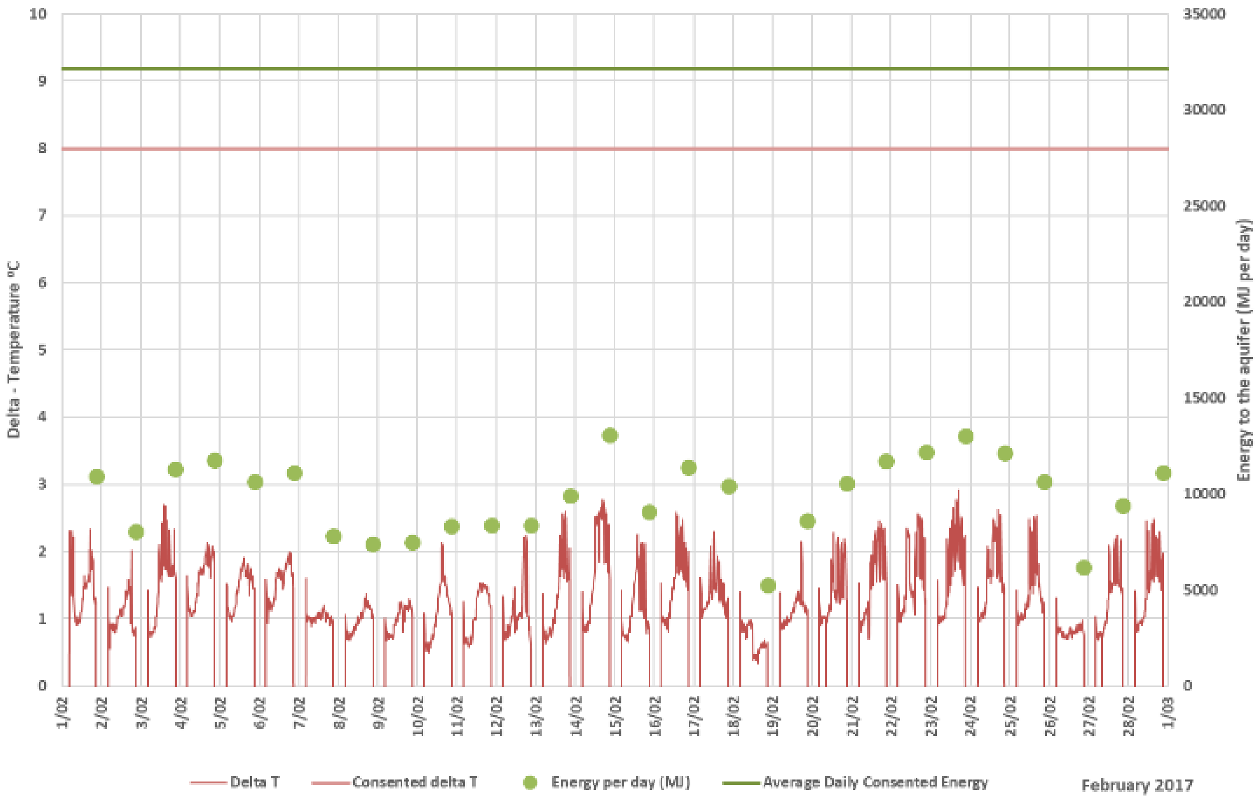

Figure 10: Consented and actual temperature difference (red - left hand axis) and average daily consented and actual energy (green – right hand axis)

The heat plant is run through the day, with aquifer water being taken at up to 105 m^3 / hour, used and returned at shallower depth. The aquifer water pump is shut down for part of the evening and the early morning. The temperature difference for the month of February 2017 (Figure 9) is about 2 to 2.5°C, compared to the 8 °C permitted by the consent and the actual energy being delivered to the aquifer is about 10,000 MJ per day being about 30% of the average daily 32,000 MJ consented value.

Justice Precinct

The Christchurch Justice and Emergency Services Precinct is a $300 million development housing justice and emergency services. It is a Central Government facility where an estimated 2,000 people work (MOJ, 2016). Construction began in mid-2014 and the facilities were officially opened on 12th September 2017. The 40,000 m^2 building over five floors uses an aquifer water energy system for heating and cooling. The system extracts groundwater from two bores drilled to 130 m. The heat is extracted or rejected using heat plant rated to 3 MW before the water is re-injected back into a groundwater aquifer above a depth of 37 m (Consent CRC173911; ECan, 2019). Figure 11 is compiled data from records for 2018 held by the Canterbury Regional Council reduced to the total instantaneous energy delivered to the aquifer water from the facility. Aquifer energy use is cooling dominant as shown in the Figure 11 where for the 2018 year energy is almost always added to the return water discharged to the two reinjection wells through all the months of the year.

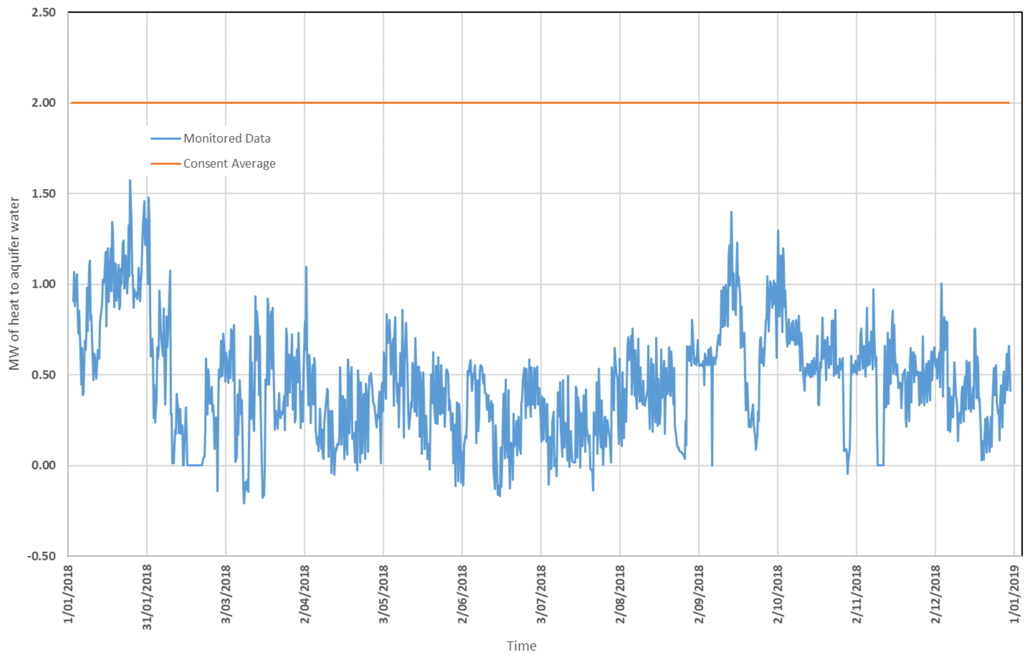

Figure 11: Instantaneous MW of heat added (+ve) or extracted (-ve) from the aquifer water. Consented average value for a year is shown as the orange line.

CONCLUSION

There has been a substantial increase in energy use in geothermal heat pump systems in the commercial sector in Christchurch, New Zealand since WGC 2015. The number reported for 2015 was about 70 TJ/year (Carey et al, 2015) and the number for 2020 is about 400 TJ/year (Daysh et al 2020). This significant increase has been associated with adopting effective aquifer water geothermal heat pump solutions as part of the substantial expenditure that has occurred in rebuilding Christchurch commercial infrastructure after the significant damage that occurred in the 22nd February 2011 earthquake.

The commissioned geothermal heat pump systems range in size from 0.5 to 3 MW, heating and cooling facilities with floor areas from 3,500 to 45,000m^2. Facilities in the development pipeline include two large facilities; the Metro Sports Centre and a Convention Centre which are expected to have heat plant capacities of about 4 and 3 MW respectively.

Aquifer water energy systems will dominate the energy use data for the New Zealand Geothermal Heat Pump Sector for the foreseeable future.

REFERENCES

Architectus. Christchurch Bus Interchange. ArchDaily. 16 July 2016. Accessed www.archdaily.com/791283/christchurch-bus-interchange-architectus-plus-athfield-architects. ISSN 0719-8884. (2016)

Carey, B., Dunstall, M., McClintock, S., White, B., Bignall, G., Luketina, K., Robson, B., Zarrouk, S., Seward, A. 2015 New Zealand Country Update. *Proceedings: World Geothermal Congress, Melbourne Australia, April 2015.* (2015)

Daysh, S., Carey, B., Doorman, P., Luketina, K., White, B., Zarrouk, S., 2015 – 2020 New Zealand Country Update. *Proceedings* World Geothermal Congress 2020, Reykjavik, Iceland, April 26 – May 2, 2020. (2020)

ECan (Environment Canterbury), Agenda and Meeting Papers Canterbury Regional Council Meeting446091 Commissioners 13 August 2015 Item 6 Canterbury Land and Water Regional Plan Volume1 (2015)

ECan (Environment Canterbury), Environment Canterbury Consent Search. Database retrieved from: http://ECan.govt.nz/services/online-services/pages/consent-search.aspx (2019)

GNS Science, New Zealand Geothermal Use Database. Retrieved from: data.gns.cri.nz/geothermal/. (2019)

Lind, L., Swedish Ground Source Heat Pump Case Study (2010 Revision), *GNS Science report 2010/54*. 30p (2011)

Marshall, P. Christchurch Town Hall for Performing Arts: CCC Workshop Final Design Report. Warren and Mahoney. August 2013. Retrieved from: http://resources.ccc.govt.nz/files/CityLeisure/projectstoimprovechristchurch/christchurchtownhall/LoResChristchurch_Townhall_EQ_Repair_CCC_Workshop_13.08.2013_HR.pdf (2013)

MFE (Ministry for the Environment), Christchurch Bus Exchange. Urban Design Case Studies. ME 581. Retrieved from http://www.mfe.govt.nz/publications/towns-and-cities/urban-design-case-studies/christchurch-bus-exchange. (2005)

MOJ (Ministry of Justice), Christchurch Justice & Emergency Services Precinct. Retrieved from: https://www.justice.govt.nz/about/about-us/our-strategy/christchurch-justice-and-emergency-services-precinct/. (2016)

Newshub. Christchurch Arts Centre to reopen after 7 years. Article 23/12/2018. Retrieved from https://www.newshub.co.nz/home/new-zealand/2018/12/christchurch-arts-centre-to-reopen-after-7-years.html (2018)

Seward, A., Climo, M., Rutter, H., Etheridge, Z., Van Meer, P., Bendall, S., and Carey, B., Rebuilding Christchurch – Using Ground Source Heat Pumps *In Proceedings 12th IEA Heat Pump Conference* (2017a)

Seward, A., Carey, B., Etheridge, Z., Climo, M., and Rutter, H., Building a Sustainably City Utilising Geothermal Heat Pumps, The Christchurch Story. Proceedings 39th New Zealand Geothermal Workshop. 21 - 25 November 2017. Rotorua, New Zealand. (2017b)

Stuff. Christchurch's $53 million bus interchange opens. Published 25 May 2015. https://www.stuff.co.nz/the-press/news/68813220/ (2015)

Stuff. $150m-plus development for Christchurch river front. Published 16 April 2016. https://www.stuff.co.nz/business/better-business/67773642/ (2016a)

Stuff. Environment Canterbury boosts inner city workforce in new $51 million building. Published 18 April 2016. Retrieved from: http://www.stuff.co.nz/the-press/business/the-rebuild/79042612/Environment-Canterbury-boosts-inner-city-workforce-in-new-51-million-building (2016b)

Stuff. Arts Centre of Christchurch restoration is $40m under budget but still faces shortfall. Published 29 January 2019. Retrieved from https://www.stuff.co.nz/national/110140621/arts-centre-of-christchurch-restoration-is-40m-under-budget-but-still-faces-shortfall (2019)

Taylor, C.B., Wilson, D.D., Brown, L.J., Stewart, M.K., Burden, R.J., Brailsford, G.W. Sources and flow of North Canterbury Plains groundwater, New Zealand. *Journal of Hydrology 106*, 311-340. (1989)

Weber, J., Bendall, B., Bertani, R., Bromley, C., Busby, J., Gregorio, M., Guomundsdottir, M., Ketilsson, J., Link, K., Muller, J., Nathwani, J., Mieve, D., Rocher, P., Romagnoli, P., Scholtysik, S., Siddiqi, G., Song, Y., Thompason, A., Tosha, T, and Wissing, L., Geothermal Trend Report 2014, *IEA Geothermal Implementing Agreement*, pp 48. (2014)

Weeber, J., 2008. A hydrogeology basis for zone boundaries, variations 6 to the proposed natural Resource Plan. Report no. U08/21. ISBN 978-1-86937-802-8.