Oral Abstracts

A-M

ASSESSMENT OF SHALLOW GROUNDWATER CONDITIONS USING DATA-DRIVEN MODELLING

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Shallow groundwater is a key issue for New Zealand's built environment, particularly as climate-induced changes to hydrological systems emerge. Understanding the occurrence of groundwater close to the land surface is important in the design and performance of critical infrastructure, including three-waters networks, as well as for assessing the impacts of natural hazards, including liquefaction risks and surface flooding.

Regional-scale mapping of shallow groundwater (i.e., within 10 m of the land surface) can help infrastructure managers to understand potential risks and prioritise maintenance and renewal activities. However, modelling shallow groundwater numerically at this scale is difficult due to data and computational requirements, as well as complex saturated and vadose zone processes that can affect shallow groundwater elevation.

We have adopted a data-driven approach to modelling shallow groundwater using the geostatistical method Regression-Kriging, that considers relationships between datasets with sparse (i.e., groundwater levels) and dense (i.e., elevation, geology) spatial coverage. A shallow groundwater surface on regional level was created using this approach, which has achieved better fits to the groundwater observations than the National water table model.

As well as median shallow groundwater conditions, elevated groundwater conditions can place acute pressures on infrastructure. Therefore, we have also modelled a 'flashiness' depth, representing short-term fluctuations in water levels in response to storm events. Flashiness is expected to vary spatially and be dependent on hydrogeological units, local recharge mechanisms (e.g., stormwater soakage) and broader hydrological drivers (e.g., surface water features).

Median shallow groundwater and flashiness surface methods have been implemented in a scripted workflow. This provides a significant advantage to infrastructure managers as the method can incorporate additional data as it becomes available. This flexibility makes our approach highly valuable and also provides potential for its use in communities across Aotearoa at risk from rising shallow groundwater.

OzCZO – THE AUSTRALIAN CRITICAL ZONE NETWORK: QUANTIFYING IMPACTS OF CLIMATE CHANGE FROM BEDROCK TO CANOPY

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Australia, the driest inhabited continent, has no shortage of water issues. It also has some of the oldest and most intensively weathered and nutrient-deficient land surfaces on Earth. As a consequence, the soils and regolith are most often deep (much deeper than 1 m) and large stores of carbon are contained therein. We have little understanding of the dynamics and quantity and characteristics of this carbon. With climatic change and a near future that is expected to be dominated by progressively warmer temperatures, increasing water deficits, increased aridity, soil salinisation and ecological change, we need to predict and quantify impacts on ecosystems (and agricultural production), and on hydrological and biogeochemical cycles and lithospheric and atmospheric processes (e.g., water resources, feedbacks from soil, vadose zones and aquifers on carbon and other greenhouse gas exchanges).

To address these knowledge gaps, we need comprehensive and continual observational data from bedrock to vegetation canopy and near-surface atmosphere from diverse environments across the continent. To this end we are establishing the foundations of the Australian Critical Zone Observatory network, OzCZO, which initially will consist of five CZOs (Critical Zone Observatories) covering four Australian states. The CZO are designed for advanced studies of hydrology and biogeochemical processes and elemental/isotope fluxes within near-surface reservoirs, including soils, water and vegetation. In this talk we will present the capabilities of these state-of-the-art observatories, some specific characteristics (geological/ hydrological/ climatic/ ecological) of each site, and some examples of early data collected. Finally, we will outline research questions that could be answered collaboratively using the OzCZO network.

A 3D NUMERICAL DENSITY-DEPENDENT FEFLOW MODEL TO QUANTIFY ROTTNEST ISLAND FRESHWATER LENS RESPONSE TO RECHARGE

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Most oceanic islands rely on limited freshwater sources stored within a thin groundwater lens positioned on top of denser saline groundwater. The size of the fresh groundwater lens is partly a function of rainfall recharge, which is the sole source of freshwater to replenish most island lenses. Field measurement has shown that the groundwater lens of Rottnest Island, Western Australia, has been reduced by 40 percent since the late 1970s.

To better quantify this reduction and estimate how the lens responds to recharge variability, we developed a 3D density-dependent groundwater model using FEFLOW. The model domain was extended to 70 meters below mean sea-level to cover the depth of the Tamala limestone, and distributed over 26 vertical layers with the higher vertical resolution to account for the accurate calculation of the saltwater-freshwater interface. Transient calibration was done by matching against historical groundwater levels and salinity data, collected from more than 30 production and monitoring boreholes on the island. To further constrain our calibration, we compared the travel time for our groundwater model against those estimated from age models based on isotopic data presented in previous studies. We then used FePEST to determine the uncertainty associated with parameters.

The response of the lens to variability in groundwater recharge was then investigated by applying the estimated recharge from a water balance model for the historical period of 1911-2019. The modelling results show a considerable lens reduction over the past few decades compared to the simulated size of the lens based on recharge estimates from before 1970s. We finally demonstrate the potential of our groundwater model to explore the lens response to recharge variability on longer timescales by introducing paleo-recharge to our model, estimated from paleoclimate proxies.

Keywords: Seawater intrusion, uncertainty analysis, lens reduction, groundwater recharge, paleo recharge

INFILTRATION AND GROUNDWATER RECHARGE: A MISSING LINK TO HYDROLOGICAL CHARACTERISATION OF THE SNOWY MOUNTAINS, AUSTRALIA?

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Alpine catchments are recognised zones of high groundwater recharge potential. Baseflow from regolith-hosted aquifers forms an important source of water for ecologically sensitive alpine bogs, and for alpine headwater-streams, sustaining perenniality of the river networks downstream. Research in the Snowy Mountains has previously focused on snowpack characterisation and catchment streamflow modelling, based on historic patterns and conditions, to understand hydrological behaviour. Limited experimental work has been conducted at a finer hillslope-landform scale. In these systems, the controls on recharge to regolith-hosted aquifers via the vadose zone and in the upper saprolite warrant further study.

Recent hydrogeological measurements show that the alpine-humus-soils (AHS) capture water (ϕ = 0.50-0.76; K = 3 $x10^{-4}$ to 1 $x10^{-5}$ $m.s^{-1}$) and introduce it to the regolith profiles at rates that allows water to pass vertically through underlying less permeable layer/s (ϕ = 0.40-0.43; K = 3 $x10^{-4}$ to 1 $x10^{-7}$ $m.s^{-1}$, for underlying periglacial/colluvial gravels) and into the unconfined regolith-hosted aquifer. This study documents the spatial variability of infiltration parameters for regolith materials in alpine meadow and woodland hillslope settings, at the Australian Mountain Research Facility 'Aqueduct' site, to better quantify this process. Infiltration, both saturated/unsaturated has been measured under a range of soil moisture conditions to inform conceptual hydrologic models that enable the evaluation of climate-change impact on the alpine regolith-hosted aquifers.

Climate change predictions for mountainous regions indicate significant temperature increases and changes in precipitation patterns (longer inter-event intervals; more short-duration, high-intensity events). There is concern that climate-related changes to precipitation characteristics and desiccation and erosion of the AHS may impede groundwater recharge and activate fast-response flow pathways at the land surface. With the potential to result in a hydrological system characterised by a higher flash-flood index and reduced year-round yield to supply threatened bog and fen ecosystems and alpine headwater inflows.

CHALLENGES AND OPPORTUNTIES AT LEGACY URANIUM MINE AND MILL SITES IN THE WESTERN UNITED STATES

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The Grants Uranium Mineral Belt is a region in New Mexico that is known for its significant uranium deposits. The deposits are located in the northwestern part of the state and cover an area approximately 100 miles long and 25 miles wide. The uranium deposits were formed during the Jurassic period, around 100 million years ago, when the area was covered by a shallow sea. The ore is concentrated in saturated sandstone formations where dissolved uranium precipitated in areas rich in organic matter and formed an extensive uranium ore deposit. There is renewed interest in uranium mining to support an anticipated growth in potential nuclear power projects buoyed by goals to reach net zero in carbon emissions no later than 2050. States like New Mexico stand to gain economically from an increase in uranium mining. Modern mining practices, strict environmental regulations, and increased demand for responsibly sourced supply chains suggest uranium can be recovered with minimal impacts to humans and the environment. However, the legacy of uranium mining and milling dating back to the 1950s is a negative undercurrent to this opportunity. Transitioning back to developing this uranium resource will be met with challenges resulting from a legacy of impacts to soil and groundwater that are currently being addressed but will take many more years to resolve. Progress towards closure is being made at several of these sites because of improved site characterization techniques, state of the art geochemical and predictive modeling evaluations, and regular collaboration with key decision makers. Resolving the uranium legacy will be a critical step in realizing the economic opportunities related to a potential “nuclear power renaissance” in the Grants Uranium Mineral Belt.

INTO THE GROUNDWATER WONDERLAND: UNDERSTANDING FREE-LIVING PROTOZOA DIVERSITY IN CANTERBURY GROUNDWATER

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Free-living protozoa (FLP) are common in both natural and engineered freshwater ecosystems. They play important roles in biofilm control and contaminant removal through predation of bacteria and other species (Finlay and Esteban, 1998). Bacterial predation by FLP is also thought to contribute to pathogen dispersal and infectious disease transmission in freshwater environments via egestion of viable bacteria. Despite their importance in shaping freshwater microbial communities, the diversity and function of FLP in many freshwater ecosystems are poorly understood.

In this study, we isolated and characterized FLP from two groundwater sites in Christchurch, Canterbury using microbiological, microscopic, molecular, and metagenomic sequencing techniques. Different methods for groundwater FLP isolation and enrichment were trialled and optimised. The ability of these isolated FLP to predate on human pathogens *Legionella pneumophila* and *Campylobacter jejuni* was assessed. Those FLP predating on *E. coli* and pathogenic bacteria were identified by targeted amplicon sequencing of the 18S rRNA gene on an Oxford Nanopore platform and standard bioinformatic analyses.

Our study showed that *Acanthamoeba* spp. (including *A. Polyphaga*) and *Hartmannella veriformis* were the main FLP species present in both groundwater sites examined. These two species are reported to be the principal replication-permissive hosts for *L. pneumophila* in the environment (Boamah *et al.* 2017) and they were both able to feed upon *L. pneumophila* and *C. jejuni* in our assays. Other FLP isolated from the Canterbury groundwater sites were identified as species of *Rhogostoma*, *Paravahlkamfia*, and *Naegleria*. *Rhogostoma* consumed both *L. pneumophila* and *C. jejuni* in our assays, whereas *Paravahlkamfia* and *Naegleria* only fed upon on *L. pneumophila.* According to the literature, *Rhogostoma spp.,* are the dominant protist colonizers of wastewater treatment plants and function as a host for *Legionellae* in these environments (Pohl *et al.* 2021). Similarly, *Paravahlkamfia*, and *Naegleria* also serve as environmental hosts for *Legionellae* (Boamah *et al.* 2017). These observations confirm that the groundwater FLP species isolated from Canterbury groundwater sites could potentially act as reservoirs for *L. pneumophila.*

As groundwater is a main source of the drinking water supply in Canterbury, these FLP could be introduced into the local drinking water infrastructure such as plumbing systems and storage tanks, where they may promote the survival, multiplication, and dissemination of *Legionella*, resulting in an elevated risk of legionnaires' disease.

We have generated foundational knowledge on FLP diversity in Canterbury groundwaters and their predation behaviours. This research is enhancing our understanding of FLP potential for pathogen dispersal and/or removal in freshwater ecosystems. With future investigations, these findings can be useful to stakeholders in conducting risk assessments and establishing novel biologically mediated pathogen removal processes for water treatment.

References

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RIVERLINK GROUNDWATER CHALLENGES

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RiverLink is a collaborative project that aims to improve flood protection within the Te Awa Kairangi/Hutt River floodplain between Kennedy Good and Ewen bridges; transport resilience, accessibility, efficiency and safety issues at the Melling intersection on State Highway 2 (SH2); and urban renewal and regeneration of Lower Hutt's city centre.

Riverbed reprofiling that includes excavation and fill in the upper and lower berms are to occur between Kennedy Good and Ewen Bridges. The groundwater – river interaction is complex and the Taita aquifer within the Project area may be recharged by the Hutt River during high river water levels. The main factors that influence the river/groundwater flow exchange are the river stage, the groundwater level in the unconfined Taita aquifer and the groundwater abstraction in the confined Waiwhetu aquifer.

Steady state two-dimensional groundwater modelling has been undertaken to quantify the increase in discharge rate and the groundwater drawdown extent during low flows from the deepened riverbed. Modelling results indicate that the proposed riverbed reprofiling is expected to result in a small reduction in the volume of groundwater exchanged between the Waiwhetu and the Taita aquifers.

To mitigate the uncertainty associated with limited available information of hydrogeological data especially near the upper reach of the project area a stochastic uncertainty approach was employed to further investigate the potential effects (bore yield reduction) of the proposed river works for the Riverlink Project to the Waterloo borefield. Model parameters affected by the river works (e.g. riverbed thickness, riverbed conductance and river stage) were considered as random variables and the potential effects to the regional flow regime and groundwater levels were assessed with an uncertainty framework. Modelling results utilising the modified 3D groundwater model are in general agreement with results estimated with the 2D modelling and assessment of effects undertaken for the project works.

CRC'S BORE INSTALLER PROGRAMME: REFELECTIONS OVER THE LAST EIGHT YEARS

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Environment Canterbury's Bore Installer Programme is now into its eighth year of operation with over 3500 wells installed since its commencement in 2015. This unique program allows its 12 certified members to drill and install wells under permitted activity rules, without the need for a resource consent. The program has resulted in a significant reduction of consents being processed by Environment Canterbury, while facilitating the collection of well-related information that is critical to effective water management.

A driller's planning toolbox including Canterbury Maps viewer allows members to undertake a series of checks to ensure the well they propose to install meets all rules within our Land and Water Regional Plan. An online portal allows members to enter detailed borehole information. Compliance with the New Zealand drilling standard is achieved through upload of wellhead photos.

Auditing of wells is currently performed manually by Groundwater scientists on a subset of wells or when problems arise. Tools for automated auditing and reporting have been developed this year using python scripting and GIS. This means every well can now be subjected to auditing in a timely manner. Our recent audits (2023) showed all our members are performing well, with just a small number of wells (around 15%) requiring further details, or better alignment with the programme's requirements.

The programme's success can largely be attributed to the relationships we have built with our members over the last eight years. Each member has a point of contact within the Groundwater Section, and we regularly offer feedback sessions via face-to-face and online meetings. Operational challenges we continue to face include providing evidence of landowner approval, ensuring borehole data is submitted within 20 working days of completion, and submission of wellhead photos.

2022 NATIONAL SURVEY OF PESTICIDES, PFAS AND EOCS IN GROUNDWATER

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Aims

In 2022 ESR co-ordinated a survey of pesticides in groundwater throughout New Zealand, which was the ninth such survey since the 4-yearly surveys commenced in 1990. Per- and polyfluoralkylsubstances (PFAS) and Emerging Organic Contaminants (EOCs) were included in the suite of compounds analysed. The aims of the survey were to update the national overview of pesticides in NZ groundwater systems and to investigate temporal variation in pesticides between surveys; to carry out the second national assessment of EOCs in groundwater, and to carry out the first national assessment of a suite of PFAS in NZ groundwater.

Method

Groundwater sampling for the 2002 survey was undertaken by Regional and Unitary Authorities mostly between September and December 2022. Wells were selected based on several factors including the importance of an aquifer to a region, the known application and storage of pesticides in the area, and the perceived vulnerability of the aquifer to pesticide contamination. Where possible, wells sampled in previous surveys were included in the 2022 survey to give a temporal comparison. Most of the sampled wells are screened in unconfined aquifers and were selected because shallower unconfined aquifers are at greater risk of contamination than confined, deeper aquifers.

While all fifteen of the Regional and Unitary Authorities with groundwater management responsibilities participated in the 2022 survey (for pesticide sampling), only eleven undertook sampling for PFAS. A total of 184 wells were sampled and analysed for the pesticide suites, including 21 wells sampled as part of Waikato Regional Council's regional surveys between January 2020 and June 2022. Samples were analysed for acidic herbicides and a suite of organochlorine, organophosphorus and organonitrogen pesticides by Hill Laboratories. A total of 118 wells were sampled for EOCs and we are currently awaiting analysis results from Northcott Research Consultants Ltd. A total of 131 wells were selected and sampled for a suite of PFAS, which were analysed by Asure Quality.

Results

Pesticides were detected in 17 wells (9.2%), with 6 (3.3%) of these wells having two or more pesticides detected. The maximum number of pesticides detected in one well was six. Pesticides were not detected in wells from Auckland Council (8 wells), Bay of Plenty Regional Council (10 wells), Hawkes Bay Regional Council (12 wells), and Greater Wellington Regional Council (8 wells). Sixteen different pesticides were detected in the sampled wells, with herbicides being the most frequently detected pesticide group with 19 detections (66%) of 12 different herbicides and their metabolites. The most commonly detected pesticide was terbuthylazine (detected in 6 wells), followed by desethyl terbuthylazine (DET) (detected in 4 wells). Only one pesticide detection concentration exceeded 1 µg/L (clopyralid, 1.1 µg/L). There is no Maximum Acceptable Value (MAV) for drinking water available for clopyralid. Dieldrin was detected above the MAV for drinking water in one well, at a maximum concentration of 0.053 µg/L (i.e., 133% of the MAV of 0.04 µg/L (Taumata Arowai (2022)). Concentrations of other detected pesticides were less than 4% of their respective MAV.

There was a total of 41 detections of PFAS in 15 wells (11%) with PFAS detected, with 6 of these wells having two or more PFAS detected. The maximum number of PFAS detected in one well was eight. PFAS were not detected in sampled wells from Auckland Council (3 wells), Bay of Plenty Regional Council (2 wells), Tasman District Council (17 wells), Marlborough District Council (7 wells), Otago Regional Council (4 wells), and Environment Southland (15 wells). Overall, ten different PFAS were detected in the sampled wells. Perfluoroalkylcarboxylic acids (PFCAs) were the group of PFAS most frequently detected with 21 detections (51.2%) of 5 different PFCAs. Of these PFCAs, the most frequently detected compound was perfluoro-n-butanoic acid (PFBA), which was detected in 9 wells, then perfluoro-n-pentanoic acid (PFPeA), which was detected in 5 wells. This was followed by perfluoroalkylsulfonic acids (PFSAs) with 9 detections (22%) of 4 different PFSAs. A total of 4 detections (9.8%) of one group of fluorotelomer sulfonic acids (FTSAs) was detected in 4 wells. The maximum value for sum of perfluorohexanesulfonic acid (PFHxS) and perfluorooctanesulfonic acid (PFOS) (Sum PFHxS+PFOS) was 16.5 ng/L in a well from the Waikato region, followed by 9.5 ng/L in a well from the Canterbury region, with the remainder of wells being < 1.5 ng/L. All detected PFAS were below the available NZ human health-based MAV for drinking water.

Overall, data from the 2022 national groundwater survey indicates a decrease in the frequency and concentration of pesticide residues detected in groundwater relative to previous surveys. In 2018 24% of wells had pesticides detected but in the 2022 survey this had dropped to 9%. Analysis of wells sampled in 2022 that had been sampled in multiple previous surveys indicate that there were 2 wells with significant ($p<0.05$) decreases over time and a further well with a decrease at the $p<0.1$ level. 26 of the 56 wells that had been sampled in 2022, and had also been sampled in 4 or more previous surveys, had no pesticides detected on any occasion. As these surveys have been focused on shallow unconfined groundwater systems, which are most at risk of pesticide contamination, this indicates that most groundwater in New Zealand should be considered safe to drink with respect to pesticides.

At the time of abstract submission, we were still waiting for the results of the EOC analysis but we will present those results at the conference.

References

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GROUNDWATER MODELLING TO SUPPORT FRESHWATER ALLOCATION IN A GEOTHERMAL-RICH CATCHMENT, ROTORUA WATER MANAGEMENT AREA

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This abstract presents the groundwater modelling undertaken by Jacobs to support the setting of fresh groundwater allocation limits for the Rotorua Water Management Area (Rotorua WMA), which also includes six geothermal fields.

Bay of Plenty Regional Council (BoPRC) is responsible for the allocation of fresh groundwater resources in the Rotorua WMA and were interested in an approach that distinguishes and quantifies the available freshwater resources separately from the geothermal water. Some of the geothermal fields, notably the Rotorua Geothermal Field (RGF) were heavily exploited in the 1980s for geothermal water leading to failure of some of the geysers and hot springs. This led to restrictions on geothermal water abstraction in the late 1980s which has resulted in a recovery of geothermal fluid pressure. The approach required for this assessment had to consider the historical and future trends in geothermal fluid pressure within the geothermal fields.

Modelling fluid flow in geothermal fields is complex because of the presence of two-phase fluids and because water density and viscosity are both dependent on temperature. Since the application of conventional geothermal simulation codes such as TOUGH2 was considered unsuitable for a regional scale numerical groundwater flow model, a number of simplifying assumptions for representing the geothermal fields in the 3D MODFLOW-USG groundwater flow model were adopted. A consequence of applying the simplifying assumptions was the difficulties that arose during model calibration for areas within and immediately surrounding the RGF. The difficulties were overcome by assigning constant head boundary conditions to represent the RGF in the groundwater model. The constant head boundary conditions were assigned based on an analysis of historical data on groundwater head variation with elevation in the RGF.

The groundwater model was used to assess the potential reduction in net groundwater inflows to Lake Rotorua and groundwater inflows selected stream segments.

PROBABLE MAXIMUM PRECIPITATION IN NEW ZEALAND

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Methods for estimating Possible Maximum Precipitation (PMP) in New Zealand are currently being updated by Bodeker Scientific, Riley Consultants, Headwaters Hydrology and NIWA. This talk will give an overview of the existing methods used to estimate PMP in New Zealand, summarise key reasons why an update has been instigated by the Dam Safety Hydrology Group, and conclude with the initial trajectory and findings from the update which is currently in progress.

Research into PMP, defined by the World Meteorological Organisation as the “theoretical maximum precipitation for a given duration under modern meteorological conditions”, has not been undertaken in New Zealand in earnest since the early 1990s (Thompson and Tomlinson, 1992, 1993, 1995; Campbell et al. 1994). In this period, two generalised methodologies were developed by the New Zealand Meteorological Service, with funding from the then Electricity Corporation of New Zealand and Auckland Regional Council.

For the last 35 years, estimates of PMP made using the existing methods have been used by practitioners to estimate Probable Maximum Floods, which are the design standard for some critical infrastructure (typically for High Potential Impact dams), and as an upper limit to depth-duration-frequency relationships for precipitation. However, since the existing methodologies were developed, the science underpinning PMP calculations has developed (internationally), there is an additional 35 years of storm records, storms have been observed which will increase PMP estimates in specific regions, and practitioners have a need to include the projected effects of climate change in PMP calculations.

UTILIZING MACHINE LEARNING MODELS FOR ONE-STEP AND MULTI-STEPS PREDICTION OF GROUNDWATER LEVELS

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Understanding and predicting the fluctuation of groundwater levels is important for effective management of water resources with changing environmental drivers and multiple water users including irrigation, mining, and environmental flows. Data-driven models in machine learning, presents potential possibilities to enhance our ability to manage these valuable water resources effectively whilst addressing the uncertain nature of groundwater systems. Data-driven models offer promising advantages for groundwater level prediction due to their capacity to capture non-linear and complex patterns that are often present in groundwater data. These models allow for the incorporation of various features, including lagged values, meteorological data, and the possibility of including hydrological parameters, enabling the integration of domain knowledge to improve predictions.
Despite recent research in groundwater models using machine learning, more studies are required to evaluate the applicability of various algorithms to predict groundwater table fluctuations, particularly for long term forecasting (up to 12 months ahead). For this study, the monthly average groundwater level data of two observation wells for a period of more than 20 years, located in the south-west of Victoria, Australia, were collected, and the potentiality of four less explored models was analysed for 1 month to 12 months ahead prediction. The latest results of this research will be presented evaluating the ability of machine learning approaches for short- and long-term predictions. An overview of the versatility and limitations of these model for groundwater level prediction will be discussed.

HUNUA WATER SUPPLY CATCHMENTS 2023 FLOOD FLOWS

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In February 2023, during the passage of Cyclone Gabrielle, the Wairoa River flow gauge at Tourist Road recorded the greatest flow in over 40 years of monitoring. Following this event and the flooding experienced in the catchment, Watercare reviewed the role of the Hunua Range water supply reservoirs in mitigating high flows from the catchments. The four water supply reservoirs are on-stream storage: Cosseys and Wairoa flow to the Wairoa River; and Upper Mangatawhiri And Mangatangi flow to tributary streams of the Waikato River.

The ten highest recorded flows were identified, and together with records of spillway flows, reservoir abstractions and changes in reservoir storage, the inflow hydrographs to the reservoirs were determined. This enabled comparison of peak flows into the reservoir, and peak discharges over the spillways to the receiving watercourses. These peak discharges were compared to frequency of discharges expected for the catchments, both with and without the dams.

This information has provided detailed analysis that can be compared to previous historical assessments, and to inform public perception. This work aims to improve community understanding of the operation of water supply dams which have different operational regimes to hydroelectric generation dams. This work also provides insight into the impacts on the natural flood hazard, and the downstream asset management with regard to flood risk.

ON THE ORIGIN OF GROUNDWATER AT THE WAIPUNAMU EROSION SURFACE IN SOUTH CANTERBURY

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Ground investigations into Cenozoic formations overlying the Waipounamu Erosion Surface (WES) in South Canterbury, have identified mineralised groundwater, of potentially ancient origin. The groundwater is hosted in the Broken River Formation (BR Fm), which is a fluvial-deltaic quartzose sandstone, and carbonaceous mudstone with local conglomerate and lensoidal coal seams.

The BR Fm groundwater is highly ionised with major ion composition Calcium-Sulphate dominated, distinct to the Calcium-Carbonate signature typically found in land-surface recharged groundwater locally. Sulphate concentrations were measured as high as 1,000ppm in the Broken River Fm, usually indicative of highly contaminated water. Here it appears to be naturally occurring, and may be indicative of weathering of jarosite in coal seams within the Broken River Fm. Chemically similar groundwater has been observed 60km south of site in the Taratu Fm (equivalent to the BR Fm), and another bore screened in the Taratu Fm, although with different geochemistry, has been dated with mean residence time of 43,000 years.

At this site, the ionised groundwater comes to surface via seeps and springs and forms a wetland. The mechanism of the upward flow is unknown and may be due to any of the following:

- The adjacent Rakaia Semischist mountain range provides 200m head of rainfall recharged groundwater, although there is ~20m of clayey completely weathered semischist at the WES which limits flow across the unconformity
- The BR Fm is fault bounded (below ground) approx. 300m east of the wetland, preventing significant flows in that direction.
- Down valley is gorged, reducing groundwater flow down valley.
- The adjacent fault has been demonstrated to have low permeability at surface, but may form a preferential pathway for groundwater from depth, or may drain the Rakaia semischist.

Biography:

Leeza is a hydrogeologist with over 7 years experience based in Christchurch. Leeza works for the engineering consultancy Beca Ltd, across a variety of infastructure, water and waste projects, and enjoys skiing and getting outdoors in her free time.

A MODEL ENSEMBLE APPROACH FOR ASSESSING THE FUTURE OF WELLINGTON'S GROUNDWATER SUPPLY

Jeremy Bennett,[1] Mark Gyopari,[2,] Cath Moore[3]
[1] Tonkin & Taylor Ltd.
[2] Earth in Mind Ltd.
[3] GNS Science

The Waiwhetū Aquifer beneath Lower Hutt is a critical water source for the Wellington metropolitan area, providing up to 70% of the Capital's water demand during summer months. Groundwater is abstracted from the aquifer at two locations: the Waterloo Wellfield in the central Lower Hutt valley area, and the Gear Island Wellfield close to the Petone Foreshore. In response to projected increases in water demand and aging well infrastructure, Wellington Water is undertaking taking a wellfield replacement programme to ensure a safe and resilient water supply for the region.
The Hutt Aquifer Model (HAM5) has been developed to support a science-based approach to the wellfield replacement strategy and comprises a three-dimensional numerical groundwater flow model that has been history-matched to extensive groundwater level observations and concurrent river gauging data. A sequential history-matching approach has been undertaken, firstly with the development of a minimum error variance (i.e., 'calibrated') model using PEST_HP. This forms the basis of model ensemble analysis using Iterative Ensemble Smoother methods that are available in the PEST++ suite.
Using predictive scenarios, the HAM5 model ensemble will support decisions regarding the wellfield replacement strategy. The scenarios have been developed for specific predictions of interest, including the influence of sea level rise on the coastal aquifer system (and risk of saline intrusion); changes in stream depletion due to potential increased groundwater abstraction; and the ability of different well configurations (and abstraction regimes) to provide sufficient aquifer yield with respect to these environmental constraints. A search grid representing potential well locations has been used as a framework for the predictive scenarios and the analysis uses PEST tools for parameter uncertainty as well as implementation of changing boundary conditions, including hydrological alteration due to climate change and flood protection schemes.

Presenter nio
Jeremy is a senior groundwater scientist at Tonkin & Taylor Ltd, based in Auckland. He specialises in conceptual and quantitative modelling of groundwater flow and contaminant transport as well as environmental data analysis. Originally from Wellington, Jeremy has over 14 years of professional experience as a consultant and researcher in New Zealand, Australia and Germany. He holds an MSc and Doctorate in Hydrogeology from the University of Tübingen, Germany, and his research has been published in international scientific journals.

STRATEGIES FOR WATER ALLOCATION; HOW CAN WE SET LIMITS TO ACHIEVE ENVIRONMENTAL OUTCOMES?

Booker, D.J.,[1] **Rajanayaka, C.,**[1] **Smith, R.G.**[1]
[1] NIWA, Christchurch

There is high demand for water abstraction from rivers and aquifers for agricultural, industrial, and municipal purposes in many locations in Aotearoa-New Zealand. Abstracting water from rivers and aquifers has the potential to augment water supply. However, water abstraction can have adverse impacts, such as impinging supply elsewhere and increasing risks to in-stream values. The National Policy Statement for Freshwater Management (NPS-FM) requires local authorities to support the achievement of environmental outcomes by setting rules in regional plans that define limits to water resource use.

To meet the requirements of the NPS-FM, it is proposed that rules must be: a) practically implementable by ensuring that new water users can calculate water availability and existing water users can operate within consent conditions linked to the rules; b) environmentally sustainable by delivering environmental flow regimes required to achieve environmental outcomes; c) water efficient to ensure allocation does not exceed reasonable water demand; and d) spatially cognisant by recognising spatial inequalities in water use, water availability, and risks to in-stream values.

A multi-band system defining rules for controlling water takes is proposed and assessed against the above four principles. The system is designed to apply to takes that abstract and then store water temporarily for later use as well as takes that abstract and then use water immediately. Each water take is assigned to one of several predefined bands positioned across the naturalised flow duration curve. Each water take can only operate when observed flow is within or above its specified band. Simulated results demonstrate how the proposed system provides fine control over hydrological alteration regardless of hydrological regime. The system is independent of governance arrangements and allows for flexibility when selecting environmental outcomes, technical methods, and level of acceptable environmental risk. However, there are technical, legal, social, and political barriers to implementation.

NUMERICAL ANALYSIS OF THE WATER TABLE RESPONSE TO SEA-LEVEL RISE

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[2] Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand

1. Aims

Coastal shallow groundwater is susceptible to negative impacts from climate change-induced sea-level rise (SLR). The mean sea level rose globally by 0.20 m over the last 140 years and impacted both the groundwater quality and levels. SLR is not a linear or gradual phenomenon and the rate of the rise is increasing from 1-2 mm per year historically to recently 3-4 mm per year. Coastal groundwater systems seek equilibrium with the ocean causing the groundwater levels to rise. The majority of investigations on the effects of SLR on coastal groundwater focused on water quality and salinization caused by saltwater intrusion. The shallow groundwater levels' response to SLR is not largely studied and could cause flooding and infrastructure issues. In this study, numerical analysis is used to quantify and predict upward movement of the water table and timescales of this process.

2. Methods

Numerical variable-density flow and transport modelling of SLR within an idealised cross-sectional unconfined coastal aquifer setting was carried out using SEAWAT. The rate of groundwater rise under both historical and predicted SLR scenarios was quantified for different inland boundary conditions and hydrogeological parameter combinations.

3. Results

The numerical analysis provides valuable insights into the relationship between the rate of SLR and the rate of water level rise. In general, for the realistic aquifer settings used in our simulations, we found that the rate of water table rise was closely related to the rate of SLR, although smaller. There was a lag of years to decades between changes in the rate of SLR and changes in the rate of water table rise. The rate of water table rise decreased with distance from the coast, and reached a maximum value faster for high hydraulic diffusivities.

LOW-TECH MONITORING AND TREATMENT OF NITRATE IN DRINKING WATER

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Drinking water supplied to remote Aboriginal communities is primarily sourced from groundwater, which commonly has solute concentrations that exceed drinking water guidelines at the point of withdrawal. While efforts are made to filter key elements of concern, equipment failures lead to breaches of drinking water guidelines that are not evident in real-time at the point of use. One common solute of concern is nitrate, which is naturally elevated in groundwater across parts of inland Australia, and can alternatively be artificially elevated by agricultural operations. The populations of remote communities are inherently mobile so that individuals will commonly be exposed to water from multiple drinking water sources. Low-tech and real-time methods of monitoring and filtering nitrate are needed to facillitate individuals and communities managing their potential health risks from nitrate exposure. To this end, we have tested two common, commercially available test-strips for screening nitrate concentrations in drinking water. We have also determined the impact of neglecting sample preservation recommendations on lab-based measurements of nitrate concentrations in drinking water that has already been treated (UV or chlorination) to reduce microbial activity. For cases where elevated nitrate concentrations are detected, we have established the efficacy of domestic-scale freeze desalination as a process for reducing nitrate concentrations. This suite of techniques provides the basis for the implementation of community-based monititoring and treatment of nitrate concentrations in drinking water in remote Aboriginal communities. These techniques would also be appropriate for citizen-science programs in regions with elevated nitrate concentrations in drinking water due to agricultural operations.

POVERTY BAY FLATS GROUNDWATER SYSTEM - NUMERICAL MODELLING CLIMATE CHANGE AND COMMUNITY-BASED RESOURCE MANAGEMENT SCENARIOS

Bower R[1], Sinclair B[1], Schätzl P[2]
[1]WGA
[2]AQUASOIL Ingenieure & Geologen

The Gisborne District Council (GDC) commissioned Wallbridge Gilbert Aztec (WGA) and AQUASOIL Ingenieure & Geologen GmbH (AQUASOIL) to develop a groundwater model for the Poverty Bay Flats/Tūranganui-a-Kiwa area. Input from Mana Whenua, including culturally sensitive areas, was incorporated throughout the model conceptualisation and scenario building. The process involved creating a 3D geological model using GeoModeller software based on bore lithological data. Subsequently, a finite element groundwater model was constructed using the FEFLOW modelling package, incorporating climatic, hydrological, hydrogeological, groundwater abstraction, and water quality data. The model used exploratory scenarios built upon a series of community questions about the Poverty Bay Flats aquifer system to guide potential groundwater management measures, considering the effects of climate change such as increasing water demands, changes in natural recharge, and prolonged drought conditions. The model addressed issues like declining groundwater levels, saline intrusion, and sea level rise, as they were major community concerns identified through a series of community engagement workshops. This oral presentation will offer an overview of the modelling process, including the approach to engagement with Mana Whenua and the wider Gisborne community.

DEVELOPING A COMMUNITY MANAGED AQUIFER RECHARGE (MAR) TRIAL SITE IN THE RUATANIWHA BASIN

Bower R[1], Sinclair B[1], Houlbrooke C[1], Howell C[1]
[1]WGA

In 2018, Hawke's Bay Regional Council's (HBRC) engaged WGA to develop a Managed Aquifer Recharge (MAR) trial programme for the Ruataniwha basin, Central Hawke's Bay. The process involved various technical stages, such as catchment-scale recharge suitability mapping, infiltration testing, and baseline surface and groundwater monitoring. Special attention was given to incorporating the perspectives of mana whenua in the site conceptualisation and developing a scientific and cultural monitoring programme. The trial aims to demonstrate the effectiveness of MAR to increase and maintain groundwater storage while restoring and enhancing baseflows to spring-fed streams, wetlands, and rivers. The trial site focuses on two MAR methods: surface infiltration into a shallow unconfined aquifer , and the targeted recharge using a bore into the deeper, confined Salisbury aquifer. The latter will involve the construction of New Zealand's first Aquifer Storage and Recovery (ASR) well, showcasing the internationally recognised technique of enhancing winter water recharge in deep aquifers showing declining trends in groundwater levels. The shallow aquifer supports down-gradient surface waterbodies and is less utilised, while the deeper aquifer is essential for uses such as drinking water and irrigation. This presentation will provide an overview of the final CHB MAR Trial site, including engineered designs, baseline monitoring programme, and the 3-year testing programme following construction scheduled in Spring 2023.

GROUNDWATER AND WESTERN AUSTRALIA'S ENERGY TRANSFORMATION

Dr Ian Brandes de Roos,[1] Chelsea Bambrick,[1] Dr Wade Dodson[1]
[1] EMM Consulting

Australia has committed to achieving net zero emissions by at least 2050. The resultant transformation of our energy sector is putting an increased focus on Western Australia's mining sector, including lithium, nickel, and rare earths mining, together with a potential market for hydrogen – all of which require significant water resources for operations and ore-processing. What will this mean for Western Australia's groundwater resources? Is Western Australia facing a scenario of increased competition for groundwater resources?

This presentation outlines the current and future landscape for energy-transition water demand, whereby groundwater will continue to be Western Australia's primary focus for mine water supply. The emerging distribution of water demand is contrasted with the distribution of groundwater resources. This presentation provides some important conclusions with respect to groundwater challenges and opportunities. Increasingly contested groundwater resources will result in increased calls for water-transfer solutions. Ore-processing circuits designs will be challenged, with an increasing focus on water use efficiency. Brine-reject disposal will require careful management. The sustainability of Western Australia's groundwater resources will be a key factor in developing our energy sector.

WORKING WITH RIVER RECOVERY. WHAT IS POSSIBLE WHERE, OVER WHAT TIMEFRAME?

Gary Brierley[1]
[1]The University of Auckland I Waipapa Taumata Rau

It seems that we're forever being told that we, and our rivers, need to be more resilient. What does that mean (Brierley & Fryirs, 2024)? Does it imply that they should stay the same, continuing to be managed as they are, maintaining the status quo? Surely here in Aotearoa that's not good enough. We have every right to expect more, and so should our rivers – they too should have their own rights. In this talk I will present a 'more-than-human' perspective upon prospective river futures in Aotearoa in light of fluvial pluralism (Hikuroa et al., 2021). An aspirational lens will explore what is possible where, what is realistically achievable, through proactive rather than reactive programmes and policies (Brierley & Fryirs, 2022). In scoping the Voice of the River (Brierley, 2020) in moves to Let our Rivers Speak (Salmond et al., 2019), I will reflect upon parallels between contemporary western science and mātauranga Māori (Te Mana o Te Wai) in contemplating the Rights of the River (Brierley et al., 2019). I will situate a traffic lights scheme that considers 'what is possible where' in the management of the Strangled Rivers of Aotearoa (Brierley et al., 2023) in relation to prospects for rewilding, and the meanings thereof (Brierley et al., 2022). Science has a key role to play in these deliberations, but which science for whom? Perhaps river stories are part of the answer (Fuller et al., 2023).

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CHARACTERISING GROUNDWATER DEPENDENT ECOSYSTEMS OF THE UPPER DARLING FLOODPLAIN USING OPTICAL AND RADAR REMOTE SENSING

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[2] Commonwealth Scientific and Industrial Research Organisation
[3] New South Wales Department of Planning and Environment / Adjunct Fellow, Macquarie University

Groundwater is critical to the survival of a range of ecosystems in Australia through provision of a direct source of water to plants with suitable root systems, and through discharge into surface water systems. Effectively managing groundwater dependent ecosystems (GDEs) alongside other water demands requires the ability to identify, characterise, and monitor vegetation condition.

As part of the Exploring for the Future Upper Darling Floodplain (UDF) groundwater project in western New South Wales, we present results from a study testing the suitability of two novel methods (a) recently available tasselled cap percentile products with national coverage through Digital Earth Australia, and (b) dry-conditions interferometric radar (InSAR) coherence images for mapping vegetation that is potentially groundwater dependent.

A combination of greenness and wetness 10th percentile tasselled cap products delineated terrestrial and aquatic GDEs with greater accuracy than existing regional ecosystem mapping, demonstrating the utility of these products for GDE identification. These results suggest the tasselled cap products can be used to support and refine the existing GDE mapping for this region, and further testing of their suitability and application for other regions is warranted.

The InSAR coherence images produced good agreement with the Bureau of Meteorology national GDE Atlas for areas of high probability of groundwater dependence. Although data availability and technical expertise currently lags behind optical imagery products, if research continues to show good performance in mapping potential GDEs and other applications, InSAR could become an important line of evidence within multi-dataset investigations.

Key next steps for improving the utility of these techniques are (a) comparison with vegetation condition data, and (b) further assessment of the likelihood of groundwater dependence through assessing relationships between vegetation condition and groundwater, surface water, and soil moisture availability.

LINKING CSG INDUCED GROUNDWATER IMPACTS TO SUBSIDENCE – A JOURNEY IN THE SURAT BASIN

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The Office of Groundwater Impact Assessment (OGIA) is an independent office that assesses and develops strategies for managing the impacts on groundwater in Queensland from resource development including coal seam gas (CSG), conventional oil and gas, and mining.
OGIA commenced its journey back in 2010 at the height of concerns about the groundwater impacts of extensive and rapid development of CSG in the Surat and southern Bowen basins. Development of multiple CSG projects in close proximity, coupled with the fact that the CSG extraction required large-scale depressurisation of a formation of the Great Artesian Basin (GAB), magnified the challenges. The Queensland Government responded to those challenges by establishing a unique and experimental framework for the cumulative assessment and management of impacts, which has largely worked well for stakeholders, regulators and the industry in terms of the groundwater impacts. However, as the development is progressing, particularly around some prime agricultural areas, new challenges are emerging – most notably, CSG-induced subsidence.
The proposed presentation will lay out key drivers behind the framework, how it has been applied, lessons learned, and how OGIA is now moving to the next challenge of the assessment and management of subsidence in that context.

LOOKING PAST NITRATE - ASSESSING THE EFFICACY OF A WOODCHIP DENITRIFYING BIOREACTOR AT MICROBIAL REMOVAL

Lee Burbery,[1] **Phil Abraham**,[2] **Liping Pang**,[2] **Andrew Pearson**,[2] **Erin McGill**,[2] **Allanah Kenny**,[2] **Louise Weaver**,[2] **Judith Webber**, [2] **Sophie van Hamelsveld**,[2] **Theo Sarris**, [2] **Murray Close**[2]
[1] DairyNZ Ltd.
[2] Institute of Environmental Science and Research Ltd.

Aims

Woodchip denitrifying bioreactors are an emerging edge-of-field mitigation practice for reducing nitrogen loads in agricultural drainage water. They are also sometimes used as bioretention systems in stormwater management. There is growing evidence that in addition to nitrate, woodchip bioreactors can potentially attenuate other water contaminants of concern, such as suspended sediment, phosphorus and microbial pathogens (Choudhury et al., 2016; Huber, 2015; Rambags et al., 2016; Rivas et al., 2020). We are conducting a practical field trial that aims to evaluate the performance of a woodchip denitrifying bioreactor installed on a farm drain. In the past we reported that routine monthly water quality monitoring data collected from the trial tended to show the bioreactor has some affinity for *E. coli* with consistent 0.7 - 2.3 log reductions in *E. coli* concentrations measured between the inflow and outflow (Burbery and Abraham, 2022). To refine these estimates and directly examine the efficacy of the woodchip bioreactor at removing other microbial pathogens we conducted a microbial tracer experiment on the woodchip bioreactor. That work is presented here and reveals there is scope for woodchip bioreactors to be adapted to treat more than simply nitrate.

Methods

<u>Site setting and background</u>

The in-stream, woodchip denitrifying bioreactor is installed on an open artificial drain, on a dairy farm in the Barkers Creek catchment, South Canterbury. Built in 2020, the bioreactor measures 75 m long, 1.5 m high and contains 430 m^3 of *Pinus radiata* woodchip (Burbery and Abraham, 2022) (Figure 1). Operation of the bioreactor has been monitored since November 2021. The flow and water chemistry of drain water entering and exiting the bioreactor is measured continuously, using a TriOS OPUS optical nitrate sensor and In Situ Aqua TROLL® 600 multiparameter sonde. These automated measurements are complemented with monthly grab sampling at which time the water quality analytical suite is extended to include phosphorus, *E. coli*, campylobacter and other chemical determinands.

Figure 1: Photos showing various stages of the in-stream bioreactor construction. (left-right): drain clearance; laying of the EPDM rubber liner in which the bioreactor is sealed; filling the bioreactor with woodchip – concrete panel that acts as a dam end can be seen in foreground; bioreactor filled with 430 m^3 woodchip - ready to be sealed and plumbed (orange dot marks where inlet pipe was later fitted); completed bioreactor headworks – dammed drain water flows through the woodchip bioreactor under an ambient hydraulic gradient. Under storm flow conditions excess water spills over the top of the bioreactor. The white riser pipes protruding from the top of the bioreactor are monitoring wells that permit water sampling along the length of the bioreactor.

<u>Microbial Tracer Test</u>

In May 2023 we performed a microbial tracer experiment on the woodchip bioreactor. We prepared a mixed tracer solution comprising three different microbial tracers - *E. coli* J6-2 as a model bacterium, MS2 bacteriophage as a model virus, and protein-coated microspheres as a protozoan surrogate (Pang et al.,

2012) - and bromide as a conservative tracer. The tracer solution was introduced instantaneously into the head of the bioreactor and breakthrough curves of the tracers for their migration through the woodchip were generated at six sampling locations, including at the outlet.

Microbial removal rates for the various microbial tracers were assessed by comparing their tracer breakthrough curves against that of the bromide reference dataset, following the methods outlined in Pang (2009). Pathogen removal rates determined along discrete sections of the woodchip bioreactor were correlated against effective hydraulic conductivity, pH and redox parameters, to provide supporting evidence of likely removal mechanisms.

Results

For the purpose of this abstract we limit presentation of our results to the *E. coli* J6-2 and MS2 phage tracers, as were measured at the bioreactor outlet. Figure 2 shows the tracer breakthrough curves obtained at that location, for which we determined 100% recovery of the conservative bromide tracer. A log removal range estimate of 2.25 - 3.91 was determined for *E. coli* J6-2, and 1.17 – 2.67 for MS2 phage. The spatial removal rate estimates were thus 0.030 – 0.052 log_{10}/m for *E.coli* J6-2 and 0.016 – 0.036 log_{10}/m for MS2 phage. The results from analysis of the remaining five breakthrough datasets, as well as the protozoan surrogate results will be presented at the conference.

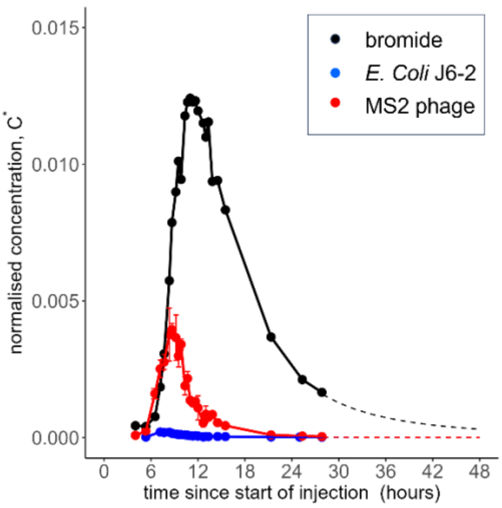

Figure 2: Tracer breakthrough curves as determined in the outflow from the 75 m-long bioreactor and from which microbial mass removal rates were evaluated. Concentrations were normalised relative to the injection concentration, as measured at head of the bioreactor ($C^* = C(t)/C_{inj}$). Dashed line denotes modelled concentration, as sampling was terminated before complete passage of the conservative bromide tracer.

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MECHANISMS OF GROUNDWATER RECHARGE AND SALINISATION IN THE GEORGINA BASIN EXPLORED THROUGH TRACERS AND ISOTOPES

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[1] Australasian Groundwater and Environmental Consultants

Groundwater samples from Cambrian and Ordovician fractured rock aquifers of the Georgina Basin (Queensland) were analysed for environmental isotopes and tracers, including oxygen-18, deuterium, carbon-13, carbon-14, strontium-87, tritium, and sulfur hexafluoride. The objective of the study was to support numerical flow modelling by underpinning the conceptual models of recharge and salinisation with a multidisciplinary investigation.

The carbon-13 and strontium-87 data indicate that carbonate weathering has occurred, and a result, the conventional radiocarbon ages were adjusted using models that assumed carbonate weathering. The modelled ages ranged from "modern" to 14,776 years, and their distribution demonstrated: 1. increases in age along upgradient flow paths of sub-basin A (where recharge becomes isolated from the surface); 2. decreases in age along downgradient flow paths in sub-basin A (where mixing with recent infiltration has occurred); and 3. modern infiltration in sub-basin B (indicating isolation from sub-basin A and recharge via a regional fault).

Radiocarbon, tritium, and sulfur hexafluoride confirm the presence of recharge zones in the north and south. The groundwater becomes more enriched in oxygen-18 and deuterium along the flow path, concurrent with increases in radiocarbon ages. This indicates that water recharged recently is depleted due to an arid climate, and water recharged in the past was sourced from precipitation in a warmer or wetter setting.

Stable isotopes also confirm that infiltration occurs in the central zone, as they become depleted along downgradient flow paths where radiocarbon ages decrease. In these areas, salinity decreases and anion dominance changes from chloride in the central zone to bicarbonate in the downgradient zone. Previously, it was not clear if the more saline chloride-dominant groundwater was palaeorecharge or recent recharge. This work indicates that younger water is fresh, and where it infiltrates in the central zone, it mixes with the older, slightly more saline groundwater, causing dilution.

WHAT LIES BENEATH: SHALLOW GROUNDWATER, A(NOTHER) HAZARD BENEATH OUR FEET

Calder-Steele, N.[1] **, Rutter, H.** [1]**, Weir, J.** [1]
[1] Aqualinc Research Limited

Aims

Traditionally groundwater research in New Zealand has focussed on groundwater as a resource, its availalbility, scarcity, and how we can set and better manage to limits.

Over the last decade plus, we have seen the impacts of large-scale events on groundwater – earthquakes disrupting flow paths and levels, and intense and repeated precipitation events as a harbinger of climate change resulting in unpredicted and unexpected system behaviours.

So what happens when a resource becomes a risk and are we equipped to deal with it?

Method

Aqualinc has been working with companies and councils to understand and predict what happens when a good resource goes bad; how shallow groundwater is increasingly becoming a hazard and exacerbating risks to infrastructure and communities.

From greenfield sites with little more than anecdotal information, through to intensely monitored and extensively modelled major cities, I will highlight how Aqualinc has sought to understand the risk of shallow groundwater and what this risk could mean.

Results

Being willing to acknowledge the change is happening and there is a need to adapt is the first step. Not everyone is yet ready to begin this journey. For those that are, acceptance comes in many forms. Join me in exploring these.

INTER-AQUIFER CONNECTIVITY AND SENSITIVE SPRING GDES - GALILEE BASIN AUSTRALIA

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[4] Australian Nuclear Science and Technology Organisation

Understanding the extent of inter-aquifer connectivity within central Queensland's Permian-Triassic Galilee Basin (Australia) is crucial for assessing the likely impacts of large coal mine developments on the region's groundwater resources. Uncertainty surrounds how dewatering of the Permian coal measures will impact overlying and underlying sequences, and whether the presence of preferential pathways may enable drawdown to propagate towards sensitive receptors, including the culturally and ecologically significant Doongmabulla Springs. A combination of geophysical, geological and environmental tracer data was used to better understand inter-aquifer connectivity near the largest of the approved Galilee Basin coal mines – the Carmichael mine. Open-access aerial electromagnetic (AEM) and seismic surveys defined a layer cake stratigraphy dipping shallowly west. The shallow Triassic aquifers contain elevated groundwater HCO_3^- and F^- concentrations and heavy fraction hydrocarbons (>100 ug/L C_{10}-C_{40}), likely originating from the underlying Permian coal measures. AEM surveys and geological logs indicate that surficial Cenozoic sediments contain a lower horizon of highly weathered sandstones and siltstones (20-40m thick) directly overlying similarly weathered Triassic Rewan Formation, and contain groundwater with lower TDS (mean: 646 mg/L) and slightly greater $a^{14}C$ (mean: 27.9 pMC) and $R^{36}Cl$ (mean: 85.6x10^{-15}) than groundwater in the shallower clay-rich Cenozoic facies (mean TDS: 6130 mg/L, $a^{14}C$: 12.1 pMC, $R^{36}Cl$: 76.6 x10^{-15}) and underlying coal measures (mean TDS: 1360 mg/L, $a^{14}C$: 6.3 pMC, $R^{36}Cl$: 77.3 x10^{-15}). Dewatering of coal seams since 2019 for mining has induced >1m of drawdown in the Cenozoic sequences over 10km away, suggesting that hydraulic connectivity between these high permeability zones may enable rapid lateral and vertical propagation of drawdown. This raises concerns as to how mining could impact water levels in the adjacent Triassic aquifers and importantly, the Doongmabulla Springs.

SOURCES OF WATER AND MEAN TRANSIT TIMES IN AUSTRALIAN INTERMITTENT STREAMS; IMPLICATIONS FOR VULNERABILITY

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Aims

Determining the time taken for water to pass through catchments from where it recharges to where it discharges into streams (the transit time) is vital for understanding how catchments function and predicting the impacts of climate change and anthropogenic contamination (Maloszewski and Zuber, 1982, McGuire and McDonnell, 2006). Streams with long mean transit times are most likely sustained by deeper, large volume catchment water stores (e.g. regional groundwater). Those streams are less vulnerable to short-term (months to years) variations in rainfall and the impact of anthropogenic contaminants will likely also be delayed. Perennial streams from middle to upper catchments in southeast Australia have mean transit times at baseflow conditions that typically range from decades to centuries (Cartwright and Morgenstern, 2015, Hofmann et al., 2018, Howcroft et al., 2018, Cartwright et al., 2020). The long transit times imply that these streams are connected to large catchment water stores, which helped maintain streamflow during the prolonged Millennium drought (1996 to 2010).

Intermittent streams have received much less attention than perennial streams. However, they comprise ~50% of total stream length globally (Shanafield et al., 2021) and, especially in dryer regions, are important water sources for the local flora and fauna. This study addresses the sources and mean transit times of water that sustains intermittent streams in southeast Australia. It was hypothesised that these streams would be less well connected to regional groundwater systems than the perennial streams and that shallower, younger, near-river catchment water stores would be more important. Understanding the sources of water is important in predicting the response of these streams to future climate change and in their management and protection.

Methods

Intermittent streams from southeast Australia were sampled at a range of flow conditions. During the summers, these streams commonly comprise a series of disconnected, persistent pools (rather than being totally dry). We also sampled regional groundwater from the catchments and water from the riparian zone within a few metres of the streams. Mean transit times (MTTs) of stream water and water from the riparian zone were determined from Tritium (^3H) activities using lumped parameter models (Maloszewski and Zuber, 1982, Morgenstern et al., 2010, Jurgens et al., 2012) with the ^3H record of rainfall in Melbourne (Tadros et al., 2014) as the input function. Mean transit times of groundwater were determined using the same lumped parameter models with a combination of ^3H and ^{14}C (using the record of atmospheric ^{14}C activities over the Holocene: Jurgens et al., 2012). Major ion and stable isotope geochemistry was used to assess the sources of water contributing to these streams, in particular to determine whether regional groundwater was a major contributor.

Results

The MTTs of the intermittent streams ranged from <1 to 10 years (Cartwright and Morgenstern, 2016, Barua et al., 2022, Zhou et al., 2022) and locally the MTTs of the water in the disconnected pools were shorter than when the streams were flowing. Regional groundwater in these catchments has MTTs of several hundreds to thousands of years. The major ion and stable isotope geochemistry of the stream water in the intermittent streams at all flow conditions is commonly dissimilar to that of the regional groundwater, which together with the disparity in MTTs, implies that regional groundwater is not a major contributor to these streams. By contrast, the water from the riparian zones has similar major ion and stable isotope geochemistry and ^3H activities to the stream water, implying that near-river water stores are important in sustaining these streams. The limited connection with the regional groundwater during the zero flow periods in summer implies that the pools that exist at those times are not sustained by groundwater inflows, which is often assumed to be the case (Shanafield et al., 2021). The combined geochemistry also implies that, despite these intermittent streams being locally losing, there is little significant recharge of regional groundwater from the streams. Groundwater and surface water in these catchments thus show a greater degree of separation than in the catchments with perennial steams.

That these intermittent streams have limited connections with regional groundwater has important implications for catchment functioning. The absence of a large-volume reservoir sustaining streamflow means that these streams are more vulnerable to short-term changes to rainfall, such as the periodic drought periods that typically last a few years in southeast Australia. In agreement with this prediction, the year-on-year streamflow of these intermittent streams is more variable than that of nearby perennial streams in catchments of similar size, geology, landuse and climate. The intermittent streams are likely, however, to be less vulnerable to the impacts of regional groundwater pumping or the contamination of the regional groundwater than the perennial streams. Protection of the riparian zone is critically important in maintaining the water quality and quantity in the intermittent streams. Climate change and groundwater use is predicted to increase the proportion of intermittent streams, implying that some currently perennial streams will be more reliant on near-river water stores than is currently the case.

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ADDRESSING WATER SECURITY CHALLENGES IN NIUE

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Addressing water security is a complex challenge for the small Pacific island nation of Niue. With no surface water resources, Niue relies on groundwater as its primary freshwater source, supplemented by household rainwater harvesting. Niue's water security challenges relate to:

Water quantity – due to reliance on a poorly quantified groundwater lens within an unconfined karstic limestone aquifer

Water quality – as there is no treatment of either the potable water source or wastewater. Current wastewater management practices, including use of historic septic tanks and disposal of untreated septage to the ground surface, could potentially impact drinking water quality and human health

Climate change – there's potential to impact both water quantity and quality through sea level rise, changed rainfall patterns and increased intensity and frequency of severe storms

Geohazards – events such as earthquakes and tsunamis could affect water infrastructure and water resources

This presentation outlines the prioritised pathways developed through a project aimed at providing designs to achieve 24/7 potable water supply across all of Niue. With a small population, economy and resource base, Niue requires adaptive thinking to best prepare for future challenges, through a planned and integrated approach to water and wastewater infrastructure planning, design, implementation and management.

Sustainability considerations were applied in the conception, planning, design and prioritisation of projects. While some technical issues and potential solutions are not unique to Niue, sustainable solutions required a developed understanding of cultural factors, obtained through in-country engagement, and alignment with cross-cutting issues like climate change resilience, environmental and social safeguards, system strengthening and capability building, and gender and disability inclusivity. Integration of these factors to project design, feasibility and prioritisation for technical (water supply, wastewater, water resource management) and non-technical (and governance) projects aims to achieve solutions that are contextually appropriate, that work towards sustainable water development and management in Niue.

GROUNDWATER STABLE ISOTOPES 3-D ISOSCAPE OF NEW SOUTH WALES, AUSTRALIA

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Spatial representations of isotopic values across a landscape (isoscapes) are increasingly being constructed because of their predictive and interpretative capabilities in water management. Rainfall and groundwater isoscapes using stable water isotopes (SWI) have been developed in a limited number of countries (Australia, Costa Rica, Estonia, Ethiopia, Finland, Ireland, Mexico, Poland, South Africa, and USA). Isoscapes can provide information on variations in water cycle dynamics and therefore any natural system that relies on water. For example, they can be used to provide information on groundwater recharge sources and processes, mixing of aquifers, infer ecological vulnerability or processes (identifying vegetation reliance on different water sources, migration of fauna) and in forensic studies (provenance of agricultural produce, human or wildlife geolocation).

Here we present the first groundwater isoscape for New South Wales (NSW). The work incorporates a state-wide sampling campaign developed in 2021 by the NSW Department of Planning and Environment and expanded with additional datasets to a total 3922 groundwater samples with SWI information. A 25x25 km grid was generated for the state, incorporating SWI data separated into four depth layers (1-30; 30-50; 50-300; >300 m). The SWIs were further complemented by looking at other existing groundwater well information (a total of 123,242 filtered groundwater works) to ascertain the existence of aquifer units, similar to the approach implemented by Bowen et al. 2022.

The isoscapes, at different depths, show the importance of snow melt, higher altitude rainfall and flooding for groundwater recharged along the large alluvial valleys of the southern part of the state. Other processes identified include irrigation induced recharge, and in the river valleys to the north, the discharge of Great Artesian Basin groundwater to alluvial aquifers.

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ARE GROUND SOURCE ENERGY SYSTEMS CAUSING RISING GROUNDWATER TEMPERATURES IN CENTRAL LONDON?

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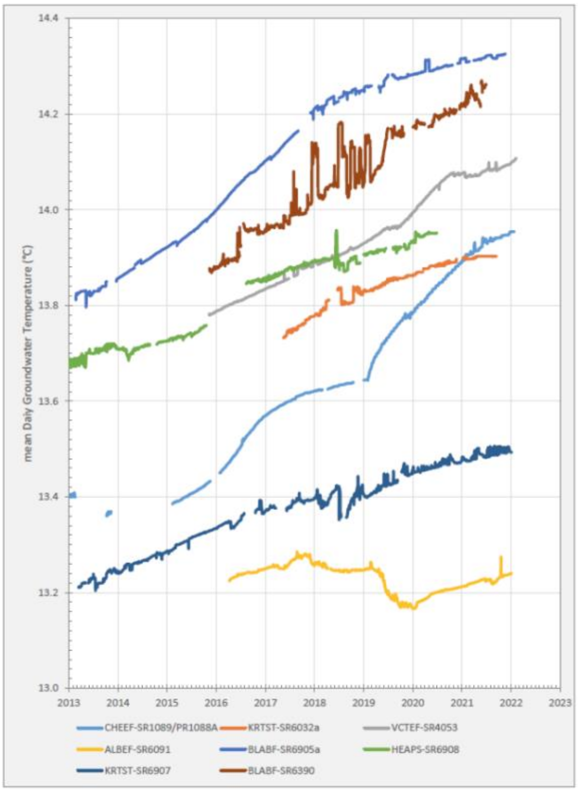
Aims

The decarbonisation of building heating is an important aspect of the United Kingdom's (UK) commitment to major reductions in greenhouse gas emissions. This has provided the impetus for installing Ground Source Energy Systems (GSES). In these systems, groundwater is used for the heating and cooling of buildings by drawing water from abstraction wells and returning it via injection wells at a warmer or cooler temperature. The constant temperature of groundwater (which generally ranges 10°C - 14°C in the UK) provides significant heat pump efficiency improvements compared to air source units, and a major reduction in greenhouse gas emissions compared to fossil fuel heating systems. From the mid 2000's, a large number of GSES have been installed in the UK to reduce greenhouse gas emissions and meet climate change targets,

Since 2005, there have been questions regarding the effects of GSES on groundwater temperatures in Central London, where approximately 45 heat pump schemes have been installed; specifically whether the increasing amount of net heat rejection to the aquifer would cause groundwater temperatures to rise. Data gathered as part of a recent GSES investigation in Central London showed the area had elevated groundwater temperatures. A report released by the Environment Agency (EA) in 2022 also showed that groundwater temperatures in the Central London area are rising, potentially due to GSES (**Error! Reference source not found.**). To assess the long-term sustainability of the scheme, we need to understand whether rising groundwater temperatures might cause the scheme to fail in the future. This paper summarises the work undertaken to evaluate whether rising groundwater temperatures in central London are likely to relate to GSES heat rejction and if so, what the long term potential temperature increase might be.



The major aquifer in Central London is the Chalk, a microporous white limestone, confined beneath 20-40 m London Clay. Water flows predominantly through the fractures that are present within these strata and the major water bearing fractures are generally located within the top tens of meters of the Upper Chalk. Groundwater abstraction dominates the outflow side of the aquifer water budget, with recharge occurring where the Chalk outcrops at the basin margins. A broad cone of depression is centred on the City of Westminster area of Central London with very low hydraulic gradients and hence limited groundwater turnover rates. The only sinks for heat rejected to the Central London Chalk from GSES are therefore transfer at the ground surface via conductive transport through the London Clay and pumping from consumptive water supply wells.

Methods

To understand the rise in groundwater temperatures in Central London and the potenital cause, we analysed and modelled groundwater temperature data, groundwater level data, and heat rejection rate data.

Groundwater temperature data from EA monitoring sites were analysed to better understand the trend within the Central London area. Groundwater level data from EA monitoring sites and static readings from GSES projects were analysed to understand the likely hydraulic gradient and its possible impact on advective heat transport, as well as the change in water levels over time.

Over 45 GSES have been installed in the Central London area. The net heat rejection rate for these schemes was analysed to estimate the rate of heat rejection to the aquifer system.

We undertook 3D numerical modelling of the Central London system to understand the potential change in groundwater temperatures associated with heat rejection from the GSESs. The observed tempratures (monitored data from the EA) were compared to model results. Energy balance calcuations and correlation analysis were carried out. None of the analysis indicates that the observed rise in groundwater temperatures can be attributed to to GSES heat rejection.

We hypothesise that the rising groundwater temperatures could be a result of a reduction in groundwater abstractions since the 1970's, which would reduce the amount of natual low temperature geothermal energy (60 W/m²) being removed from the aquifer. The impacts of anthropogenic climate change and the urban heat island effect may also be contributing factors. Further work is needed to confirm this.

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AN OPPORTUNITY TO IMPROVE HYDRAULIC CHARACTERISATION FOR CONTAMINATED SITE INVESTIGATIONS

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Contaminated groundwater site investigations primarily focus on characterising soil and groundwater quality to understand human health and ecological risks. The assessment of hydraulic conditions (the hydrogeological component) becomes relevant during later stages of assessment when an understanding of the hydraulic conditions of the underlying aquifers is needed to assess risk to offsite receptors and inform the design of groundwater remediation systems. Due to a delayed requirement for hydraulic data it often becomes a site investigation afterthought, which can result in a limited assessment of site hydraulic conditions.

Low flow purge methods used for collecting groundwater quality samples, and sometimes well development, during contaminated site investigations provide an additional opportunity to improve hydraulic characterisation that is often missed.

This study assesses the applicability of using groundwater purging and development data to provide an increased understanding of a site's hydraulic status. The study includes more than 50 wells located across more than ten sites in NSW that are screened within unconsolidated and consolidated lithology. It includes the calculation of specific capacity from purging and well development data and converting the results to hydraulic conductivity using standard equations in the available literature.

The results are compared with slug testing data collected from the wells to critically assess the applicability of using specific capacity to improve hydraulic conductivity characterisation across contaminated sites. The study also explores the applicability of the specific capacity method across different lithologies and whether alternative relationships can be developed to estimate hydraulic conductivity from specific capacity data. It also proposes alternative field methods that can be adopted on a site-by-site basis to reduce uncertainty in the adoption of the specific capacity method for estimating hydraulic conductivities while improving spatial characterisation.

INCORPORATING KAUPAPA MĀORI INTO OUR UNDERSTANDING OF CATCHMENT HEALTH

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Aims

The purpose of this work was to compare and contrast western science indicators of stream health (e.g. nitrate, ammonium, phosphorus) with mātauranga Māori through the use of a kaupapa Māori assessment tool.

Methods

Water samples were taken during low, median and high flow gauging events at selected sites in the Waiotapu catchment, in the North Island of Aotearoa New Zealand (Fig.1). Field parameters (dissolved oxygen (DO), pH, temperature and electrical conductivity) were measured and samples analysed for nitrate+nitrite nitrogen (NNN), ammonium-N (NH4-N), dissolved reactive phosphorus (DRP and other analytes of interest.

Ngati Tahu-Ngati Whaoa are mana whenua for the catchment and are represented in this study by the environment team from the Ngāti Tahu-Ngāti Whaoa Runanga Trust (the Runanga), who are the mandated iwi authority.for their people. The Runanga has spent many years researching the state of mahinga kai (wild foods) within their rohe (tribal boundaries) because iwi surveys indicated that such tikanga practices were in decline. This research led to the developed of a phone app to capture how iwi members used their senses to rate whether a waterway was fit to gather mahinga kai from. The Wai Ora app applies a cultural lens to each site by focussing on three aspects: Mauri Ora (essence of vitality), Whanau Ora (thriving families) and Taiao Ora (flourishing nature). The first aspect asks the assessor to rate the health of the stream using their senses and connection to the site. The second aspect rates whether traditional iwi practices are or can be applied to the site and the third aspect rates presence (or absence) of mahinga kai as well as abundance for manakitanga practices (whether there is only enough to feed the immediate whanau versus enough to feed whanau and visitors staying at the marae).

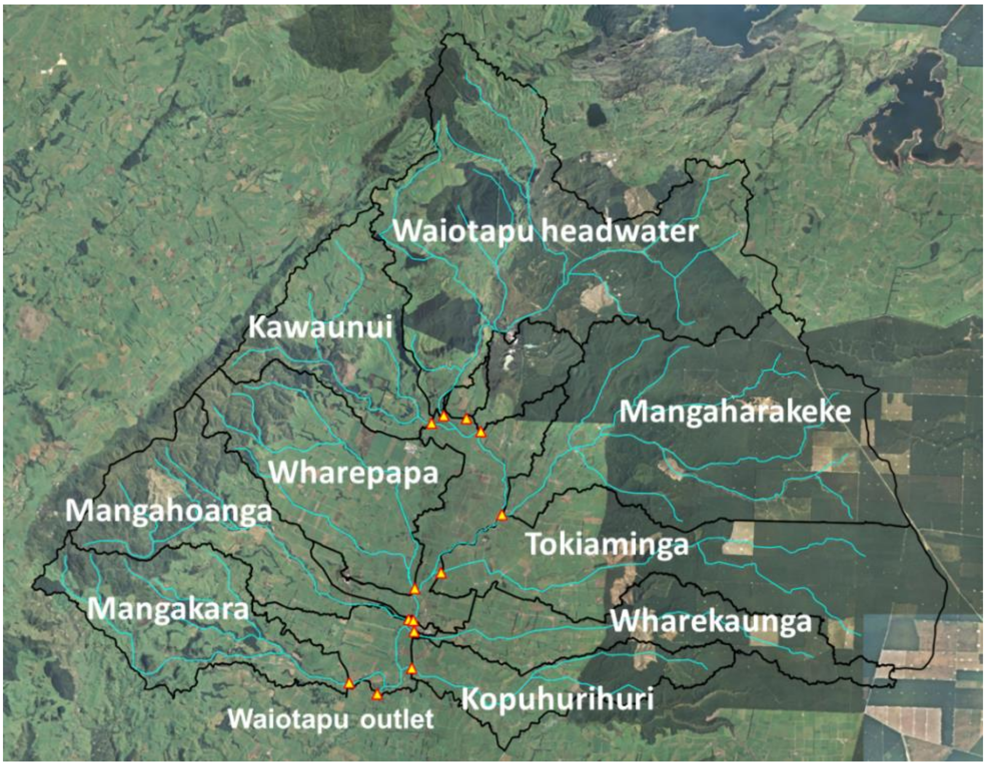

Figure 1: The Waiotapu catchment in the central North Island, Aotearoa New Zealand showing nine sub-catchments and the assessment points used in this study.

Results

Our results show that for many sites, the Kaupapa Māori assessment aligned with the water chemistry results, as exemplarily shown in Table 1 for the Tokiaminga stream.

Table 1: Summary of information for Tokiaminga stream

Tokiaminga Stream		
Parameter measured	**Concentration range/ assessment**	**Classification if applicable**
DO	76-94% saturation	
Mean residence time	7.5-35 years	
NNN	1.32-2.21 mg/L	B*
NH4-N	0.78-0.85 mg/L	C*
DRP	0.003-0.02 mg/L	C*
Mauri Ora	Senses are not awakened, connection is not felt with the site and mahinga kai habitiat is poor	Noho (dormant)
Whanau Ora	Traditional practices are not applied to the site as access is restricted and water quality is poor	Aue (not good)
Taiao Ora	Traditional practices are not applied to the site as access is restricted and kai is considered not safe to eat	Aue (not good)

* We applied the National Policy Statement for Freshwater Management (2020) to our spot measurement data rather than an annual median to provide an indication of water quality.

Conclusions

Addition of the kaupapa Māori assessment provides complementary information about our locations and provides context for the western science indicators. For example, high concentrations of nitrate, DRP and sediment mean a site will be overgrown with weeds, will not engage the senses, is less able to support kai species and whanau will not feel a connection to the stream as they do not trust the water quality.

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RATES OF SEAWATER INTRUSION IN THE PRESENCE OF OFFSHORE FRESH GROUNDWATER

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Introduction

When water supply demands lead to low groundwater heads near the coast, there is a danger of seawater intruding into freshwater resources. In many cases, the presence of fresh groundwater which extends offshore provides some resilience against salinization (Knight et al., 2018; Morgan et al., 2018; Morgan & Mountjoy, 2022). However, if this offshore fresh groundwater is not part of the modern hydrological cycle, then abstraction is non-renewable (Edmunds & Milne, 2001). We hypothesize that low coastal groundwater heads causing a landward hydraulic gradient, will lead to salinization after sufficient time. This is regardless of the presence of offshore fresh groundwater.

Methods

We present the results of a numerical investigation into the rate of seawater intrusion in the presence of offshore fresh groundwater, using MODFLOW 6 (Langevin et al., 2020). We analysed the sensitivity of the rate of salinization to variation in aquifer characteristics, using a simple numerical model. The results highlight the aquifer characteristics which are likely to lead to rapid salinization and give a first order estimate of time to exhaustion.

Results

We found that the aquifer hydraulic conductivity and the aquitard vertical hydraulic conductivity have the greatest effect on salinization rate. Multiple simulated aquifers experienced complete salinization after a period of 100 years. For aquifers with high hydraulic conductivity, rapid salinization occurred even under a small landward hydraulic gradient.

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REGIONAL SYNTHESIS OF OTAGO GROUNDWATER AGE, DYNAMICS AND HYDROCHEMICAL EVOLUTION

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We present a regional synthesis of environmental groundwater age tracer results for samples collected across Otago. This data was collected in collaboration with Otago Regional Council to develop a better understanding of the conceptual groundwater flow, groundwater recharge sources, connection with surface water, nitrate pathways, and ‘Future nitrate loads to come’. Environmental tracers including groundwater age (residence time), stable isotopes, temperature, gas concentrations (tritium, sulphur hexafluoride (SF_6), chlorofluorocarbons (CFCs), and Halon-1301), and hydrochemistry are used to characterise: (i) the dynamics of the groundwater from recharge to discharge, (ii) its groundwater interaction with surface water, (iii) source(s) of groundwater recharge and (iv) the processes that control the hydrochemical properties (quality) of the groundwater (including sources of contaminants). This data is needed to better manage groundwater allocation, through an improved understanding of recharge sources and flow, and water quality, through a better understanding of nitrate dynamics.

Across the Otago Region, the complex topography and basement geology result in numerous disconnected basins that may contain multiple aquifers. As such, a comprehensive dataset that well-characterizes the diversity in groundwater ages and flow pathways is currently lacking. To address this issue, a regional sampling effort was undertaken in March 2023 during which 24 groundwater samples from bores and 5 additional samples from groundwater-fed springs were collected across Otago. This sampling campaign was part of the MBIE Endeavour programme ‘Te Whakaheke o Te Wai’. Of the bore samples, 79% were State of the Environment (SOE) sites targeted because they have long-term hydrochemistry (including nitrate) data that will be included in this data analysis to understand trends over time. In addition to these 29 new samples, we include >100 historic groundwater and surface water tracer analyses to significantly improve our spatial coverage and understanding of the origin of groundwater recharge, time lags, and nitrate flow pathways.

THE IMPORTANCE OF ESTABLISHING BASELINE GROUNDWATER QUALITY FOR REGULATORY COMPLIANCE MONITORING

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Many activities regulated by the Environment Protection Authority (EPA) in South Australia (SA) include a requirement to undertake periodic groundwater quality monitoring. Historically, groundwater monitoring programs for regulated sites have focussed on an assessment of risk to receptors by establishing environmental values and comparing the groundwater quality data with associated default guideline values. However, this methodology is not consistent with the primary objective of compliance monitoring, which is to enable the early identification and management of impacts to groundwater associated with an activity so that site contamination can be prevented, or at least minimised. In order to achieve this objective, a good understanding of the existing, or baseline, groundwater quality is required. The EPA has recently worked with two major landfills in SA to develop new groundwater monitoring and management plans that establish baseline groundwater quality and derive subsequent assessment criteria to indicate when impacts to groundwater quality are identified. For both of these sites, historical groundwater monitoring data was subject to exploratory data analysis to understand the quality of the data, as well as identifying any temporal or spatial heterogeneity in groundwater quality at the site requiring consideration before establishing the baseline. Whilst the impact of this approach in preventing or minimising site contamination won't be able to be measured for many years, the establishment of baseline groundwater quality in order to set clear assessment criteria and management actions has already resulted in a number of benefits, including improved regulatory certainty for all stakeholders, as well as the provision of a more effective framework for industry and consultants to manage sites with groundwater quality that exceeds default guideline values. The EPA is currently in the process of drafting a series of guidelines to reflect this new approach to groundwater monitoring for regulated sites in SA.

THERE IS A PLACE FOR TRADITIONAL OWNER WATER MANAGEMENT IN THE PILBARA

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Iron ore mining in the Pilbara commenced in the 1960's. The early developed deposits were relatively easy to mine, usually being a hill that involved mining the top off. Since the early 2000's deposits have become more challenging to exploit. Some 70% of current ore bodies are now below the water table resulting in signficiant volumes of groundwater needing to be dewatered and then disposed of to extract the ore.

This dewatering and disposal has resulted in adverse impacts to groundwater dependent ecosystems that have signficant cultural and heritage value to Traditional Owners.

The Pilbara is a patchwork quilt of mining tenements and the competing companies will not or can not (due to competion laws) work together to properly manage the impacts. With the imment closure of several major iron ore mines, the focus is now on what the post mining landscape will look and feel like. This represents an opportunity for Traditional Owners to fulfil their custodial obligations and to sustainably manage water for cultural, environmental, social and economic outcomes for all stakeholders.

This paper provides an insight to the work being done with Traditional Owners to help the miners manage and address the current impacts from mining. It will also explore the principles the Traditonal Owners are setting to direct the miners on what is acceptable closure (versus industry *rehabilitation*) with an aspirational view focussed on restoration of Country.

This work is occuring with the backdrop of miners now needing *free, informed, prior consent* (FPIC) from Traditional Owners for all approvals (operational and closure) and a growing awareness of the need for water rights for First Nations People.

COMPETING SCALES IN GRAVEL RIVER MANAGEMENT HIGHLIGHT IRRELEVANCE OF THE STABILITY CONCEPT

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Aims

The notion of “stability” has been a focal aspiration for generations of river managers. However, a general a lack of critical review means basic tenets underlying practice remain unproven, specifically that: 1) stability is achievable and 2) management actions implicitly produce more stable rivers. River behaviours at different spatiotemporal scales are presented and provide opposing interpretations of stability on the same wandering, multi-thread gravel bed river on New Zealand’s North Island.

Methods

Assessment of multidecadal/riverscape scale stability used an aerial-photo time-series from 1941 and 2010 to map active channel extents. Active channel widths were extracted at 20 m increments perpendicular to the belt centreline over the ~16 km profile of the lower Waingawa River to produce a sample of 896 +/-6 for each of eight years for statistical evaluation. A subset of the time series 1963 and 1983) were ortho-corrected using common geodetic control to 2012 and 2017 commercial orthoimagery as a check on absolute belt positions.

Event-based stability was evaluated for a 3.5 km segment nested within the multidecadal/riverscape extent. Very-high resolution orthoimage (5 cm resolution) and topographic (10 cm resolution) time-series were used to compare absolute changes in channel position and bed volume, respectively. The time-series was generated from four low-elevation (70 m AGL) aerial photograph collections (surveys) by Remotely Piloted Aircraft System (RPAS) with rigorous ground control in November and December 2019. Collections were interspersed between flow events with peak magnitudes between 0.12 (34 cumecs) to 1.01 (291 cumecs) times the mean annual flood (QMAF) based on Greater Wellington Regional Council’s gage at Kaituna. An empirical change threshold of 0.2 * QMAF was determined from observations of unit-scale (e.g., bars) changes during earlier surveys (2017-2019) and used to compute excess discharge.

Results

The statistical distribution of active channel width decreased (-48% mean) and became more uniform (-62% std. dev.) at the riverscape scale over the multidecadal time-series (Figure 1, left). Observed changes are progressive in time and converge on contemporary management design widths which may support interpretation of increased stability (as commonly applied in management) through time. However, at no time was the absolute position of the active belt completely within training lines (nor entirely single-thread form).

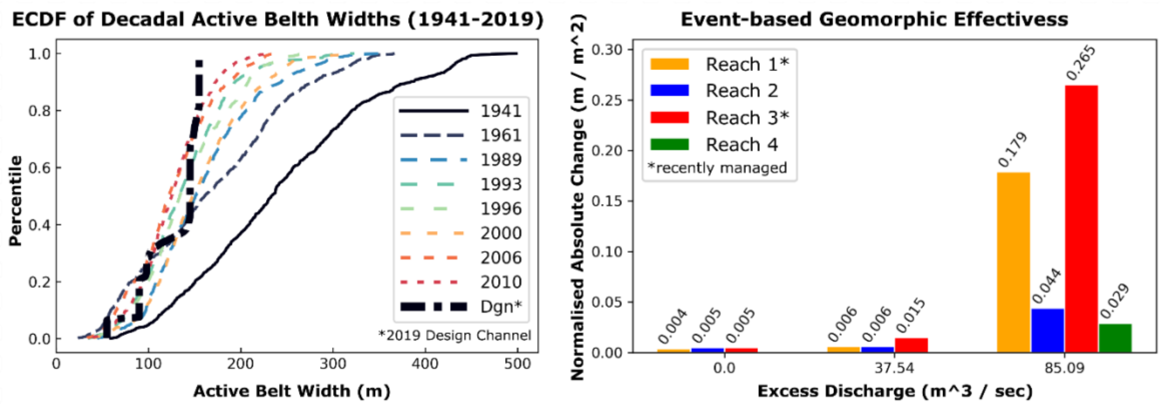

Figure 1: Left: Empirical cumulative frequency distribution (ECDF) of active belt width shows multidecadal decrease at the riverscape scale. High-resolution subannual data indicate greater event-based vertical change within reaches trained within prior thirty months compared to adjacent untrained reaches.

Analysis of high-resolution data at the event-based/segment scale found channel changes varied between events as well as within the segment for a given event. Specifically, reaches that experienced training earthworks in the prior 30 months exhibited up to 2.5 times more volumetric change after a peak discharge with one-half the mean annual flood (37.54 cumecs of excess discharge) and six times more change from the MAF event (85.09 cumecs of excess discharge; Figure 1, right). Propagation of incision upstream and aggradation downstream originated from managed areas contributing to lateral shifts of the wetted channel up to 50 metres including up to 16 metres of bank erosion. Thus, over shorter time periods recently trained sub-reaches were less stable than adjacent untrained areas.

Comparing the observed channel change threshold (0.2 * QMAF) relative to the QMAF (as a hypothetical flow threshold) shows not only an increase in duration (Figure 2, bottom-left), but also much greater inter-annual variability. Over a decade, cumulative effectiveness duration is 310 times greater for threshold at 0.2 * QMAF than the QMAF and maximum within-year duration increase by 88 times. Given the flashiness of the hydrology (Figure 2, top), it is also prudent to consider the number of effective instances (Figure 2, bottom-right) as each event presents an opportunity for change potentially independent of duration effects. The total number of instances over the decade is roughly 60 times greater at the higher frequency threshold and the range within any given year increases by an order of magnitude. Effectively, as the change threshold is lowered (such as in trained sub-reaches) channel change becomes more likely and less predictable.

While management appears to have been effective at narrowing the active belt over many decades (often interpreted as stability), it also appears to amplify channel changes from common flow events. This is believed to be the first documented anti-pattern in fluvial geomorphology and makes a strong case for adopting uncertainty-based approaches in lieu of traditional stability aims.

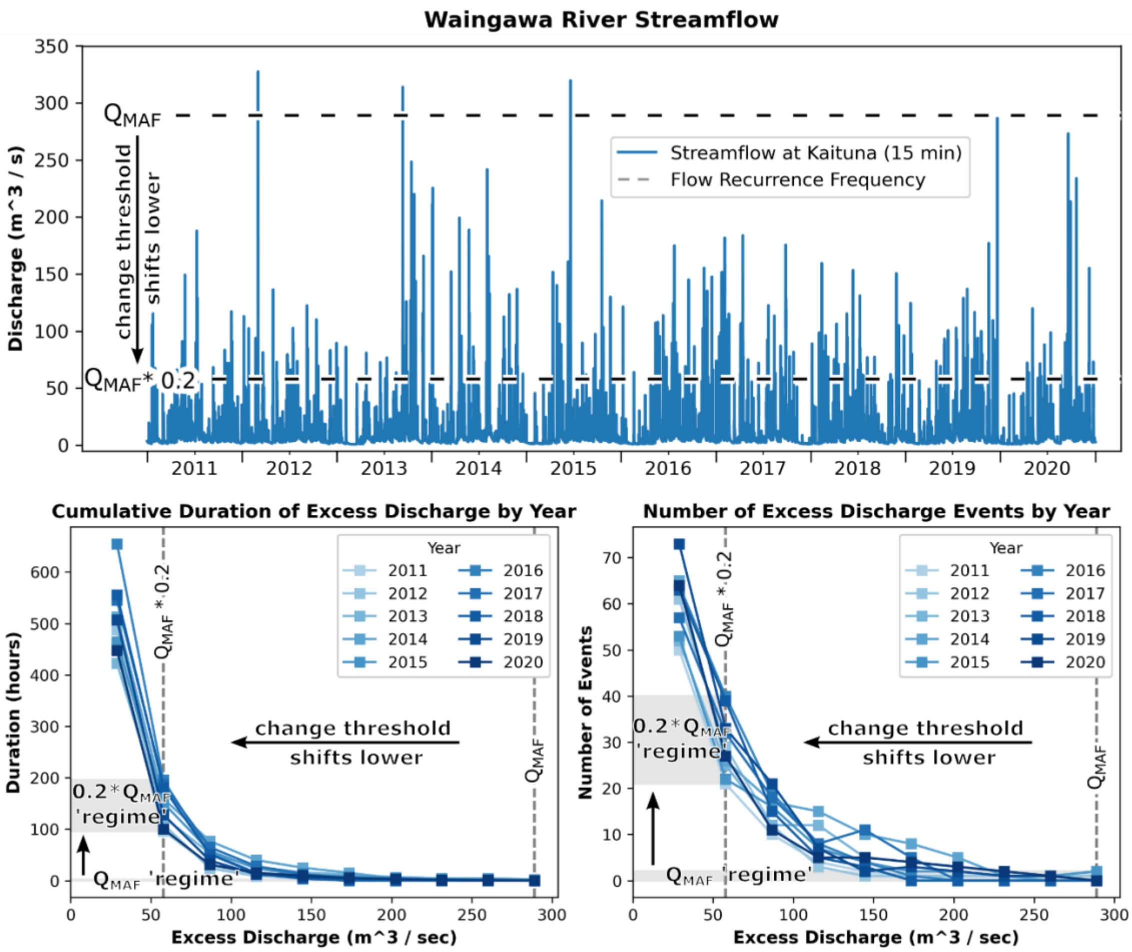

*Figure 2: As the threshold at which channel change occurs shifts to lower flow magnitude, the behavioural regime of the river becomes more active. Top: A lower flow threshold (0.2 * QMAF) intersects many more runoff events than a higher threshold (QMAF) as indicated for the Waingawa River from 2011 through 2020. Bottom: As the flow threshold decreases, intra-annual frequency and interannual variability both increase. Cumulative duration of excess discharge year (bot. left) and number of excess discharge events (bot. right) both increase by year with grey boxes indicating the envelope for each behavioural 'regime' with the observed, anthropogenically-forced regime (threshold of 0.2 * QMAF) resulting in greater magnitude and variability of both driving forces and event frequency, respectively.*

ENVIRONMENTAL MODELLING OF A MAJOR INLAND FLOOD DIVERSION SCHEME ON THE RIVER THAMES, UK

Mike Cope, DHI-NZ, Philipp Huttner, DHI-Germany, Sam Bishop, Stantec-UK

The River Thames between Windsor and Teddington, west of Heathrow Airport, has the largest area of undefended, developed floodplain in England, with over 15,000 properties at risk. It is an area of complex hydrology and hydrogeology, also home to historic landscapes, landfill sites, major water supply reservoirs and sensitive lake waterbodies and their associated habitats. A period of major flood events culminated in the historic 1947 flood which largely filled the floodplain, and such flooding is certain to occur again. Subsequent less severe flooding has occurred on a regular basis however, with the recent floods of 2003 and 2013/14 affecting many homes and businesses.

The identified sustainable solutions include the River Thames Scheme (RTS), a major (NZ$1bn) engineering project of national significance. The RTS was conceived as mainly comprising three diversion channels, using a landscape-based approach to creating healthier and more resilient and sustainable communities, responding to socio-economic issues while increasing biodiversity.

With Channel 1 dropped from the scheme due to lack of funding, RTS now comprises the ‘Spelthorne’ Channel 2 (Egham to Chertsey) and ‘Runneymede’ Channel 3 (Chertsey to Shepperton). These channels pass through the floodplain areas, impacting on many side streams and other waterbodies.

The presentation outlines the environmental modelling carried out to inform the required Habitats Regulations Assessment and Water Framework Directive compliance assessments, covering:

- Integrated MIKE HYDRO River - MIKE SHE numerical modelling to help assess impacts on water levels, flows, water quality and sediment transport;
- The flux between groundwater and surface water, and lake residence times;
- Predicting changes in nutrient levels (specifically nitrogen and phosphorus) in the lakes;
- Potential effects on existing surface water and groundwater abstraction locations; and
- Risk of eutrophication and algal blooms.

Further modelling continues at the pre-application stage, including an assessment of augmentation flows within the RTS channels under drought conditions.

WHERE'S THE SOURCE?

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Divining where groundwater comes from, where it breaks the surface and, particularly in light of groundwater-dependent ecosystems (GDEs), where it does not reach the surface, requires a gamut of techniques, used in a variety of ways, commonly bespoke to any given location and generally to provide a weights of evidence approach to characterisation, quantification and understanding of both the ecosystems requirements and dependencies as well as tolerances and limitations.

Over a number of jobs across the country for multiple clients, we have trialled multiple technologies ranging from far-remote to near-remote; from non-invasive to invasive; from qualitative to quantitative and used a variety of modelling packages, across the whole spectrum of GDEs and often still struggle to provide proponents with a set of tools that are consistent and effective, reproducible and defensible and without a lot of effort and a lot of tears!

We will present cases that have proven fruitful and enlightening and a few that are perplexing and frustrating and some new attempts at some old problems that might be getting us somewhere. A key approach has been to match techniques at multiple scales and refine to the scale relevant to a specific ecosystem. Satellite vegetation indices thus provide useful first approaches, but do not work efficiently for most sites and must be refined using drones and ultimately on-ground surveys.

Similarly, regional groundwater assessments paint a broad picture that must be refined to the local area and ultimately to the ecosystem scale, integrating both quantity and quality conditions.

Using this nested approach to GDE characterisation and groundwater facilitation tackles GDEs from both sides of the coin: refining the ecosystems requirements and matching to site-specific groundwater capability that both provides a clearer understanding of GDE function and a testable and manageable systems approach.

DEVELOPING NOVEL APPROACHES TO SIMULATE CSG-INDUCED SUBSIDENCE

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Subsidence has been extensively studied in the context of groundwater abstraction; however, new challenges arise in conceptualising and simulating subsidence due to coal seam gas (CSG) depressurisation. CSG-induced subsidence is a result of multiple interrelated processes including poroelastic compaction of coal and interburden, coal shrinkage and pressure changes resulting from dual-phase flow. While remote sensing data such as InSAR can be used to estimate subsidence referenced to a particular date, modelling is required to understand the entire subsidence history and predict any future subsidence. The study documents our adventures in developing a robust modelling framework for replicating and predicting CSG-induced subsidence.

The primary components of the framework include: 1. A subregional/local-scale design to account for local variability critical to agricultural activities; 2. Pseudo dual-phase modelling in order to represent pressure changes induced by CSG extraction; 3. Coupled flow and geo-mechanical modelling that considers both poroelastic compaction and coal shrinkage; 4. Multiple regularisation strategies to ensure model-generated subsidence aligns with expert knowledge and InSAR measurements; 5. Model calibration using multiple types of data including groundwater levels, water production of CSG wells and Sentinel-1 InSAR measurements.

The framework was applied to a pilot study area (15 km x 15 km) in the Surat Basin where rich InSAR data are available. Simulation spans the period from year 1995 to 2099. The modelling results shed light on the spatial-temporal evolution of subsidence in a typical CSG field. Variables such as maximum subsidence and time required to realise maximum subsidence will be presented. System properties which govern such evolution will also be discussed based on parameter sensitivity analysis.

STRENGTHENING THE ROLE OF INDEPENDENT EXPERT ADVICE IN ASSESSING IMPACTS ON GROUNDWATER AND CONNECTED ECOSYSTEMS

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There is widespread community concern over impacts of large coal mining and coal seam gas (CSG) developments on water resources, and the ecosystems they sustain. In 2013, community concerns led to the amendment of Australia's EPBC Act (Cth) 1999, to include a Water Trigger, to enable the Commonwealth Government to assess the impacts of coal mining and CSG on ground and surface water resources, with such assessment to be informed by an independent committee of scientific experts (the IESC). This presentation examines the extent to which the IESC's advice on coal and gas proposals around Australia has been effective in protecting waters and their connected values at risk of impacts from coal mining and CSG. Review of case studies demonstrate that the IESC has consistently provided rigorous advice into potential impacts of coal and gas developments on groundwater, surface water and groundwater dependent ecosystems (GDEs), and it has often identified important data gaps and uncertainties during the early stages of assessment. However, there are multiple examples where such knowledge and/or data gaps have remained un-addressed at the time of an approval decision. This has led to potential risks of unforeseen impacts, and erosion of public confidence in the process. There is scope to strengthen the regulatory process, and how the IESC's advice informs assessments. A binding requirement for proponents to address critical data and/or knowledge gaps identified by the IESC prior to an approval decision, would ensure these decisions and the basis on which they are made, are sufficiently robust. Providing resources and powers for the IESC to commission independent studies to address key knowledge gaps would provide further rigor and enhance public confidence that impacts of coal mining and CSG are being thoroughly assessed and understood, before decisions with major long-term implications for ground and surface water are made.

EXPLORING THE USE OF REMOTE SENSING INDICES TO ENHANCE MONITORING OF GROUNDWATER DEPENDENT VEGETATION CONDITION IN THE MURRAY DARLING BASIN

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The increasing demand of surface and groundwater resources has seen the NSW Government put in place Water Sharing Plans to enable the equitable sharing of water between irrigators, the environment, industry, towns and communities under the Water Management Act 2000 (WMA 2000) and water resource plans under the Murray-Darling Basin Plan. The NSW Government has implemented an ecological health/condition monitoring and evaluation reporting program for groundwater dependent vegetation to fulfil requirements under both state and commonwealth legislation.

Vegetation condition monitoring in NSW has been conducted by various NSW state and Commonwealth agencies (Commonwealth Environmental Water Holder (CEWH), Department of Planning and Environment (DPE) and the Murray Darling Basin Authority (MDBA) since 2008. This dataset however is largely confined to the large terminal wetlands in the Gwydir, Narran, Maquarie and Murrumbidgee catchments, and focused on the influence of surfacewater inundation regimes to vegetation condition. This dataset, however, offers a unique opporuntity to explore groundwater influences on vegetation community condition and the applicability of using remote sesning indices to enable a broader coverage of monitoring in data poor areas of the Murray Darling Basin.

This presentation explores the hypothesis that the use of normalised difference vegetation index (NDVI) either on its own or in combination with tasseled cap greenness or wetness will provide a more representative vegetation condition score specific to each vegetation community structure (floodplain woodlands, riparian woodlands, forested wetlands and non woody wetlands) for the dominate species of *Eucalyptus camaldulensis* (River Red Gum), *Eucalyptus coolabah* (Coolibah), *Eucalyptus largiflorens* (Black Box), *Acacia salicina* (River Cooba), *Muehlenbeckia florulenta* (Lignum) and mixed marsh wetlands across the Murray Darling Basin.

CHARACTERISATION OF SUB-CATCHMENT CONTAMINANT LOADS USING LOW-COST IOT TECHNOLOGY

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Aims

Catchment hydro-chemical responses typically occur on timescales of minutes to hours (Kirchner, 2006). However, regional council water-quality monitoring is often limited to monthly samples due to resource constraints. This temporal mismatch has been likened to trying to understand a symphony by listening to only a few notes (Kirchner *et al.*, 2004; Kirchner, 2006), resulting in less-informed decision making by environmental managers.

The Waihi Estuary Focus Catchment Investigation (WEFCI), initiated by the Bay of Plenty Regional Council (BOPRC), combines traditional water quality monitoring methods, with cost-effective Internet of Things (IoT) technology and innovative analytical methods. The main goal is to elucidate spatial and temporal patterns of total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) loads to the eutrophic Waihi Estuary, which requires significant load reductions to meet sustainable targets (Park, 2016). By using IoT technology and advanced analytical approaches, the investigation aims to characterise short-frequency storm events, enabling more nuanced information on contaminant mobilisation, and facilitating more informed land management decisions.

Method

Ten IoT-enhanced monitoring stations were established at critical locations within the Waihi Estuary catchment. Each station utilised an EnviroDIY Mayfly data logger board (Stroud Water Research Center, 2020), specifically designed for environmental IoT applications. Each board includes a microSD memory card slot, an optional telemetry module, a solar power regulator, and options for communication with a number of commercial water quality sensors (Hicks *et al.*, 2019). Stations were equipped with a HYDROS 21 CTD and YOSEMITECH Y511-A nephelometer providing data on conductivity, temperature, water depth, and turbidity every 15 minutes. The monitoring stations were programmed to collect data continuously since December 2021.

Water quality samples were collected monthly at each monitoring station, supplemented with additional samples from at least one storm event at each site using an ISCO 6712 portable water quality sampler. Estimated discharge at each site was calculated by the BOPRC Environmental Data Services using rating-curves, where applicable.

Soft-sensing models based on artificial neural networks (ANNs) were developed to predict TN, TP, and TSS concentrations. ANN models are popular for predicting water quality parameters due to their ability to deal with nonlinear data and solve complex problems, while being less sensitive to smaller datasets than comparable machine learning methods (Wang *et al.*, 2018; Tiyasha, Tung and Yaseen, 2020).

Predicted concentrations from ANN models were then input into the Weighted Regressions on Time Discharge and Season (WRTDS) model (Hirsch, Moyer and Archfield, 2010) to estimate annual loads and temporal loading characteristics at each site.

Results

The WEFCI Mayfly network has been operational for close to two years, experiencing numerous storm events and maintaining close to an 80% capacity. Preliminary ANN models have achieved TN concentration predictions with accuracy of over 70% at specific sites.

Load estimation and temporal characterisation results from three Mayfly stations will be presented in this oral presentation, including discussion of how this information can potentially be used to better inform future land management decisions.

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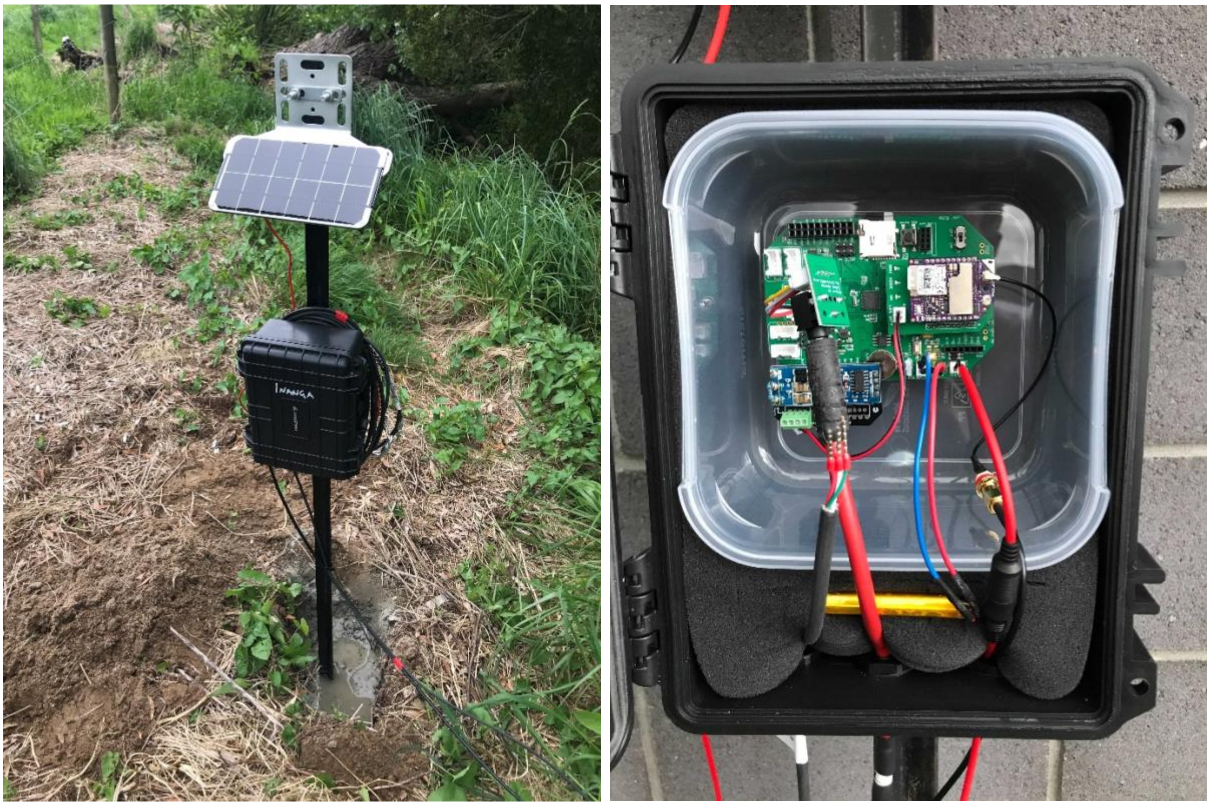

Figure 1: A deployed Mayfly monitoring station (left) and internal board components (right).

RE-IMAGINING THE LOWLAND WATERWAY NETWORK IN THE ARARIRA (LII) CATCHMENT, CANTERBURY

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[2] EOS Ecology
[3] Learning for Sustainability
[4] Fonterra
[5] Department of Conservation

Aims

Much of New Zealand's lowland agricultural land was developed by converting vast areas of wetland into pasture through land drainage. This began in the late 19th century, and by the 1960s most of New Zealand's lowland wetlands were converted to agriculture.

With their networks of straight lines and deeply incised channels, agricultural drains are often seen to have low ecological value. However, because they are the remnants of vast areas of wetland, they often make up the only remaining habitat for freshwater species.

Living Water (a partnership between the Department of Conservation and Fonterra) has conducted trials of alternative ways to manage waterways while maintaining drainage functions, including sediment traps, channel shading to reduce weed growth, bank reshaping, two-stage channels and instream habitat enhancements. While generally successful, these trials have been at a small-scale and therefore lack a holistic perspective which could be gained from a catchment scale approach.

The project to re-imagine the drainage network in the Ararira / LII catchment, a 6,760 ha lowland catchment (figure 1) draining to Te Waihora / Lake Ellesmere in the Selwyn District of Canterbury, focused on building a picture of what alternative waterway management could look like at the catchment scale. The project provides a vision for change, and guidance across a range of key activity areas that support a joined-up and collective approach to implementation.

Figure 3 – Ararira / LII Catchment waterway types

Methods

The project team was made up of the hydrological and ecological consultants (Aqualinc, EOS Ecology, Cawthron), a social consultant (Will Allen, Learning for Sustainability), DOC and Fonterra staff, representatives of mana whenua (Te Taumutu Rūnanga) and landowners (via the LII drainage committee), and ECan and Selwyn District Council staff. Through this process of co-design, the project aimed to create enduring outcomes for the rural community, mana whenua and the environment by matching management techniques to problems or values across the catchment and providing an implementation pathway to support the practice change needed. The project team agreed a vision for the catchment, and key values to support this. The past and present state of the catchment, along with the pressures and challenges, were first determined. This then informed the selection of both site-specific and catchment-wide solutions that were most appropriate for the catchment and for different waterway types.

A major component of the methodology for developing the suite of solutions was understanding the waterway types and their spatial distribution. The catchment includes the mainstem of the Ararira / LII River (which has its headwaters in the Lincoln urban area), permanently-flowing and intermittent / ephemeral drains, as well as numerous springs, and the downstream end of a water race network (sourced from outside of the catchment). In addition to Selwyn District Council's rated drainage network, there are a large number of privately-owned drains and informal flow paths that contribute water and contaminants to the network. Site visits and GIS analysis were used to identify waterway types and flowpaths. Solutions that were suitable for the different waterway types were then selected and evaluated against the project's multiple values.

In parallel, a number of key linked activity areas that support the change required to implement such a vision were identified. These were developed from the Ararira project team discussions, past experience from the project team, and "learning the lessons" interviews and analysis from the wider Living Water work and projects. These have also been informed by principles of water governance developed by the OECD Water Governance Indicator Framework.

Results

The key outputs of the project are:

- a Catchment Management Plan (EOS Ecology, Aqualinc and Cawthron Institute, 2023)
- an Implementation Guide (Aqualinc, Learning for Sustainability and EOS Ecology, 2023)

The Catchment Management Plan documents the past and present state of the catchment, the pressures and challenges, and the catchment-scale and site-specific solutions. Solutions include:

- Transformative "better than good" on-farm practices
- Land acquisition / strategic land use change
- Smart systems for drainage monitoring
- Changing maintenance practices
- Bank-reshaping with riparian planting
- Constructed wetlands
- Sediment traps
- Planting and protective interventions
- Instream habitat enhancements

The Implementation Guide identifies twelve key areas that underpin effective implementation of the Catchment Management Plan. Not all of these areas will be necessary in every situation, but missing out on a key area that is needed may result in missing an opportunity for leveraging change:

- Shared direction
- Ensuring a Te Tiriti-based approach
- Partnering, engaging, communicating
- Supporting collective action
- Capacity and capability
- Regulations
- Consenting and compliance
- Financing

- Operational sequencing
- Knowledge, information and insights
- Monitoring and evaluation
- Adaptive management

The project outputs have been handed over to Selwyn District Council and Te Taumutu Rūnanga. A secondary aim of the project is to provide a template for developing management plans for other lowland catchments with land drainage networks. This process is underway for Selwyn District's other drainage networks. Project outputs are also being used to develop a national-scale cost-benefit analysis of lowland drainage restoration.

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OBSERVATIONS OF A SCIENCE ADVISOR: IT AIN'T (JUST) WHAT YOU DO, IT'S THE WAY THAT YOU DO IT

Chris Daughney[1]
[1]NIWA and Te Uru Kahika

Globally and in Aotearoa New Zealand, several interrelated and acute environmental crises are occurring at the same time. These include climate change, biodiversity loss, pollution, and lessening availability of key resources such as water and land. At the same time, our societies are also grappling with a wide range of other social, cultural and economic wellbeing issues.

Science is one form of evidence that helps to identify and implement responses to today's 'poly-crisis'. But not only do we need to consider what research should be undertaken, we also need to think about the way it should be conducted and delivered to be most useful.

I certainly can't claim to know the answers to such difficult questions, but I can try to offer some insights from working simultaneously as a science advisor for two different organisations: the National Institute of Water and Atmospheric Research (NIWA); and Te Uru Kahika. NIWA is a government-owned research organisation charged with delivering benefits for the nation through climate, marine and freshwater science. Te Uru Kahika is the collective of New Zealand's 16 regional authorities, which have statutory local government responsibilities including integrated management of air, land and water, delivering biosecurity and biodiversity functions, and helping communities be resilient to natural hazards and a changing climate.

Using examples from hydrogeology, this presentation will cover topics such as: how science can help organisations navigate the tensions between conflicting goals; how experimentation and lateral thinking can tease out pathways forward through complexity; how communication and 'windows of opportunity' can increase science uptake; how valuable it can be to try to quantify the future benefits of science (and why impact shouldn't be our only objective); and how personal and professional networks can provide resilience when the unpredictable becomes reality.

BEST OF BOTH WORLDS: COMBINING DETAILED HYDROGEOLOGICAL CHARACTERIZATION AND FAST NUMERICAL MODELS USING BULK PARAMETERIZATION

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The fundamental importance of developing rapid and efficient numerical models for groundwater studies is evident in decision support scenarios. Traditional complex numerical models often hinder testing and exploration of concepts and hypotheses, particularly when time and cost constraints are factors. The significance of creating efficient models has grown over the past decade, as techniques like data assimilation and uncertainty quantification have gained widespread acceptance in the groundwater modeling community. On the other hand, the inclusion of detailed hydrogeological features within these models can offer multiple benefits. This not only aids in constraining predictive uncertainty, especially when monitoring data is limited, but also minimizes model deffects stemming from oversimplification and incomplete representation of physical systems. This study introduces a novel approach that involves simulating high-definition hydrogeological features through bulk parameterization. Numerical model parameters are derived by considering a weighted average of the various features present within each model cell. The effectiveness of this methodology is demonstrated through two examples: one in a structurally-controlled volcanic environment and another in a sedimentary aquifer where extensive borehole log data is available. Results from both cases indicate that the proposed models achieve numerical efficiency while aligning well with the conceptualization of the actual systems.

ARE WE UNDERESTIMATING THE NITROGEN CONTRIBUTION FROM GROUNDWATER-DERIVED IRRIGATION?

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Aim
Elevated levels of nitrate in drinking water pose a risk to human health (Ward et al., 2018). In the context of irrigation however, nitrate-containing groundwater becomes useful as a potential source of nutrients for crops. The pump-and-fertilise (PAF) approach consists of pumping nitrate-contaminated groundwater for irrigation purposes. That is, by monitoring the nitrogen concentration in pumped groundwater, and including this ambient nutrient source in calculations of added fertiliser volumes, it is possible to reduce the concentration of nitrate in aquifers (Bastani and Harter, 2019; Liang et al, 2016; Martin et al. 1982). Further to the environmental benefits, the ambient nutrient source in irrigation water presents a potential cost saving for farmers due to a reduction in the required conventional fertilsers (Hayman, 2016). The aim of this research is to estimate the volume of nitrogen applied to the land surface from groundwater sourced irrigation, in a New Zealand agricultural setting.

Method
The Hinds Plain in Canterbury was selected as the case study area. The Hinds Plain covers approximately 1,380 km^2 of mostly agricultural land, bound by the foothills of the Southern Alps, the Rangitata River, the Ashburton River, and the coast. Irrigated agriculture is widespread, and commonly sourced from groundwater that contains elevated levels of nitrate (Dench and Morgan, 2021). As such, the catchment was considered suitable for assessing the potential discharge of nitrogen to land surface.

To calculate the potential discharge of nitrogen to land, a 3-dimensional estimation of the nitrate-N concentration within the Hinds Plains groundwater system was developed. More specifically, a nitrate-N value was estimated at the intake of all 1,088 irrigation bores within the Hinds Plains, and matched with corresponding pumping data to estimate the total discharge of pumped nitrogen to the land surface.

The horizontal and vertical distribution of nitrate-N in groundwater was estimated using Leapfrog™. The input data used to generate the Leapfrog™ estimations was based on the average nitrate-N value in groundwater samples collected between 2017 and 2021, sampled from 64 bores. The average nitrate-N value from each bore was assigned vertically to the middle point of each well screen.

Results
The results of this study show that the average concentration of irrigation water applied to land within the Hinds Plains contains 9.17 mg/L nitrate-N. The authors are in the process of calculating the mass load by linking the nitrogen estimations with pumping data and will present this at the oral presentation.

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GROUNDWATER CONCEPTUALISATION EAST OF LEVIN, LOWER NORTH ISLAND – ŌTAKI TO NORTH OF LEVIN ROADING PROJECT

James Dommisse[1], Eleni Gkeli[2], Ken Clapcott[2], Hisham Zarour[2]

1 GHD

2 Stantec New Zealand Ltd

Aims

Stantec undertook ground investigations between 2021 and 2023 to assess the geological, geotechnical, and hydrogeological conditions for a proposed 24 km road corridor from Ōtaki to north of Levin (Ō2NL), on the west coast of the Lower North Island for Waka Kotahi (Figure 1). On its completion, the new road will provide improved safety and resilience as well as supporting growth in the region. One focus of this investigation, and discussion for this presentation, is the road corridor east of Levin. For this investigation, Stantec worked with Waka Kotahi and partners Muaūpoko Tribal Authority and hapū of Ngāti Raukawa ki te Tonga, sharing information, ideas and ultimately helping to avoid potential impacts from the new road, especially on Lake Horowhenua.

Prior to the ground investigations, there was limited information on the groundwater east of Levin. Existing bores were generally screened from 20 m to 40 m below ground level, with water levels ranging from 15 m to 30 m below ground level. It was assumed that an unsaturated zone thickness of at least 10 m from ground level existed beneath this section of the road. As such, initial road design options included a vertical alignment with an 8 m deep cut below ground level. Investigations had initially preferred cut options as it appeared to be a lower effect option in terms of potential effects of new state highway adjacent to existing and planned urban development, as well as providing potential source for material.

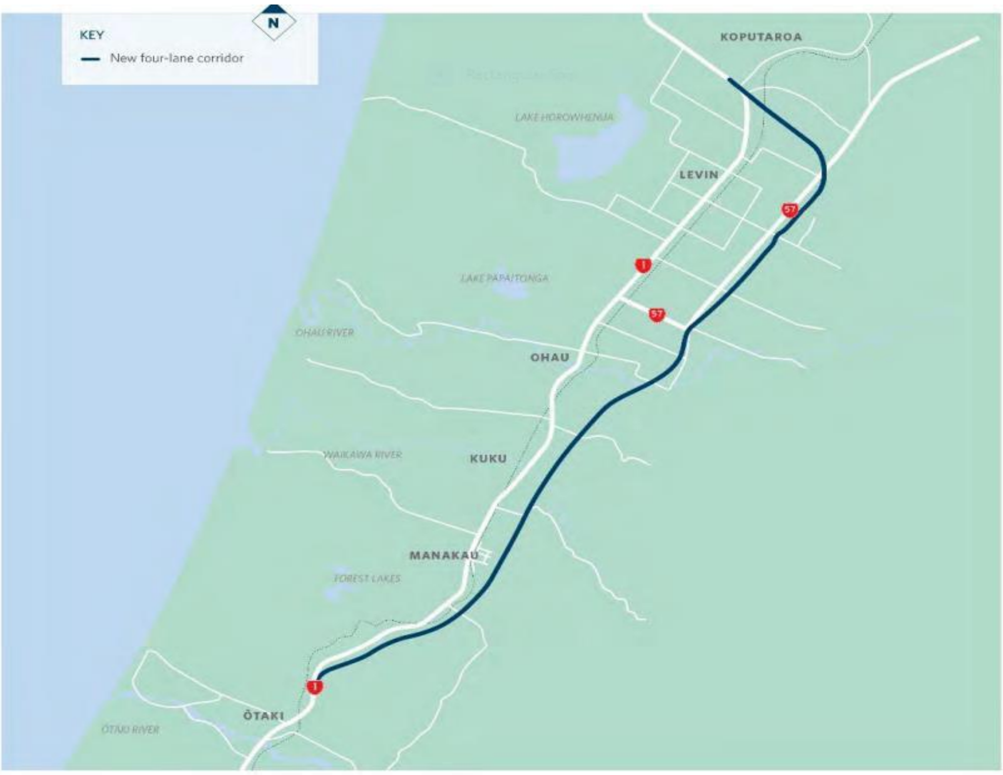

Figure 1: Schematic of the new Ō2NL highway

Method

Iwi were involved early and throughout the Project decision making on road design and particularly with regards to water. Ground investigations were undertaken across multiple stages of work and Iwi involvement helped set the objectives and priorities for each stage. Practical examples included updating iwi with information on depths to groundwater, seasonal variations in water levels, and spring locations. This led the ground investigation to focus much more heavily on understanding groundwater east of Levin, with additional bore holes, water level monitoring and sampling undertaken in this area.

During the ground investigations, east of Levin, approximately 20 nested and single standalone monitoring bores were constructed over an 8 km section of the proposed road east of Levin. The bores were screened into alluvial gravel material at many depths, ranging from 2 m to 20 m below ground level. Many of the bores were fitted with pressure transducers to automatically record groundwater levels and capture seasonal and groundwater recharge events.

Results

Water levels from bores east of Levin showed a large vertical hydraulic gradient with depth to groundwater highly dependent on the screen depth. There was no evidence for perched groundwater, or clearly defined layers of different material hydraulic properties that might be causing this. Water levels in shallow bores (screened < 5 m deep) were as high as one metre below ground level, intermediate depth bores (screened 5 m to 10 m deep) were around 5 metres below ground level, and bores with deeper screens had deeper water levels again. The information was interpreted to show that this section of the road is located in a groundwater recharge zone. It was also observed that the deeper the bore, the larger the seasonal variation in groundwater level.

One take home message is to not assume that a lack of shallow bores, and deep groundwater levels, means that shallower groundwater is absent. Maybe there was a preference for landholders to avoid shallow groundwater and screen their bores at deeper depths to obtain higher yields or better-quality water? Or maybe people were following what their neighbour was doing, or the advice of their drilling contractor?

Iwi partner involvement helped shape the ground investigation program and ensure that the road was designed to avoid any potential environmental impacts. Following completion of investigations, the cut option was discontinued because of effects on groundwater, the cultural effects of a cutting through 'Horowhenua' and the difficulty of accommodating overland and groundwater flow across the cutting in a manner that was not cost prohibitive and did not mix catchments. There was also concern about potential effects of a cutting on streams and on Lake Horowhenua. These investigations were undertaken in partnership with Iwi Partners.

PROCEDURE AND TOOL TO STREAMLINE GROUNDWATER MODEL ASSESSMENTS TO ENSURE FAIR AND SUSTAINABLE MANAGEMENT

Rachel Dewhurst[1], Fabienne d'Hautefeuille[2], Richard Green[2], Llyle Sawyer[2], Hisham Zarour[3]

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2 New South Wales (NSW) Department of Planning and Environment (DPE)

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Aims

DPE provides groundwater advice on Major Projects in NSW. Assessment of environmental impacts commonly include groundwater models. Table 1 presents exaxamples of Major Projects in NSW that require groundwater modelling. The sensitivity of model environments vary from low to moderate.

Similarly, the models vary in technical complexity. DPE reviews groundwater models to assess their fitness for purpose and technical robustness. To create a collaborative, transparent, fair, and enabling environment for the preparation and reviewing of groundwater models in NSW, DPE commissioned the preparation of a groundwater model assessment procedures and evaluation tool (GW-PET). It includes a proprietary computerised Groundwater Model Assessment Tool (GW-MAT). The procedure and criteria are compatible with the guidance provided in the NSW minimum groundwater modelling requirements for Major Projects (DPE 2022) and the Australian Groundwater Modelling Guidelines (Barnett et al. 2012).

Table 1: Examples of Major Projects in NSW that require groundwater modelling.

Mines, quarries, and gas	Infrastructure & energy production	Residential, commercial, and services
Mining exploration and operation: Underground coal mines (long wall, bord and pillar, drive shafts), hard rock mineral mines (open cut and underground), open cut coal mines, underground mineral sand mines	**Power stations:** Solar farms, hydroelectric stations, transmission lines, substations, wind farms, battery farms	**Residential:** Subdivisions, basement car parks, tower blocks
Quarries: Sand dredge (rivers or coastal dunes), hard rock, gravel (river dredge), limestone	**Roading infrastructure:** Motorways, tunnels, road cuttings, bridges	**Commercial:** Transport depots, intensive farming (piggeries, chickens, fish), abattoirs, industrial estates, office/commercial towers
Gas: Coal seam, conventional	**Railway Infrastructure:** Overground railway lines, underground railway lines, underground stations, tunnels, bridges	**Services:** Hospitals, correctional facilities
	Utilities: Water supply (pipelines groundwater supply bore fields), waste management facilities (landfills)	

Method

The Project collated data on groundwater model review via a widely publicised online survey. The survey, completed by 90 global practitioners, questioned what made a good groundwater model, and where it was common for errors or a lack of information to occur. Respondents identified conceptualisation, data availability and boundary definition as common key deficiencies. Calibration criteria were commonly water balance error and groundwater peak shape and decline, while most respondents, outside of Australia, did not use PEST or predictive uncertainty modelling. Respondees commented on the lack of data reporting, or misuse of that data to represent system either in a way that is too complex, or too simple, and the exclusion of data either because they cannot be modelled in the tool selected or is inadequately constrained. There is a perception that models are constructed without first considering the purpose of the modelling exercise and the hydrogeological conceptualisation.

Results

Different levels of skills and effort are required for competent development and review of groundwater models. To help determing the appropriate level of modelling experties, DPE produced a **G**roundwater **M**odel **C**omplexity **A**ssessment **M**atrix (GM-CAM) (Figure 1).

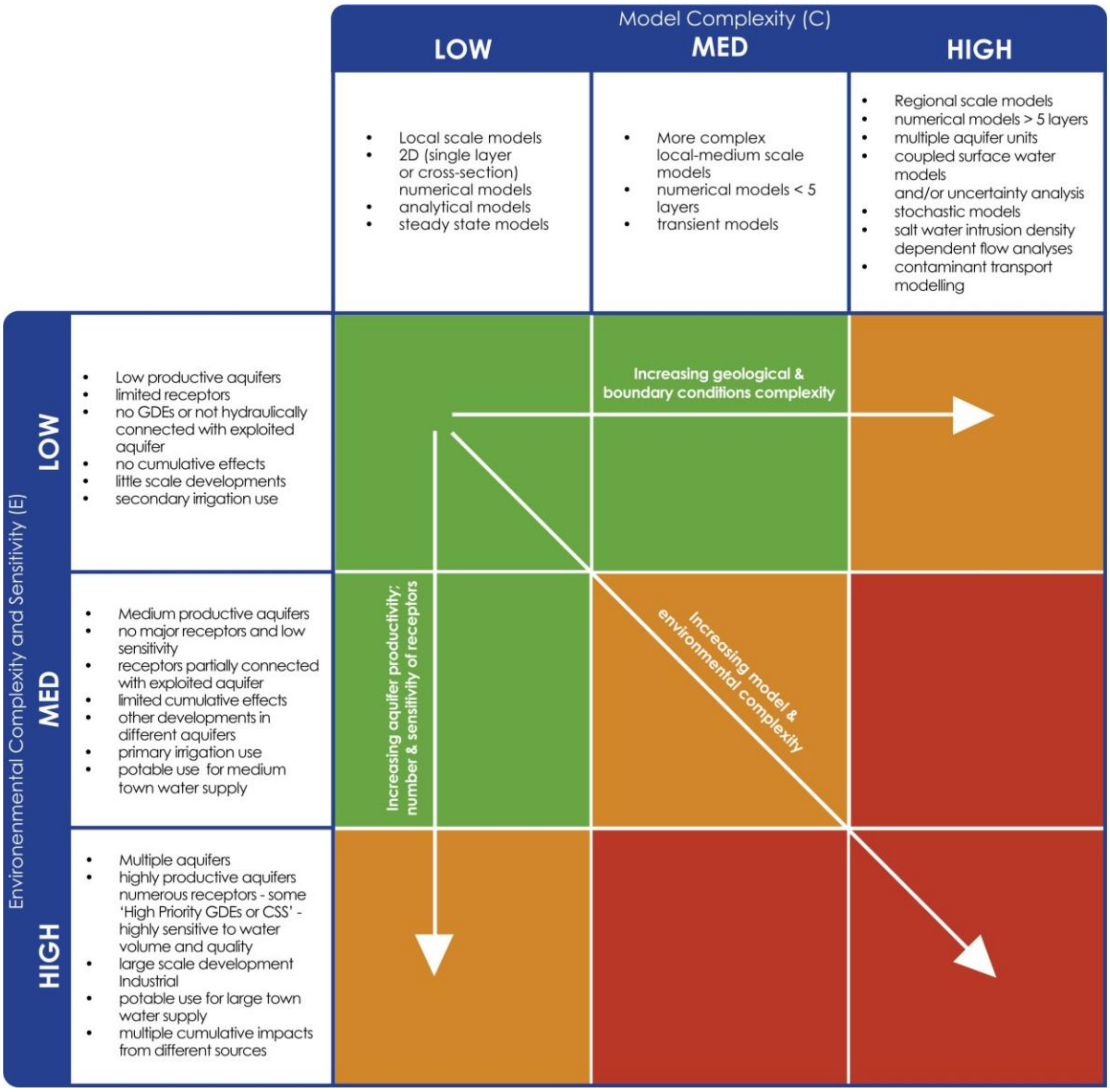

*Figure 1: **G**roundwater **M**odel **C**omplexity **A**ssessment **M**atrix (GM-CAM).*

DPE's GW-MAT tool brings insight from the survey, together with international guidelines, and assessment of the minimum requirements for a major development model, into a consolidated Excel tool. It incorporates a standard scoring matrix, assessment of cumulative impacts, and defined criteria for acceptance of an application. Use of the tool enables DPE to ensure a consistent approach to protecting the water environment, while enabling development. In developing the tool, DPE have increased awareness of applicants that a mathematical/numerical model is not always the answer to getting consent and thorough conceptualisation, and the use of good data, is the key.

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GROUNDWATER RECHARGE FROM THE UPPER SELWYN RIVER OVER THE LAST DECADE DERIVED USING SATELLITE IMAGES

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[2] ENGEES
[3] Suez Consulting

The Selwyn River, flowing across the Canterbury Plains from the Southern Alps foothills to Lake Ellesmere, holds significant importance for water resources and biodiversity. Recently, Di Ciacca et al. (2023) introduced a framework to estimate transmission losses in ephemeral rivers using satellite images, which they applied to the Selwyn River data from April 2020 to May 2021. One of the key findings was that groundwater recharge to the regional aquifer system could be derived from these estimates by excluding data points shortly after flood events. In our study, we employed the same approach but with a longer timeframe, utilizing the extensive flow record from Whitecliffs and the full Planet Monitoring satellite image collection. This allowed us to estimate the wetted river length and groundwater recharge from the Selwyn River between Whitecliffs and the Hororata confluence, from 2010 to 2020.
Our findings revealed a compelling linear correlation between average transmission losses and the logarithm of river discharge. Leveraging this relationship, we predicted the annual groundwater recharge from the upper Selwyn River, which ranged between 55 and 110 million m^3, with an average of approximately 80 million m^3. Notably, the years 2013, 2017, and 2018 were the wettest, experiencing the highest recharge volumes, exceeding 95 million m^3. In contrast, the driest years, 2015, 2016, and 2020, had lower recharge volumes, falling below 65 million m^3. During wet years, approximately 0.7 of the annual flow contributed to recharging the regional aquifers. In contrast, during dry years, this percentage increased, approaching one, and the river dried up in our study section most of the time (> 90%), resulting in almost all its water being lost to the underlying aquifers. Current work is focused on the interpretation of these results and the investigation of their correlation with climate, surface water and groundwater data.

Di Ciacca, A., Wilson, S., Kang, J., Wöhling, T., 2023. Deriving transmission losses in ephemeral rivers using satellite imagery and machine learning. Hydrol. Earth Syst. Sci. 27, 703–722. https://doi.org/10.5194/hess-27-703-2023

MODEL SIMPLIFICATION TO SIMULATE GROUNDWATER RECHARGE FROM BRAIDED RIVERS

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[2] Technische Universität Dresden

Braided rivers are an important source of groundwater recharge in New Zealand, but their interactions with groundwater are complex and highly variable in space and time. Recently, the gravels of the contemporary braidplain of these rivers have been described and referred to as the 'braidplain aquifer'. It is within this aquifer that hyporheic and parafluvial flows occur and through this aquifer that the river is recharging the regional aquifers. This complexity calls for the use of 3D fully integrated hydrological models to represent groundwater – surface water interactions in these environments, but their computational intensity limits their practicality for parameter inference, uncertainty quantification and regional scale problems.

We present a modelling framework that combines a 3D fully coupled HydroGeoSphere model, three 2D cross-sectional HYDRUS-2D models (with 1, 2 and 3 distinct layers) and an analytical equation. This framework aims at simplifying the model while ensuring the appropriate simulation of the groundwater recharge. We demonstrate our modelling approach on the Selwyn River as piezometric data and groundwater recharge estimates, derived from satellite imagery, were available. First, stochastic simulations were run using the 2D models and compared to observations, to test different subsurface conceptualizations and parameter values, which were subsequently used to parameterize the 3D model. Next, the groundwater recharge simulated by the 3D, 2D and analytical models were compared.

Our results demonstrate that a minimum of 3 distinct layers, including a lower permeability layer in the middle, were required to reproduce the observations. Moreover, we show that the model complexity can effectively be reduced but this introduces uncertainties due to the simplifying assumptions. We conclude that braided rivers can be incorporated into regional groundwater models by considering the base of the braidplain aquifer as an impeding layer, but the water level and the width of the braidplain aquifer need to be estimated.

UNDERSTANDING IMPACTS OF MINING ON GROUNDWATER USING EXPLORATORY DATA ANALYSIS (EDA)

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[1] WSP

Aims

Exploratory Data Analysis (EDA) was used to identify influences on groundwater behaviour across a 40,000+ hectare area as part of a site-wide surface water catchment risk assessment.

The EDA explored relationships between the depth to groundwater (DTW) and various topographic, climatic, vegetation and land use factors. Where groundwater levels are closer to surface, there is an increased risk of groundwater discharge which potentially could lead to surface water salinity impacts. The understanding of factors that influence depth to groundwater contributed to an index-based risk methodology that identified areas with an elevated risk of groundwater discharge to surface. In combination with risk factors considered in the site-wide surface water risk assessment, mine planners are able to plan mitigation measures to manage any potential issues unique to specific catchments.

This abstract discusses the EDA process, and the index-based risk approach is discussed in a separate abstract.

Method

WSP was supplied with over 186,000 individual groundwater monitoring measurements from 2,171 bores, covering the period from May 1974 to March 2023. Each unique groundwater monitoring reading was assigned temporal and spatial attributes extracted from various public and client-provided datasets (Figure 1). The aim was to assign data from a variety of sources to capture the most relevant information to reflect actual conditions and allow a level of forecasting for planners to make proactive and informed decisions.

The selected natural parameters included in the EDA were topography-related indexes e.g. Topographic Wetness Index (TWI), Multi-resolution Valley Bottom Flatness (MrVBF) and Topographic Position Index (TPI); upstream Leaf Area Index (LAI)); rainfall (60 day and annual); and evaporation. These datasets were primarily chosen due to their availability and reduced processing time due to tight deadlines.

The EDA approach used a combination of correlation analysis and two machine learning methodologies - Principal Component Analysis (PCA) and Feature Importance - to collectively offer a comprehensive evaluation of the interactions among the selected natural parameters and their correlation to DTW. This enabled an understanding of the extent to which the parameters influence each other and their impact on the overall system. The application of PCA identified the most significant underlying patterns or components within the dataset, simplifying its complexity and facilitating interpretation. The evaluation of Feature Importance provided insights into the relative significance of different parameters in influencing DTW.

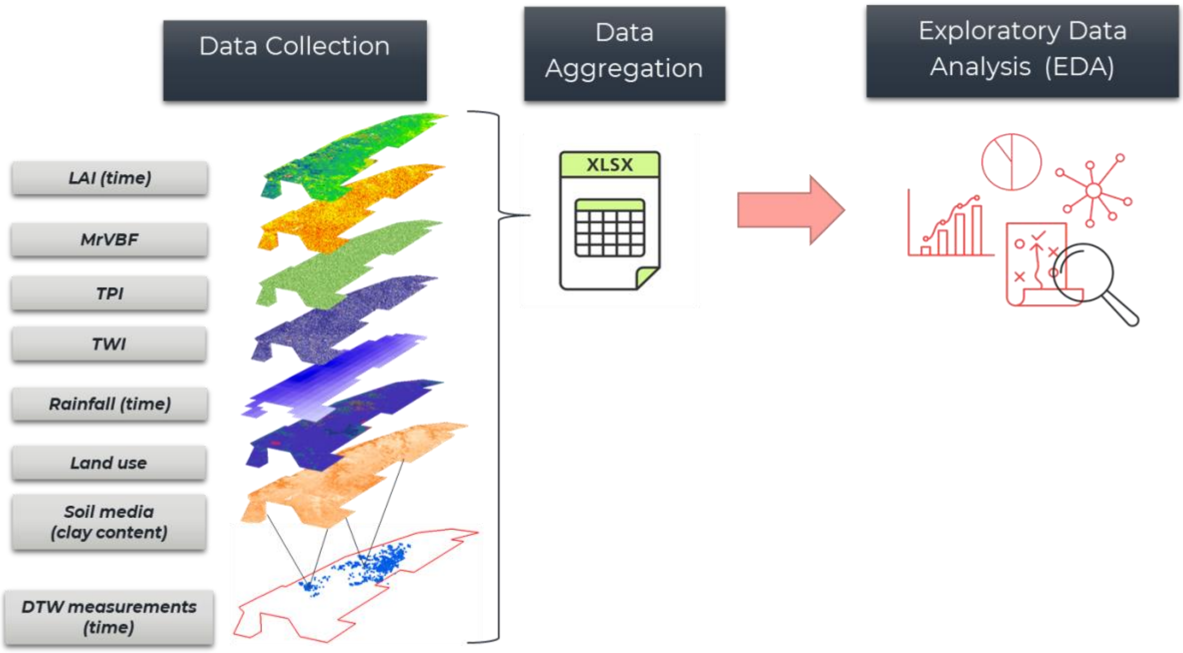

Figure 4 EDA methodology

Results

Using a simplification process, where natural parameters are separated into bands (or ranges), the EDA correlation demonstrated relationships between various natural parameters with respect to DTW. The strongest correlation with DTW was the topographical-related indexes such as landscape position. Correlation was weaker for LAI, which was not consistent with what was expected.

Results from the PCA also indicated a strong relationship between DTW and the landscape position indexes as did Feature Importance. This suggested that terrain characteristics and wetness indices significantly impact DTW predictions.

Due to the 'noise' with the various datasets, further refinement will be undertaken as it is believed that combining various natural parameters will allow for greater understanding and forecasting of groundwater rise and fall in response to mining.

WHEN NUMERICAL GROUNDWATER MODELS SHOULD TAKE THE BACK SEAT...

Isabelle Dionne[1]
[1] Rio Tinto Iron Ore

The author of these lines does not believe numerical groundwater models are obsolete or not fit for purpose to answer most groundwater questions but argues that for certain problems other tools available these days can do a better job. In the Pilbara, Western Australia, mine dewatering is fundamental to the viability of most mines and requires large resources and management. During mine dewatering operations, groundwater models need to be regularly updated and recalibrated, and multiple predictive scenarios are frequently requested, requiring significant time and effort by the modelling team. For this study, time series analysis is used as an alternative to numerical groundwater modelling to quantify and predict the effects of open pit mine dewatering during operations. Time series analysis is a data-driven approach to help uncover relationships between input (stresses) and output (head) signals. Time series analysis models are much easier and quicker to build than conventional numerical groundwater models, and often provide a much better model-to-measurement misfit at an observation well. The relative simplicity, small number of parameters and short amount of time required to develop, calibrate and run a model make time series analysis a great tool for modellers. These advantages become more obvious in the mine operations space where mine plans are continually changing, and data are readily available. The performance of time series models to simulate the effect of pumping wellfields for mine dewatering is showing great promise, both during calibration and prediction, but like any modelling approach has its challenges and limitations.

HOW WELL IS THE WELL?

<u>Matt Dodson</u>,[1] **Ollie Gibson,**[2] **Mel Griffiths**[3]
[1] GHD Limited
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[3] Griffiths Drilling Limited

Aims
Wellington Water Limited (WWL) have assessed the condtion of five of their public supply wells (aged between 35 to 47 years) within the Waterloo and Gear Island borefields, in order to inform a well replacement strategy. These wells, which are approaching their design life, are critical assets for WWL and understanding their condition is an important consideration for future proofing the region’s water supply. GHD, RDCL and Griffiths Drilling undertook this work and reported on the results of the survey.

Methods
Information and data analysed for this project came from a range of sources, including:

1. Well surveys that collected:
   - Downhole wireline scanning data (Mechanical Calliper, Acoustic and Optical Televiewer).
   - Downhole camera footage.
   - Field observations including casing, well head, riser and pump condition.
2. Literature review.
3. Drawdown levels.
4. Groundwater quality data collected from source (grab samples and SCADA data).

Field surveys took between 3-5 days per well and produced a detailed understanding of the condtion of the wells at that point in time. Condition assessment methods developed by GHD (2010) were used to estimate the relative life expectancy of the wells. The relative life expectancy method charaterises the condition of wells using a number of criteria (hydorgeological, maintenance schedule, well use etc.) and then plotting the results on a matrix.

Results
All the bores showed signs of deterioration, which is not unexpected given their age and that they are installed in a slightly acidic aquifer (pH generally less than 7, greater than 6). The bores are likely to continue to deteriorate over time.The results of the relative life expectancy method plot near the centre of matrix, which is consistent with the survey results (i.e., likely signs of deterioration, but no obvious indications of major, large defects). The survey results provided WWL with significant asset management benefit, whereby they could justify the reallocation of capital spending to other projects of greater immediate need.

References
GHD 2010. *Groundwater bore deterioration: Schemes to alleviate rehabilitation costs*. National Water Commission Water Report Series No 32. October 2010.

DATA SPACE INVERSION: REAPING THE BENEFITS OF MODEL COMPLEXITY

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[1] Watermark Numerical Computing and GMDSI
[2] CHYN, University of Neuchatel

Integrated, surface-subsurface, hydrological models (ISSHMs) such as HydroGeoShere are finding increasing use because of their ability to simulate complex flow and transport processes over a multitude of temporal and spatial scales. This comes with a numerical cost, however; their slow run times make assimilation of site data difficult. This limits the information that they can harvest from these data, and hence the decision-support services that they can provide.

Two relatively new technologies have the potential to change this. The first is an ability to generate complex three-dimensional stochastic hydraulic property fields based on spatially-varying variograms. These can populate structured, as well as unstructured, model grids. The second new methodology is data space inversion (DSI). Based on the outcomes of only a few hundred model runs that employ stochastic fields of arbitrary complexity, DSI constructs a statistical relationship between the measured past and the decision-pertinent future. This relationship is encapsulated in a stochastic model. This model can be history-matched against whatever field data is available. Robust predictions of future system behaviour can then be made, and the uncertainties of these predictions explored.

A synthetic example that represents the typical configuration of drinking water production wells in a near-stream alluvial aquifer is used to demonstrate DSI. It shows how explicit simulation of environmental gas tracers such as ^{222}Rn and ^{4}He can enable assimilation of borehole measurements of their concentrations, thereby exposing and reducing uncertainties associated with predictions of water quality in near-stream extraction wells during and after a pollution event. This information can be used to optimise the design of a monitoring system that can support early pollution-event detection, and optimisation of bore field management at times of water supply vulnerability.

LAG TIMES AND FLOW PATHWAYS FOR RIVERS: DEVELOPING ROBUST NATIONAL SCALE METRICS USING STABLE ISOTOPES

Bruce Dudley,[1] Alice Hill,[2] Andy McKenzie,[3] Jing Yang[1]
[1] NIWA, Christchurch
[2] NIWA, Nelson
[3] NIWA, Wellington

Sub-surface flow pathways and transit times of water to rivers are vital catchment characteristics that determine how climate change and land use affect surface water quality and flows. These catchment characteristics may determine the appropriateness of water quality mitigation methods, and water allocation and land use decisions.

Conservative hydrologic tracers remain reliable, accurate tools to partition river flows among flow pathways, and calculate transit times; hydrogen (H) and oxygen (O) stable isotopes provide the data for particularly powerful methods to quantify the young (less than a few months old) fraction of river flow. H and O isotopes also have the potential to be integrated into the next generation of 'isotope-enabled' hydrological models, which are designed to provide accurate flow-source partitioning and flow estimates outside the range of historical climate conditions.

Currently, the use of H and O stable isotopes as hydrologic tracers in New Zealand is hindered by the requirement for extensive, non-routine precipitation sampling. These sampling requirements limit the spatial scales of studies using stable isotopes, and hence decision making based on them. To address this, NIWA are collaborating with GNS, Scion, citizen scientists and regional councils to develop national-scale, time varying precipitation isotope models (isoscapes).

In this talk, I describe development of time-varying precipitation isoscapes for New Zealand. This has comprised an extensive programme of sampling, and a range of statistical modelling techniques. Using the examples of forested and unforested catchments I describe how we combine these precipitation isoscapes with regular river water sampling to provide comparitive measures of transit times for rivers.

Results indicate that precipitation isoscapes can now be combined with regular river sampling to provide robust comparisons of young water fractions at a regional level. Further work is required to compare catchments at national scale.

THERE'S SOMETHING FUNKY GOING ON BELOW LAKE HAWEA: DETERMINISTIC GROUNDWATER MODELLING, GLACIAL GEOMORPHOLOGY, AND HAIR-LOSS.

Matt Dumont[1] Jens Rekker[1]
[1] Komanwa Solutions Ltd.

The Lake Hawea groundwater system is an unconfined – semi confined groundwater system located in the Quaternary sediments infilling the graben between The Cardrona and Grandview Faults. The aquifer is bounded by Lake Hawea on the North and the Clutha River on the South. The sedimentology is dominated by a sequence of glacial and periglacial deposits. The system was previously modelled using a steady state, 2D (1 layer), model in 2011. Since 2015 a number of high frequency monitoring bores were introduced which allows transient modelling to better constrain the relationship between Lake Hawea and the groundwater system. As part of an upcoming plan change the Otago Regional Council commissioned an updated groundwater model of the aquifer system.

Here we present the new groundwater model. The transient observations show that groundwater levels are highly correlated with the Lake Hawea stage, but that there is a significant vertical gradient between the lake and the groundwater system. Our hard won results suggest that the new transient observations are incompatible with the previous model structure. Instead, we propose that a complex glacial-geomorphological structure is required to replicate the new observations. We wax poetically about the possible nature of that structure and discuss its implications – specifically that the groundwater system could become disconnected from Lake Hawea and see significant declines. Finally, in an odd twist of fate, we are proven right.

NEW ZEALAND’S ABILITY TO DETECT REDUCTIONS IN AGRICULTURAL NITROGEN CONTAMINATION IN GROUNDWATER

Matt Dumont[1] Zeb Ethridge[1] Evelyn Charlesworth[1] Richard McDowell[2] Olivier Ausseil[3] Alasdair Noble[2]
[1] Komanawa Solutions Ltd.
[2] AgResearch
[3] Aquanet Consulting Ltd.

Groundwater provides base flow for surface water and is an important source of drinking water; however many areas in New Zealand have enriched groundwater nitrate-nitrogen (N) concentrations. Reducing groundwater N concentrations is an essential component of meeting the National Bottom Line of 2.4 mg/l N in surface waters. In addition, concentrations above half of the MAV (MAV = 11.3, 1/2 MAV = 5.65 mg/l N) burdens drinking water providers with additional monitoring requirements. This has led a number of regional authorities to require a reduction in N loss rates from agricultural land. The rate at which these reductions are implemented (e.g. a 10% reduction every 10 years) often seek to balance economic and environmental goals, but the ability of the available monitoring networks to detect these changes is often overlooked. Temporal variability in observed N concentrations and groundwater travel times (e.g. lag) reduce the probability of detecting N reductions at the specified implementation rates and often leave regional authorities and stakeholders without a mechanism to determine if on-farm actions, which require major investment, are achieving the desired outcomes.

As part of the National Science Challenge’s Our Land and Water programme, we have developed a python package to estimate the statistical detection power of groundwater monitoring wells. We have incorporated the ability to model multiple N loss reduction pathways and have included several common age distribution models to account for groundwater travel times. In addition, we have compiled a national dataset of groundwater N monitoring wells. We then conducted analysis on all of these monitoring points to ascertain whether or not the current monitoring regime is sufficient to detect a range of probible groundwater N reductions. Finally, we provide an indicative estimate of the level of investment that would be required to confidently detect these changes within a timely manner.

USING STRONTIUM ISOTOPES ($^{87}SR/^{86}SR$) AND END-MEMBER MIXING ANALYSIS (EMMA) TO DISCRIMINATE FLUX MIXING PROCESSES IN COMPLEX THERMO-MINERAL HYDROSYSTEMS

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In non-tectonically active zones, the diversity of spring hydrochemical properties results from an accumulation of multi-factorial processes including biotic activity, residence time, water-rock interactions or from mixing between deep inflow, local aquifer and the subsurface. However, discriminating each pathway and its impact on groundwater mineralization is a complex exercise for hydrogeologists and modelers.

This study applied a multi-tracer approach combining geochemical and isotopic environmental tracers ($\delta^{18}O/^{2}H$, $^{87}Sr/^{86}Sr$ and ^{3}H) to differentiate regional (inter-aquifer) from local (intra-aquifer) water-rock interactions and subsurface mixing through End-Member Mixing Analysis (EMMA).
For this purpose, 22 mineral water representatives of complex mixing processes in diverse geological contexts were collected in the eastern part of Corsica Island (France). The groundwater samples were compared to 12 magmatic, metamorphic, and sedimentary rock samples of the study area, which were analyzed for oxide (SiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O), Rb and Sr content as well as $^{87}Sr/^{86}Sr$.

First results highlight a wide range of $^{87}Sr/^{86}Sr$ in spring water (from 0,7095 – 0,7202) controlled by water-rock interactions within the regional geological units (with whole rock $^{87}Sr/^{86}Sr$ ranging from 0.7083 in schist to 0.7499 in granitoid rocks). The ionic composition of Sr and Rb were used to determine the alteration degree of the predominantly percolated rocks. The Sr, Rb content and $^{87}Sr/^{86}Sr$ signature were subsequently compared with $\delta^{18}O/^{2}H$, ^{3}H or NO_3 content in water, allowing the mixing model to discriminate inter- and intra- aquifer mixings from surface waters influx.
This ongoing work aims to quantify inter- and intra- aquifer mixing processes at the regional scale and refine the vulnerability assessment of local hydrosystems. The improved understanding and quantification of mixing processes will help to improve management and protection of the groundwater resources across Corsica Island.

IMPROVEMENTS IN GROUNDWATER MODEL CALIBRATION WITH DYNAMIC TIME WARPING (DTW)

Dariarne Edwards,[1] Brian Rask,[2,3]
[1] SLR Consulting Australia Pty Ltd

Groundwater model calibration plays an important role in minimising uncertainty, improving predictive accuracy and the reliability of model results. Misguided calibration can lead to potential biases and hinder effective decision-making and risk assessment based on model outputs.

PEST is a widely utilised software for automated groundwater model calibration, that optimises model parameters by minimising the objective function. The objective function is assessed through comparison of observed data and corresponding model outputs. When temporal trends in stresses, such as pumping rates, recharge rates, and other boundary conditions, are inadequately captured in the model setup, it can hinder the model's ability to accurately match the observed responses, despite parameter optimisation. This can give rise to the issue of 'flattened' responses, where PEST minimises the objective function by muting the simulated response to a stress. In many cases, while PEST can be successful in minimising the objective function, calibration hydrographs often show the calibrated model achieves a poor match to observed trends.

To overcome this problem, this study tested Dynamic Time Warping (DTW) combined with PEST. DTW has been successfully utilised in calibration in various modelling applications however DTW has not yet been documented for use in numerical groundwater model calibration with PEST. In this application, DTW works by allowing PEST to consider the objective function after the manipulation of model outputs through non-linear mapping of observed to simulated time-series data.

A simple, synthetic groundwater model was built to assess the effectiveness of DTW during PEST calibration. Temporal errors were introduced in the model setup. The model was calibrated in parallel, using DTW-PEST combined and by using PEST only. Comparison of the calibrated model hydrographs showed that the integration of DTW-PEST presents a legitimate solution to the issue of 'flattened' simulated responses, when compared to calibration achieved using PEST alone.

ASSESSING SUBSIDENCE IMPACTS FROM CSG GROUNDWATER EXTRACTION: LEVERAGING LIDAR TO ESTABLISH BACKGROUND LANDFORM CONDITIONS

Dean Erasmus[2], Steve Flook[1], Sanjeev Pandey[1], Jenna McGovern[1]

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The process of coal seam gas (CSG) extraction involves pumping out water and releasing gas trapped within the coal seams. The groundwater pressure reduction and coal layer shrinkage lead to subsidence or ground movement above the extraction area. Understanding slope and spatial variability is necessary to assess subsidence and the potential for change. The consequences depend on both the magnitude of subsidence and the background slope - where a location has a low slope, minor subsidence may have higher consequences.

Light Detection and Ranging (LiDAR) is a laser scanning technology that produces three-dimensional representations of the Earth's surface and objects. This study explores the application of LiDAR-derived Digital Terrain Models to establish background landform conditions in dryland and irrigated cropping lands of the Condamine Alluvium – examining attributes such as slope and surface drainage – to assess changes in response to natural, anthropogenic, and coal seam gas induced subsidence.

By utilising multiple LiDAR acquisitions at different time intervals, where possible, the study provides a basis for statistically evaluating background variability for different land use and slope classes. Integrating LiDAR data with other geospatial datasets, such as high-resolution imagery, groundwater extraction information, and Interferometric Synthetic Aperture Radar (INSAR) data, assists in identifying LiDAR acquisitions representative of background conditions.

EMPLOYING DENOISING METHODS FOR DEFINING BASE POWER OF MICROWAVE LINK FOR ENHANCING RAINFALL ESTIMATION

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[1] The University of Waikato
[2] Toi Ohomai Institute of Technology

Commercial Microwave links (CMLs) have emerged as a promising tool for rainfall rate estimation due to their sensitivity to atmospheric attenuation caused by precipitation. The drop in the power of the CML signal due to precipitation is related to the rainfall rate, making the base power a reference for comparing fluctuations due to rainfall attenuation. Nevertheless, it's important to note that the reference power level is not constant and changes over time. Conventional methods of CML rainfall estimation often rely on calculating the median of dry periods within the last 24 hours. However, this approach has limitations, and researchers are actively exploring alternative methods to enhance accuracy and mitigate the wet antenna effect.

Aims

In this research, we examined a range of signal-denoising methods to define the base power of the microwave link to be used in rainfall estimations. The methods investigated include moving average, Butterworth, and Chebyshev filters. The study investigates electromagnetic concepts in the attenuation of waves instead of hydrological concepts of wet-dry periods and rainfall duration to detect falling in power due to rainfall from other sources of fluctuations.

Method and Materials

Data was applied from a study in the Netherlands for four CML links, covering a study period of 300 days. The power of the microwave signal was logged 20 times per second. Therefore, they aggregated to 30-second steps to be used as the time step of all methods. The well-known relationship between signal attenuation (*A*) and rainfall (*R*) with suggested constants (*a* and *b*) are used for calculating rainfall intensity ($R = aA^b$). The attenuation was calculated with different reference power for each method.

Analysis was conducted to minimise the RMSE of the simulated rainfall when using different methods for defining the base power. Codes in R prepared to apply each method. Reference power is calculated by the median of dry periods within the last 24 hours for the conventional method. An R package, signal, is used for Butterworth and Chebyshev filter calculation. Then, the wet antenna parameter (*Aa*) is optimised for each method to find the best result. Prior to the Aa analysis, filtering factors also were calculated by iteration to reach the best performance in NSE, RMSE and R-squared values.

Results

The results demonstrate that the denoising methods perfectly rival the conventional median approach in estimating the base power. The results show a significant change in the base power level, and filters present a closer power level to the time series of power. Figure 1 compares three filters of moving average, Butterworth and Chebyshev versus the conventional median method for seven hours of records.

The denoising methods produced notable results for simulating 300 days of rainfall. The moving average filter achieved an impressive NSE of 0.82, outperforming other methods. The Butterworth filter and Chebyshev method also demonstrated comparable results with NSE values of 0.80 and 0.74, respectively. Furthermore, the RMSE values for the three methods improved significantly from 0.56 in the median to 0.50 for the moving average and 0.51 for Butterworth filters.

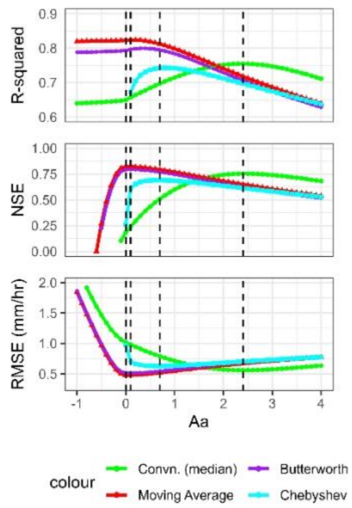
Although some methods show less error and higher precision, however, the accuracy of the estimation of rainfall by different methods, including the conventional method, varies from day to day, Figure 3 shows rainfall estimation by 4 different methods compared to the conventional technique.

The other finding is the effect of *Aa* in different methods. Optimisation shows that the highest required *Aa* value is for the median method by *Aa*=2.4, while the lowest is found to be zero in the moving average method. The Butterworth filter also needs an *Aa* as low as 0.1, while Chebyshev optimised NSE and RSMSE at *Aa* equal to 0.7. Figure 2 shows the performance of different filters versus the conventional median method and indicates the *Aa* position for four methods. This achievement reduces the number of unknown factors and consecutive errors.

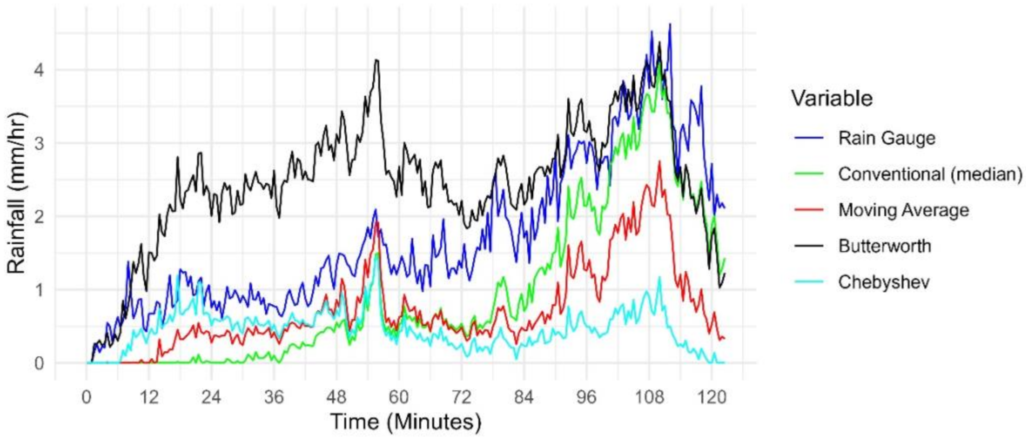
Rainfall simulation accuracy varies over time. To assess the effectiveness of each method across different periods and rainfall events, we calculated NSE, RMSE, and R-squared for 10-day intervals throughout the 300 days. Figure 4 illustrates the NSE variation for each method in 10-day periods. The results reveal that no single method consistently predicts rainfall with the highest accuracy.

In conclusion, this research highlights denoising methods' potential for rainfall rate estimation by CMLs, showing accuracy improvements and reduced wet antenna effect impact with reliable accuracy. In conclusion, the moving average method could result best in rainfall estimation in this site.

- *Figure 1: Comparing the base power in filtering methods with the conventional median method*



- *Figure 2: Maximum performance of Moving Average filter*



- *Figure 3: Simulated rainfall with 4 methods comparing to measured by rain gauge*

- *Figure 4: NSE calculated for 10 days periods for each method*

ENHANCING RUNOFF PREDICTION: EXPLORING ATTENUATION-RUNOFF AS AN ALTERNATIVE TO RAINFALL-RUNOFF MODELS

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[1] The University of Waikato
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The accurate estimation of runoff in catchments, particularly in urban areas, is crucial for designing effective drainage systems. However, the complexity of rainfall-runoff relationships, influenced by temporal and spatial variations, poses challenges in obtaining precise estimations. While catchment characteristics play a role, rainfall rate remains the most influential factor in runoff models. Meanwhile, Commercial Microwave Links (CMLs) have emerged as a promising alternative for rainfall measurements, enhancing rainfall-runoff modelling and hydrological predictions. Yet, accurately transforming CML power attenuation to runoff relies on precise rainfall estimation.

Based on the better spatiotemporal resolution of CML attenuation data over land areas, there is a possibility of establishing a stronger relationship between attenuation and runoff, rather than rainfall-runoff. This approach has the potential to enhance the accuracy of rainfall-runoff transformations and improve the overall reliability of hydrological models.

Aims

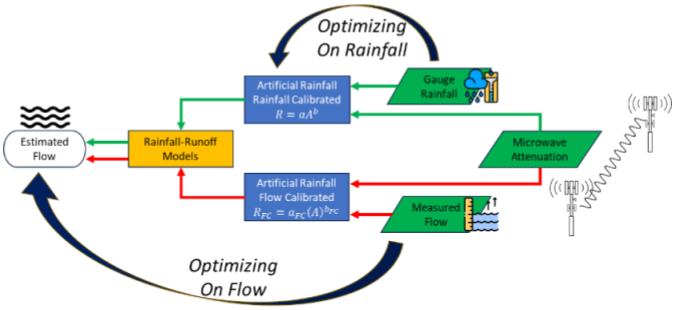
In this research, we explore a direct correlation between microwave attenuation and flash floods in urban catchments. The results are aiming to assess if the power of microwave links could be a better indicator of water yield in a catchment, rather than targeting the rate of rainfall. By utilizing the extensive coverage of microwave links and their indicative measure of water yield, the study seeks to improve flood forecasting by avoiding errors associated with estimating rainfall depth by any tools, including rain gauge or CML.

In this approach, we aim to find the best coefficients and correlations in all interrelationships between attenuation and flow. The primary focus here is on the quality and strength of the relationship between CML and flow, not rainfall and flow.

Method

This study examines the relationship between the attenuation of a microwave link and quick flow in 15 small urban catchments in Yarra and Bunyip river basins, in Melbourne, Australia. The study utilizes a 22.715 GHz microwave link located in Burwood East and Glen Waverley suburbs to measure received powers every 15 minutes. Rainfall data is collected from 12 electronic rain gauges and the flow meters at the outlets of the catchments provide flow measurements. The study aims to synchronize the data from microwave links and rain gauges with a common hourly interval for consistent analysis.

Figure 1 illustrates the conceptual framework of this study. Different correlations were investigated initially. Rain gauge-quick flow, and then simulated CML rainfall with rain gauge or quick flow are inspected. The well-known relationship between signal attenuation (*A*) and rainfall (*R*) and the effects of the wet antenna (A_a) is used for calculating rainfall intensity ($R = a(A\text{-}A_a)^b$). However, two methods are used for finding constants *a* and *b*. The first approach is calibrating constants with rain gauge data. As a new approach, we also calibrated the constants with the measured flow to find a new relationship as ($R_{FC} = a_{FC}(A – A_{aFC})^{b}{}_{FC}$.



- *Figure 1- Conceptual Framework of the study*

Therefore, the CML rainfall, calibrated with the flow, may not be directly equivalent to rain gauge measurements. R_{FC} actually is a new understanding of the rainfall depth over the land area and its effectiveness in simulating flow is thoroughly investigated to assess its applicability in this study.

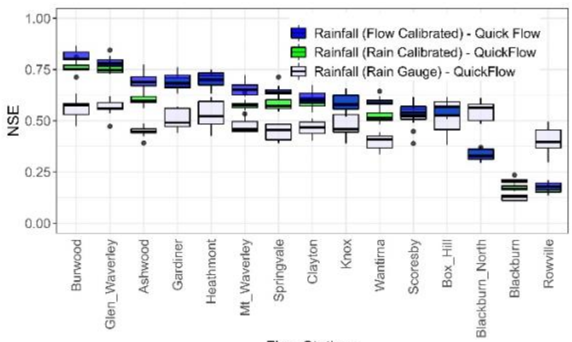
Analysis was conducted to minimise the RMSE and maximise the NSE of the correlations through 180 pairs of rain gauge-flow stations. The results helped to find the strongest constants in attenuation-rainfall relationships. Then, the constants for three methods of rainfall simulations were employed to simulate runoff with GR4J daily rainfall-runoff model. This simple lump model uses precipitation, flow and evapotranspiration as inputs.

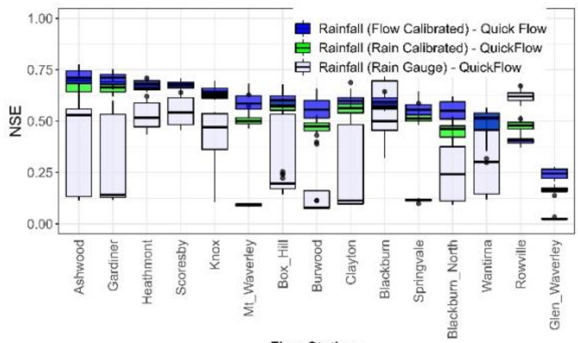
Results

The findings demonstrate that calibrating CML rainfall with flow outperforms the conventional calibration method using rain gauges. In the first step, linear correlations were examined to determine the factors with the strongest relationships and to find the coefficients in equations. Figure 2 illustrates the range of NSE variations for the correlation between quick flow and three rainfall estimation methods (rain gauge - white boxes, CML rain calibrated - green boxes, and CML flow calibrated - blue boxes). The flow-calibrated rainfall exhibits the highest NSE factor, indicating a stronger relationship.

Subsequently, the three rainfall methods were applied in the GR4J rainfall-runoff model. Figure 3 compares the NSE factor among the results of the three methods. Similar to the correlations, the rainfall-runoff model performs better and predicts runoff more accurately when utilizing flow-calibrated CML rainfall. Figure 4 displays a sample of simulated quick flow in the Ashwood flow station, coupled with the Mitcham rain gauge.

Another significant accomplishment of this study is the successful mitigation of wet antenna effects when calibrating CML rainfall with flow data. Figure 5 clearly demonstrates that all flow stations, comprising most of the 12 paired rain gauges for each, lie above the 1:1 line. This result indicates that the wet antenna correction factor (*Aa*) is lower when CML rainfall is calibrated with flow data compared to calibration with rain gauges.





- *Figure 2: Comparing NSE for three correlations*
- *Figure 3: Comparing NSE for three rainfall-runoff models*

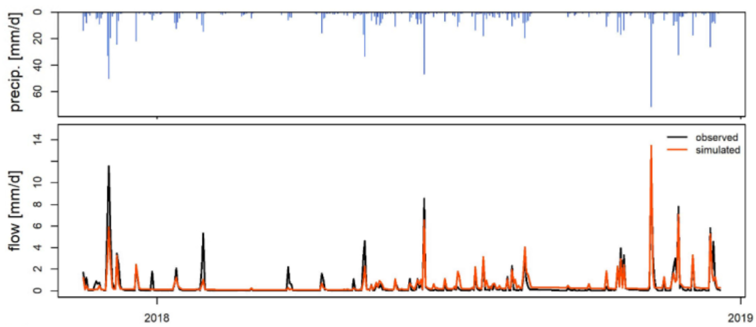
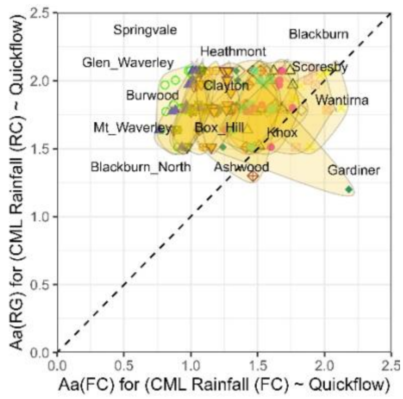


Figure 4: Simulated runoff in GR4J for Ashwood flow station, coupled with Mitcham rain gauge



- *Figure 5: Comparing Aa in CML rainfall calculations, calibrating with rain or flow*

APPROACHES FOR PEAK FLOW ESTIMATION IN HASTINGS DISTRICT FOLLOWING CYCLONE GABRIELLE

Isabelle Farley,[1] Will Conley,[1] Sarah Yeo[1]
[1] WSP New Zealand

Cyclone Gabrielle caused widespread damage, loss of life, and critical assets destruction throughout the Hawkes Bay and Gisborne regions of New Zealand in February 2023. Extensive damage to the hydrometric network means that for many stations, the highest water levels during the cyclone were not directly measured. For stations that continued to function, some measured water levels produce widely divergent flow estimates using the existing stage-discharge relationships. These conditions challenge development of robust replacement designs for numerous road crossings damaged by the storm across Hastings District.

To support infrastructure longevity, a range of desktop and field methods were employed to constrain event-based flow estimates and update return period relationships. These methodologies include:

- NIWA Regional Method (2018),
- Frequency analysis and flow scaling using empirical data from nearby flow gauges,
- Preliminary 2D hydraulic modelling of the study areas using flow scaling and 2020 LiDAR, and initially calibrated using post cyclone aerial imagery to approximate flood extents and depths,
- Hydraulic modelling of indicative boundary conditions based on field surveys of geomorphic and hydrographic conditions by fluvial geomorphologists.

Models were calibrated using information from post cyclone aerial imagery and high-water marks identified on site. Comparison of outputs from each method was undertaken to constrain design flows and these are being compared to other work being undertaken in the region. Initial results show large variations in the flow estimates using these methodologies. Investigations into these differences are being undertaken but are likely due to selected statistical distributions based on extreme value records, transient hydraulic boundary conditions, roughness values, and channel geomorphology such as newly created planar sand beds with related bedforms of dune and antidunes resulting in higher flow resistance than customarily considered. This investigation highlights the importance of understanding the variation between flow estimation methodologies and the role of empirical validation following large events.

AUTOMATING THE QUALITY ASSURANCE PROCESS FOR CONTINUOUS ENVIRONMENTAL DATA

Preston Ferreira,[1] Sandrine Le Gars,[1] Antonin Caen[2] Sagar Soni[2]
[1] Northland Regional Council
[2] Orbica Limited

In the context of the current emphasis on climate change, monitoring and managing New Zealand's limited water resources is critical. The Resource Management Act of 1991 mandates councils to collect, process, and store environmental data to support the creation of fit-for-purpose policies, data-driven decisions, and efficient water resource management. However, manual data processing results in significant delays in obtaining reliable data, leading to a growing backlog of unprocessed environmental data, with up to a 15-month backlog for specific datasets. This problem is expected to worsen with the continuous increase in data collection in the future. To address this issue, the Northland Regional Council (NRC) has initiated a project to automate the handling and cleaning of continuous environmental data to a standardised approach. The National Environmental Monitoring Standards (NEMS) is being used to ensure consistency across councils for most datasets. This project has gained sector-wide interest as it aims to tackle common issues, including inconsistencies at both organisational and individual levels, the resource-intensive and ineffective nature of current processes, and the expanding data network. Initially focusing on automating the processing of water level data, which amounts to about 5.5 million data points collected annually across 80 sites, the presentation will share the NRC's journey, lessons learned, and future steps. By streamlining and automating data processing of continuous environmental data, the project seeks to make the quality assured data readily available to the stakeholders and to be prepared for the challenges posed by increasing data volumes in the future.

EVOLUTION OF THE UNDERSTANDING OF POTENTIAL IMPACT PATHWAYS BETWEEN CSG DEVELOPMENTS AND THE PRECIPICE SANDSTONE

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The Precipice Sandstone is the basal unit of the Surat Basin and a regionally significant aquifer which supports extensive groundwater use and significant groundwater discharge areas in northern areas of the Basin. The Precipice Sandstone is partially underlain by the Bandanna Formation of the Bowen Basin, which is a target for coal seam gas (CSG) extraction. The formations are generally well isolated by the low-permeability mudstones of the Rewan Group. In two locations however, the Surat Basin sediments were deposited over the erosional surface of the Bowen Basin, providing two areas where the coal measures of the Bandanna Formation are interpreted to be in direct contact with the Precipice Sandstone. Over the last decade there has been extensive drilling, investigations, data collation and a progressively evolving understanding on the hydrostratigraphy of the region. Additional connections between the two formations may also be present due to minor faulting in the post-depositional period.

To inform future assessments the Office of Groundwater Impact Assessment (OGIA) is undertaking a multi-disciplinary investigation into potential connectivity pathways between the Bandanna Formation and receptors dependent on the Precipice Sandstone. Targeted investigations are being undertaken to evaluate indicators of connectivity and to continue to advance the understanding using geophysical, hydrodynamic and geochemical datasets.

This presentation summarises the evolution of our understanding of potential and verified impact pathways, and describes the ongoing work being conducted to reduce remaining uncertainties.

RAIN RAIN EVERYWHERE – THE FUTURE OF RAINFALL DATA

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[1] Auckland Council, Healthy Waters Department

[2] Weather Radar New Zealand Limited

During rainfall events there is significant spatial variability of rainfall in the Auckland region. While the region is well served by a network of 84 rain gauges, the network only accounts for a small sample area of the region, therefore often fails to capture the full extent of rainfall. Increasing the rain gauge network to achieve denser spatial coverage is not practical due to both cost and a lack of suitable sites for additional gauges in many catchments. An alternative approach to determine the spatial and depth distribution of rainfall was required.

A regional Rainfall Analysis System (RAS) was developed including three component parts: Tipping bucket rain gauges, Metservice radar and vertical profiling radar. Together these observation systems enable estimation of rainfall depths and intensity at any point over the region. In effect, the approach provides “virtual” historical rainfall timeseries at 20,000 representative locations across the Auckland region since 2009. Near real-time data processing provides continuously updated rainfall information within a few minutes of rain occurring, providing unprecedented operational insights as rainfall events unfold.

This paper describes the different observation system components and how they fit together to deliver a more robust and reliable regional rainfall analysis than what can be achieved with the individual components alone.

The improvements afforded by incorporating national and vertically profiling radar data alongside the incumbent gauge network is highlighted by the event on the 27 January 2023. This was a significant rainfall event resulting in extensive flooding of community, residential and commercial areas across Auckland. During this event the RAS helped to understand the severity of the event compared to predicted forecasts and provided data resilience as rainfall stations were flooded, evidence of how the unified analysis provides confidence in each component of the system and in the characterisation of the rainfall event overall.

GROUNDWATER HINDCASTING: WHAT IS IT, HOW DO WE DO IT, AND WHY IS IT IMPORTANT?

Forstner T[1], Morgan LK[1], Moore C[2], Kitlasten W[1,2]
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[2] GNS Science | Te Pū Ao

Aims

Although extensive groundwater resource development has occurred mainly within the industrial period (circa 1970s), changes to land use, landscape modifications and extensive clearing of native vegetation has been occurring since early anthropogenic settlement. Future water resource management increasingly demands a more robust understanding of past hydrological conditions such as (a) past hydrological trends and variability, (b) conditions to support sustainable restoration strategies, and (c) responsibly recognize alternative facets to human-water relationships and Indigenous cultural values associated with water.

Hindcasting is a modelling approach which simulates or predicts past conditions based on historical data and proxies. One of the major limitations to our understanding of past hydrological conditions is the lack of historical data, where most of our current groundwater observations exists within the era of modern measurement (~100 years). In addition, although paleo-research studies have been widely applied in other disciplines, such as climate and atmospheric sciences, fewer studies have explored methods and approaches in reconstructing past groundwater conditions or processes.
In this study, we aim to highlight the previous applications of groundwater hindcasting through the first synthesis of groundwater hindcasting studies from global peer-reviewed literature and discuss data and methodological approaches and limitations. We discuss future opportunities for groundwater hindcasting research with an example application to a case study in the Heretaunga Plains, New Zealand.

Methods

We reviewed available literature which apply methods of hindcasting groundwater systems either in-part (ie. recharge, water levels) or holistically (ie. catchment scale flow dynamics). From the literature, we identify key themes, classify broad methodologies, and discuss unique challenges and opportunities of modelling past groundwater systems.

Future opportunities in groundwater hindcasting are discussed with a case study in the Heretaunga Plains, New Zealand. Hindcasting is being undertaken to investigate the evolution of groundwater discharge to local springs and streams of high cultural significance for the tangata whenua (indigenous peoples) of the Pakipaki community. This case study provides a novel application of hindcasting with future resource management implications.

Results

Our resulting synthesis reviewed hindcasting modelling methods based on analog, data-driven and numerical techniques. Applications to groundwater hindcast modelling are generally limited to multi-disciplinary applications, using data (ie. speleothems, tree rings, oxygen isotopes) and drawing from methods within specific disciplinary knowledge. Available proxies to constrain history matching show a decreasing resolution (record of temporal frequency) with increasing record extent. In addition, reconstructions are often regionally limited and have associated dependencies in temporal and spatial scales dependant on proxy data and modelling methods. We discuss observed gaps in the literature and illustrate a novel application of hindcasting using a transdisciplinary approach on the reconstruction of groundwater discharge to local springs and streams using traditional western science and Indigenous Knowledge.

DEVELOPING VILLAGE GROUNDWATER COOPERATIVES FOR SUSTAINABLE GROUNDWATER MANAGEMENT AND COLLECTIVE ACTION IN DHARTA WATERSHED, RAJASTHAN, INDIA

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Groundwater serves as a classical common pool resource, yet its invisible nature poses significant challenges in understanding its dynamics of use and management. This difficulty applies not only to the users but also to the scientific community. Moreover, the evolving social dynamics with transgenerational involvement in groundwater usage add another layer of complexity to ensuring its long-term sustainability.

Addressing these challenges requires active efforts in recharging, sharing, caring for, and valuing groundwater resources. To this end, our study aimed to establish local-level institutional arrangements that empower communities to lead in groundwater management. These arrangements involve engaging various actors in groundwater governance and sustainable use.

In this paper, we present the findings from our research conducted in the Dharta Watershed, Rajasthan, India, focusing on community-led groundwater management through establishing "Village Groundwater Cooperatives (VGCs). To gain insights, we analysed data collected through key informant interviews, encompassing a range of stakeholders from the study areas and beyond. Our analysis considered the changing socio-economic context and applied Ostrom's Design Principles for Sustainable Governance of Common-Pool Resources.

The results demonstrate that collective action within the community has fostered a positive shift in how they perceive groundwater as a common pool resource. This shift highlights the growing appreciation for the importance of sharing and valuing water. However, the study also underscores the fact that groundwater management cannot rely solely on community efforts. Instead, it necessitates robust collaboration involving local governments and other stakeholders.

In conclusion, our research advocates for establishing community-led groundwater management initiatives to safeguard this vital resource. There is a need to collectively ensure groundwater's long-term availability and equitable use through VGCs by engaging multiple stakeholders and adhering to sustainable governance principles.

MANGEMENT AND MODELLING OF ARTIFICIALLY RECHARGED AQUIFERS: ALEXANDRA BASIN, OTAGO, NEW ZEALAND

Tom Garden[1], Neil Thomas[1], James Scouller[1]
[1] Pattle Delamore Partners Limited

Aims

The Earnscleugh Flat and Dunstan Flats aquifers are located in the Alexandra Basin in Central Otago, on opposite sides of the Clutha River / Mata-Au ('Clutha River'). The area has a semi-arid climate, and direct rainfall infiltration comprises a relatively small proportion of recharge. The aquifers present unique challenges in terms of freshwater management and consistency with the National Policy Statement for Freshwater Management (NPS-FM), due to much of the recharge being from "inefficient" irrigation water race transport. It is possible that future measures to improve the efficiency of surface water take use and reductions in water race losses could significantly reduce the recharge to the aquifers and adversely affect groundwater users and surface water receptors.

We created 3D groundwater models of the Earnscleugh Flat and Dunstan Flats aquifers in order to support Otago Regional Council (ORC) groundwater allocation decisions. The models had the specific aims to:

- Estimate the water balance and overall groundwater flow pattern of the aquifers.
- Constrain which parameters and boudnary conditions the modelled aquifer water balances are most sensitive to, to guide future investigations .
- Investigate the possible implications of reduced irrigation race losses on the aquifers and groundwater receptors.

Method

The aquifers were modelled separately, using a two-layer MODFLOW 6 model with a 100 x 100 m cell size. Recharge from rainfall and irrigation application was calculated using a soil moisture model developed for the area as part of the modelling project. Losses from irrigation water races were based on estimates from previous ORC work (ORC, 2012). The Clutha River was modelled using the MODFLOW river (RIV) package, major streams were modelled using the MODFLOW stream package (SFR), while groundwater abstractions were represented via the MODFLOW well package (WEL).

The models were calibrated using Parameter Estimation software (PEST) (Doherty, 2010). The Earnscleugh model was calibrated to 33 groundwater level observations (the groundwater level in bores at the time of drilling) and surface water flow observations (the flow in the middle Fraser River at the Earnscleugh Road bridge and the flow in the lower Fraser River at Marshall Road). The Dunstan model was calibrated to 74 groundwater level observations from the time of drilling, and one surface water flow observation.

Results

The model results indicate a reasonable calibration to both stream flows and groundwater levels, where this data was available. The modelled water balance and groundwater flow pattern for each aquifer is generally consistent with our conceptual understanding, with some differences for each aquifer.

The Earnscleugh Flat scenario results indicate that without irrigation water race recharge, groundwater levels in the southern part of Earnscleugh Flat would reduce by up to 1 – 1.5 m, and groundwater infiltration to the lower Fraser River would reduce by at least 7 L/s. The Dunstan Flats scenario results indicate that without irrigation water race recharge, groundwater levels in the central Flats could reduce by up to 3.5 m, which could have an adverse effect on some bore owners. Surface water flows in the Dunstan Flats area would not be expected to change significantly, although slightly greater recharge to the aquifer from the Clutha and Manuherekia Rivers would be expected as a result of lower groundwater levels. However, analysis of the results from the PEST calibration indicates that many parameters are poorly constrained, and there is significant uncertainty around the results of the scenarios.

The existing groundwater allocation limits for the Earnscleugh Flat and Dunstan Flats aquifers are based on an estimated 50% of total recharge (assuming efficient irrigation methods), not including estimated irrigation race losses. If groundwater allocation was revised to be based only on land surface recharge (i.e. excluding recharge from irrigation races and/or streamflow seepage) then both aquifers would be considered significantly over-allocated. Ideally groundwater allocation volumes should be based on acceptable environmental effects on existing groundwater users or surface water receptors. Limited information is available regarding the location and/or sensitivity of surface water receptors in either aquifer, however it is expected that there could be potentially significant reductions in groundwater levels and inflow to the lower Fraser River if the full current allocation limit was abstracted.

The groundwater modelling for the Dunstan Flats aquifer indicates that a reduction in irrigation water race losses could have a significant adverse effect on bores in the central part of the Flats (many of which are already drilled to near the base of the aquifer), even without additional abstraction pressure. It is also important to note that groundwater inflow from the adjacent Manuherekia Claybound Aquifer would also be likely to reduce if water race losses and/or irrigation application losses lessen, due to those losses also being a significant source of recharge to the Manuherekia Claybound Aquifer.

The modelling highlights the challenges of managing groundwater allocation where recharge from historical, inefficient water race transport provides a large proportion of the recharge to the aquifer, and most existing bore owners installed their bores once the existing artificially recharged system had established. Additional work is underway to provide additional calibration data, and to identify whether there any ecologically sensitive groundwater receptors that could be adversley affected by future decreases in groundwater levels caused by changes to more efficient irrigation or water transport. Consideration could be given to splitting the Earnscleugh and Dunstan groundwater allocation zones based on where abstraction could have a greater effect on stream flows, and/or where groundwater levels are sensitive to changes in recharge or abstraction.

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RECHARGE PATTERNS IN THE GNANGARA GROUNDWATER SYSTEM EXHIBIT NONSTATIONARY BEHAVIORS IN RESPONSE TO DRYING CLIMATE

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Understanding the impact of climate change on groundwater recharge is crucial for the sustainable management of groundwater systems, especially when regulatory bodies are managing aquifer already fully-allocated. The accurate modeling of the recharge response to climate change faces challenges such as the lack of empirical data to validate predicted changes. From a quantitative point recharge fluxes are fundamentally influenced by climatic factors, but they are also dependent on land use, soil type, and water table depth. The way these variables, combined with climate change, impact recharge fluxes becomes essential in understanding how effectively constraining the numerical models utilized for groundwater allocation management and decision-making.

Through the synthesis of field observations and a meta-analysis of 34 recharge studies spanning the last 50 years, we establish a connection between real-world data, underlying processes, and theoretical concepts to examine changes in recharge patterns within the Gnangara groundwater system of the Swan Coastal Plain. We emphasize the importance of deploying recharge monitoring stations, which are based on multiple observation packages, across key land use and soil combinations. Through these stations, we derive variables and parameters necessary for understanding recharge dynamics and accurately estimating recharge fluxes.

The analysis of historical data shows that reductions in rainfall lead to nonlinear (3 to 4 times higher), decreases in recharge. Additionally, data from the installed monitoring station highlights how the dynamics of wetting fronts are influenced by the types and densities of vegetation. This suggests the presence of distinct local recharge mechanisms operating within the transient systems of the area. The insights obtained from these monitoring sites can be benchmarked against broader observations, such as data provided by remote sensing or borewell measurements, to generate databases of recharge estimates useful for numerical models.

RADIOKRYPTON CAPABILITY AT THE ADELAIDE ATOM TRAP TRACE ANALYSIS FACILITY

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Aims

Sustainable extraction of groundwater is essential to supply freshwater and address water scarcity. It impacts town and domestic water supplies, irrigation supply for crops and pastures, and industrial processes. The age distribution of groundwater aids in management by informing on recharge rates and history, the fate of contaminants, aquifer connectivity and its geochemical evolution.

The radiokrypton isotopes are chemically inert, have well understood input functions, and low underground production rates, making them the most reliable tracers for the assessment of groundwater residence time. Krypton-85 (half-life 10.7 years) is most suitable for short term hydrological process of decades, and krypton-81 (half-life 229,000 years) is a near-ideal tracer to characterize ancient groundwater [Lu 2014]. However, because of the very low natural abundance, the application of these tracers has, in the past, been extremely limited due to the challenge presented by measurement. The development of Atom Trap Trace Analysis (ATTA) has overcome the measurement challenge and now the use of ^{85}Kr and ^{81}Kr is becoming more routine [Purtschert 2023, Seltzer 2021].

Globally there are two recognized ATTA facilities for measurement of ^{85}Kr and ^{81}Kr, Argonne National Labs in the USA and USTC in Hefei, China. Because the application of these isotopes continues to grow, there is already a need to build a greater global capacity. A partnership between the University of Adelaide and CSIRO has established a new Adelaide ATTA facility for measuring radioactive noble gases in groundwater and the environment. The facility represents a new infrastructure available for monitoring, observation and characterisation of the environment in the Southern Hemisphere. Sampling is now much simpler than previously via a method using 20L commercial propane bottles. The water sample is then sent to the CSIRO Waite campus in Adelaide where the gas is extracted and purified before being measured for ^{85}Kr and ^{81}Kr at the University of Adelaide ATTA facility.

Method

ATTA employs the technique of laser cooling to separate isotopes and is therefore fundamentally different from other isotope counting techniques such as Accelerator Mass Spectrometry (AMS). ATTA works due to a shift in atomic energy levels that is a consequence of the change in the number of neutrons in the atomic core. Laser absorption is extremely sensitive to this shift in energy, and the ATTA system is therefore only sensitive to the trace isotope.

A schematic of the apparatus is shown in figure 1(a) and an image of a single trapped ^{85}Kr atom is shown in figure 1(b). Single atoms are confined and counted in the ATTA system with a rate that is dependant on the isotope concentration in the sample. The mean residence time, t, is estimated based on the radioactive decay of the individual tracer between the time of groundwater recharge and sampling, according to:

$$t = \frac{1}{\lambda} ln\left(\frac{C_0}{C}\right)$$

where λ is the decay constant related to the half-life of the trace isotope, and C and C_0 are the sample and initial concentration, respectively. We measure count rates of modern samples up to 1000 ^{85}Kr/hr or 100's of ^{81}Kr/hr, sufficient for analysis of environmental samples.

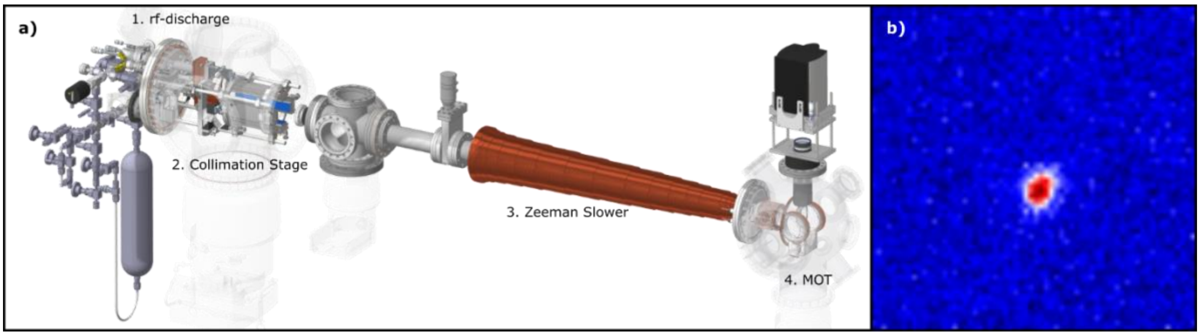

Figure 1. a) A schematic of the apparatus showing the 1. rf-discharge 2. Collimation Stage 3. Zeeman Slower 4. MOT, and b) a single 85Kr atom imaged on the EMCCD.

Results

We present our most recent results demonstrating the capabiltiy of the new Adelaide ATTA facility for measuring ^{85}Kr and ^{81}Kr. We present results from the Eromanga Basin and demonstrate a sufficient sensitivity to measure environmental samples. Importantly, these tracers provide more robust age estimates, and the interpretation is less complicated when compared to other age tracers, such as ^{36}Cl, ^{14}C or CFCs. We also describe a new sampling methodology with 20L commercial propane bottles that enables collection without complicated field degassing.

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LEVERAGING DATA ANALYTICS FOR GROUNDWATER MONITORING OPTIMIZATION

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The accumulation of extensive monitoring data often requires laborious data processing prior to commencing any assessment. This study explores the optimization of groundwater monitoring data through the integration of data analytics and digital platforms to streamline decision-making processes in resource management.

Business intelligence tools enable rapid data integration of temporal groundwater and climatic data. Interactive digital dashboards expedite data visualization, facilitating quality control and expediting the identification of trends. Automation of data processing and computation tasks results in time and cost efficiencies. Impact assessment criteria can be incorporated to digital platforms for periodic or event-based assessment and evaluation.

In this case study, groundwater conditions were analysed prior to project construction, to define baseline conditions and assess changes during project operation to assess potential project impacts. Control monitoring locations established to assess non-project related changes to groundwater levels were instrumental in defining the scale of change identified due to climatic conditions.

The cumulative change in groundwater level over time was computed at various monitoring sites and was compared with these control locations. A hierarchical ranking was formulated based on this cumulative change, delineating three distinct impact classifications. The utilization of different visuals from bar charts, histograms and bubble maps allowed an integrated spatio-temporal analysis, substantiating the ranking and highlighting the sites primarily affected by the project. Concurrently, sites unaffected by the project were identified and this informed the rationalisation of the monitoring program.

The utilization of a digital platform facilitated bore data integration with climate data, reduced processing and calculation times, and facilitated the use of multiple tools to assess the influence of natural and project-induced impacts at each monitoring location, to inform future monitoring focus.

QUANTIFYING THE EFFECT OF ABSTRACTION ON RIVERS

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Regional Councils are required to give effect to the National Policy Statement for Freshwater Management (NPS-FM). Key tools to achieve this are Regional Policy Statements and Regional Plans. Under the policies and appendices of the NPS-FM, river flows are an important consideration.
River flows are affected by many factors including climate, geology, water abstractions, discharges, and vegetation. As we look to give effect to Te Mana o te Wai, our rivers and stream flows need to be estimated without the influence of existing water abstractions to enable the consideration of important values associated with surface waters (e.g., environmental, cultural, recreational, economic). The process of estimating a new flow series by 'adding back' the surface water abstractions and hydraulically connected groundwater abstractions to a flow record is called naturalisation.
We have created an automated python based tool that extracts data from our cloud-based Water-Data Repository and visualises a naturalised flow time series for sites that have sufficient data. Estimates of abstraction using metered abstraction are made where metered abstraction data is unavailable or poor quality.
Environment Canterbury's naturalisation methodology has been through several iterations of continual improvement, can be broken down into five steps:

1. Catchment delineation for the area upstream of the given flow site(s).
2. Identification of Water Abstraction Points (WAPs) and consents that are within the catchment defined by step 1 during the period of interest.
3. Extraction of metered water abstraction data followed by estimation of water abstraction where required. This step also calculates a time varying stream depletion for groundwater takes.
4. Extraction of flow data from our Water-Data Repository and naturalisation of these flows for the period of interest using results from step 3.
5. Visualisation of the results in a web based data viewer application.

EARLY UNDERSTANDING AND DESIGN COLLABORATION IS THE KEY TO ENSURING WETLAND PROTECTION DURING DEVELOPMENT

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Aims

New Zealand has lost over 90% of its original wetland extent since European settlement, with almost 5,400 hectares of freshwater wetland being lost between 1996 and 2018 (Denyer and Peters, 2020). The National Policy Statement for Freshwater Management 2020 (NPS-FM) and the National Environmental Standards for Freshwater (NES-F) came into effect on 3 September 2020, with amendments to the legislation coming into effect on 5 January 2023. One of the aims of this legislation is to avoid any further loss or degradation of wetlands and encourage their restoration.

As a result, a more detailed level of assessment of the potential impacts on wetlands is required in the early stages of the consenting process, and at the initial planning and design stages of projects that could impact wetlands. These projects include construction, infrastructure and mining projects. Depending on the nature and scale of the project, being outside required offset boundaries is frequently insufficient to avoid effects on wetlands. A detailed understanding of the wetland hydrology and ecosystems is critical to ensure that the altered land use will maintain or enhance existing wetlands. This paper focuses on the hydrological controls on wetland health and how to undertake thorough assessments of effects to assist with planning and designing suitable land use controls.

Lowland freshwater wetland

Method

As with all hydrology assessments, a good conceptual understanding of the site is key because it is impossible to assess the effects of changing the surrounding land use without fully understanding the baseline conditions, i.e. how the wetlands are currently sustained. There are three principle hydrological controls on freshwater wetlands:

- rainfall and rainfall run-off,
- groundwater discharges into and out of the wetland area, and
- surface water inflows and outflows.

The relative importance of each of these controls will depend on the topography, wetland vegetation, soil type, geology and climate and will vary throughout the year. Frequently, the relative contributions of each of the contributions are poorly understood at the outset of a project, with limited available data. Stormwater assessments may have been completed, but these generally focus on large-scale rainfall and flooding events, which are less critical for wetland health, and are usually not sufficient for assessing potential impacts on wetland environments. Typically, wetlands are more reliant on smaller regular rainfall run-off events or groundwater discharges than large rainfall events.

The potential effects of land-use change on the wetlands will depend on the proposed change in land use and the nature of any associated engineering designs. For example, in a change from pastural to suburban residential landuse the following alterations could impact on hydrological flows into the wetland:

- Earthworks, resulting in changes in catchment sizes and topography, which can affect run-off, surface water flows and groundwater recharge.
- Retaining walls, reducing run-off effects, potentially increasing groundwater recharge and altering flow directions.
- Storage tanks for rainfall re-use that can reduce groundwater infiltration and run-off from smaller rainfall events.
- Stormwater discharges can change surface water flows, run-off and potentially affect water quality, depending on the engineering solution selected.
- An rincrease in impervious surfaces can cause an increase in run-off and reduction in groundwater recharge, depending on the stormwater design.
- Changes to vegetation with the planting or removal of mature trees, hedges, parks etc, can alter run-off volumes and timing.

- Construction of soakage pit drainage solutions may cause a reduction in runoff and an increase in local groundwater recharge.

The scale of the hydrological assessment needs to be commensurate with the scale and importance of the wetlands, which will need to be considered in conjunction with ecologists. If the wetland hydrology is sufficiently understood, it is possible to tailor the design to avoid adverse effects. It is therefore critical to consider the wetland environment in the early phases of a project.

The scale of the hydrological assessment needs to be commensurate with the risk of the activity to the extent and values of the wetlands, and needs to be considered in conjunction with ecologists and other stakeholders. For larger, more sensitive or valuable wetlands, or where the proposed activity is considered to be higher risk, a quantitative assessment is likely to be required. However, for low risk activities near small, lower-value wetlands, a basic, high-level assessment may be appropriate.

In its most basic form the assessment could comprise an annual water balance model but for larger or more sensitive wetlands a catchment model may be required. These models should be developed and used in collaboration with the design team. This enables the early development of effective solutions to avoid impacts on wetlands, whilst minimising impacts on the wider project.

The available data is frequently a constraint on the type of model that can be developed. Obtaining sufficient baseline data is usually critically important, not only for the development of a robust conceptual model, but to verify modelling results and provide regulators with sureity that the assessment is valid. Obtaining sufficient data does not have to be expensive, with simple hand installed piezometers in wetland areas and stage and flow gauging of streams often proving sufficient. However, it does need to be put in place as soon as possible to allow sufficient data to be obtained prior to the application for consent. It can also be used during and post construction/ development to monitor the impacts to ensure that the mitigation measures are effective.

Typical Wetland Monitoring Point

Results

Examples of effective modelling techniques will be presented, along with an indication of when these are applicable and how these can be used to assess the potential impacts of changing land use. These will range from high level qualitative assessments to catchment models and will focus on the key considerations, potential impacts on the wetlands and the mitigation measures developed. The design phase and development of mitigation measures is generally an iterative process, with significant inputs from a wider team of consultants, engineers and planners. For more complex wetland systems, adaptable catchment models with an interactive display can offer the best option to allow the wider team to understand and test the effects of different design options to enable the protection of the wetlands.

Wetlands are rare and valuable ecosystems that need to be protected and the freshwater regulations appear to be driving a positive change in attitude. The early use of appropriate assessment methods during the design phase helps developers to see that wetland areas may present a an opportunity to enhance the proposed development with additional environmental, aesthetic and leisure benefits.

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STRUCTURALLY SIMPLE AND PARAMETRICALLY COMPLEX INTEGRATED MODELLING FOR DETAILED DESIGN OF HYDRAULIC BARRIER REMEDIATION SYSTEM

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Structurally complex groundwater models are often required to accurately simulate hydrogeological processes and geometry of physical systems (such as subsurface geology and hydrological features). However, large complex groundwater models can suffer from long run times and are sometimes susceptible to numerical instability, which can pose challenges to run intensive procedures such as automated calibration and uncertainty analysis. For projects with a tight time frame, complex models may not be suitable for decision making processes that rely on a clear understanding of model uncertainty and risks.

In some cases, where the outputs from the modelling are required to address specific questions, it is possible to reduce model's structural complexity without compromising its intended use by prioritising the processes that matter the most to the predictions of interest. The key benefit of reduced structural complexity is a more numerically stable and efficient model that can be run many times with large number of parameters to examine the model performance and uncertainty in detail.

This presentation will provide an example of a structurally simple yet parametrically complex modelling approach used to inform the detailed design of a hydraulic barrier system for remediating a swamp of high ecological importance. The modelling involved loose coupling of a rainfall-runoff model GR4J with a flood model TUFLOW and a groundwater model USG-Transport to accurately simulate the interaction between the surface water and groundwater systems. The efficient modelling approach allowed the groundwater model to be rigorously calibrated to measured stream flows and flood-induced groundwater responses using 611 adjustable parameters, which provided considerable insights into the hydrological behaviour of the swamp. A non-linear uncertainty analysis was completed to assess the effectiveness of a hydraulic barrier system to redistribute flood waters, maintain stream flow and top up the water table.

NEW CUMULATIVE HYDROLOGICAL ESTIMATION SOFTWARE

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[1] NIWA

New Zealand's surface and groundwater resources are used to supply a range of domestic and industrial users. As the demand for water increases however, the reliability of supply for some users may be impacted where water resources become scarce. NIWA's Cumulative Hydrological Estimation Software (CHES) was developed as a tool to help regional councils keep account of surface and groundwater takes and assess their impact on river flow and water supply reliability. The tool was dependent on the ARCGIS (ESRI) platform however, which led to operational challenges related to both software's versioning and compatibility.

To resolve the above issue CHES is now available through the web-based New Zealand Water Model (NZWaM) HydroDesk platform. In addition to providing a more manageable environment for the tool, this change allows direct linkage with natural flow timeseries outputs from surface and groundwater models used within NZWaM (i.e., TopNet, TopNet-GW, TopNet-MODFLOW 6). The new CHES tool will continue to allow estimation of the changes to surface water flow timeseries (upstream and downstream of consent locations) and quantify the availability and reliability of the water resources. The tool will now be able to model stream networks of any Strahler stream order (previously only 3rd order streams could be modelled), and a more accurate method of representing the impact of groundwater takes on river flows is being developed.

In this presentation we illustrate how the updated CHES tool can be used via the HydroDesk NZWaM interface with minimum user data requirements (apart from consenting data). It is envisaged that the new tool will provide water resource managers with a quick and cost-effective method to assess the cumulative effects of potentially complex surface water allocation scenarios. Whilst in its beta-testing stage CHES (HydroDesk) can be accessed freely by interested users.

WHAT DO WE KNOW ABOUT WNOS?

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Wastewater network overflows (WNOs) are a significant issue for regional and local authorities across the country. Over 3,000 wastewater overflows were reported across Aotearoa New Zealand last year[3]; at least 60% of these occurred during dry weather as a result of blockages or plant failures, while the remainder occurred during wet-weather conditions.

Wastewater overflows from network infrastructure can present a risk to public health as a source of disease-causing pathogens and chemicals, and cause objectionable odours and gross pollution. In some urban areas overflows can occur frequently during dry conditions, and impinge on public areas and private properties. Issues with overflows often develop as a result of chronic underinvestment and lack of understanding about how and why these discharges occur. Councils can face intense media scrutiny and public pressure to find solutions.

Regulation of overflows in Aotearoa New Zealand is poor. Overflows have been notoriously difficult to consent under the *Resource Management Act 1991* and many regional and local plans; and even if they are consented the consent requirements can be technically, practically and financially challenging to meet. It is difficult to obtain a longer-term consent (over 20 years, up to the current maximum of 35 years) for overflows, which are intermittent and temporary in nature.

We have supported several local authorities to seek approval for wastewater network overflow discharges in recent years.Through this experience we have identified knowledge gaps, common challenges, and the key technical considerations that inform any assessment of effects involving overflow discharges. The paper communicates these findings for the benefit of our peers, and is targeted to inspire discussion of potential solutions for the future management of network overflows in Aotearoa New Zealand. It discusses the aspects of overflows that set them aside from other types of discharges in terms of risk, as well as the inherent difficulty in characterising them and assessing potential impacts on values in the receiving environment. The paper provides a high-level analysis of the tools currently available to characterise overflows including monitoring and network modelling techniques. It also considers the chllenges faced by decision-makers in continuing beyond the consenting process, to implement changes and monitor compliance and environmental outcomes.

[3] 2021/22 Financial Year; as reported by Table 5 in Water New Zealand 2022 National Performance Review 2021/22, available online at [National Performance Review : Water New Zealand (waternz.org.nz)]

CONSTRAINING THE PARAMETERS OF GROUNDWATER INFLOW ESTIMATION BASED ON RADON CONCENTRATIONS AND BASEFLOW INDEX

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Inflow of groundwater to streams supports the health of many groundwater dependent ecosystems. These ecosystems provide ecological value and support significant biological diversity. Quantifying these inflows of groundwater to surface water sources is of great importance when evaluating the sustainability of groundwater resources. In this study, radon (Rn) is used as a tracer for estimating groundwater inflow to an ephemeral creek located at Tamborine Mountain, Southeast Queensland. A sensitivity analysis revealed that groundwater inflow estimates are highly dependent on the aeration constant due to the heterogeneity and small size of the streams. Ranges for the aeration constant applied in previous studies for small streams resulted in large uncertainties impacting the reliability of estimates for inflow rates. Therefore, the aeration constant was constrained based on gauged stream flows. This was achieved by estimating the Baseflow Index (BFI) at two stream gauges and correlating it to the predicted inflow based on a range of aeration constants with different assumptions regarding flow and velocity between each radon sampling site. A correlation between the estimated BFI and the radon estimated inflow revealed a best-fit aeration constant varying from 0.32 to 3.9 d^{-1}. The average groundwater inflow in the creek was estimated as 0.71 m^3/d for each meter of the creek in June 2019, with a peak inflow of around 2.0 m^3/d in upstream sections. Given the total average creek flow was 0.88 m^3/d for each meter of the creek, results demonstrate a large dependency on groundwater inflow to support the creek flow. Constraining the aeration constant based on streamflow recordings lowered the uncertainty of the estimated inflow compared to applying the previous reported potential ranges and provides a simplistic methodology for assessing groundwater inflow based on radon concentrations and stream gauge measurements in small heterogenous streams.

OPTIMISING WAIKATO GROUNDWATER QUALITY MONITORING

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[2] GNS Science

A collaborative review and redesign of groundwater quality monitoring in the Waikato is currently being undertaken by Waikato Regional Council and GNS Science to meet regional and national objectives. It is in part a response to recent criticism by the Parliamentary Commissioner (2019) of the regionally specific and variably ad-hoc nature of current monitoring in New Zealand. The principal aim is to optimise monitoring in the Waikato to meet current and future needs in a consistent and transparent manner. These include to provide long-term state and trend information to inform management and indicate policy efficacy at the regional and national scales. This work has potential applicability to other regions.

Recent reporting of Waikato groundwater quality monitoring results (2022), based on current networks of 110 state of the environment (SOE) wells and 80 community wells clearly showed impacts from intense agricultural land-use. Safe concentrations for drinking water were exceeded at many sites, for example at 11% of SOE wells due to nitrate contamination (the primary issue). The fundamental importance of monitoring network design was indicated by differences between network results, reflecting in part dissimilar representation of redox conditions.

The monitoring program will be redesigned taking account of our current understanding of the region's groundwater systems (distribution, use and character) as well as future needs. Design elements include wells, analytes and sampling frequency. Data handling and management will also be reviewed. Design optimisation approaches in international literature range from index-based maps to statistical analysis and modelling. At least one technique will be applied to Waikato's groundwater quality monitoring networks (including the national programme component). The aim of this paper is to obtain feedback on the approach and design to date.

SEMI-AUTOMATIC WORKFLOW FOR THE NATIONAL FLOOD ASSESSMENT

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Aims

The MBIE funded project "Mā te haumaru ō ngā puna wai ō Rākaihautū ka ora mō ake tonu: Increasing flood resilience across Aotearoa" aims to better understand flood hazard and risk across all Aotearoa New Zealand, now and in the future, to manage current flood hazard and to help develop climate change adaptation strategies. A crucial part of this project is the generation of nationally consistent flood maps for the whole country for the current climate and future climate projections. To do this for all of Aotearoa, we have created a workflow to semi-automatically create these maps. This workflow uses river network information to identify the catchment upstream of a flood domain, it then pulls together the necessary information (DEM, roughness, infrastructure, tide, etc) and runs a cascade of model from the creation of the design storm through a hydrology model in the upper parts of the catchments to a hydrodynamic model in the flood plain. This workflow is based on open-sources tools to be accessible and freely usable. Its semi-automatization allows for regular regeneration of the results with the improvement of the input data, or the scientific method used.

Method

This workflow is based using the workflow engine Cylc (Oliver et al. 2019). This tool is used to develop and run large complex workflows such as weather forecasting. It allows us to prepare the inputs, convert data between models, and optimize the scheduling of the tasks. Our workflow is composed of five main parts:

- First, Aotearoa New Zealand is divided in computational domains. The flood plains are identified manually. The associated catchments are identified using a river network model. Factors including steepness of subcatchment, population and building density are used to define the lower part of the catchment or flood plain, where the inundation model will be run and the upper part where only a hydrology model will be used.
- A design storm is built for this domain, for a 100 Annual Exceedance Probability (AEP) and for a duration related to the size of the domain. These storms, based on HIRDS (High Intensity Rainfall Design System, Haan 2011), are built for the current or a projected future climate (temperature increase).
- The NIWA hydrology model TopNet (McMillan et al. 2016) is used uncalibrated in the upper catchment area, forced by the design storm. The model has been upgraded to use soil conductivity. By adding a variability to this parameter, the model can reproduce a more realistic routing of the water as run-off or ground-water flow and improve the performances of the model in non-monitored catchments; and give a consistent response between gauged and ungauged catchments. The model is initiated by running the code for 10 years to extract representative antecedent conditions for each catchment.
- The DEM (Digital Elevation Model) and roughness maps for the lower catchment area are created by downloading data from LiNZ including latest LiDAR and from OpenStreetMap for infrastructures using the GeoFabrics suit (Pearson et al. 2023). This model provides a conditioned DEM, with a basic riverbed estimation and the opening of culverts, bridges, or other infrastructures.
- Finally, a hydrodynamic model BG_Flood (Bosserelle et al. 2022) is used to model the inundation in the lower catchment area. This code is a shock capturing St Venant solver, open source and based on GPU. It uses the elevation and roughness maps created by GeoFabrics. The rivers and streams are injected using the results of the hydrology model and the design storm is included as rain on grid for the computation. Tide is added and synchronised to the maximum of the flood. This model is based on a quad mesh. The results of a first quick coarse run are used to identify the areas of interest are used to automatically refine the mesh. Finally, all the maps will be stitch back together.

Results

The cascade of models has been validated on real events (Westport 2021, Waikanae 2012, Cyclone Gabrielle 2023 ongoing work), using the measured rain instead of design storms. The workflow is run semi-automatically on a first set of domains. The results are compared to flood statistic data and discussed.

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MINES TO MOANA: HYDROCHEMICAL LEGACIES IN A HISTORICALLY MINED WATERSHED

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The Hauraki gold rush (1860 – 1906, Aotearoa-New Zealand), as the name implies, was an unregulated and chaotic affair. In the Thames-Coromandel area, miners targeted epithermal quartz veins found in heavily faulted Mio-Pliocene volcanics, including in the steeply-incised Tararu Valley (ca. 4 km north of Thames). Twelve decades later, and somewhat obscured by vegetation, the original mine workings and tailings of the Tararu Valley remain, but with undetermined environmental effects.

In this reconnaisance study, we draw on water stable isotope ratio analysis, geochemical modelling and diffusive gradients in thin films (DGT) deployments, to document the still profound degree of hydrochemical alteration in the catchment. Atypically, summertime (Nov - Jan) surface water stable oxygen isotope ratios ($\delta^{18}O$) were negatively displaced from meteoric values (ca. -0.28 ± 0.13 ‰), indicating a remarkable degree of low-temperature water-rock interaction. Isotope ratios in the Tararu's tributaries showed less alteration than the main stem, suggesting shorter residence times in areas of high relief. Conversely, in the main stem, isotope ratios revealed higher mineral weathering, accompanied by elevated dissolved metal concentrations, consistent with dominant inputs from shallow groundwater (i.e. interflow) in drier months. Weathering of primary sulfides contributed pronounced acidity to the Ohio Creek (pH ca. 3.8), but overall, carbonate buffering appears sufficient to ameliorate acid mine drainage across the catchment (pH ca. 7-8). Nevertheless, our results confirm ANZECC ecological trigger value exceedances (> 80% protection threshold) for a suite of toxic metals including Al, Zn, Cd and Pb. Further research is recommended into metal loading rates and slope stability in the most contaminated areas, with view to protecting coastal water quality in Tikapa Moana-o-Hauraki, the Firth of Thames.

INCLUDING UNCERTAINTY IN GEOLOGICAL CONCEPTUAL MODELS IN NUMERICAL GROUNDWATER MODEL PREDICTIONS THROUGH MULTI-POINT GEOSTATISTICAL SIMULATIONS.

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Over the past decade, predictive uncertainty analysis in applied groundwater modelling has been widely adopted. However, in most studies, many numerical modelling aspects which can influence predictions, are fixed, and based on uncertain conceptual models of groundwater flow, such as zone extents and layer elevations. It is well established that inaccuracies in the conceptual model used for a numerical groundwater model can cause structural error. This results in incorrect, biased predictions that persist despite use of advanced nonlinear predictive uncertainty analysis methods. Ensemble and data space inversion methods for groundwater model calibration and uncertainty analysis have expanded the possibilities of using large numbers of adjustable parameters while maintaining computational efficiency. Larger number of adjustable parameters allows for more aspects of a numerical model be represented included in predictive uncertainty and can reduce the potential for fixed aspects of a numerical to lead to biased predictions. However, representing more of a conceptual model with stochastic parameter sets is a challenge.

This study applied multipoint geostatistical simulations to represent the uncertainty in geological conceptualization in a groundwater model. The numerical modelling study was conducted to assess the potential range of dewatering volumes necessary to develop a mine, with sparse groundwater data, and groundwater flow dominated by regional faulting. Multipoint geostatistical simulations were based on a training image and produced alternative realizations of categorical geological models. A local scale structural geological model of fault locations was used to create a training image and alternative models of fractured vs non fractured rock across the larger regional domain were generated. Alternative realizations of hydraulic conductivity and storage parameters were then generated from the multiple geological fracture models. This approach allowed the uncertainty of both geological conceptual model and model parameter values associated with geological units to be included in a groundwater model predictive uncertainty analysis.

WHEN AND HOW TO USE GROUNDWATER TRACERS TO INFORM REGIONAL-SCALE NUMERICAL MODEL PREDICTIONS?

Brioch Hemmings,[1] Catherine Moore,[1]
[1] Te Pū Ao, GNS Science

Groundwater tracer data, such as the age tracer, tritium, is potentially rich with information relating to water flow pathways and provenance. As such, there is a strong temptation to assimilate this data, formally and exhaustively, into predictive numerical models, through history matching (model calibration). Previous studies have shown that the formal numerical assimilation of age tracer data can have unintended consequences for the predictive capacity and veracity of groundwater models. Furthermore, extracting information from tracer data, and effectively and appropriately directing it to necessarily deficient groundwater model parameters, requires significant additional logistical and computational effort. In this study, we ask the questions: For what types of predictions is assimilation of tracer information worth it? and: Where and how should we direct the effort of incorporating this information?

We explore different methods for using tritium data in the numerical groundwater modelling process. We assess the benefit of assimilating such data for a real-world, predictive, regional groundwater model (Heretaunga Plains, NZ). Benefit is assessed based on the reduction in uncertainty of model predictions. To ensure some conceptual alignment between the tracer data and model predictions, the predictions of interest relate broadscale aggregated budget components of the system, and age distributions at wells and springs, under changing system stresses.

We quantify the value of formally assimilating tritium tracer data in the numerical model history matching, relative to just assimilating observations of flow and water level. Recognising that tracer data also has potential to influence and inform system conceptualisation, we also explore the relative value of assimilating the information, less formally, during model conceptualisation, construction, and formulation of the prior (parameter values and uncertainty).

REACH-SCALE MORPHOLOGICAL IMPACTS OF LANDSLIDING INTO ALPINE RIVERS DRAINING THE SOUTHERN ALPS

Kate Hodgson,[1] Sarah Mager,[1]
[1] University of Otago

Slope failure is a common occurrence in mountain catchments and is an effective mechanism of sediment delivery into mountain rivers. The impacts of land sliding on river shape and form depend on the variety of pathways through which sediment delivery and subsequent catchment impacts occur. Delivery and response are, however, dependent on the type of landslide, particularly the volume of material and the subsequent scale of the event disturbance that is initiated. As such, the impacts of stochastic slope failure in a river catchment reveals a multifinality of outcomes in channel morphological change, even when controlling for similar lithological environments as exemplified in our case study catchments in Tititea/Mt Aspiring National Park of Ka Tiritiri o Te Moana/Southern Alps. Following existing landslide classification types we have mapped the morphological disturbance of three types of landslide: 1) where existing channels are completely buried or blocked resulting in dam formation and occlusion of channel form (blockage/obliteration); 2) landslides impact channel directly resulting in an intrusion of material to active channel (point/riparian) and; 3) landslides that are decoupled from rivers channel and outside of tributary drainage (nil/buffered). Of these classifications three key case studies are investigated; the blockage/obliteration event of the Dart/Te Awa Whakatipu Valley and eventual lake formation; the channel response to ongoing semi-decoupled land sliding in the Siberia Valley; and the pulsing land slide activity occurring over the Muddy Creek fan present in the Rees/Puahiri Valley. This paper describes morphological change and channel response to mass movement through early aerial (1966-1984) and satellite imagery (2010-2023) using Natural Character Indices (NCI), alongside grain size analysis. Such data may be useful for understanding the potential hydrological and sedimentary hazards associated with future landslides and whether different scaled events present ongoing management risks for infrastructure in mountain regions.

INVESTIGATING THE CONNECTIVITY OF ALLUVIAL AQUIFER GROUNDWATER TO DEEPER GREAT ARTESIAN BASIN AQUIFERS IN THE YELARBON DESERT

Harald Hofmann[1], Dylan Ford[1], Julie Pearce[1,2], Adrian Mckay[3], Nakita Bartlett[3], Phil Hayes[2], Chenming Zhang[4], Kim Baublys[1], Matthias Raiber[5], Dioni Cendon[6]

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The area around the Yelarbon Desert has been of great interest to soil scientist, hydrogeologists, ecologists and water and land managers because of its bare and scalded landscape in the middle of relatively productive agricultural land. High sodic soils limit the growth of freshwater ecosystems and agricultural use and only very adapted, specialised vegetation can sustain. The high sodic soils are believed to be a result of sodium-bicarbonate rich groundwater from the Surat Basin aquifers, a sub-basin of the Great Artesian Basin (GAB), which discharge into the shallow Macintyre Brook and Dumaresq River alluvial aquifers near the Peel fault in the QLD – NSW border, Australia. Consistantly, shallow sub-surface groundwater levels have led to an increase of concentration of salts in groundwater by evaporation and evapotranspiration with subsequent precipitation of evaporites.

This study clarifies the hypothesis of the connectivity between deeper GAB aquifers the shallow alluvium and if they are the cause of the existence of the Yelarbon Desert. The main objectives of this study are, 1) Identifying GAB aquifers in the vicinity of the Yelarbon Desert that have potential to discharge groundwater into the alluvium, 2) Establish the locations where groundwater salinity and water quality in the alluvium decline and are conducive to the formation of highly sodic soils and 3) conceptualise the groundwater flow system using major ion geochemistry, $^{87}Sr/^{86}Sr$, stable (d^{18}O and d^{2}H) and cosmogenic isotopes (^{36}Cl and ^{14}C).

Initial results indicate a change from Na-Cl dominated groundwater to Na-HCO_3 dominated water in the alluvial aquifers along the Macintyre Brook and the Dumaresq River and mixing of alluvial groundwater with water from deeper GAB units. The stable isotope content suggests a potential connection to the Hutton Sandstone and Springbok aquifers. The results help in identifying and quantifying GAB discharge in the most southeastern corner of the Surat Basin.

TE MAUNGARONGO O TE KOOTI RIKIRANGI WETLAND RESTORATION – UNDERSTANDING AND MANAGING HYDROLOGY

Holmes, G. [1], **McConchie. J,**[1]
[1] SLR NZ Consulting Limited

Background

Te Maungarongo o Te Kooti Rikirangi wetland is located approximately 9 km northwest of Gisborne City and was formed when a meander of the Waipaoa River was by-passed by river straightening during the construction of the Waipaoa River Flood Control Scheme in the 1950's. The wetland (Figure 1) is approximately 4.5 km long, 120 m wide and covers an area of 54 hectares.

Te Maungarongo is a regionally significant wetland and has been identified with the Tairāwhiti Resource Management Plan as having threatened/ at risk/endemic wetland-dependent species. The wetland contains, a high diversity of indigenous flora or fauna, high naturalness, high cultural values, and has a high restoration potential.

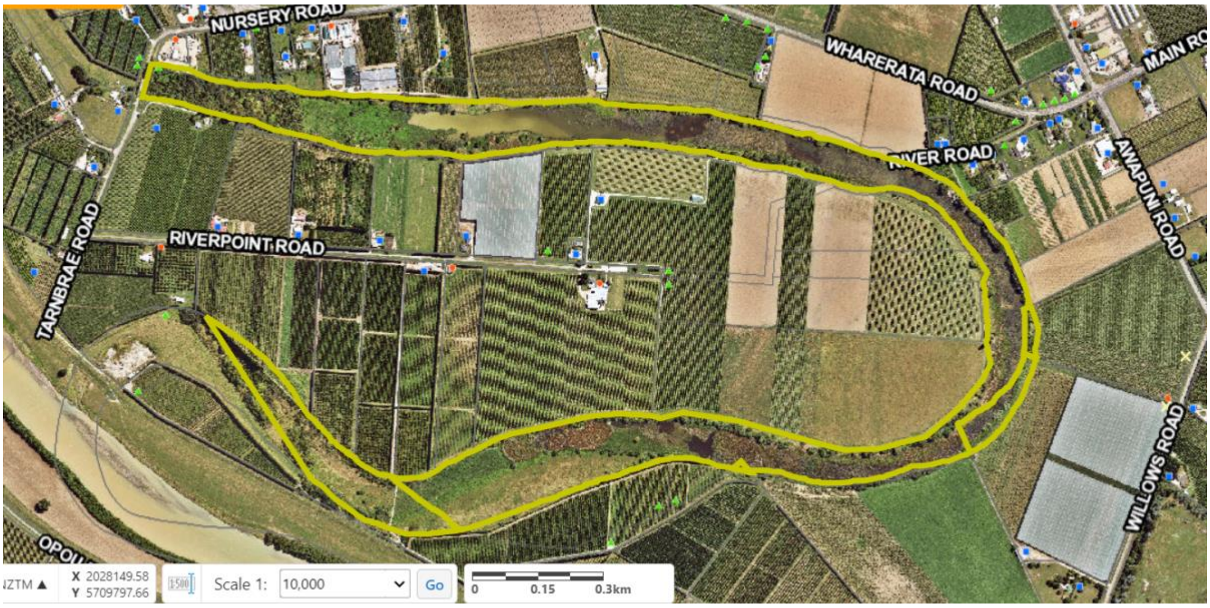

Figure1: Te Maungarongo o Te Kooti Rikirangi Wetland

Te Maungarongo was returned to Nga Uri o Te Kooti Rikirangi who aspire to restore the area to a world class wetland environment. Nga Uri o Te Kooti Rikirangi are partnering with Te Kaunihera o te Tairāwhiti | Gisborne District Council to meet the obligations of the National Policy Statement – Freshwater Management (NPS-FM) and ensure that future management of Te Maungarongo gives effect to Te Mana o Te Wai. The partnership is incorporating aspects of both "western" science and mātauranga Māori to meet holistic and integrated outcomes.

Current challenges to the management of Te Maungarongo include water quality (discharges to the wetland from surrounding areas), water quantity (surface water, discharges, groundwater takes, and the effect of flood gates on water levels), fish passage, pest plants and animals, multiple objectives from interested parties, access to the wetland, encroachment on wetland boundaries, and the scale of work associated with a wetland of this size. Nga Uri o Te Kooti Rikirangi will develop their long-term vision for the wetland, which may be informed by hydrological processes, including the extent to which these can be managed.

To increase understanding of the dynamics and relationships between water levels within the wetland, groundwater, and adjacent surface water bodies, Te Kaunihera o te Tairāwhiti have commissioned a hydrological and hydrogeological assessment of the Te Maungarongo wetland. The first stage involves information gathering, data gap identification, and the development of a conceptual model (to be refined later) to inform discussions regarding management options and outcomes.

METABARCODING OR METAGENOMICS? COMPARING APPROACHES TO MONITORING GROUNDWATERS USING eDNA

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[1] Macquarie University
[2] CSIRO Energy

Major developments that impact aquifers require assessments of potential impact as part of the approvals process. Environmental (e)DNA has great potential to improve the way that groundwater ecosystems are monitoried and impacts assessed, yet the relative merits of different eDNA-based methods to groundwater monitoring have rarely been considered.

The aim of this study is to compare the outputs of metagenome and metabarcode analysis of eDNA to characterise groundwater biota for monitoring and assessment. We collected samples from 15 wells that access shallow alluvium in the Namoi R catchment (NW NSW) and 15 wells that access fractured sandstone in the Sydney Basin.

More than 10900 functional genes were identified in the metagenome analysis. The functional profiles of the microbial communities differed between aquifer types and pre- and post-purge samples. Taxonomic assemblages derived from the metagenomes also varied by aquifer types and pre/post-purge sample type, consistent with the patterns derived from metabarcoding of the same samples. Functional and taxonomic profiles based on metagenome and metabarcode analyses responded to similar environmental gradients.

Metagenome analysis provides a large amount of information on the functional genes present within a sample, which is more detailed than can be inferred from metabarcoding analyses. However, the greater depth of information comes at considerably higher financial cost and greater complexity of analysis. For routine sampling and environmental assessments, it is currently more feasible and cost efficient to complete metabarcoding as an adequate alternative to metagenome analysis.

This research was funded by the Department of Climate Change, Energy, the Environment and Water on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development.

GROUNDWATER EFFECTS OF RECYCLED WATER DISPOSAL

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[1] Jacobs
[2] Presenting Author

Disposal to land of treated effluent is a common method of management of treated effluent. Disposal to land is often preferred over disposal to waterways or oceans as it avoid direct contamination of surface water. However, disposal to land can also include unintended groundwater effects, including contamination of groundwater by effluent constituents. This study involved assessing the groundwater effects of effluent disposal to land at 8 recycled water plants in Victoria, Australia. Potential groundwater effects include contamination by nutrients and by other chemical species. This study characterised the issues facing water treatment organisations seeking to balance treatment cost with disposal robustness.

The effect on groundwater was found to vary across the sites depending on the site characteristics. Common factors were identified that affected the level of effect. These were: depth to groundwater, irrigation method and management, soil capability, operator awareness, groundwater gradient. Most commonly it was found that where the disposal requirements for effluent were not matched to the plant/crop requirements and soil capability, groundwater effects were more likely. The study also identified that biosolids management is a key consideration for groundwater effect.

Assessing the level of effects and predicting the consequence of effluent disposal requires a detailed understanding of sites, which is often outside the skill set of water treatment operators. Further, in areas where landscapes have been altered by development, understanding the background groundwater condition and thus the potential effect of effluent disposal requires consideration of the conceptual hydrogeological setting. In this case it was found that human effects on groundwater outside of the site of effluent disposal can have a large bearing on the potential level of effect of the disposal operation. This is a consideration when seeking to site disposal. These factors are especially relevant when considering the possibility of selling or providing treated effluent for use by others, where this may lead to effects on groundwater that are away from the treatment plant site.

CLOSED-LOOP DECISION-SUPPORT MODELLING

Rui Hugman,[1] Jeremy White,[1] Eduardo de Sousa[1],Cecille Coulon[1]
[1] INTERA Geosciences

Groundwater modelling is a valuable tool for informing future management actions, especially when the groundwater system is facing a new stress or condition for which there is no historical precedent. In such cases, the most valuable data to inform a decision is usually obtained after it is implemented. Traditional approaches to modelling rarely make the best use of this fact. Yet, advances in quantity and quality of data that characterizes various aspects of groundwater systems is growing rapidly, increasing the value of more frequent modelling-based data processing to support decision making.

We present a workflow for efficient, semi-autonomous higher frequency modelling in a decision-support context. Using closed-loop management, we demonstrate how data assimilation and management optimization under uncertainty can be used to not only extend the lifespan of groundwater resources, but also to provide more frequent and accurate forecasts of future conditions. We apply this workflow to a synthetic coastal groundwater system facing overexploitation, reduced rainfall, and rising sea levels, with the goal of maximizing the longevity of freshwater pumping. To measure the value of higher frequency updating, we repeat the workflow for multiple realizations of the truth.

ON-SITE WASTEWATER SYSTEMS – INSIGHTS INTO THEIR FUNCTION, LOCATION AND RISKS TO GROUNDWATER

Bronwyn Humphries,[1] **Rachel Qiu**,[1] **Gemma Langley**,[1] **Andrew Pearson**,[1] **Lisa Scott**,[2] **Marta Scott**,[2] **Louise Weaver**,[1]
[1] Institute of Environmental Science and Research
[2] Environment Canterbury

Aims

On-site wastewater management systems (OWMS) release chemical and microbial contaminants into the environment, potentially posing risks to surface water, groundwater, and human health (Richards et al., 2016). Although OWMS effluent quality has been characterised internationally, in Aotearoa the chemical and microbial quality of effluent is poorly characterised. Thus, water regulators and engineers for OWMS manufacturers typically rely on international data, which may not adequately represent a New Zealand context, to inform policy and estimate environmental and public health risks. Another issue is locating historic OWMS which did not require a resource consent to install, as prior to approximately 1998 OWMS were considered a permitted activity within most contexts throughout Aotearoa. To address these knowledge gaps, in collaboration with Environment Canterbury, we present within a Waitaha/Canterbury context:

- On-site wastewater effluent quality results from a field-scale research site and 30 discrete OWMS sampling locations
- A GIS model which estimates the location of unknown OWMS
- Factors that increase the risk of OWMS impacting groundwater, particularly drinking water quality

Methods

OWMS effluent samples were taken from a field-scale research site as well as from 30 OWMS across Canterbury including 17 primary and 13 secondary treatment OWMS. Additionally, composite samples were taken from a primary and secondary treatment system over a period of 4 days. Effluent sampling occurred between December 2022 and April 2023 with samples analysed for 2 microbial (*E. coli* and total coliforms) and 26 chemical analytes.

A OWMS GIS model was developed for the 10 districts within Waitaha/Canterbury. The model utilised publically available spatial datasets to estimate the location of previously unknown OWMS by:

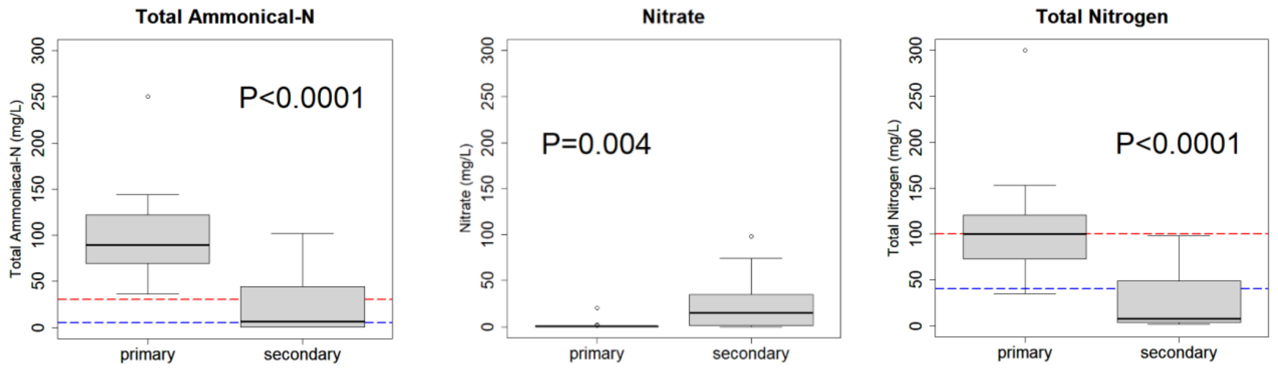
Unknown OWMS = occupied dwellings – reticulated dwellings – active OWMS consents

By interrogating the above datasets insights were gained to assist in determining the potential risks to environmental and human health.

Results

Results for samples taken from the 30 OWMS in terms of nitrogen species are shown in Figure 1. The results show that secondary treatment OWMS provide an environment (i.e., mechanical aeration) in which nitrification can occur and results in higher nitrate concentrations when compared to primary OWMS. However, primary systems were found to have a significantly greater total nitrogen concentration than secondary systems indicating enhanced treatement and nitrogen removal by secondary treatemnt systems.

Figure 1: Nitrogen species results from 17 primary and 13 secondary treatment OWMS within Waitaha/Canterbury between December 2022 and April 2023. The dotted lines indicate the expected values associated with primary (red line) and secondary (blue line) OWMS (Auckland Council, 2021).



Results from the GIS model estimate that within Waitaha/Canterbury there are a total of approximately 34,265 OWMS with 26,176 (76%) of those OWMS locations unreported prior to this research (Table 1). Figure 2 shows the number of OWMS estimated to be located within Drinking Water Protection Zones (DWPZ) across the 10 districts of Waitaha/Canterbury.

Table 1: Number of consented and estimated OWMS within the 10 districts of Waitaha/Canterbury.

District	Total OWMS estimate	Consented OWMS	Estimated unknown OWMS
Selwyn	9,405	2,716 (29%)	6,689 (71%)
Waimakariri	6,749	2,081 (31%)	4,668 (69%)
Timaru	4,367	725 (17%)	3,642 (83%)
Ashburton	3,819	723 (19%)	3,096 (81%)
Hurunui	3,226	614 (19%)	2,612 (81%)
Christchurch	3,028	552 (18%)	2,476 (82%)
Waimate	1,781	271 (15%)	1,510 (85%)
Kaikoura	757	197 (26%)	560 (74%)
Mackenzie	711	147 (21%)	564 (79%)
Waitaki	422	63 (15%)	359 (85%)
Total	**34,265**	**8,089 (24%)**	**26,176 (76%)**

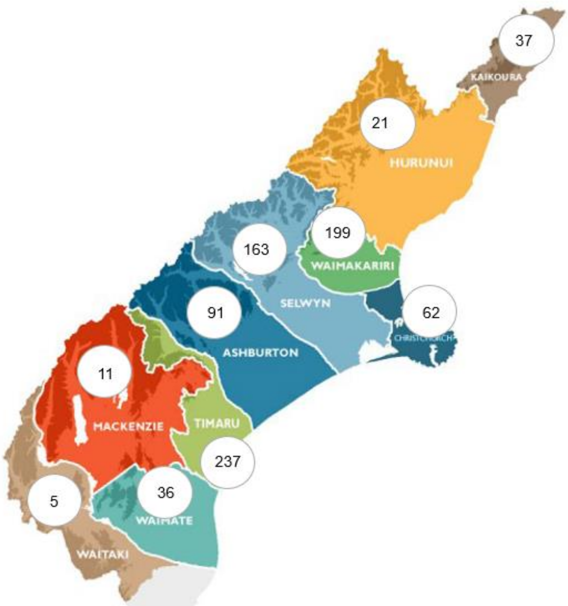


Figure 2: Estimated number of OWMS within Drinking Water Protection Zones across the 10 districts of Waitaha/Canterbury.

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FLOOD WARNING SYSTEM IMPLEMENTATION AND PERFORMANCE– ARNOLD DAM CONSTRUCTION

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[1] Riley Consultants Limited

Aims

The purpose of this project is to provide contractors working at the Arnold Dam advanced warning of flood events. The dam strengthening works being undertaken at the Arnold Dam require contractors to work within the active river channel downstream of the dam. The dry working area is maintained via an earth bund. In the event of a flood large enough to overtop the diversion bund, the contractors require 4 to 6 hours of advanced warning to extract their equipment and prepare the working area for inundation.

This flood warning system was required to provide advanced warning to the contractors. This presentation will provide a brief overview of the work completed to derive the rainfall and flow thresholds used by the warning system, and present in greater detail the work done to implement the system and the operational performance of the system.

Method

To develop rainfall and flow thresholds used in the flood warning system, the following was completed:

- Hydrologic modelling of the Arnold River catchment in HEC-HMS
- Hydraulic modelling of the Arnold River downstream of the dam based on the proposed diversion bund in HEC-RAS.
- Installation of flow and rainfall monitoring within the Arnold River catchment, which was telemetered via the Harvest network.
- Derivation of flow and rainfall thresholds to predict flows in the Arnold River at the Arnold Dam. This was completed by using R programming to interpret HEC-HMS model results.
- The system returns “warning levels” based on the likelihood of a flood exceeding the capacity of the diversion bund.
- Validation of the selected rainfall and flow thresholds based on the data recorded at the installed rainfall and flow sites.

The contractors required real time results from the flood warning system. This required an automated process to compile the telemetered data from the installed flow monitoring as well as the real time data available from the West Coast Regional Council (WCRC). This process applied the rainfall and flow thresholds to the data and conveyed the information to the contractors. An R script was developed which automatically downloads the Harvest and WCRC data, computes rainfall depths over various durations, applies the derived thresholds, plots the data along with the suggested “warning level”, then saves the key information to a google drive and sends email alerts when the warning level increases. The contractors can access the results saved to the google drive onsite via a starlink internet connection. The R script runs on an onsite computer as well as on an offsite computer as a backup. The script runs automatically every 15 minutes.

Results

The reliability of the system was assessed prior to implementation to ensure adequate warning times could be achieved without returning too many “false alarms” (i.e., predicting a flood which does not eventuate). Interpreting the system results it was found that 50% of the time when the system predicted the design flow would be exceeded, this actually occurred. In all cases, reasonably large flows still occurred at the dam, even if the full design flow was not reached.

During construction, there have been several moderate floods and one flood which inundated the in-river working area (to August 2023). This has allowed the levels predicted in the hydraulic model to be confirmed and assess the actual performance of the system. For the event where the in-river working area was inundated, the system did predict flood flows would exceed the design capacity.

There were several challenges while implementing the system, including system outages due to lack of internet access, loss of the Harvest telemetry units due to lightning strike during a flood event, and various errors and glitches in the R script. Most of these issues have been addressed, although the risk of lightning strikes has not been eliminated. Other challenges include overnight events, as the system is not typically monitored outside of working hours. The contractor must still pay close attention to weather forecasts to mitigate this risk.

The R script was developed specifically for the Arnold River and has not been made publicly available. The script could be adapted to other projects with similar requirements, provided adequate telemetered rainfall and flow data is available for the catchment and appropriate hydrologic analysis is completed to derive rainfall and flow thresholds required as input to the warning system.

CHARACTERISATION OF EARTH EMBANKMENT SEEPAGE USING STABLE ISOTOPE ANALYSIS AT TEKAPO CANAL, MACKENZIE DISTRICT, NEW ZEALAND

Jowsey, N [1]
[1] Beca Limited
[2] Genesis Energy Limited
[3] University of Canterbury

Aims

The aim of this study was to characterise the origin of suspected embankment seepage water from Tekapo Canal using stable isotopes of hydrogen (δ^2H) and oxygen ($\delta^{18}O$) as natural tracers.

Genesis Energy (canal owner) was interested in investigating potential issues with the canals earth embankment after assumed seepage water had been observed for some years at the toe of the embankment, purportedly forming *Pattersons Ponds*.

The tracers were used to establish the isotopic signature of the canal water, *Pattersons Ponds,* and surrounding water bodies in order to quantify which water bodies were linked, and if so, to what extent.

Method

Physical processes such as evaporation cause fractionation, through which mass differences allow lighter ^{16}O isotopes to preferentially evaporate, causing the proportion of ^{18}O to ^{16}O isotopes to change in a water body. As a result of such processes, water bodies develop unique isotopic compositions which can be used to ascertain their origin, whether they are connected, and if so by what proportion.

Water samples were collected at nineteen locations spread across the Mackenzie Basin, including the main lakes (Tekapo and Pukaki), tributaries of the lakes, and various ponds at the embankment toe of Tekapo Canal. This broad sampling regime established groups of isotopically distinct waters, hence allowing the assumed seepage water of *Pattersons Ponds* to be connected to a known source.

The ratio of hydrogen (δ2H) and oxygen (δ18O) stable isotopes were analysed in a Picarro L2140-i Isotope and Gas Concentration Analyzer.

Results

- The assumed canal seepage water thought to be recharging the main group of canal embankment ponds (*Patterson's Ponds)* was found to be isotopically distinct evaporated Forks Stream water/ groundwater, hence not connected to the canal and not indicative of active seepage (*Figure 1*).
- At a high level, there are two broadly distinct clusters of water in the area sampled:
    1. High-altitude snow melt feeding Lake Tekapo, Tekapo Canal, Lake Pukaki and Pukaki-Ohau Canal (shown by blue text in *Figure 1*); and,
    2. A broadly linked area from Lilybank Road (adjacent to the eastern shores of Lake Tekapo) to Lake Alexandrina (adjacent to the west of Lake Tekapo and Mt John) to Tekapo Canal embankment toe ponds. This cluster is likely southward migrating shallow groundwater in the Tekapo Outwash Gravels. The majority of canal embankment toe ponds (including *Pattersons Ponds*) act as depression springs, intersecting the groundwater table (Cooksey 2008). This group is shown by both black and red text in *Figure 1*.

- ‘Ford Seep’ and ‘Forks Stream Culvert Embankment Seep’ were isotopically similar to canal water, plotting in the same closely constrained cluster. Both sites therefore appear to be recharged by Tekapo Canal. This connection was well-known to the asset owner and serves as probable confirmation of active seepage.
- The local meteoric water line (LMWL) shown by the dotted red line in *Figure 1* trends along a different slope from the global meteoric water line (GMWL) (shown by the solid black line), and is derived from Forks Stream/ Tekapo River samples but is highly evaporated.

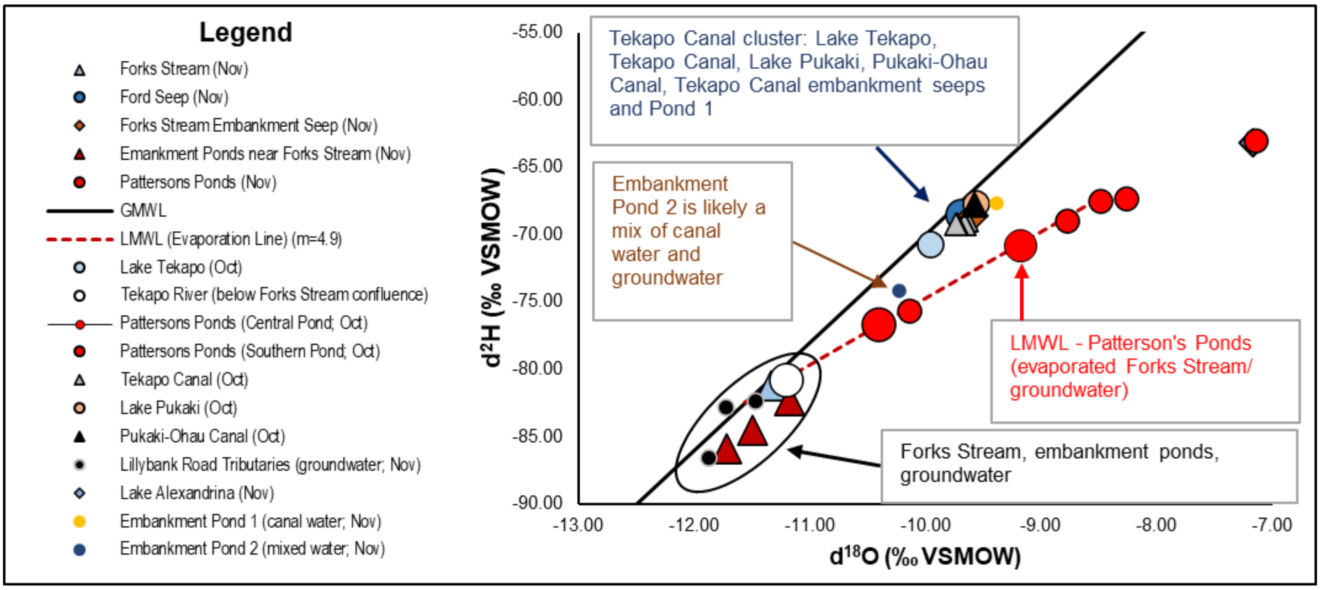

Figure 1. Stable isotope results.

Out of thirteen embankment toe ponds between chainage 0 – 6 km, only ‘Pond 1’ (plus the two active seeps) are canal water. This is a positive result for the integrity of the canal structure given the hypothesis that most or all of the embankment toe ponds were canal seepage water. *Figure 2* illustrates the results of the stable isotope analysis.

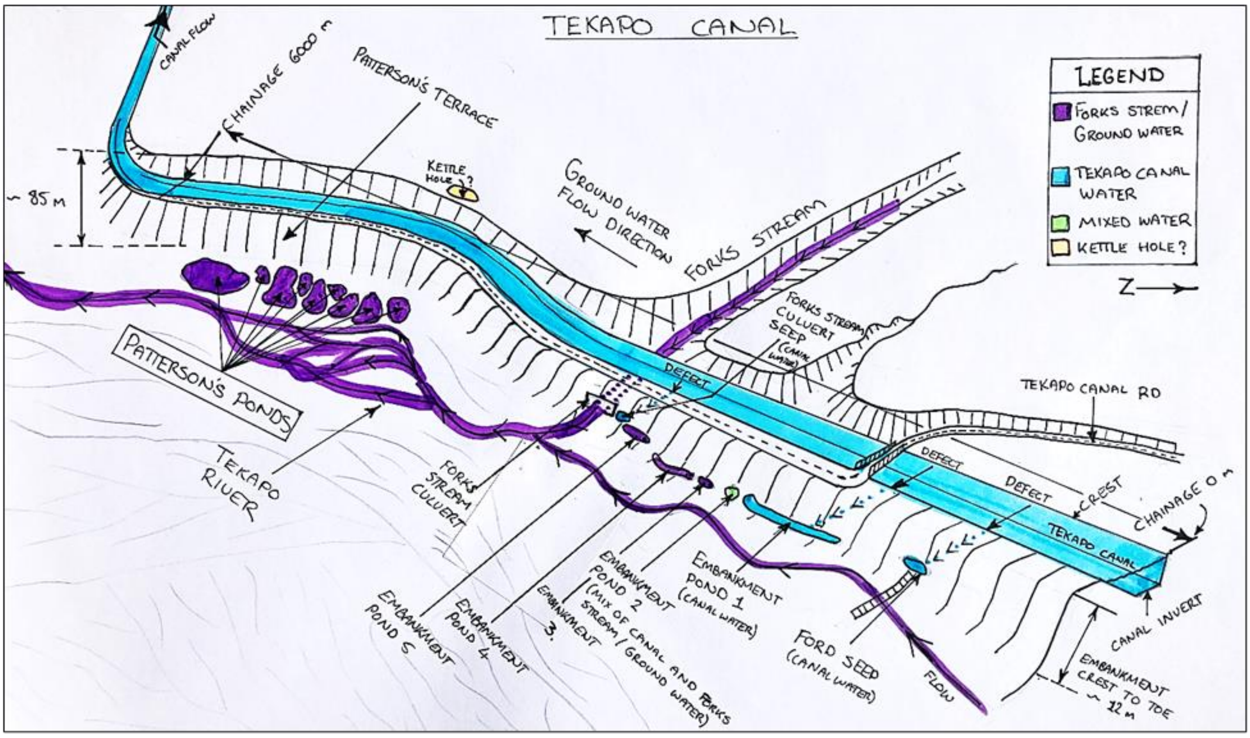

Figure 2. Schematic showing the source of various water bodies at and near the canal embankment.

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NUMERICAL DELINEATION OF SOURCE PROTECTION ZONES IN HETEROGENEOUS ALLUVIAL AQUIFERS: GUIDELINES AND RECOMMENDATIONS

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[1] Institute of Environmental Science and Research Ltd. (ESR), New Zealand
[2] GNS Science

Protecting groundwater sources from contamination is crucial for ensuring safe and reliable water supplies. Due to heterogeneity, variations of aquifer properties can create preferential flow pathways, leading to contaminant and pathogen transport characteristics that are highly unpredictable.

This presentation provides an overview of a forthcoming report being prepared by ESR and GNS, to provide guidance and recommendations for the numerical delineation of source protection zones (SPZs) in heterogeneous aquifers.

The guidelines will include recommended methodology and workflow/data requirements for complex SPZ analysis, and how simplifications can reduce complexity without significantly affecting the predictions. Key steps include:

- Using lithology data to characterise geological uncertainty
- Parameterising the flow and transport model, while considering aquifer heterogeneity
- Deriving the probabilistic SPZs where their extent is expressed as the probability that contaminants and pathogens from the zone will be transported to the well screen.

The most commonly utilised method of SPZ delineation involves tracking particles backwards in time in an established flow system to delineate the well capture zone within a chosen timeframe. The guidelines will offer recommendations on the choice of particle tracking direction (forward or backward), as well as considering the potential effects of well pumping rates and screen depths on the extent and vulnerability of SPZs.

Additionally, the guidelines will include a comparison of results from the complex stochastic flow and transport simulations with simple homogeneous models and available analytical solutions. Scaling/safety factors for various parameters (porosity and anisotropy in particular) are obtained when using a simple “proxy” model to approximate a complex model. Examples of simple models include 3D and 2D homogeneous numerical models and the uniform flow equation.

By providing detailed methodologies, recommendations, and considerations for various scenarios, these guidelines aim to support effective source protection and safeguard groundwater supplies from contamination risks.

HISTORY-MATCHING TO TRITIUM: SEQUENTIAL CONDITIONING OF PRIORS

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Information contained in diverse observations of system behaviour can inform model parameters and model structure in ways that may not be apparent in the background descriptions of the hydrogeologic system. For example, Tritium concentrations can be used to condition forecasts of groundwater travel time (e.g., Zell et al. 2018). However, simulations of groundwater travel times based on Tritium measurements are still uncertain. This is in large part due to the temporal distribution of input concentrations, which sharply peaks at the time of atomic bomb testing, providing non-unique estimates of age (e.g., Suckow, 2014). History-matching to Tritium concentrations can lead to biased predictions as parameters in over-simplified models take on surrogate roles to facilitate fitting the data (Knowling et al., 2020). However, inappropriate priors can also cause bias and exacerbate any existing model structural bias (e.g., Gupta et al. 2022). History-matching using highly parameterized models can help reveal aspects of system behaviour, which may be used to assign more appropriate priors to avoid such bias and/or mitigate the impacts of a too-simple model structure (Manewell and Doherty, 2021; Doherty and Moore, 2023).

We demonstrate these issues using a steady-state model of the Wairau Plains, with a highly simplified representation of the geology. The iterative ensemble smoother method (PESTPP-IES) was used to sequentially history-match to subsets of data (i.e., first heads, then tritium, then both). The results of each history matching run were used as new prior parameter values for the subsequent step. Estimates of groundwater age from this sequential history-matching approach indicate an improved ability to extract information from data, and are compared to those using the more traditional approach of simultaneously history-matching to all the available data at the same time.

STYGOFAUNA RESEARCH - IS AUSTRALIASIA PUNCHING ABOVE ITS WEIGHT OR DOES MORE NEED TO BE DONE?

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[2] Karlsruhe Institute of Technology (KIT)

Groundwater ecology is a relatively young field, and the volume of research and understanding of the science lags behind that of surface waters. Despite this, groundwaters and the ecosystems they support are increasingly being recognised for their ecosystem services that include carbon and nutrient cycling and water purification through biogeochemical processes. Globally, common threats to groundwater ecosystems include abstraction, contamination and climate change, all of which are placing unprecedentent pressure on groundwater availability, but also may compromise ecosystem services and impact biodiversity.

Knowledge of groundwater ecosystems, their functions and biota is unevely distributed across the globe. We conducted a meta-analysis of over 850 publications investigating the trends in stygofauna research, beginning with the earliest work dating back to 1537 through to 2021, as well as an analysis of the global research effort. We outline the concentration of stygofauna research and knowledge from Europe (358 studies), Australia (126 studies) and New Zealand (22 studies). However, this highlights issues for the global knowledge of groundwater ecosystems, as there is limited research being disseminated from Asia, Africa, and the Americas. As such our currently biased views on groundwater biota may hinder the identification of broader biodiversity patterns and the ability to detect ecosystem functions in different climatic regions of the world. As climate change potentially alters climatic boundaries and the way in which groundwater is used, it is essential that there is a shift from localised studies to a global perspective, with a world-wide effort to collect information on these important ecosystems.

CITIZEN SCIENCE IN THE DARK: CAN VOLUNTEERS BE UTILISED TO FILL GROUNDWATER KNOWLEDGE GAPS?

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[1] Macquarie University

Since the mid-1800s, Australia has been engaging citizens in scientific research, particularly in the life sciences. Presumably the vast and remote nature of the continent coupled with a relatively small population has meant that the collection of meaningful data requires additional efforts. Using citizen scientists (CS) to aid in the collection of data in surface ecosystem is logistically simple and engaging volunteers in well understood ecosystems with charismatic biota is relatively easy. Groundwater ecosystems are neither well known, easy to sample or have any 'trophy' species, thus engaging CS in these unknown environments is difficult.
In this project we engaged farmers as citizen scientists to collect water quality and biological data for the assessment of groundwater health within the shallow alluvial aquifers of the Namoi catchment in NW NSW. We emphasised the 'values' of groundwater biota in providing ecosystem services as a tool to engage CS in a program to monitor groundwater health using the Groundwater Health Index. Sampling was undertaken on 4 occasions between 2016-2018, coinciding with agricultural activities and irrigation seasons. Sampling revealed several species of stygofauna as well as water quality, indicating a 'moderate' health score on many of the farms. In addition to providing data this project was also successful in raising the profile of the poorly understood but important ecosystems. It also provided participants credit as part of their industry Best Management Practice program. In this case, the Citizen-Scientist collaboration matched deep site knowledge and on-ground logistical capabilities with skills in stygofauna identification and water quality analysis, in the context of a mutual passion for environmental improvement. As the need and urgency for knowledge on groundwater quality and health is much greater than the limited number of professionals in this field can supply, we should be actively seeking CS to fill this data gap.

UNDERSTANDING GROUNDWATER-SURFACE WATER INTERACTION AND POTENTIAL PATHWAYS THROUGH A HYDROGEOLOGICAL CONCEPTUAL MODEL AT A COASTAL WETLAND

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Aims

Marton Park wetland is a coastal wetland located on the Kurnell Peninsula in NSW. It feeds into Quibray Bay and the Towra Point Nature Reserve, a RAMSAR protected wetland and the largest of its kind within Greater Sydney. A hydrogeological conceptual model (HCM) was developed to understand the interaction of surface water and groundwater, providing insight into potential contamination migration pathways.

Method

Over the years, urbanisation has shaped Marton Park wetland. Previously a saltwater system, development has restricted tidal influence and the wetland's connection to Quibray Bay (Molino Stewart Pty Ltd 2009). Currently residential and industrial areas surround the wetland and lie within its catchment area. Potential contaminants from surrounding industrial areas may enter the wetland via surface water and groundwater.

The wetland overlies the Botany Sands, a highly permeable aquifer system. The shallow groundwater levels surrounding Marton Park and the transmissive nature of the aquifer suggest strong surface water-groundwater interaction. The wetland is a potential contaminant sink, filtering pollutants before they enter the downstream RAMSAR protected reserve via an outlet drain (Molino Stewart, 2009).

To gain a better understanding of the wetland, field data was gathered through the installation of monitoring wells (shown on **Error! Reference source not found.**) and a three-month monitoring program.The monitoring program included continuous salinity and water level measurements using data loggers and water quality sampling for groundwater and surface water, hydraulic testing, and surface water flow measurements at the inlet (MP01) and outlet of the wetland (MPSW01).

Figure 5 Site location, monitoring locations and cross-section

Field data was analysed and combined with a review of publicly available information to create a HCM, presented in Figure 6. The HCM is a summary of the current understanding of the groundwater system and the influences on it, including 'natural' processes, such as recharge and discharge as well as man-made stressors. The HCM will assist in understanding possible future changes to the wetland as a result of groundwater-surface water interaction.

Results

The HCM in Figure 6 shows that groundwater levels are generally shallow, and above the base of the wetland, indicating groundwater–surface water interaction is taking place. The groundwater and surface water hydrographs show a clear response to rainfall with groundwater levels taking somewhat longer to return to baseline levels (Figure 7). Long-term groundwater levels measured at a government monitoring bore at Marton Park showed a maximum seasonal fluctuation between 0.87 and 1.68 mAHD from April 2002 to May 2021. Limited groundwater-surface water interaction is observed during periods of low rainfall, while more interaction is observed during periods of higher rainfall when groundwater levels come close to the ground surface as observed in the hydrograph of PMW03 (higher than surface water level at MPSW01). Groundwater is likely to contribute significant inflow to the wetland during high rainfall events.

The major ion chemistry pie charts (Figure 6) show the relative concentrations of major ions and can be used to determine water type and discern processes affecting water samples including precipitation or dissolution, mixing and ion exchange. The results show a clear difference in water types between surface water and groundwater. The dominant ions for groundwater are bicarbonate (HCO_3) and calcium (Ca), while the dominant ions for surface water vary somewhat across the monitoring locations with sodium (Na) and chloride (Cl) dominance at the outlet of the wetland and an increase in bicarbonate dominance at the centre of the wetland (MP06) and the northeast monitoring location (MP01). The salinity of groundwater is lower than surface water. The relatively higher salinity of surface water in the wetland may be related to the subtle and slow inflow of brackish water through the outlet drain of Marton Park wetland during high tide. The invert level of the outlet drain is lower than the high tide level, but very close to the surface water level at MPSW01 (Figure 7). A strong tidal influence was not observed in the hydrographs, however the salinity graphs at MPSW01 and PMW03 showed a salinity increase occurring at the same time as the highest monthly tides. The higher salinity of surface water at Marton Park may also be related to evapo-concentration.

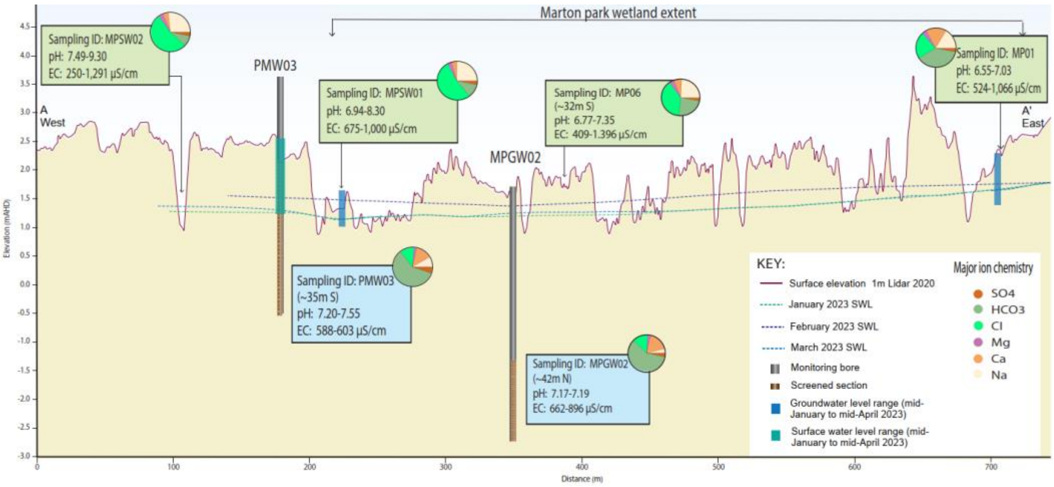

Figure 6 *Conceptual hydrogeological cross-section A-A'*

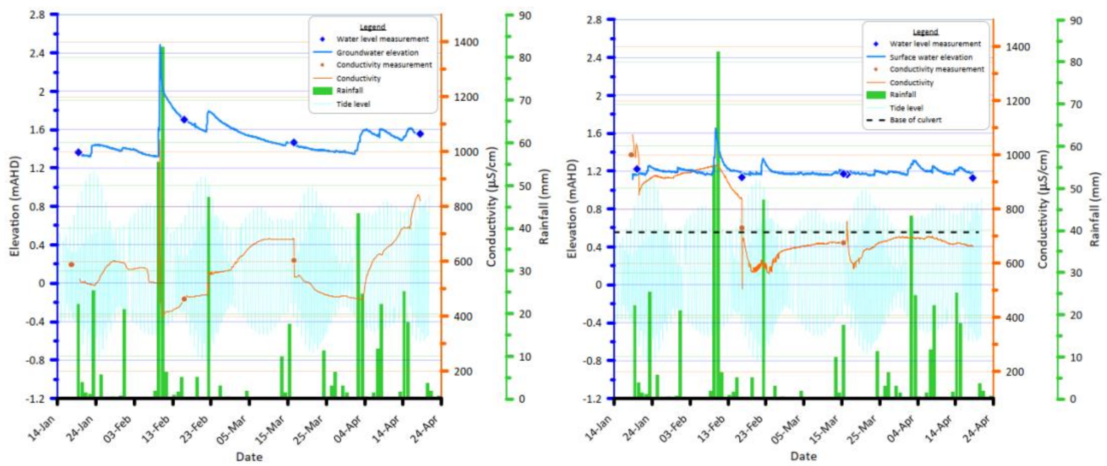

Figure 7 *Hydrographs for PMW03 (groundwater well) and MPSW01 (surface water monitoring location)*

This study demonstrated the complex interaction of surface water with groundwater and tides at Marton Park wetland. The improved hydrogeological understanding of the Marton Park wetland resulting from this study will help inform future management of the wetland including managing potential contaminant migration via wetlands to down-gradient sensitive environmental receptors.

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THE TREATMENT OF NITRATE POLLUTED GROUNDWATER USING BIO-ELECTROCHEMICAL SYSTEMS INOCULATED WITH LOCAL GROUNDWATER SEDIMENTS

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Groundwater contamination of nitrate (NO_3^-) is prevalent in agricultural regions and can lead to methemoglobinemia in infants (Fewtrell, 2004). Current household nitrate removal (e.g. ion exchange membranes, reverse osmosis) and industrial nitrate removal systems using heterotrophic microbial denitrification both require high capital investment and operating costs. In this study, denitrification was demonstrated using a bio-electrochemical systems (BESs), operated continuously as microbial electrolytic cells (MECs) with poised potentials between -0.7V and -1.1V vs Ag/AgCl. Three MECs were inoculated using hydrogen-driven denitrifying enrichments, stream sediments, and biofilm harvested from a denitrifying biotrickling filter and operated continuously for > 1 year as various operating conditions were optimised. The mass loading rate of nitrate was varied between 10 – 70 mg NO_3^-/d and the maximum observed nitrate removal rate was 22 mg NO_3^-/(cm^2·d) with a current of 2.1 mA. For volumetric load experiments, the dilution rate of 1 mM NO_3^- feed was varied between 0.01 – 0.1 hr^{-1} to achieve a nitrate loading rate similar to the mass loading rate experiments. Under these conditions, the maximum rate of denitrification observed was 15.8 mg NO_3^-/(cm^2·d) with a current of 1.7mA. Hydrogen (H_2) was supplied intermittently to investigate the hydrogenotrophic potential of the denitrifying biofilm electrodes; with its supplementation resulting in a 250% increase of nitrate removal in the hydrogenotrophically subcultured reactor. H_2 supplementation had no impact on the reactors exhibiting direct electron transfer. Results from this study depict the denitrification performance of the immobilized biofilm electrodes, either by direct electron transfer or hydrogen-driven denitrification. Microbial community analysis via 16s rDNA amplicon sequencing revealed the presence of several common denitrifying taxa. Overall, these findings highlight the potential for sediment inoculated MECs to remove nitrate and will be used for the future development of sustainable solutions for the treatment of nitrate polluted groundwater.

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THE MOUSE THAT ROARED: PART 2

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Introduction

MHV Water Ltd (MHV) is a farmer owned water co-operative that provides water from the Rangitata Diversion Race to over 200 farm shareholders via 320km of open race and approximately 100km of piped infrastructure, servicing an area of approximately 58,000 ha of the Hekeao Hinds Plains in Mid Canterbury. MHV has operated under Plan Change 2 (PC2) of the (Canterbury) Land and Water Regional Plan (LWRP) since 2018, that requires that 'Hill-fed Lower' and 'Spring-fed Plains' surface waterbodies of the Lower Hekeao Hinds Plains have an annual median NO_3-N concentration of 3.8 and 6.9 ppm, respectively, by 2035 (Environment Canterbury, 2019) as well shallow groundwater NO_3-N concentrations to have an annual median concentration less than 6.9 ppm.

MHV commenced routine groundwater monitoring of Nitrate-Nitrogen (NO_3-N) within the MHV scheme area in September 2016 – with an initial objective to understand the changes in NO_3-N in the groundwater of the Hekeao Hinds Plains as farmers recognised the importance of improving their understanding the groundwater processes and systems. As the focus of the monitoring programme has evolved over time, so too did the design of the programme, resulting in survey sizes of 25 bores between 2016 and 2019. Following a comprehensive review in 2020, the programme was revised and extended to some 150 bores nominally spaced at 2 km (based on a WQN10 drawdown assessment (Kaelin, 2015) representing an area of over 1000 ha.

In late May 2021, Central Canterbury experienced a 1 in 200-year rain-event, with the Ashburton Catchment receiving ≈450 mm over a 4-day period (Carey-Smith, 2021). In response to this event, MHV immediately altered its pre-existing groundwater monitoring program and commenced monitoring 56 bores – initially on a weekly basis, then extending this to monthly for a period of 12 months.

This higher frequency data combined with the larger quarterly surveys provided an invaluable opportunity for MHV to observe the hydrological processes across the Hekeao and how NO_3-N subsequently responded. From these observations, a conceptual model has been developed that identifies and (at a secondary level), quantifies the key drivers of NO_3-N migration and retention.

3 key drivers have been identified as being influential on NO_3-N migration and concentration.

1. The heterogeneous nature of geology and soils across the plains resulted in differing NO_3-N responses across the Hekeao Hinds Plains.
2. NO_3-N levels increased as expected following the 2021 rain and were further influenced by subsequent rainfall events during 2022 resulting in high river flows that mobilised NO_3-N in already saturated soils due to the 'hydraulic piston' effect.
3. The increase in groundwater levels in the lower catchment correlated with a reduction of NO_3-N in groundwater within Gley soils and an increase in NO3-N in lighter Lismore Soils.

This paper provides an update to the 2021 NZHS paper by the same author that seeks to demonstrate the value of well managed community science programme.

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LONG-TERM FIELD MONITORING OF MOISTURE MIGRATION IN A CAPPING LAYER AND EXPANSIVE SOIL SUBGRADE

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Expansive soils pose a significant challenge to the stability and integrity of railway structures built upon them due to their susceptibility to shrinkage and swelling caused by changes in moisture content. Understanding the spatiotemporal behaviour of moisture within the subgrade and the role of a capping layer in managing water infiltration is crucial for mitigating potential damage. This paper presents the results of a long-term field monitoring study on moisture migration and deformation within a capping layer and the underlying expansive soil subgrade under natural weather conditions. The study was carried out at the site along the West Moreton system of Queensland Rail, situated 141 km away from Toowoomba in the subtropical Western Downs Region, QLD, Australia. The monitoring area comprises two sections located 50 m apart from each other, including a controlled section without a capping layer and a reconditioning section with a capping layer constructed on the expansive soil subgrade. Each section contains two bores, one located at the toe of the ballast and the other one on the natural ground, reaching a depth of 1.5 m to accommodate soil sensors. In each borehole, a string of soil moisture and suction sensors was installed at different depths. This study aims to investigate the spatiotemporal profiles of moisture and suction in the capping layer and underlying expansive soil subgrade under natural weather conditions. Additionally, it aims to assess the effectiveness of a capping material in intercepting water infiltration to the underlying subgrade. During the nearly two-year monitoring period, field observations indicated that the capping material effectively acted as a drainage layer, diverting water laterally to the neighbouring natural ground and slowing down the water propagation in the underlying expansive soil subgrade. However, it was unable to entirely prevent water infiltration to the lower layer during continuous rainfall.

GROUNDWATER-RIVER INTERACTION IN THE UPPER TAIERI SCROLL PLAIN, OTAGO

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Groundwater can significantly impact the hydrology, water quality, and ecology of rivers and wetlands. This field-based research aims to investigate the magnitude and temporal/spatial dynamics of groundwater-river interaction in the Upper Taieri Scroll Plain. The Taieri is New Zealand's 4th longest river and it has significant ecological, cultural, and economic values. However, there is currently sparse information regarding groundwater-river interaction in the Upper Taieri Scroll Plain. This study continuously monitored groundwater levels in 12 narrow (32mm diameter), shallow bores (4-6m deep). Each site has a transect of three shallow bores situated near the river, within the flood zone, and above the maximum flood level. River levels were monitored near each transect. The water table is shallow, ranging between approximately 0.80 and 2.5m below Measuring Point, with shallower water table closer to the river. Water level data shows dynamic interaction between the river and groundwater, with a fluctuation between gaining and losing conditions, particularly close to the river. Groundwater fluxes were calculated using Darcy's Law and field measurements of hydraulic conductivity and hydraulic gradient. Hydraulic conductivity was determined from short pumping tests conducted using a peristaltic pump. Although limited due to the narrow diameters and low pumping rates, the tests provided useful insights. The results showed very low drawdown near the river, suggesting it serves as a recharge boundary. Conversely, notable drawdown was measured in bores located further from the river. The calculated hydraulic conductivity ranged between 1.0×10^0 and 1.0×10^1 metres/day. The calculated groundwater fluxes are low, and usually only comprise a small portion of the river flow. This is likely due to the shallow aquifer depth, moderate hydraulic conductivity, and the low hydraulic gradient.

TOWARDS PRIORITISING REGIONAL GROUNDWATER ASSESSMENTS USING THE NATIONAL HYDROGEOLOGICAL INVENTORY OF AUSTRALIA

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Geoscience Australia's Exploring for the Future Program (EFTF) is supporting regional and national-scale initiatives to address Australia's hydrogeological challenges using an integrated geoscience systems approach. An important early step in the EFTF groundwater program focused on developing a national hydrogeological inventory of Australia's major groundwater basins and fractured rock provinces. The inventory has its roots in the seminal 1987 Hydrogeology of Australia map, the first continental-scale map of groundwater systems and principal aquifers (Jacobson and Lau, 1987). Seeking to enhance and modernise the supporting information base for the national map, the inventory combines a curated selection of geospatial data attributes supported by focused narrative on the geology and hydrogeology of each basin and fractured rock province.

The national hydrogeological inventory has a broad range of benefits for Australian groundwater users, managers and policy makers. These include the provision of an updated knowledge base covering the hydrogeology and groundwater systems of the major hydrogeological provinces of the nation, as well as important contextual information. The extensive catalogue of knowledge contained in the inventory also enables an objective approach to identify and prioritise areas for further regional assessment.

Based on analysis of data compiled for the national inventory, the Lake Eyre Basin in arid central Australia was the first region prioritised for more detailed hydrogeological assessment during EFTF. The integration of a variety of basin- to national-scale geoscience datasets enabled significant advances in geological and hydrogeological understanding and the development of a new geological model for the three main basin depo-centres, namely the Tirari and Callabonna Sub-basins, and the Cooper Creek Palaeovalley. The geological modelling has further supported a range of hydrogeological applications, including substantial improvements in the number of bores with aquifer attribution, as well as the first regional watertable map across the basin.

DO FLASH DROUGHTS OCCUR IN NEW ZEALAND AND WHAT WEATHER AND CLIMATE PATTERNS DRIVE THEIR OCCURRENCE?

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Flash drought is a relatively new term describing drought events that develop rapidly, differentiating from typical droughts that gradually develop over the course of months to years. Their rapid development means they can have detrimental impacts on agriculture, water storage and electricity production, yet there has been limited study of this phenomenon in a New Zealand context. Relationships have been found elsewhere between flash drought events and patterns such as ENSO and SAM, however, these relationships are highly subject to locality. In this study, flash droughts were identified using a criterion of a decrease from the 40^{th} to the 20^{th} soil moisture percentile within 20 days and a decrease of at least 5% per pentad. 13 locations were analysed, based on data availability and geographical spread of stations. Research showed that Lake Tekapo has experienced the highest number of flash droughts (12), and Blenheim the second highest (10). Flash drought events across these stations have an average initiation period of 2.5 pentads with an average change of around 9% per pentad. Analysis of Kidson weather types showed an increase in blocking of 9.28% compared to the average and a decrease in trough and zonal types. There were especially large increases in the HW and HSE blocking types and decreases in the T and H trough and zonal types. Analysis of climate patterns show an increase in the La Nina phase during the month before and initiation of flash drought events. There were also increases in the positive phase of SAM and the neutral phase of IOD. These findings show that flash droughts are an important feature of the hydroclimatology of New Zealand with links to weather and climatological patterns at a national and local scale.

EFFECT OF WATERTABLE DEPTH ON SALT PRECIPITATION AT THE SURFACE OF ADJACENT DISSIMILAR SOIL TYPES

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Lateral variations in soil types can occur due to natural and artificial processes, including geological deformation, aeolian processes, field cultivation, and mine backfill. These differences in soil properties can impact surface salinity distributions, especially when salts are transported and accumulated at the surface through evapotranspiration from a shallow saline groundwater table. Since salinity directly affects vegetation growth, it becomes essential to understand how the depth to the watertable influences evaporation and salt transport in vertically heterogeneous soils. We conducted laboratory experiments in a column filled with vertically heterogeneous sand and carried out corresponding numerical simulations. The experimental results revealed varying patterns of salt precipitation at different depths to the watertable. Precipitation did not occur at the surface for either very deep or shallow watertable conditions. However, when the watertable was at an intermediate depth range, salt precipitated at different locations, including the fine sand surface, the interface, and the coarse sand surface. The numerical simulations confirmed these results and further elucidated the relationship between surface saturation, permeability, evaporation, and density-driven flow. Notably, higher surface permeability facilitated salt dissipation through intense density-driven flow, thereby maintaining a low salinity level. Conversely, surfaces with lower permeability were unable to sustain evaporation, cutting off salt transport and accumulation. As a result, salt precipitation was observed at the surface within a specific permeability range for both sands. This study sheds light on the underlying mechanisms governing salt accumulation in different soils and provides valuable insights for understanding and predicting surface salt distribution in regions with shallow saline groundwater. The results have implications for managing soil salinity, especially in areas affected by heterogeneity and shallow groundwater conditions, and can aid in developing strategies for sustainable vegetation growth and land use practices.

RELATING TIDAL WETLAND SOIL CONDITION TO PLANT ZONATION: A COMBINED FIELD AND NUMERICAL MODELLING STUDY

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The ecological and environmental functions of tidal wetlands depend on the structure and stability of the wetland plant community. Plants in these wetlands are commonly distributed in spatial patterns, i.e., plant zonation. The zonation phenomenon overall indicates connections between plant species properties and wetland subsurface soil conditions. Therefore, understanding the factors that control plant zonation in tidal wetlands is critical for predicting the outcome of wetland restoration projects and the future evolution of tidal wetlands under a changing climate. Previous studies have identified strong correlations between plant zonation and wetland soil water flow conditions, mostly characterised by mean soil saturation (MSS) and soil saturation index (SSI). However, soil water salinity (PWS), which is an important feature of the naturally saline tidal wetland, has never been quantitatively characterized for its connection to plant zonation. In this study, we conducted field investigations on the rootzone soil water conditions and plant zonation of a subtropical tidal wetland. Statistical analyses were conducted based on the field results to identify the correlations between soil water conditions and plant zonation. A 2-D soil water flow and solute transport model was further developed to simulate the rootzone soil water flow and salinity levels, and then used to evaluate the significance of different soil water flow and salinity indices in controlling plant zonation. This study confirms that SSI and PWS are both significantly different among different vegetation zones but there were no singificant differences in terms of MSS. PWS, as the result of tide and surface evaporation impacts, is the dominating factor in organizing plant zonation in tidal wetlands subjecting to strong salinization.

FLOOD FORECASTING CYCLONE GABRIELLE THROUGH PAEROA

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A state of emergency was declared at many northern and eastern coastal communities of New Zealand as Cyclone Gabrielle made landfall. In the Waikato region this occurred on the 13th February 2023. Weather warnings were issued across the country, the impact was truly devastating and in many areas, far worse than anticipated.

Flood forecasting for the Waihou River and Ohinemuri River, provided Waikato Regional Council's (WRC) Emergency Operations Centre with forewarning of the cyclones potential impacts on river levels. The knowledge that State Highway 2 at Karangahake George would close, and that it would be necessary to close the stoplogs at Paeroa allowed for the early positioning of critical resources.

A calibrated DHI MIKE Hydro 1D model was in the final stages of completion when the country received the weather warning. The model was run using observed rainfall from WRC's gauge network up to the time of forecast, and forecast rainfall extracted from MetService's short range and long range forecasts.

Without an automated process for compiling the rainfall inputs it was only possible to run one forecast model a day in the lead up to, and during the event. WRC have now developed a tool to generate model input timeseries files in a timely manner providing the ability to run river models for flood forecasting purposes.

The event also highlighted oppportunities to improve the models performance. By reconfiguring the model to harness the spatial resolution of historic rainfall data available in MetService's Quantitative Precipitation Estimation (QPE) product during model calibration, we expect that we will be able to better account for the spatial distrbution of forecast rainfall.

This paper discusses how rainfall is applied to the 1D model, the benefits and limitations of the model and our roadmap for model improvement.

STRATEGIC INVESTIGATION METHODS: TAILORED APPROACHES TO GROUNDWATER ASSESSMENT FOR SUSTAINABLE RESOURCE MANAGEMENT

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Applications to take groundwater with the regional councils of new zealand traditionally require a standard set of supporting investigations and reports to substantiate the assertation that the proposed activity will have 'less than minor' effects on the environment and other groundwater users. Although these components of the application address the potential for adverse effects comprehensively in most hydrogeological settings, there are situations where more targeted monitoring and direct measurements of effects can provide a more reliable and practical assessment.
In situations where the geology is poorly understood due to complexity in structure or heterogeneity, standard pumping testing and modelling may not provide a good representation of actual groundwater flow, making predictions of drawdown at distance and related effects unreliable. Investigations and analysis that fail to predict drawdown accurately can conservatively be applied to set appropriate abstraction rates for a trial period of operation borefield management and monitoring. Through active management and targeted monitoring, the actual effects of pumping can be determined and extrapolated.
Although supplementing or even substituting the borefield management option for the standard assessment components and consent conditions is unorthodox and would need to be specifically requested and approved by the regional council, providing a robust explanation of the planned methods and reasons they are appropriate for the current investigation has been successful proposed and accepted in several regions.

WHAT WILL BE THE LEGACY FOR OUR MOKOPUNA? CASE STUDY FROM ROTORUA'S WATER SUPPLY SPRINGS

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Introduction

Rotorua is a city in the Bay of Plenty region of New Zealand's North Island and is a famous tourist destination. Hidden in the Whakarewarewa forest, close to popular mountain biking tracks, are two crystal clear springs that are used to supply drinking water to the eastern area of the city.

The Waipā and Hemo Springs are within the Puarenga Stream catchment which has significant cultural value to Māori, including three marae along its banks as well as the internationally renowned visitor attractions of Whakarewarewa village and Te Puia. The springs were originally used as a source of drinking water by Māori (Kusabs and Shaw, 2008). Following establishment of the Rotorua township in 1880, a new water supply was needed, and from 1906 the Hemo Spring was utilised, and from 1962 the Waipā Springs added to meet the growing demand for water.

Resource consents granted by the Bay of Plenty Regional Council authorise Rotorua Lakes Council (RLC) to use part of the outflow from the two springs for municipal supply: up to 110 L/s from the Waipā Springs and up to 31 L/s from the Hemo Spring. There are currently no limits in the resource consents about how much water needs to remain in the downstream water bodies to maintain the "health and wellbeing" and/or protect mauri, or life force, of the water, but this is expected to be implemented in the future.

The Waipā and Hemo Springs resource consents expire in 2024 and two other spring supplies also require replacement consents before 2026 including the central city water supply from the Karamū Tākina Springs. A change in mindset was required for these consent applications, to ensure positive outcomes and learn from the past.

Resource consent to take municipal supply water from the Pekehaua Puna (also known as the Taniwha Spring) was granted in August 2021 (White et al, 2021), and is viewed as a positive long-term outcome for the joint consent holders (the Pekehaua Puna Reserve Trust and RLC) and the wider iwi Ngāti Rangiwewehi. It is also recognised that there is no one size fits all approach given the significant differences between the water supply springs across Rotorua and the cultural identities and values. The Ngāti Rangiwewehi experience and learnings will shape the future consent applications for the other four spring supplies.

Method

It is important to allow time to develop genuine partnerships. A wānanga was held at the start of the consenting process on 5 September 2022 with iwi and hapū across Rotorua and a haerenga ki ngā puna wai Māori (site visit to the water supply springs) on the 29 September 2022. Working Groups were then established reflecting the different rohe, cultural identities and tangata whenua, mana whenua and hau kāinga who whakapapa to the different water supply springs.

The Waipā and Hemo Springs resource consent application was then prepared in partnership with representatives of Ngā Hapū e Toru; (Ngāti Hurungaterangi, Ngāti Taeotū, Ngāi Te Kahu), Te Komiti Nui o Ngāti Whakaue and Tūhourangi Tribal Authority who have formed the Waipā / Hemo Collective. A formal Terms of Reference set out how the Working Group would operate in a collaborative manner to guide the development of a joint resource consent.

Technical studies undertaken for the resource consent application included detailed hydrological and ecological surveys. A moderate to high in-stream habitat supports kōura (freshwater crayfish) and a limited fish community due to the geothermal area on the Puarenga Stream forming a barrier to fish passage. A habitat survey and modelling approach was used to develop catchment specific "minimum flows" to identify a flow below which the available habitat for key species present in the Waipā and Hemo Streams begins to decline sharply (Jowett, 2023).

Ten Working Group hui have been held between November 2022 and July 2023, initially monthly and then fortnightly from May 2023 including three wānanga in June and July 2023 to discuss the technical details of the consent application. A key focus was on how much water is needed to meet population growth, ensuring that it will be used efficiently, and the minimum flows developed through the habitat modelling to protect ecological stream health. The approach to sharing scientific information was carefully considered, including the hydrological cycle from the rain falling on the Moerangi Maunga, entering a rhyolite aquifer, flowing out of the springs into the Puarenga catchment, through Lake Rotorua, into Lake Rotoiti, down the Kaituna River and ultimately out to sea at Maketu.

Results

In July 2023, RLC lodged the application for a replacement resource consent to continue to use the Waipā and Hemo Springs for drinking water. The deadline was fixed by legislative timeframes within the Resource Management Act 1991, however this was only one step in the journey.

In recognition of the timeframes to develop a meaningful and trusted partnership and to support the application, RLC, with agreement from the Waipā / Hemo Collective, requested that BOPRC place the consent applications "on hold" to provide the Collective time to develop a genuinely meaningful cultural assessment process led by iwi. This approach will ensure that there is sufficient regard to iwi as a Te Tiriti o Waitangi Partner and give effect to Te Mana o Te Wai, the fundamental concept of the National Policy Statement for Freshwater Management (2020).

The aspirations for the sustainable use of drinking water from the Waipā and Hemo Springs will need to be defined and building these into a lasting resource consent document is a challenge, particularly in the context of the other activities in the Puarenga catchment and the changing regulatory environment on the horizon. It is vital that iwi and hapū are involved in managing and protecting these precious taonga in the years to come, long after the resource consent has been granted.

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RETHINKING PUMPING TEST INTERPRETATION: HOW TO APPLY ESTIMATED HYDRAULIC PARAMETERS TO A REGIONAL GROUNDWATER MODEL

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Abstract
Processing of aquifer test drawdowns to obtain estimates of transmissivity (T), and sometimes storativity (S), is an integral part of hydrogeological site investigations. Analysis of these data often relies on an assumption of hydraulic property uniformity. Aquifer properties are often estimated by fitting a Theis curve to measured drawdowns. Where an aquifer exhibits heterogeneity, quantities that are forthcoming from such analyses are assumed to represent spatially-averaged properties. This study uses Fréchet integrals and inversion theory to show where most of the averaging occurs when drawdowns are matched to a Theis curve. It is shown that these hydraulic property spatial averaging functions are complex and cross hydraulic property boundaries.
Traditional pumping test interpretation is a blunt regularization device. Hydrogeologists typically learn little of the uncertainty of T and S through their use. A new pumping test interpretation methodology is proposed that seeks to reduce the uncertainty of T and S within an 'area of influence' around the pumping test configuration. Parameter calibration is undertaken using numerical models, data-space inversion, and iterative ensemble techniques. The mean hydraulic estimates and posterior standard deviations are then used to condition upscaled realisations of T and S for use in a regional groundwater model.

GROUNDWATER-SURFACE WATER INTERACTION IN A COASTAL LOWLAND STREAM: ŌTŪKAIKINO CREEK, ŌTAUTAHI/CHRISTCHURCH

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Aims

The Ōtūkaikino River is regarded as the jewel of Christchurch due to its relatively pristine water quality alongside its high ecological values (Environment Canterbury, 2021). Local residents however, have raised concerns that its springs could be losing flow. This is a concern as a healthy waterway needs an adequate amount of flow to allow the ecosystem to operate (Ministry for the Environment, 2020). While the Ōtūkaikino has been included in many ecological surveys, there is a lack of scientific literature that specifically focuses on how the hydrological system operates, particularly how it responds to local rainfall and nearby Waimakariri river flows. This study aims to address this gap by analysing meteoric, surface and groundwater fluxes around the Ōtūkaikino catchment.

Method

Over a period of 4 months, groundwater and surface water levels at two springs of the Ōtūkaikino River were monitored at a 15-minute interval. Over the same period, a set of high temporal resolution water samples (bi-weekly to daily; n=96) were collected throughout the catchment. These collected sets of data were also compared to longer term groundwater depth data, collected at the nearby Crossbank monitoring array and long-term Environment Canterbury monitoring wells.

Results

This research shows that there is a high variability in hydrochemical tracers in precipitation in the Ōtūkaikino catchment which can be related to the direction, intensity, and source of weather events, allowing for different rainfall events to be fingerprinted within the Ōtūkaikino catchment.

The hydrological system was found to be remarkably dynamic, with hourly-scale hydrological and hydrochemical responses to significant events. Rapid short-term changes in spring flow are driven by local rainfall events in which the springs of the Ōtūkaikino catchment were found to be chemically and physically responsive to local rain events but unresponsive to Waimakariri flood flows (790 m^3/s) during the study period.

Chemical tracers (□^{18}O, Cl^-), showed that the Waimakariri River provides 70-85% of the flow to the springs and associated waterways of the Ōtūkaikino. Additionally, quick chemical turnover times between rainfall events shown in this research suggests that while local rainfall causes short term fluctuations, groundwater in the Ōtūkaikino catchment receives a steady source of recharge from the Waimakariri River.

This thesis research highlights the importance of using high-resolution physical and chemical data for recording spring dynamics in alluvial systems. Furthermore, it provides a foundation which may inform future hydrological and hydrogeological investigations designed to understand the complexities of the recharge of the Christchurch aquifer system.

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ANALYSING WATER QUALITY VARIATION WITHIN FARM DRAINS IN CANTERBURY, NEW ZEALAND

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New Zealand's variable freshwater quality is increasingly under scrutiny from freshwater scientists and the public, particularly in areas dominated by agricultural land use. Dairy farming in Canterbury has increased significantly since 1990 due to various economic pressures and technological developments such as irrigation. The increase in Canterbury dairy farming has been linked to several environmental issues that have taken decades to emerge. The compound nitrate-nitrogen (NO3-N) is a key freshwater pollutant in regions with substantial dairy farming, such as Canterbury, exacerbated by fertiliser application and effluent management practices. The objective of this research project is to analyse the water quality within farm drains and evaluate quality changes throughout the length of the drains. Any changes in water quality, particularly nitrate concentrations, are then analysed to see if there is a correlation between the surrounding land use and drain management. Within the water quality measurements are a mixture of biotic and abiotic parameters collected by an ecological consultancy that relate the water chemistry to ecology as a supplementary analysis. This research aims to understand better how different land uses and drain management practices affect the nitrate and water quality within farm drains so effective solutions can be implemented. The importance of this research is significant, given farmers in the study region are under legislative pressure to improve the freshwater quality.

ESTIMATING FLOOD FREQUENCY FOR OMARAMA STREAM

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Flood Frequency updating at ECan – Omarama at Tara Hills

Aims

The purpose of this piece of work is to assess the Flood Frequency values of the Omarama Stream at Tara Hills post the July 2022 flood event. This event was the highest recorded flow on record.

Method

For this piece of work, the previous flood frequency analysis done in 2017 is updated. This analysis was carried out by Tonkin and Taylor (Tonkin and Taylor 2017) under contract by Environment Canterbury, the results are shown in Table 1. This updated analysis used, as in the previous work, the annual series data from the site. The new data set covers 34 years.

Table 1: Omarama Stream at Tara Hill Flood Frequency data 2017

Distribution	Flood Peak in m^3/s for ARI							
	5-year	10-year	20-year	50-year	100-year	200-year	500-year	1000 year
	Annual Flood Series, Mean Annual Flood = 18 m^3/s							
TCEV	25	45	65	90	110	120	150	170

As part of the work by Tonkin and Taylor a series of spread sheets were developed to create the frequency distributions for the site. This spreadsheet is designed to be updated as and when required. For this site the best distribution is the Two Component Extreme Value Distribution (TCEV). The TCEV distribution was used by Tonkin and Taylor in 2017 and it was found that the TCEV distribution still was the best fit for the data.

Results

Results will be presented, and current method discussed to inform future method.

Refences

Tonkin & Taylor, 2017. Flood Frequency analysis for Canterbury Rivers, prepared by Tonkin & Taylor for Environment Canterbury, Content Manager ref: C17C/109083.