

# GroundsWell

## GROUNDWATER SCIENCE IN AOTEAROA

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### INVITATION

## GROUNDWELL 2019: Symposium on groundwater management and research

Bringing the best minds together to discuss how we can improve the understanding and quality of groundwater in New Zealand

Join the conversation as we explore what needs to be done to improve the understanding, information, tools, and research capacity of groundwater in New Zealand.

**Where:** Bentleys at the University of Canterbury Students' Association Event Centre, 90 Ilam Road, Ilam, Christchurch 8041  
**When:** Friday 5 April 2019 9.30am – 4.30pm  
**Register by:** 25 March 2019 on [www.eventbrite.co.nz](http://www.eventbrite.co.nz) at [GroundsWell 2019](#)  
 For more information email [groundswell@esr.cri.nz](mailto:groundswell@esr.cri.nz)



Welcome to the second edition of GroundsWell, a newsletter for those who are interested in the science and management of groundwater in New Zealand. In this edition we tell you about the work being done in the groundwater space and why groundwater is so important to New Zealand.

As the government embarks on huge reforms in the area of water, with the Three Waters review and the Essential Freshwater programme underway, it is critical that groundwater is not forgotten, particularly in the face of new challenges such as climate change and emerging organic contaminants. In fact, the health of groundwater is critical to the quality of surface water in New Zealand.

On 5 April 2019, we are holding **GroundsWell 2019**, the inaugural **Groundwater Management and Research Symposium**. This will be held in Christchurch for people interested in groundwater science and management in New Zealand. We warmly invite any person who would like to attend to come along and participate in the discussion.

Registration by 25 March can be made through Eventbrite at this link: [GroundsWell 2019](#). We can assure you this will be an interesting and important day and we hope to gain consensus at the end of it about what needs to be done to improve the management of groundwater in New Zealand.

For more information email us at [groundswell@esr.cri.nz](mailto:groundswell@esr.cri.nz).



ESR, Aqualinc, Lincoln Agritech and GNS Science groundwater scientists are working together, building on each other's strengths, to improve the understanding and quality of groundwater in New Zealand.



## The critical role groundwater plays in water quality



**Water pollution regularly comes up in opinion polls as a top concern for New Zealanders. However, while algal blooms and restricted swimmability in rivers and lakes attract plenty of attention, the important role of our groundwater systems is largely overlooked. For many, groundwater is out of sight, and therefore, out of mind. The general public is largely unaware that**

**discharge from groundwater systems provides the water flow that sustains most rivers during dry periods. So, next time it has not rained for a few days, remember, the water in the river is essentially groundwater.**

Along with sustaining the flow of fresh water, groundwater systems provide a key link between land use activities and surface water quality. This applies particularly to nitrate that is lost from agricultural production systems. The pathways that water and nitrate travel through the groundwater system varies both spatially and by the length of time taken to reappear in surface water. The average time lag between nitrate loss from the root zone and reappearance in a surface water body can vary significantly. In shallow groundwater pathways, nitrate may reappear within weeks or months. In deeper pathways, such as the North Island's Volcanic Plateau, the lost nitrate may not reappear for decades. Understanding the contributions that different pathways make to the overall water and contaminant fluxes in a catchment is critical. It helps to understand which combination of past and present practices is responsible for the current surface water quality. Importantly, it also determines how today's land use activities will affect the water quality experienced by generations to come.

We need to understand issues such as the 'nitrogen time bomb' – where large amounts of nitrate from farm fertiliser runoff is trapped in the subsurface environment and over time is released into the groundwater. While we have made significant progress in recent years, our understanding of the role of groundwater as a contaminant store in New Zealand's diverse landscapes is still very limited. Dedicated effort including further measurements and modelling will be required to prevent unfortunate environmental surprises in the future.

Apart from acting as a passive transmitter of contaminants, our groundwater systems can also actively transform some contaminants and even neutralise them. In particular, nitrate originating from agricultural land use can be denitrified in groundwater where suitable biogeochemical conditions occur. Where oxygen-depleted conditions and a food source such as carbon or reduced iron and sulphur compounds exist, groundwater microorganisms can convert nitrate into gaseous forms of nitrogen, predominantly environmentally benign dinitrogen gas ( $N_2$ ). This process represents a massive ecosystem benefit provided by groundwater systems, as it protects precious surface water bodies from pollution.



*Water quality issues in a Lake Waikare drain.*

Increasing our ability to determine where these conditions are likely to occur is important as future land use patterns may be spatially matched to the distribution pattern of this natural ecosystem service. More intensive land use activities, such as dairy farming, could preferentially be carried out where the denitrification potential is high, while only low-loss land uses are appropriate where little or no denitrification potential exists. We are working on improving our ability to predict the potential, but it is a very challenging space to work in, due to the difficulty of obtaining crucial aquifer information. Not all regions have high densities of bores, making developing techniques to accurately predict denitrification potential from sparse data sets very important.

It is critical to recognise that the combination of increased knowledge of pathways and lag times and increased understanding of the biogeochemical controls on denitrification will reap the greatest reward. You can have all the denitrification potential in the world, but if no water flows through those groundwater zones you cannot take advantage of this natural mitigation. We must continue to invest in understanding the role of groundwater in connecting land use activities to surface water quality. While it is out of sight, the role of groundwater cannot be ignored and should most definitely be front of mind.

**Blair Miller, Group Manager Environmental Research, Lincoln Agritech.**

## How groundwater contamination processes work



**Groundwater is the source of most of the water flow in streams, rivers and lakes, sustaining its flow and quality. When groundwater quality is poor the surface water quality is impacted. If we want to improve the quality of freshwater, it is vital we understand groundwater contamination processes and how to protect its quality. This is especially so as groundwater provides up to 40% of New Zealand's drinking water supplies. Groundwater is also used in food processing, provision of stock water, and irrigation.**

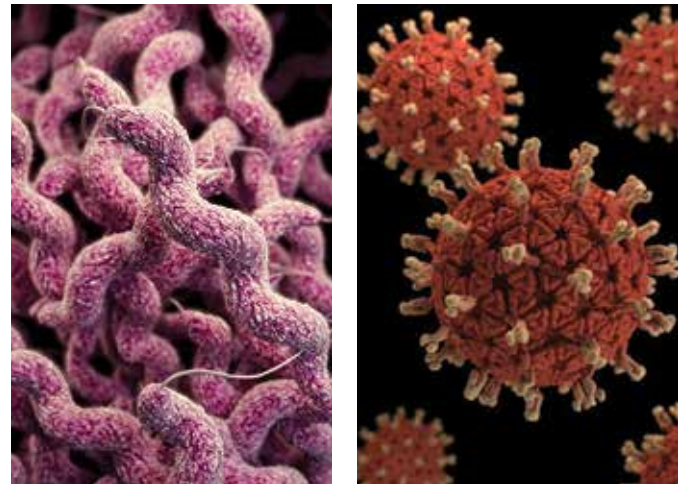
Both natural and human-induced chemicals can contaminate groundwater systems. As groundwater flows through the ground, metals can dissolve and later be found in high concentrations in the water.

Agriculture and industrial discharges, urban activities, groundwater pumpage, and disposal of waste all can affect groundwater quality. Pesticides and fertilisers applied to lawns and crops can accumulate and migrate to the water table. Leakage from septic tanks and/or waste-disposal sites also can introduce bacteria to the water, and pesticides and fertilisers that seep into farmed soil can eventually end up in water drawn from a well.

Contaminants can have different mobility and persistence characteristics. Mobility means how fast they can move through the system and persistence means how long they stay there. Some contaminants such as nitrate are very mobile and move with the groundwater flow. Nitrate is very persistent and is not removed unless it enters a zone with little or no oxygen (anoxic) allowing denitrification to take place. This process transforms nitrate back into nitrogen gas which makes up most of our atmosphere. It is a key nutrient for plant growth. When nitrate concentrations in streams are high this promotes algal and slime growth. This can have a detrimental effect on plant and aquatic life and it is why nitrate is a significant contaminant both in New Zealand and overseas.

In contrast microbes (viruses, bacteria and protozoa) are particles that can be filtered out as they are transported through the groundwater system. In a fine sand groundwater system, microbes are rapidly filtered out within a few metres but in a coarse alluvial gravel aquifer or a karstic limestone system there is much less filtration and microbes can travel long distances (up to 1-2 km). If ingested some microbes (pathogens) can cause illness. Microbes vary in size from viruses (10's of nanomicros), bacteria (a few microns) to protozoa (5-20 microns) and filtration is more effective for the larger particles. Microbes have charged surfaces, which determine what sort of surface they adsorb to and how strongly they are adsorbed. Bacteria are able to multiply and grow in favourable environments but will die off in adverse conditions. Viruses and protozoa are very resilient and can survive for long periods in the environment compared to bacterial pathogens. The small size of viruses coupled with this long potential survival can lead to outbreaks of disease associated with contaminated groundwater.

ESR has carried out research over a number of years to determine the transport and removal of indicator microbes, such as *E. coli* and MS2 phage, and pathogens, such as *Campylobacter*, adenovirus and rotavirus, in New Zealand's main groundwater system types. We study what microbes are naturally present in our groundwater systems and the role that they play in keeping our aquifers clean and flowing.



*Campylobacter* (left) and rotavirus (right) are two pathogens that can contaminate groundwater systems.

Other contaminants that can be of concern with respect to drinking water are manganese, heavy metals such as arsenic, and organic chemicals such as pesticides and industrial solvents. Low concentrations of heavy metals can be found in acidic and/or anoxic environments, as acidic conditions will dissolve heavy metal precipitates and anoxic conditions can often reduce metals such as arsenic, manganese and iron to more mobile species of each metal. Pesticides are commonly used in agricultural activities to control pests. Pesticides have an extremely wide range of properties that affect their leaching and transport behaviour. Their persistence can range from a few days to many decades such as organochlorine compounds DDT and dieldrin. Their mobility can range from very mobile compounds like bromacil which moves rapidly, to very immobile compounds like dieldrin which may take over 40 years to leach four metres through the soil and into the underlying shallow groundwater.

We need to know the sources of these various contaminants, their transport pathways through the soil, unsaturated (vadose) zone and groundwater, as well as the attenuation or removal processes along these pathways. This enables us to understand and predict groundwater quality, where contamination may be coming from, and how to better manage and protect these resources in New Zealand. We believe groundwater protection needs to be undertaken in a multiple stage approach to reduce inputs, prevent or minimise transport and utilise removal processes.

ESR is proud to play a role in each of these stages as it fits with our mission to keep our communities safe and healthy through the provision of with high quality groundwater.

**Murray Close, ESR Science Leader, and Manager of Groundwater in the Health and Environment Group.**

## Understanding nitrogen transfer in small waterways

Many water catchments are quite large, covering hundreds and even thousands of square kilometres. Large catchments inevitably have variable natural and land use characteristics located within them. This makes it difficult to link a nitrogen load at the catchment outlet to the activities, past and present, that have occurred within the catchment and have collectively caused it.

If we can establish a link between activities on the land and their effects on freshwater quality at the smaller, sub-catchment scale (tens of square kilometres) then we could better target land use, land management, mitigation and policy options.

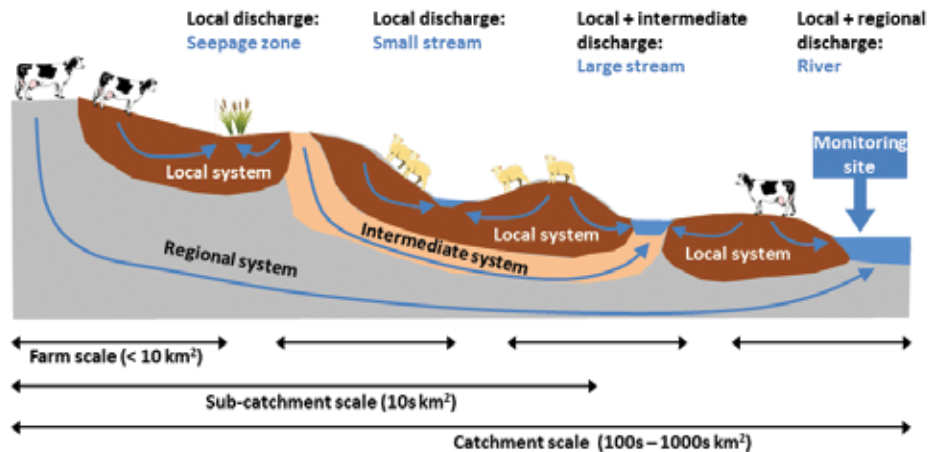
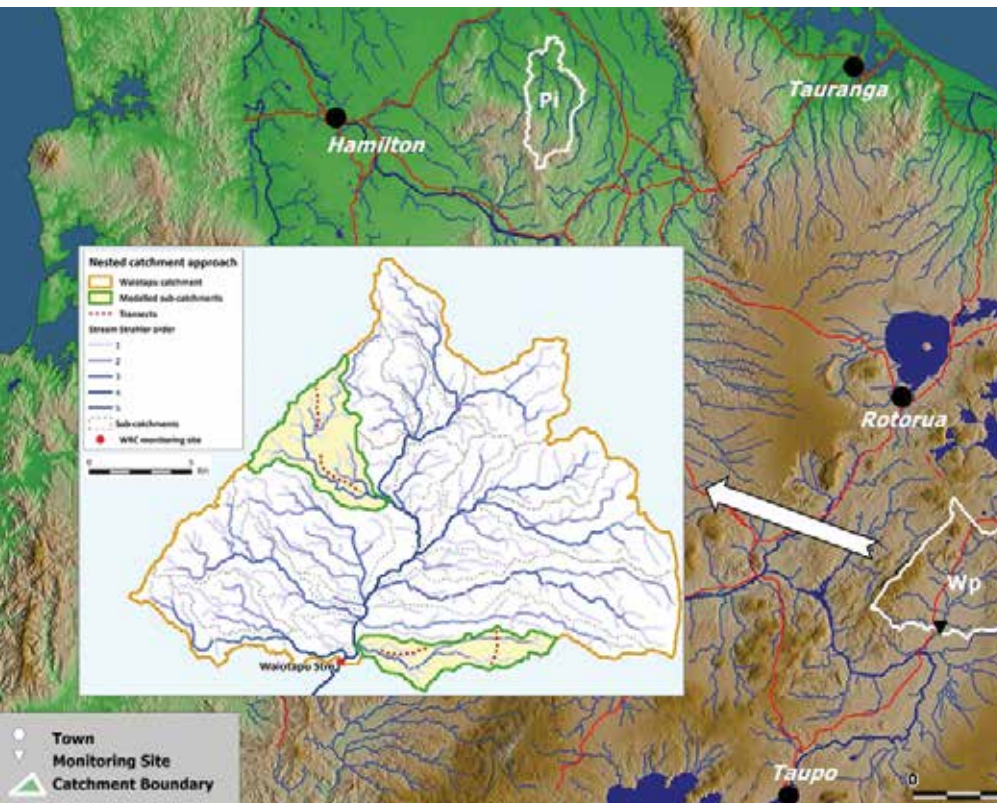


Illustration of the shallow and relatively fast pathways that are often crucial for nitrogen transfers at the sub-catchment scale.



Waikato Regional Council and DairyNZ.

Key innovations include a novel suite of airborne and ground-based geophysical measurements and innovative techniques for the analysis of the resulting 'Big Data' that, in combination, allow gaining currently unavailable information on structural, hydrological, and chemical characteristics of the shallow subsurface (particularly the upper 20 metres). The resulting new understanding will be integrated into advanced nested models that make it possible to use high-resolution data in those sub-catchments.

This new approach will be tested in two intensively farmed catchments with contrasting characteristics. The Waioatapu Stream (Wp) catchment (approx. 300 km<sup>2</sup>) on the North Island's Central Plateau represents a baseflow-dominated upland catchment with large groundwater store in young volcanic deposits. In contrast, the Piako Stream (Pi) headwater catchment is a lowland catchment (approx. 100 km<sup>2</sup>) in the upper part of the Hauraki Plains with aquifer deposits of lower transmissivity and a high quickflow fraction in the stream hydrograph. Given that dairy land alone accounts for more than 17,000 km<sup>2</sup>, Dr Stenger acknowledges that the two pilot catchments represent only a tiny fraction of intensively used land in New Zealand.

However, he expects substantial uptake of the approach, once the research team has been able to demonstrate its merits.

Map showing the location of the two pilot catchments (Pi, Wp) and schematic illustrating the nested sampling and modelling approach, stretching from the transect scale via the sub-catchment scale to the catchment scale.

The Critical Pathways research programme, led by Lincoln Agritech aims to develop methods to capture this smaller catchment area. Programme leader, Dr Roland Stenger, says it will introduce an innovative multi-scale measurement, data analysis and modelling approach in two pilot catchments. Collectively, it will enable the team to unravel the typically shallow and

relatively fast pathways between a parcel of land and a local stream or small river.

The project is a collaboration between Lincoln Agritech, Aqualinc Research, Manaaki Whenua Landcare Research, Lincoln University, GNS Science, AgFirst, and Ian Kusabs & Associates. It is funded by the Ministry of Business, Innovation and Employment and co-funded by

## Understanding groundwater-surface water interaction on the Wairau Plain

**Researchers from Lincoln Agritech and Technische Universität Dresden in Germany are collaborating with Marlborough District Council staff to understand how water from the Wairau River interacts with the underlying aquifer. As the river flows across the upper part of the Wairau Plain, water is drained to the underlying aquifer, a process that provides over 96% of the groundwater recharge. Water level surveys across the river suggest that the river is hydraulically perched above the regional water table in its upper reaches, which supports theoretical predictions.**

The monitoring of groundwater levels in the recharge sector of the Wairau Aquifer began in 1982. Records indicate that groundwater levels in this recharge sector of the aquifer have declined by as much as 780mm since then. The records also show a corresponding decline in flow within lowland springs such as Spring Creek.

Our research indicates that the aquifer gravels consist of both a shallow and deeper horizon level that is separated by a lower permeability gravel. Modelling the water chemistry indicates that 50% of the groundwater flowing into Spring Creek is sourced from the deeper horizon level during winter. This drops to less than 10% during summer when groundwater pressures are low, thus making the springs highly vulnerable to lower groundwater recharge rates when river flows are low during the summer period.

A 3D model of the river and aquifer system was developed at the university in Dresden to better understand the river-groundwater exchange process, groundwater flow pathways, and the time water takes to travel between the river and Spring Creek. The model can predict dynamic river recharge rates to the aquifer, which can be as low as 5 m<sup>3</sup>/s and rarely exceed 12 m<sup>3</sup>/s even during high flow events. This suggests the river saturation footprint reaches a maximum width at high flows and the rate of drainage beneath the river becomes limited by the vertical hydraulic conductivity.

## ESR groundwater scientist honoured

ESR groundwater scientist Murray Close has been recognised for his outstanding contribution to hydrology in New Zealand with a New Zealand Hydrological Society Award presented at their annual conference on 7 December 2018. The nationally recognised groundwater quality expert has been lauded for his high quality science and scientific leadership. The award, which was presented by Hydrological Society President, Joseph Thomas, notes the esteem in which he is held by his peers and colleagues and the significant contributions he has made to issues of national importance over a nearly 40-year career in groundwater science.

Murray started working at the Water and Soil Division of Ministry of Works and Development in 1979. He transferred to DSIR in 1988 and then when DSIR was disbanded, moved to ESR shortly after it was established in 1992. ESR is a Crown Research Institute which delivers scientific services and research across public health, forensics, food safety, and water and the environment.



*The Wairau River looking upstream to the Wairau Valley. Water from the river leaks into the Wairau Aquifer which lies beneath the Wairau Plain on the left.*

Tracking flow particles within the aquifer has shown that water stays in the aquifer for less than a year. This indicates the aquifer is highly dynamic and drains rapidly. The implication of this is that storage within the aquifer, and associated spring flows, depends on the frequency and duration of low flows in the Wairau River.

The model-based investigations have helped to explain the long-term decline in groundwater levels as a combination of climate variability, long-term climate oscillations, and changes of the Wairau River channel. We now understand that aquifer storage is particularly vulnerable to a succession of dry summers with prolonged low river flow periods. This research was funded by the Ministry of Business, Innovation and Employment with additional funding from Marlborough District Council.

**Scott Wilson, Hydrogeologist Lincoln Agritech Limited**

His citation includes the important work establishing the national survey of pesticides in groundwater, work on developing ESR's groundwater testing site at Burnham and long term research into the effects of irrigation on groundwater quality.

In the 1990s, Murray started to characterise groundwater in the Canterbury Plains, work which continues using new tools and methods to understand groundwater, including the study of the transportation of nitrate. He is also recognised for his collaborative approach to working with regional councils to help understand and manage groundwater resources, with a focus on coming up with practical solutions for groundwater problems.

New Zealand Hydrological Society President Joseph Thomas says the award is a well-deserved honour.

"Murray has been a passionate and dedicated scientist in the area of groundwater quality for many years. He deserves the recognition this award brings."

## Nitrate levels reduced in ESR groundwater project

**In November 2018, ESR installed a denitrification wall in an aquifer near Kaiapoi, as part of a field trial testing the use of passive groundwater remediation systems to effectively remove nitrate in shallow gravel aquifer system.**

Since the wall was installed, groundwater nitrate concentrations have dropped at the study site.

The 25-metre-long, five-metre-wide wall has been installed across the direction of natural groundwater flow. The wall is built from a mixture of woodchip and gravel that has been entrenched three metres below the water table. The denitrification wall – also referred to as a denitrifying permeable reactive barrier – acts like a filter for nitrate in the groundwater.



*The denitrification wall being installed near Kaiapoi last November 2018.*

ESR senior scientist Lee Burberry says the monitoring of wells on the North Canterbury site is showing a reduction of groundwater nitrate from 7mg/l upstream to effectively zero downstream of the wall.

“The initial results show that it is doing what we hoped it would do.” Dr Burberry says although denitrifying wall technology is not new, it is the first time such a system has been trialled in gravel aquifers such as those found in Canterbury.

He says gravel aquifers like those in Canterbury are relatively inert chemically and have effectively no natural ability to reduce nitrate. Adding woodchips to the aquifer provides a carbon food source for bacteria that live in the aquifer to convert nitrate to nitrogen gas – a respiration process known as denitrification.

ESR scientists have been working on the details of the pilot project for almost two years and been working with a local



*Murray Close and Lee Burberry surveying the completed denitrification wall.*

geophysics company Southern Geophysical to expand the use of applied hydrogeophysics for groundwater investigation. They have been examining the groundwater flow conditions and nitrate concentrations at the test site, as well as the groundwater ecology, and testing the permeability of the wood and gravel mixtures they are using.

Principal Scientist Murray Close says the project's aim is to offer landowners another tool to enhance the removal of nitrates. He says that while there are a number of things that can be done to improve the overall water quality and prevent contaminants from entering water systems, ESR's focus in this project has been to address the problem of removing nitrates once they get into the groundwater.

“The preliminary results are indicating that it is working to remove nitrate. The next part is looking at whether it will be cost effective enough to be widely used. That will be one of the key questions.”

It is hoped that long term the Kaiapoi project will be used as a demonstration site where farmers and landowners can take the technology and use it on their own properties. The aim is to study the performance of the denitrification wall over the long-term. Its impact on the local groundwater conditions is being intensively monitored over the next two years, although the scientists say the structure will last a lot longer than that.

Dr Burberry says that whilst there are no exemplars for gravel aquifers, evidence from case studies in sand aquifers tends to indicate the denitrification wall should function for several decades.

***Murray Close, Manager Groundwater Science and Lee Burberry, Senior Scientist, Health and Environment Group, ESR.***

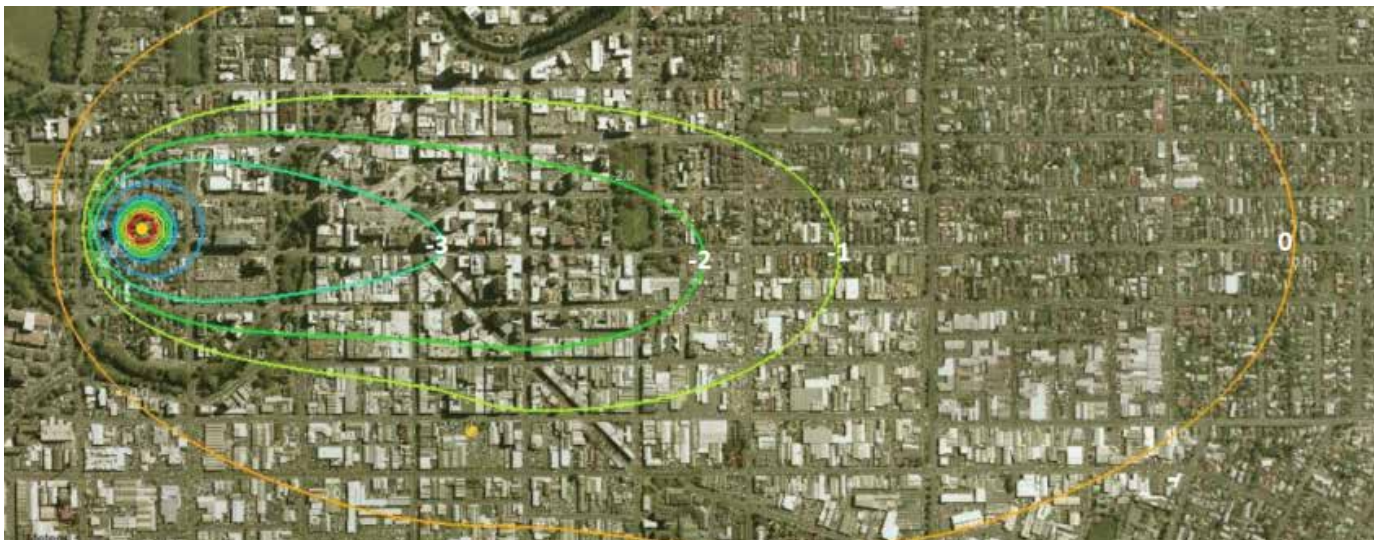
## Using groundwater as an energy source

**We do not usually think of groundwater as a source of energy but it certainly can be through using ground sourced heat pumps. These have the potential to provide efficient and sustainable large-scale heating and cooling options, although the environmental effects must first be understood to ensure its viability.**

Underneath Christchurch lies a series of confined aquifers ranging in depths from five metres to more than 200 metres. These aquifers are highly productive, with yields in excess of 100 litres of water per second possible from single wells. In many areas groundwater flows freely to the surface under artesian pressure. This abundant source of water makes the Christchurch aquifers ideal for supporting ground source heat pump (GSHP) systems.



Dr Helen Rutter



*Predicted groundwater temperature plume after 35 years of continuous injection in layer 3 (difference from ambient temperature).*

These operate on a similar principle as air-sourced heat pump systems, except they use groundwater (taken from onsite wells), rather than air. The water is passed through heat exchangers to extract or reject heat energy as required for heating or cooling. It is then discharged into a soak pit or reinjected into bores, thus returning it to the ground. This in turn reduces or increases the groundwater's temperature.

The advantage of these heat pumps is that the groundwater temperatures are consistent, usually in the 12-14°C range. This compares with air temperatures which, in Canterbury, vary between below freezing and over 30°C. As a result, GSHPs are more energy-efficient. At certain times of the year, groundwater can be used directly for cooling, with no need for heat exchangers.

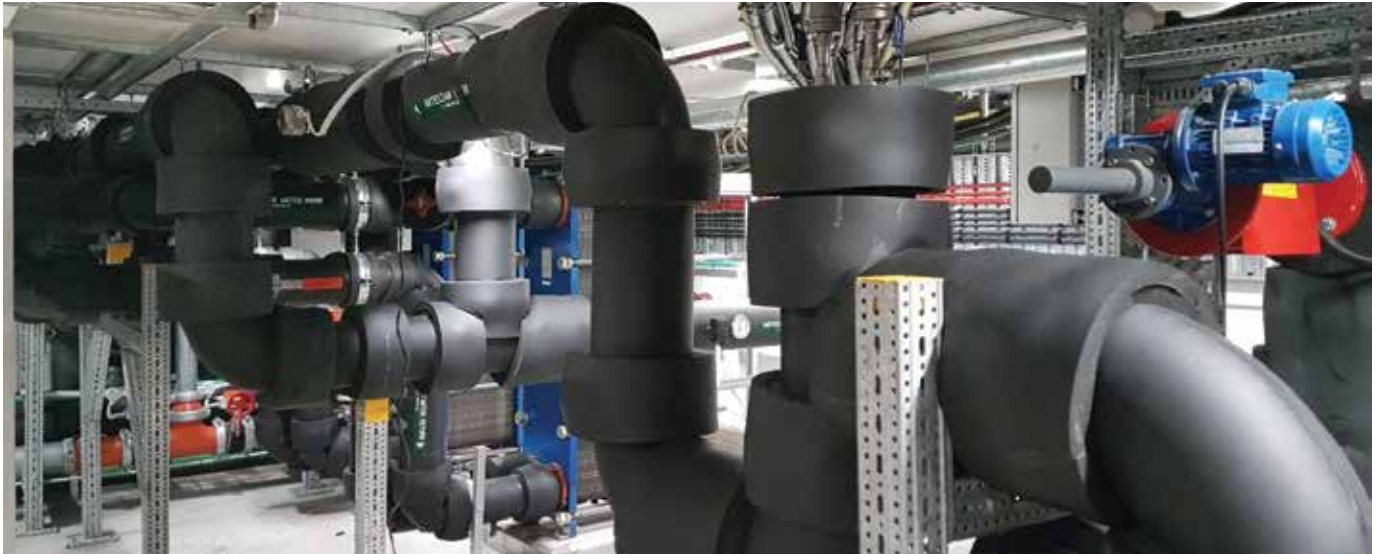
Christchurch aquifers were already being used for ground sourced heat pump systems prior to the earthquakes and these systems are still in operation. At the University of Canterbury, groundwater is used to cool laboratories and lecture rooms. Christchurch International Airport has the largest groundwater heat source pump system in Christchurch. The Airport's older diesel and LPG boiler system was replaced in 2011, and now comprises two 1.5 MW and one 600 kW GSHP systems for heating and cooling.

New systems have been recently developed as the city centre rebuilds post-earthquake. These include systems at the Arts Centre, Bus Interchange, new Central Library, Justice Precinct, and King Edward Barracks. They abstract groundwater from



*Heat exchangers for a groundwater sourced heat pump system.*

one aquifer layer and inject it into a different layer. In this way, recirculation of the warmed or cooled water, which reduces system efficiencies, can be avoided. However, some schemes have found that while abstracting groundwater is straightforward, injecting it back poses more of a concern due to problems with shallow groundwater mounding. Being able to understand how permeable the aquifers under Christchurch are, in a three dimensional way, will help with understanding which ones can viably service a ground sourced heat pump.



Groundwater input pipework for a groundwater sourced heat pump system.

Abstraction and reinjection GSHP systems do not usually result in a net removal of groundwater from the aquifer system as a whole. The injection rate is usually the same as the abstraction rate. The abstraction of groundwater causes a cone of depression in the source aquifer and the subsequent reinjection results in mounding in the destination aquifer. These effects may overlap, depending on the amount of leakage between the two aquifers.

Furthermore, adjacent GSHP systems in the same aquifer will also interfere with each other. The same occurs thermally, whereby injecting water that is warmer or cooler than the receiving groundwater will result in a thermal plume that will propagate and dissipate away from the injection well,

affecting the efficiency of down-gradient GSHP systems. Numerical modelling of the groundwater system can help us understand and quantify both the hydraulic and thermal effects in groundwater from operating GSHP systems. This is achieved using solute transport models where solute transport properties are exchanged for heat transport properties.

Understanding the effects of heat pumps on the groundwater system and on other nearby heat systems is key to making these systems a truly efficient and sustainable option for large-scale heating and cooling.

**Dr Helen Rutter and Julian Weir, Aqualinc.**

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