TE WHAKAHEKE O TE WAI

A quarterly newsletter for stakeholders of the TWOTW Research Programme

Sampling in Taranaki: Reagan and Reuben (GNS Science) following steps outlined by Uwe to purge a groundwater well under challenging conditions.

FROM THE PROGRAMME LEADERS

Catherine Moore and Uwe Morgenstern

Kia ora koutou,

Welcome to our December 2023 update for the TWOTW research programme. It was a very busy end to 2023 so apologies that our update newsletter was delayed until now. During the last quarter, fieldwork kicked off for the latest groundwater sampling campaign, team members prepared and delivered a range of presentations at the joint NZHS/Australasian Groundwater Conference, and both paper writing and modelling continued. We present a summary of highlights from these events in this newsletter. In addition, staff from regional councils were trained in groundwater sampling techniques, including gas tracers. Sampling resumed in the multilevel wells in Canterbury and in Taranaki. Two GNS Science technicians (Reagan Lithgow and Reuben Rodricks) were trained in sampling, under very difficult conditions (see photo above). They showed unwavering enthusiasm despite challenging field conditions, for a successful sampling campaign! We would like to wish all of our stakeholders a happy and successful 2024!

Ngā mihi,
Cath and Uwe.

FOCUS - DATA AND MODELLING

HERETAUNGA PLAINS AQUIFER STUDY (Uwe Morgenstern)

Did Cyclone Gabrielle increase the risk of pathogen contamination for drinking water supply wells in the confined aquifer of the Heretaunga Plains?

The Heretaunga Plains aquifer is a key drinking water supply source for Hastings District and Napier City. Monitoring of age distributions in drinking-water supply wells provided insights to help councils understand the groundwater resource and identify potential pathogen pathways. Absence of young water in drinking-water supply wells significantly reduces the likelihood of pathogen contamination through an aquifer.

During flood events, due to extreme hydraulic loading in recharge areas of aquifers, groundwater flow dynamics can change, causing a risk of pathogens being flushed into aquifers used for drinking water supplies. Extreme flood events are increasingly experienced with climate change, and have potential to cause impacts not seen before. For example, drinking water sources that were free of pathogen contamination in the past may become contaminated in the future. As an example, in the Heretaunga Plains contaminated water from heavy rain-inundated paddocks entered an unconfined part of the aquifer and drinking water wells in it, resulting in >6,260 cases of illness including 42 hospitalisations, and Campylobacter infection contributed to at least four deaths (Gilpin et al., 2020).

Most of the c. 30 drinking water wells in the Heretaunga Plains, including those supplying the cities of Hastings and Napier, are, however, in the confined part of the aquifer and these were not affected by pathogen contamination. But will more extreme flood events, predicted with climate change eventually also compromise drinking water sources in the confined aquifer which were deemed safe in the past? Wells in the confined aquifer have shown indications of changing groundwater flow dynamics, for example variable water age, and changing hydrochemistry after flood events, which might be associated with younger water, bearing the risk of pathogen intrusion.

While immediate hydraulic pressure responses in aquifers due to flood events are well understood (celerity), water and contaminant transport is determined by how quickly water moves through aquifers (velocity) and changes in groundwater flow velocities are less understood (McDonnell, 2017). Groundwater ages are required to understand changes in groundwater flow velocities.

On 13 and 14 February, 2023, Cyclone Gabrielle lashed Hawke's Bay. Record rainfalls caused rivers to burst their banks resulting in a death toll of 11. To improve understanding of the impact of the extreme hydraulic loading on the aquifers through such events, specifically changes to the water flow dynamics with potential for new, previously unrecognised contaminant pathways and associated risks for drinking-water supply wells, we measured age-tracers in selected wells again, two months after Cyclone Gabrielle. Comparing the results of this survey with age-tracer data from just three months prior to the cyclone provided an opportunity to test how extreme events like Cyclone Gabrielle change groundwater flow dynamics in confined aquifers.

FOCUS - DATA AND MODELLING

HERETAUNGA PLAINS AQUIFER SUDY (continued)

On 12 and 13 April 2023 we re-sampled for age tracers a selection of drinking-water supply wells in partnership with Hastings District Council and Napier City Council, and of private and monitoring wells in the central and marginal confined parts of the aquifer system in partnership with HBRC

The data indicate that groundwater ages in these wells have not changed significantly because of Cyclone Gabrielle. The wells that showed slight changes in age-tracer concentrations consistently showed older water after Cyclone Gabrielle. Other wells, despite showing no detectable changes in age-tracer concentrations, contained water that was more evolved after the cyclone, indicated by decreased dissolved oxygen and elevated methane, ammonia, and phosphorous concentrations.

These observations all point toward older (probably deeper) groundwater having been pushed into the active groundwater flow paths by the increased hydraulic loading. With no younger water detected in the investigated wells following Cyclone Gabrielle, there is no indication of increased risk of pathogen contamination in the confined aquifer system following extreme flood events.

These results were unexpected. This example shows how our research, using the water signature of unique age tracer concentrations, contributes to fundamentally new understanding of our groundwater systems. It provides much needed information for managing groundwater resources.

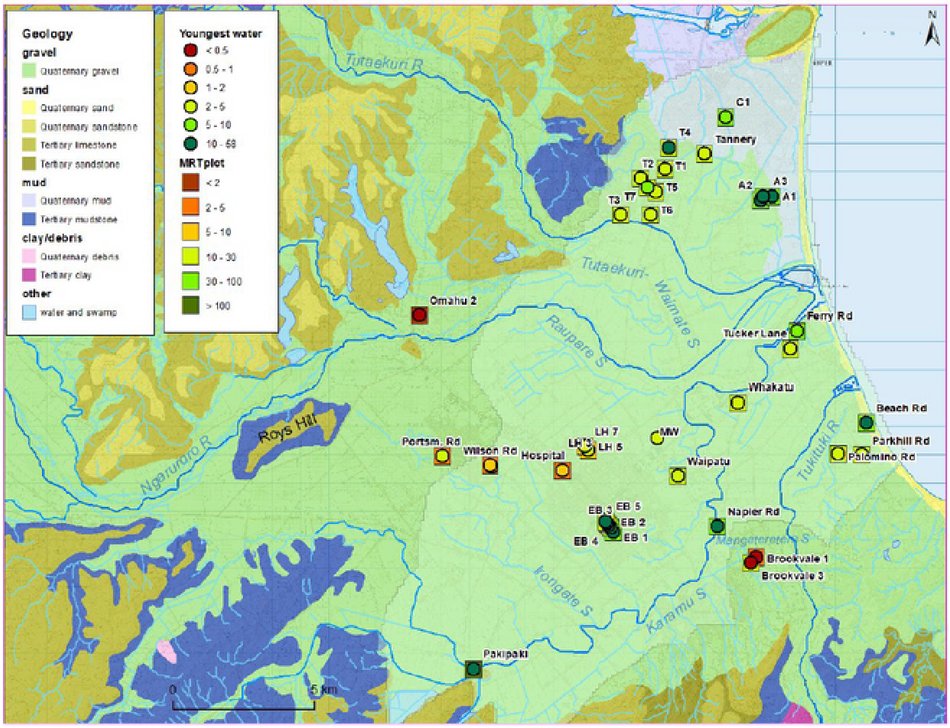


Figure 1: Map showing mean residence time and minimum groundwater age for the drinking-water supply wells in the Heretaunga Plains aquifers. The confined aquifer is indicated in light green.

Morgenstern U., 2023. 2023 groundwater residence time assessment of Heretaunga Plains municipal water supply wells in the context of contamination risk via young water flow paths and impact by Cyclone Gabrielle. Lower Hutt (NZ): GNS Science. 33 p. (GNS Science report; 2023/44). https://doi.org/10.21420/2CHQ-N017.

Gilpin B.J etal., 2020. A large scale waterborne Campylobacteriosis outbreak, Havelock North, New Zealand. J Infect. 2020 Sep;81(3):390-395. doi: 10.1016/j.jinf.2020.06.065. Epub 2020 Jun 29. PMID: 32610108.

McDonnell JJ (2017). Beyond the water balance. Nature Geoscience, vol. 10, no. 6, pp. 396

FOCUS - DATA AND MODELLING

REGIONAL GROUNDWATER MODEL (Brioch Hemmings)

With the regional groundwater model for Heretaunga Plains we are exploring the ability of large-scale models to make predictions of local importance, in comparison to a more focussed "local" numerical model. We are also exploring the ability of the model to assimilate tritium concentration observations and the value of these relatively "pin-point" observations for informing regional model predictions, including predictions that relate to age groundwater distributions, and system changes under different climate regimes. The regional model is also being used as a real-world testbed for exploring and refining methods of incorporating geophysical data like that from airborne electromagnetics (e.g. SkyTEM) in to numerical models, for improving model predictions.

The Heretaunga model has updated with the addition of surficial layers to support greater complexity in the interaction between confined and unconfined aquifer systems (including surface water). Layering and initial hydraulic conductivities are guided by the current geological model for the region (Begg et al., 2022). Building on insights from Uwe's groundwater dating and geochemistry investigations in Heretaunga, and Wes' numerical studies in Wairau Plains, Heretaunga numerical model updates also incorporate uncertainties in boundary inflows at the perimeter of the plains ("mountain-block recharge"). Recharge and stream inflow estimates are provided by NIWA's TOPNET model (although still represented as highly uncertain).

Preliminary results indicate that for some predictions (e.g. net offshore flow) formal assimilation of tritium has little impact on model predictions (Figure 1).

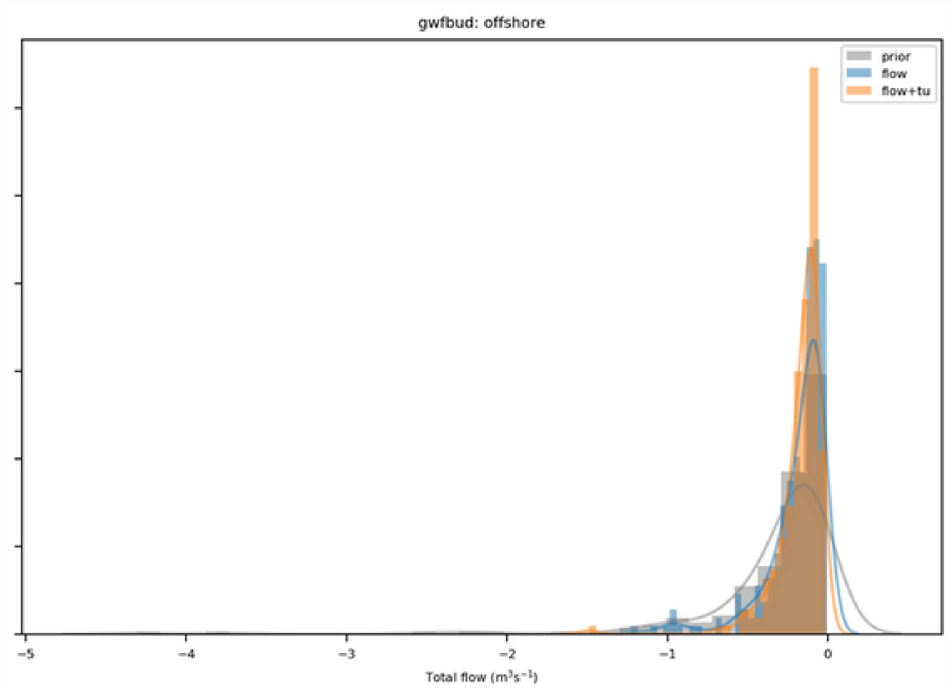


Figure 1: Numerical model prediction of offshore groundwater flow (negative values represent flow offshore). Grey bars and lines represent the prediction distribution reflecting prior uncertainty (before history matching). Blue is the prediction distribution after a rapid history matching to water levels and stream flows. Orange is the prediction distribution after a much more computationally intensive history matching to tritium observations. The distributions are similar indicating that the assimilation of data is not impacting the prediction significantly.

FOCUS - DATA AND MODELLING

REGIONAL GROUNDWATER MODEL (continued)

Even some groundwater age related predictions appear relatively insensitive to the assimilation of tritium (e.g. median age, Figure 2). However, other predictions are significantly modified by the use of tritium in history matching (Figure 3). It is also worth noting that the tritium and groundwater age data is also assimilated into the numerical modelling via a less formal route, in informing the conceptual model that is incorporated in the model structure. For example, the expected presence of reasonably significant groundwater inflows for the perimeter of the plains. The impact of the data at this point is in the modelling workflow is harder to quantify but is also part of the current study.

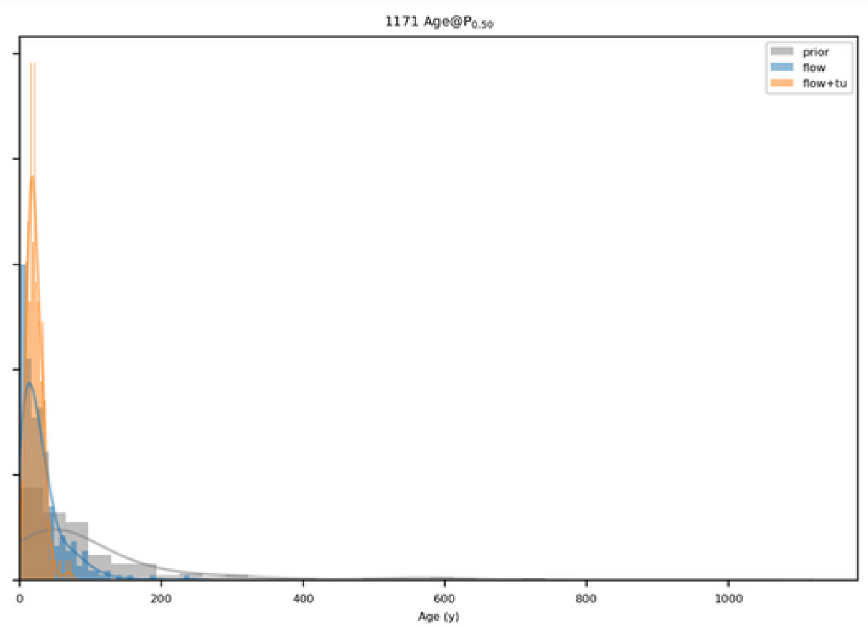
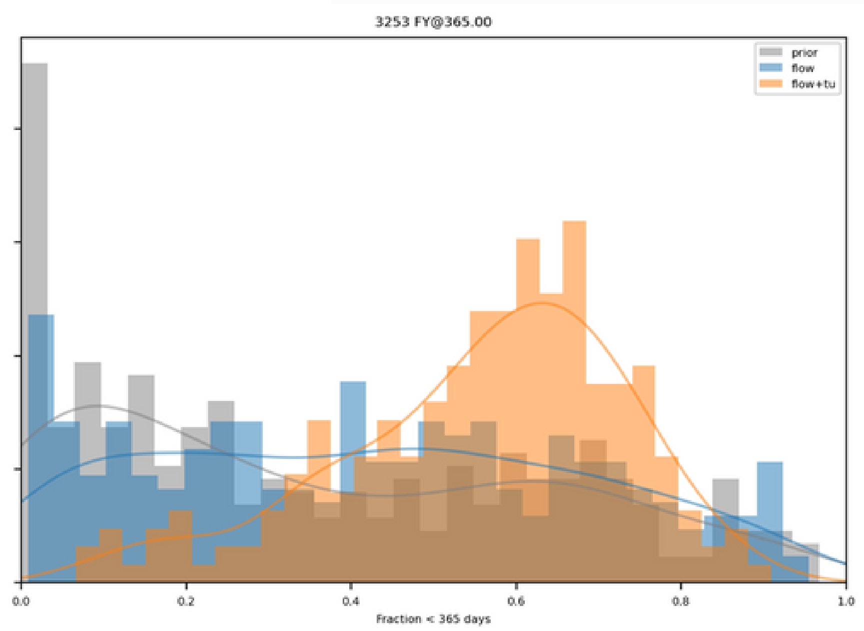


Figure 2: Numerical model prediction of median age at a well in the expected confined aquifer region of Heretaunga. Grey bars and lines represent the prediction distribution reflecting prior uncertainty (before history matching). Blue is the prediction distribution after a rapid history matching to water levels and stream flows. Orange is the prediction distribution after a much more computationally intensive history matching to tritium observations. Again, the distributions are similar indicating that the assimilation of data is not impacting the prediction significantly.

Figure 3: Numerical model prediction of the fraction of groundwater that is younger than 1 year for a well in the expected unconfined aquifer region of Heretaunga. Grey bars and lines represent the prediction distribution reflecting prior uncertainty (before history matching). Blue is the prediction distribution after a rapid history matching to water levels and stream flows. Orange is the prediction distribution after a much more computationally intensive history matching to tritium observations. Significant differences between the distributions before (grey and blue) and after (orange) history matching to tritium indicate that for this prediction is sensitive to assimilation of the tritium data.



Begg J.G., Jones K.E., Lee J.M., Tschritter C. 2022. 3D geological model of the Napier-Hastings urban area. Lower Hutt (NZ): GNS Science. (GNS Science geological map; 7b). https://doi.org/10.21420/71JG-1928

FOCUS - DATA AND MODELLING

NATIONAL MODEL (Wes Kitlasten)

Recent work has focused on history matching to tritium and ages in the Wairau using highly parameterized models to quantify uncertainty. We have explored several conceptualizations and parameterization schemes for the numerical model representing the Wairau Plains aquifer. We found that results are very sensitive to the representation of groundwater age at the aquifer boundary, which unfortunately is also spatially variable and highly uncertain. The prior parameter distributions play a crucial role in history matching using the iterative ensemble smoother approach. As such, the wrong priors (initial estimates) of groundwater age at the model boundary can compromise the history matching results. We have developed scripts to sequentially update the prior parameter distributions (mean and variance) using varying levels of parameterization (e.g., pilot points at 2000m, 1000m, and 300m).

PUBLICATIONS

Tschritter C., Daughney C.J., Karalliyadda, S., Hemmings B., Morgenstern U., and Moore C., . 2023. Estimation of groundwater age distributions from hydrochemistry: comparison of two metamodelling algorithms in the Heretaunga Plains aquifer system, New Zealand. Hydrology and Earth System Sciences. Articles, Volume 27, Issue 23, HESS, 27, 4295–4316, 2023. https://doi.org/10.5194/hess-27-4295-2023.

INTRODUCING THE TEAM - BEHIND THE SCENES

Damon Clarke is the project manager for the TWOTW programme and joined the project in late 2019, a year after it started. He has been working for GNS Science for over seven years and belongs to the Project Management Office (PMO). Damon's other projects are also all groundwater projects, covering many different aspects of groundwater research activity at GNS Science. Damon's background is in IT project management and geoscience. He studied geology at Victoria University of Wellington, graduating with an MSc in 1998. He also leads one of GNS's seismology teams.

Abigail Lovett is a hydrogeologist with experience in stakeholder engagement and project management. Abigail provides support to the TWOTW Programme Leaders (Cath and Uwe) and PM (Damon), such as minute/note taking for meetings, seminars, and workshops, preparing stakeholder engagement material, and assisting with project reporting to MBIE. At E&E Science, Abigail works on a wide range of other research and consulting projects, for and alongside regional councils, CRI's, central government, and landowners. She has a keen interest in using science to better understand our environment and water resources, for sustainable management.

Lucia is an experienced geologist with interests in stratigraphy, sedimentology, and environmental research. Her expertise has been applied to the management and delivery of large-scale multi-disciplinary projects and research associated with environment and climate, natural hazards and risks and energy across many aspects of geosciences in New Zealand. Her team at GNS Science also provides scientific leadership, oversights and development for GNS's laboratory and collections. Lucia has previously led the Paleontology Department, and she joined the Science Management Team in 2019 as Department Manager of Surface Geosciences.

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NZHS & AUSTRALASIAN GROUNDWATER CONFERENCE

The Australasian Groundwater & NZHS Conference was held at Auckland University of Technology (AUT) City Campus, in Tāmaki Makaurau / Auckland from 28 November – 01 December. The conference was organised by NZHS and the New Zealand and Australian Chapters of the International Association of Hydrogeologists (IAH). This year's conference theme was "*Manaaki Wai (caring for our water): learning from the past, adapting for the future*". The theme captured the idea that water is a living entity, with its own mauri (life force) that needs to be respected and cared for, which is central to te ao Māori (the Māori worldview). Around 380 delegates attended with papers and posters covering a wide range of topics with a strong groundwater focus .

The following presentations associated or aligned with the TWOTW programme were given :

- *Groundwater and surface water conceptual flow from environmental tracer signatures in the Pukekohe & Bombay Area, Auckland. Uwe Morgenstern (GNS Science).*
- *Groundwater contributions to streamflow in New Zealand: A BACH method study. Paul Oluwunmi (GNS Science).*
- *Groundwater Hindcasting: What Is It, How Do We Do It, And Why Is It Important? Tara Forstner (University of Canterbury).*
- *History-matching to tritium in the Wairau Aquifer: Sequential conditioning of priors. Wes Kitlasten (GNS Science).*
- *If the prior is uncertain, is a complex simulator worth it? Cath Moore (GNS Science).*
- *Lag times and flow pathways for rivers: developing robust national scale metrics using stable isotopes. Bruce Dudley (NIWA).*
- *Numerical delineation of source protection zones in heterogeneous alluvial aquifers: guidelines and recommendations. Allannah Kenny (ESR).*
- *Robust Source Water Risk Management Area Modelling. Catherine Moore (GNS Science).*
- *When and how to use groundwater tracers to inform regional-scale numerical model predictions? Brioch Hemmings (GNS Science).*

Mihi Whakatau from Ngāti Whatua Orākei at the conference opening ceremony.

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TWOTW PROGRAMME SUMMARY

Te Whakaheke o Te Wai (TWOTW) is a research programme funded by MBIE's Endeavour Fund and led by GNS Science. Originally planned to run for five years, the programme has been extended by another year. Multiple national and international organisations and stakeholders are involved in the collaboration. Primary collaborators of the research programme include NIWA, ESR, Te Tai Whenua O Heretaunga, Victoria University of Wellington, and Watermark Numerical Computing. Hawke's Bay Regional Council support the major case study area, the Heretaunga Plains. Other regional councils and organisations also contribute to the research project, including with co-funding.

The TWOTW programme aims to better support water management based on improved understanding and integration of flow sources, pathways, water travel time, and cultural knowledge and values in New Zealand. The research is underpinned by the concept and defining of 'Te Whakaheke o Te Wai' of groundwater throughout the main catchments and aquifers in New Zealand. The 'Te Whakaheke o Te Wai' of groundwater - our largest freshwater resource - is largely unknown, yet stakeholders recognise that this knowledge is urgently needed to protect and sustainably manage groundwater and the rivers and streams it feeds. Outputs from this research are to provide decision-makers with much needed knowledge for improved water management at national, catchment, and local scales. Outputs from the research will be publicly available and benefit people and institutions involved in water management.

The programme is currently developing the world's first nationally continuous maps of groundwater age, origin and flow paths. A technical foundation of the research project is the development of new modelling technologies. This project builds on the current knowledge and implementation of data assimilation and uncertainty quantification commonly expected and often required in modelling projects. This research is evolving modelling capability from simply understanding uncertainty (which is now generally accepted in modelling), to the design of novel models with an ability to reduce that uncertainty. This includes combining mātauranga Māori and mōhiotanga Māori with aquifer models to reduce this uncertainty. This is a unique combination of western science and indigenous knowledge that demonstrates the importance of combining the two knowledge systems. New stochastic approaches for source protection zone modelling (SPZ) are also being developed.

Key researchers

***GNS Science:** Catherine Moore, Uwe Morgenstern, Brioch Hemmings, Conny Tschritter, Sapthala Karalliyadda, Wes Kitlasten, Mike Taves, Paul Oluwunmi, Susana Guzman, Lee Chambers, Magali Moreau, Stewart Cameron*

***VUW:** Ocean Mercier, Amber Aranui*

***ESR:** David Scott, Murray Close, Theo Sarris, Alannah Kenny*

***NIWA:** Bruce Dudley, Jing Yang, Chris Daughney*

***Students:** Tara Forstner, Willow Milligan, Oscar Arnold, Alyssa Thomas*