TE WHAKAHEKE O TE WAI

A quarterly newsletter for stakeholders of the TWOTW Research Programme

Researchers attending the Maimai Catchment field day, 19 - 20th February, 2023.

FROM THE PROGRAMME LEADERS

Catherine Moore and Uwe Morgenstern

Kia ora koutou and welcome to our May 2023 update for the TWOTW research programme.
What a quarter! We continued major field work in several regions, held a 6-day hui in the Heretaunga Plains with our iwi partners and regional and local authorities, and co-organised a catchment workshop at Maimai near Reefton together with Jeff McDonnell from the University of Saskatchewan. Groundwater modelling work has also continued apace. ESR has made good progress on the drinking water Source Protection Zone (SPZ) modelling, and a collaborative GNS-ESR guidance document for robust and practical SPZ modelling is now underway. In addition, GNS is working on national, regional, and local scale models and rapid model build tools. This model flexibility and agility will ensure that the salient information is best able to flow from data to water management decisions. It also supports decisions across a range of scales, using information from diverse sources, and addressing a range of issues. Some of this work was presented by GNS at an international modelling conference in March (PEST 2023: The path from data to decisions). Finally, two of the programme's students have submitted and passed their courses with excellent theses. Alyssa's thesis "*Ngā Rangatira Mō Apōpō. Rangatahi aspirations for Pukekauri dam in Patuharakeke rohe: an educational wānanga for youth engagement and visioning*" and Oscar's thesis '*Wāhi Ngaro: an offering to cross-cultural management of groundwater*' will be described in greater detail in the next edition of the newsletter.
Ngā mihi,
Cath and Uwe.

HERETAUNGA HUI

The group convened on Sunday 7th May at Te Taiwhenua o Heretaunga - and the hui was opened with a karakia from Marei. The group then visited various sites of hydrological interest, including the cyclone devastated areas at Ōmahu, Awatoto, and Esk Valley where they learnt about the impacts of such extreme weather events. Next, they visited Ōmahu marae, where they were welcomed with pōwhiri, and the following presentations were provided:

- **Uwe Morgenstern** (GNS Science) provided a summary of the Heretaunga Plains aquifers, with a focus on the aquifers as a drinking water source. Uwe described how Ōmahu is located on the unconfined part of the Ngaruroro River gravel fan where the groundwater is very young. As a result, there is potential of pathogens being present in drinking water supply wells. Questions raised by the local community and discussed included the status of nitrate contamination of the Heretaunga aquifers, and potential of the aquifer to help remove water loads at flood events.
- **Amber Aranui** (Te Papa) focused on modelling and groundwater Mātauranga - including the importance of exploring the aquifer through the lens of mātauranga Māori from the past through to the present in order to gain a more holistic evidence base for the modelling. Amber discussed examining archival material, oral histories, and whakataukī in relation to our relationships with the wai and the changing landscape from pre-European times to today. The presentation highlighted the importance of working together and acknowledging these two knowledge systems.
- **Marcus Vandergoes** (GNS Science) presented on the Lakes380 research programme, with a focus on the current and past state of our lakes' health in the Heretaunga region, and outlined future opportunities. Overall, analysis and modelling of current lake health for the region predicted that 90% of the lakes were in poor or worse condition and likely to experience high levels of algae, poor water quality and ecological conditions. Analysis of sediment cores indicated that many of these changes occurred in more recent times, likely to be after the 1950’s and linked to changing land use and water use practices. Future opportunities were discussed and included using information about past lake and ecosystem health to guide restoration plans and management targets for the future.

On Monday the group visited various sites of hydrological interest in the southern hills and learned about iwi engagement in monitoring Paritua Stream. The group was welcomed to Houngarea marae with a pōwhiri, and the following presentations were given:

- **Uwe Morgenstern** (GNS Science) discussed the Heretaunga Plains water discharge via Tukituki, Ngaruroro, and Tutaekuri Rivers from bedrock formations, and the uniqueness of the Karamu Stream discharging very old water from the limestone formations. The reasons for Paritua Stream depletion were discussed, and further sites identified for sampling that are of special interest to local iwi.
- **Amber Aranui** (Te Papa) repeated her presentation on modelling and groundwater Mātauranga (as described above).

HERETAUNGA HUI

- **Tara Forstner** (PhD student, University of Canterbury) presented on plans for a Pakipaki model. This included exploring the past groundwater-surface water regime in and around Pakipaki, and the evolution of changes since early-European settlement. Her research aims to contribute to the understanding of te mana o te wai and the restoration of important cultural sites and local streams under future climate change scenarios.
- **Tom Gleeson** (University of Victoria, Canada) described groundwater sustainability and partnering with indigenous communities in Canada. He described the 'Xwulqw'selu Connections' project, which is motivated by perennial concerns of decreasing summer flows in the Xwulqw'selu Sta'lo' (Koksilah River). The project has the potential to radically improve water governance and shared management between Indigenous and Settler Governments through the first Water Sustainability Plan in British Columbia.

On Tuesday, various springs and water sources were sampled (Uwe Morgenstern) and a stakeholder engagement event was held. The following day the TWOTW team met with Hawke's Bay Regional Council modelling and science teams and discussed a conceptual groundwater flow model based on age and isotope tracer signatures. Key topics included that the model indicated that there is no recharge into the aquifer from the Ngaruroro River south of Roy's Hill, and that the Tutaekuri River does not recharge the main aquifer. The discussion included the impact of cyclone Gabrielle on water flow through the confined aquifer. A meeting was also held with Napier City Council to discuss contamination risk posed by extreme flood events to their community water supply wells. Thursday involved meetings with the communications teams of the Waiaroha water centre and discussion on how GNS Science can tell their stories about the Heretaunga groundwater system to the wider public, through interactive displays at the Waiaroha learning centre. On Friday the TWOTW team toured the Hastings District Council Waiaroha facility (under construction).

Robert Turner (third from left) describes recent flow behaviour of the Paritua stream to hui attendees.

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HERETAUNGA HUI

Heretaunga hui attendees inside the Wharenui at the Ōmahu marae.

Attendees of the Heretaunga hui outside the Wharenui of the Ōmahu marae.

Attendees of the Heretaunga hui during a presentation at the Houngarea marae.

WORKSTREAM FOCUS - SOURCE PROTECTION ZONE MODELLING

A summary and update of the ESR component of the SPZ workstream has been provided by Theo Sarris. (ESR). Capture zone delineation is particularly important for assessing contamination risk and the security of groundwater drinking supplies. Numerous approaches have been reported in the international literature for the calculation of SPZs. These approaches vary greatly in terms of problem conceptualization, underlying simplifications, level of detail, and the amount of resources that need to be invested. As part of the TWOTW project we are exploring how hydrogeological information can be used to assess the probability of contaminants reaching a pumping well with reasonable accuracy and efficiency. In our numerical experiments we have explored how some of the most commonly used tools to delineate these zones could potentially affect their size. One example of this work are the results presented in Figure 1. On the top row the probabilistic SPZ has been delineated using forward particle tracking, where particles are released on the water table and tracked until they reach the well or any other model boundary.

In the other three plots the probabilistic SPZ has been delineated using the same ensemble of flow models, where the difference is that particles were tracked backwards; particles were released in the vicinity of the well screen and tracked until they reached various elevations in layer 1. Backward tracking particles to the top of layer 1 does not produce the full extent of the SPZ. The majority of particles in the forward tracking simulation terminate on the upper face of the pumping cell, whereas in the backward tracking particles are typically distributed throughout the pumping cell and most do not reach the top of layer 1. Using starting particles randomly distributed on the surface of the cell (rather than within) does not make any significant difference. These results clearly suggest that backwards particle tracking should be used with caution as it would significantly underestimate the risk of contaminants reaching the well.

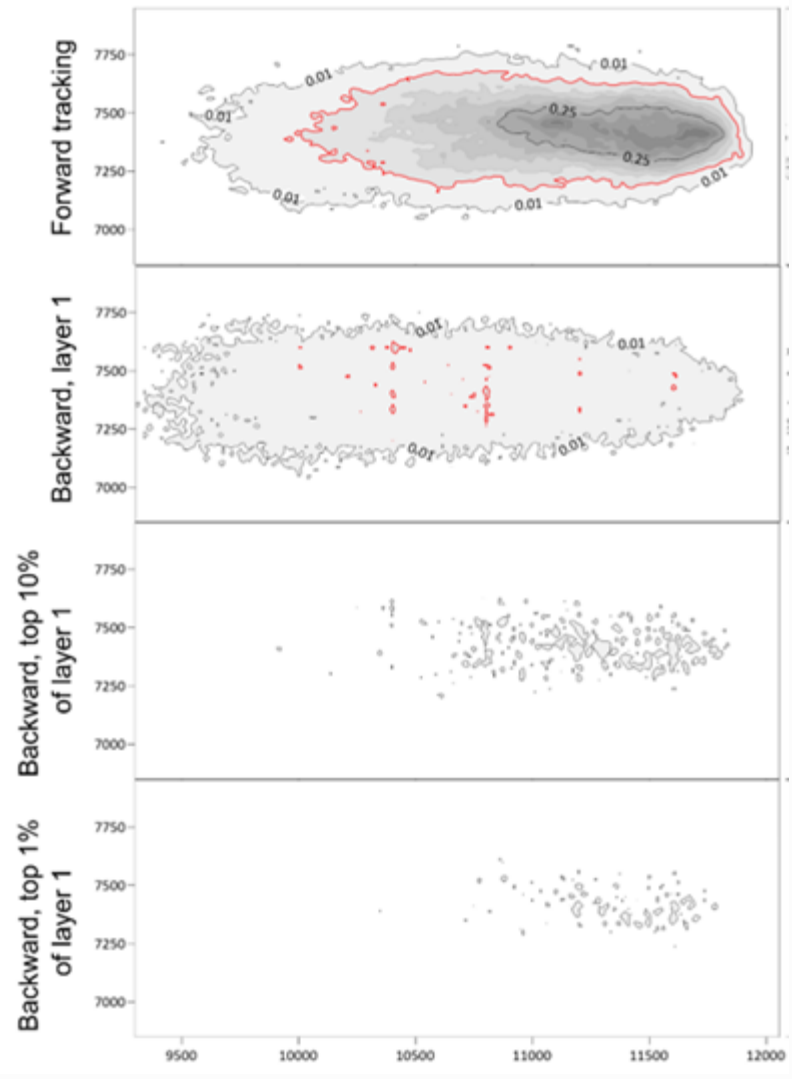

Figure 1: Probabilistic SPZ using forward particle tracking (top row) and backward particle tracking (rows 2-4). The red line denotes 5% probability.

WORKSTREAM FOCUS - SOURCE PROTECTION ZONE MODELLING

Our focus recently has been concentrated on exploring how simple numerical and analytical approaches can approximate the SPZ calculated using numerically demanding stochastic flow and transport modelling. For example, Figure 2 compares the probabilistic SPZ delineated using 200 heterogeneous realisations with SPZ delineated using two 3D-homogeneous models (blue and green lines – using homogeneous models the SPZ becomes binary as there is no estimation of prediction uncertainty). Assuming that the vertical anisotropy is the same in the homogeneous and heterogeneous models results in no SPZ from the homogeneous model. As a result we reduced vertical anisotropy from 10 to 1 (i.e. Kx = Kz), while in both homogeneous models the porosity has been used as a scaling factor and had to be reduced by a factor of 2 and 2.5 so that the deterministic SPZ could match the 5% and 1% probabilistic zones respectively.

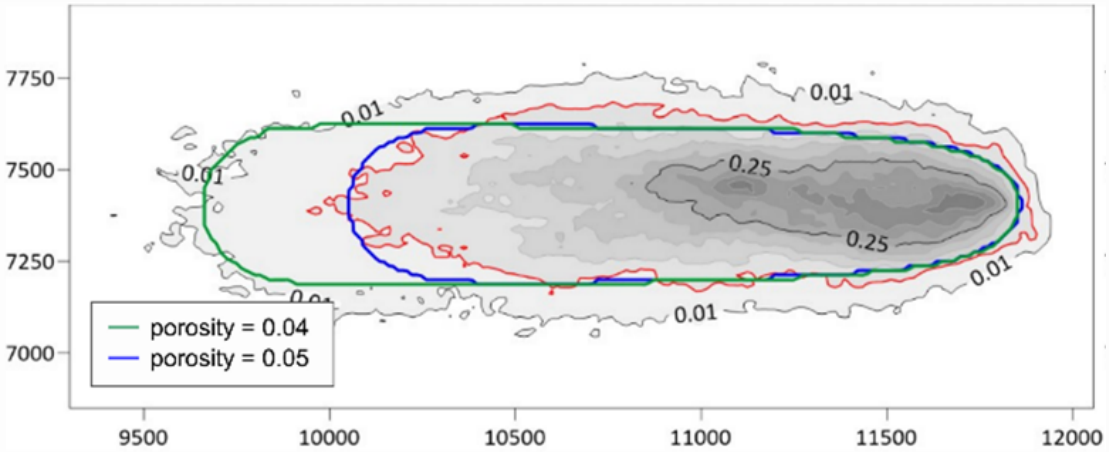

Figure 2: SPZs derived from an isotropic homogeneous model with varied porosity, overlaid on the probabilistic SPZ.

In Fig.3 the probabilistic SPZ is compared with those derived using 2D homogeneous modelling, as well as the uniform flow equation:

$$t_x = \frac{n}{ki}\left[r_x + \frac{Q}{2\pi kbn} ln\left(1 + r_x \frac{2\pi kbi}{Q}\right)\right].$$

Once again, the porosity is used as a scaling factor, and in order to reach comparable results, porosity needs to be scaled by a factor ranging from 2.5 to 5.

In all cases homogeneous modelling significantly underestimates the extend of the SPZ. Our findings will be collated in a technical report that will provide practical guidance on the "do's and don'ts" of using numerical modelling to delineate SPZs.

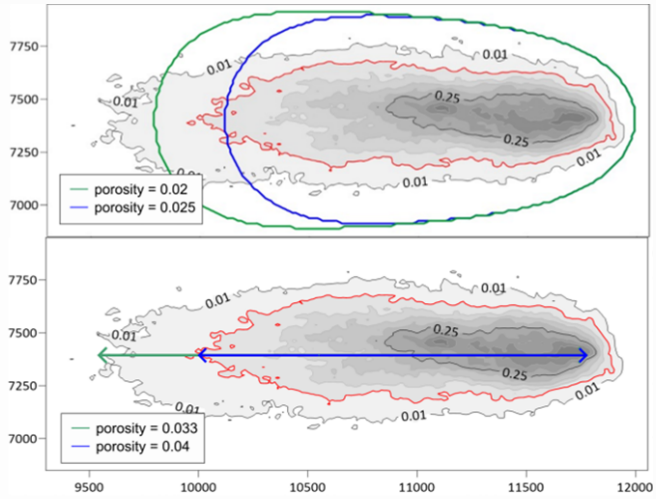

Figure 3: SPZs derived from a 2D homogeneous model (top) and the uniform flow equation (US EPA, 1994) (bottom). In both cases SPZs were delineated with varied porosity and are overlaid on the probabilistic SPZ.

INTRODUCING OUR TEAM

We would like to introduce the following key scientists who are working on the Source Protection Zone workstream within TWOTW. The team is composed of staff from ESR Christchurch and the team are collaborating with Environment Canterbury on case studies.

Theo Sarris

Theo Sarris leads the modelling team in the Water Group at ESR, Christchurch. He has 25 years' experience in groundwater modelling in New Zealand and internationally, across research, government, and engineering consulting. His research interests include the development of theory and methodologies for modelling the transport of nutrients and pathogens in aquifers, environmental risk analysis, and the quantification of uncertainty in groundwater management. His current work focuses on minimising the risk for drinking groundwater supplies from contamination (microbial, viral, and nitrate). Theo is interested in optimisation problems and incorporating Artificial Intelligence and Deep Learning tools and techniques to groundwater hydrology.

Allanah Kenny

Allanah Kenny is a groundwater modeller with a Masters in Mathematics and a PhD in Mechanical Engineering. In 2020, and after finishing a postdoctoral fellowship at University of Canterbury, Allanah joined ESR's water group as a groundwater modeller. Her current research focuses on a range of topics including contaminant transport modelling, source protection zone delineation, and visualisation of groundwater flow for the improvement of public awareness.

David Scott

David is a groundwater hydrologist with more than 40 years' experience in water resources with a particular interest in groundwater modelling. Before joining ESR as a part-time contractor, David worked for Environment Canterbury where he focused on groundwater resource management issues and, prior to that, he undertook research on the use of groundwater models while working for the Hydrology Centre of the Ministry of Works and Development. He has also worked as an aid advisor in the Pacific Islands and has provided consultancy services in Malaysia, Kyrgyzstan, and Malawi.

NATIONAL TRACER SURVEY UPDATE

National tracer survey worksream

A further report has been completed utilizing the age tracer and isotope data for detailed understanding of a volcanic groundwater system. The report describes the Pukekohe-Bombay basalt aquifers, including conceptual groundwater flow, connection with surface water, nitrate pathways, potential risk of nitrate contamination of deeper aquifers, future nitrate loads to come, and connections within the aquifer system (Figure 4). Deeper groundwater recharge and flow in areas outside of basalt lavas is negligible, with the water being stagnant. Major water drainage through large groundwater systems occurs only through the basalt lavas (red arrows), with flow rates indicated by blue arrows (blue numbers indicate flow rates in m/y, length of arrow proportional to flow rate). Dashed red lines indicate approximate catchment boundaries. Black arrows indicate baseflow water contribution to streams from sources other than basalt lavas. Numbers superimposed on streams are measured baseflow rates in L/s.

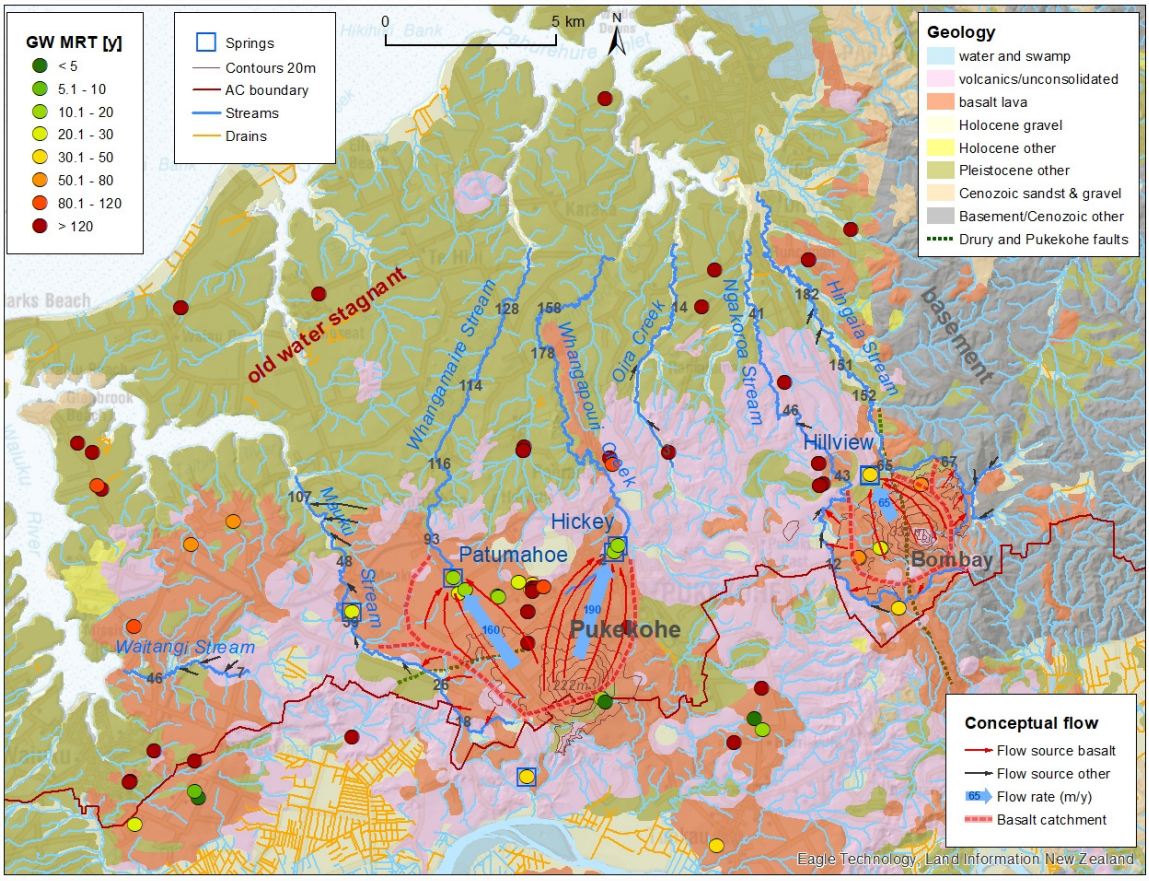

Figure 4: Groundwater dynamics and conceptual flow in the Pukekohe–Bombay area inferred from groundwater ages (MRT, circles) in conjunction with stable isotope and nitrate data (not shown).

North Island sampling has predominantly been completed - with Taranaki sampled in May, and Horizons planned for later in 2023. Sampling in the South Island has been completed in Otago. However, a 'no-work order' for road sides has been issued to Environment Canterbury, which has delayed the sampling programme. Sampling in the Canterbury, Southland, and Marlborough regions is yet to be completed.

CONFERENCE AND PUBLICATIONS

Catherine Moore and Brioch Hemmings attended the PEST conference in La Jolla, San Diego, USA, from 6 - 10 March 2023. The conference was hosted by INTERA and focused on how model-based processing of environmental data can better serve decision-making. A workshop for users was also held on March 11, 2023. The conference included all forms of environmental simulation models, and provided a forum to discuss how the latest advances in data assimilation, optimization, and uncertainty analysis can advance all disciplines - including groundwater. The conference included individual, panel and poster presentations, as well as opportunities for networking with colleagues. Both attendees presented and led workshops and discussions.

The following papers have been published or are online for review:

- Kitlasten, W., Moore, C.R., Hemmings, B., 2022. Model structure and ensemble size: Implications for predictions of groundwater age. *Frontiers of Earth Science*, Section: Hydrosphere, Volume 10 - 2022, https://doi.org/10.3389/feart.2022.972305.

- Moore, C., Scott, D., Burberry, L., Close, M., 2022. Using sequential conditioning to explore uncertainties in geostatistical characterization and in groundwater transport predictions. Frontiers in Earth Science. Section: Hydrosphere, Volume 10 - 2022. https://doi.org/10.3389/feart.2022.979823.

- Tschritter, C., Daughney, C. J., Karalliyadda, S., Hemmings, B., Morgenstern, U., Moore, C., 2022 (in review). Estimation of groundwater age distributions from hydrochemistry: Comparison of two metamodelling algorithms in the Heretaunga Plains aquifer system, New Zealand, Hydrological Earth Systems Science Discussions. [preprint], https://doi.org/10.5194/hess-2022-258.

- Robson-Williams M., Harcourt N.R. Mercier O.R., 2022. Achieving societal collaboration and impact in Aotearoa-New Zealand through transdisciplinarity. GAIA Ecological Perspectives for Science Publications and Society.

In addition, the following report has been prepared:

- Morgenstern U, Moreau M, Coble MA, Johnson K, Townsend DB. 2023. Groundwater and surface water conceptual flow from environmental tracer signatures in the Pukekohe and Bombay area. Lower Hutt (NZ): GNS Science. 97 p. (GNS Science report; 2022/63). doi:10.21420/VNBF-3X96.

MAIMAI CATCHMENT: FIELD DAY

The Maimai Field Day was held from Febuary 19-20, 2023 and co-hosted by Jeffrey McDonnell (University of Saskatchewan) and Uwe Morgenstern (GNS Science). The Maimai Catchment includes a set of small headwater catchments near Reefton. Over the past 40 years of Maimai catchment studies, national and international researchers have increased our fundamental understanding of forest flows, hillslope geomorphology, and streamflow generation processes.

The aim of the field day was to stimulate interest and continued research in the catchment. The field day included 34 participants from CRI's, DoC and universities. The event included an introduction to the Maimai Catchment and its role in knowledge creation in catchment hydrology. The field site visit topics included:

- early native forest research by the Forest Research Institute on canopy interception, forest harvesting experimental findings for water and sediment,
- early hillslope hydrology and geomorphology research revealing the importance of macropore flow, subsequent isotope tracing research that showed the importance of stored water and its link to channel stormflow and debris flow initiation,
- sequencing of different landscape units through storm events, scaling relations for water and water quality, catchment complexity and groundwater age
- a steep slope section tour of a new forest water use, isotope tracing experiment that will continue through 2023.

Following the large interest in this event, the group are discussing the potential to designate Maimai as a Research Reserve. There is interest from DoC and across the research institutes to improve our understanding of catchment functioning and predicting their response to climate change. The legacy of the Maimai catchment research, together with the collaborative interest across the CRIs and Universities, will provide momentum for future research proposals. Jeff is compiling a repository of the Maimai Catchment, including the history of hydrology wiki site.

Maimai Catchment.

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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*