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.

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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]
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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

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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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[1] Geoscience Australia
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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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[1] Office of Groundwater Impact Assessment (OGIA), Queensland Department of Regional Development, Manufacturing and Water

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

Site setting and background

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.

Microbial Tracer Test

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.

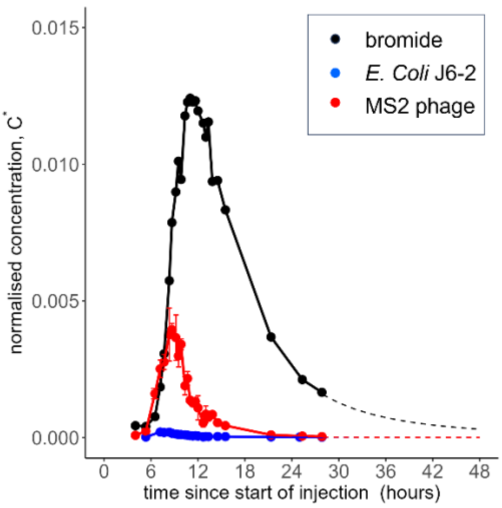

Figure 2: Tracer breakthrough curves as determined in the outflow from the 75 m-long bioreactor and from which microbial mass removal rates were evaluated. Concentrations were normalised relative to the injection concentration, as measured at head of the bioreactor ($C^* = C(t)/C_{inj}$). Dashed line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

Angus Campbell,[1] Matthew Currell,[1] Ian Cartwright[2] John Webb[3] Dioni Cendón[4]
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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 (^{3}H) activities using lumped parameter models (Maloszewski and Zuber, 1982, Morgenstern et al., 2010, Jurgens et al., 2012) with the ^{3}H 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 ^{3}H 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 ^{3}H 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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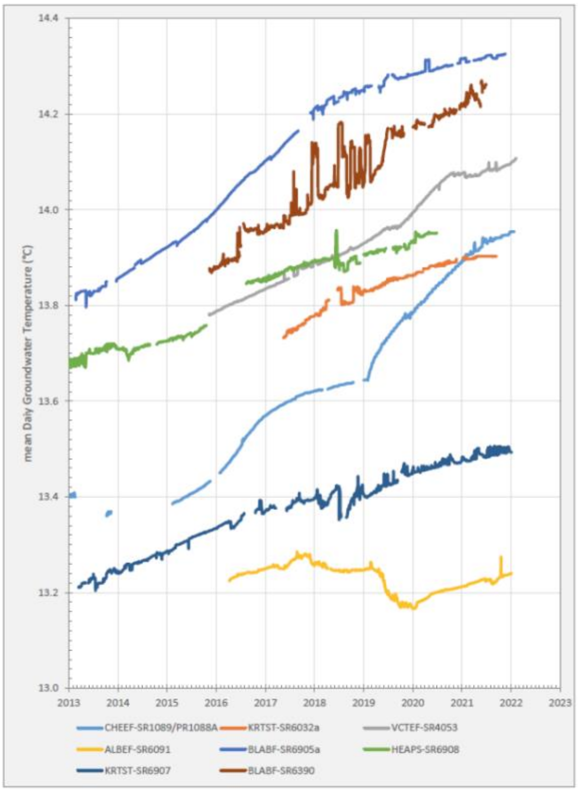
Aims

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/m^2) 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).

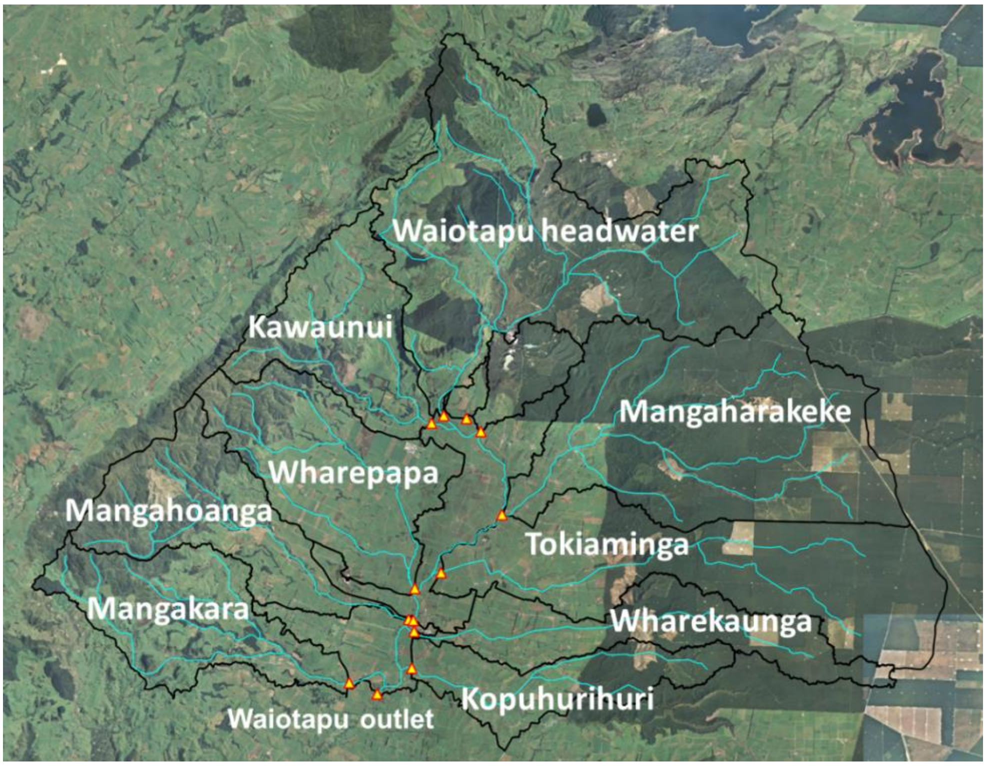

Figure 1: The Waiotapu catchment in the central North Island, Aotearoa New Zealand showing nine sub-catchments and the assessment points used in this study.

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).

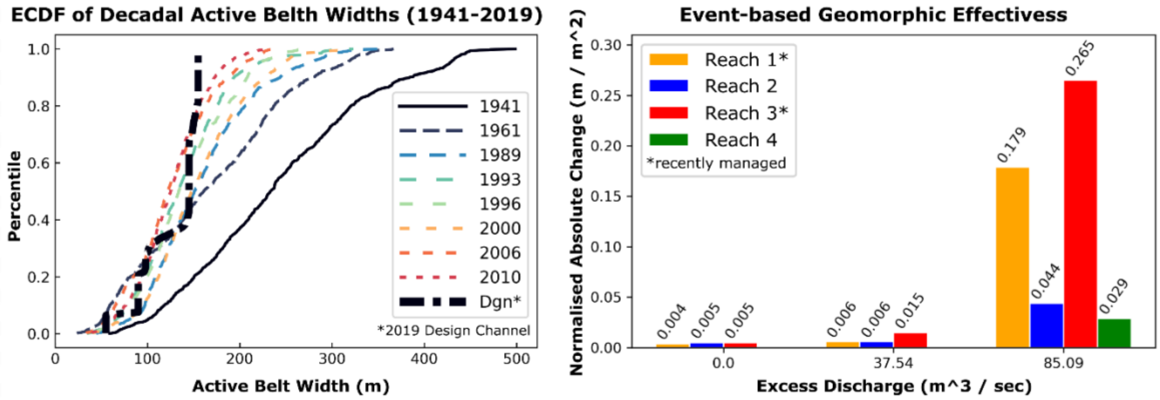

Figure 1: Left: Empirical cumulative frequency distribution (ECDF) of active belt width shows multidecadal decrease at the riverscape scale. High-resolution subannual data indicate greater event-based vertical change within reaches trained within prior thirty months compared to adjacent untrained reaches.

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.

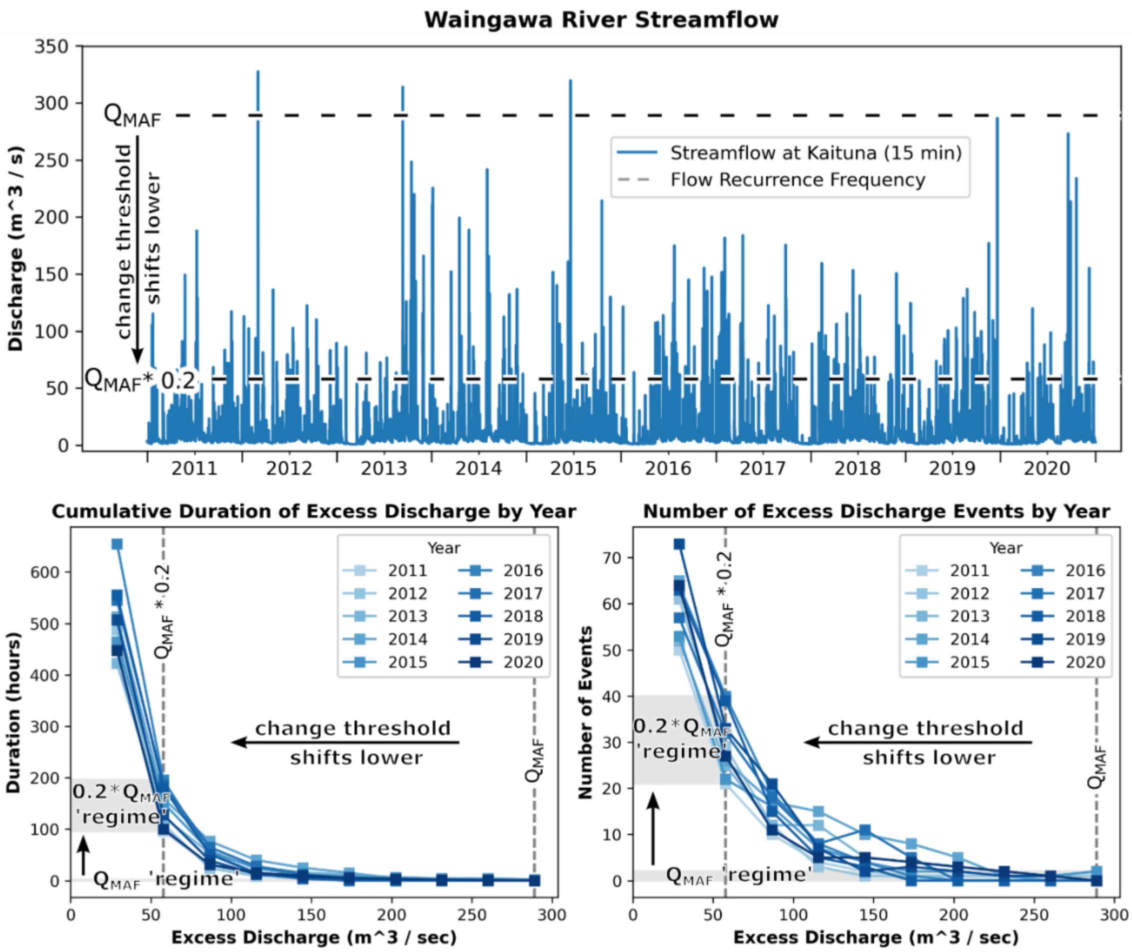

*Figure 2: As the threshold at which channel change occurs shifts to lower flow magnitude, the behavioural regime of the river becomes more active. Top: A lower flow threshold (0.2 * QMAF) intersects many more runoff events than a higher threshold (QMAF) as indicated for the Waingawa River from 2011 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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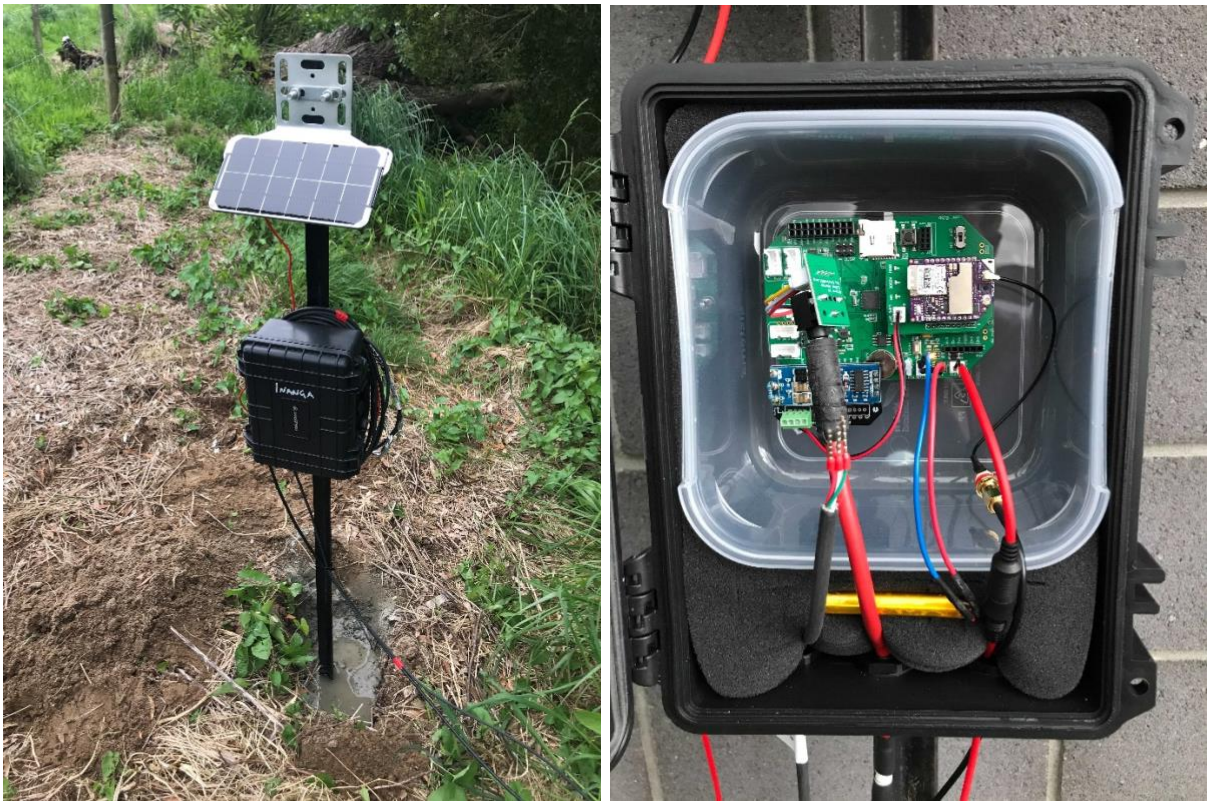

Figure 1: A deployed Mayfly monitoring station (left) and internal board components (right).

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.

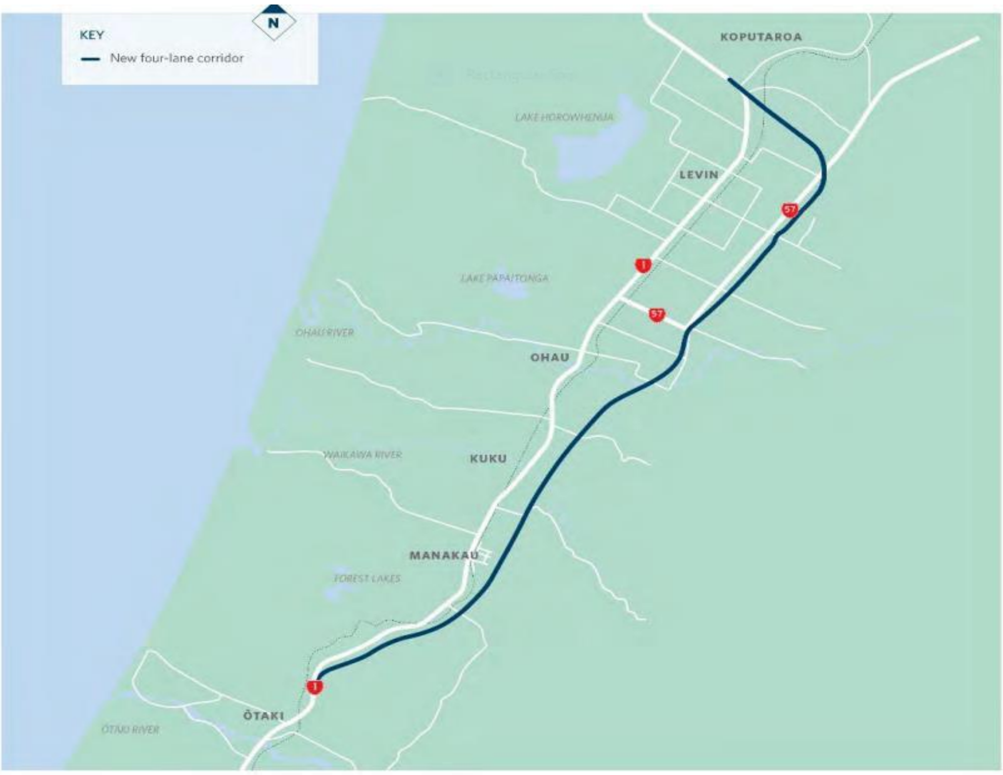

Figure 1: Schematic of the new Ō2NL highway

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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3 Stantec New Zealand Ltd

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 **Quarries:** Sand dredge (rivers or coastal dunes), hard rock, gravel (river dredge), limestone **Gas:** Coal seam, conventional	**Power stations:** Solar farms, hydroelectric stations, transmission lines, substations, wind farms, battery farms **Roading infrastructure:** Motorways, tunnels, road cuttings, bridges **Railway Infrastructure:** Overground railway lines, underground railway lines, underground stations, tunnels, bridges **Utilities:** Water supply (pipelines groundwater supply bore fields), waste management facilities (landfills)	**Residential:** Subdivisions, basement car parks, tower blocks **Commercial:** Transport depots, intensive farming (piggeries, chickens, fish), abattoirs, industrial estates, office/commercial towers **Services:** Hospitals, correctional facilities

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).

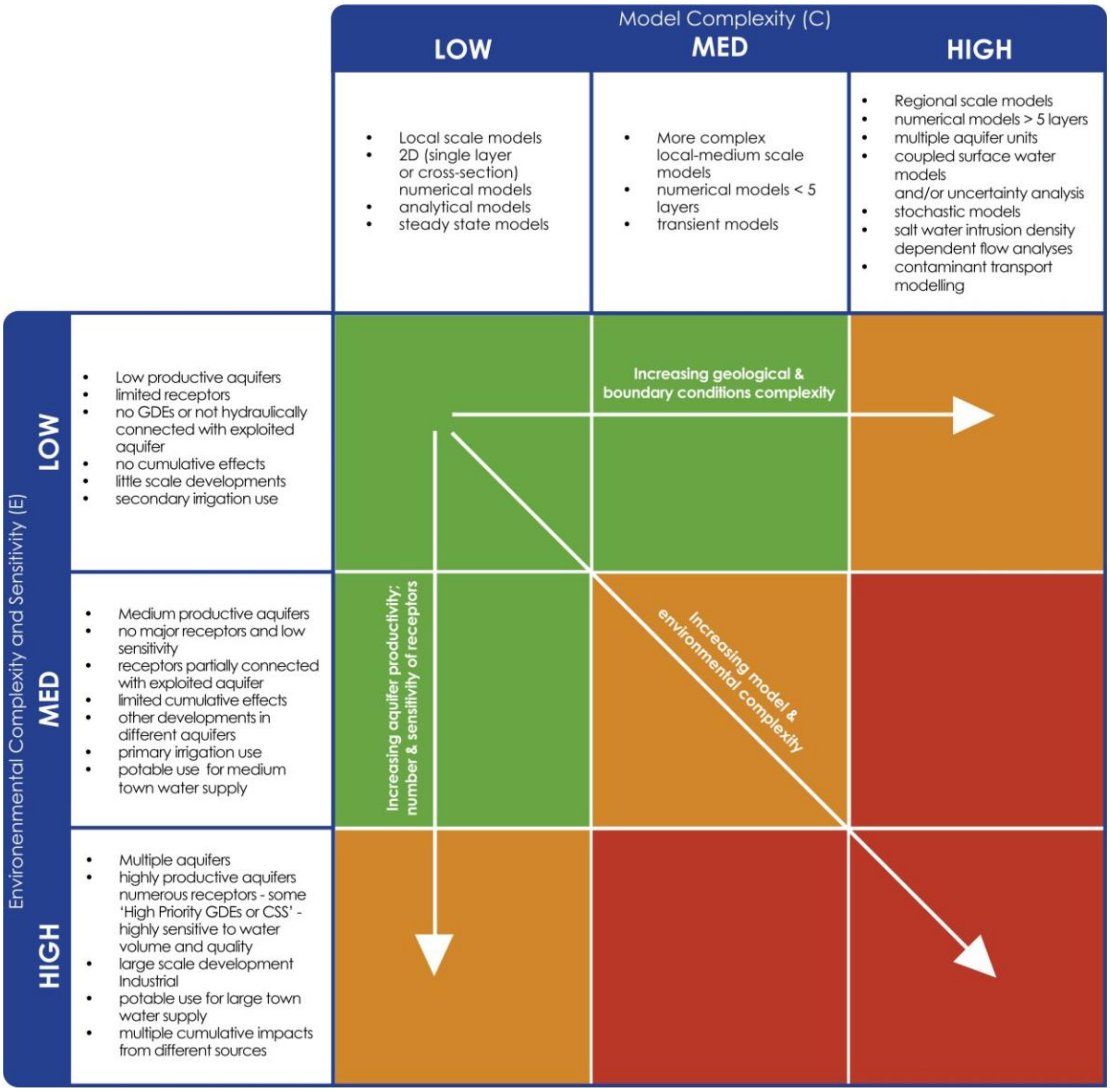

*Figure 1: **G**roundwater **M**odel **C**omplexity **A**ssessment **M**atrix (GM-CAM).*

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.

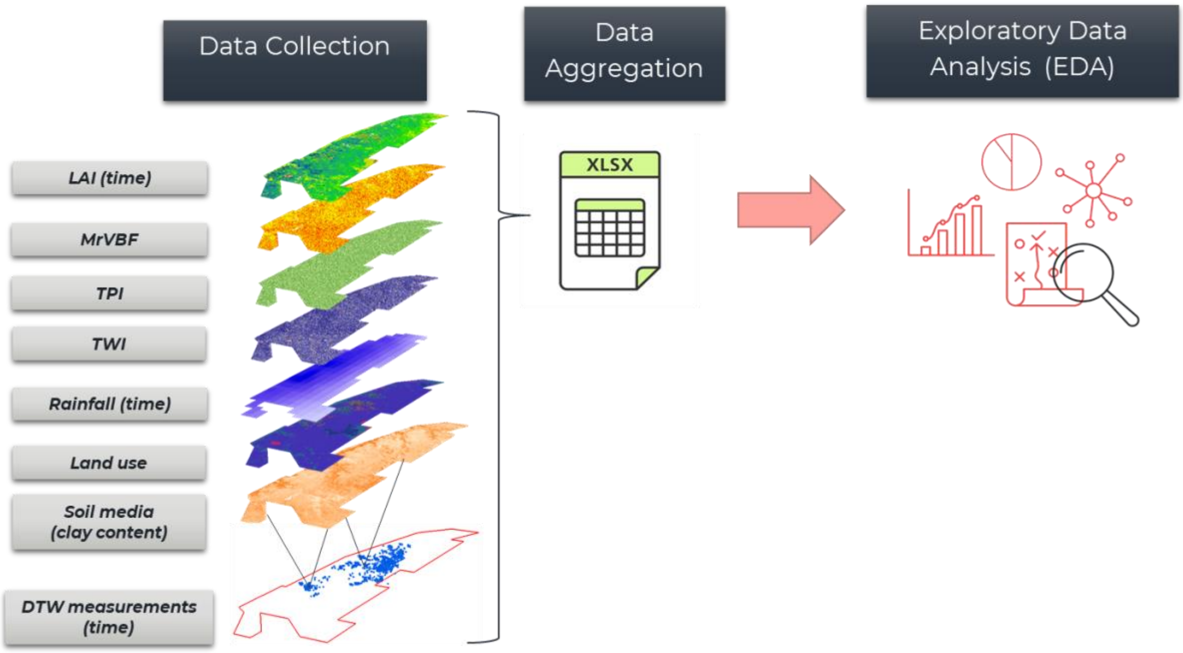

Figure 4 EDA methodology

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.

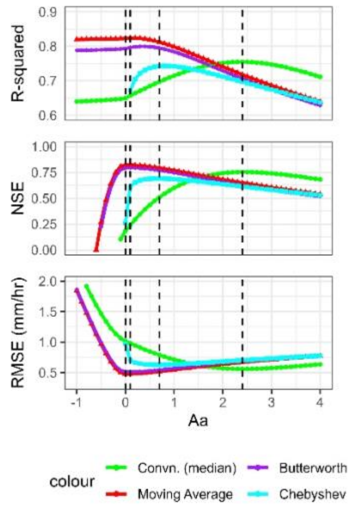
Although some methods show less error and higher precision, however, the accuracy of the estimation of rainfall by different methods, including the conventional method, varies from day to day, Figure 3 shows rainfall estimation by 4 different methods compared to the conventional technique.

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.

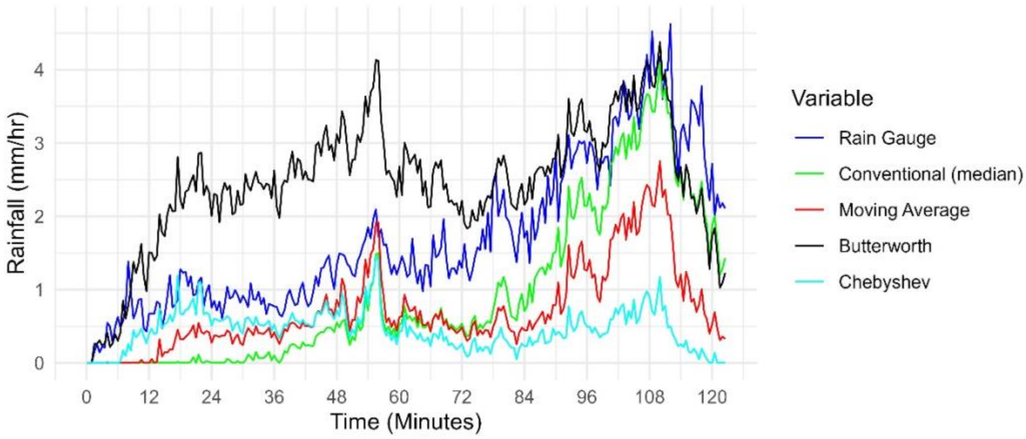
Rainfall simulation accuracy varies over time. To assess the effectiveness of each method across different periods and rainfall events, we calculated NSE, RMSE, and R-squared for 10-day intervals throughout the 300 days. Figure 4 illustrates the NSE variation for each method in 10-day periods. The results 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

Saeid Esmaeil Nia,[1,2] Ali Shokri,[1]
[1] The University of Waikato
[2] Toi Ohomai Institute of Technology

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

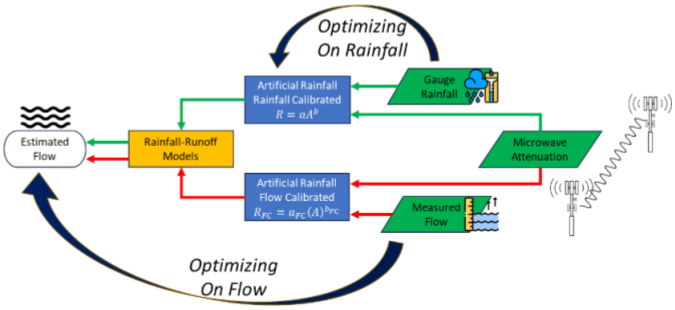
In this research, we explore a direct correlation between microwave attenuation and flash floods in urban catchments. The results are aiming to assess if the power of microwave links could be a better indicator of water yield in a catchment, rather than targeting the rate of rainfall. By utilizing the 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 ($R = a(A-A_a)^b$). 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.

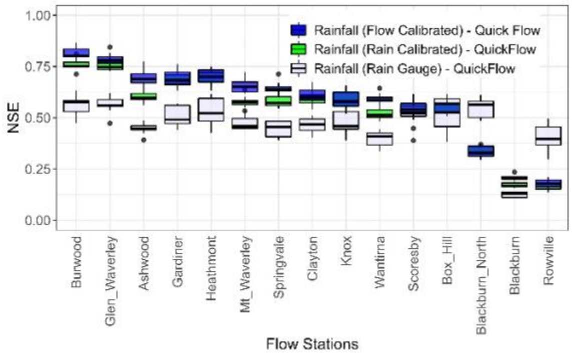
Analysis was conducted to minimise the RMSE and maximise the NSE of the correlations through 180 pairs of rain gauge-flow stations. The results helped to find the strongest constants in attenuation-rainfall relationships. Then, the constants for three methods of rainfall simulations were employed to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

Results

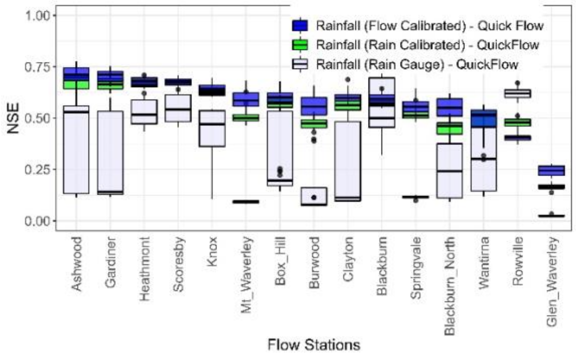
The findings demonstrate that calibrating CML rainfall with flow outperforms the conventional calibration method using rain gauges. In the first step, linear correlations were examined to determine the factors with the strongest relationships and to find the coefficients in equations. Figure 2 illustrates 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*

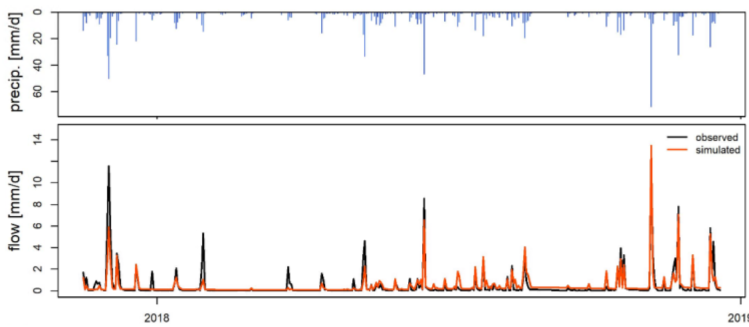
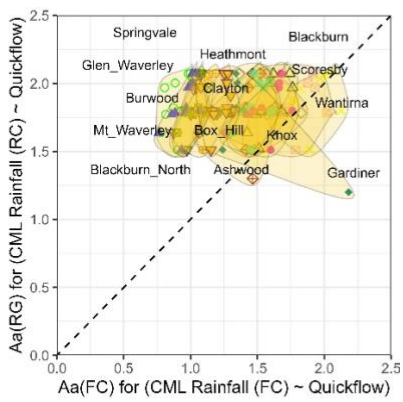


Figure 4: Simulated runoff in GR4J for Ashwood flow station, coupled with Mitcham rain gauge



- *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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[3] Mekong Region Futures Institute, Laos PDR
[4] Maharana Pratap University of Agriculture and Technology, India
[5]Development Support Centre, India
[6]Vidya Bhawan Krishi Vigyan Kendra, 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.

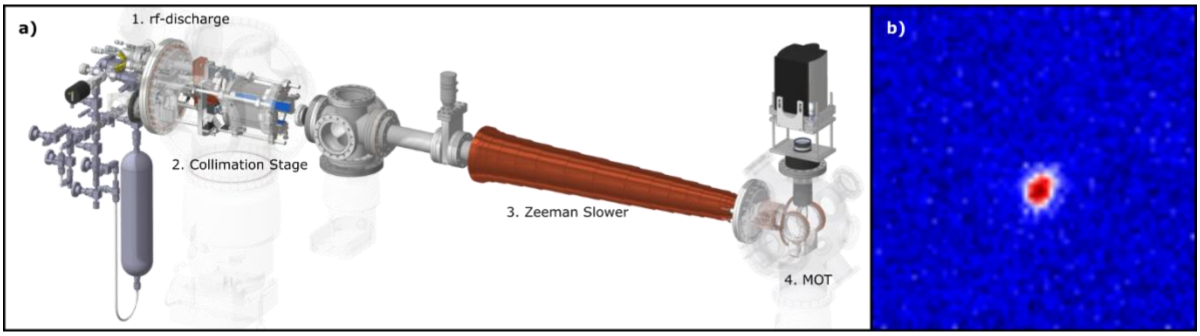

Figure 1. a) A schematic of the apparatus showing the 1. rf-discharge 2. Collimation Stage 3. Zeeman Slower 4. MOT, and b) a single 85Kr atom imaged on the EMCCD.

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 the 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 ($\square^{18}O$) 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.

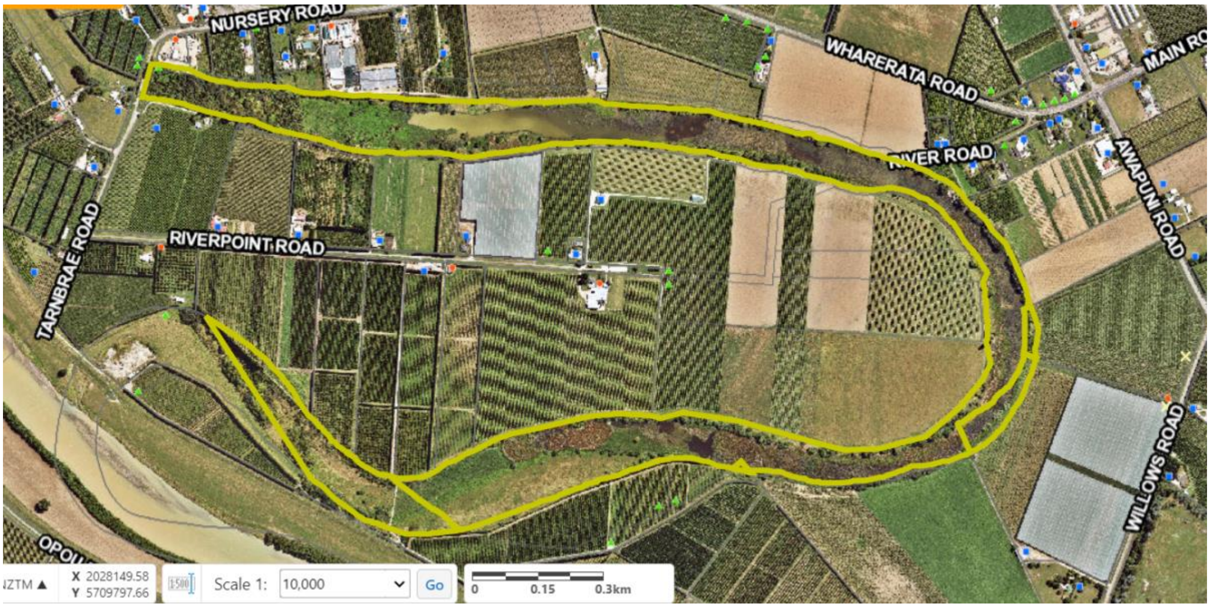

Figure1: Te Maungarongo o Te Kooti Rikirangi Wetland

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

Kate Dowsley,[1] Greg Hoxley,[1,2]
[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:

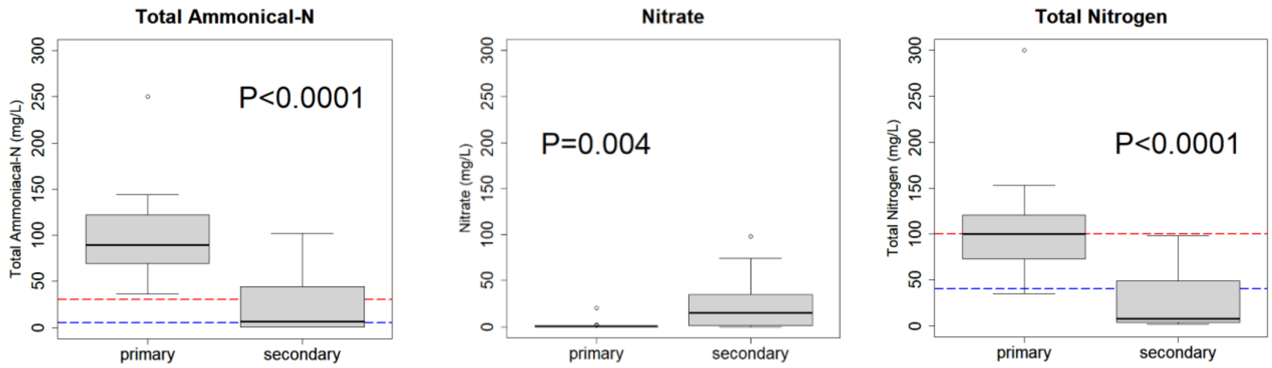
Unknown OWMS = occupied dwellings – reticulated dwellings – active OWMS consents

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

Results

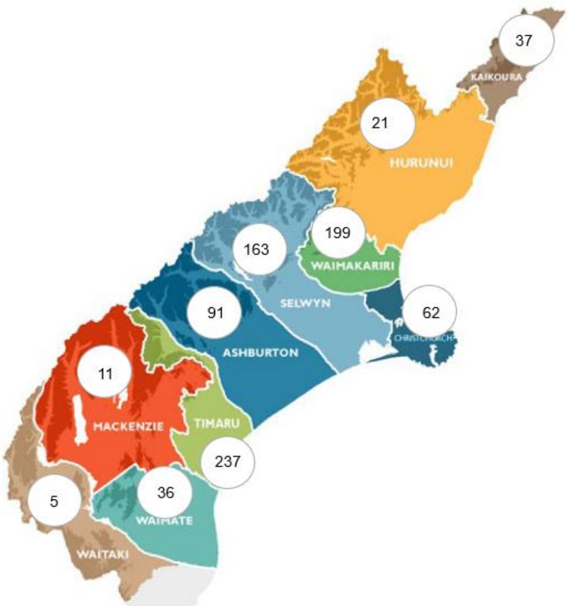
Results for samples taken from the 30 OWMS in terms of nitrogen species are shown in Figure 1. The results show that secondary treatment OWMS provide an environment (i.e., mechanical aeration) in which nitrification can occur and results in higher nitrate concentrations when compared to primary OWMS. 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.

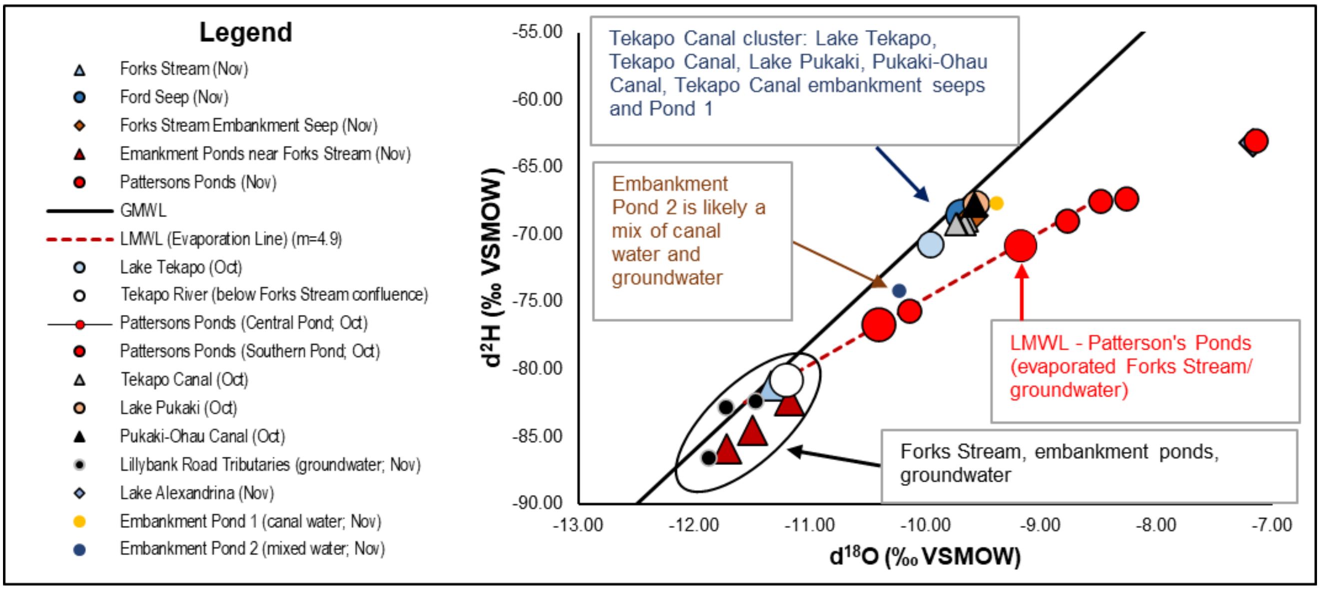

Figure 1. Stable isotope results.

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.

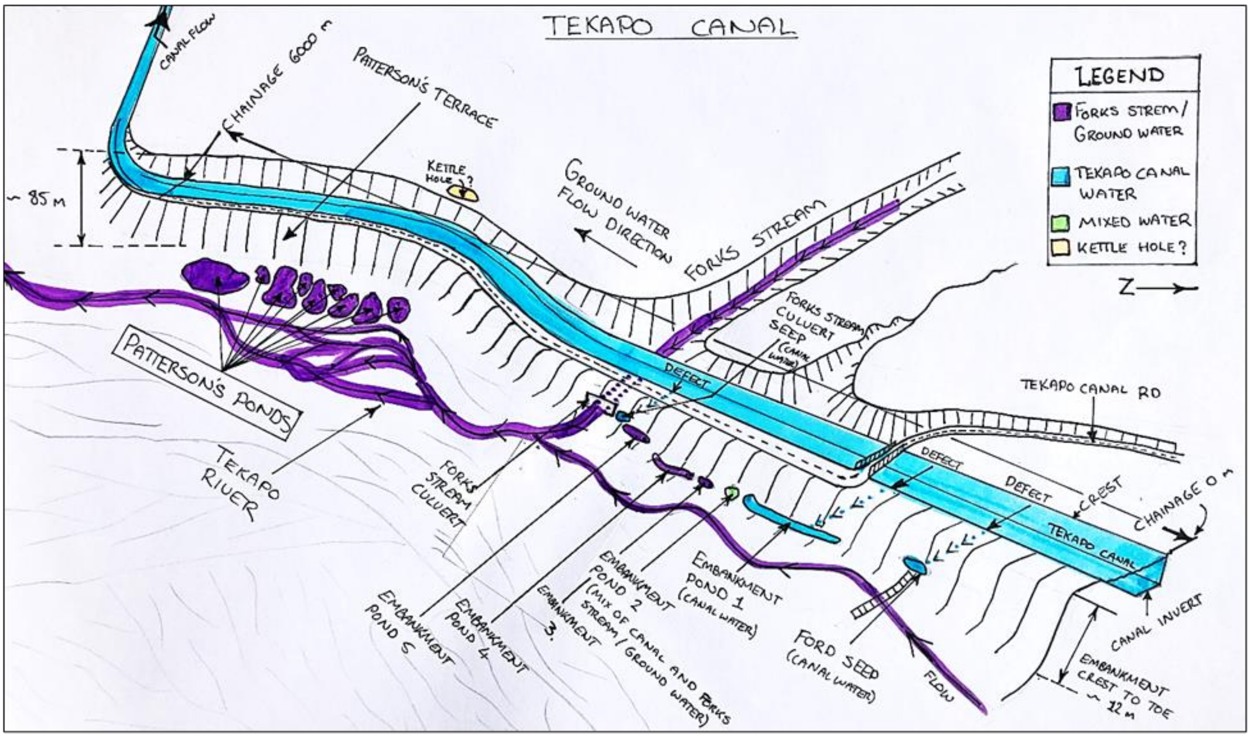

Figure 2. Schematic showing the source of various water bodies at and near the canal embankment.

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

Kenny, A.[1], Sarris, T.S.[1], Scott, D.M.[1], Moore, C.[2]
[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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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.

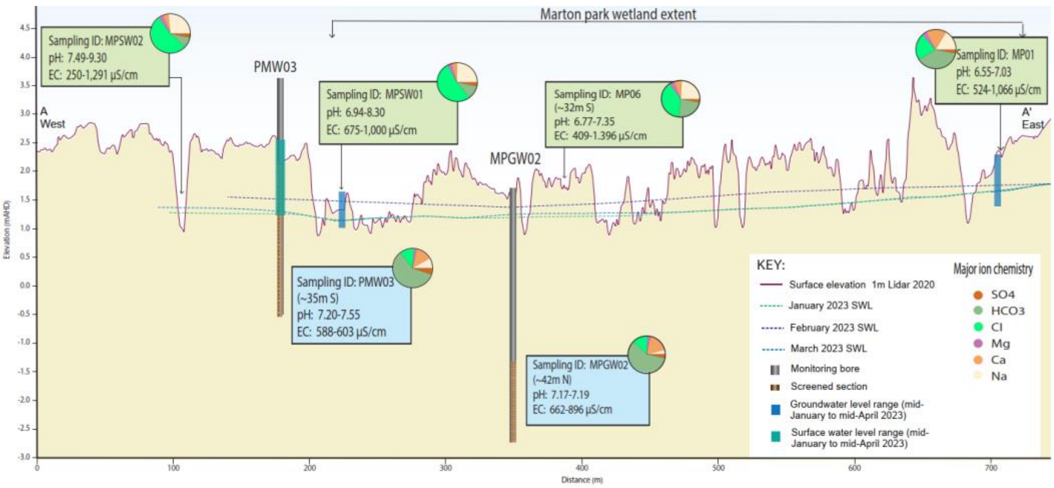

Figure 6 *Conceptual hydrogeological cross-section A-A'*

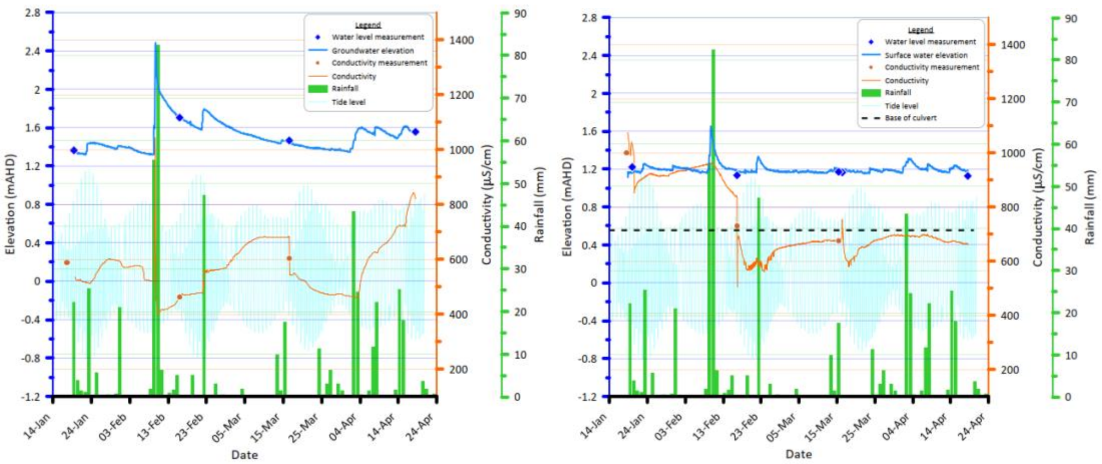

Figure 7 *Hydrographs for PMW03 (groundwater well) and MPSW01 (surface water monitoring location)*

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 40th to the 20th 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

Manning, J. F[1]
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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.

Oral Abstracts

M-Z

WATER MONITORING FOR CLIMATE RESILIENCY

Adam Hobson, PG, MSc[1]
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Introduction

Most impacts from climate change are related to water. Escalating temperatures are causing sea level rise, altering precipitation patterns, and intensifying the occurrence and duration of extreme events like floods, droughts, and storms. These hazards and stressors significantly affect both the quantity and quality of water resources, creating a cascade of effects that extend to people, resources, ecosystems, infrastructure, and the services they provide.

To effectively adapt to and build resilience against the challenges posed by climate change, requires understanding the exposure and assessing the vulnerability and risk to these assets. A critical tool to enhance this understanding and assessment is reliable, authoritative, and understandable water data. Traditionally, organizations initiate the adaptation and resilience building process with qualitative methods that are based on projections developed with global or regional models. While rapid and effective, this method lacks the granularity required to assess the specific impacts of climate change at actionable scales. Gathering and ensuring accessibility to localized water data can provide essential information needed to craft effective adaptation and resiliency strategies and gain deeper insights into the hydrologic effects of climate change.

Historically, perceived barriers related to water monitoring and data accessibility have hindered data collection efforts. The complexity of setting up and operating water monitoring systems, their perceived excessive cost and maintenance demands, data reliability concerns, and labour-intensive nature of data management and interpretation have limited the range of parameters measured, the frequency of readings, and the spatial coverage of monitoring sites.

In this presentation, we will explore solutions to these barriers with examples of straightforward, cost-effective, and reliable continuous groundwater monitoring systems.

Methods

The Water Replenishment District (WRD), a groundwater management agency, and the City of Miami Beach, a municipality, are both adapting and building resilience to climate change impacts based on local, continuous water monitoring networks that are easy to use, economical, and reliable.

The WRD is the largest groundwater management agency by population in the United States. Located along the Pacific coast, groundwater is sourced primarily from freshwater coastal aquifers which are recharged naturally and through managed aquifer recharge with recycled water and stormwater capture. In the past several decades, the agency has faced unprecedented extremes in droughts and floods, sea level rise, and population growth and development which have all impacted the agency's ability to provide a reliable supply of high-quality groundwater.

Recognizing the local impacts of these hazards and stressors and the need for adaptation and resiliency measures, the agency deployed a local water monitoring network to better understand the hydrologic system, impacts of these hazards, and the effectiveness of their mitigation and enhancement efforts. The agency measures water level, temperature, salinity, and other water quality parameters in most of their 350 wells across an area of almost 1,100 square kilometres. At most sites, data are transmitted by telemetry directly to their database system.

The City of Miami Beach is located on allow-lying barrier island on the southeast Atlantic coast of the United States. Like many coastal cities and small islands around the world, Miami Beach is at risk of flooding from sea level rise, storm surges, and extreme precipitation. In addition to direct flooding, sea level rise, storm surges, and extreme precipitation can also raise groundwater levels, increase saltwater intrusion, and increase the risk of flooding from precipitation by reducing infiltration capacity.

To adapt and develop resilient solutions to these changing conditions, the city deployed a local groundwater monitoring network to understand the unique nature of their hydrologic system. The monitoring network consisted of water level, temperature, and salinity sensors in 42 wells at 14 sites across the city with each site equipped with an easy to set up telemetry unit that securely transmits data to a cloud data management service.

Results and Discussion

The continuous groundwater monitoring networks of the WRD and the City of Miami Beach are providing essential data to understand the exposure and assessing the vulnerability and risk to people, resources, ecosystems, infrastructure, and the services they provide.

Continuous groundwater level and quality data measured by the WRD and used for:

- Daily operations planning of injection wells to prevent and mitigate saltwater intrusion
- Planning of pumping
- Developing and refining local groundwater models for forecasting water supplies
- Planning and assessing various projects to create a sustainable and resilient water supply

Continuous groundwater level and salinity data are measured by the City of Miami Beach and used by city engineers and others for:

- Designing and optimizing an effective stormwater management system
- Assessing the effectiveness of raising street heights
- Proposing and accelerating passage of city ordinance to raise seawall heights
- Refining numerical models for planning and decision-making processes
- Assessing performance and effectiveness of pump stations
- Defining risk to infrastructure from saltwater intrusion

While having reliable, authoritative, and understandable water data is essential to effectively adapt to and build resilience against the impacts of climate change, a bigger challenge is the perceived barrier of collecting and accessing data. Both organizations did not have the capacity in terms of knowledge and staff to install a complicated system, maintain it, and manage the large volume of data. In these cases, the organizations selected a monitoring system that was designed to work together from the sensors, the cables, the telemetry, and the data management system. The system was developed to be simple to set up and use, have an overall low cost of ownership, including trips to the field and maintenance, include reliable instrumentation and sensors that are purpose-built to work in difficult conditions, and include an efficient, data management system.

Conclusion

Climate change affects the quantity and quality of water resources. However, the impacts to specific assets are often at a local scale. Local water monitoring systems play a pivotal role in assessing and mitigating the impacts of flooding, drought, saltwater intrusion, and rising temperatures. By offering reliable, authoritative, and easily interpretable water data, they are essential tools in enhancing climate adaptation and fortifying resilience strategies. These objectives can be achieved through water monitoring systems that are simple to set up and use, have a low total cost of ownership, include reliable instrumentation that provide accurate field readings, and include an efficient data management system. These systems provide access to data that is accurate, comprehensive, and understandable to help stakeholders and decisionmakers adapt and build climate resiliency.

RUAHUWAI DECISION SUPPORT TOOL

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[1] Williamson Water & Land Advisory Limited

Aim

The development of a set of hydrological, hydrogeological, and solute transport models for the catchments draining into the Waikato River between Lake Taupo and Lake Ohakuri was initiated in 2015, for a large land estate comprising approximately 25,000 ha known as Wairakei Pastoral ("the Estate"). The work was completed some four years later in 2019, and was used to inform the Estate's planning with regard to the Waikato Region Plan Change 1 (PC1) process.

The combined integration of these modelling tools was referred to as the Ruahuwai Decision Support Tool (RDST). The objective for the RDST was to allow the Estate and neighbouring properties to explore and understand:

- the hydrologic (surface water) and hydrogeologic (groundwater) functioning of the land and sub-surface within the Ruahuwai model domain;
- the likely water quality outcomes at a sub-catchment scale, resulting from different land use options; and
- to test and make informed land management and mitigation decisions.

The RDST enables landowners to explore and optimise land utilisation within the PC1 environmental objectives framework. In other words, to meet environmental objectives and optimise land productivity concurrently.

Method

The RDST comprises three model components that couple together to inform the understanding of catchment hydrology and the environmental impact land management decisions may have on water quantity and quality outcomes across the Ruahuwai model area. The RDST comprises three interdependent models that each account for the following process:

- The Agricultural Production Systems Simulator (APSIM) – for nitrogen loading at the subsoil level;
- MODFLOW and MT3DMS – for groundwater flow and constituent transport; and
- SOURCE (with SMWBM and dSedNet) – for surface water flow and water quality accounting.

A schematic overview of the key inputs and interactions between the three coupled models (APSIM, MODFLOW / MT3DMS and SOURCE) is illustrated in Error! Reference source not found..

The following constituents were simulated within the RDST:

- Total nitrogen (TN);
- Total phosphorous (TP);
- Total suspended solids (TSS); and
- Escherichia coli (E. coli.).

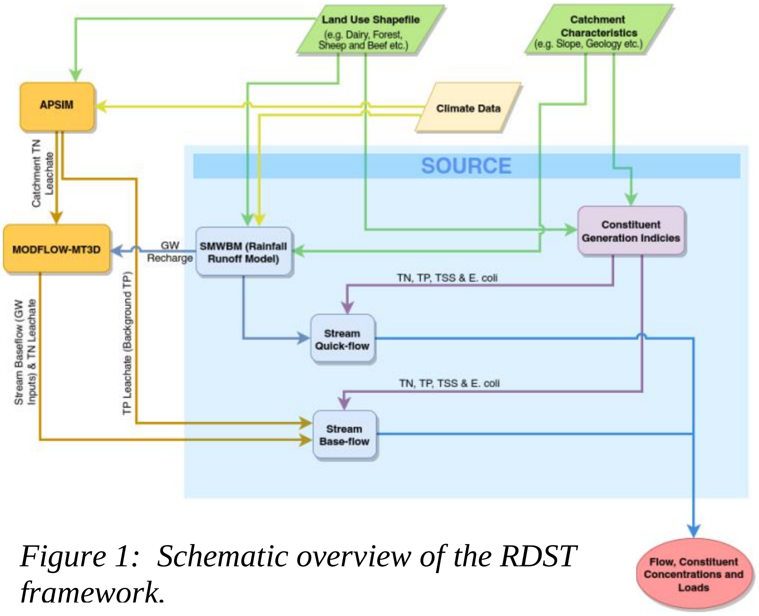

Figure 1: Schematic overview of the RDST framework.

Model Development

The fundamental architecture of each of the RDST component models (APSIM, MODFLOW / MT3DMS, SOURCE and SMWBM), such as structure and boundary conditions, were initially constructed in isolation from each other until the model calibration stage where transfer of water and constituents between each component was required.

The model calibration process was iterative and involved the swapping of inputs and outputs from the component models until all models were satisfactorily calibrated (i.e., the various simulated features matched available monitoring data).

Simulation of the Model

The SOURCE model provided an over-arching framework that allowed the integration of each of the modelling components to provide daily outputs of streamflow (including separation of base flow and quick flow) and constituent concentrations.

The model operated on a daily timestep over the period 1972-2018. The key input datasets to three models were climate data (e.g., rainfall, evaporation etc.), catchment physical characteristics (e.g., soil properties, underlying geological properties etc.), and land use classifications.

The Soil Moisture Water Balance Model (SMWBM), a rainfall runoff model, was used to simulate the surface and sub-surface processes of stream quick-flow and groundwater recharge (percolation) for each sub-catchment. Groundwater recharge outputs were passed to the groundwater model which simulated groundwater flow and the re-emergence as stream baseflow.

APSIM was used to simulate the daily mass of TN leaching from the soil profile from various land use types and management regimes. The groundwater model utilised the daily mass of TN leachate from APSIM to simulate the transport and attenuation (through denitrification) of TN in groundwater.

The SOURCE catchment model (utilising the SMWBM and dSedNET plugins) handled the generation of all remaining constituents (e.g., quick-flow TN, E. coli, TP, TSS). Constituent generation was undertaken on a land use basis. The load of a particular constituent from each sub-catchment was calculated as an area weighted average aggregation of all land uses within a given sub-catchment.

RDST outputs were post-processed outside of SOURCE to produce a wide range of maps, plots, summary statistics, and annual constituent loads to enable the landowners to investigate catchment water quality outcomes resulting from proposed land management options.

Results

Eight scenarios were assessed, which ranged from “Stop Farming” to various different farming intensity systems, and farming land management options.

The model was able to provide a deeper hydrological understanding of the catchment functionality, which enabled the following key conclusions to be drawn.

The Groundwater N “load to come” concept which is defined in the PC1 background documents as a load of N in groundwater derived from land surface recharge that will take many decades to discharge into the receiving environment, is overly simplistic, and a more nuanced understanding is required to consider future water quality outcomes. As demonstrated by the calibrated model, old groundwater (which is responsible for the groundwater lag) has been subjected to redox reactions involving the progressive depletion of dissolved oxygen followed by nitrate conversion to benign nitrogen gas.

Observed recent N concentration increases in surface waters were explained by the model via “quicker flow processes” including surface runoff and young groundwater discharges, which are relatively short and medium-term responses, respectively.

The calibrated model demonstrated that the constituent generation footprint of land parcels vary, not only on the basis of land use, but also across differing sub-catchment physical characteristics, including the sub-surface. Spatial variability in the landscape’s assimilative capacity across sub-catchments is also a matter that should be considered when designing and deciding upon land use regulation rules in a Regional Plan.

To adopt a more dynamic landscape-based approach, cognisant of the differing assimilative capacity of the landscape, will provide greater flexibility for landowners to manage their activities within the constraints of agreed freshwater objectives. It follows that both environmental sustainability and economic utility of the land will be optimised.

THE MURIWAI GOLF PROJECT – ANCIENT UNDERSEA VOLCANOES, A PERCHED DUNE LAKE, AND NATURAL WETLANDS

Williamson, J.L.[1] **Scherberg, J.,**[1] **Mawer, J.**[2]
[1] Williamson Water & Land Advisory

The Bears Home Project Management Limited proposed the development of a luxury golf resort facility of international standing, including an international marquee standard 19-hole golf course, 9-hole short course, driving range, clubhouse, practice areas, indoor and outdoor tennis facilities, Sports Acadaemy, and a world-class luxury accomodation lodge and wellness centre. The site comprises 507 hectares of rural land, northeast of the Muriwai Township, on Auckland's west coast.

The site was historically used for diary, drystock sheep and cattle farming, and with an active sandstone quarry. However, the dairy and quarry operations recently ceased. This site contains two picturesque waterfalls, and a dune lake, which are classified as Outstanding Natural Features, and an abundance of wetlands – some of which are classified as Significant Ecological Areas.

The restoration and enhancement of these features are fundamental part of the vision for the property, and integral to delivering a golf course with Marquee status.

This presentation highlights a small selection of the investigations and modelling undertaken to support water and environmental management across the site, including a lake water balance model, Electrical Resistivity Tomography (ERT) Survey, and groundwater modelling and how these studies informed one another and the overall development.

Lake Okaihau

Lake Okaihau is a dune lake located in the western extent of the site, covering approximately 6 ha, and up to 9-10 metres deep near the centre of the lake. The Lake is classified as an Outstanding Natural Feature, and is intended to be a showcase feature of the golf course. Undertsanding the hydrological functioning of the lake was requried to ensure the development would not negatively impact the lake.

A lake water balance model was developed to understand the relative contributions of surface water inflows and direct rainfall, balanced against evaporative losses and seepage to groundwater. The water balance assessment supported the hypothesis that the lake bed consists of low permeabiltiy sediment that varies in thickness radially within the lake, becoming thinner at the extrematies, which results in low seeapge when lake levels are low. Conversley, as lake levels increase, so do seepage losses.

Lake seepage losses corroborate with observations of increased specific flow yield in the Okiritoto Stream, located approximately 500 m to the north-west. There were concerns that lake seepage losses may be exacerbarted as a result of groundwater abstractions associated with the golf development for irrigation and potable supply. The rate of groundwater flow away from the lake was also investigated with a groundwater model of the site.

ERT Survey

A pilot bore was drilled at a small basalt outcrop on site. The drilling indicated a thin outcrop of pillow lava at the surface, extending to a depth of 15 m, underlain by sandstone and siltstone to 120 mBGL, with deeper highly fractured pillow lava structure encountered below to at least 230 mBGL, where drilling ended. Initial test pumping over three days indicated a high yielding supply. However, the extent of the basalt aquifer and thus indication of sustainable yield was unknown.

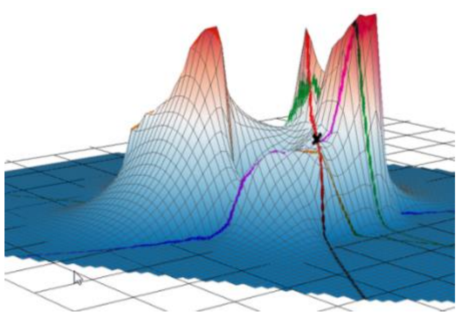

Figure 1. ERT survey 3D interpolation of basalt dyke.

An Electrical Resistivity Tomography (ERT) survey was undertaken to better characterise the three-dimensional extent of the basalt feature. The four ERT profiles showed a contrast in electrical resistivity between the basalt and surrounding sandstone of the Nihotupu Formation, and was used to define the extent. A three-dimensional surface model was developed, and indicated the basalt is likely a complex of at least three basalt dykes with associated deeper lava flows.

It was estimated the basalt aquifer could contain in the order of 500,000 m^3 to 1,000,000 m^3, assuming porosities of 5% and 10%, respectively.

Groundwater Modelling

A numerical model was developed using the USGS MODFLOW code to represent the primary geologic features across the catchment, covering an area of approximately 3,400 ha. Available bore log data was used to determine the thickness of the geologic features, the configuration of the basalt dyke based on ERT survey results. The model was then calibrated using data collected over the course of the test pumping exercise at four monitoring locations, ranging in depth from 4 to 200 m, as well as water level measurements collected across the catchment.

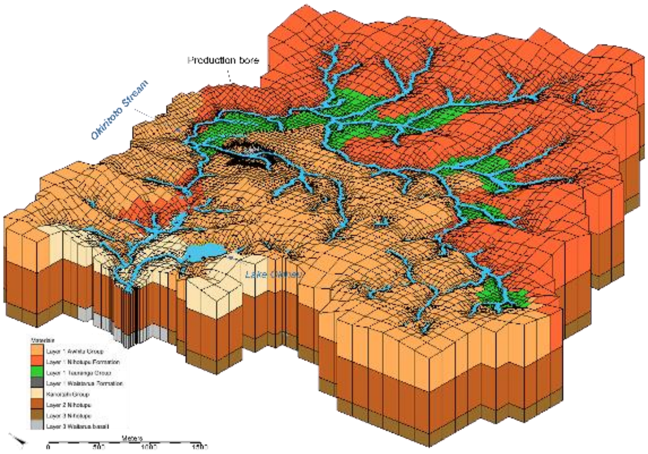

Figure 2. Groundwater model domain (3X vertical exaggeration).

A key finding of the calibration process was that to replicate the vertical pressure gradient observed in the monitoring data there must be a down gradient outlet for deep groundwater. This was presumed to be a deep basalt flow toward the ocean based on similar formations in the area. Modelling analysis supported that the basalt-dyke was a high conductivity feature, while the overlying sandstone was low conductivity, and the presumed deep basalt-flow had intermediate conductivity. This was subsequently confirmed by observations of spring emergence along the northern portion of Muriwai Beach that align with the presumed groundwater outlet.

Figure 3. Basalt outcroppings near Muriwai Beach.

Indications from the modelling analysis confirm that there is high conductivity within the basalt dyke, and additional storage in connected basalt flows, albeit with somewhat lower conductivity, altogether making groundwater a viable water source. These basalt features occur within low-permeability sandstones, with basalt recharge rates limited by the low transmissivity of the surrounding material.

Sustainably sourcing a long-term water supply from the basalt formations underlying the golf course will require a management strategy that aligns with the characteristics of the native material. This will entail allowing the sandstone materials to gradually fill the storage within the permeable basalt during the wet season, while allowing abstraction to proceed through dry summer periods when water is most needed. While geologic constraints will influence water management from the production bore, it is also noted that sourcing water from 200 m below ground in low permeability material will assure that stream flows and wetland water levels will not be affected by groundwater use.

HYDROLOGICAL IMPACT OF CYCLONE GABRIELLE IN WAIROA

Deborah Maxwell,[1] Jack McConchie,[1] Oliver Anderson[1]
[1] SLR Consulting Ltd

During Ex-tropical Cyclones Hale, and particularly Gabrielle, Wairoa suffered extensive flooding. As part of a larger study, the rainfall and runoff response (including specific yield) throughout the Wairoa catchment were investigated. This included the rainfall and runoff processes leading up to and during these events.

Three periods were considered during the study. The first included the situation and conditions in the months leading up to Cyclone Gabrielle. This was followed by a more detailed review of conditions during the first two weeks of February. A particular focus was on the forecasts relating to the cyclone in the days leading up to the event (i.e., the track, timing and predicted rainfall) and how these forecasts changed over time. Finally, the hydrological response of the catchment to the cyclone and during the following the weeks was examined.

The first indication of an ex-tropical low developing that may impact New Zealand was on 6 February. At that time the catchment was already quite saturated because of higher-than-average rainfall over November to January. Although considerable rain fell within the upper part of the Wairoa catchment (i.e. in and around Lake Waikaremoana), the largest specific yields and contributions to the flow at Wairoa came from the Wairoa and Waiau sub-catchments. It was these sub-catchments which caused the extensive flooding and wide-spread damage at Wairoa.

GROUNDWATER PUMPING IN A CHANGING CLIMATE – LESSONS LEARNT AND FUTURE CONSIDERATIONS

William McCance[1]

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Groundwater can be an important resource, particularly during dry periods when surface water resources are already stressed or depleted. However, forecasting and understanding the volume of water that can be taken without causing harm to human health or the environment is no easy feat, particularly when there are multiple aquifer systems or competing demands.

Between 1982 and 2016 Barwon Water intermittently accessed groundwater from the Tertiary-aged sediments within the Barwon Downs Graben to supplment drinking water supplies during dry periods. As a result of management of pumping activities in the Barwon Downs Sub-basin, water levels within the Lower Tertiary Aquifer declined by up to 60m in the confined portions of the aquifer in the vicinity of the borefield, and up to 4 and 22m in the Kawarren and Barwon Downs Sub-basins respectively, where the Lower Tertiary Aquifer outcrops at surface. Subsequently, these groundwater level declines have led to a reduction in groundwater discharge to select surface water features located within outcropping areas. While this was anticpated to some degree, recent work undertaken to assess the influences of groundwater pumping and its management on surface water features has also highlighted the importance of developing a robust conceptual site model that can interogate the influences from multiple factors to understand the cumulative effects of these activities on both surface and groundwater resources.

This presentation will provide an example of how our understanding of the Barwon Downs Graben and the management of groundwater pumping-related impacts have changed over time and provide an overview of the climate related and other factors that have led to where we are today. The presentation will also touch on elements of the Boundary Creek and Big Swamp Remediaiton Plan, engaging with diverse groups of community members and stakeholders, and future considerations for the holistic management of groundwater and surface water resources.

A 3D RADIOCARBON ISOSCAPE OF GROUNDWATER AGES ACROSS NEW SOUTH WALES, AUSTRALIA

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Isoscapes, or isotopic landscapes, represent an innovative approach to understanding spatial variations in isotopic data. In hydrogeology, radiocarbon isoscapes provide an essential tool for deciphering the age distribution of groundwater across large spatial scales. In this study, we constructed a groundwater radiocarbon isoscape for New South Wales (NSW), Australia. The project, undertaken for the Department of Planning and Environment, involved a field campaign in 2021, during which 331 radiocarbon samples were collected from bores across NSW. We supplemented this dataset with an additional 916 radiocarbon data points sourced from both published and unpublished literature.

Radiocarbon correction methods such as Fontes and Garnier, Tamers, and a ^{13}C isotope exchange model were applied using Netpath XL to account for changes in radiocarbon ages caused by gas exchange and carbonate dissolution in the soil and aquifers. A 25x25 km grid was then generated using kriging, and groundwater ages were mapped at four distinct depth intervals: 0-30m, 30-50m, 50-300m, and >300m below ground surface. Our study identifies a trend of increasing groundwater age towards the west and north of the state. Conversely, we identified areas with younger groundwater ages which are potentially associated with recharge from snowmelt along the Great Dividing Range. The analysis also reveals possible anthropogenic impacts on the shallowest layer, including irrigation activities, and natural processes such as the mineralisation of aged organic matter. This work underscores the utility of radiocarbon isoscapes in discerning groundwater ages and recharge sources on state-wide scales. The results can be used to inform future hydrogeological studies and water management strategies in NSW.

TRACING GROUNDWATER INPUTS TO LAKES ACROSS MACQUARIE ISLAND

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The study of environmental isotopic data from lakes can provide valuable insight into how catchments respond to different environmental changes such as rainfall, nutrient cycling, and ecosystem health. Despite their potential, isotopic tracers have not been widely used in lakes located on Southern Ocean Islands (SOIs) where environmental change is occurring rapidly and significantly. Previous studies have shown that geochemical drivers, such as geology, vegetation, and sea spray contribution can have a localised effect on lake water chemistry. However, the role of groundwater in lake hydrology and hydrochemistry across SOIs has not been identified until now.

We conducted the first comprehensive, island-wide hydrochemical and isotopic survey of lakes in the Macquarie Island region, examining 40 lakes for various isotopic ratios including stable carbon ($\delta^{13}C_{DOC}$ and $\delta^{13}C_{DIC}$), oxygen ($\delta^{18}O$), hydrogen ($\delta^{2}H$), and strontium ($^{87}Sr/^{86}Sr$) in water. These baseline data will be useful in understanding hydrological, biological, and geochemical processes in the lakes, and any shifts that may occur under future climate change. Results show that lakes on the western side of the island are affected by sea spray aerosols, while lakes at higher elevations are dilute and those located in lower elevation catchments show more water-rock interactions. The isotopic tracers suggest that terrestrial-sourced ions, which may come from groundwater, are more common in lakes located in lower elevations. With changing rainfall patterns and increasing temperatures predicted for the region, nutrient cycles will shift, and unique ecosystems on the island will be impacted. The use of isotopic tracers will be critical in monitoring these unique and difficult-to-access environments where there is no groundwater monitoring infrastructure in place.

AQUIFER THERMAL ENERGY STORAGE (ATES) USED FOR DISTRICT COOLING IN A NEW URBAN DEVELOPMENT IN HILLERØD, DENMARK

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[1] Ramboll Denmark

Introduction

Aquifer Thermal Energy Storage (ATES) is a "green" open-loop geothermal technology used for energy conservation. The technology is based on seasonal storage of warm and/or cold water in an aquifer to provide cooling in the summer and warming in the winter.

ATES is highly efficient because it takes advantage of natural heating and cooling available during summer and winter and stores that heat in the target aquifer until the subsequent cooling or heating season when it can be used. Hence no burning of fossil fuels or use of electricity is required.

An ATES system can be considered if there is a suitable aquifer available, into which at least two thermal wells are installed. A system typically involves a cold well and a warm well. Cold groundwater is abstracted from the cold well during summer months and used for cooling. After the water has been used for cooling, it has been warmed and is recharged into the warm well. In winter the cycle is then reversed so that warm groundwater is abstracted from the warm well and used for heating and so forth. There is no net withdrawal or addition of groundwater to the aquifer making ATES an environmentally friendly solution.

Hillerød Utility Services (Hillerød Forsyning) plans to provide sustainable district cooling from a new energy central for the new urban development Favrholm and a new regional hospital. The anticipated requirements for cooling of up to 11.4 MW will be provided by a combination of heat pumps and ATES. This presentation describes the results of the hydrogeological investigations for an ATES system based on groundwater aquifers in limestone.

Method

The investigations included installation of 2 full-scale investigation wells to depths of 152 m and 112 m, respectively, located approximately 210 m apart, geophysical borehole logging, completion of the wells as production wells and subsequent pumping testing and groundwater quality sampling.

Pumping testing with an abstracting and injection of 24 l/s was carried out for 2 weeks followed by measuring the recovery period.

Subsequent numerical groundwater modelling was used to assess the capacity of the system and the interference effects on existing users.

Results

The limestone aquifer is covered by 40 to 45 m quaternary deposits consisting mainly of clay till. Furthermore, the piezometric level in the limestone is found 3 to 4 m below ground level.

Based on geophysical flow logs in the limestone it was assessed that 1/3 of the water bearing capacity – the transmissivity - of the wells is associated with the upper approx. 5 m of the limestone and 2/3 with a zone from about 20 to 45 m below the limestone surface, corresponding to 60 to 90 m below ground level. The results from the pumping test showed that the transmissivity of the limestone is very high, of the order of 0.01 to 0.04 m^2/s.

The electrical conductivity of the formation is derived from the geophysical borehole logging and indicates an increase in salinity from around 95 m depth and down.

The ATES wells are completed as open holes from 60 to 95 m below ground level targeting the high-yielding flow horizon encountered from 60 to 90 m depth thus not directly affecting the overlying flow horizon in the upper 5 m of the limestone that the nearby existing well field is targeting or the deeper lying saline groundwater. Furthermore, the system configuration reduces the risk of elevated groundwater pressure near recharge wells thus mitigating the risk of affecting the foundation of buildings.

The results of the investigations were used to update and calibrate a numerical 3D-groundwater model based on the program FEFLOW to simulate flow and heat transport for development of a sustainable ATES system considering existing groundwater users.

The results from the simulation of scenarios with the calibrated groundwater model show that the hydraulic pressure in adjacent abstraction wells is not significantly affected by operating an ATES system with one well-pair and circulating groundwater at a flow rate of 70 l/s. When the operating yield is this high, some of the cold water recharged in the cold well will eventually reach the warm well.

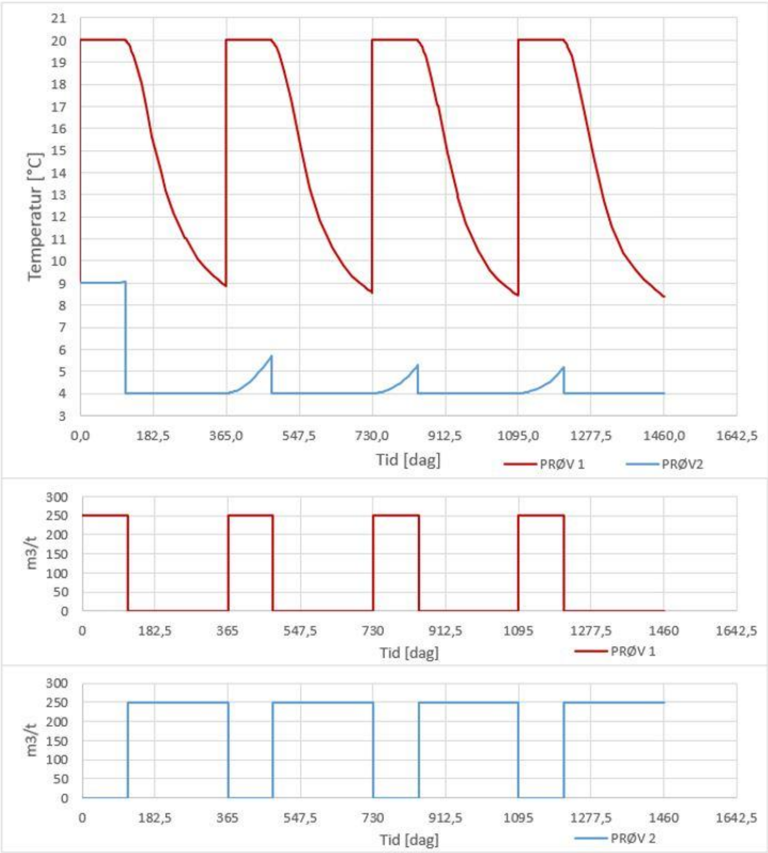

Figure 1; Simulated temperature variations of abstracted and injected groundwater and associated flow rates for one well-pair

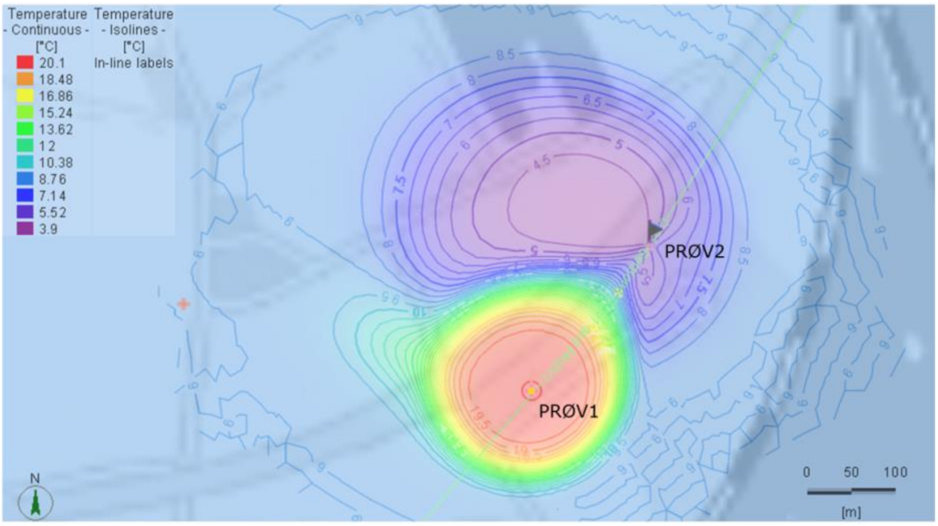

Figure 2; Simulated groundwater temperature of the targeted limestone aquifer after 3 years of operation.

Conclusions

A conservative estimate is that the ATES-system can provide 1.8 MW cooling. The conclusion of the investigations is that the encountered limestone aquifer is suitable for installation of a sustainable ATES system used for district cooling (and heating) for the relatively large urban development and the new regional hospital.

IF THE PRIOR IS UNCERTAIN, IS A COMPLEX SIMULATOR WORTH IT?

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The magnitude and timing of recharge fluxes originating from rainfall percolation provides critical information for groundwater management. However, the implications of adopting a "simpler" rather than a "complex" recharge simulator are seldom considered. Complex recharge simulators can represent the physical processes of groundwater recharge with greater integrity, but can be numerically unstable, with long run-times, and be difficult to parameterise. In contrast, simpler recharge simulators represent recharge processes with less physical integrity, and can incur bias, but generally avoid the numerical issues associated with complex models. This can enable simpler models to quantify and reduce the uncertainty of model predictions more effectively through history matching against field data.

Considerations of whether the trade-offs involved in selecting a simpler recharge simulator are acceptable, within a particular decision context, rely on answering questions such as:

- 'Are simplification errors significant in comparison to total prediction uncertainty?'.
- 'How does the definition of prior parameter values impact uncertainty quantification, regardless of the model?'.

These trade-offs are explored using a synthetic case-study, loosely based on the coupled recharge-groundwater models used to manage regional groundwater in the Perth Basin of Western Australia. These involve predictions that are made by one complex and four simpler recharge simulators. Predictions of recharge magnitude made by simpler simulators incur some bias and an inflated uncertainty compared with those made by the complex simulator. Predictions of groundwater head are largely immune to these simplifications.

One simplification involved the common practise of spatially lumping a complex simulator's parameters. In this case, the simplification impacts were most benign compared with other simpler recharge simulators, under the assumption of perfectly known geostatistical descriptors of lateral hydraulic property heterogeneity. However, where the prior is uncertain, the superiority of this spatially lumped complex simulator was eroded to a level commensurate with alternative simpler recharge model simulators.

ROBUST SOURCE WATER RISK MANAGEMENT AREA MODELLING

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Delineation of Source Water Risk Management Areas (SWRMA) is a type of risk-based decision support modelling. It is undertaken to assist land-use decisions within a defined area, where there is potential for land-use associated contaminants to impact the quality of water in a well, and the associated health risks of those drinking this water.

Implicitly or explicitly, uncertainty quantification (UQ) is a central part of any risk-based modelling. To be robust, any model designed for assessing these risks as part of a SWRMA delineation must be capable of quantifying and reducing the uncertainty of the SWRMA given relevant available data (Doherty and Moore, 2020). The level of risk also dictates which model design and UQ should be adopted.

Assuming that a contaminant source is present, the risk of drinking water well contamination is impacted by: (i) the well pumping rate, which is related to the numbers of people being supplied by the drinking water supply well, (ii) the characteristics of the aquifer, and (iii) the aquifer recharge sources and rate of recharge. Of these three components, it is modelling of flow and transport through the hydrogeological system, that represents the greatest challenge in SWRMA delineation. This modelling must consider the movement of contaminants toward a source. Dispersion, adsorption, diffusion and filtration and die off (all of which vary spatially) will strongly influence the degree to which a well is exposed to contaminants.

We discuss two complementary programmes of work which focus on providing guidance for appropriate risk-based modelling for delineation of SWRMA. The first explores how the risk environment alters model design requirements. The second programme specifically explores modelling requirements in highly heterogeneous alluvial aquifer systems, where contaminant transport can be particularly rapid.

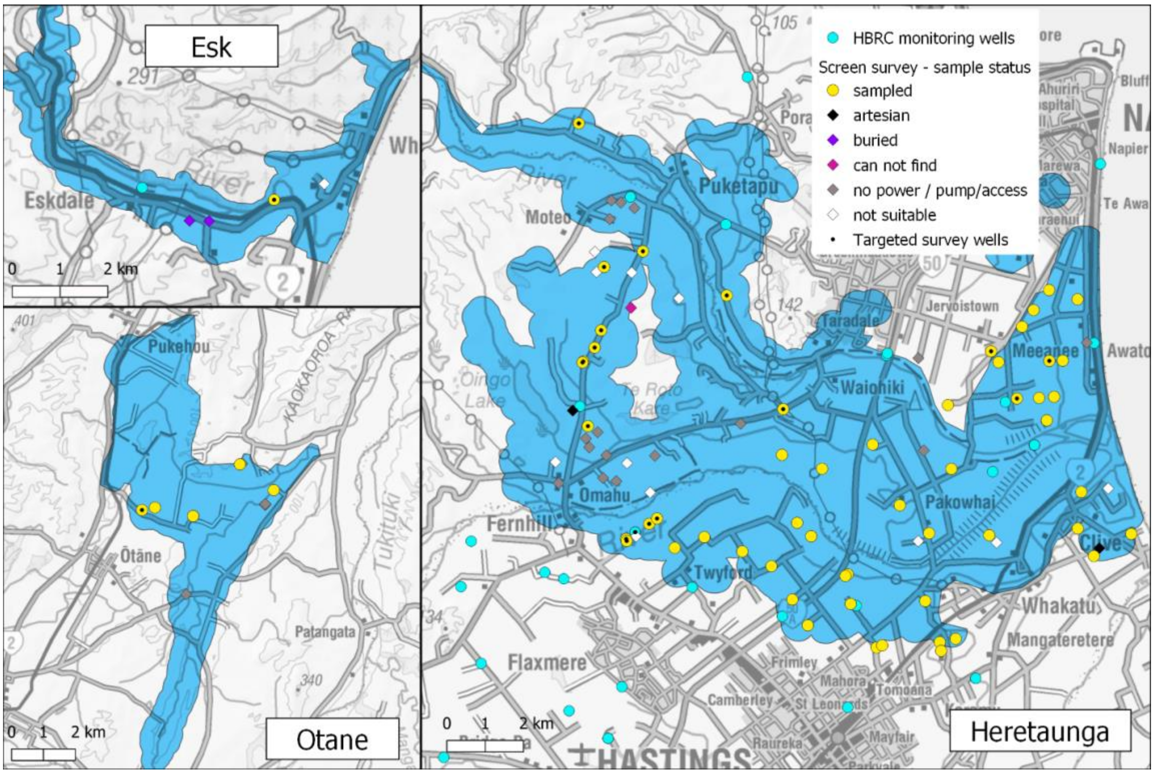

Figure 1: Distribution of locations visited during the screen survey and sampled for the targeted survey.

CYCLONE GABRIELLE 2023 EVENT-RESPONSE GROUNDWATER SAMPLING IN HAWKE'S BAY FLOODED AREAS

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[2] Hawke's Bay Regional Council, New Zealand
[3] ESR, New Zealand

Aims

Cyclone Gabrielle caused unprecedented flooding and damage across parts of the North Island in mid-February 2023. In the month following the event Hawke's Bay Regional Council (HBRC) initiated this project to identifying potential contamination of groundwater that were subject to significant flood water inundation. We believe this project is the first coordinated event response to assess the impact of widespread flooding on groundwater quality undertaken in NZ. The areas of concern identified were the central north-western part of the Heretaunga Plains, Esk Valley and Otāne (Figure 1). The project was contracted by MBIE to GNS Science to lead and included HBRC, Napier City Council (NCC), Hasting District Council (HDC), and Institute of Environmental Science and Research (ESR).

Method

The project took a collaborative approach and started with cross-organisational meetings to collect and review available datasets, develop a sampling approach and identify sampling parameters, establish criteria for sampling bore selection, plan and resource fieldwork, within a defined timeframe and resource. The applied approach consisted of a first-up, rapid, low-cost survey to screen a large number of wells to inform a follow-up targeted survey where a more comprehensive suite of contaminants were sampled for at a lesser number of wells. This approach represents a compromise between operational constraints, cost and the high likelihood of non-detection.

Results

Prior to the surveys, State of the Environment sampling returned two E.coli exceedances at a cluster piezometer site which was flooded. The screening survey was undertaken by a field team from multiple organisations (HBRC, GNS, NCC, HDC) in early May 2023. A total of 105 sites were visited of which 39 wells were found either unsuitable (e.g. lack of access prior to storage tank or filter), or could not be sampled (e.g. lack of pump or power). Field parameters and E.coli samples were collected at 61 sites. Only one site exhibited detectable E.coli (13 cfu per 100 mL) which was confirmed by a repeat sample. The targeted survey was undertaken by HBRC in June 2023. Twenty wells were identified, with 12 wells visited, and nine wells sampled. None of the nine wells sampled had detection for pesticide or volatile organic variables (144 and 64 compounds, respectively).

An output of the project includes recommendations of how regions and entities of responsibility could better prepare and approach a future survey to investigate groundwater contamination eventuating from a flood event of significance.

COASTAL SYSTEMS FACIES MAPPED IN THE NATIONAL HYDROGEOLOGICAL-UNIT MAP

Moreau M.[1], **White P.**[1], **Clark G**[1]., **Udawatta N.**[1], **Strogen D.**[1], **Crundwell M.**[1], **Cameron S.**[1], **Santamaria E.**[1], **Tschritter C.**[1]

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Aims

Hydrogeological maps are resource management tools that integrate geology, aquifer properties, and groundwater quality and quantity information (Gleeson et al. 2014). To develop the first 3D hydrogeological map of New Zealand, geological and depositional facies are incorporated into the nationally-consistent, 2.5D hydrogeological-units map (White et al. 2019). These units are qualified through attributes and used as a key to move between local and national scale. Ultimately, these maps will characterise our geologically-complex aquifer systems at a national scale, providing digital resources in a consistent template for evaluating aquifers. This is to be achieved by growing the number of attributes to include, for instance, unit thickness (to bring 2.5D into 3D), hydraulic properties and/or groundwater chemistry data.

Facies mapping has been sequenced using the recently developed hydrogeological systems classification (Moreau et al. 2019). Coastal systems were prioritised as they host the main groundwater systems of NZ and because of their vulnerability to climate change/sea level rise. This paper presents the completed 244 nationwide surface and subsurface facies mapping and attribution of representative facies models of the coastal systems. The project is a GNS Science-led collaboration involving consultation with regional experts and water managers to ensure the produced maps are fit-for purpose. It is funded by the New Zealand Ministry of Business, Innovation and Employment Strategic Science Investment Fund (contract C05X1702) through GNS's Groundwater Research Programme.

Method

The published NZ Hydrogeological-Unit Map (HUM) was reviewed to ensure consistency between the hydrogeological systems and the 1:250,000 geological map (QMAP, Heron et al. 2014) and modified to include an outcrop identification flag and facies attributes. In parallel, facies classifications were developed for all New Zealand hydrogeological units outcropping within the 2D coastal systems.

Surface facies were mapped using QMAP and associated monographs using geological units as a basis. Subsurface facies were subsequently developed using surface facies and HUM subsurface unit extents based on existing geological information and expert knowledge. Where geological units comprised multiple depositional environments over a large time period, secondary facies were developed. The mapping process was recorded within a national mapping guideline document which will be available upon completion of the project. This document describes the rationale for HUM modifications, facies mapping rules and references.

Results

Modifications to the HUM units since 2022 included: facies mapping of the South Island and consistency checks between North and South Island facies. In total, 23 surface facies were developed and associated with each corresponding hydrogeological unit (Figure 1). Facies were defined to encapsulate geographical and geological distinctive environments, an example is the "Clastic Fluvial/Coastal Plain" facies. In addition, examples of HUM applications of groundwater resources assessments will also be presented.

To enable collaborative refinement of this national dataset, a time-stamped interim dataset is now publicly available, alongside a release note documenting unit modifications. Further releases are anticipated as mapping progresses in other hydrogeological systems.

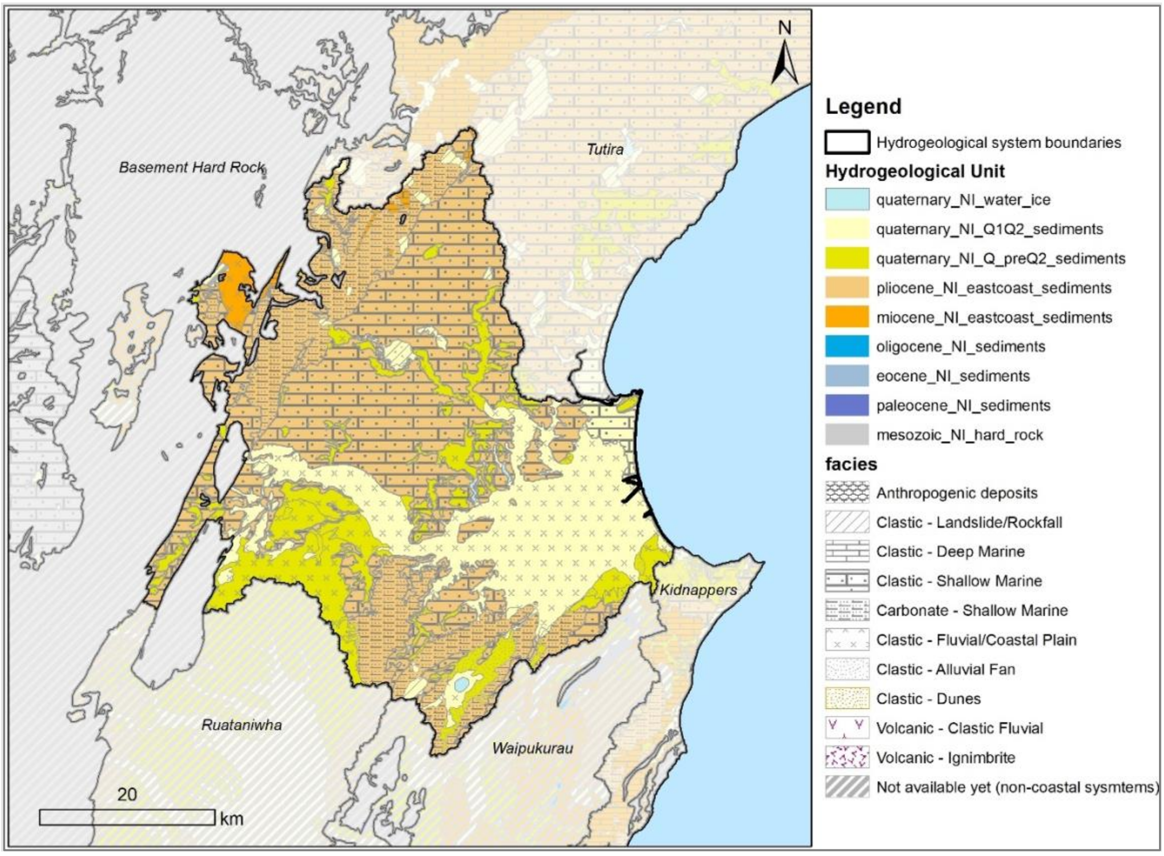

Figure 1: Hydrogeological units and associated depositional facies within the "Heretaunga Coastal System". Hydrogeological system were named as part of the mapping exercises. Coastal systems, names were based on geographical location.

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GROUNDWATER AND SURFACE WATER CONCEPTUAL FLOW FROM ENVIRONMENTAL TRACER SIGNATURES IN THE PUKEKOHE AND BOMBAY AREA, AUCKLAND

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Aims

Elevated nitrate concentrations in groundwater are an established historical and current issue in the Pukekohe–Bombay area (White et al. 2001; Foster and Johnson 2021Contaminated springs have a negative effect on the health of streams, with observed concentrations exceeding the national bottom line for nitrate toxicity in rivers set in the National Policy Statement for Freshwater Management 2020 (Ministry for the Environment 2020). Better understanding of the conceptual groundwater flow, connection with surface water, nitrate pathways, and 'Future nitrate loads to come' is needed to inform improved nutrient-management tools and water-take regimes in the Pukekohe–Bombay area.

Methods

Groundwater residence and stream transit times based on tritium, SF_6, Halon-1301, and ^{14}C were used to establish the connection between groundwater and surface water and estimate flow rates and lag times. Isotopes, noble gases, and hydrochemistry provided information on recharge sources. The dataset included historical and new data, acquired as part of this project.

Results

Groundwater ages provide a consistent picture. Water drainage through active groundwater flow systems occurs through the basalt lavas (Figure 1, red arrows). The active groundwater flow systems in the Pukekohe and Bombay basalt lavas have sufficient storage to maintain significant stream baseflow over the course of years. Baseflow is sourced primarily through three large springs, Patumahohe, Hickey, and Hillview, draining the volcanoes on their northern perimeters. On average, it takes 18 years for the groundwater to travel through the Pukekohe basalt lava and 36 years to travel through the Bombay basalt lava.

The long groundwater lag times pose challenges to mitigation action for achieving National Policy Statement for Freshwater Management 2020 national bottom lines (NBL) for nitrate toxicity in rivers. With decades of lag times for nitrate, the response to improved land use management for these hydrologic systems will also be in the order of decades. If nitrate loading stopped in 2024, improvement to below NBL would only be seen by 2050 for Pukekohe and by 2080 for Bombay. Auckland Council and its partners will be using this information to help with long-term planning in the Franklin area.

Groundwater recharge and flow in areas outside of basalt lavas (Figure 1) is negligible, with the water being old and therefore stagnant. Rain onto the Pleistocene deposits therefore drains, mainly during the wet season, through shallow, fast-flow paths, without a sufficient storage reservoir to sustain significant stream baseflow during the dry season.

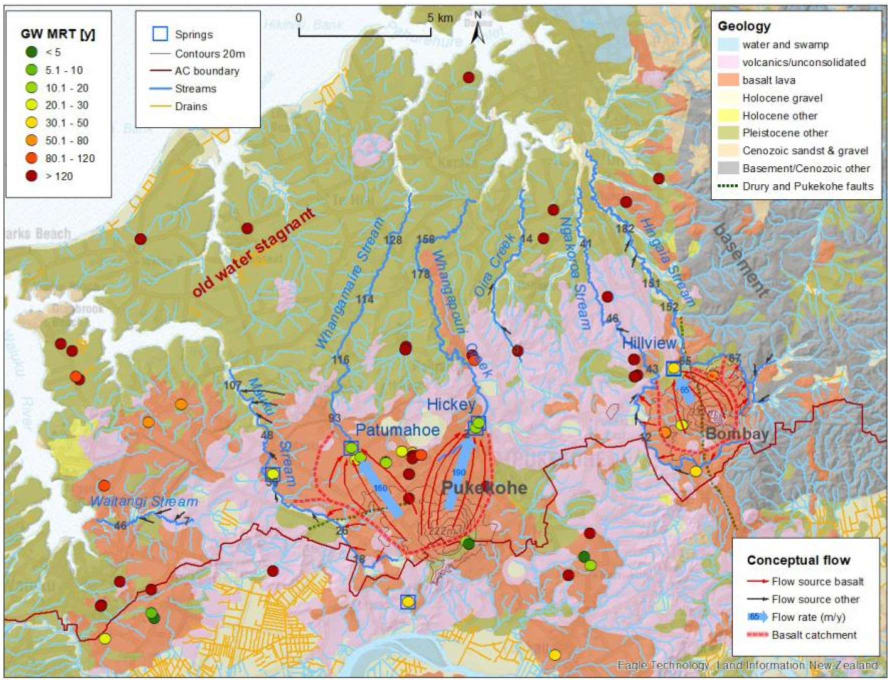

Figure 1: Groundwater dynamics and conceptual flow in the Pukekohe–Bombay area inferred from groundwater ages (MRT, circles) in conjunction with stable isotope and nitrate data (not shown). Active groundwater flow systems are shown in red arrows, flow rates are indicated by blue arrows of length proportional to flow rate, flow rates (in m/y) are shown in blue text. Dashed red lines indicate approximate underground catchment boundaries. Black arrows indicate baseflow water contribution to streams from sources other than basalt lavas. Numbers superimposed on streams are measured baseflow rates in L/s.

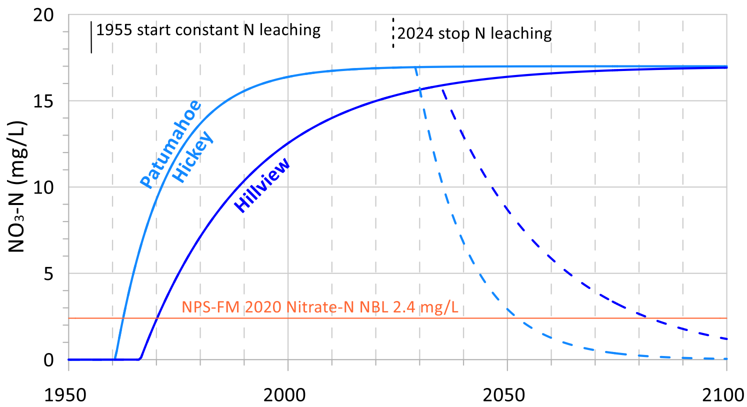

Figure 2. Response of nitrate concentrations for the main spring discharges from the Pukekohe and Bombay basalt lavas to the land-use scenario of start of constant nitrate loading at 1955 (full lines), followed by a theoretical discontinuation of nitrate loading in 2024 (dashed lines). Patumahoe and Hickey springs (MTT = 18 years) drain the Pukekohe basalt lava, and Hillview Spring (MTT = 36 years) drains the Bombay basalt lava.

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LEARNING MORE ABOUT RUAMĀHANGA VALLEY AQUIFERS – AERIAL ELECTROMAGNETIC PROJECT (SKYTEM): OVERVIEW AND UPDATE

Kellett, R.,[1] Morris, R.,[2] Kirkby, A.,[1] Keats, B.,[1] Rawlinson, Z.,[1] Reeves, R.,[1] Geden, B.,[2]Annear, L.,[2] Thompson, M.,[2] Gyopari, M.[2]

[1] GNS Science

[2] Greater Wellington

The Ruamāhanga (Wairarapa) Aerial Hydrogeological Survey is a two-year project (January 2023 – December 2025) that is jointly funded by Kānoa (Regional Economic Development & Investment Unit), Greater Wellington (GW), Masterton District Council, Carterton District Council, and South Wairarapa District Council. The central part of the project is the Airborne Electromagnetic (SkyTEM) survey and follow-on hydrogeological mapping and interpretation.

After a 2-year delay due to Covid-19 and border closures, SkyTEM Australia completed the Airborne Electromagnetic (AEM) survey of the Ruamāhanga river valley using the SkyTEM 312 system. The SkyTEM survey was flown to deliver data that will contribute to improved knowledge and understanding of Wairarapa's critical groundwater systems. The flying commenced on 28th January 2023 and was completed on 2nd March 2023. A total of 5653 kilometres of geophysical survey were flown in blocks from Lake Onoke to north of Masterton. The blocks varied in size, line spacing, and line orientation dependant on the geological trends and the available budget.

Processing of the AEM data is underway and the associated borehole and surface geophysical data are being gathered to form a common database. An overview of the project and an update will be provided on progress to-date, including the survey design and objectives, the successful community engagement approach taken, areas covered, preliminary datasets, and the advanced data processing and inversion being undertaken.

CLIMATE CHANGE, GLOBAL WATER CYCLE SHIFTS, AND LOCAL GROUNDWATER PROJECTIONS IN AOTEAROA NEW ZEALAND

Mourot F. [1]**, Westerhoff R.** [1]**, Cox S.C.** [2]**, Chambers L.**[3]
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[2] GNS Science, Dunedin, New Zealand
[3] GNS Science, Lower Hutt, New Zealand

Groundwater plays a significant role in supporting the health and well-being of communities and the environment worldwide. However, this resource is often overlooked and mismanaged. The United Nations released its first annual World Water Development Report in 2022, primarily focused on groundwater, with the aim of making this invisible resource visible.
Climate change and associated projected shifts in the water cycle, coupled with anthropogenic impacts, are placing groundwater under increasing stress due to the intensification of the water cycle, rising sea levels, and population growth. Gaining a deeper understanding of these impacts has never been more crucial.
This presentation has a dual focus. First, it provides an overview of the broader landscape by summarising the projected changes in the global water cycle, as outlined in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment report from 2021. Subsequently, it narrows its scope to the local context of Aotearoa New Zealand, delving into groundwater projections derived from ongoing research at GNS Science. This research primarily centers on the projected alterations in rainfall recharge to groundwater and the potential impacts of sea-level rise on a city built on a shallow coastal aquifer.
Recognising the inherent uncertainties in hydrological projections, the presentation also offers insights into a methodology for communicating these uncertainties, facilitating better informed decision-making. The overarching goal of this presentation is to underscore the critical significance of groundwater within the context of climate change, offering scientific perspectives that can aid in risk assessment, resource planning, and policy development.

CHALLENGES FOR MANAGING EFFECTS FROM BELOW GROUND LEVEL CONSTRUCTION PROJECTS IN AUCKLAND.

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Since the 1990's some of New Zealand's tallest buildings, and biggest infrastructure projects have taken place in the Auckland Central Business District. These have included the Sky Tower, Britomart Transport Centre, Waterview Tunnel, and the Central Rail Loop (work in progress). Running in parallel has been in-fill housing, accelerated recently by more permissive planning rules that allow replacement of single dwellings with multiple multi-story units. What these projects have in common is below ground elements, the construction of which has potential to cause ground settlement that damages adjacent buildings and structures.

Auckland Council has developed it's Unitary Plan (Operative in Part; AUP(OIP)) to address this issue, through inclusion of objectives policies and effects-based rules. These same rules are applied to all scales and types of activity that requires dewatering of the ground. The current permitted standards are simple to interpret but conservative, in order to put construction activity through a process that evaluates its potential to cause off-site damage; and where appropriate applies monitoring requirements and contingency actions that adequately mitigates any residual risk.

The rules that trigger a proposal requiring a groundwater dewatering and diversion consent include the duration of the water take, groundwater drawdown at the site boundary, and the depth of excavation in relation to the distance to any adjacent building or substantive structure. An application must demonstrate the effects from ground settlement of a proposal on these existing buildings, structures and services. As monitoring doesn't distinguish between dewatering and retaining wall deflection related ground settlement, both components form part of the assessment of a proposal.

The challenge that this presents to both developer and regulator is to implement a process that strikes an appropriate balance between the conservative and pragmatic; resulting in an outcome that adequately mitigates risk, while avoiding unnecessary time and expense.

SUBTERRANEAN ECOSYSTEM ECOHYDROLOGICAL RESPONSE TO INDUCED GROUNDWATER DRAWDOWN IN AN ALLUVIAL AQUIFER.

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Globally, approximately half the water required for irrigation is derived from groundwater sources, much of which is drawn from shallow alluvial aquifers. This is particularly the case in arid and semi-arid environments in Australia, where groundwater supports both rural communities and agricultural production. Over abstraction of groundwaters resulting in aquifer drawdown is a common occurrence world-wide, with impacts on the quality and availability of water in these systems documented. However, the impacts of drawdown on subterranean ecosystems, their functions and biota are relatively unknown.

As prokaryotic communities are largely responsible for biogeochemical cycling within aquifers, understanding their responses to aquifer drawdown and subsequent impacts on water quality are essential for assessing the sustainability of groundwater abstraction. The aim of this study was to understand the impacts of groundwater drawdown on aquifer microbial communities. The study was conducted on the alluvial floodplain of the Namoi River catchment. A decline in groundwater levels was induced by pumping 0.5 ML/day continuously over 28 days. Environmental DNA and water quality samples were taken from 12 monitoring bores (and the extraction well) prior to abstraction, every 2-3 days during abstraction and once a month for three months post-abstraction to monitor aquifer recovery. The aquifer hydrology was additionally impacted by several flooding events over the project duration which influenced the results. The prokaryotic and water quality trends reveal dynamic patterns of surface water-groundwater connectivity and rapid responses to the influx of surface water to the aquifer. Although the experiment did not induce the drawdown response expected, valuable insight into how prokaryotic and aquifer chemistry are impacted by recharge events was gained.

UNCERTAINTY IN PREDICTIONS OF FLOOD INUNDATION CAUSED BY BATHYMETRY ESTIMATION

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River bathymetry plays a critical role in accurate flood modelling. However, bathymetric data are not always available due to the time-intensive and expensive nature of its acquisition. It is often necessary, therefore, to estimate riverbed bathymetry, with several conceptual models and interpolation algorithms and approaches available. This introduces implicit uncertainties that will influence directly the river flow discharge, and in turn will impact the predicted flood depths in the floodplain. Here, we assess the impact of this estimation on flood model predictions for 2005 flood event at the Waikanae River area, New Zealand.

We investigated the sensitivity of flood model predictions to uncertainties in two bathymetric estimation approaches: the uniform flow (Manning's) and the conceptual multivariate regression formulas. We used a Monte Carlo framework to vary channel width, topographic slope and discharge (estimated from LiDAR) by both approaches to produce multiple model grids with different realisations of estimated riverbed bathymetry but otherwise the same topography. The uncertainty in these parameters was accounted for by adding random values from normal distributions of their expected errors (10% of their best estimates). For each parameter, 50 model realizations of the riverbed bathymetry were generated, with additional 50 grids which varied all parameters. Each of these grids was then used in the hydrodynamic model LISFLOOD-FP to generate flood predictions to assess their variability and sensitivity.

The results show that when random parameters values are applied to the uniform flow formula, the uncertainty in flood depths and flooded areas is higher than when they are applied to the conceptual multivariate regression formula. The highest variability is found when all of the parameters are changed at once, whereas varying the channel slope values produces the lowest variability. The findings demonstrate that flood model predictions are sensitive to the parameters used to estimate river bathymetry.

IS THERE A PLACE FOR GENERATIVE AI IN PROBABILISTIC SIMULATION OF CONTAMINANT TRANSPORT IN GROUNDWATER?

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Groundwater contamination is a major environmental concern with far-reaching consequences for human health and ecological balance. Predicting and understanding contaminant transport in groundwater is crucial for developing effective remediation strategies and protecting water resources. In previous decades, risk-based decision-making relied on high-resolution dynamic simulation models compatible with complex geological structures and accounting for structural, parameter, and physical process uncertainties. Therefore, these models are very computationally expensive and time-consuming, while new data are not often assimilated. In addition, traditional simulation models necessitate a high level of expertise for development, maintenance, and execution.

Recent advances in Deep Learning research have made significant progress in the ability of neural networks to autonomically obtain problem-relevant features and capture complex data relationships. Despite these advantages and the abundance of non-deep groundwater applications, Deep Learning adoption in groundwater hydrology has so far been limited. In this presentation, we explore the viability of novel generative AI models for the simulation of solute transport in heterogeneous alluvial aquifers.

We propose a comprehensive, more efficient Deep Learning based approach that links conceptual geological representations, conditioning data, and field measurements to probabilistic space-time distributions of model states. Specifically, our Image-to-Image models aim to identify cross-domain mappings between the pairings of the heterogeneous hydraulic conductivity field and plume propagation, with the ability to integrate physical conditioning parameters. Our models perform with high accuracy and computational efficiency in predicting both the temporal and spatial development patterns of the plume propagation, as compared to the initial data obtained from a high-resolution dynamic simulation model.

A COLLABORATIVE APPROACH TO POLICY, PLANNING AND MANAGEMENT IS IMPROVING OUTCOMES IN THE GREAT ARTESIAN BASIN

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The Great Artesian Basin (GAB) is Australia's largest groundwater resource, providing water to over 120 communities across arid areas of inland Australia. Like many of Australia's natural resources, the GAB faces many challenges. New, rapidly evolving industries now compete with traditional pastoral and agricultural users for a share of GAB water.

The GAB underlies parts of Queensland, New South Wales, South Australia, and the Northern Territory with each of the four Basin governments having responsibility for managing and protecting the water resources in accordance with their regulatory instruments. Approaches to management and governance of the GAB are continually reviewed and adapted to support sustainable use.

Early settlers began drilling bores into the basin in the late 1800s, and by the 1960s there were thousands of free-flowing bores, leading to a significant reduction in groundwater pressure. In response, the Australian and Basin governments jointly prepared the GAB Strategic Management Plan, and undertook a cross-jurisdictional, basin-wide approach to bore rehabilitation. This collaboration continues through the implementation of the current GAB Strategic Management Plan 2019-2034, in conjunction with the GAB Stakeholder Advisory Committee, communities and industry.

As part of their commitment to continual improvement, the Australian and Basin governments have undertaken the GAB Programs Review, published in 2023. This Review highlights the success of the jointly funded, past programs in improving efficient water use, educating water users, and implementing compliance programs. From 1999 to 2023, over 820 bores have been rehabilitated across the GAB, which has delivered estimated water savings of 269,000 ML/y.

Activities currently underway include the preparation of a Basin-wide condition report to be published in 2024. The Australian and Basin governments are using the updated information to consider the current needs of the basin which include options to manage the remaining free-flowing bores across the Basin.

GROUNDWATER CONTRIBUTIONS TO STREAMFLOW IN NEW ZEALAND: A BACH METHOD STUDY

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Groundwater and surface water systems are highly interconnected. The impacts of groundwater pumping on decreasing stream flows are increasingly receiving global attention. Understanding and incorporating this interconnection into land and water management is crucial to avoid further strain on already stressed freshwater systems.

To enhance our understanding of surface and groundwater connectivity across New Zealand, we employed the Bayesian chemistry-assisted hydrograph separation (BACH) method. We investigated the potential magnitude of the groundwater component of streamflow for 54 catchments throughout New Zealand, utilising streamflow data monitored by the National Institute of Water and Atmospheric Research (NIWA). Our analysis estimates the variation in groundwater contribution to flow under various conditions, ranging from low flow to floods.

The BACH method focuses on identifying three distinct flow paths in the stream catchment: near-surface flow, shallow local groundwater flow, and deeper regional groundwater flow. By analysing monthly water quality and daily streamflow data, the study indicates groundwater flow components are often contributing more than 80% flows, even at high stream flows, for the sites monitored sites.

Further exploration has focused on identifying mappable catchment characteristics that can be used to extrapolate the BACH analyses to unmonitored catchments. This involves identifying factors that may influence the magnitude and fluctuation of groundwater contributions to river flows. Factors explored to date include catchment size, aquifer size, geological features, man-made structures such as dams, as well as phosphorus and nitrogen nutrient fluxes.

The findings from this research provide valuable insights into the role of groundwater in sustaining river flows and offer essential information for water resource management and environmental conservation efforts.

UNCERTAIN PRIORS AND THE NON-CENTERED PARAMETERIZATION APPROACH FOR HISTORY-MATCHING AND PREDICTIVE UNCERTAINTY QUANTIFICATION

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The goal of groundwater modelling for decision support is to quantify predictive uncertainty, which can be performed in several ways ranging from linear analysis to the most complex posterior sampling methods such as Markov Chain Monte Carlo (MCMC). A method with a reasonable compromise between approximately sampling the posterior and minimizing numerical burden is the use of ensemble methods, such as the Iterative Ensemble Smoother (IES), where an approximate posterior on model parameters and therefore on model predictions is obtained from the minimization of data and model mismatch using an ensemble of realizations sampled from the prior. As the prior is generally defined by simple probability density functions with the trusting intention to represent the subsurface geological complexity, it is likely to be wrong and therefore uncertain. However, its uncertainty is rarely accounted for when performing history matching and predictive uncertainty quantification in groundwater modelling, potentially leading to predictive bias and underestimation of predictive uncertainty. In this work, we implemented a variation of the non-centered parameterization method that allows not only to include uncertainty in the prior but to also account for non-stationarity on the prior structure accommodating the potential existence of connected geological features, providing more flexibility to the history-matching process, and reducing the potential for predictive uncertainty underestimation. By using a synthetic and highly non-linear groundwater flow and transport case we tested the history-matching and predictive uncertainty quantification performance of IES compared with several other methods, and we show how the success of the predictive uncertainty estimation can be challenged by the non-linear and non-gaussian nature of the problem. We complement this work with linear analysis to explore the factors influencing predictive bias and predictive uncertainty estimation using ensemble methods.

HOW LONG IS LONG ENOUGH: LONG DURATION RAINFALL EVENTS

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This presentation describes the methods assessed to derive long duration Probable Maximum Precipitation (PMP) events for the Lake Taupo catchment, and their application within a catchment rainfall-runoff model to derive design inflows and levels for Lake Taupō.

Riley Consultants are undertaking floods assessments up to the Probable Maximum Flood (PMF) for Mercury NZ Ltd (electricty generator / retailer) on; the dams on the Waikato Hydro Scheme (WHS), the WHS as a region, and for the Lake Taupo catchment. Previous WHS and Lake Taupō PMF assessments determined the critical duration event was 84-hours. For Lake Taupo this was the longest storm duration assessed. For the WHS, this represented a Cyclone Bola (1988) type storm over the catchment.

New Zealand's existing Probable Maximum Precipitation (PMPNZ, 1992) methodology can be used to derive design hyteographs to 84-hours, and with extension, to 96-hours. However the severest storms assessed by PMPNZ (1992) were 72-hours or less. The PMPNZ Addendum (1994) provides a method to extend PMP estimates beyond 96-hours to 8-days. In effect, it was recognised that for large storage lakes, durations longer than 84-hours were important and that such events were most likely a sequence of storms. The Appendum provides two methods to derive long duration PMP events; 4-day to 8-day durations based on Cyclone Bola, and from an assessment of observed long duration rainfall events.

Temporal patterns based on Cyclone Bola, with a storm duration around 96-hours have most of the rainfall occurring in the back half of the storm. However, 8-day to 12-day hyteographs derived from observed storms, such as the 30 June to 16 July 1998 storm sequence (which generated large floods in parts of the WHS and Lake Taupo), have quite different temporal patterns. Further storms were analysed, and rainfalls maximised (adjusted (up) to represent higher storm dew point temperatures) and compared against the long duration PMP depths.

PROTECTING OUR FRESHWATERS FROM WATERBORNE DISEASES USING NOVEL PATHOGEN SURROGATE TECHNOLOGY

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Contaminated freshwater can harbour many disease-causing pathogens. To improve the management of water quality, there is a strong need to better predict pathogen transport and removal in water systems. By mimicking the physicochemical properties of important waterborne pathogens, synthetic particles can be used to predict water contamination risks in freshwaters and help to design improved water treatment systems and water-supply bore protections to keep our drinking water safe.

We have developed two generations of synthetic pathogen surrogates for water quality applications. The first-generation was based on biomolecule-modifications of commercially available microspheres and nanoparticles to produce surrogates for the pathogens *Cryptosporidium*, rotavirus and adenovirus. The second-generation is based on biomolecule-modifications of microparticles and nanoparticles that we have made from food-grade natural biopolymers to produce surrogates for the pathogens *Legionella*, *Cryptosporidium* and rotavirus.

The surrogates have closely mimicked the physicochemical properties (e.g., size, shape, surface charge, hydrophobicity) of the target pathogens. Experiments conducted have validated surrogates' performance against the actual pathogens in different water systems and porous media; the surrogates displayed the same order of magnitude removal as the target pathogens.

The first-generation *Cryptosporidium* surrogates were used in pilot-scale studies to evaluate the efficacies of protozoan removal by drinking-water filtration systems commonly used in New Zealand under typical operating conditions. These included testing rapid sand filtration systems at a water treatment plant in collaboration with the Invercargill City Council and domestic point-of-use water filters in a domestic plumbing test rig. The experimental findings were incorporated into quantitative microbial risk assessments. Health-risk scenarios were identified and recommendations for improving water treatment performance were communicated to end-users. Our experimental results have also highlighted that turbidity, a key test of water clarity and a proxy for water quality used by water plant operators, may not be a reliable indicator of protozoan removal.

We have demonstrated that the surrogates can be labelled with unique synthetic DNA sequences for tracking purposes. Degradation of the surrogates' DNA was found to mimic pathogen's DNA degradation to some degree. The DNA-tagged surrogates, even at very low concentrations, can be analysed sensitively and rapidly using qPCR. Working with ECAN and Waikato Regional Council, we have validated DNA encapsulated biopolymer particles (as pollution source tracers) in surface water, groundwater and soils, and they were readily trackable in a surface stream for up to 1 km.

Recently, we have advanced our pathogen surrogate technology by producing and testing of a second-generation of surrogates that are more compatible with use in natural water systems. These surrogates, made from food-grade natural biopolymers, can be applied in operational water treatment systems and eco-sensitive freshwater environments. Our preliminary studies suggest that these new pathogen surrogates show great promise as new tools for water applications. We will conduct further validations.

The surrogate technology approach has opened a new avenue for assessing pathogen removal and transport in water systems without the risk and expense that accompany work with actual pathogens. The research findings will facilitate improved management systems and engineering approaches to reduce waterborne infection risks and safeguard public health in Aotearoa New Zealand and around the world.

ASSESSMENT OF A CATCHMENT'S FLOW CHARACTERISTICS USING READILY AVAILABLE GIS DATA ACROSS NEW ZEALAND

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[1] Lincoln Agritech Ltd

Aims

Near-surface flow (NS), shallow groundwater (SGW), and deep groundwater (DGW) contribute to the stream flow of a catchment. These three flow paths are of great interest because they traverse different subsurface environments and often result in different patterns of contaminant transport and reactions. For example, TP concentration is often elevated in near-surface flow due to particulate phosphorus transport and TN concentration is generally lower in deep groundwater due to nitrate reduction. Using the BACH model (Woodward and Stenger, 2018), we can evaluate these flow components. However, while being a parsimonious model, it still requires at least 5 years of continuous flow monitoring and monthly water chemistry data. Alternatively, we can try to estimate the three flow components based on existing geospatial datasets, e.g. covering climatic, topographical, geological, and land use factors. To predict the three flow components of a catchment, we used a wide range of readily available GIS datasets in New Zealand, processed the data to produce derived parameters and modelled the data using machine learning.

Method

To produce derived parameters, we processed Integrated Multi-satellitE Retrievals for GPM (IMERG) for rainfall, Nationally Consistent Hydrogeological Map for groundwater discharge, Depth to Hydrological Basement map for potential aquifer depth, QMAP, SMAP, Landcover, River Environment Classification (REC), and DEM. The total number of derived parameters was 165 and after removing some highly correlated (duplicate) parameters, the final number of parameters was reduced to 109. We chose 47 catchments located in Waikato, Hawke's Bay, and Taranaki, evaluated three flow components using BACH models, cut GIS datasets using catchment boundaries and processed the GIS data to evaluate the 109 derived parameters.

We randomly divided the 47 catchments into 38 training catchments and 9 test catchments (20 % test). For training, we fitted a machine learning model (XGBoost model) using a small subset of 109 derived parameters to the 38 sets of flow fractions (NS, SGW, and DGW) of BACH model outputs. Then, we tested the model on the flow fractions of the 9 test catchments to determine whether it could reproduce the BACH results. Since we used 38 training catchments, the maximum number of parameters (variables) to yield a unique solution is 38. Unfortunately, when we tried a large parameter set (over 10), the sensitivity of the model was significantly reduced, and it resulted in a poor fitting. To overcome this issue, we reduced the number of the parameter set to 5. If we chose 5 parameters out of 109, the resulting number of combinations would be 117 million. We randomly chose 1 million models, modelled each with 38 randomly selected training catchments and tested the model with the remaining 9 catchments.

Results

The results showed that most models were weak, performing only slightly better than random guessing. This indicates that the majority of parameters did not control the flow characteristics. Out of the million models, we selected 150 models with the highest sensitivity. Their ensemble average showed a distinct correlation between the modelled flow fractions and BACH flow fractions (Fig 1). However, we could not achieve a 1:1 relationship. The low slopes (sensitivity) indicated that the derived GIS parameters could only partially explain the BACH modelled flow fractions of the 47 catchments. The modelled deep groundwater flow showed the highest slope, indicating that the GIS parameters explained a significant portion of the BACH flow fraction. On the other hand, the near-surface flow fraction showed the lowest slope. This result was unexpected because earlier analysis suggested that the most readily available GIS datasets, such as rainfall, surface topography, drainage density, etc., were closely related to near-surface flow and that near-surface flow would be the easiest to model. However, our model suggested that the current model would best explain the flow fractions of deep groundwater. The correlation of the fitted equation also showed the same pattern, with deep groundwater having the highest r^2. To achieve a 1:1

relationship, we scaled the machine learning results from the intersection of the fitted line and the 1:1 line (Fig 1). The scaled model showed a reasonably good 1:1 relationship (Fig 2).

We found that maximum elevation (a weakly positive correlation with fast flow fractions), SMAP deep soil (negative), and QMAP ignimbrite (strongly negative) contributed to the predictions of near-surface flow. For shallow groundwater flow, SMAP sandy soil texture (negative), REC valley landform medium grade (negative), and maximum depth to hydrological basement (positive) contributed to it. For deep groundwater flow, rainfall coefficient of variation (negative), REC climate cold and wet (positive), and SMAP sandy soil texture (positive) contributed to it. As we used readily available NZ-wide GIS datasets, we can generate derived parameters for any NZ catchments, feed these parameters to our fitted model, and evaluate three flow fractions. At the conference, we will present and discuss the modelled flow fractions of near-surface flow, shallow groundwater, and deep groundwater for 940 New Zealand catchments over 20 km^2 in size.

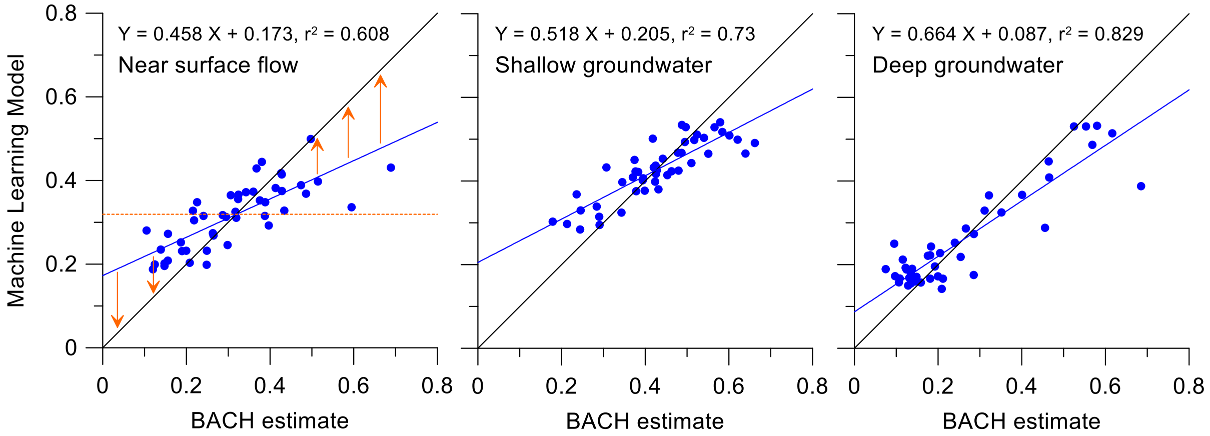

Fig 1: The ensemble model (XGBoost) consists of 150 mini-models estimating flow fractions using GIS data. The fitted regression lines of machine learning results on BACH estimate are shown in blue. The slope represents the sensitivity of the model.

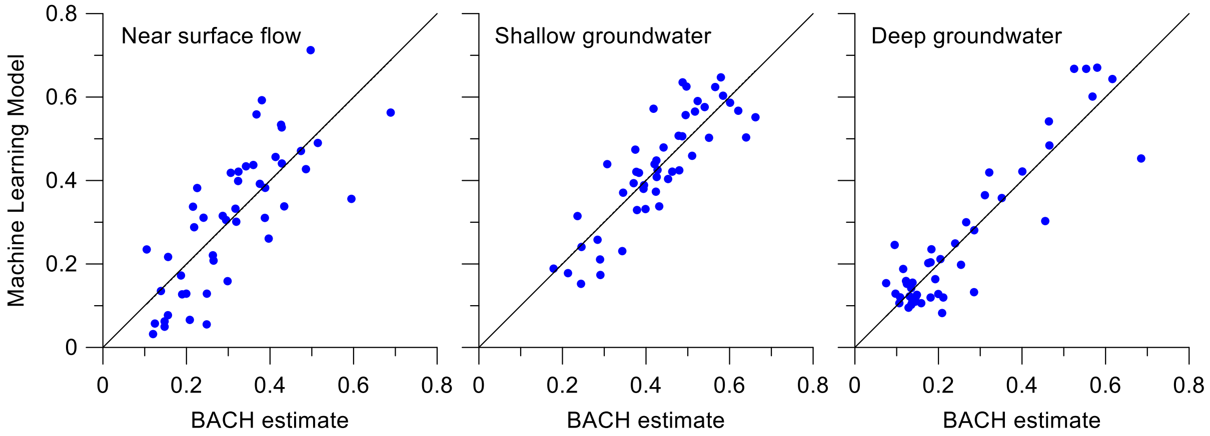

Fig 2: The scaled ensemble model.

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NUMERICAL SIMULATION OF FLOOD AND SEEPAGE THROUGH STOPBANKS

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A common task in the design and/or upgrading of flood protection embankments, such as stopbanks or levees, is the assessment of saturation during a flood event, the quantification of seepage, and the changes in saturation and water pressures during and immediately after the recession of the floodwaters. This can become quite complicated, as these embankments are constructed over different soils with variable material and hydraulic parameters, often composed of diverse construction materials. The authors have developed a methodology that incorporates geophysical multichannel surface wave surveys, which are calibrated and coupled with intrusive site investigations, laboratory data, LiDAR surveying, and walk-over inspections. Subsequently, a three-dimensional model is created to represent the stratigraphy of critical cross-sections. These models are then input into a two-dimensional finite difference stress-strain numerical model capable of fluid-mechanical calculations. The constitutive models used incorporate material properties based on in situ and laboratory testing, as well as interpretations of geophysical records and local geology. The outputs of the numerical analyses encompass the distribution of stresses, strains, seepage, pore pressures, saturation, and stability during flood and drawdown events. To accommodate the variability in fluid and mechanical properties and parameters of natural materials, a probabilistic code is developed. This code introduces a plausible range for each property in every soil/material layer. Changes in saturation, pore pressures, and seepage are monitored and coupled with assessments of deformations and the stability of the stopbanks.

COMPARISON OF RECHARGE ESTIMATION METHODS IN THE SOUTH EAST OF SOUTH AUSTRALIA

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An integral part of the groundwater balance, recharge estimation is notoriously difficult and uncertain given the difficulty to directly measure it. In this work we explored recharge estimation and its uncertainty in the Lower Limestone Coast region located in the south east of South Australia. The study area is of particular interest as rainfed forestry requires a water licence and is subject to water allocations. For recharge estimation we considered both point-based at various well locations and gridded estimates of recharge over the study area at 50 m x 50 m resolution. We applied the following approaches to estimate recharge: water table fluctuation (WTF), chloride mass balance (CMB), water balance (WB), and time-series analysis (TS). These recharge estimation methods are not all directly comparable as some estimate net recharge and others gross recharge. We applied the WTF method in its common form with intra-annual fluctuations (gross) and also considered a variation with inter-annual fluctuations (net), both of which are based on groundwater head and specific yield data. We used gridded rainfall and actual evapotranspiration products to apply the WB approach (net). The use of a gridded chloride deposition product and well chloride concentrations allowed for application of the CMB approach (gross). Finally we applied transfer function noise time-series (TS) models to model the groundwater head and recharge (net) based on time-series of rainfall and potential evapotranspiration. Application of the different methods showed signifcant variability in both the net and gross recharge estimates and each of the methods were accompanied by large uncertainties. We conclude that no particular method is superior but stress that each method warrants communcation of its limitations and uncertainty when applied to water resource management.

SOURCES OF METHANE AND GROUNDWATER IN AQUIFERS OVER A COAL SEAM GAS RESERVOIR

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Aims
An understanding of the migration or leakage of gases and groundwater inter-aquifer connectivity over gas reservoirs is important for environmental protection and social licence. The Surat Basin is part of the Great Artesian Basin (GAB) in Australia, that is the largest artesian groundwater system in the world. The overlying Condamine Alluvium is the head of the Murray Darling Basin, and an important farming region. Groundwater is extracted from these aquifers for town water or private supply, livestock, agriculture, energy production and mines.

Methane may be present naturally in an aquifer from the action of microbes (microbial or biogenic gas). Thermogenic methane can alternatively migrate in for example up fault from depth where it was generated by heat, or biogenic methane may migrate from nearby gas reservoirs if leakage pathways are present. Coal seam gas (CSG) and production water are extracted from coal seams in the Walloons Subgroup reservoir in the Surat Basin, this CSG is microbially produced gas (Baublys et al., 2021). This study aims to understand the sources of gas in the aquifers overlying the CSG region, and identify any inter aquifer or aquifer-reservoir connectivity.

Methods
Groundwater and dissolved gas was sampled from water bores in GAB aquifers, the Condamine Alluvium, and from CSG production waters in the Surat and Clarence-Moreton basins, Queensland, Australia. In addition river and raintank water was sampled from the region. Stable isotopes of gases, water, DIC and sulphate were performed at the University of Queensland (UQ) Stable Isotope Laboratory. Metal concentrations and $^{87}Sr/^{86}Sr$ were analysed in the UQ Environmental Geochemistry laboratory, and Radiogenic isotope laboratory respectively. Tritium, ^{36}Cl and ^{14}C were measured at ANSTO. Gas concentrations were analysed at ALS Environmental and Stratum Reservoir Isotech laboratory.

Results
Dissolved methane concentrations (up to 2100 mg/L) had an inverse trend with sulphate concentration; and no trend with Cl concentrations, indicating upwelling saline water was not a likely methane source. Stable isotopes indicated the majority of methane in water bores was generated in situ by primary microbial CO_2 reduction. A gassy Springbok bore however had overlapping signatures with CSG. Samples from the CSG reservoir and a gassy Springbok bore had enriched ^{13}C-DIC, $^{87}Sr/^{86}Sr$ signatures of 0.07034 to 0.07036 (Figure 1), depleted $\delta^{18}O$-H_2O (Figure 2), and relatively high B and Li concentrations. The Condamine Alluvium, river and rain samples have more radiogenic $^{87}Sr/^{86}Sr$ than the CSG reservoir, low Li concentrations, enriched $\delta^{18}O$-H_2O, with CO_2 but low to no methane content. Groundwaters from the Mooga, Orallo, Gubberamunda and shallow Walloons water bores also had more radiogenic $^{87}Sr/^{86}Sr$ than CSG waters (Figure 1). Deep Precipice aquifer samples are characterised by high Li concentrations and radiogenic $^{87}Sr/^{86}Sr$. Bacterial sulphate reduction is occurring in the low salinity Gubberamunda bores located close to recharge, with low dissolved methane concentrations associated with acetoclastic methanogenesis. However, dissolved sulphate is likely sourced from evaporites in the Condamine Alluvium and Marburg aquifer. Cosmogenic isotopes and tritium indicate mixing of long residence time and younger waters in shallow Walloons water bores (supported by water stable isotopes) and in a shallow Springbok bore. The Condamine Alluvium groundwaters have short residence time (younger) waters consistent with recent recharge, as do the Marburg bores. The CSG reservoir and gassy Springbok water bore have the longest residence time waters, consistent with previous work (Baublys et al., 2021). Of 12 additional Springbok bores recently sampled, 6 also have overlapping gas stable isotope signatures with the CSG reservoir. The Springbok contains coal, and this could generate the biogenic methane within the aquifer. However, the boundary between the Springbok and Walloons Subgroup can be transitional as well as erosional. Differences in identifying this boundary using geophysical methods mean that different stakeholders may pick the boundary at different depths resulting in CSG wells completed into the Springbok. Analyses are ongoing to understand gas sources in the Springbok. The results are consistent with generation of methane *in situ* in the shallower aquifers (Gubberamunda, Orallo, Mooga) and the Condamine Alluvium bores sampled in this study (not CSG leakage). The lack of evidence for CSG leakage in these Condamine Alluvium bores is different to the results of studies on agricultural bores to the southeast. Further work is suggested to incorporate further lines of evidence such as microbial characterisation, noble gases, methane clumped isotopes; and to concentrate further on the Condamine

Alluvium, Walloons water bores, and Hutton Sandstone aquifers predicted to be impacted by water drawdown in the future that may release further gas.

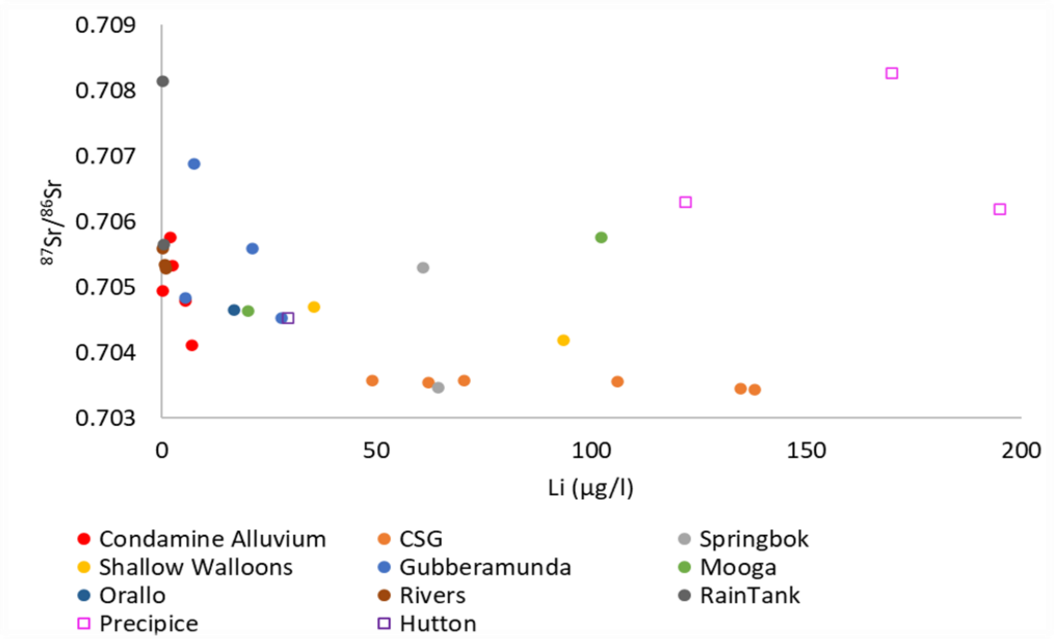

Figure 1: Groundwater, CSG production water, river and rain water $^{87}Sr/^{86}Sr$ signatures vs Li concentration.

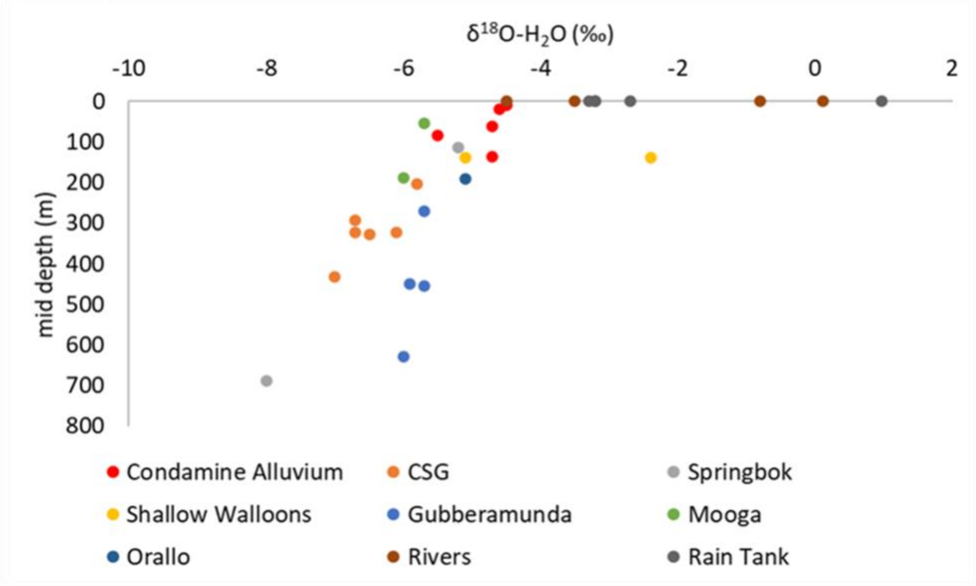

Figure 2: Groundwater, CSG production water, river and rain water $\delta^{18}O-H_2O$ with depth.

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AN ALGORITHMIC APPROACH FOR TAILORING SPATIAL DETAIL OF NATIONAL-SCALE RIVER NETWORKS FOR SPECIFIC APPLICATIONS

Rose Pearson[1], Doug Booker [1]
[1] National Institute of Water and Atmospheric Research, Christchuch.

Aims

Digital river networks (DRNs) are commonly produced for hydrological modelling purposes but are also used in other applications such as water quality modelling, species distribution modelling, river classification mapping, and defining freshwater management units. The first national-scale DRN of Aotearoa-New Zealand was produced around 25 years ago in conjunction with development of the River Environment Classification (REC) system described by Snelder and Biggs (2002). The availability of more detailed sources of topographical data has led to improved river alignment and increased representation of network detail within recent DRNs. The latest DRNs therefore tend to include more detailed spatial representation of overland flow paths and ephemeral channels compared to earlier DRNs.

Different applications for DRNs require different levels of detail within their representation of river channels and flow paths. For instance, physically based flood hydrography modelling often requires detailed spatial representation of ephemeral overland-flow pathways, while ephemeral flow paths are generally unhelpful for large-scale species distribution modelling or representation of freshwater management units.

We present a flexible, repeatable, and automated approach for reducing the spatial complexity represented by a DRN, whilst retaining the network alignment and routing. The approach involves the removal of selected segments from the more detailed DRN until its overall characteristics match those from another less detailed DRN. The aim of this approach is to allow the adaption of newer more detailed DRNs for applications requiring reduced network detail in terms of number and configuration of segments that comprise a DRN. We demonstrate how this approach can be applied to reduce the detail in a fine-detailed DRN (e.g., NIWA's latest DN3) to match the characteristics of a coarse-detailed DRN (e.g., NIWA's DN2). We then consider the impact of reducing network detail has on maps of REC classes mapped onto the network. Maps of REC classes are used in the National Objectives Framework (NOF) of the National Policy Statement for Freshwater Management (NPS-FM).

Methods

We have developed an algorithm for iteratively pruning a source network until it more closely matches the characteristics of a target network (Figure 1). The algorithm allows the user to specify both the pruning strategies to apply and the comparison criteria to consider when checking if the characteristics of the source network have converged with those of the target network. This approach allows the same algorithm to be applied across different applications and networks. Pruning strategies have included alignment and overlap checks of river and catchments between the source and target.

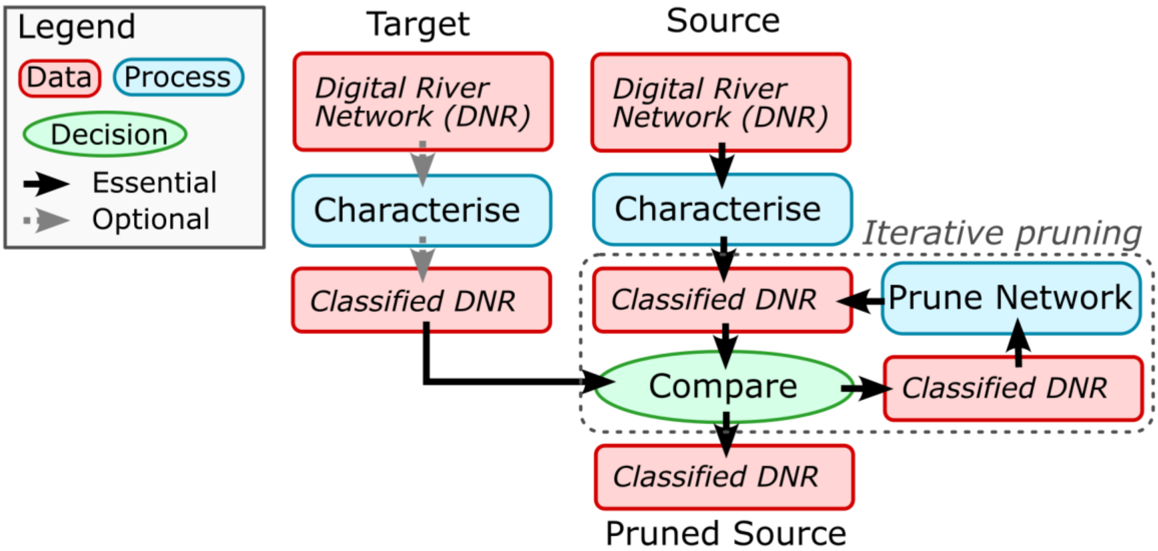

Figure 1: An algorithm for pruning a source network until it matches the characteristics of a target network.

Results

We apply this approach across a range of catchments and regions in Aotearoa New Zealand to robustly consider the effectiveness of technique across a range of network detail. Initial results indicate that a more detailed source network can be pruned to better match some general characteristics of a less detailed target network while maintaining the routing and alignment of the detailed network (Figure 2). In our talk, we will demonstrate the utility of the developed algorithm by comparing maps of REC classes calculated for a detailed source network against those calculated for the pruned source network, and the target network.

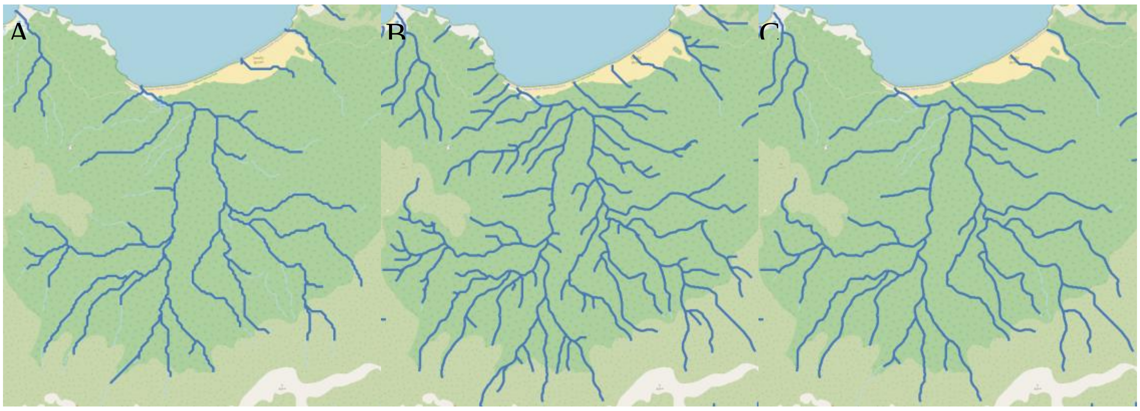

Figure 2: An illustration of the algorithm's ability to prune a source network to represent a target network more closely at Smokey Beach in Northern Raikora. A. NIWA's DN2, B. NIWA's DN3, C. NIWA's DN3 after iterative pruning to more closely resemble NIWA's DN2.

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Biography

Rose is a remote sensing scientist at the National Institute of Water and Atmosphere and a visiting researcher at the Geospatial research institute. Her work primarily focuses on developing tools and processes for manipulating geospatial data and products for modelling applications.

AUTOMATED GENERATION OF ROUGHNESS LENGTHS FROM LIDAR FOR NATIONAL-SCALE HYDRODYNAMIC MODELLING.

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[1] National Institute of Weather and Atmosphere
[2] The Geospatial Research Institute at the University of Canterbury

Aims

We present an approach for estimating roughness length from LiDAR point cloud data and other geospatial information. Accurate roughness maps are important for accurate flood modelling, and incorporating the information included within LiDAR point cloud data allows us to improve upon roughness maps generated from less detailed data sources. We focus on roughness length as this provides a measure of hydraulic drag which is more independent of water depth than Manning's n coefficient and that can be related to the vertical distribution of observed LiDAR points. This work has been undertaken as part of the Mā te haumaru ō te wai: Flood resilience Aotearoa Endeavour project.

We began our consideration of estimating hydraulic roughness from LiDAR by implementing the theoretically grounded approach proposed by Mewis (2021) based on the Beer-Lambert law. However, after finding this approach did not work well on our much less dense data, we developed the empirical approach presented here. In our talk we discuss these differences in more detail. Our approach is integrated within GeoFabrics: an open-source Python framework and tool for simplifying and automating the process of producing hydrologically conditioning DEMs and roughness maps for flood modelling. We show that by integrating the hydrological conditioning and roughness length estimation processes, we can ensure the same alignment, resolution and assumptions are shared between the DEM and roughness map.

Methods

A series of expert derived roughness length maps were used to develop an empirical relationship between the vertical distribution of a LiDAR point cloud within a particular grid cell and the roughness length at that location. Specifically, our empirical relationship relates the mean height and standard deviation of all LiDAR points within the grid cell to the roughness length of the grid cell. The mean height is defined as the difference between the mean elevation of the grid cell LiDAR points and the ground elevation at the grid cell as defined by the GeoFabrics generated hydrologically conditioned DEM.

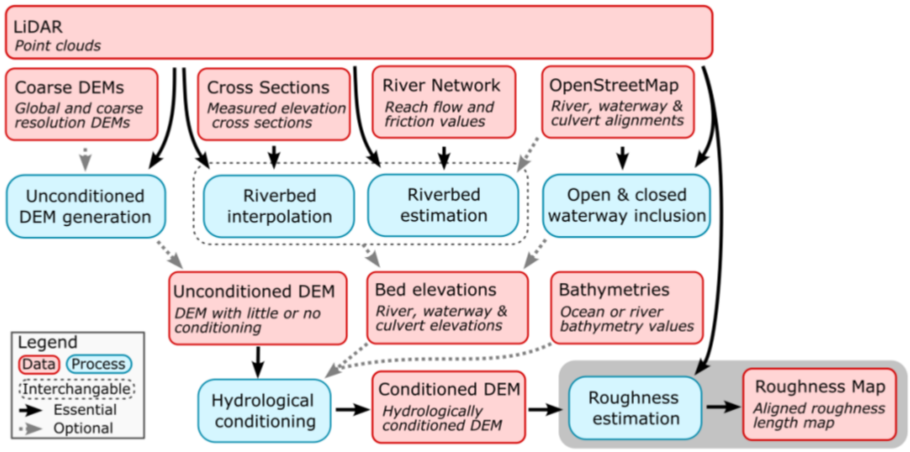

Figure 1: GeoFabrics is a multistage framework for producing hydrologically conditioned DEMs from a range of elevation data. REC stands for river environment classification (Snelder 2002), and OSM stands for Open Street Maps.

This process is applied in the final stage of our GeoFabrics framework (Figure 1) in grid cells where the hydrologically conditioned DEM elevation is measured from LiDAR. In the grid cells where the elevation is estimated from other sources (e.g. ocean bathymetry contours, riverbed elevations, daylighting waterways and culverts, or a coarse DEM) the GeoFabrics framework allows the user to specify the roughness length using a fixed value depending on the source of the elevation value, or from LiDAR if it is available. This allows a fixed value to be provided for the ocean, while the LiDAR data can still be used to estimate the roughness lengths along vegetated waterways.

Results

This integrated approach to roughness length integration has been applied across a range of catchments in Aotearoa with different catchment characteristics. We focus our discussion on Waikanae (Figure 2) and demonstrate how the integrated approach can be used to produce paired roughness maps and hydrologically conditioned DEMs using the Wellington (2013-2014) LiDAR dataset.

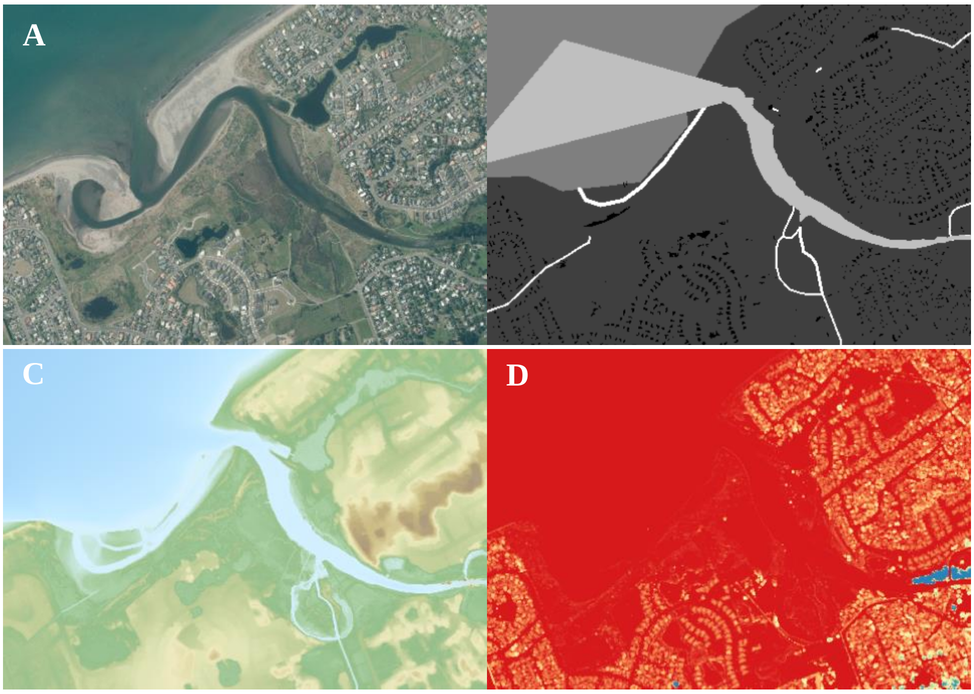

Figure 2: A roughness map and hydrologically conditioned DEM generated from the Wellington (2013-2014) LiDAR survey for the Waikanae River using GeoFabrics. A. Aerial image of the region, B. The data sources, C. The hydrologically conditioned DEM generated, D. The roughness map.

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Biography

Rose is a remote sensing scientist at NIWA and a visiting researcher at the Geospatial research institute. Her work primarily focuses on combining geospatial data, primarily LiDAR point clouds, to produce hydrologically conditioned DEMs and roughness maps for use in river flood modelling. Her research interests centre on surface generation and attribute mapping from a wide array of spatial and geospatial datasets.

WARMING INCREASES DISSOLVED ORGANIC CARBON EXPORT FROM PRISTINE ALPINE SOILS

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[2]University of Waikato.
[3]University of Huddersfield.
[4]University of Melbourne.
[5]GNS Science.
[6]Northumbria University.

Aims

Increases in dissolved organic carbon (DOC) export from soils may alter the global carbon cycle, and impact groundwater and surface water quality (Rae *et al.*, 2001; Cole *et al.*, 2007; Hartland *et al.*, 2012; McDonough *et al.*, 2020). Yet, despite decades of research, the influence of climate on the export of DOC from soil remains poorly constrained because contemporary monitoring data covers a period of ongoing climate reorganisation and confounding anthropogenic activities.

Our aim was to assess the long-term influence of climate on DOC export using palaeo-environmental archives, such as speleothems (i.e., cave carbonates) and lake sediments, which reliably record DOC during their accumulation. In Aotearoa New Zealand, these palaeo-archives extend beyond human arrival, therefore the long-term relationship between climate and DOC trends can be assessed in the absence of anthropogenic impacts.

Methods

We reconstructed soil DOC leaching over the last ~14,000 years using alpine environmental archives (two speleothems and one lake sediment core) across 4° of latitude from Te Waipounamu/South Island of Aotearoa. Alpine and sub-alpine areas were preferred because of their sensitivity to change; warming rates and landscape response times are amplified at elevation, and thus high-altitude archives represent sentinels of environmental change (Williamson *et al.*, 2009; Pepin *et al.*, 2015).

We applied 3D excitation-emission matrices (EEM) fluorescence (an established technique for DOC monitoring and characterisation (McDonough *et al.*, 2020)) to measure allochthonous DOC concentrations in speleothems, enabling reconstruction of soil DOC export to two underlying caves located at different latitudes on Te Waipounamu/South Island (Hodge Creek, Kahurangi National Park (41°S) and Dave's Cave, Fiordland National Park (45°S)).

Although cave carbonates reliably record aqueous DOC concentrations during mineral precipitation (Pearson *et al.*, 2020), DOC reconstructions from speleothems are rare compared to those from lake sediment archives. As a check on our results, we compared our speleothem-based reconstructions to a sediment-based reconstruction from Adelaide Tarn, an alpine lake ~32 km from Hodge Creek Cave located at a similar altitude.

Results

Our reconstructions of DOC trends at Hodge Creek Cave and Adelaide Tarn are remarkably consistent. Given the proximity and similar altitudes of these sites, the comparable DOC records provide evidence that speleothems (like lake sediments) are reliable DOC archives, and that DOC reconstructions reflect broad, landscape-level change.

At each site, warmer temperatures resulted in increased allochthonous DOC export through the last 14,000 years, most notably during the Holocene Climatic Optimum (HCO) (~11.5–9 kyrs ago) (Marcott *et al.*, 2013), which was some >1.5 °C warmer and had reduced seasonality compared to the late pre-industrial period (McGlone *et al.*, 2011). Following the HCO, soil DOC export declined through the cooler mid-Holocene. Thus, future warming is likely to accelerate DOC export from mountainous catchments, affecting the global carbon cycle, water quality and aquatic ecosystems (McDonough *et al.*, 2020).

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NYRRIMPA SPRING – RESTORING WATER FLOW AFTER 20 YEARS. COLLABORATION BETWEEN YINHAWANGKA TRADITIONAL OWNERS AND RIO TINTO FOR SUSTAINABLE WATER STEWARDSHIP

Paul Hedley,[1] Eva Pellegrini[1], Saeed Torkzaban
[1] Rio Tinto

Near Paraburdoo, one of the oldest mining areas in Western Australia's Pilbara region, one of the rare persistent water features in this semi-arid region has been observed to exhibit reduced spring flow and increasingly long dry periods. Recognizing that groundwater abstraction from two adjacent supply borefields was one of the contributing factors to decreasing groundwater levels in the aquifer supporting this spring, Rio Tinto committed to cease all abstraction in the area.

This process began as a desktop study to investigate inconsistently reported springs based on anecdotal evidence. We sifted through paper archives and incorporated groundwater level data into an electronic database. Two years on, we shared our findings with the Traditional Owners, the Yinhawangka People. Various mitigation options, including managed aquifer recharge, were presented to Yinhawangka. Following discussions, Rio Tinto reduced abstraction rates from the relevant borefields, culminating in a commitment to cease all abstraction in the Turee Creek Valley to allow groundwater level recovery and eventually restore spring flow.

Numerical modelling has suggested that a return to artesian conditions of the deep palaeovalley aquifer will take 2 to 4 years, with full aquifer recovery expected within 75 years. We have collected groundwater observation data since the borefields' shutdown in December 2021. In this presentation we will compare predicted and actual groundwater rebound curves, review the hydrogeological conceptual understanding and discuss recent ecological changes on the spring site. We will also discuss the historical context and the significance of the site to the Yinhawangka as well as the impact of borefield loss on the water supply of Greater Paraburdoo Mine Operations.

THE DETECTION OF PLANT DNA IN ALLUVIAL AQUIFERS

Loren Pollitt,[1] Kathryn Korbel, [1] Grant Hose.[1]
[1] Macquarie University

Groundwater dependent ecosystems (GDEs) rely on the presence and supply of groundwater for ecosystem functioning, provide valuable services for tourism and agriculture as well as limiting erosion and maintaining water and land quality. A major challenge of managing groundwater dependent ecosystems is determining when and where plants are accessing and using groundwater. In arid and semi-arid regions of Australia, groundwater is of particular importance for the local vegetation, as plants are often exposed to extensive dry periods where surface water is scarce. Addressing this knowledge gap is particularly pertinent where remnant stands of old growth trees reside within areas where groundwater is being used at an unsustainable rate. Environmental DNA (eDNA) consists of DNA shed from an organism within its environment and can be extracted from the non-living components of the ecosystem such as the air, water, and soil. eDNA samples collected from groundwater in the alluvial aquifers of the Gwydir, Namoi and Macquarie catchments in the Murray Darling Basin identified the presence of tree species known to access the groundwater. Plant species such as *Eucalyptus camaldulensis, Eucalyptus largiflorens* and *Eucalyptus populnea* were routinely detected in shallow groundwaters close to remnant vegetation. Isotopic analysis in conjunction with the use of eDNA may shed a new light on plant groundwater interactions. While further investigations into the factors influencing the presence of plant DNA in groundwater is needed, eDNA could provide a real time indication of trees accessing and using groundwater thus conclusive evidence of GDE status.

GROUNDWATER EXTENT DELINEATION THROUGH INTEGRATING HYDROLOGICAL MODELLING AND GEOSPATIAL INFORMATION SYSTEM (GIS)

Rasool Porhemmat,[1] Ude Shankar,[1] Christian Zammit,[1] Wes Kitlasten ,[2]
[1] NIWA
[2] GNS Science

Abstract
The delineation of Groundwater Potential Zones (GWPZs) provides crucial insights into the spatial distribution and availability of exploitable groundwater resources. GWPZs are areas identified based on their potential to yield a significant quantity of groundwater. Various methods are employed to delineate these zones, including geospatial techniques, hydrogeological analysis, geophysical methods, groundwater modelling, analytical hierarchy process (AHP), and multi-criteria decision analysis (MCDA).

The present research aims to **a-priori** delineate and assess GWPZs through the integration of hydrological and hydrogeological modelling (MODFLOW- Equilibrium Water Table) and geographic information system (GIS) in New Zealand. The groundwater network is derived from GNS's national groundwater table depth levels and the corresponding hydraulic heads from their MODFLOW 6 model. Using the hydraulic gradient (GW-DEM) we derive the groundwater flow network (flow lines corresponding to the gradient) and groundwater sub-catchments. The groundwater flow within an aquifer can be easily estimated when the water table is considered as a continuous series of pipes or streamlines controlled by hydraulic gradients. Groundwater flows from areas of higher hydraulic head to that of lower hydraulic head. Once the extent of the groundwater aquifers is identified, we compare the extent of the groundwater aquifers with surface water catchments. This will be used to select baseflow contributing surface water catchments.
A toolbox in ArcGIS Pro was developed to trace upstream reaches across surface and groundwater domains and create integrated surface water/groundwater watersheds characteristics draining any location on a digital river network. The resultant watersheds are then used to investigate recharge zones and surface water-groundwater interactions, such as losing and gaining streams.

ANALYSIS OF NEW ZEALAND DAILY WEATHER PATTERNS AND LARGE-SCALE CLIMATIC PATTERNS AS HEAVY RAINFALL DRIVERS

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[2]School of Earth and Environment, University of Canterbury, Christchurch, New Zealand

[3]Departamento Ciencias y Técnicas del Agua y del Medio Ambiente, Universidad de Cantabria, Santander, Spain

[4]National Institute of Water and Atmospheric Research (NIWA), Christchurch, New Zealand

Aims

The overall aim of this research project is the generation of flood inundation maps for a specific study site, namely the Wairewa catchment (Little River, Canterbury) for the benefit of community stakeholders. To this end, accurate analysis and characterization of extreme rainfall is required since this is the main inundation driver. This work aims to study extreme rainfall events that can potentially lead to flooding using synoptic climatological techniques. It builds on previous work in the field (Jiang 2011; Kidson 1997,2000) and proposes a new weather type classification; consisting of 49 Daily Weather Types (DWTs) and with a focus in characterizing heavy rainfall events. This synoptic classification is based on ERA5 reanalysis (Hersbach et al. 2020) daily fields of mean sea level pressure (MLSP) and 500 hPa geopotential height. This combination of predictor variables was introduced in the New Zealand context by Kidson (1997); and has proven successful in different places (Vallorani et al. 2018). The relationship between the DWTs, heavy rainfall and historical flooding events is investigated in the study site; as well as the influence of three large-scale climatic patterns: El Niño Southern Oscillation (ENSO), the Southern Annular Mode (SAM) and the Indian Ocean Dipole (IOD). To accomplish this two rainfall databases are used: a Weather Forecast Research numerical model (WRF) (Skamarock 2008) generated gridded dataset (from 2002 to 2022 with 1 km grid spacing at hourly scale, previously validated against rain gauge records in the North Canterbury area, which proved that WRF performs well reproducing extreme rainfall events statistics); and rain records available (a station with hourly data from 2012 to 2022). This study builds towards the construction of a sample of flooding scenarios for the Wairewa catchment based on the temporal and spatial characteristics of the rainfall extreme events. Selected scenarios from this sample will be modelled through a hydrological model to simulate rainfall–runoff processes (such as HEC-HMS, developed by the US Army Corps of Engineers) and a 2D hydrodynamic model (like LISFLOOD-FP), to obtain the corresponding maximum water depth map. These results will be used to train a machine learning algorithm to produce inundation maps for the remaining events, allowing rapid estimation of flood inundation in the catchment.

Methods

Firstly, the data for both the predictor (MLSP and 500 hPa height) and predictand (rainfall) is downloaded and processed to the required spatial domain (New Zealand region for the predictor and Wairewa catchment for the predictand) and time span (1979-2020 for the predictor and available years for the rainfall data). Then, to obtain the DWTs classification, a combination of three data mining techniques is used: principal component analysis (PCA) to reduce the high dimensionality of the original predictor data space and simplify the classification process; Maximum Dissimilarity Algorithm (MDA) to select a subset of representative points focusing in representing in the best possible way the data extremes; and K-Means clustering algorithm (KMA) initialized by the output from the MDA, to obtain 49 groups. The classification is analysed through the probability of occurrence of the DWTs, their seasonality and their chronology. To explore the relationship between the rainfall extreme events and the synoptic conditions, a sample of storms is built from each rainfall dataset (based on the 95th percentile of the rainy hours) and they are linked to the DWTs; as well as the historical flooding events. The sample of storms based on the rain gauge is used for the study of the storms' temporal characteristics, whereas WRF's storm sample is mainly used to investigate rainfall spatial pattern (e.g., how much each pixel in the catchment contributes to the total rainfall with respect to the mean of the whole catchment). The influence of large-scale climatic patterns influence is explored through three climatic indexes (SOI for ENSO, SAM index, and DMI for IOD) and their relationship with the DWTs and the storms.

Results

The resultant DWTs classification with the predictor variables is shown below (Figure 1). A smooth transition is observed between patterns characterized by high pressure centers and geopotential heights, , which have higher probability and are generally associated with calm weather; to low pressure centers and geopotential heights clusters, which have a lower probability of occurrence and are usually related with troughs, more atmospheric moisture and thus more precipitation. Useful relationships have been found between the DWTs and extreme rainfall events that can potentially lead to flooding. DWTs from the second half of the classification are generally linked with higher heavy rainfall probabilities, as well as greater intensities. However, some patterns that are characterized by anticyclones and high gepotential heights (such as 4 or 5) are also linked to some occurrence of heavy rainfall and flooding, this weather configuration can, under specific circunstances, lead to these events. Regarding storms' features, there is a big variability in storms duration, peak intensity, volume or spatial pattern across the DWTs. Additionally,a strong seasonality has also been found, with the DWTs probabilities varying grealty according to the season. Lastly, there is a relevant signal of the large-scale climatic modes in the DWTs, with their frequency varying according to the phase of the phenomena occurring (negative or positive).

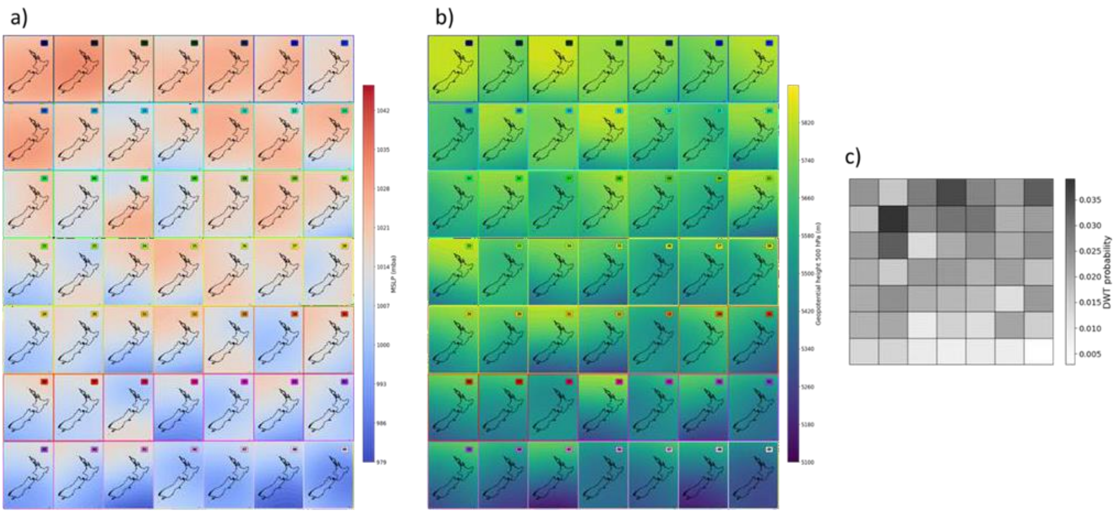

Figure 1: Composite patterns of MSLP (a) and 500 hPa geopotential height (b), and probability of occurrence of each DWT (c)

Acknowledgements

This research is part of the NIWA-led five-year Endeavour Programme 'Mā te haumaru ō ngā puna wai ō Rākaihautū ka ora mō ake tonu: Increasing flood resilience across Aotearoa', supported by the New Zealand Government via the Ministry for Business, Innovation and Employment (MBIE).

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FEASIBILITY OF UNDERGROUND TECHNOLOGIES IN QUEENSLAND, AUSTRALIA

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The National Water Grid Authority (NWGA) is the Australian Government agency responsible for delivering targeted water infrastructure investments that will increase resilience for Australia's existing agriculture and primary industry sectors to drought and climate change and create opportunities for the development of new agriculture and primary industries. In consultation with the Queensland Government, the NWGA through its Science Program is funding further water resource assessments. The Queensland Government's Bulk Water Opportunities Statement (QBWOS) provides a framework for sustainable regional economic development through better use of existing water infrastructure and appropriate investigation into new bulk water infrastructure. QBWOS identified 11 alternative technologies or approaches to augment existing bulk water storage. Together with the NWGA the Queensland Department of Regional Development, Manufacturing and Water (DNRMW) requested Department of Environment and Science (DES) to spatially investigate three of the QBWOS-identified technologies, namely aquifer recharge, sub-surface dams (permanent below-ground structure comprising alluvium) and sand dams (permanent above-ground structure infilled with sand and gravel), collectively known as underground technologies, to understand the constraints and the feasibility for their development in locations across Queensland. Building upon the prefeasibility work completed by DES, GHD completed a more detailed regional-scale feasibility assessment that utilised our proprietary GIS-based MCA methodology (InDeGO) which combined traditional MCA techniques with desktop-based GIS analysis to generate a digital site suitability surface layer using identified key criteria. Within this framework, MCA techniques were used to identify, rate, and weigh the performance criteria guiding the site suitability modelling process. Workshops with key stakeholders identified a range of criteria that identified the potential for developing sand dams and sub-surface dams that offered the best balance between the primary goals including environmental, social, physical and built environment. The outcome of the assessment identified areas across Queensland that provided the greatest potential for establishing underground technologies.

RECHARGE PROCESSES AT A SITE WITH EPISODIC CREEK LOSSES & MINEWATER RELEASES, PILBARA PROVINCE, WA

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Aims

The Study Area is located around 80 km north-north-west of Newman, Pilbara Iron Ore Province, Western Australia, with proposed mining at the Project likely comprising a number of open pits. The Study Area lies above an alluvial fan, which is in turn underlain by channel iron deposits and iron formations and dolomitic bedrock. The ephemeral Weeli Wolli Creek runs through the site, with mines located upstream discharging surplus mine waters into the creek.

Numerous studies have been undertaken to define aquifer recharge processes and rates in the Pilbara region (e.g. Skrzypek *et al.*, 2013; Cook *et al.*, 2017; McCallumm *et al.*, 2017; McFarlane, D., 2015; Skrzypek *et al.*, 2023). More recently, Chmielarski *et al.* (2023) has used a transient deconvolution approach, paired with spatial kriging, to spatially infer groundwater recharge areas across the catchment. It also identified specific times in the last 100 years where storm events appear to have resulted in major recharge inputs.

Given the above background, the following aims were defined:

1. establish an understanding of the relationships between recent storm events and potential creek losses (point recharge inputs),
2. better understand the temporal and spatial contributions of recharge by way of rainfall infiltration (diffuse recharge inputs), and
3. characterise catchment-wide groundwater inflows, using the above, including the potential contributions of upstream mine water releases (if possible).

Method

Multiple assessment tools have been used to address the above study aims, including hydraulic flood modelling of Weeli Wolli Creek, evaluation of temporal changes in groundwater levels and vertical hydraulic gradients during dry periods and recharge estimation based on other, generally accepted methods.

A two-dimensional Tuflow hydraulic (surface water flow) model was developed to simulate flood hydraulics and infiltration losses between two flow gauges on a reach of Weeli Wolli Creek. The model was calibrated to recorded flood events at the gauges and calculate creek leakage into the alluvial bed material. Volumetric transmission losses were then related to the results of the above transient, deconvolution assessment, to estimate point recharge inputs over a significant climate period.

Groundwater level data obtained from 19 No. vibrating wire and open standpipe-type piezometers, which screen an unconfined, alluvial aquifer, were assessed. Temporal changes in groundwater levels and vertical hydraulic gradients during dry periods were assessed to help define the spatial distribution of recharge due to diffuse sources (i.e. rainfall infiltration) and interpret groundwater inputs arising from mine water releases.

The *'water table fluctuations'* and *'chloride mass balance'* methods were used to estimate diffuse recharge rates for specific storm events and define their spatial variability across the catchment.

Using the results of the above assessment methods, a catchment wide evaluation of diffuse versus point sources of recharge was undertaken, with a groundwater balance developed accounting for temporal and spatial variabilities.

Results

The results of the study indicate the following:

1. Discrete recharge due to creek losses, during infrequent flood events, was found to be the most significant contributor to inflows to the shallow, unconfined aquifers in the catchment.
2. Recharge due to creek losses is spatially concentrated in the main creek channel during lower flow rate, more frequent flow events but also occurs across the main creek and related overflow anabranches for the higher rate, less frequent flow events.
3. Diffuse recharge due to rainfall infiltration is a much smaller contributor to inflows to the shallow unconfined aquifers, with rates being around two to three times smaller than creek loss rates.
4. Diffuse recharge rates appear to be slightly higher in the upper catchment area where vegetation denisities and evapotranspiration losses are both lower and higher runoff flows are concentrated.
5. Antecdent moisture conditions do not appear to be a significant factor in controlling recharge occurrence and rates, due to the highly episodic and infrequent nature of rainfall events.
6. Upstream mine water releases are estimated to be a significant component of overall aquifer recharge rates but have significant uncertainty in the groundwater balance.

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EXPLORING THE INFLUENCE OF BIOPHYSICAL AND SOIL PARAMETERS IN FORESTED CATCHMENT MODELLING USING SWAT+

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Aims

Accurate simulation of water balance components provides valuable information for land and water management decisions. The parameterisation of hydrological models is critical to obtain reliable results regarding the water balance. However, the availability and/or determination of these input parameters can be challenging as measurements of these parameters are often scarce. Here the influence of biophysical parameters and soil properties on water balance modelling of forested catchments using the Soil and Water Assessment Tool (SWAT+) is investigated. The study area is a forested subcatchment of the Mohaka catchment (96% *evergreen* forest cover) located in the Hawke's Bay region on the North Island (Figure 1).

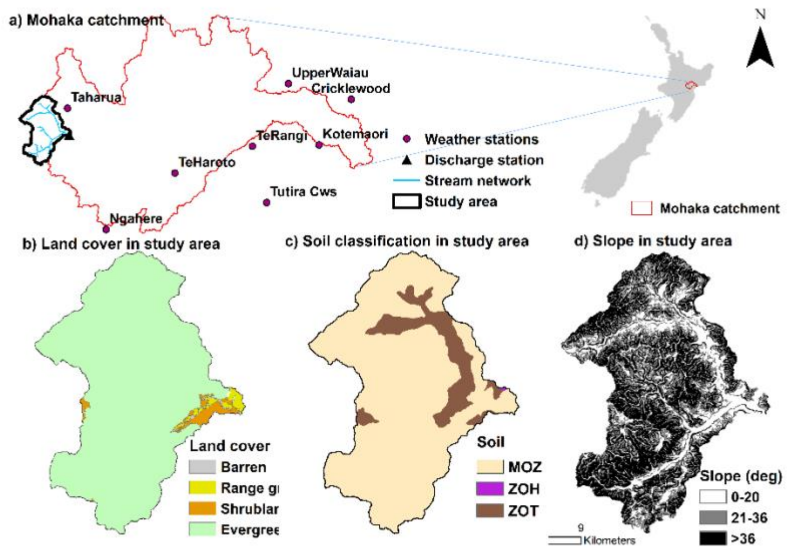

Figure 4: Top: Forested subcatchment study area within the Mohaka catchment showing streamflow network and nearby weather stations; Bottom: (a) land cover map, (b) the soil classification, and (c) the terrain slope.

Method

To estimate the sensitivity of modelling results to biophysical parameters, the SENSitivity ANalysis (SENSAN) program of the PEST suite (Doherty, 2004) was linked to SWAT+. A total number of 35 Hydrologic Response Units (HRUs) were used in model discretisation. The catchment was simulated for a 10-year period (2013-2022). In total 17 parameters related to biophysical plant properties were considered. Parameter ranges for the biophysical parameters were obtained from the literature. The local sensitivity analysis using SENSAN was carried out between the upper and lower bounds of each parameter.

To assess the effect of soil depth on the performance of the model, the depth was altered from the default 1 m to 15 m in 0.5 m increments. Along with different soil depths, two different soil types with different proportions of sand and clay were investigated (Table 1). Three different rainfall scenarios were simulated:1) low rainfall scenario (25% reduction of actual rainfall), 2) actual rainfall scenario (measured rainfall data obtained from NIWA), 3) high rainfall scenario (25% increase of actual rainfall). The resulting water yield, percolation and evapotranspiration were compared.

Table 1: Proportion of soil texture parameters in two different soil classifications used in modelling experiments.

Soil type	Clay (%)	Silt (%)	Sand (%)	Rock (%)
Sandy	0	23	77	2
Clay	60	38	2	2

Results

For the purpose of this study the model was calibrated/validated using discharge-related parameters only, with a Nash-Sutcliffe efficiency of 0.55/0.47 for daily and 0.84/0.76 for monthly time step. The results of the sensitivity analysis revealed that water fluxes within the catchment are significantly altered by several of the parameters studied. The results for the maximum and minimum leaf area index (LAI) are shown in Figure 2. The plausible ranges of parameters are represented on the x axis, and the corresponding water balance component for each of these values is represented on the y-axis. The variations in the initial ranges of the upper and lower bound for maximum and minimum LAI had the largest impacts (27-100%) on water balance components. This links to the higher water uptake of trees during their initial stages of growth when there is intensive competition for sunlight (Vertessy et al., 2001).

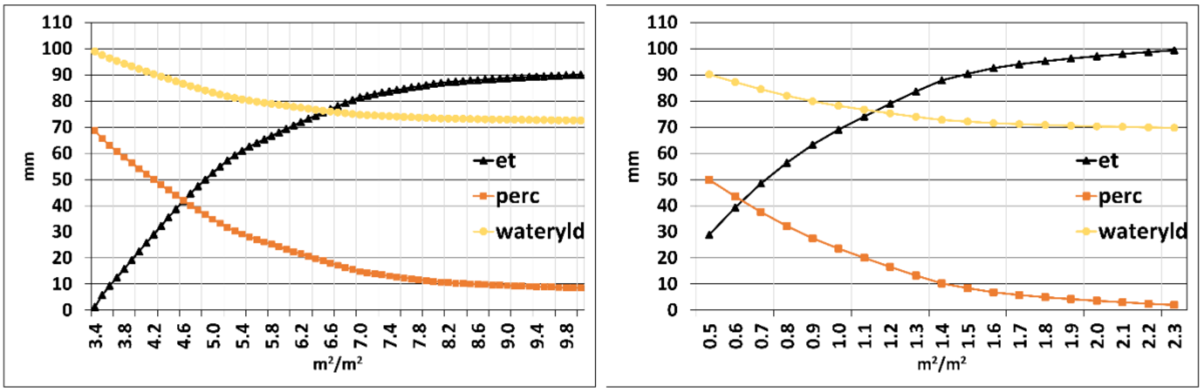

Figure 5: Sensitivity of water balance components evapotranspiration (ET), percolation (perc) and water yield (wateryld) to the variation of the maximum (left) and minimum (right) leaf area index.

Increasing the depth of the soil profile led to a decrease in percolation (>60%), and to less water yield. In contrast, evapotranspiration (ET) showed an increasing trend (>50%) for an increase in soil depth. Sandy soil contributed to more water yield compared to clay soil. Soil type has also resulted in different ET and percolation patterns in different depths of soil layer. Water yield and percolation were affected most in the low rainfall scenario, decreasing noticeably as the depth of the soil increased. ET was the largest component in each rainfall scenario, increasing as the depth of the soil increased (Figure 3). In the low rainfall scenario, ET accounted for the largest share of the total water balance ranging from 41% in shallower soils to 50% in deeper ones. The increase in soil depth has also increased the share of transpiration of plants from 35% to 45%. The results indicate that in the forested catchment studied, biophysical parameters and soil parameters (depth/type) can have a significant impact on modelling the water balance.

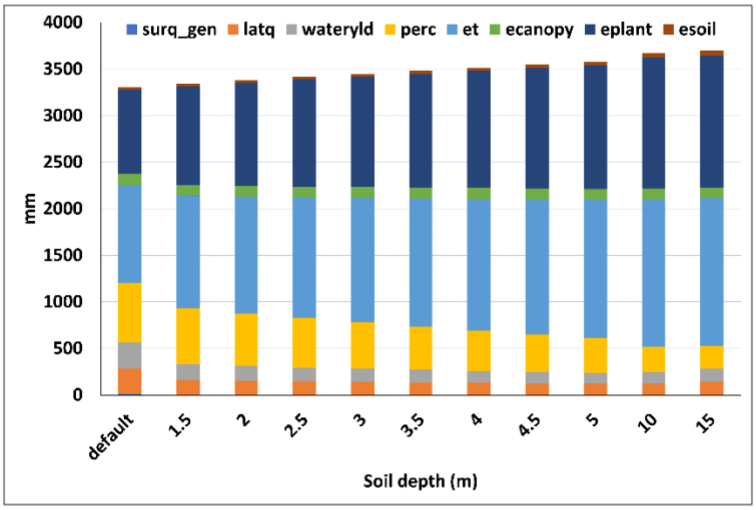

Figure 6: Water balance values for the actual rainfall scenario for different soil depths.

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A HYDROCHEMICAL ASSESSMENT OF GROUNDWATERS IN THE GREAT ARTESIAN BASIN: IMPLICATIONS FOR RECHARGE AND CONNECTIVITY PROCESSES

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The Great Artesian Basin (GAB) covers more than 20% of the Australian continent and is one of the world's largest groundwater basins. The GAB hosts groundwater, gas and hydrocarbon resources, sustains important agricultural activities and provides water for town water supplies. As part of the Geoscience Australia project 'Assessing the Status of Groundwater in the GAB', we assessed the spatial patterns of hydrochemistry and selected environmental tracers across the GAB.

This involved the compliation of historical, hydrochemical, and environmental tracer data from the GAB, underlying older and adjacent sedimentary basins and from Cenozoic volcanic aquifer systems located along the eastern margins of the GAB. The hydrochemical records (>18,000) and environmental tracer data (e.g. a comprehesive suite of 'age' tracers, $^{87}Sr/^{86}Sr$, stable water isotopes and isotopes of methane) were subjected to comprehensive data quality checks. Subsequently, we have applied multivariate statistical and graphical techniques to identify spatial patterns of hydrochemical parameters including major ions, minor ions and $^{87}Sr/^{86}Sr$, allowing us to identfiy processes controlling the hydrochemical evolution along inferred local to regional scale flow paths and areas of hydrochemical anomalies.

Environmental tracers allowed us to deduce dual porosity systems and to better quantify recharge in the Surat Basin and Coonable Embayment. Hydrochemical and tracer signatures gave clear indications for connections to deeper systems and to overlying aquifers in some areas. Ratios of $^{87}Sr/^{86}Sr$ vary considerably across the GAB, but show systematic differences for key aquifers such as the Cadna-owie–Hooray aquifer, Hutton Sandstone and Precipice Sandstone and intervening aquitards and coal seams; this confirms the usefullness of Sr isotopes as a "fingerprinting" tool of water–rock interactions within the GAB.

The assessment confirmed that recharge and connectivity processes within the GAB are spatially highly variable and that understanding from one area cannot necessarily be extrapolated to other parts of the GAB without conducting geological and hydrogeological assessments.

TOWARD SUSTAINABLE WATER ALLOCATION: AN INTEGRATED SOCIOECONOMIC-HYDROLOGICAL MODEL FOR ADAPTIVE CATCHMENT-SCALE MANAGEMENT

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The increasing demand for water in Aotearoa-New Zealand for agriculture, domestic, and industrial use has led to heightened stress on aquatic and wetland ecosystems. Competing interests for water have resulted in unsustainable water allocations in various catchments and aquifers, with some exceeding their allocation limits. Climate change exacerbates these challenges, altering precipitation patterns seasonally and annually. Although water abstraction and use provide wide spectrum of socioeconomic benefits, current first-in first-served allocation regime does not prioritise environmental and human health ahead of commercial practices, especially when water is already fully allocated. The Ministry for the Environment (MfE) initiated a pilot study to assess catchment-level water management systems in preparation for implementing the National Policy Statement for Freshwater Management 2020 (NPSFM). To aid this policy initiative and the freshwater science community, we developed a catchment-scale water allocation model that integrates socioeconomic and hydrological aspects to support water allocation decisions, with a focus on the agricultural sector. In our study, we examined the Mid-Mataura catchment in Southland, which faces water scarcity issues due to consumptive use under existing allocation rules. Two major agricultural water users, pastoral farming and crop production, were considered. The water allocation model comprises a hydrology model and a socioeconomic model, providing insight into the value of water in different agricultural practices. This value estimation enables water allocation decision-making processes across agricultural practices. Additionally, we explored dynamic allocation to optimise water usage and economic benefits such as financial performance of agricultural practices in the catchment. Our presentation demonstrates the model's capacity to sustainably allocate water among competing users, maximising socioeconomic output within policy parameters, and dynamically allocating water (e.g., using storage) to enhance economic benefits.

EXAMINING GROUNDWATER DYNAMICS AND RAINFALL RECHARGE PATTERNS IN THE KAITUNA FRESHWATER MANAGEMENT UNIT, BAY OF PLENTY

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Aims

The Bay of Plenty (BOP) Region is facing significant challenges due to a surge in water demand (BOPRC, 2019). There are over 1,250 active resource consents for water abstraction and usage in the BOP region, with 71% of these consents pertaining to groundwater. Kroon (2018) estimated that approximately two-thirds of the water resources in the region's streams have been over-allocated. Similarly, several groundwater aquifers are over-allocated (BOPRC, 2023). Currently, Kaituna Draft Freshwater Management Unit (FMU) has an annual groundwater allocation of 11.5 Mm^3/year, but the estimated available sustainable limit is 10 Mm^3/year, which is an overallocation of 15%. These over-allocation issues are expected to exacerbate in the future due to climate change, which is projected to alter the seasonality of rainfall, with spring and summer generally becoming drier.

In order to assist with groundwater management responsibilities at the Bay of Plenty Regional Council (BOPRC), scientifically rigorous statistical methodologies were developed for assessing groundwater levels and land surface recharge of lysimeters in the BOP. These methodologies comprised two main components: (1) long-term trend analysis of groundwater levels*;* and (2) evaluation of the relationship between weather conditions and groundwater recharge data. These approaches were formulated and validated using the data available for the Kaituna FMU. BOPRC requires this information to increase the effectiveness of the management of groundwater resources within the FMU. This presentation will demonstrate the approaches to using statistical analysis and modelling of monitoring data to support effective and sustainable groundwater resource management.

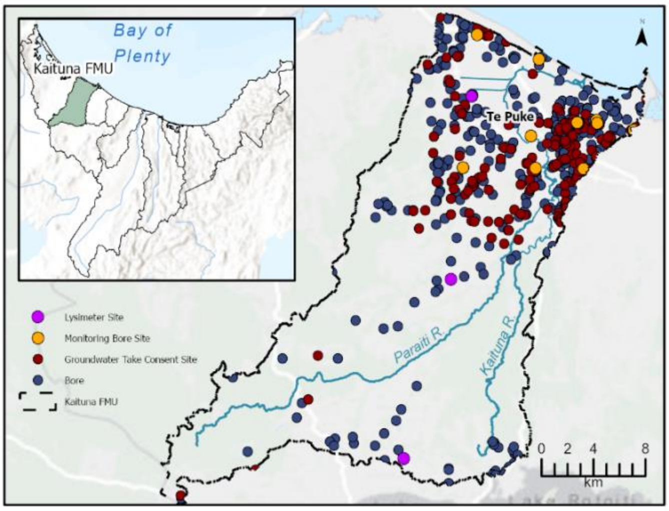

Figure 1: Bores and Lysimeter sites in Kaituna FMU.

Methods

The analysis of long-term groundwater level trends utilised 22 groundwater level time series from 15 monitoring sites situated within or in close proximity to the Kaituna FMU. These datasets comprised both manual measurements and automatically logged data. The Mann-Kendall statistical test was used to assess long-term trends in groundwater levels. Multiple summary variables, including monthly averages, annual minimums, annual maximums, level changes during the non-irrigation season, and level changes during the irrigation season, were employed to better understand the overall trend, and identify potential causes of the trends observed.

Additional datasets, such as climate data, groundwater abstraction records, streamflow measurements, sea level data, and lysimeter data, were utilised to investigate potential factors contributing to the observed groundwater level dynamics.

Statistical analyses were employed to determine the optimal duration of data collection at a lysimeter site to ensure robust and accurate predictions of groundwater recharge while maximising monitoring resource use. To enable the assessment, the correlation between land surface recharge data obtained from three lysimeters, and environmental variables within the Kaituna FMU was investigated. Using the sensitive parameters identified through the assessment of correlation, a multiple regression modelling approach was developed to predict recharge at specific sites using environmental data from the vicinity as bore as recharge data from nearby lysimeter sites. For each monitoring site, four possible combinations of models, which utilise different combinations of datasets from various sites, were developed.

Results

Among the 22 groundwater level time series analysed, two of the manual measurement series exhibited statistically significant decreasing long-term trends (one of these sites, Bore 1690 at Mangatarata Orchard, is shown in Figure 2). The magnitude of these decreasing trends ranged from 10 mm/year to 30 mm/year. The primary driver of aquifer fluctuation is the climate, as represented by the lysimeter data. From the qualitative assessment of the groundwater level plots, it seems apparent that some aquifers do not fully recharge every year unless there has been a high recharge season. Determining the magnitude of the recharge required to restore the aquifers would enable an assessment of the likelihood of aquifer depletion, and the likelihood of multiple years of depletion.

Land surface recharge, as measured by the lysimeters, and stream flow showed the highest correlation to groundwater level variability, indicating climate rather than groundwater use is the primary control on groundwater levels.

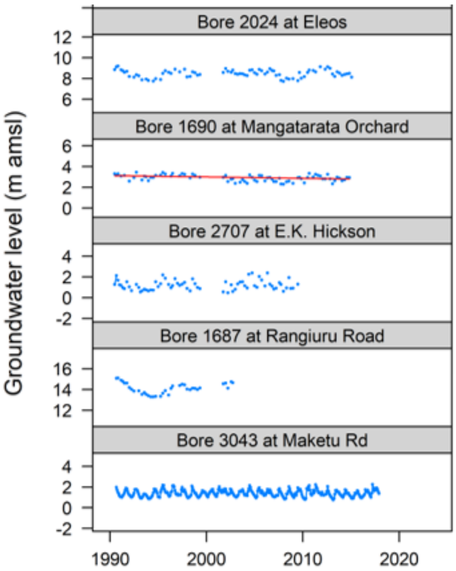

Figure 2: Time series plots of monthly averages of groundwater level for five sites analysed. Red line shows the trend for the sites where statistically significant (corrected p < 0.05) trends were identified.

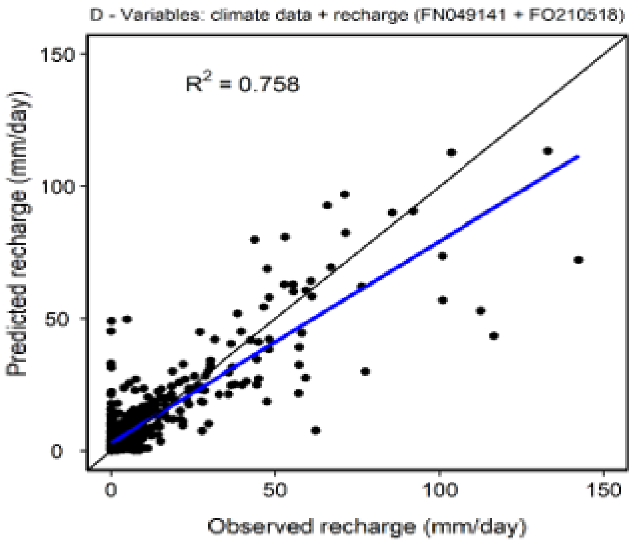

Figure 3: Observed versus modelled recharge using a multiple regression model with daily data at lysimeter site EL051775 using site specific data and recharges from nearby sites.

The multiple regression modelling approach successfully explained over 75% of the daily recharge variability at two sites. However, the accuracy of recharge prediction for the site located near the coast was lower at 65%.

The optimal duration of data collection at a lysimeter site was determined by utilising the best-performing models specific to each site. However, the assessment did not produce definitive results, as the optimal duration varied across the different sites. It is likely that the approach employed may have yielded inconclusive outcomes due to the limited duration of the available data.

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HAWKE'S BAY 3D AQUIFER MAPPING PROJECT USING AIRBORNE TIME-DOMAIN ELECTROMAGNETICS (SKYTEM): 2023 UPDATE

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[1]GNS Science

[2] Hawke's Bay Regional Council

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The Hawke's Bay 3D Aquifer Mapping Project is a four-year project (Sept 2019 – December 2023) that is jointly funded by the Provincial Growth Fund, Hawke's Bay Regional Council (HBRC) and GNS Science (GNS).

In early 2020, SkyTEM data for the project was collected by SkyTEM Australia using a specially equipped helicopter flying over Hawke's Bay along flight lines about 200 m apart. Close to 8000 km of data was collected over the Heretaunga Plains, the Ruataniwha Plains, and the Otane and Poukawa Basins.

Overviews and updates at the NZHS annual conferences in 2020 and 2021 described the survey design and objectives, the successful communication approach taken, flight details, supporting datasets, the advanced data processing and inversion undertaken, the resistivity models developed for all three survey areas, hydrogeological interpretations of the Otane and Poukawa Basins, preliminary hydrogeological interpretation information from the Heretaunga Plains, and details from supporting drilling that was undertaken within the Heretaunga and Ruataniwha Plains.

This 2023 update will focus on the Heretaunga Plains hydrogeological interpretation and implementation approach being undertaken into numerical groundwater models, as well as an online tool enabling public access to information and 3D model visualisations.

UNIVERSITY LED GROUNDWATER MONITORING TO INFORM COMMUNITIES AND WATER POLICY

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In data poor areas, groundwater management is particularly challenging. A model for university led community engaged groundwater monitoring is proposed as a potential solution. Through a seven year case study in Tamborine Mountain, in Queensland, Australia, groundwater monitoring has been carried out by university staff and students with community support. This monitoring has included monitoring of groundwater levels with pressure transducers and monitoring of water chemistry. The outcomes of this case study have included community benefits (information for community members on groundwater level trends and water quality), educational benefits (undergraduate and postgraduate training) and input into water management policy. As the water regulation for this region has evolved, the university led monitoring and research has provided the data needed for decision-making. Water chemistry monitoring has also provided essential background information for investigation of human health impacts of drinking the groundwater in this region.

UNRAVELING NITRATE AND FLOW DYNAMICS IN AGRICULTURAL STREAMS USING HIGH-FREQUENCY MONITORING

Aldrin Rivas,[1] Roland Stenger,[1] Jungho Park,[1] Juliet Clague,[1] Greg Barkle,[2] Brian Moorhead[1]
[1] Lincoln Agritech, Hamilton, New Zealand
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Nitrate in agricultural streams has been a major contaminant problem in many countries, especially those with economies relying heavily on agricultural production, including New Zealand. In an effort to understand and mitigate this problem, relationships between concentration and discharge (i.e., *c-Q* relationships) have been used to determine nitrate export mechanisms and infer source areas and pathways. More recently, investigations of *c-Q* relationships at event, monthly, seasonal, and annual scales have revealed that source areas and pathways may vary temporally, providing opportunity to identify optimal times for interventions to improve water quality. However, nutrients in most of the streams in New Zealand are monitored only monthly by discrete sampling and there has been a lack of high-frequency monitoring of nitrate, especially in highly impacted agricultural catchments. This study uses high-frequency monitoring of both flow and nitrate to enhance our understanding of nitrate dynamics in agricultural streams and, subsequently, provide insights on loading mechanisms and potential mitigation options.
In this study, we monitored flow and nitrate-N concentrations at high frequency (15-minute intervals) between 2020 and 2023 at several streams in two agricultural catchments with contrasting hydrological characteristics in the Waikato region, New Zealand. The Piako River in its headwater area is characterised by highly dynamic flow, resulting from predominantly shallow pathways (near-surface and shallow groundwater). In contrast, the comparatively steady flow in Waiotapu Stream results from a dominant flow contribution by the deeper groundwater system. Nitrate concentrations were measured using an optical nitrate sensor, whereas flows were determined by rating curves using water level sensors coupled with flow gaugings. Nitrate and flow dynamics observed at event, monthly and seasonal scales will be analysed and compared between these contrasting streams.

A REVIEW OF THE EUROPEAN FLOOD CATASTROPHE OF JULY 2021

Harvey J. E. Rodda,[1] and Terry Kim[2]
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This paper considers the July 2021 floods which impacted Germany, Belgium, The Netherlands and Luxembourg, and were the most devastating floods experienced in Europe for the past 60 years. The flooding not only caused the largest loss of life from a flood event in continental Europe this century but also caused the highest economic and insured losses ever recorded. The flood surpassed the August 2002 floods as the benchmark flood event in terms of emergency management and the assessment of insured loss. The flooding was caused by a large slow moving depression (Storm Bern) which brought heavy rainfall to large areas of Western Europe over a period of 5 days. The death toll exceed 200 and overall economic losses were estimated at 46 Billion Euros. When comparing the 2021 event with 2002 however, from a hydrological perspective the 2002 event was much more significant. The maximum 24-hour rainfall total recorded in 2002 was almost double that in 2021, and the 2002 flood affected major rivers flowing through capital cities. The 2021 event in contrast did not impact on any major rivers or large cities with the flooding being concentrated on headwater tributaries affecting smaller towns and villages. This paper will focus on why particular catchments were so badly affected in 2021 due to a combination of the hydrology, geomorphology, land use; and present reasons why the why the damage and loss of life was so catastrophic compared to the 2002 floods which covered a much larger area.

CLIMATE CHANGE ADAPTION IN THE PERUVIAN ANDES: AN INTEGRATION OF PRE-HISPANIC AND MODERN WATER MANAGEMENT

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The provision of water for agriculture in four small highland catchments located in the Cordillera Blanca and Cordillera Negra mountain ranges within the Peruvian Andes has been impacted by climate change. In all catchments, land up to 3700 m in altitude is cultivated throughout the year for a variety of crops. The climate has a distinct wet season from October to April which receives over 90% of the annual rainfall, and dry season agriculture is heavily reliant on irrigation. Farmers have observed less water available for irrigation in recent years and over a longer period, the glaciers in the Cordillera Blanca have been observed to recede. Field measurements over the dry season in 2019, 2022 and 2023 provided an assessment of stream flows and the extent of cropped lands requiring irrigation. The types of crops grown were obtained from interviews with farmers and the extent of cropping was estimated using GIS from existing mapped data and satellite imagery. The CROPWAT model was applied to estimate water requirements for each of the crop types, and water requirements per catchment were then estimated based on the area extent of each crop type. Initial results showed irrigation requirements exceeded available water based on dry season stream flows indicating the need for storing and harvesting wet season flows. Further CROPWAT simulations included the latest climate change projections, which indicated increase temperatures, and less rainfall in dry seasons. The use of water infrastructure surviving from the pre-Hispanic civilisations is now being considered as a way of improving water conservation and availability in combination with the more recent irrigation infrastructure.
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NITRATES IN DRINKING WATER: BLENDING OF SCIENCE WITH COMMUNITY INITIATIVES

Rogers, K.M.,[1] Abel, S.,[2] Bain, I.,[3] Bradshaw, D.[4] Buckthought, L.,[5] Chambers, T.[6] Dewes, A.,[7] Fischer, S.,[8] Heath, T.,[1] Joy, M.,[8] Kay, T.,[9] Legg, J.,[10] Pannell, J.,[2] Redmile, C.,[6] Royal, H.,[6] Rutter H.,[11] Tio, P.,[1] Trolove, P.[12] Tschritter, C.[4]

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New Zealand's drinking-water quality is increasing threatened by land-use intensification, urbanisation, high stock numbers, application of agricultural fertilisers and climate change. Elevated nitrate concentrations are now common in both surface water and groundwater across New Zealand (StatsNZ 2019, 2022; Rogers et al. 2023). This presentation summarises the efforts of a core group of individuals and teams supporting community initiatives and citizen science to identify and map nitrate hot spots across New Zealand, and undertsand the time-carrying nature of nitrates in drinking water.

These initiatives include regional and national mail-in programmes, marae-focused testing, town-hall testing, citizen science led catchment testing, government funded research and volunteer fieldwork studies. We will provide insights into each of these benchmarking programs and show how our combined efforts are starting to spatially and temporally define nitrate concentrations of New Zealand's rural freshwaters for future discussion and debate.

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TOWARDS DEVELOPING A 3D HYDROGEOLOGICAL FRAMEWORK FOR AUSTRALIA

Rollet, N.,[1] Vizy, J.[1] Norton, C.J.,[2] Hannaford, C.,[3] McPherson, A.,[1] Symington, N.,[1] Evans, T.,[1] Szczepaniak, M.,[1] Bradshaw, B.,[1] Wilford, J.,[1] Wong, S.,[1] Nation, E.,[4] Peljo, M.,[1]

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Aims

Groundwater is vital for community water supplies and economic development in Australia. It also supports indigenous cultural values and sustains a range of groundwater dependent ecosystems, including springs and vegetation communities. Geoscience Australia's regional assessments and basin inventories are investigating Australia's groundwater systems to improve knowledge of the nation's groundwater systems under the Exploring for the Future (EFTF) Program. Where applicable, we applied integrated basin analysis workflows to build models of geological and hydrostratigraphic architecture and link them to a nationally consistent chronostratigraphic framework. While the focus of this paper is the Great Artesian Basin (GAB), the overlying Lake Eyre Basin (LEB) and the Upper Darling Floodplain (UDF) region, these datasets and surfaces continue expanding beyond this current study area by linking additional studies using this consistent approach, towards building a national picture of groundwater systems.

Method

Geoscience Australia continues to refine the chronostratigraphic framework that correlates time equivalent geological units from neighbouring basins and hydrostratigraphy for the GAB, LEB and UDF (Figure 1), infilling key data and knowledge gaps from previous compilations and adding new interpretation. In collaboration with Commonwealth, State and Territory government agencies, we compiled and standardised data from thousands of boreholes, including stratigraphic (Norton & Rollet, 2023; Vizy & Rollet, 2023a) and biostratigraphic picks (Hannaford & Rollet, 2023), 2D and 3D seismic (Szczepaniak et al., 2023) and airborne electromagnetic derived conductivity sections across the study area (McPherson et al., 2022a &b; Wong et al., 2023). We undertook a detailed stratigraphic review of thousands of boreholes with geophysical logs to construct consistent regional transects across the GAB, LEB and UDF (Norton & Rollet, 2023). In addition we applied geological time constraints from hundreds of boreholes with existing and newly interpreted biostratigraphic data (including from legacy palynological preparations from the Geoscience Australia archives where old reports could not be found) (Hannaford & Rollet, 2023). New biostratigraphic data from core samples has been analysed from bores in the Northern Territory, South Australia and Queensland. The biostratigraphic data was calibrated to the most recent biostratigraphic zonation scheme and used to provide geological time constraint to the stratigraphic picks.

Results

We infilled the stratigraphic correlations along key transects across Queensland, New South Wales, South Australia and the Northern Territory to refine nomenclature and stratigraphic relationships between the Surat, Eromanga and Carpentaria basins, improving chronostratigraphic understanding within the Jurassic–Cretaceous to Cenozoic units. We extended the GAB geological framework to include the overlying LEB and UDF as well to better resolve the Cenozoic stratigraphy and structure and potential for hydrogeological connectivity. The new data and information fill recognised gaps and refine the previous 3D geological model of the entire GAB and extend it to the LEB and UDF region (Vizy & Rollet, 2023b).

The updated 3D geological and hydrostratigraphic model provides a framework to integrate additional hydrogeological and rock property data. It assists in refining hydraulic relationships between aquifers within the GAB, LEB, UDF and provides a basis for developing more detailed hydrogeological system conceptualisations.

The improved cross-jurisdictional chronostratigraphic understanding supports improvements to the common agreed terminology for Australian hydrogeological units and groundwater provinces between jurisdiction borders (http://www.bom.gov.au/water/groundwater/naf/). This enables the delivery of geologically and hydrogeologically consistent datasets to inform decision makers and the broader groundwater community in Australia.

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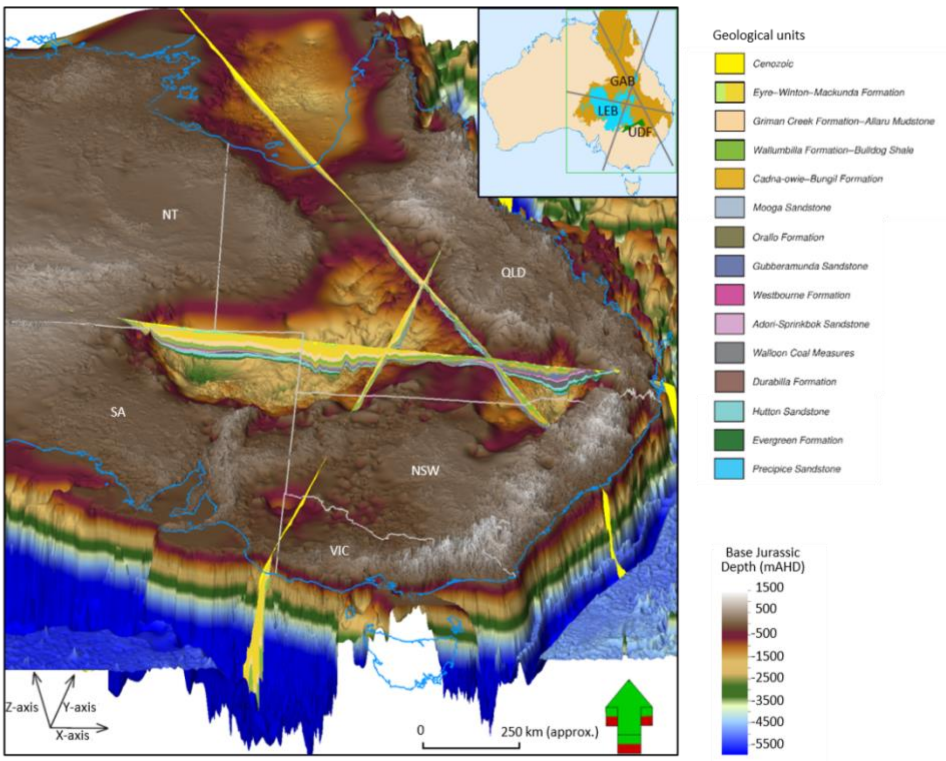

Figure 7. Three-dimensional hydrogeological model (Vizy & Rollet, 2023) showing the base of Jurassic surface (m AHD) for eastern Australia and cross-sections through the modelled hydrogeological units along three regional transects. The base of Jurassic surface corresponds to the base of the Great Artesian Basin. This inset shows the extent of the GAB, LEB and UDF outlines.

MITIGATING IMPACTS TO THE WEELUMURRA CREEK THROUGH CONSTRUCTION OF A DEEP HYDRAULIC BARRIER WALL

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Channel iron ore deposits (CID) are being mined below the water table in the Queens Valley at Fortescue's Solomon operation located in the Pilbara Regiona of Western Australia. Mining will extend to the western end of the Queens deposit, adjacent to the Weelumurra Creek valley, which is host to surface groundwater-sustained pools that are ecologically and ethnographically significant.

Mining below the water table will require extensive dewatering, which may result in impacts to the surface groundwater fed pools. To effectively manage these potential impacts, a groundwater management strategy has been implemented that includes constructing a groundwater barrier in conjuction with aquifer reinjection and supplementary abstraction systems to manage base flow conditions adjacent to the Solomon lease boundary and the Weelumurra Creek.

The groundwater barrier is being constructed using a combination of cut-off wall and curtain grouting methods. Mineralisation occurs in the CID which is in deeply incised valleys that extend up to 100 m below the existing surface. The 1 m wide cut-off wall extends through overburden alluvial materials and the grout curtain will extend to target depths of up to 100 m across the CID with tie-in to the underlying bedrock units. Prior to comencing construction of the hydraulic barrier, a series of key studies and analyses were completed. These included feasibility level activities such as site investigations and test pumping, conceptualisation of the barrier through technology reviews and groundwater modelling, and a full-scale grouting trial to establish means and methods for effectively injecting grout into the CID at deep depths. The results and finding from the various studies were then used to inform the full-scale design and implementation of the hydraulic barrier.

ESTIMATING RECURRENCE INTERVALS FOR THE 2023 AUCKLAND RAINFALL EVENTS – EMBRACING THE UNCERTAINTY

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Rainfall induced flooding is of great societal relevance as it imposes substantial risks on communities worldwide. Reliable extreme value statistics for rainfall are indispensable for accurate flood risk assessments and quantification of flood resilience. This was recently demonstrated during the 27 January 2023 Auckland rainfall event, which, extrapolating from HIRDS V4 statistics, had a return period in the order of 1,000 to 10,000 years. Recording such an extreme event in 150 years of measurement is very unlikely and indicates that the statistics need an update.

In this study, we create a statistical model to explain rainfall depths across the Auckland Region by applying Bayesian inference to 15 million rainfall records across more than 50 gauges. From this, we obtain uncertainty estimates of annual maxima for every location in the Auckland region, from 1862 to the present day. With the Bayesian sampling technique Markov-Chain Monte Carlo, the uncertainty of these annual maxima estimates is integrated in the extreme value statistics. This approach significantly increases the accuracy in the range of extreme events compared to using only recorded site-specific data.

Our findings indicate that the January 2023 event had recurrence intervals that are significantly less than those obtained using prevailing statistics, noting that the latter were generated prior to recording the January event. Incorporating these updated statistics into water infrastructure planning and flood risk assessments enables better informed and more proactive measures to mitigate the potential impact of rainfall induced flooding.

NEGATIVE INDIAN OCEAN DIPOLE DRIVES GROUNDWATER RECHARGE IN SOUTHEAST AUSTRALIA

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Understanding the links between climatic drivers and groundwater recharge is crucial for water resource planning and management, especially in semi-arid environments. This will allow for assessment of the impact of climate change on the occurrence and timing of groundwater recharge and the sustainable management of this resource into the future. Measuring groundwater recharge is difficult as it occurs in the subsurface and subjected to considerable spatio-temporal variability. However, caves situated in the unsaturated zone give us the opportunity to observe these subsurface processes.

In this study we investigated recharge events in Cathedral Cave, Wellington, NSW and in bores located in non-karstified lithologies at the nearby Wellington Research Station. Over the 10 year study period (2012-2021) we saw good agreement between the recharge events measured in the cave system and the groundwater bores. The minimum threshold for recharge was determined to be 54 mm of rainfall in the 21 days prior to observing recharge. The role of antecedent conditions in controlling groundwater recharge could be seen through only 48.1% of occasions where this threshold was exceeded was groundwater recharge observed.

During the study period there was only one significant recharge event, which occurred during a particularly strong negative Indian Ocean Dipole period. The climatic drivers associated with recharge was further explored through the use of a daily soil moisture model to determine periods of potential groundwater recharge for the site dating back to 1900. The results confirmed a significant link for groundwater recharge with negative Indian Ocean Dipole events.

IMPACTS OF CUMULATIVE RAINFALL EVENTS ON SURFACE AND GROUNDWATER SYSTEMS

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Abstract

The hydrological response to rainfall for rivers may occur over a few days, but the groundwater response may be much more delayed and/or prolonged. This paper assesses the effects of rainfall events through 2017/18 on river and groundwater in the Selwyn catchment in Canterbury, and the likely interaction between sustained rainfall, groundwater levels and river flows.

The Selwyn River is sourced from the foothills of the Southern Alps and flows for 80km before discharging into Te Waihora/Lake Ellesmere. Larned et al. (2008) observed that the Selwyn is a complex river with strong surface water/groundwater connection and an expanding and contracting dry segment. From April 2017 through to mid-2018, rainfall totals were higher than for any other period on (the relatively short) record, with key events in April 2017, July 2017 and February 2018, resulting in high rivers flows and very high groundwater levels. The close connection between surface water and groundwater is likely to have been a key driver of flooding issues in 2017/18 in the catchment beyond the foothills.

Cumulative Rainfall

Based on the High Intensity Rainfall Design System (HIRDS), the 24 and 48 hour rainfall totals for the Selwyn rain gauge at 13 Mile Bush for 21 July were both around a 1 in 10-year event. However, it was the cumulative and prolonged rainfall over several months that caused problems. By the end of the 2017/2018 hydrological year, total rainfall exceeded previous years' by close to 200mm.

River Flow

The Selwyn River (at Whitecliffs) has a long flow record, with data from the late 1990s. The flow recorder site is in the foothills, around 7.5km upstream from the upper plains. There were flood events recorded at this site in 2000 and 2002 that were much larger than the 21/22 July 2017 flood, the peak flow for which was estimated to be around a 1 in 8 to a 1 in 10 year event.

However, the total monthly discharge reveals a much different pattern, with monthly average discharge for the Selwyn River exceeding long term average discharges by a large margin, for July through to October 2017 (see Figure 1).

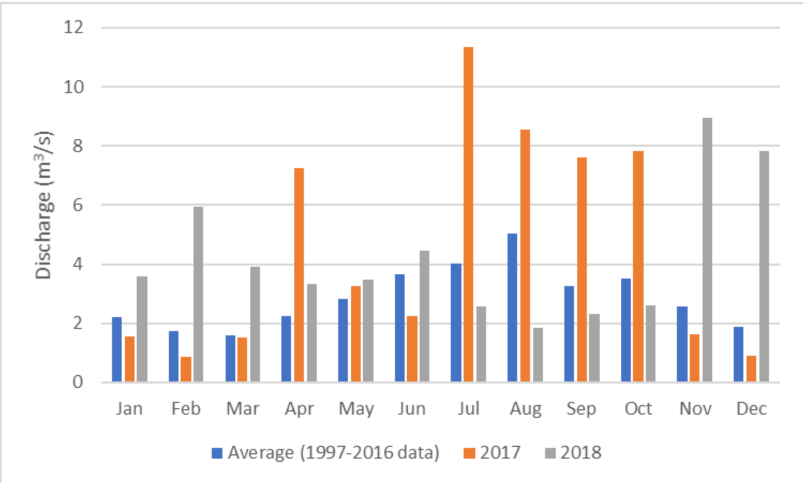

Figure 1: Monthly average discharge for the Selwyn River illustrating 2017 and 2018 against the longer term record

Groundwater levels and contribution to flooding

Assessing the responses in 2017, it appears that the usual lag between river flow response and groundwater level response had reduced from an estimated 12 days (Larned et al (2008)) to zero for the July 2017 event. This suggests a much more connected groundwater/ surface water system, either with the river still losing but with a fully saturated connection. It is possible that, at times, groundwater contributed to river flow, rather than vice versa. The rapid groundwater level response reflects very wet conditions in the subsurface and a more rapid response of groundwater to rainfall and river flow. Continuing, rainfall events through August, September and October contributed to extreme high groundwater levels, and the lack of available unsaturated sediment would also have contributed to surface water flows being maintained at very high levels.
The result was unprecedented groundwater levels and throughflow that caused severe issues for construction being carried out in the upper Plains.

Discussion
Whilst short-term hydrological events are critical in terms of flood risk, the longer-term, more complex interaction between rainfall, river flow and groundwater levels, highlights the need to consider cumulative events when assessing risks. When groundwater levels rise in response to longer-term rainfall and recharge, the river flow response will change due to either the land becoming an impermeable surface with no infiltration capacity and/or groundwater contributing to river flow. This is likely to affect the rainfall/river flow response and result in much more severe flooding than might be anticipated.

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Keywords
Rainfall, river flow, groundwater, cumulative effects

ASSESSING TEMPORAL VARIATION IN GROUNDWATER RECHARGE TO A BRAIDPLAIN AQUIFER USING ACTIVE-DISTRIBUTED TEMPERATURE SENSING

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Aims

Globally, braided river systems are a major groundwater recharge mechanism for alluvial aquifers, yet little is known about this process (Coluccio and Morgan, 2019). Recently, Active-Distributed Temperature Sensing (A-DTS) was shown to hold significant promise for quantifying braided river loss to groundwater, highlighting spatial variation in these losses beneath the active river channel (Banks et al., 2022). Just as braided river loss varies spatially, it is likely that they change temporally under varying river conditions, but to date this has not been explored. The aim of this project is to validate the use of A-DTS for measuring temporal variations in braided river losses. We hypothesise that under stable river conditions (constant flow and river stage), there will be minimal change in river leakage over the course of a survey.

Methods

Twelve consecutive A-DTS surveys were conducted during a 24-hour period when river stage height and discharge varied very little. This A-DTS experiment was conducted using a horizontal subsurface hybrid fibre optic and heating cable installed perpendicular to the braided Waikirikiri Selwyn River. Using the temperature measurements, and fitting the Hantush-Jacob analytical solution, specific discharge was estimated at high spatial and temporal resolution across the entire width of the active channel.

Results

Specific discharge within the braid plain aquifer exhibited minimal variation occurring at each location along the cable during the 24-hour period. This confirms our hypothesis and validated the use of A-DTS for quantifying temporal variation in braided river loss. In future, this will enable quantification of seasonal variation in groundwater recharge from braided rivers to inform water allocation and management practices.

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UNCERTAINTY ANALYSIS OF A GALLERY FLOW FORECAST IN THE NORTH OF BUCARAMANGA, COLOMBIA.

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Groundwater modelling for infrastructure design requires a robust quantification of forecast uncertainties associated with porous media and other hydrological variables. Understanding, quantifying, and minimising the uncertainty associated with numerical models reduces costs and optimises investment; therefore, a reliable, open, and replicable model is appropriate. We built a groundwater numerical model to forecast flows yielded by a drainage gallery construction. The gallery is over an unconfined alluvial aquifer in Bucaramanga, Colombia, where groundwater is causing ground instability in an urbanized area greater than 1 km2. The model implemented emerging approaches for workflow modelling such as programmatic modelling, forecast first, and early uncertainty quantification (EUQ) in a decision support modelling workflow. The software used included MODFLOW 6 and PEST++ for forward and inverse modelling, respectively, with Flopy and Pyemu packages as Python interfaces, all of them open source. Python's programmatic approach using open-source software combined with Git and GitHub for model documentation allows high transparency and reproducibility for anyone who wants to audit the model construction process and forecast uncertainty analysis. Quantification of forecast flow uncertainty was performed using iterative ensemble smoother (IES). The assessment of the model structure through an EUQ workflow tested the effects of prior parameterization of the grid refinement in the flow forecast helping to find and fix several flaws in the model conceptualization. The IES was relatively light in computational burden and robust enough to handle the non-linearity and instabilities of the model. Although data assimilation was scarce in the model, showing little improvement in the forecast after the first iteration, the model's purpose was achieved. The results of this study case showed the convenience of using IES with an EUQ workflow to lead the model design and achieve a reliable forecast uncertainty quantification, especially when reduction of the uncertainty is pursued through history matching.

ANALYSING STAKEHOLDER NARRATIVES TO SUPPORT DECISIONS RELATED TO WATER AND ENVIRONMENTAL ISSUES

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Narratives provide simplified concepts of reality that can foster communications between individuals and groups. They offer explicit expressions of the 'patterns of thought and action' of individuals and their communities, including what they most strongly care about and are willing to express. These "resonance factors" can help recognise emotionally-driven and/or lifeway-driven expressions, without any attached value judgments.

We present a database of 81 resonance factors from Aotearoa New Zealand. The initial set has been drawn from diverse sources, and authors' expert knowledge, reading and experiences. The approach included formal cross-connecting of factors with established social science theories (e.g., modern versions of Maslow); testing them through the analysis of different types of narratives found in policy, planning and research (e.g., "Protecting Lake Taupo Project"); and establishing connections between the factors and ten biocultural propensities.

The resulting database has the potential to inform stakeholder and community engagement, and decision-making processes related to water and environmental issues. The resonance factors in the database reveal core values, and community concerns that may be used to foster more reflective critical thinking. Factors may also help develop shared understanding of different stakeholders' positions and perspectives, and the needs held by different constituencies. Also, greater clarity on resonance factors may enhance the translation of science into policy, and support the uptake of different sources of knowledge into thoughtful, societally-acceptable actions. In doing so, resonance factors may help better address complex environmental problems currently faced by society.

We anticipate the database will be a living document that can be improved with time, experience, and the contributions of other scientists and practitioners. This rich compendium of resonance factors can help advance narratives research, and inform future typologies to address complex environmental problems. We welcome feedback and are open to opportunities to test and refine our database and theories.

HYDRAULIC PERFORMANCE OF DENITRIFYING PERMEABLE REACTIVE BARRIERS USING ELECTRICAL RESISTIVITY IMAGING AND TRANSPORT MODELLING

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Woodchip denitrification walls as an in-situ groundwater nitrate remediation system, has been successfully demonstrated for shallow sandy aquifer systems. Such systems have the potential to be an extremely useful edge-of-field nitrate-mitigation practice for addressing the challenge of farming within catchment nutrient limits.

Over the last few years, ESR has been testing the technology in an aquifer composed of outwash gravels. These aquifers represent the most common and important groundwater systems in NZ, often with very little natural denitrification potential. There are no previously published cases of woodchip denitrifying permeable reactive barriers (PRBs) tested in these fast-flowing and highly heterogeneous systems.

A critical element in the design and performance evaluation of such PRBs is understanding the effect of aquifer heterogeneity in the vicinity of the barrier and how heterogeneity affects its hydraulic performance. In this work we illustrate how electrical geophysics are used to quantify the advective and dispersive transport of water and nutrients through the PRB. We are using a series of solute tracer experiments, coupled with three-dimensional time-lapse electrical resistivity imaging and flow and transport modelling to characterise flow paths and residence times in and around the two PRB cells. Results suggest highly complex solute pathways within the PRB and the surrounding aquifer media and highlight the potential for aquifer bioclogging, even within these highly permeable groundwater systems.

USING SYNTHETIC DNA TRACERS IN A HETEROGENEOUS ALLUVIAL AQUIFER TO QUANTIFY ADVECTIVE AND DISPERSIVE TRANSPORT

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Alluvial gravel aquifers are inherently heterogeneous because of their complex sedimentary architecture. This has significant implications for making reliable predictions regarding the transport characteristics of nutrients, contaminants, and pathogens. Tracer tests can provide valuable information on groundwater flow velocities and improve quantitative contaminant movement predictions. Large-scale field studies conducted at heavily monitored and well-known field sites have provided valuable insights in understanding complex transport processes.

Solute and heat tracer tests are quite common, but can be very expensive to conduct, as sampling and analysis costs, detection limits and interference with background groundwater chemistry and with the porous media matrix, generally limit the horizontal, vertical and time density that would be typically desired for detailed analysis. Non-toxic, synthetic DNA tracers have been shown to be a promising alternative. They can be detected and quantified at low concentrations by quantitative polymerase chain reaction (qPCR, a DNA amplification technique) using only a few microliters of sample volume, while multiple DNA tracers, each one with a unique identifier, could be injected and tracked concurrently.

In this study we present the results of a multi-well multi-DNA tracing experiment that was undertaken at ESR's Burnham experimental site, located 25 km southwest of Christchurch, NZ. Three new double-stranded DNA tracers, that were previously produced in the laboratory and validated in the field, were mixed in situ with groundwater extracted from the site before the experiment, to create three injection solutions. Each solution was injected in a separate well. Water samples were collected from 17 monitoring wells at one or two depths, using 30 sampling pumps. In total 162 samples were collected over a 30-hr period. Each tracer's concentration in each sample was quantified and analysed at least in triplicate using qPCR. Clean breakthrough curves were obtained in most sampling locations and the results are being compared with previous tracing studies at the Burnham site.

A METHODICAL GUESSING GAME: FINDING A DEEP GROUNDWATER RESOURCE IN AN UNEXPLORED PART OF THE RANGITIKEI

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[1] Stantec NZ Ltd
[2] Massey University
[3] Manawatu District Council

Aims

High country sheep farms located in the desiccated hills of Rangiwahia, Mangaweka, Ōhingaiti, and Waituna West have historically relied on small, unconsented, surface water takes from springs, streams, creeks, and rivers as a water supply. Considering several of the subcatchements within these areas are nearly fully allocated for surface water many of these takes will not be consentable in future. Replacing these surface water takes with groundwater will mean a more resilient supply to farmers in particular, during drier conditions when supply is needed most. Furthermore, the reduction in surface water use will help Horizons Regional Council achieve its Values and Management Objectives stated within the One Plan.

The Manawatu District Council (MDC) representing the Vinegar Hill Farmers Liaison Group approached Stantec New Zealand Ltd (Stantec) with a question. Is there a viable and economically attractive source of groundwater to supply 1,600 m³/day to the Vinegar Hill stockwater supply scheme (*Figure 8*).

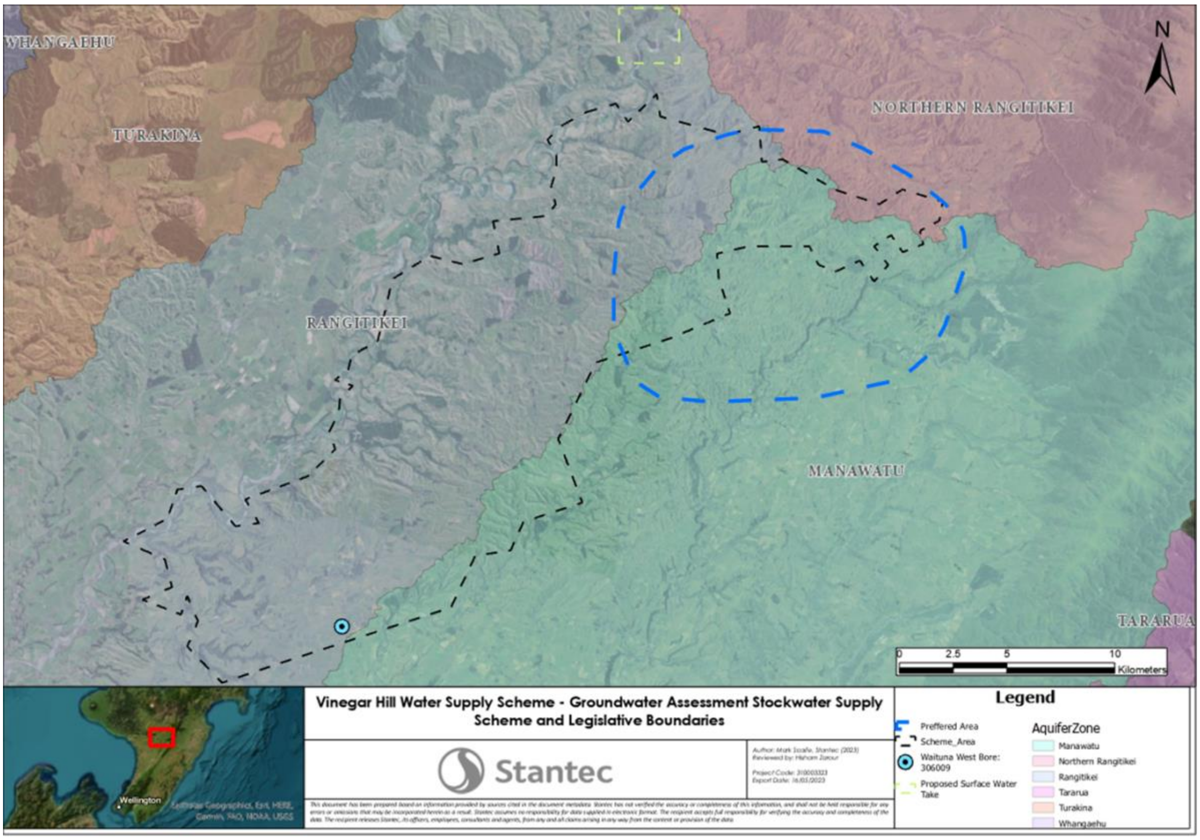

Figure 8: The extent of the Vinegar Hill Stockwater Supply Scheme, MDC's preferred bore location and regulatory boundaries.

Method

Stantec considered the available resource (potential aquifer yield), legal requirements (consenting requirements), and cost (installation and operating) to be critical to the feasibility of groundwater abstraction. We assessed the areas hydrology, geomorphology, geology, and hydrogeology through available resources. This was followed by a 2-day field mapping verification campaign.

The available existing and field verification data were synthesized to produce a geological conceptual model (*Figure 9*), the basis of further assessment.

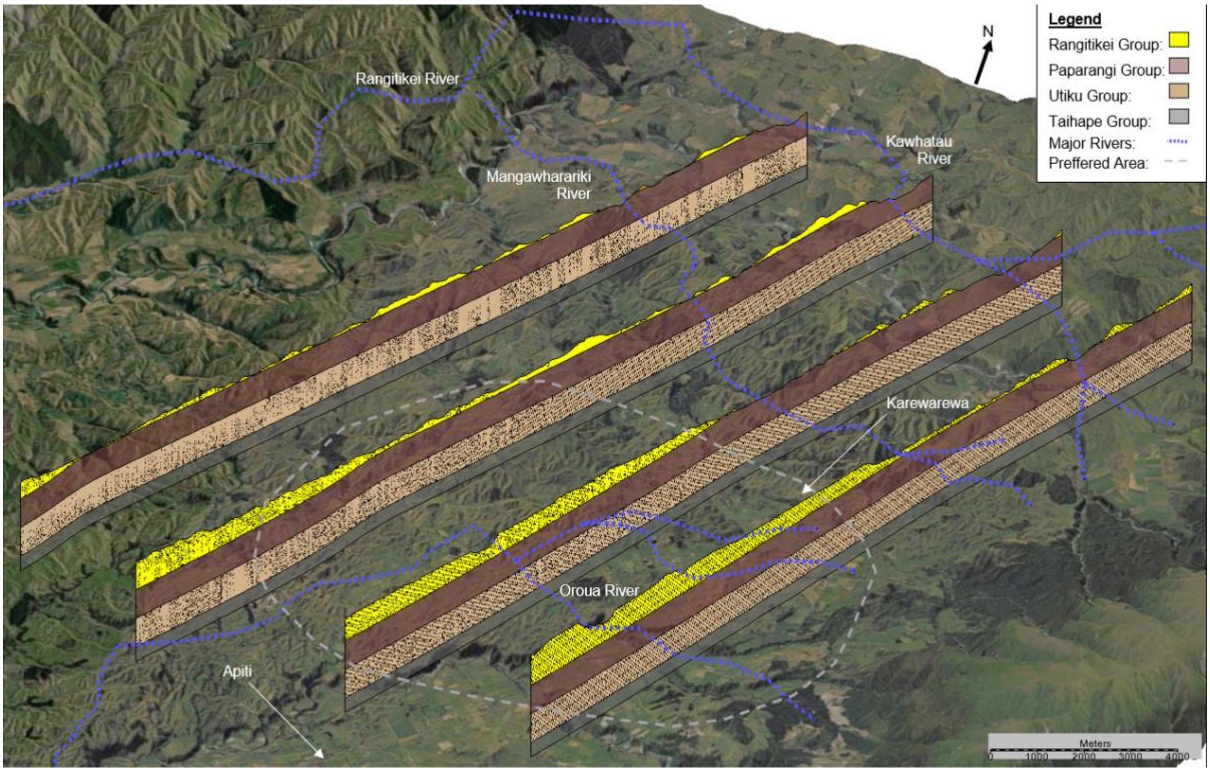

Figure 9: A series of cross sections cut through the geological conceptual model, 2×Vertical Exaggeration

Basic hydrogeological principles, recharge, piezometric pressures, and aquifer parameters, were applied to the geological model. Three geologic units were identified within the area that may yield a significant volume of groundwater within the area. Multi-criteria analysis (MCA) was used to compare potential aquifers, this process considered the available resource, legal requirements, and cost.

Results

The MCA process clearly indicated that the 'East Rangitikei Aquifer' was the most suitable for extraction. Using the geologic conceptual model an area adjacent to the Mangiora and Mangahuia streams was identified as the best location for the bore. At this location a thick, porous, uncemented sand unit is expected to be approximately 250 m deep. The unit is believed to outcrop at the surface some 5 km away in the base of the Mangawhararikí River.

Based on methodical examination of available data and the application of basic hydrogeological principles Stantec has identified a potential groundwater source for the scheme. An exploration bore is proposed within the identified areas to conclude the educated guessing game.

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SEEKING THE BALANCE OF POLICY AND PROGRESS: THE CASE OF PROPOSED RESTORATION OF LAKE ŌMĀPERE

Jake Scherberg,[1] Jon Williamson[1]
[1] Williamson Water & Land Advisory

Aims

In recent years there has been considerable investment in supporting economic development for rural communities across Northland. Much of this development relies on water storage. Of equal importance is maintining or improving environmental conditions in keeping the principal of *Te Mana o te Wai*. Raising the water level of Lake Ōmāpere is an example where there is an opportunity to advance both objectives simulataneously by improving water quality and increasing water availability for economic use.

Lake Ōmāpere is the largest lake in Northland, approximately 1,214 hectares (ha) in area with a maximum depth of approximately 2 m. The lake is primarily fed by direct rainfall and surface inflows from a catchment that comprises approximately 3,300 ha, with the outlet being a stream flowing out the southwestern side of the lake into the Utakura Stream.

The lake has been heavily impacted by human activities which have caused significant degradation of lake water quality, to the point where toxic algal blooms have occurred repeatedly with detrimental effects on habitat and human use, and a negative cultural impact on local Iwi (WSP Opus, 2018).

The restoration proposal is to increase the lake water level by 2.5 m above its current level and construct a kauri sanctuary around the entire perimeter of the lake. The intention of the project is that 1.5 m of the increased water level will be for environmental benefit while the remaining 1.0 m will comprise water storage for economic use.

It is conservatively projected that this proposed storage within the lake will be suitable to irrigate at least 2,667 ha of horticultural land. For comparison, the entire Te Tai Tokerau Water Trust scheme aimed to develop water storage across the Mid-North will irrigate approximately 3,000 ha of land, using approximately 8 Mm^3 of constructed storage (WWLA, 2021).

This study assessed the feasibility and potential environmental and economic benifits of the proposed lake restoration strategy by:

- Evaluating hydrological interactions between the lake and regional surface water and groundwater; and
- Providing preliminary design and costings for the infrastructure required to enable the restoration of the lake.

Methods

A numerical model was developed of Lake Ōmāpere and the surrounding catchments including the upper Waitangi River catchment. The model was calibrated to Lake Ōmāpere water level monitoring data and stream flow monitoring data for the Utakura River and Waitangi River.

The hydrological modelling analysis indicated that the lake is primarily fed by direct rainfall and surface runoff, with limited groundwater generally reaching the lake only as baseflow in tributary streams. The Utakura Stream is the primary lake outflow. There is limited connection between the lake and regional groundwater due to low permeability of the surrounding geologic materials.

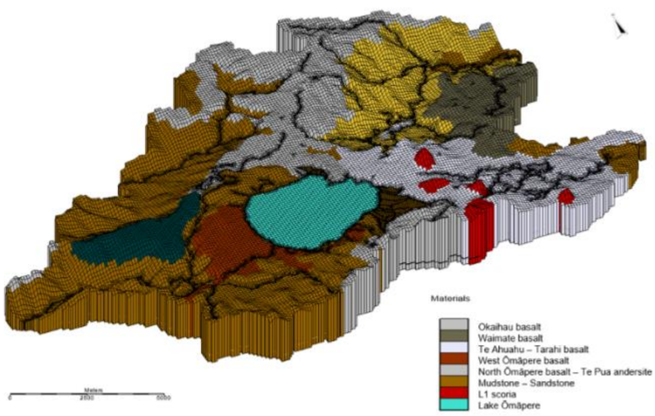

Figure 10. Numerical Groundwater Model of Lake Ōmāpere and surrounding catchments.

Raising the lake level can be achieved by constructing two earthen embankments. One will be across the Utakura Stream along the southwest shore of the lake to raise the level of the lake outflow, and the second will be designed to protect the highway and adjacent property from flooding. A radial gate would be used for controlling flows out of the lake under normal operating conditions with an emergency spillway for flood conditions. A natural rock lined low-gradient fish passage would be installed to discharge water at a low rate into the historical outlet channel. The costs developed for the above work are estimated in the range of $9.0 to 11.0 M; though it is acknowledged that there is some uncertainty in the design details on account of untested ground conditions.

Modeling analysis indicated that the proposed increase in water level would be expected to slightly increase baseflow in Utakura River with negligible effect on groundwater largely due to the low lake bed permeability. The model also indicated there would be little impact on hydrological conditions in the lake catchment and negligible impact on adjacent catchments.

Water quality modelling was undertaken by NIWA to evaluate the likely effect of raising the lake level as proposed. Their conclusions were that over time there would be:

- Increased nutrient removal (denitrification) due to increased lake residence time.
- A decrease in water column disturbance due to wind, with a corresponding decrease in suspended sedminent and nutrients.
- A possibility of oxygen depletion at the bottom of the lake due to reduced mixing.

Results

It is estimated that the proposed lake level increase would lead to the direct innudation loss of up to 330 ha of land, including areas of pasture, wetland, shrubland and swamp forest habitat. It is estimated that approximately 159 ha of this area could be existing wetlands while approximately 77 ha of new wetlands may develop as the shoreline changes. Ecological management practices could be developed to protect against losses in biodiversity as new habitats became established. On the other hand, water quality improvements would offer clear benifit to some threatened species such as tuna (eels) and kākahi (freshwater mussels), while prospects for human use would also improve.

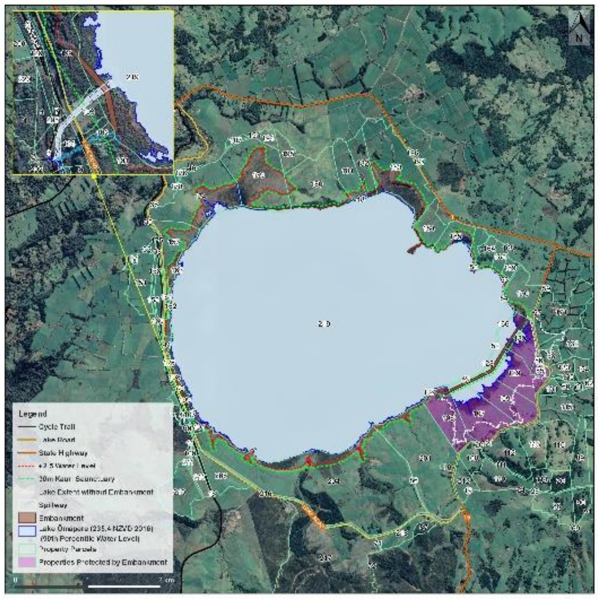

Figure 11. Lake Ōmāpere with 2.5 m water level increase indicated by red dash line.

A land aquisition would be essential for the project to proceed, on account of the innundation that would occur, with an associated cost estimated to approach $10 M.

Further to this point, an ecological assessment undertaken by NZ Environmental (2021) concluded that an offsetting and compensation package of >35,000 ha, including >9,000 ha of wetlands would be required to adequately offset and compensate for the potential adverse effects on biodiversity which could result from raising the lake water level. This is based on a multiplier of 150 to 1 for the effected habitat area, as an interpretation of the Management of Effects Hierarchy called for under Specific Requirement 3.22 in the National Policy Statement – Freshwater Management.

The offset requirent effectively prevents the advancement of the Lake Ōmāpere restoration project.

These findings amount to a case where policy requirements may be preventing the advancement of a project that has great potential community benefit and is largely in keeping with the principals of environmental protection promoted throughout New Zealand. Can policy account for cases where potential improvements may outweigh potential effects?

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A HYBRID DATA-DRIVEN MODELLING FRAMEWORK TO LEVERAGE INSAR IN SUBSIDENCE AND GROUNDWATER ASSESSMENTS

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Differential Interferometry Synthetic Aperture Radar (DInSAR) is a remote sensing technique used to detect ground surface deformation over time. It has been successfully applied worldwide for monitoring subsidence. The Office of Groundwater Impact Assessment (OGIA) has a statutory mandate to assess groundwater and subsidence impacts of resource development and has utilised InSAR data for monitoring Coal Seam Gas (CSG) induced subsidence. The nature of InSAR data presents several challenges to deriving the true CSG-induced subsidence. These include design of appropriate metrics for spatio-temporal coverage and separation of the intermingling signals from the source CSG signal, e.g. atmospheric noise, climatically-driven soil moisture variability and interference caused by vegetation.

To address these challenges, OGIA has developed a hybrid process and data-driven modelling framework that utilises formal data analysis techniques to curate a high quality, high resolution InSAR dataset for history-matching with a series of groundwater, geomechanical and lumped-parameter models for generation of CSG-induced and climate-related subsidence. This accommodates temporal correlation, and estimation of “nuisance parameters” that describe this temporal correlation as well as spatial-variation of climate-induced ground motion. These signals were combined to estimate ground motion and calibrated using PEST-HP on a High Performance Cluster (HPC).

Utilising the InSAR data to calibrate a composite groundwater and subsidence model has yielded improved constraints for hydraulic properties that govern the propagation of drawdown at a scale that cannot be informed by a traditional groundwater monitoring data.

The signal-separation method has ultimately demonstrated the utility of combining several signals for the purpose of extracting the CSG-induced subsidence signal. This reduces bias in calibrated parameters. It also supports an improved understanding of historical CSG induced subsidence while providing a tool for exploring future impacts.

NITRATE TIME LAGS IN WAITAHA/CANTERBURY GROUNDWATER

Lisa Scott,[1] Marta Scott,[1] Amber Kreleger[1]
[1] Environment Canterbury

Regional Councils across New Zealand have been working with communities to set nutrient limits for freshwater management. Many conversations in Waitaha/Canterbury region have been about nitrate leaching from farms reaching groundwater, streams, and lakes.

People accept that groundwater transport is slow and there will be a time lag before water quality responds to farming changes. Relying on catchment-scale models and mean residence times (MRT) from groundwater age tracers, scientists have been saying it will take a decade or more to see improvements over large catchments. And that nitrate will take hundreds of years to reach deep public supply wells. Groundwater age estimates have even created perceptions that water quality now is a legacy of past practices and may have nothing to do with today's land management.

But what happens if we ask a different question? Not "how long until we get there?" but "how soon can we see a change?". If we shift focus from looking at far-field, steady-state responses to looking at quick pathways and how soon we see nitrate arriving at nearby monitoring sites, the picture becomes quite different.

In our paper we present case studies from across Waitaha where monitoring wells showed some initial changes in nitrate concentrations at the water table within one to five years of when the land use intensified nearby. Age tracers and statistical correlation methods also show residence times for surface water bodies are short, with averages of around six years for springs and rivers across the region.

Environment Canterbury monitors many wells and streams across Waitaha where time lags from physical transport are relatively short. If region-wide land use changes or significant mitigation of nitrate leaching are happening, we should start to see water quality improvements at these sites within years rather than decades.

UTILISING STOCHASTIC METHODS IN NUMERICAL SIMULATION MODELS FOR MANAGING GROUNDWATER SALINITY AND DECISION-MAKING

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Groundwater modelling involves creating mathematical representations of groundwater systems to simulate water and solute flow in subsurface environments. It is a crucial tool for understanding and managing groundwater resources, particularly in water-scarce regions. These numerical simulation models can predict future water availability, assess the impact of land use changes on groundwater, and evaluate water management strategies. In this study, we developed a 3D numerical simulation model using the SEAWAT code and applied it to an illustrative study area to address saltwater intrusion in a coastal aquifer. Randomised hydraulic conductivities were used in our simulations, and various scenarios with different hydraulic barriers were tested. The results indicated that the use of injection and barrier wells effectively reduces saltwater intrusion rates. Additionally, we successfully demonstrated the feasibility of using randomised hydraulic conductivities at different nodes with the SEAWAT code. These study findings are of great importance in a world where water scarcity is a pressing issue, providing valuable insights for groundwater modellers dealing with saltwater intrusion in coastal aquifers. However, due to the complexity of groundwater systems and data limitations, modelling remains an ongoing challenge, and uncertainty must always be taken into account. Nonetheless, continuous improvements in modelling techniques and data availability ensure that groundwater modelling will continue to be a vital tool for managing groundwater salinity and making informed decisions.

PREVALENCE OF PFAS IN SHALLOW GROUNDWATER: A VIEW FROM THE U.S.

Matthew Silver[1,2] and others credited in the presenter biography and presentation
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[2] Wisconsin Department of Natural Resources, Bureau of Drinking Water and Groundwater—Groundwater Section, Madison Wisconsin USA (where work being presented was conducted)

Per- and polyfluoroalkyl substances (PFAS) are synthetic chemicals that have been in production since the 1950s and put into increasing numbers of products over time. PFAS have been detected throughout many environmental media, such as treated wastewater, precipitation and soil, but less is known about prevalence in groundwater away from sites with known direct discharges (e.g., fire training, some industrial releases). The Wisconsin Department of Natural Resources and partner organisations conducted a recent study* on PFAS in shallow groundwater in the State of Wisconsin, known as “America’s Dairyland” and having a mix of land uses including agricultural, forested and developed. Samples were collected from 450 residences with private water supply wells across Wisconsin and analysed for 44 individual PFAS and other water quality parameters, including two artificial sweeteners as indicators of human waste sources and four herbicide metabolites as indicators of agricultural sources of contaminants to groundwater. Lab results showed presence of one or more PFAS in 71% of the samples (perfluorobutanoate, a.k.a. PFBA, and perfluorooctanoate, a.k.a. PFOA, were the most frequently detected). One or more PFAS were above the U.S. EPA’s March 2023 proposed Maximum Contaminant Levels in 4% of the samples. Correlations and principal component analysis indicate associations between PFAS and artificial sweeteners, as well as developed land use. Onsite wastewater treatment (septic) systems are likely one contributing waste stream. Meanwhile, although PFAS were detected less frequently in agricultural areas compared to developed ones, a few lines of evidence suggest that land application of waste sludges may be an important source of high levels of PFAS found at a relatively small number of the study sites.

* A manuscript on the study results is in review with a journal at the time of abstract submission and may be published by the time of the conference.

GROUNDWATER: WHY SCIENCE ALONE IS NOT ENOUGH

Craig T. Simmons

For as long as humans have existed on planet Earth groundwater has been a fundamental resource for our survival. Even today half of the world's drinking water and nearly half of the water used for growing food is groundwater. Unfortunately, however, our groundwater resources often pay the price of the very progress they enable. Groundwater is front and centre in critical contemporary issues about our environment, food and water security, coal seam gas and fracking, mining, energy and nuclear waste disposal. In its Global Risks 2015 Report, the World Economic Forum ranked water crises as the number one risk in terms of impact to society – ahead of weapons of mass destruction, spread of infectious disease, failure of climate change adaptation and fiscal crises.

Because of its importance, groundwater use and management is a divisive, contentious, controversial and emotive issue. Tensions between farmers, mining companies, and the environment are at an all-time high. The community is alarmed by fracking in shale gas production and the possibility it could contaminate groundwater. Managing groundwater – scientifically, environmentally, economically and socially – is a grand challenge.

Humans are fundamentally community creatures. We often hear about a social license to operate for mining or a new government policy, but what does that really mean, and what does it take to gain such a license? We, as scientists, tend to think and act as if science is enough and that having 'found' a solution it is someone else's problem to 'make it happen'. However, the truth is much more complex, and however much we might not like to hear it, science is necessary but insufficient for effective, efficient groundwater management and governance.

It is no longer enough to produce a report and send it out for implementation. We no longer live in a world in which there is one single source of truth. Science itself is challenged on a daily basis. There is public misinformation and disinformation, understanding and misunderstanding, interest and disinterest, unconscious bias, emotion, perceptions, not to mention psychosocial and socioeconomic drivers that shape how we think. As scientists, policy makers, managers and human beings we ignore these at our peril.

Groundwater – as we think of it within our academic and scientific context – is a science. Groundwater is also fundamentally and crucially a social science. This talk explores bridging the gap between these two worlds, making the case for a broader understanding of science and the many roles it plays upon which to build a more inclusive and effective future.

THE INTENSITY-DURATION-FREQUENCY (IDF) CURVE: A REVIEW

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The Intensity-Duration-Frequency (IDF) curves are crucial tools that establish the relationship between rainfall intensity, duration, and frequency of occurrence. These curves are specific to different regions and are derived from historical rainfall data. They play a vital role in designing and managing infrastructure such as stormwater systems, drainage systems, and flood protection measures. The main objective of this work is to explore the various scientific approaches used to develop IDF curves globally and emphasize the need to review and update these curves in the face of extreme events.

Several methods are employed to develop IDF curves, and the choice of method depends on factors like data availability, climate variations and hydrological characteristics. Common methods include empirical formulas, the index-flood method, L-moments method, frequency analysis, regionalization techniques, and non-stationary methods. The accuracy and reliability of IDF curves hinge on data availability, data quality, and the appropriateness of the chosen method for the specific region. For instance, in Australia, the Bureau of Meteorology is responsible for producing IDF curves. They utilize historical rainfall data from weather stations across the country to develop region-specific curves, considering the diverse climatic regions and unique rainfall patterns in different areas.

Advancements in technology and improved access to data have contributed to continuous enhancements in the methods and accuracy of IDF curves. Engineers and hydrologists in each region must consistently work to ensure that the IDF curves accurately represent local rainfall characteristics and consider the influence of climate change on precipitation patterns. This way, effective water management and infrastructure planning can be achieved.

The review of IDF curves highlights the importance of region-specific curves, as rainfall characteristics can vary significantly from one location to another. Therefore, local climatic and hydrological conditions must be taken into account while developing IDF curves for a particular area.

OUR RECENT FLOODING - CLIMATE CONTEXT AND CONSEQUENCES

G.M. Smart,[1]
[1] NIWA

Over the past 2-3 years we have had record-breaking rainfall intensities in New Zealand. Overseas, there are instances of multiple “thousand-year” rainfalls occurring in a single month. As a result, rainfall and flood probabilities have changed and, for example, a flood level expected to occur on average every 100 years may now occur on average every 50 years. Consequently, many of our flood and stormwater schemes, bridge waterways, dam spillways… are under-designed because the Annual Exceedance Probability of the original design flow is now higher than when the schemes or structures were built. Our agricultural production, water supplies, water rights, river-crossings, lifelines, hydroelectric & wind generators, stormwater and flood protection schemes are all based on the assumption that past hydrologic behaviour is indicative of what will happen in the future. This assumption is no longer true. And there is no “new normal”. So there are important questions to address regarding potential results of the changes. It is also possible that climate change effects are bigger and/or arriving earlier than anticipated. We will therefore discuss why extreme events have been happening, looking at both climate change factors and other climatic patterns. We will consider predictions for future decades.
Changes in rainfall and floods will also result in unanticipated developments. For example, in recent events many water level gauges failed because water levels exceed the highest levels thought possible. Telemetry was lost from rain gauges when extreme winds damaged communication networks. In Lismore NSW, Australia, around 50 rain and river gauges that failed in their 2022 extreme floods. Where these gauges are used for flood warnings such unanticipated failures may lead to loss of life. We list other potential predicaments and suggest some locations for future NZ floods.

STRATEGIES FOR WATER ALLOCATION; CAN WE REDUCE FLOW ALTERATION WHILST MAINTAINING IRRIGATION SUPPLY?

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[1] NIWA, Christchurch

Aims
Potential conflict between taking water from the natural environment and leaving water in rivers and aquifers arises because river flows are vital for maintaining healthy ecosystems and local customary practices, but taking water for irrigation and other purposes can alter river flows. High-flow harvesting involves taking water from a river, generally during times of high river flows, to be stored temporarily for use at a later date. High-flow harvesting has been suggested as a viable option for allowing economic development whilst decreasing abstractions from waterbodies during lower flow periods and therefore minimising the risk of detrimental effects on in-stream values.

Water allocation rules could be developed by councils to meet target environmental river flow regimes and encourage high-flow harvesting. In determining effective water allocation rules, councils need to consider whether the allocation rules encourage efficient water use, as required by the National policy statement for freshwater management (2020). It is also important to consider how water allocation rules could interact with water user behaviour to impact the timing and amount of water that is taken.

This work presents results from a model designed to assess the impacts of different water allocation scenarios on river flow and irrigated farm productivity. The model provides a way to evaluate how irrigation users may need to change strategy for taking and storing water in response to a change in water allocation rules. The model can also show how much of consented rate of take users would need to implement efficient irrigation practices. This work can help councils to allocate water in a way that delivers the target environmental flow regime and is consistent with efficient water use.

Methods
A modelling approach is used to explore possible irrigation strategies and the resulting river flow alteration for different water allocation rules. In the model, irrigation users take water according to consent rules, irrigate to meet target soil plant-available water (PAW), and add to storage water if excess consented water is available for harvesting from the river. The resulting plant growth rate, used as a measure of irrigation productivity, is determined from a model based upon physically-based soil-water-crop balance tool, IrriSET (Srinivasan, et al., 2021). Altered river flows are calculated by subtracting abstracted water from measured flow time-series.

River flow alteration and plant growth rate are assessed for several water allocation rules and irrigation strategies, using a hypothetical irrigated area and storage size, but real flow data for a 10-year period. A single irrigation user with a fixed land area and storage size is consented to take all allocated water. The irrigation strategies considered are: no irrigation; taking the maximum allowable water take to maintain target PAW of 60% (with no storage); and taking the maximum allowable water take to maintain target PAW of 60% and a fill a storage.

The “status-quo” water allocation is a cease-to-take flow of 90% 7-day mean annual low flow (7d-MALF) and a maximum take rate of 30% 7d-MALF. This is compared with allocation rules that limit altered flows to be within a specified percentage at points along the natural flow duration curve (FDC). To achieve FDC alteration targets, nine allocation bands are used. Each band has a cease-to-take flow and a maximum take rate calculated as a function of the natural FDC such that higher maximum take rates are allowed at higher flows.

Preliminary Results
The preliminary results for this hypothetical scenario are shown in Figure 1. Comparing the “status quo” and “within 30%” allocation scenarios, the latter yields lesser FDC alteration at low flows without reducing irrigation productivity. For the “within 30%” allocation, all strategies use less than the full allocation amount, demonstrating more water is consented under the “within 30%” allocation than required for efficient use. The more stringent “within 10%” allocation leads to the least FDC alteration, but irrigation productivity is also reduced. The use of storage results in better plant growth rates for all allocation scenarios, and the benefit of storage is greatest for the “within 10%” allocation scenario.

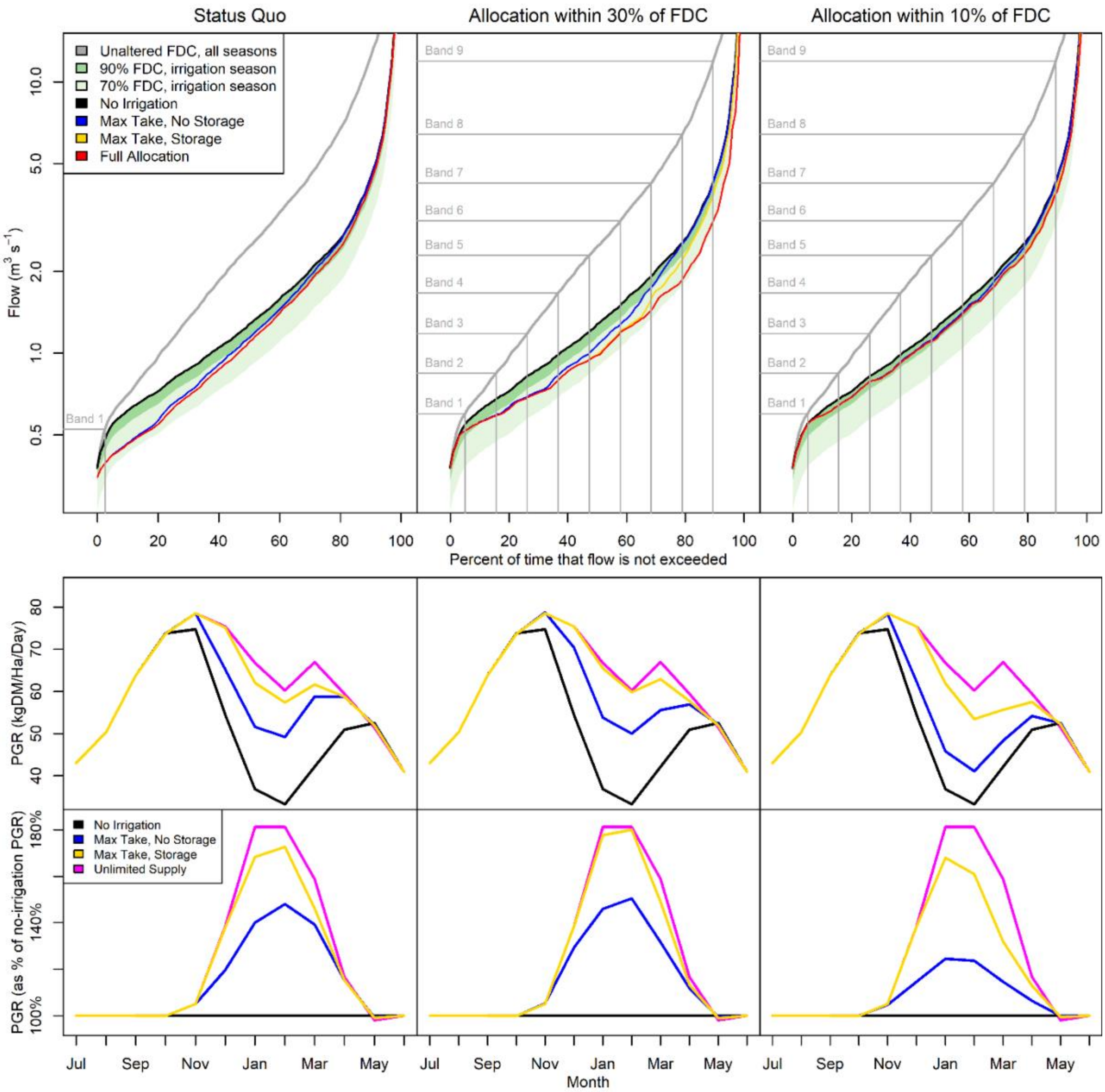

Figure 12: FDCs showing river flow alteration (upper row) and plant growth rate (PGR) (lower rows) for different allocation rules and irrigation strategies. Flow allocation bands are calculated from the all-time FDC. Resulting irrigation season FDCs are shown for each user strategy (No Irrigation; Max. Take, No Storage; Max. Take, Storage) and for if all consented water was to be taken (red). PGR for each month (averaged over the full 10-year simulation) is shown in kg dry matter per hectare per day, and as a percentage of PGR for the "no irrigation" case. PGR for irrigation using a 60% PAW target in the case of unlimited water supply is also given (pink).

Future Work

We have demonstrated the utility of this approach by evaluating river flow alteration and irrigation productivity for different water allocation rules and user strategies, for a hypothetical scenario. We plan to use this modelling procedure to develop agent-based models to explore learned behaviour and interactions between water users to assess the impacts of changing water allocation rules.

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LARGE-SCALE, MANAGED AQUIFER RECHARGE FOR MINE CLOSURE IN THE PILBARA, WESTERN AUSTRALIA

Smith, M,[1] **Hedley, P.**[1]
[1] Rio Tinto Iron Ore

Large-scale, managed aquifer recharge for mine closure in the Pilbara, Western Australia

Dewatering to achieve safe mining conditions of an open pit in the Pilbara of Western Australia has been occuring at cumulative rates in the order of 100ML/d. The outflow from the dewatered aquifer is via a spring system, approval to dewater is conditional on maintaining spring flow via managed irrigation. The irrigation must be maintained after dewatering has ceased until the spring is self-sustaining.

A large-scale, managed aquifer recharge (MAR) is proposed to re-instate the aquifer. With a prescribed period of 20 years post closure to re-insate the aquifer, significant volumes of water, of appropriate quality, will be required.

The scale of Closure MAR is unprecedent within the region, and therefore closure planning is underway to determine the most effective way to transfer and re-instate the aquifer. Groundwater modelling has been undertaken and will assist in MAR scheme design and application.
Integration of large scale MAR within a partially closed mining operation present a number of technical challenges and complexities.

USING TRANSFER FUNCTION NOISE MODELLING TO INFORM GROUNDWATER RESOURCE MANAGEMENT

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Groundwater resources require adaptive planning and management to consider emerging issues, and changes to the resource in terms of development and usage, that could result in changed pressures to the system. Groundwater resources are an essential source of water for many urban centres and agricultural regions in Victoria, and to maintain the longevity of this resource, sustainable extraction needs to be achieved.

Transfer Function Noise (TFN) modelling is being trialed in Victoria for the Victorian Government, to estimate a relationship between groundwater levels and stresses within confined aquifers, as a predictive tool on which to base groundwater management decisions. There are several benefits of using this approach, including that a minimum of only two inputs is required – groundwater levels and a stressor (for example, groundwater extraction). TFN modelling is also more simplistic than traditional 3-dimensional numerical groundwater modelling and can be conducted using no-cost Python packages such as Pastas, which already has groundwater functions programmed into it.

Using Pastas and other Python packages, a large number of datasets can be rapidly analysed to derive a relationship between groundwater level and groundwater use . From this, statistical measures and calculations can be programmed into the model, which can be used to evaluate the suitability of the model. These include the Root Mean Square Error, goodness of fit (R^2), thickess of the 95% confidence interval and the number of observations falling within it.

Once model calibration is achieved, the relationship can be used to estimate future groundwater levels based on a series of forecasted groundwater use scenarios. The results from these future groundwater use scenarios can be used to inform sustainable resource extraction decisions based on tested scenarios. Additionally, once the models are set-up, a repeatable approach is developed that allows updates or iterations as additional data becomes available.

IDENTIFYING GROUNDWATER RISK TO DRINKING WATER RESERVOIRS WHEN KEY DATA IS MISSING – THE DATA SCIENCE APPROACH

Stanmore, E.[1], Diaz, M.[1],Filder, S.[1]
[1] WSP

Aims

The risk that groundwater poses to water quality in drinking water reservoirs can be difficult to determine when a representative groundwater surface contour is not available. Facing a complex scenario, a mine site with over 3,000 hydrologically connected sub-catchments and no groundwater surface contours – WSP took a new approach.

The team developed a qualitative groundwater risk map to inform the likelihood of groundwater expressing above the ground. Risk was conceptualised as the likelihood of potentially saline groundwater expressing at surface in response to mining, then reaching drinking water reservoirs via surface water runoff.

The groundwater risk map was developed by first doing an exploratory data analysis (EDA) to identify correlations between measured groundwater levels and other environmental factors. It was further developed by using an index-based qualitative approach to assess the risk of groundwater expression at surface based on topographic and other environmental parameters. These parameters were identified during the EDA evaluation as having an influence on the depth to groundwater.

Method

The methodology was developed using an adaption of a DRASTIC model (Balaji et al., 2021; USGS, 1999) – which is an index-based groundwater vulnerability mapping model. It was adapted to assess groundwater behaviour in the local mine setting and use EDA results to select parameters with strong correlations (either positive or negative) to depth to water (DTW).

This allowed WSP to develop a spatial representation of risk for groundwater to potentially rise and contribute to surface flow (Figure 1).

The EDA results also enabled WSP to refine the conceptual hydrogeological model (CHM) where hydrostratigraphic units were only derived from a typical soil profile (Anand and Paine, 2002). Based on integrating the EDA results and refining the CHM, hydrogeological parameters were selected and ranked according to significance by assigning a rating (r) from 1 to 10 (with 1 being the least important), and its affect or weight (w) being between 1 and 7. The standard DRASTIC methodology was consequently modified to reflect the local setting and the following equation was used called DRAST-Lu where:

$$DI = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + Lu_rLu_w$$

DI = DRAST-Lu Index (the potential of groundwater rising)
D = depth to water or DTW
R = net recharge
A = aquifer media
S = soil media
T = topography
Lu = land use
and:
$_r$ = rating
$_w$ = weight.

Results

In the DRAST-Lu equation, the D_r rating is an indicator of the risk that groundwater will rise above the ground surface and cause groundwater discharge. As no groundwater contour map was able to be produced (as the site covers a large area), the assessment of the risk rating for D_r was based on a DTW of approximately 15 m (as an indicator of risk); where groundwater depths greater than 15 m are likely to represent a lower risk of groundwater discharging at surface, and groundwater depths of less than 15 m are likely to represent greater risk. This arbitrary depth was selected due to the depth of the site's pit voids and seasonal groundwater level fluctuations of up to 8 m a year.

The CHM identified two groundwater systems, the first and shallowest resides in the upper gravelly soils (Grigg and Kinal, 2020). It is fed by infiltrating rainfall and often forms a perched aquifer above the clay subsoil, generating shallow throughflow, which travels laterally and downslope to the stream. The perched aquifer can be laterally and vertically discontinuous, seasonal and extend over large distances, and is typically 'fresh'. A permanent groundwater system is also usually present as a single unconfined aquifer in the saprolite and lower pallid zone, typically in areas where annual rainfall exceeds 1,100 mm (Grigg and Kinal, 2020). When the permanent deeper groundwater connects with the shallow system (or daylights at surface), this can lead to increased salinity in overland flow, potentially affecting reservoir water quality.

Using the EDA results, D_r was calculated using DTW and various topographic parameters (in addition to a weaker correlation to annual rainfall), noting the correlation between rainfall and streamflow (as summarised in Griggs and Kinal, 2020). Where actual DTW measurements were available, they were not explicitly considered, as there were often multiple bores (points as x,y) with varying depth to water readings (z) within a single grid (i.e., the grid size for the risk map). Major dams and streams, including a buffer, were defaulted to the highest risk rating.

A spatial approach was used to calculate diffuse recharge over the full mining lease using the Piscopo method (as defined in Balaji et al., 2021). The remaining hydrogeological parameters were derived from public databases such as CSIRO, TERN, the Western Australian government, SILO data, and National Soil Attribute maps.

The groundwater risk map shows results where the DI (DRAST-Lu Index) for each grid cell were calculated using the DRAST-Lu equation. The results depicted the likelihood for groundwater to rise to within 15 m of surface, from the lowest to the highest likelihood.

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STREAMLINING MINING APPROVALS – HOW TO MAKE 100+ UNIQUE MANAGEMENT PLANS IN 12 HOURS

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Aim

Obtaining an 'approval to mine' is an essential process for any mining company. Mining approval applications often comprise multidisciplinary technical reports, where regulatory requirements are stringent, client requirements can be fluid and most have hard deadlines. In response, WSP recently developed a semi-automated reporting process that is flexible, fast, and can input clients changes quickly.

Method

WSP hydrogeologists developed a dynamic Python-enabled workflow to compile over 100 individual surface water and groundwater water management plans (MP) as part of a larger mining application. The coding language allowed us to automate the reporting process, so we could input thousands of changes across 100 individual MPs. Changes included adjustments to text in Microsoft Word related to study area boundaries or even the addition of a new calculation that automatically updated a tick box. The potential to apply this technique on complex projects is immense. Rather than manually changing text, figures or table data in each of the 100 MPs, this workflow allowed for quick, accurate changes to be actioned across multiple documents in moments.

On this project, our client had numerous surface mines within a 40,000+ hectare area, where hundreds of small parcels of unmined land were scattered amongst existing mining areas. Each land parcel required an individual Management Plan (MP) to adequately assess risk to surface and groundwater and had to include provision with regards to management, mitigation, and monitoring measures. Each MP was a Word document containing six figures, 13 tables, and a hydrogeological assessment supported by cross-sections.

Some of the proposed mining areas were within drinking water catchments so accurately reporting on risks to water was centrally important. Surface water was the principal environmental risk and therefore the regulator's primary concern. It followed that the MPs were complex technical documents integrating input from mine planners, geotechnical engineers, environmental scientists, surface water and groundwater SME's, along with approvals specialists – all reports required technical and legal review prior to submission.

Each MP had to:

- Explain the methodology used to evaluate risk to surface water and groundwater, including any interactions between the two.
- Outline the basis of the drainage design for the sub-catchment.
- Detail the unique surface water and groundwater MP, including mitigation measures and emergency responses, for that specific mining area.
- Outline the current and proposed monitoring plans specific for that mining area, and
- Recommend rehabilitation measures.

Our team, in close liaison with the client, developed and automated the process to generate over 100 MPs and 15 main area reports within 12 hours using geospatial data (shape, dxf, tiff), as well as information from Excel and Word, as well as update the geological Leapfrog model and produce unique MPs and main reports (in Word). As inputs, the client supplied the surface water risk assessment and other management and mitigation data via shapefiles, plus any changes to the Word templates. Geological data had already been consolidated but was further refined in the Leapfrog model as drilling data became available, and groundwater monitoring data was supplied intermittently.

Results

It took six weeks to streamline the process. We developed focused work streams, created well-defined roles, built the Leapfrog model, set up templates, and fine-tuned the communication and data dump process with the client, all while developing quality assurance processes such as strict naming protocols, QA/QC test runs as well as manual spot checks. Although our team was in five different states across three time zones, we learnt to mass produce individual high-quality *and* accurate approval documents at speed.

UNRAVELLING THE PATHWAYS RESPONSIBLE FOR LAND-TO-WATER NITROGEN TRANSFERS IN DIFFERENT TYPES OF CATCHMENTS

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Aims

Understanding how much the different hydrological pathways contribute to nitrogen transfers from the land to surface waterways is important, as the identification of source areas and fit-for-purpose mitigation measures, as well as suitable policy responses depend on this understanding. In this study, we aimed to unravel the relationship between hydrological pathways and nitrogen transfers in a group of 47 Taranaki, Waikato and Hawke's Bay catchments, which differed widely in their environmental and land use characteristics.

Methods

Catchment selection criteria included the availability of high-frequency flow and monthly water chemistry data for the 15-year period of 2006 - 2020 and the absence of major point-source discharges or water takes/flow controls. While a preference was given to smaller catchments with lower order streams, limited data availability for such catchments meant that catchment areas ranged from 26 - 2184 km^2 (median 136 km^2) and Strahler orders from 3 - 7 (median 5). Mean annual rain varied between 778 mm and 4338 mm, with a median of 1595 mm. Agricultural land use in the catchments ranged from non-existent to 96% of the area (median 58%).

The Bayesian chemistry-assisted hydrograph separation and nutrient load apportionment model (BACH; Woodward and Stenger, 2018) was applied to the catchment monitoring data. BACH is based on two underlying hypotheses: Firstly, that the dynamic behaviour of stream flow and stream water chemistry can be explained by the temporal variation of contributions from three hydrological pathways connecting the land with the stream monitoring site. Secondly, that these pathway contributions differ in their typical concentrations of environmental tracers, which in first approximation can be considered time-invariant. BACH uses two environmental tracers for 3-component chemistry-assisted hydrograph separation (into near-surface (NS), shallow groundwater (SGW), and deep groundwater (DGW) pathways). Depending on the physical characteristics of the catchment, surface runoff, interflow (lateral flow within the soil zone), and artificial drainage (surface drains or subsurface pipes) can all contribute to NS flows of very young water (typically within days). SGW represents the young groundwater (weeks – months) that in response to seasonal rainfall excess discharges via shallow and short pathways into local surface waters, while DGW represents that component of the older (years – decades) and regional groundwater system that contributes to the streamflow at the monitoring site via deeper and longer pathways. The model also estimates pathway-specific tracer concentrations and loads for each tracer. Based on the analysis of the available monitoring data, Electrical Conductivity (EC) and Total Nitrogen (TN) were identified as the most promising tracer combination for the group of 47 catchments of this study. The selection of TN was particularly advantageous, as TN is not only a valuable tracer, but also of interest in its own right as a major water contaminant. A Hierarchical Cluster Analysis was carried out to group the 47 catchments in catchment types based on their relative stream flow contributions by NS, SGW, and DGW.

Results

The cluster analysis for the 47 catchments identified 10 clusters; the three high-level clusters were used for the TN transfers analysis. In 10 catchments, the DGW pathway contributed the most flow (>50% in six of them); most of these catchments have substantial recharge areas on the Central Plateau. SGW was the most important pathway in the majority of the catchments (n=27; >50% in 11), geographically spread across all three regions, particularly in lowland areas. NS flows were most important in the remaining 10 catchments (>50% in two); these catchments mainly comprised steep catchments in high rainfall areas (e.g. Mt Taranaki, Coromandel Peninsula). It is important to note that at least two pathways contributed ≥20% of the flow in all but one catchment. This is reflected in the the top row of Fig. 1, which illustrates that the average flow contribution of the dominant pathway of each catchment type did not exceed approx. 50%. While the corresponding TN yield fraction profiles (Fig. 1 bottom) broadly reflect the flow contribution profiles, important differences arise from the vertical gradient in TN concentrations (Fig. 1 middle).

Estimated TN concentrations were relatively similar for the NS and SGW pathways ('young' water), but lower for the DGW pathway ('old' water). This pattern reflects that NO_3-N typically accounts in these catchments for the majority of TN and due to its high mobility is readily leached out of the soil zone into the shallow groundwater zone. Based on results of N dynamics studies in the regions concerned, we interpret the distinct decrease in TN concentrations between SGW and DGW as result of one of two processes, or a combination of both. Firstly, where oxic subsurface redox conditions prevail, the concentration gradient is predominantly due to the age gradient of the water, reflecting the steady land use intensification experienced in many of the catchments during the last few decades. Secondly, denitrification has been recognised as substantial N attenuation process in catchments featuring a vertical redox gradient from upper oxic to deeper reduced groundwater zones.

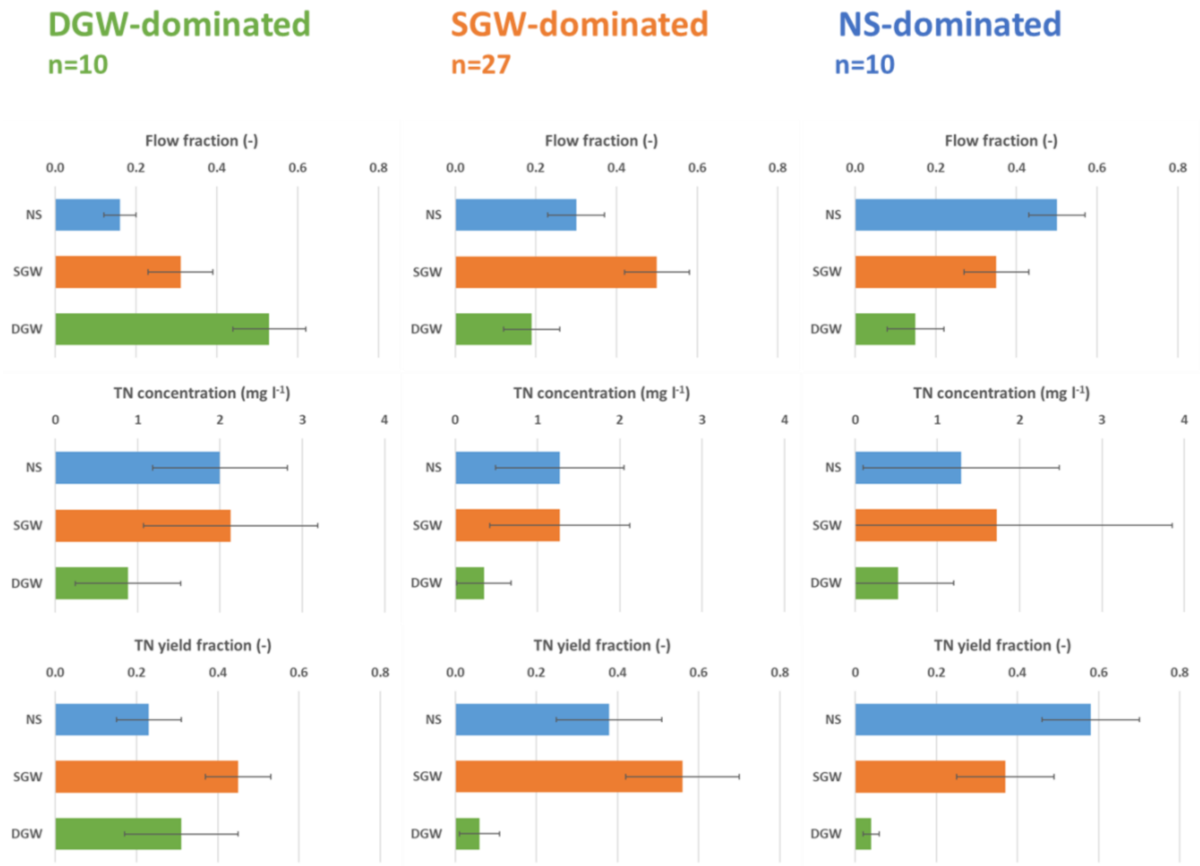

Figure 1: Vertical profiles of water flow contributions (top), TN concentrations (middle) and TN yield fractions (bottom) for DGW flow dominated catchments (left), SGW flow dominated catchments (middle), and NS flow dominated catchments (right). Based on long-term average BACH estimates (2006 – 2020).

Due to these concentration gradients, the fraction of the TN transferred by DGW was in all three catchment types smaller than the corresponding water flow fraction (0.31 vs 0.53 in DGW-dominated catchments, 0.06 vs 0.19 in SGW-dominated catchments, 0.04 vs 0.15 in NS-dominated catchments, 0.11 vs 0.25 overall). This made the SGW pathway the most important TN transfer pathway in DGW-dominated and SGW-dominated catchments (0.45 and 0.56, respectively) and the most important TN transfer pathway across all 47 catchments, on average accounting for 49% of the current TN yield.

Even without further intensification, TN yields could potentially increase in the future in catchments with high DGW flow contributions due to legacy TN still being in transit in the DGW system. Long hydrologic lag times could potentially result in a significant TN 'load to come' in such catchments. While it is generally not known what fraction of the observed vertical TN concentration gradient is due to denitrification rather than lag time, at least the maximum 'load to come' can be estimated. If DGW TN concentrations were over time to reach current SGW TN concentrations, TN yields of the DGW-dominated catchments would increase on average by 54% (from 9.2 to 14.2 kg ha^{-1} y^{-1}).

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REACTIVE NITROGEN DEPOSITION ON NEW ZEALAND: PAST AND FUTURE

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1. Aims

The objective of this work is to gain understanding of reactive nitrogen deposition via wet and dry deposition on New Zealand through time.

2. Methods

The rise of industry worldwide led to the phenomena of acid rain which has been shown to have damaging effects on ecosystems including lakes and forests in some areas of the world. Increases in acidity in the atmosphere and rainfall comes mainly from release of sulphur as SO_2 and reactive nitrogen as NO during combustion of fossil fuels. As cleaner (lower S) fossil fuels are being used and as the use of fossil fuels is phased out in favour of cleaner energy sources, so has rainfall acidity declined.

In their 1986 study of acid rain in New Zealand, Holden and Clarkson (1986) considered only the effects of sulphur from industrial sources in Australia on New Zealand, and concluded that ".. acid rain is not a significant problem in New Zealand, and is never likely to be .. Also, because the majority of our soils are sulphur deficient, small additional quantities of sulphate deposition may be beneficial to many hill country areas."

However, there is another potent source of reactive nitrogen - industrial fixation of atmospheric nitrogen to ammonia via the Haber-Bosch process invented in 1908. Ammonia is used to produce fertilisers and for the armaments industry. In the 100 years since invention, Haber-Bosch fertilisers have enabled the world's population to be fed, and to increase to 6 billion, about double what could have been sustained without Haber Bosch nitrogen (Erisman et al., 2008). In the next 100 years, the consumption of Haber Bosch nitrogen is expected to double based on IPCC storylines. This suggests that deposition of reactive nitrogen on New Zealand will not be going away, even if acid rain is declining.

3. Results

Australia as a continent upwind of New Zealand is the most obvious source region for reactive nitrogen. What happens in Australia is reflected in the atmosphere and precipitation over New Zealand, although modified by passage over the Tasman Sea. The influence of Australia on the stable isotopes of rainfall in New Zealand was documented by Stewart et al. (2020). Atmospheric circulation models show a lesser influence of other population centres in the Southern Hemisphere.

One effect of reactive nitrogen deposition on New Zealand freshwater systems is to add to the background nitrogen load of pristine streams and lakes (where there is no agricultural runoff, McGroddy et al., 2008). In oxygenated systems these become nitrate loads. Such background nitrate has been reported for Te Waikoropupū Springs where the level of nitrate is considered critical for the continued health of the springs (Stewart et al., 2023).

These effects will be explored in the talk.

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POWERING SAFE DRINKING WATER FOR AUSTRALIAN FIRST NATIONS REMOTE COMMUNITIES.

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Background:

Australia is home to more than 1,100 diverse and culturally rich First Nations communities. A significant number of these communities, particularly in remote regions, face challenges in accessing clean affordable drinking water, including desert regions where groundwater is the only reliable source.

Barriers to providing clean drinking water include a lack of proven fit-for-purpose technologies to treat water across the range of remote settings. Communities differ in how much water is available, how much is required, what chemical or biological contaminants are present and what treatments are required to meet safe drinking water guidelines. For example, in some places groundwater contains high levels of salts or heavy metals like arsenic and uranium, necessitating thorough treatment. This also poses a unique set of obstacles in terms of energy requirements (high as often involves a number of different stages) and system maintenance.

The challenge:

The Department of Climate Change, Energy, the Environment and Water leads the integrated delivery of the Australian Government's agenda across climate change, energy, the environment, heritage and water. While some water treatment systems are able to be solar powered, additional innovative technologies are required which:

- integrate renewable energy and water purification solutions
- are suitable for First Nations remote community needs and
- can withstand harsh environmental conditions with little maintenance.

Systematic, repeatable and scalable solutions would reduce capital costs, simplify decision-making and make it much easier to maintain systems across remote locations. Ideally, any solution will be developed in partnership/collaboration with First Nations communities to ensure a fit-for-purpose result.

This presentation will outline a current project on the above.

CAPABILITY UPGRADES TO THE AUCKLAND-BASED HIGH RESOLUTION MOBILE WEATHER RADAR

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Characterizing the spatio-temporal structure of rainfall remains a significant challenge in hydrology. Catchment monitoring of rainfall in New Zealand is typically undertaken with rain gauges, yet the resulting interpolated rainfall fields are well known to introduce significant biases which propagate into modelling applications. A pragmatic mitigation is to combine rain gauge and weather radar observations in order to include information about how rainfall patterns vary between gauge sites. In New Zealand, rainfall analysis systems which provide Quantitative Precipitation Estimates (QPE) by merging of local-government rain gauge networks and MetService radar have been established by the authors for urban centres such as Auckland, Wellington and Dunedin.

However, national weather radar networks, such as that run by MetService, are operated for a range of forecasting applications including transportation/aviation safety requirements and are not (and will never be) configured for optimal generation of QPE products. The operational and safety-critical nature of the national network means it is also not possible to temporarily reconfigure the radars for research purposes. Furthermore, many hydrologically interesting catchments are located outside the coverage of the national network. Mobile research weather-radar systems address these limitations by providing observation platforms which can be optimally configured for catchment hydrology studies.

In this presentation we report on the outcomes of a Ministry of Business, Innovation and Employment funded “Smart Ideas” project to make science capability improvements to the “Trailer Radar” platform, a high-resolution mobile weather radar constructed at the University of Auckland circa 2005. A novel receiver chain based on Software Defined Radio (SDR) was developed allowing velocity spectral data processing from low-cost marine-radar hardware. The upgraded equipment has similar performance to much more costly weather radar and the ability to estimate drop-size distributions. The platform was deployed in the Auckland region to collect data at exceptionally high spatial and temporal resolution (<100m pixels, <30 sec sampling intermittency, in comparison to 1 km pixels with a 7.5-minute sampling intermittency for the MetService radar data). The equipment was operated during a variety of recent notable weather including Cyclone Gabrielle. Preliminary results showing how the precipitation data from the new equipment aids in understanding rainfall processes is presented.

DIFFICULTIES OF PREDICTING CONSTRUCTION DEWATERING EFFECTS VS ACTUAL MEASURED EFFECTS NEAR CRITICAL INFASTRUCTURE

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Large Infrastructure projects, particularly tunnelling require excavations through soil and rocks, often encountering groundwater. Groundwater monitoring and mitigation measures are necessary to prevent large scale dewatering and settlement of previously saturated geological formations. This is particularly important near high-value or high-risk infrastructure.

A stormwater outfall upgrade project located within Auckland's CBD across two sites joint by 280 m of pipe-jacked subsurface construction through a mixture of reclaimed land, marine sediments and Waitemata group near residential and industrial areas The project connects an existing twin-pipe to a new outfall.

The potential effects of dewatering during the construction were predicted during the conceptual modelling and assessment of environmental effects (AEE); however, continued monitoring has been undertaken during the construction phase to determine the actual observed groundwater drawdown effects. The aim of this study was to assess the predicted drawdown effects against the observed groundwater drawdown effects through real-time telemetry monitoring.

24-hour monitoring of the groundwater levels was installed due to the risk of ground settlement and the potential of damage to critical infrastructure and transport networks. Tidally influenced saline groundwater was an additional challenge to monitoring. Periods of temporary dewatering were required throughout the duration of the project, therefore trigger levels were set. Constant telemetered pressure transducers were deployed at multiple onsite monitoring boreholes and monthly manual measurements were taken. Due to complications of the monitoring network systems; manual pressure transducers were also installed, and the frequency of manual measurements increased to capture any data gaps or failures.

Although the project is ongoing, the dewatering phase has ended with groundwater levels returning to previous levels. The observed drawdown during the construction phase was greater than predicted in the AEE due to existing infrastructure complications. As a result of the above exceedances, the monitoring frequency was modified to minimise any future settlement risks.

SUBSIDENCE IN LELOCLE (SWITZERLAND): GEOLOGIC CHARACTERIZATION AND IMPACT OF URETEK RESIN INJECTION ON GROUNDWATER FLOW

Giulio Taietti,[1]
[1] Beca - Christchurch

The city of Le Locle has alwaiys being affected by land subsidence due to the presence of a thick layer of peat underneath the city, and enhanced by the canalisation of the river Le Bied below the city and hypothetically also by climate change, which has caused extensive structural damage. To respond to this problem and preserve some historical buildings, the city council decided to inject Ureteck resin (high-pressure expansion resin) to lift the sunken buildings and prevent further subsidence.

Using all the boreholes logs of the city and its surroundings, several cross-sections of the area and a map of peat thickness were created, making it possible to identify the expansion of the peat and the areas most susceptible to ground subsidence. Because of this, it was possible to correlate the cases of subsidence observed within the city with the expected subsidence calculated due to the load, which on average represents only 30% of the value, confirming the already existing hypothesis that the main cause of the phenomenon is the lowering of the water table within the peat. In addition, using the sections, it was possible to recreate a groundwater model using FeFlow software, which recreated the groundwater flow in the peat layer underneath the city and estimated the alteration of it and the potential subsidence caused by Uretek resin injections.

While the damage caused by the Ureteck resin injections is estimated to be low or negligible, the future does not look too optimistic for Le Locle. Although the situation is relatively stable for now, there is a high probability that with climate change, the further we go, the higher the temperatures will rise and the lower the water level will drop in Le Locle, leading to a gradual but steady increase in the subsidence problem.

ASSESSMENT OF EMPIRO-ANALYTICAL DRAWDOWN ESTIMATION METHODS IN THE AUCKLAND REGION

Mauricio Taulis,[1] Sian France[2]
[1] Beca Ltd

Projects involving excavation works that could lead to groundwater diversion are subject to compliance with chapter E7 of the Auckland Unitary Plan in the Auckland region. Specifically, if such projects induce a natural groundwater level reduction of more than 2 meters along adjoining site boundaries, they must demonstrate that potential drawdown-induced settlement will not damage existing structures and infrastructure. To this end, developers in the Auckland region commonly utilise various drawdown estimation techniques, which encompass analytical approaches based on the Dupuit-Forchheimer Theory as well as empirical formulas like Sichardt (Powers et al., 2007).

Although these methods are useful for estimating groundwater discharge into excavations, they may exhibit inaccuracies when estimating drawdown away from excavations. Notably, Dupuit methods are based on wells of small radius in comparison to the radius of influence, which does not align with actual excavation scenarios. Also, Hantush (1962) has shown that equations based on the Dupuit-Forchheimer Theory can result in considerable errors when used to predict drawdown. Our experience with excavations in Auckland's low permeability soils and rock underscores that Dupuit-Forchheimer and Sichardt-based methods tend to underestimate drawdown away from excavation sites.

This assessment offers a comparative analysis between these commonly used methods and a 2D numeric modelling approach using SEEP/w. These methodologies are applied to a hypothetical Auckland site with an excavation through Puketoka Formation soils overlaying ECBF rock. Moreover, the findings are contrasted with actual drawdown data derived from our practical experience in the region's excavation projects. This study provides a comprehensive understanding of the strengths and limitations of various drawdown estimation methods, enhancing the ability to make informed decisions and implement effective monitoring strategies in excavation projects within the Auckland region.

COUPLING OF GROUNDWATER AND SURFACE WATER MODELS IN NZWAM

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[2] NIWA

Informed water management decisions require understanding the interactions between groundwater and surface water. Models provide a way to represent various hydrologic processes with different levels of complexity. Groundwater models often simplify atmospheric, surface water, and unsaturated zone processes and focus on representation of subsurface properties. Surface water models often simplify groundwater flow and focus on partitioning of water between the atmosphere, surface water, and shallow subsurface. Combining the complexity of both approaches provides the potential of improve simulation of shallow groundwater and surface water interactions. However, care must be taken to ensure the conceptualization of the groundwater and surface water systems are compatible to avoid misrepresentation of important system behaviour.

This work explores the results from various combinations of TopNet and MODFLOW 6 for the Parawa catchment (Mataura, Southland). TopNet is a surface water flow model based on TopModel that has been developed and used by NIWA for the last 10 years. Recent developments have extended the representation of the groundwater system using various levels of complexity. TopNet-GW routes groundwater based on "groundwater catchments" defined using external estimates of groundwater heads. TopNet has also been coupled "offline" to the EWT and MODFLOW 6 models using estimates of recharge from TopNet as MODFLOW recharge inputs. Finally, a direct coupling of MODFLOW 6 and TopNet was implemented using XMI (eXtended Model Interface, based on Basic Model Interface). This coupling allows groundwater-surface water exchanges to be passed between two dynamic (transient) models at the time-step level. This implementation requires converting catchment-based TopNet drainage to grid-based MODFLOW recharge and grid-based MODFLOW stream discharge (implemented using the Drain package) to catchment-based TopNet streamflow. These conversions are accomplished using the Gridit Tool.

CATCHMENT-WIDE MEASURES TO MITIGATE THE EFFECTS OF DROUGHTS ON AGRICULTURAL PRODUCTION, NATURE DEVELOPMENT, AND STREAMFLOW: A MODELLING-APPROACH

Wilco Terink,[1,2] Gé van den Eertwegh,[2] Dion van Deijl[2]
[1] Q-Hydrology (https://q-hydrology.co.nz)
[2] KnowH2O (https://www.knowh2o.nl)

As a result of climate change, periods of high-intensity rainfall and prolonged droughts are becoming the new normal in many parts of the world. The Netherlands is no exception to this. During the last decade, prolonged periods of minimal rainfall and high summer temperatures had detrimental effects, including reduced biomass production in the agricultural sector, ecological damage, and the depletion of streamflow, causing streams to run dry.

The Dutch water system was traditionally engineered to drain excess water, facilitating early access to farmland for cultivation. This involved the installation of drain pipes and the excavation of trenches. However, as meteorological droughts are becoming the new normal, a new holistic catchment-wide approach is needed. Such an approach is crucial to sustain agricultural production, safeguard natural areas, and prevent streams from running dry in the future.

In order to assess the effects of various catchment-wide measures on agricultural production, nature potential, and streamflow sustainability, we undertook the development of a novel spatially distributed agro-hydrological model. This model was built from scratch, utilising the PCRaster dynamic modeling framework. Concepts from well-established models were implemented to enable the separation of evapotranspiration into interception, soil evaporation, and plant transpiration, with the latter being a proxy for agricultural production. The model was then calibrated on measured streamflow, and validated against groundwater levels and local farmers' knowledge on transpiration fluxes and irrigation volumes. The Reusel upstream catchment was selected as a pilot area because agriculture has intensified in this area over the last few decades, streamflow was zero for several months during 2018, and the catchment is drought-sensitive due to its sandy soils, relatively high elevation, and low groundwater table.

The effects of the following catchment-wide measures will be shown:

A) No irrigation
B) Different crops and crop-rotations
C) Reforming nature areas
D) Region-wide increase of groundwater table

MANGANESE CONTAMINATION INCIDENT AT TIMARU WATER SUPPLY

Callander, P.,[1] Harper, A.,[2] Hall, G.,[2] Rosado, C.,[3] Massey, M.,[3] Thomas, N.[1]
[1] Pattle Delamore Partners Limited
[2] Timaru District Council
[3] Environment Canterbury

Aims

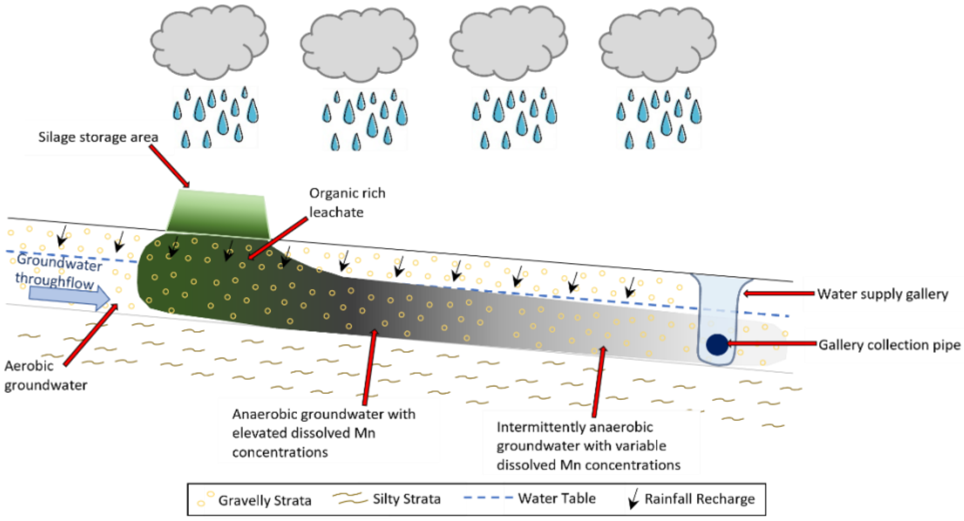
The Timaru water supply is partly sourced from a shallow gallery adjacent to the Opihi River near Pleasant Point which has two limbs, a riverside limb oriented parallel and adjacent to the river and a landward limb, extending perpendicular to, and away from, the river. The gallery was being used as the main source of supply during December 2020 and January 2021 when complaints of discoloured water were reported by residents. The aim of this paper is to describe the cause of the contamination and the measures that have been put in place to avoid a recurrence.

Methods

Investigations by Timaru District Council (TDC) demonstrated that the discolouration was caused by elevated manganese (Mn) concentrations. Measured concentrations exceeded aesthetic guidelines for staining and taste, with a maximum measured concentration of 0.36 g/m^3. There were no reports of adverse health effects and the Maximum Acceptable Value of 0.4 g/m^3 was not exceeded in any of the gallery water samples.
There were no known anthropogenic sources of manganese in the area, but groundwater sampling from monitoring bores indicated that organic matter in the groundwater was causing sub-oxic conditions. Subsurface bacteria obtain energy through redox reactions involving electron donors (typically organic matter) and a variety of electron acceptors that generally occur in a sequence from high energy release to lower energy release. First, oxygen is depleted, and anaerobic respiration becomes dominant. Oxygen depletion is typically followed by depletion of nitrate through denitrification, then release of manganese and iron into solution, followed by the depletion of sulphate. The source of manganese and iron is the manganese and iron oxides that are present in or on the sediments of the alluvial gravel aquifer used for the water supply.

Results

The organic matter in the aquifer appeared to be from agricultural activities in the area ~0.5–1 km upgradient of the gallery, including a silage storage area and intensive stocking. The contamination coincided with heavy rainfall events of 160-240 mm/month, which could have pushed the low-oxygen groundwater toward the gallery, and also caused a change in gallery operations whereby all the water was drawn from the landward limb, since the riverside limb was shut down due to turbid river conditions.



The silage stack has now been removed from the area. TDCs response has been to more actively monitor water quality using continuous pH and electrical conductivity probes and handheld testing meters for manganese, and to improve the ability to separate off different sections of the gallery to avoid drawing in contaminated water. In the longer term, the proposed new Timaru Urban Water Treatment Plant will enable the treatment and use of water that is more turbid than that which currently can be used.

This is an example of commonplace farming activities within a drinking-water source water risk management area causing a change in groundwater conditions leading to contamination. The challenge in the future is to identify these circumstances and manage them before they become a problem.

DANCING IN THE RAIN – EVALUATING HYDRAULIC CONNECTIVITY FROM SURFACE TO UNDERGROUND

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Hydrological science, engineering and creativity are needed to inform evaluations of hydraulic connectivity between the surface and sub-surface. We need multiple approaches to evaluate and mitigate increasing stresses on our freshwater resources. Ensuring that freshwater resources are not polluted is challenged by increasing water demands, developments in water sensitive areas and a more variable and extreme climate. This presentation considers potential connectivity between the earth's surface and groundwater, proposes several principles for prioritising data and provides examples of recent advances to evaluate hydraulic connectivity. For example, passive water level techniques are useful to verify conceptual models of surface water and groundwaters and degree of hydraulic disconnection by soils or rock strata. Another approach quantifies thresholds of rainfall events needed for soil moisture responses and 'drips' through the vadose zone to the watertable. Hydrological shifts from gaining to loosing streams or wetlands can occur quickly or gradually, and compound challenges with water quality and ecosystem health.

DEWATERING OPTIMIZATION FOR OPEN-PIT IRON ORE MINES BASED ON A COMBINED FLOW SIMULATION-OPTIMIZATION FRAMEWORK

Saeed Torkzaban[1], Lucy Du[1], Paul Hedley[1], Sylvie Ogier-Halim[1], Keith Brown[1]
[1]RioTinto, Perth, WA, Australia

Dewatering is a crucial process in open-pit iron ore mines, ensuring safe and dry mining conditions. However, significant groundwater extraction can lead to environmental and cultural impacts, including reduced groundwater levels near groundwater-dependent ecosystems and the disposal of excess water on surface.

In this study, we propose an innovative approach to optimize dewatering strategies by integrating an optimization algorithm with a calibrated groundwater flow model. This novel method allows for the identification of the most water-efficient dewatering scheme while meeting mine-plan objectives.

The study demonstrates the potential of using a groundwater-flow model as a decision-making tool to achieve sustainable dewatering while minimizing the overall dewatering volumes. This approach addresses environmental concerns and contributes to responsible water management in open-pit iron ore mining operations. The findings offer valuable insights for the mining industry to achieve their objectives while reducing their environmental impacts.

A RADICAL REFRAMING OF WATER MODELLING?

Sam Trowsdale,[1]
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A predictive urban water quality model was developed based on the familiar foundation of adaptive sampling algorithms and machine learning. This was nothing particularly new or novel. However, the model was explicitly designed to be a political actor that worked to improve water quality by developing a new public engaged in the conversation about water quality. This is quite different to the normal apolitical act of modelling, whereby politics is kept out of modelling and modelling should humiliate politics. The success of the model can be understood using the theory of orders of outcomes. A first order outcome was the ability of the model to accurately predict water quality. A second order outcome was the production of a new public with the desire to improve urban water quality. A third order outcome was a public commitment to fund infrastructure upgrades to address the root cause of the water quality issues. A fourth order outcome was improved water quality itself. Here, then, we have a case of a model working to improve water quality; which, after all, is the aim, is it not? It is our contention that with a little tweaking of the way we understand our models to work, the hydrological discipline could make more powerful interventions in the management of water quality.

DOES NEW ZEALAND NEED A COLLABORATIVE GROUNDWATER/FRESHWATER CENTRE?

Conny Tschritter,[1] Karyne Rogers,[1] Chris Worts[1], Stewart Cameron[1], Jamie Brathwaite[1], Ryan Willoughby[1],
[1] GNS Science

Interviews and discussions with representatives from regional councils, research organisations and universities have highlighted the lack of groundwater and, in general, freshwater capacity/capability in New Zealand as an ongoing issue. Other issues identified were for example the lack of coordination and collaboration between research organisations, regional councils, and universities etc; the lack of outreach materials available; and the lack of profile and awareness of groundwater underneath the ‘freshwater’ umbrella term.

Potential solutions could include development of outreach and education material, investigating avenues to increase groundwater/freshwater education at primary and secondary schools as well as universities, and the development of freshwater-related training courses and ‘hydro’ camps. While these initiatives could be a first step, there is currently no organisation or initiative in New Zealand who is driving these.

A collaborative groundwater/freshwater initiative or centre, collectively driven and supported by research organisations, universities, regional and central government, and industry may provide a solution to these issues, for example by providing training, outreach and education material, and a coordinated infrastructure between organisations.

In this presentation, we will enable audience feedback about whether we need a collaborative initiative or centre; what the scope would be (groundwater/freshwater); what it could involve; how it could align with the Te Ara Paerangi – Future Pathways Programme; and who could be involved.

HOW CERTAIN ARE WE OF THE PARAMETERS OBTAINED FROM AN AQUIFER TEST?

Kurt van Ness,[1]
[1] Environment Canterbury

Effective management of groundwater resources is critical for ensuring freshwater availability and sustainability. Traditionally, this requires a conceptual understanding and modeling of aquifer characteristics, such as transmissivity or hydraulic conductivity, to determine how groundwater in an aquifer will respond in different situations. These characteristics are often estimated through the use of aquifer pump tests and observing how groundwater levels respond to different rates of pumping.

Many tools exist to help analyse observed drawdowns in groundwater levels in a bore, but they typically produce a single best-fit solution, which may not be suitable for decision-making in situations where conservative estimates are needed. Utilising a Monte Carlo approach, it’s possible to find an entire range of potential aquifer parameter values that effectively describe the observed water level response to pumping from a bore. Under some decision-making situations, having a better understanding of the potential range of aquifer parameter values could be essential in providing desired outcomes.

In this presentation, I will discuss the concepts above and demonstrate the use of a small-scale web app that was developed to make it easier for anyone to take a Monte Carlo approach in their aquifer test analysis.

EXPLORING MANAGED AQUIFER RECHARGE FOR AUGMENTING WELLINGTON'S WATER SUPPLY IN AN UNCERTAIN FUTURE

Eric van Nieuwkerk, MSc.,[1] Dr. Jeremy Bennet,[2,3] Dr. Katie Coluccio,[1]
[1] WSP New Zealand
[2] Wellington Water
[3] Tonkin + Taylor

Wellington Water and Connect Water undertook a water source options assessment to ensure a long-term sustainable water supply for Wellington. With uncertainty in population growth, regulatory change and the long-term effects of climate change and sea level rise, ensuring water availability for the capital is crucial. The rivers and aquifers of the Hutt Valley, that currently serve as Wellington's primary water source, are already susceptible to seasonal water storage deficits, prompting consideration of options such as increasing storage capacity, recycling, and managed aquifer recharge (MAR).

MAR often forms part of water supply adaptation strategies due to its small footprint, cost-effectiveness, scalability, and adaptability. It has proven successful both locally and internationally, providing reliable and clean water sources for diverse purposes over several decades. Therefore, MAR was considered as part of the water source options assessment for Wellington.

Currently, Wellington Water abstracts groundwater within the Lower Hutt Valley from the Waiwhetū Aquifer. Because of the proximity of the wellfield to the coast, and extension of the aquifer beneath Wellington Harbour, there is a risk of saline intrusion. This is managed by continuous monitoring requiring and abstraction reduction when alert levels are approached. This forms a challenge in dry summer periods when demand is highest. MAR could potentially provide a storage and supply solution to bridge dry periods.

We completed a preliminary feasibility assessment of MAR exploring different model scenarios with varying abstraction and injection well configurations and pumping regimes. This showed that MAR could potentially allow for sufficient summer recovery while avoiding saline intrusion risks. Despite uncertainties, the study provided the evidence needed to progress further investigations to improve understanding of the hydrogeology possibly leading to a MAR pilot. If MAR is feasible, it could provide an attractive option for Wellington Water to balance supply and demand in an uncertain future.

GROUNDWATER REPLENISHMENT FROM CARTERTON WATER RACE SCHEMES SEEPAGE

Louise Soltau,[1] Lawrence Stephenson,[2] Eric van Nieuwkerk[1]
[1] WSP New Zealand Limited
[2] Carterton District Council

Rural water distribution schemes provide for economic benefits to farming, however, they are also associated with losses to groundwater which can be undesirable from water allocation perspectives. Carterton District Council (CDC) operates two water distribution schemes to distribute water taken from the Waingawa River and Mangatarere Stream around the district, predominantly for agricultural and some industrial purposes. To show the water is used for consented purposes, an estimation of loss from the water races to groundwater is needed for consent renewal.

Limited data is available and water losses were estimated using two methods: a high-level water balance and a groundwater seepage analysis.

For the seepage analysis we considered the aquifer is unconfined and water can readily seep through the base of the water races into either a saturated or an unsaturated flow system. Groundwater seepage will occur as a dual system: 1) Where the unsaturated zone is thick (i.e., groundwater level is more than 1 m below the race level), slow seepage into the vadose zone is likely. The water races are effectively perched and seepage to groundwater was estimated assuming vertical seepage. 2) Where the unsaturated zone is thin (i.e., groundwater level is close to or above the race elevation) there is likely a direct hydraulic connection between the race and the groundwater, with seepage along a “wet” front. The seepage along these sections is estimated assuming wet front radial outflow.

Losses were estimated at 31-61%, so considerable. It is acknowledged there are inherent uncertainties in the methods and assumptions, and further investigations are recommended. Despite this loss to groundwater, there is also evidence of benefits to overall aquifer replenishment and support to downstream groundwater dependent wetlands and streams. The leakage from the water races should therefore be viewed on it’s overall impact on water resources, including beneficial effects.

REMOTE SENSING. A TOUR OF THE PRACTICAL, THE IMPRACTICAL AND OUR REASONABLE EXPECTATIONS ON TODAYS TECHNOLOGY.

Dirk van Walt[1]
[1] Van Walt Ltd

One-size-fits-all, universal adaptor, silver bullet, miracle elixir, plug and play, general purpose. Some are a myth, some might work (sort of) but ultimately all are underwhelming. When it comes to remote sensing in the field there are many variables and challenges that make every monitoring site unique. Is there any cell reception? What are the chances of rats chewing the cables? Will the heat of the day affect a long cable run? Is it a hot spot for vandals? Do I need a helicopter to access? Do I need a hot-works permit? The list goes on. So, let's dive in and take a look at some real-world systems and the challenges that were overcome when installing kit in middle of the city, the top of a mountain and even in the hot-works of a fuel terminal to get reliable data to your office desktop. We'll take a look at the challenges of access to busy construction sites, how to protect equipment from heavy machinery and traffic, how to protect equipment from flooding, snow and extreme weather events, how to overcome poor reception at the sample location and how to plan an install on a remote location. We will also talk about the availability of parameters and discuss which are reliable in the field and which require more maintenance.

THIS IS ONLY THE BEGINNING - AUSTRALIA'S INDIGENOUS GROUNDWATER DECLARATION

Kelly-Jane Wallis,[1] Sarah Bourke,[2] Brad Moggridge, [3]

[1] SLR Consulting
[2] University of Western Australia
[3] University of Canberra

The Indigenous Groundwater Declaration aims to raise awareness among the groundwater community, and beyond, of the value of Indigenous perspectives and knowledge of groundwater systems. The declaration was signed at the Australasian Groundwater Conference in Perth in November 2022 when it became a live declaration available for anyone to sign on to. Whilst the declaration was created a year ago, it is acknowledged that no traction is to be lost with this initiative and conversations are encouraged to continue.

This presentation provides an introduction to the Indigenous Groundwater Declaration to bring everyone up to speed, reflects on the knowledge sharing that been achieved through the declaration to date, and offers some practical ideas on how we can better integrate Indigenous knowledge and connections into groundwater resource management.

IAH Australia invites everyone to read and sign the Indigenous Groundwater Declaration to acknowledge, champion and support through actions for the betterment of including and respecting Indigenous knowledge in groundwater activities, deliberations, decisions and policies. The full declaration can be viewed and signed at: http://declaration.iah.org.au.

Biography

Kelly-Jane is a Principal Hydrogeologist at SLR Consulting with over 15 years' experience in hydrogeological assessments. Kelly-Jane is skilled in conceptual hydrogeology, groundwater impact and risk assessments, water quality assessments and project management. Kelly-Jane has managed large, multi-disciplinary projects with technical, client and regulator stakeholders. Kelly-Jane actively contributes to the national hydrogeological community through promotion of Early Career initiatives and is a volunteer for The Groundwater Project. Kelly-Jane was a core Committee Member for AGC2019, AGC2022 and is on the AGC NZHZ and IAH International Congress 2025 organising committees. Since the start of 2022, Kelly-Jane is President of IAH Australia and a councillor of the Australian Geoscience Council. Prior to this Kelly-Jane was on the Queensland IAH committee since 2017.

SIMULATION OF DRAINAGE FLOW IN UNSATURATED FRACTURED ROCKS

Xuyan Wang
Klohn Crippen Berger, Brisbane, Australia

Effective representation of groundwater behaviour in unsaturated zones within the fractured aquifer system is essential for addressing natural disaster issues line landslides and slope stability in engineering design. Groundwater modelling software, like FEFLOW and MODFLOW, provide some convenience in modelling the unsaturated flow in such complicated groundwater systems. However, modelling drainage flow in unsaturated zones is still a big challenge due to the difficulties in model boundary setting and the determination of unsaturated hydraulic properties for various scales of fractures. The goal of this study is to provide a feasible way to simulate the drainage flow in a multiple perched groundwater system with an upper scaling approach. A 3D FEFLOW model was built to simulate subsurface flow mitigation with a shear (fracture) across multiple unsaturated/saturated transition zones. An upper scaling approach is invoked by synthesizing data from literature to determine the representative parameters of the van Genuchten (VG) function, which is used for simulating unsaturated flow in fractures. Both Hydraulic-Head (flow constraint) and Fluid-Transfer boundary conditions with a DFE for modelling drainage flow are tested in saturated/unsaturated transition zones. The proposed method showed that the complex flow behaviours such as multiple water tables and wedge-shaped unsaturated zones, and drainage flow in highly heterogeneous fractured structures, could be simulated with acceptable engineering accuracy.

PRACTICAL EXAMPLE OF THE POWER OF MICROBES UNDERGROUND – SAMPLING IN TAKAKA OVER 5 YEARS

Weaver, L.[1] Thomas, J.[2] Webber, J.[1] Bolton, A.[1] Abraham, P.[1] Masterton, H.[1] Doake, F.[1,3] Sitthirit, P.[1] Gowo, P.[5] Westley, M.[2] Shearer, K.[4] Taylor, W.[1] Dupont, P-Y.[1] Close, M.[1]

[1] Institute of Environmental Science and Research (ESR) Ltd.

[2] Tasman District Council

[3] currently Ministry of the Environment

[4] Cawthron Institute

[5] University of Auckland

Aims

Groundwater provides us with a vital Source of drinking water as well as supplying water for irrigation. Moveover, groundwater provides the baseline flow for our surface waters and is an integral, but often overlooked, part of the water cycle. Within groundwater a host of living organisms undertaken a complex range of services that cleans our water so we have safe drinking water and, maintains the flow of groundwater ensuring the water cycle continues. We know surprisingly little about this ecosystems and the services they provide as well as their vulnerability to anthropogenic and climate stress.

As part of our research investigating the diversity of organisms present in our groundwater, their function and their susceptibility, we have undertaken an extensive survey of a catchment in the Upper South Island over the past five years. We have sampled the complex aquifer systems in the Takaka Valley, Nelson. With the assistance of Tasman District Council we have sampled diversity present, from micro- to macro-scale across the shallow gravel aquifers, limestone aquifers, and the deep Arthurs Marble aquifer . From this data, we are building a picture of the diversity present in the aquifer systems and begin to understand their function and vulnerability.

Methods

The sites sampled were selected based on the suitability for collection of Stygofauna (groundwater macrofauna), the location of the bore or spring (which aquifer connected to), and accessibility for sampling (Figure 1). Using the guideline protocols[1] we have sampled for water chemistry (analysed by Hill Laboratories, Christchurch), fished for stygofauna, and filtered for meiofauna (Protists) and microorganisms (bacteria, archaea, fungi).

Results

During our sampling over the past 5 years we have seen a diverse range of organisms present, from micro-to macro- scale. We can see a relatively stable diversity in microbes present (and example of results given in Figure 2)[2] over the sampling period indicating the keystone functions within the aquifers are stable. The functions the microbial fauna undertaken provide the primary Source of food for higher organisms as well as providing a key role in reducing contaminants entering the system. In terms of the Stygofauna (macrofauna) present, we have seen a more varied picture (examples of specimens collected given in Figure 3). During the first two sampling occassions we did not recover any Stygofauna from any of the wells/bores sampled. Since this period we have recovered Stygofauna on each occassion. Stygofauna were collected from 7 of 11 samples taken from wells/bores *i.e*. both gravel and marble aquifers. Macroinvertebrates, including Stygofauna were recovered from the springs fed from the karst/gravel aquifer systems. Total abundance and species richness were low, compared to ecosystems examined in other South Island locations e.g., Canterbury, Southland. We have collected unique specimens which indicate an endemic ecosystem is present. At present it does not appear to be abundant, but more species could be discovered with more sampling. The karst system in Takaka itself is unique in its evolution and geochemistry and a system that evolves with karst dissolution. In the past three sampling occassions we have also collected and identified a range of protozoan species present (examples shown in Figure 4).

Overall, the data we are collecting is providing key information that can help us understand our groundwater systems better. The information is also being developed into a national database of diversity that we are building into predictive modelling tools for assessment of the health of an aquifer. We are also using this information to develop sentinel markers that can be used for assessment of groundwater depdendent ecosystems, similar to the surface water MCI index. Using these measures will provide a method for upholding Te Mana o te Wai and could be developed into tools for assessment of groundwater within the NPSFM in the future.

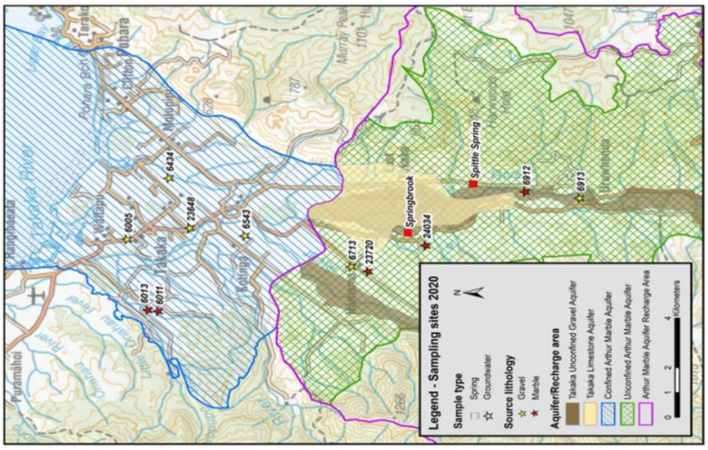

Figure 13 Location of sampling sites. Stars denote bore/well groundwater samples, squares denote Spring samples, Blue striped area confined Arthur Marble Aquifer, Green cross-hatched the unconfined Arthur Marble Aquifer. Pink line shows Arthur Marble Aquifer recharge area.

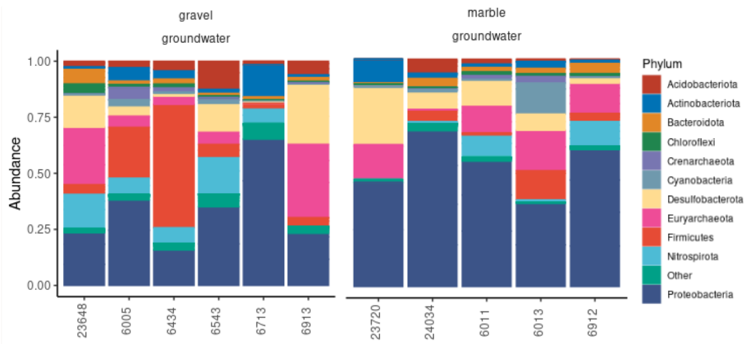

Figure 14 Phyla present across the gravel and marble aquifers.

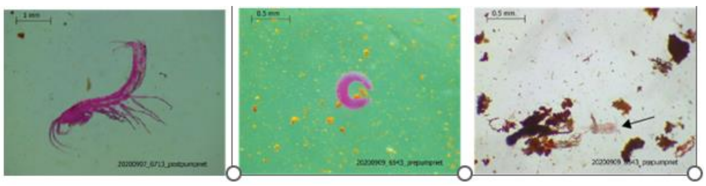

Figure 15 Example of the macrofauna (Stygofauna) present. Images from left to right are amphipod, worm, copepod.

Figure 16 Example of the Protista collected from the sites. Left to right are small spherical protist, ciliate, amoeba.

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CAN AQUIFER MICROBIAL COMMUNITIES PREDICT CHANGES IN THE HEALTH OF GROUNDWATER?

<u>Webber, J.[1]</u> Weaver, L.[1] Abraham, P. [1] McGill, E.[1] Sarris, T.[1] Close, M.[1]
[1] Institute of Environmental Science and Research (ESR) Ltd.

Aims

Globally 2.5 billion people depend solely on groundwater to satisfy their daily drinking water needs[1]. As the global population continues to increase, there is not only a greater demand for freshwater resources but also the risk that groundwater aquifers will be affected by human activities, e.g., chemicals entering the aquifer systems through industrial applications (solid/liquid wastes, chemical compounds, mining activities, spills, and leaks), urban development (municipal wastes, land use practices, and others), and agricultural practices (pesticides and fertilisers). Such pollutants can potentially impact and alter the natural aquifer communities by releasing nutrients, pathogens, chemicals, and toxic pollutants into the environment[2-4]. These bacterial communities are highly diverse and functionally complex and play an essential role in driving the dynamics of aquatic ecosystems[5-8]. Bacteria that live within aquifer communities utilise contaminants as energy (carbon) sources and remove harmful pollutants from groundwater sources, helping to protect our drinking water supply. A better understanding of the biodiversity of bacterial aquifer communities and their interactions is vital and urgently required to enable the future protection of these ecosystems and protect the worlds drinking water supplies.

Methods

This study identifies bacterial communities in shallow groundwater aquifers systems across four geographic regions (Southland, Canterbury, Nelson, and Hawkes Bay) of New Zealand using eDNA metabarcoding. Bacterial diversity was evaluated using Miseq[9] sequencing, taxa comparisons were assessed, correlations between physiochemical parameters and the groundwater communities were evaluated using machine learning (Random Forest[10-12]), and functional profiles were mapped with PICRUSt[13].

Results

Communities (bacteria) significantly differed for Southland aquifers (Adonis $p = 0.001$). Southland aquifers typically have lower groundwater temperature and pH levels than the other study regions resulting in a unique microbiome. On average, the bacterial phylum, Thaumarchaeota, occurred in higher abundances in the Southland aquifers and was highly correlated with conductivity, pH, total alkalinity, nitrogen, and nitrate. Investigation into predicting nitrate levels in the groundwaters found that when ratios of Thaumarchaeota and Proteobacteria were used, Random Forest correctly predicted the nitrate classification of groundwater samples with 90% accuracy. The functional profile of the bacterial communities was highest for the Southland aquifers when analysed for a small selection of marker genes (Figure 1.), potentially indicating higher denitrification activity, i.e., reducing nitrate to nitrite. Work is underway to analyse a larger gene set targeting pollutants commonly found in groundwater aquifers. It is hoped that this work will lead to the development of a hand-held sensor that could predict contamination based on the ratios of microbes present.

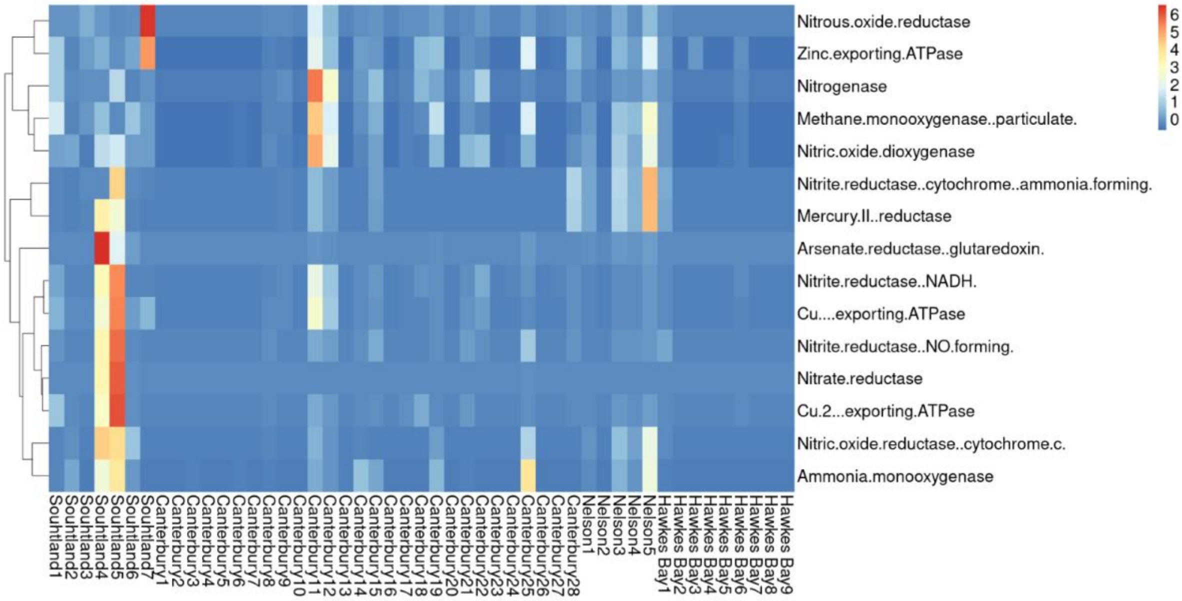

Figure 17 An example of the outputs from a PICRUSt2 generated heatmap of the selected gene markers across samples. Colours present a scaled index of the amount of genes identified in samples (blue less through to red higher number).

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INVESTIGATING PATHOGEN SURVIVAL IN GROUNDWATER

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Aims

Globally, there is still an all-too-common occurrence of contamination of groundwater by enteric pathogens leading to disease outbreaks. Reliance on indicator organisms often do not correlate with the presence of pathogens. Microbial pathogen survival within the environment can be variable and can depend on many criteria, including environmental conditions e.g. oxygen concentration, temperature, pH, sunlight etc. (e.g. Horswell et al., 2010[1]). Groundwater has been shown to enable prolonged survival of pathogenic organisms due to the absence of sunlight and relatively stable temperatures[2]. In other studies, however, survival has been lower in groundwater when compared with a sterile environment (e.g. sterilised groundwater or artificial groundwater) due to the presence of competing organisms and adverse conditions of pH and redox.
We have previously investigated the survival of the Havelock North, New Zealand outbreak strain of *Campylobacter jejuni* and compared it to a type strain of *C. jejuni*. We tested the survival of both strains in oxic and anoxic groundwater. We found that the outbreak strain of was able to survive longer than type strain.
We have since investigated the effect of additional organic carbon on the pathogen *Salmonella typhimurium*. The results show *S. typhimurium* survived in all types of groundwater for over 60 days. The results indicate both the conditions in groundwater and the presence of organic contaminants affect pathogen survival. In addition, again the use of a single indicator namely *E. coli* has been brought into question.

Methods

Environmental isolates used in this study to look at survival of more relevant samples than the usually used laboratory type strains. The Salmonella, isolated from a stream in Wellington, New Zealand, was identified as *Salmonella enterica serovar Typhimurium*. The *Escherichia coli* used was a phylogroup A, isolated from stream sediment in Whangarei Falls, New Zealand.

Mesocosm experiments were established containing ultrafiltered groundwater, groundwater amended with 1% or 10% dissolved organic carbon (DOC). pH, dissolved oxygen (DO) and temperature were monitored over the experimental period. The temperature maintained at 12-14°C during both experiments.

Samples (5 mL) of the groundwater from each jar was taken aseptically at set time points over the experimental period. Samples were then serially diluted in sterile peptone water to give a dilution series from 10-1 to 10-4. Samples were analysed by plating onto selective media.

Results

Die off rates for *Salmonella* were similar over the course of the experiment when no or low levels of DOC were present (Figure 1). At high levels of DOC, however, Salmonella showed similar survival to the control. After 84 days only a 1 Log decrease was observed. In comparison, *E. coli* died off at a faster rate than *Salmonella* in all mesocosms (Figure 2). It is interesting to note that in the high DOC mesocosms after day 56 counts of *E. coli* remained at 10^3 per mL until the end of the experiment.
We have demonstrated the survival of pathogenic microorganisms in varying groundwater conditions. This *Salmonella* experiment has indicated the presence of additional organic carbon can enhance the survival of pathogens in groundwater. In addition, the variation between the microbial indicator *E. coli* and *Salmonella* provides evidence of differences in survival of microbes in the environment and indicates caution is needed when considering survival of pathogens in groundwater if reliance is made on microbial indicator organisms.

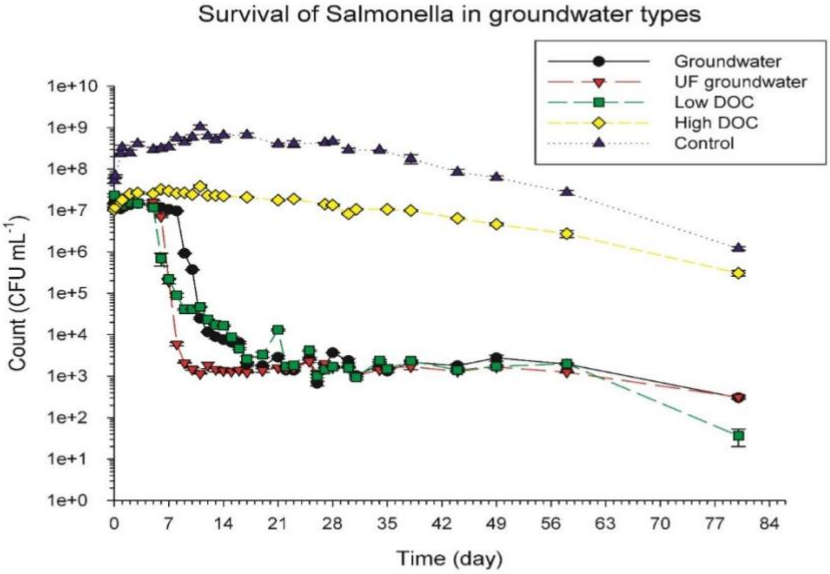

Figure 18 *Salmonella typhimurium* survival in four different groundwaters. The symbols are average (mean) counts (n = 3), lines are the standard error of the mean.

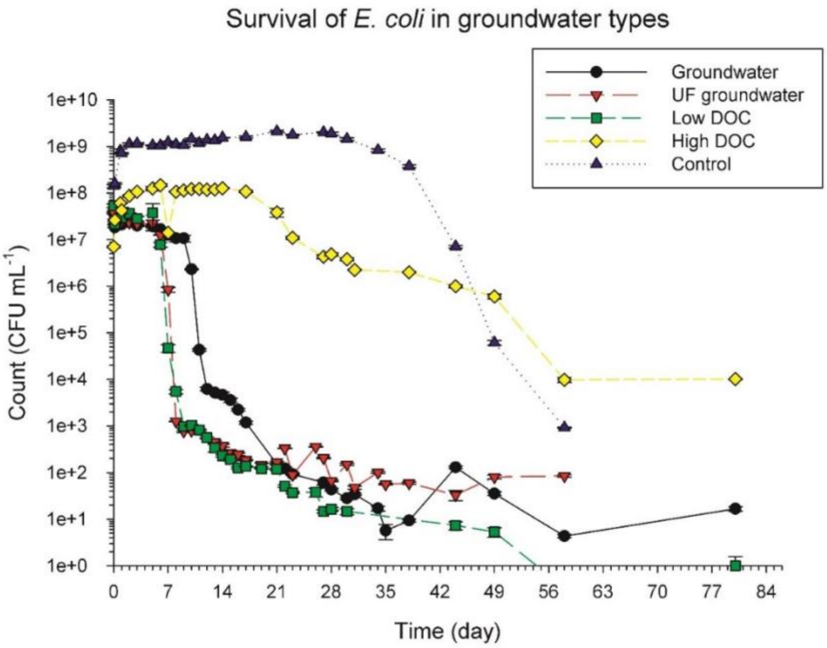

Figure 19 *E. coli* survival in the four different groundwater types over time. The symbols are average (mean) counts (n = 3), lines are the standard error of the mean. Control counts are included for comparison.

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GROUNDWATER MODELLING TO TEST REVERSAL OF RIVER DRYING – WAIMEA PLAINS, NELSON

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Introduction

The Waimea Plains (Figure 1) are situated in the Tasman District, southwest of Nelson. The valuable groundwater resources of the catchment are found within alluvial deposits primarily from the Wairoa and Wai-iti rivers which converge mid-plains to form the Waimea River. The groundwater-surface water system supports a thriving horticultural industry (renowned for the fertile soils over the plains) and the town of Richmond.

Figure 1: Waimea Plains, Nelson

One of the most significant hydrological issues in this catchment is drying of the lower reaches of the river system during summer when water demand is high. Water used for irrigation and industry is frequently constrained to reduce ecological impacts and to manage the risk of salt water intrusion. But these restrictions impact the viability of horticultural businesses.

Method

With the advent of the Waimea Community dam, river augmentation is proposed to improve low-flows and enable additional allocation. A three-dimensional numerical model has been fundamental in sizing the dam, testing release scenarios, predicting net responses and quantifying the resulting state of the integrated groundwater-surface water system. The latest model has been progressively developed and enhanced since 1988 and includes time-varying land and water use, and as much existing data as possible.

Multiple datasets were used to calibrate the MODFLOW-NWT model, specifically groundwater levels and river flows. A key model purpose is the reproduction of river flows at Tasman District Council (TDC)'s Nursery site on the lower Waimea River. This site is considered for triggering water take restrictions and for assessing ecological flow requirements. Due to the severity of the 2000/01 drought, this season was fundamental for both setting the current allocation limits in the Tasman Resource Management Plan and the forecasted hydrogeologic responses of the proposed Waimea Community Dam. TDC's groundwater allocation methods focus on the effects of water taken during drier, low-flow periods. Therefore, river flow calibration primarily focussed on the replication of low flows. An example calibration hydrograph for river flows is shown in Figure 2 and for groundwater levels in Figure 3.

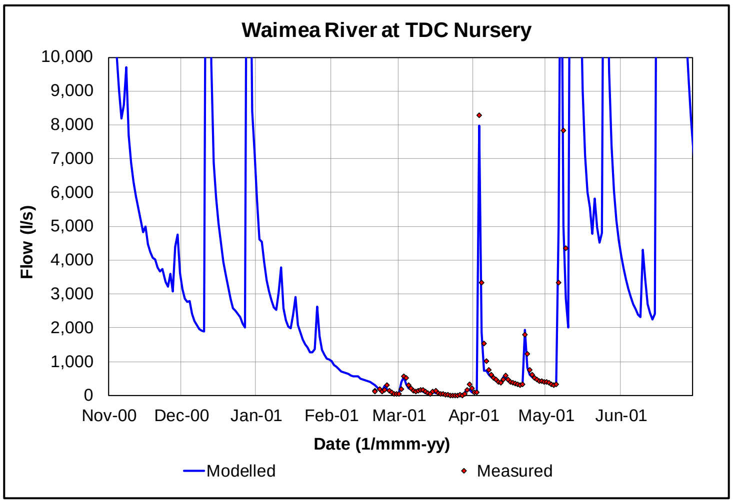

Figure 2: Example river flow calibration

Model Scenario Results

The numerical model has been used to test various groundwater allocation and water management regimes. Key findings from these scenarios are as follows:

- Existing water use dries up the Waimea River during extreme dry periods.
- TDC's existing restriction regimes are effective in delaying drying (by ~1 month). Restrictions early in a season can reduce the need for more severe restrictions later.
- Completely ceasing all water use returns river flows to ~355 l/s (Figure 4).
- River flow augmentation from dam releases are needed to maintain min. 1,100 l/s at Nursery (Figure 5). Weekly- versus daily-release decisions result in noticeable differences. When releases are decided weekly, river flows are often over compensated. Automation (with near-real time decision making) is recommended to optimise the use of stored water.
- The model scenarios predict the ability of released stored water to maintain desired low flows with full demand for the design drought and security of supply. Groundwater levels at the coast are also maintained, thereby not exacerbating the risk of saltwater intrusion.
- Weirs on the Wairoa and Waimea rivers significantly increase river recharge and groundwater storage, but this comes at the expense of lower Nursery flows (with no augmentation).
- Positive effects from the existing weirs on the Wai-iti River remain largely local near the weirs.

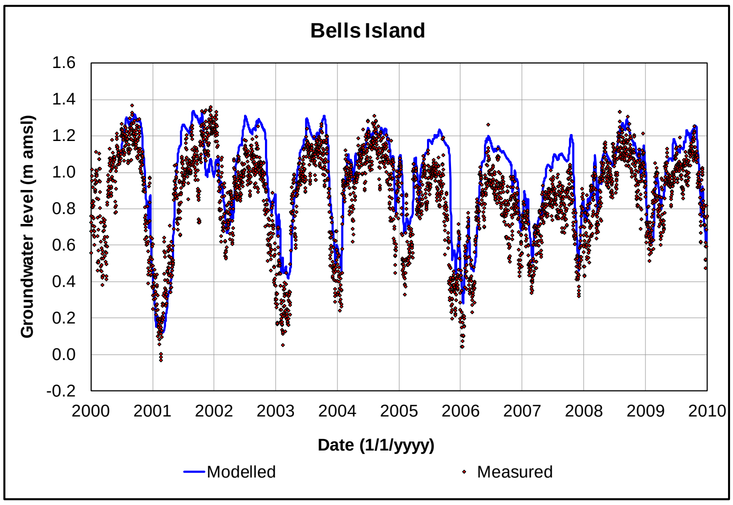

Figure 3: Example groundwater level calibration

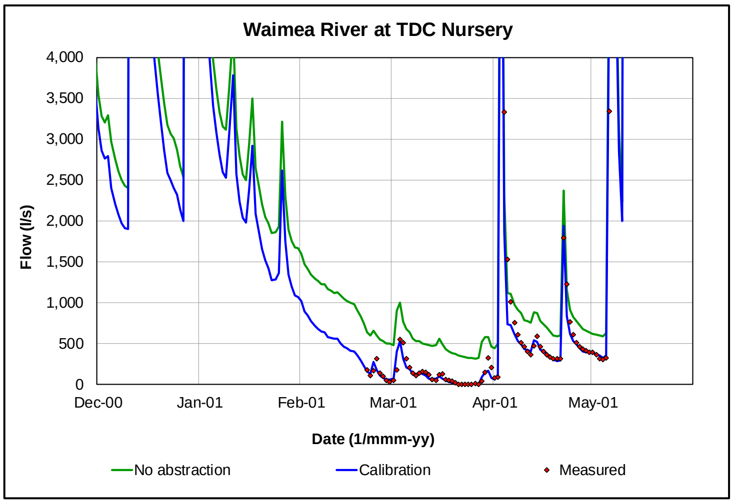

Figure 4: No abstraction scenario

With TDC's proactive and long-term development vision, the Waimea Plains model has developed into a valuable asset, and it is maintained as such (similar to how infrastructure assets are managed). This results in robust, defendable model development and avoids last-minute scrambles for plan changes, consents, hearings or other important decision making processes.

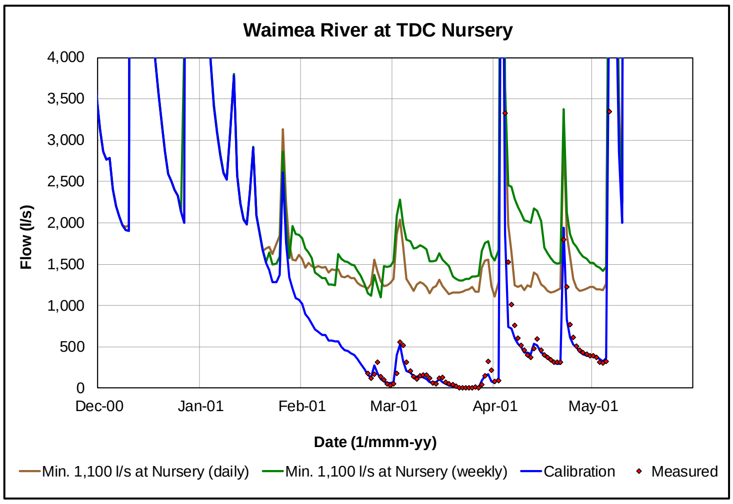

Figure 5: Dam release scenarios

MAKING THE MOST OF IT: PRIOR BUILDING WITH IMPRECISE DATA AND IMPERFECT MODELS

Jeremy White,[1] Broich Hemmingsr,[2]
[1] Intera
[2] GNS Science

The data scarcity of subsurface environmental simulation is a source of so many of our problems. We often lament how little we "know" about the aspects of the natural systems we are studying and modeling. Aren't we living in the information age? Maybe we need to rethink what it is to "know" something about these complex systems. For example, the location of a high-capacity extraction well must indicate a relatively high transmissivity in and around that location in the subsurface. Or a farmer may "know" that a certain field has never produced more than a certain yield in a growing season. Or site personnel "know" that certain monitoring wells go dry during sampling. Are these bits of knowledge useful? The answer is, as always, "it depends" (on many factors), but in some settings, when taken collectively and used appropriately, the answer is a definitive "yes, these bits are valuable to reduce predictive uncertainty". An efficient and general technique for using these imprecise data in predictive modeling workflows will be presented, as well as demonstration of its use.

COASTAL GROUNDWATER SYSTEM CHARACTERISATION AND CLIMATE CHANGE IMPACTS, WITH THE EXAMPLE OF THE WAIRAU PLAINS

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GNS Science New Zealand

Aims

Coastal groundwater systems are amongst the most important aquifers in New Zealand. Much of the population lives near the coast and use groundwater for drinking water, industry and recreation, e.g., Napier, Hastings, Lower Hutt, Wellington, Blenheim, Richmond and Christchurch (White et al., 2016). However, these systems are vulnerable to the impacts of changing land use (e.g., drainage, industry, and groundwater use) and to climate change (e.g., rising sea level and changes in rainfall patterns and groundwater flows).

The geology (stratigraphic architecture) of coastal groundwater systems is a fundamental control on system response to climate-change forcings and to the practice of climate change adaptation. A geological approach therefore is being developed to assess these systems nationally (Moreau et al., 2023). This paper describes methods that assess the four-dimensional (4D) development of the architecture of Late Pleistocene and Holocene coastal groundwater systems, with particular application to the impacts of climate change until 2100 in the Wairau Plains, Blenheim (Figure 1).

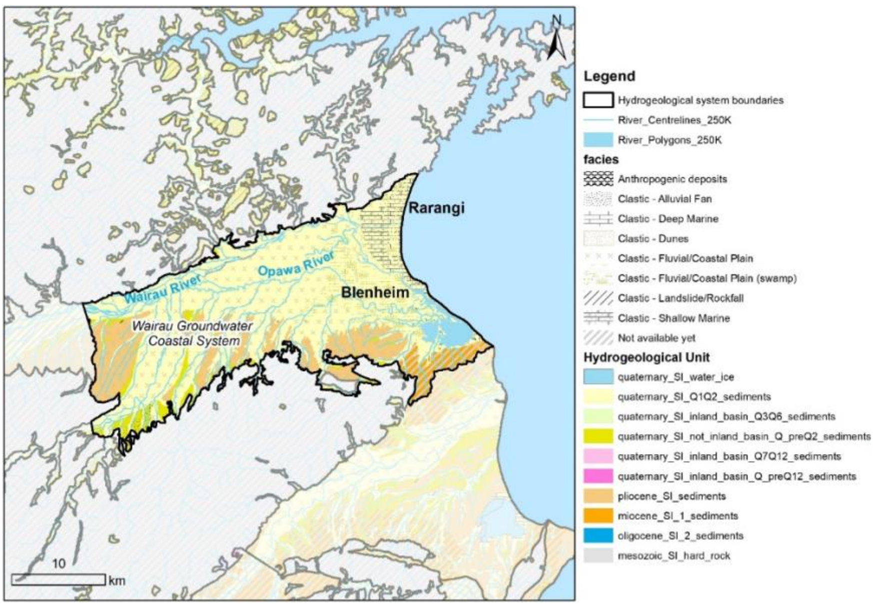

Figure 1. The boundary of the Wairau groundwater coastal system, South Island, New Zealand.

Methods

Surface and sub-surface methods were used to characterise and model coastal groundwater-system geology. Topographic maps, including contour or LiDAR data, identified low-lying areas near the coast, digital filtering (high-pass and low-pass) of topographic data mapped landforms (depositional and erosional) and sedimentary facies. Pre-historic groundwater conditions were assessed with historical information (e.g., iwi knowledge and early-European maps, White et al., 2007), current infrastructure (e.g., drainage networks) and modern geomorphic maps.

Geological analysis used surface information, borehole logs and facies models. For example, pre-historic depositional facies were calculated with 'Boolean operators' on borehole log descriptions and 3D geological modelling. Radiological measurements (e.g., Carbon 14 dating) of geological samples, and provenance, provided data on the timescales of coastal system development.

Current groundwater features susceptible to the effects of coastal climate-change include: locations of recharge (e.g. river discharge) and discharge (e.g., artesian wells, springs, seeps swamps); piezometric pressures (and 3D pressure gradients), groundwater budgets and 3D groundwater flow models. The 3D distribution of coastal facies and terrestrial facies were identified in the Wairau Plains with models of the system geology and static head measurements using well log observations from nearly 1000 wells. Together, surface and subsurface information was interpreted as a 4D Holocene model of the Wairau groundwater coastal system. Potential impacts of climate change-induced sea level rise to 2100 were then considered.

Results

Digital topographic maps identified land within 2 m of present-day mean sea level in the Wairau coastal groundwater system. Features of the Wairau pre-historic ground surface include large areas of swamp (now largely drained) and river channels of southern Wairau Plains streams, now rerouted. Current infrastructure was identified by digital processing including, embankments (river and road), river stopbanks (levees), utilities (e.g., wastewater treatment plants) and excavations (e.g., the Wairau Diversion); some of which may be impacted by sea level rise to 2100.

The 4D deposition of coastal facies followed Holocene sea level rise, in a westward direction up the surface of Late Pleistocene terrestrial gravel, in a zone approximately 5 km west of the current shorline. Paleo-estuarine and shallow marine deposits were identified over a wide area of the zone and Carbon 14 dates were in the age range approximately 9,000 years ago to modern. Buried paleo-beach deposits were mapped with modern beach deposits at the coast (e.g., Rarangi). Formation of vertically-upwards groundwater gradients in the lower Wairau Plain came with emplacement of relatively low-permeability Holocene deposits. These gradients led to progressive development of modern groundwater features, i.e., springs, spring-fed streams and artesian aquifer conditions.

Climate-induced sea level rise to 2100 may induce larger vertical groundwater gradients in the lower Wairau Plain leading to higher flows in springs and spring-fed streams, shallower water tables and a widening zone of artesian conditions.

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CLIMATE CHANGE-INDUCED SEAWATER INTRUSION RISK ASSESSMENT FOR THE LAURA LENS, REPUBLIC OF THE MARSHALL ISLANDS

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Beca Ltd

The communities of the Republic of the Marshall Islands (RMI) have been grappling with the increasing impacts of climate change for several years. RMI's primary atoll, Majuro, is the nation's capital and encompasses an area of 9.7 km^2 and ~23,000 inhabitants. The Majuro atoll is composed of a string of islands and reefs separating a lagoon from the open ocean. The atoll consists of calcareous sediments overlaying limestone formations. The most significant sources of water at Majuro include groundwater extracted from freshwater lenses and rainwater harvested from roof water collection systems. The Laura lens, located on the western side of the atoll, is an important source of water for local inhabitants. The objective of this assessment is to evaluate the vulnerability of water resources to climate change, with a specific focus on the implications of Sea Level Rise (SLR) and changing precipitation patterns for the intrusion of saline water on groundwater lenses at Majuro.

The assessment uses a Multi Criteria Decision Making Method, GALDIT, to assess the potential impacts of climate change on the vultnerability on groundwater. The GALDIT method incorporates factors such as groundwater occurrence, aquifer hydraulic conductivity, groundwater levels, distances from the shoreline, water salinity and aquifer thickness. This information is spatially conveyed as a 'heat map' to display the various levels of climate change-related risk. Additionally, the vulnerability of roof water collection systems was assessed by analysing water usage and precipitation trends and evaluating the exposure of the current population by using the latest census data. Our assessment shows that groundwater, including the Laura Lens, is subject to a high risk of seawater intrusion, particulary during drought events, when reliance on roof water collection is also susceptible. Adaptation measures such as water storage and alternative sources will be required to meet future water shortages for the island.

MULTISCALE APPLICATIONS OF CONTINUOUS NITRATE SENSOR DATA: A CASE STUDY OF BALMORAL NITRATE DYNAMICS

Ben Wilkins[1]
[1] Environment Canterbury

A nitrate sensor has been installed at Balmoral in the Culverden Basin since 2018 to monitor the effect of land use change from forestry to irrigated beef farming. The continuous nitrate data from this site has been used at a small scale to understand nitrate dynamics in groundwater and at a larger scale to investigate discrete monitoring frequencies and nitrogen loads from groundwater to surface water.

The Balmoral site shows a strong response in nitrate concentrations to rainfall recharge, which results in spikes of high nitrate concentrations occurring over short periods of time. Further investigation of the time series data using an eigenmodel from nearby lysimeter data indicates that in addition to recharge, nitrate mobilisation can also occur from rising groundwater levels in the vadose zone.

The rapid fluctuations of nitrate recorded by the Balmoral nitrate sensor could indicate that some of our discrete monitoring network might not capture enough data to understand nitrate dynamics. A metric for determining the variability of nitrate concentrations in our monitoring network was developed and used to assess which wells have spikes of nitrate. The antecedent rainfall before these nitrate spikes was also investigated using NIWA's Virtual Climate Station Network data. It was found that nitrate spikes predominantly occur in wells that are less than 20 metres deep and are located close to a river.

The proximity of the Balmoral well to the Hurunui River, an upward gradient in the nearby deeper well and the rapid decrease in nitrate concentrations suggests that groundwater may discharge to the Hurunui River after recharge events,. The Balmoral case study was used to compare nitrate load calculations from groundwater to surface water using the integration of a continuous record from a nitrate sensor to regression from discrete samples.

GROUNDWATER RECHARGE RESPONSE FROM BRAIDED RIVERS

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Aims

The aim of this presentation is to show the relative influence of dynamic and steady river leakage rates on groundwater recharge, and how river management interventions influence recharge rates. A new conceptual model to represent surface water-groundwater exchange for braided rivers have been developed based on reserach over teh last four years (Wilson et al. 2022 & 2023). This model recognises that braided rivers create their own high-permeability shallow aquifer system through the process of mobilising bed sediments during flood events. The base of this “braidplain aquifer” can be therefore in different hydrological states of hydraulic connectivity with the regional aquifer determined from coring in the riverbed, or from bathymetric surveys carried out after high flow events. Recharge to the regional aquifer is determined by the relative transmissivity to the braidplain aquifer, and underlying sediments which act as an impeding layer. The dynamic response is determined by the state of hydrological connectivity between the braidplain and regional aquifers.

For braided river systems that are hydraulically disconnected from their regional aquifers, we know that braidplain storage volume determines the groundwater recharge rate, particularly braidplain width. For braided river systems that are hydraulically connected to their regional aquifers, bed elevation is paramount, which can be altered via the river gravel balance in the recharge reach.

Method

The conceptual model enables an intuitive understanding of how river management decisions influence groundwater recharge rates. New and long-term groundwater monitoring data are assessed with time series analysis to test this understanding. The history of river management is considered by including knowledge of river engineering history and the change in gravel balance within the recharge reach.

Results

Recharge to groundwater is steady for braidplain aquifers that are hydraulically perched above the regional water table. The wetted width of the braidplain aquifer is structurally controlled, and fixed, so the recharge rate depends on the transmissivity of the underlying sediments that can impede vertical flow (Di Ciacca et al. 2023a). However, the recharge rate can decrease when the saturated footprint of the braidplain aquifer shrinks from the braidplain aquifer margins. This can occur when braidplain aquifer storage volume is low, and the water table at the braidplain margins drops below the aquifer base, for example in ephemeral rivers (Di Ciacca et al. 2023b).

For braidplain aquifers that are hydraulically connected to the regional water table, the recharge rate depends on the transmissivity of the regional aquifer adjacent to the braidplain aquifer (ie the transmissivity of the receiving horizon), and the head difference between the braidplain aquifer and regional aquifer. The groundwater recharge rate in a hydraulically connected situation is therefore dynamic, and dependent on antecedent conditions in the regional aquifer.

Regardless of the hydraulic situation, we have observed that a steady rate of river recharge provides the most benefit for sustaining groundwater levels throughout the year. This is because the periodic recharge pulses provided by high flow events propagate through New Zealand’s highly transmissive alluvial aquifers quite rapidly. This indicates that river management has a greater influence on maintaining storage in the regional aquifer system than high flow events.

River engineering works were carried out in the main recharge reaches of the Wairau and Ngaruroro rivers during the 1960s. A result of both schemes was to reduce the active braidplain width by approximately half. The influence of braidplain narrowing appears to have had little effect on Wairau Aquifer recharge, since its braidplain aquifer is hydraulically connected to the regional aquifer, and the transmissivity of the braidplain and regional aquifers are similar in the recharge zone. For the Ngaruroro River, the upper reach of the recharge zone is hydraulically disconnected from the regional aquifer. River engineering in the Ngaruroro occurred prior to groundwater monitoring, so we cannot directly see the influence of river narrowing on the Heretaunga Plains recharge in any hydrological records. However, both the Wairau and Ngaruroro rivers do show a relationship between groundwater levels and river bed levels, which is evident in groundwater monitoring records. It is this degradation of the river bed elevation, resulting from excessive gravel extraction, which appears to be responsible for the long-term decline in groundwater levels observed in these two aquifers.

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UNINTENDED CONSEQUENCES OF A PREDATOR FENCE: NUTRIENT LOADS TO LAKE ROTOPIKO FROM EXOTIC ROOSTING BIRDS

Nicola Wilson[1]
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Background

Rotopiko Lakes are a complex of three small peat lakes in the Waipa District of Waikato, New Zealand. Rotopiko East Lake is the smallest of the three and is nationally signifcant due to the macrophyte community supported by the lake (Sukias et al., 2006). In 2013 a predator fence was constructed around a 10 ha area surrounding Rotopiko East Lake as part of larger restoration project (Sandoval et al., 2023). Following the removal of mammalian predators by 2014, a dramatic increase in roosting exotic birds estabilshed themeselves in a kahikatea forest within the predator free zone. Nutrient inputs to the lake from guano deposition by roosting birds is very high and has resulted in a significant decline in lake water quality (Kelly & Robertson, 2022).

Aim

The aim of this research is to understand groundwater and surface water transport pathways of nutrients associated with the guano deposition of roosting birds. Results have been used to inform mangement actions to mitigate nutrient inputs to the lake and restore water quality.

Method

Extensive monitoring of groundwater and surface water quality in and around the roosting area has been undertaken. Slug testing and piezometric information have been used to inform groundwater flow to the lake.

Results

Intial results indicate that a surface drain and very shallow groundater flowing through the roosting area are contributing high nutrient loads to the lake. Initial mitgation efforts will be focused on the drain. Groundwater near the top of the water table has higher nitrate-N concentrations than deeper groundwater which is higher in ammoniacal-N. Investigations to further understand groundwater quality and movement are ongoing.

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THE IMPACT OF BRAIDED RIVER MORPHOLOGY ON RIVER – GROUNDWATER EXCHANGE – A MODEL-BASED ANALYSIS

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[2] Lincoln Agritech Ltd, New Zealand

Aims

Alluvial aquifers in the coastal plains of braided rivers throughout New Zealand are recharged by their respective rivers. The river-groundwater exchange fluxes are spatially heterogeneous and can include both recharge and discharge within a short section of the river. Sustainable use of groundwater resources in these aquifers neccesitates knowledge of the net exchange rates and also about the structural mechanisms driving the exchange. A particular feature of braided rivers is the often and drastic change in river morphology, where major floods can lead to a major shift in flow channel geometry due to sediment transport and relocation. We analyze the effects of such morphology changes on river-groundwater exchange by comparing model results from two physically-based models of a section of the Wairau River before and after a major flood.

Method

A complex, three-dimensional surface water – groundwater model of a section of the Wairau River and underlying aquifer, was set up in HydroGeoSphere (HGS). This model incorporates recent knowledge of the structure and hydrogeological controls of the immediate subsurface under the river. It also represents the river morphology by a detailed computational mesh derived from lidar data. The major hydrogeological parameters are tuned to fit transient groundwater level data for a number of piezometers installed at the study site before the flood.

A second flow model was then generated by replacing the surface of the model domain with a mesh derived from a similarly detailed post-flood lidar survey. The two models, named pre-flood and post-flood, respectively, are then utilized to simulate various flow scenarios, both transient and steady-state. The spatial and temporal characteristics of river-groundwater exchange flows are then analysed and compared for the models with different morphology.

Results

The results indicate significant shifts in the spatial distribution and the local magnitude of groundwater exchange fluxes. In some instances, an altered bathymetry can even lead to a local reversal of the exchange flow direction. However, the pattern of exchange fluxes remains similar for similar morphological features. The most important feature for the exchange seems to be the state of hydraulic connection of the parafluvial gravels to the regional groundwater table. The nature of the hydraulic connection shifts across the river from North (connected) to South (not/partially connected). Other hot-spots for exchange are pool-riffle sequences where pools are potential areas for discharge of parafluvial flow. Changes in river morphology have an impact of river-groundwater exchange at the local scale, but the differences in net exchange rates over the river reach is less pronounced. This is promising for upscaling effective river-aquifer exchange rates in regional scale models.

MODELLING WAIRAU PLAINS GROUNDWATER RESOURCES – A DETAILED ANALYSIS OF THE WAIRAU AQUIFER WATER BALANCE

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Aims

There are growing concerns that current limits and thresholds in the regional water plan for the Wairau Aquifer would a) lead to more frequent and more prolonged cut-offs of farmers water access in the fulture and b) that the current annual volume limit is too high to sustain acceptable groundwater levels and spring flows, particularly in summer. The aim of this work is the model-based analysis of the whole Wairau Plains Aquifer water balance and its strong seasonal and annual variability. Particular emphasis is placed on the integration and extrapolation of metered groundwater abstraction data (vineyard irrigation, industrial, municipal) that has compiled specifically for this purpose.

Method

A detailed 3D surface water-groundwater flow model (MODFLOW) has been set up for the Wairau Plain based on earlier work by Wöhling et al. (2018). The domain of the new regional model includes the Wairau Plain Aquifer domain, and extends southwards to include the southern valleys with seasonal groundwater flow contributions from their alluvial fans. Transient model simulations are performed and the highly parameterized model is calibrated using PEST and a range of different data types such as groundwater levels, spring flows, river-groundwater exchange flows. Uncertainty bounds are derived using Null-Space Monte Carlo simulations.

A distributed soil water balance model is used to estimate irrigation demand and land-surface recharge on the entire Wairau Plain. For the first time, metered abstraction data provided by the Marlborough District Council for a larger number of water permits was used to test the soil water balance and abstraction model. In addition to vineyard irrigation demand we now also developed estimates for industrial water abstraction and implemented pumping for municipal water use.

The majority of the dominant model components are now informed by data which provides a higher confidence in model simulations. We derived a detailed transient water balance for the Wairau Aquifer domain and determined all its boundary fluxes.

Results

The regional-scale model performs well with respect to observed groundwater heads, spring flows and river-groundwater exchange flows in the region of the Wairau Plains Aquifer. The regional groundwater flow field and the overall water balance are plausible and in agreement with earlier investigations. As expected, the majority of recharge to the aquifer (>90%) originates from Wairau River leakage, and most of this water is later discharged as spring flow or river return flow. Groundwater abstraction for irrigation can vary widely between years, depending mainly on rainfall, while industrial and municipal water demands remain relatively stable. The total annual abstraction volume is typically less than 30% of the annual allocation limit. The majority of abstractions are used for irrigation, typically between October and April, when river recharge and groundwater storage are on a seasonal low. The abstraction of the full annual allocation volume during this period would lead to significantly lower groundwater levels and storage and thus to more frequent cut-offs. However, a lower allocation volume would have no impact on irrigators because actual water use is well below the consented ones. The regional flow model will be used to develop and test alternative strategies for limit setting and the sustainable management of the Wairau Aquifer groundwater resources.

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EXCHANGE OF SURFACE WATER AND GROUNDWATER DURING THE 2022-2023 RIVER MURRAY FLOOD IN SA

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Natural flooding of the River Murray in SA is thought to freshen the saline groundwater of the floodplain and store freshwater for vegetation, hence reducing the future groundwater salt load to the river and improving the riparian ecosystems. However, it is unclear how much recharge occurs during flooding, how the fresh surface water mixes with the saline groundwater, and how long before the elevated groundwater level returns to the pre-flooding conditions. The 2022-23 flood provided an opportunity to investigate these processes through detailed monitoring at a site within the Lower River Murray floodplain at Murtho, South Australia.

Before the flood, seven non-vented, self-logging piezometers were deployed in boreholes around the floodplain. The surface water level was measured at the nearest river lock. Water samples were collected for chemistry and isotope analysis.

Results suggest that before November 2022 when the floodplain was inundated, the floodplain groundwater level rose steadily with piezometric heads 1 - 2 metres lower than the surface water level, likely due to recharge near the river channel where the surface water-groundwater connectivity are strong. During the flood recession, floodplain groundwater levels were maintained up to 1 m higher than the surface water level, and such head difference may sustain a within-bank groundwater discharge.

The groundwater temperature, EC, stable isotopes, and chemistry indicate the upper aquifer was partially mixed with surface water. No evidence suggests the saline groundwater was substantially diluted.

At the highland, groundwater level rose steadily even three months after the peak of the flooding. It may take months for the elevated groundwater level to return to pre-flooding conditions.

This study provides useful insight into the exchanges of groundwater and surface water during a natural flooding event and may shed light on floodplain hydrology and ecosystem management in extreme events.

HYDROLOGIC PROCESSES IN FOREST CATCHMENTS: AN INTEGRATED MODELLING APPROACH IN NEW ZEALAND

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In spite of the importance of planted forests for wood supply and carbon sequestration, providing water to downstream users, and resilience to different hazards (e.g. climate change, droughts, and floods), aspects of hydrologic processes in forest catchments are not well understood. For example, it is currently difficult to quantify the effects of different forest management options (e.g. tree species, planting density, and harvesting) on hydrologic processes. In New Zealand, these knowledge gaps are especially stark considering the economic importance of the forestry industry. In this study, we integrated different models to study hydrologic processses in two small forest catchments (Ashley and Mawhera Forests) in New Zealand. These models include a vadoze model Hydrus-1D , a process-based forest growth model CABALA (CArbon BALAnce), and a groundwater model (Pauwels hillslope model). Firstly, two years of data (weather, river flow, groundwater level, etc.) were collected and compiled at each catchment. These data were then to train and validate the integrated modelling approach. Results indicate the integrated model can correctly simulate hydrologic processes in these two forest catchments. Although there are still some work in model calibration, it can be applied to assess the impacts from forest management options in New Zealand, as well as water supply from existing and new forests under current and future climate conditions.

2023 UPDATE ON THE NEW ZEALAND WATER MODEL (NZWAM)

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Aims

NZWaM-Hydrology (NZWaM) is a multi-year science project that aims to improve the understanding of hydrological process using field observation associated to an ensemble of hydrological models, to facilitate the development and implementation of land and water policies in New Zealand.

The objective of the project is to improve hydrological understanding of New Zealand landscapes by combining targeted field experiment (co-developed with research partners) and hydrological information data mining, to support development of novel hydrological models that can be incorporated into operational tools to assist water resource managers to implement national land and water policies.

Methods
The project is designed around a national-scale suite of hydrological models that integrate surface water and groundwater processes. This suite provides accurate hourly flow predictions for all reach-scale segments of the latest digital river network (> 3 million sections of the river network), corresponding catchment reach-scale hydrological fluxes, and groundwater level on a 250 meter national grid.

The project is a collaboration between three CRIs (NIWA, GNS Science, and Manaaki Whenua Landcare Research), three regional councils (Environment Southland, Horizons Regional Council, and Gisborne District council) and three central government departments (Ministry for Environment, Ministry for Primary Industry, and Stats New Zealand). This forms NZWaM's Stakeholder Reference Group (SRG).

The NZWaM framework provides hydrological data for land and water management in New Zealand. This data could be used for regional and catchment planning (implications of land use and climate change impacts); water take and use consenting; and setting resource-use limits (contaminant load estimation) as required by the National Policy Statement for Freshwater Management.

Results
The highlights of outputs produced by the project during 2022-2023 are given below:

Hydro-geofabric (national-scale spatio-temporal database of hydro-geological data)
- ArcGIS tool enabling identification of potential groundwater catchments using models with a-priori parameterization (with GNS);
- Provided public access to surface-water hydro-geofabric data;
- Implementation of DN2.5 derived surface water hydro-geofabric data;
- Hydro-geofabric guidance manual for end-users.

Isotope hydrology
- Completion of the national steady state young water fraction map;
- On-going stable isotope sampling (rainfall and surface water) and analysis within GDC;
- Dissemination of updated isotope data via the Isotope Hydrology webpage

HydroDesk-NZ (online tool to run models using NZWaM)
- Development of user and guidance manual;
- Refinement of output visualization;
- Implementation of steady state Modflow 6 model (MF6-ST) in HydroDeskNZ;
- One way coupling TopNet-EWT and TopNet-MF6-ST using land surface recharge scenario;

- Dynamic coupling TopNet/MODFLOW6 using Basic Model interface (BMI);

TopNet-GW module

- Refinement of a-priori parametrization of TopNet-GW at national scale;
- Comparison TopNet-GW MDOFLOW for Mid-Mataura catchment.

Observation dataset ingestion

- Point scale high temporal resolution data set for precipitation (1389 sites), air temperature (221 sites), soil moisture (351 sites), continuous discharge (1304 sites);
- 3 daily gridded rainfall time series at 5km and 500m spatial resolution;
- 2daily gridded temperature time series at 5km and 500m spatial resolution.

Benchmarking

- Benchmarking of climate input uncertainty on hydrological simulations;
- Development of methodology to upscale point scale S-map derived soil characteristics to watershed scale
- Public github post-processing code repository.

UPDATE ON CLIMATE CHANGE PROJECTIONS FOR NEW ZEALAND

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Work is underway at NIWA to dynamically downscale the latest generation of global climate models (GCMs) from The Coupled Model Intercomparison Project phase 6 (CMIP6). The output from this regional climate model ensemble will significantly enhance the atmospheric model resolution of selected GCMs (typically 100-150-km) to 5-km across New Zealand. Output from the full model ensemble and detailed guidance will be made publicly available to support the first National Adaptation Plan.

The downscaling involves a 2-step procedure in which simulations from coarse-resolution GCMs are first dynamically downscaled to 12-km with the Conformal Cubic Atmospheric Model (CCAM) and then further empirically downscaled and bias-corrected to 5-km using machine learning. CCAM is a non-hydrostatic global atmospheric model which employs a stretched grid and scale-aware physics. This model configuration provides a computationally efficient approach to enhance the spatial resolution over the New Zealand domain while retaining seamless physical consistency across spatial scales.

The climate model ensemble consists of 6 GCMs driven by multiple Shared Socioeconomic Pathways (SSPs). The selection of GCM simulations to downscale has been informed through balancing: historical model performance across the region, the model equilibrium climate sensitivity, and model independence. While CCAM is the primary model employed for dynamical downscaling, for a smaller number of selected runs, comparisons were made against The Unified Model (UM, 12km) and The Weather Research and Forecasting Model (WRF, 12km). This comparison between regional climate models evaluates the historical reanalysis-driven performance as well as the regional climate change signal.

The paper aims to i) outline the main differences between the CMIP5 and CMIP6 climate ensembles, ii) provide an update on climate bias correction process, and ii) present the outcome of coupling of the raw CMIP6 climate ensemble with New Zealand Water Modelling Framework (NZWaM) over two contrasted catchments in New Zealand.

GUIDANCE ON MINIMUM GROUNDWATER MODELLING REQUIREMENTS IN NSW: PROMOTING CONSISTENCY IN IMPACTS ASSESSMENT THROUGH MODELLING

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The New South Wales (NSW) Department of Planning and Environment (DPE) provides advice to proponents of Major Projects (SSD & SSI projects) on meeting requirements of water-related regulatory requirements including the Water Management Act (WMA) and the Aquifer Interference Policy (AIP). Proponents submit results from groundwater models as part of their submittals. DPE engaged Stantec to develop technical guidance on minimum groundwater modelling requirements to help proponents streamline their submittals, increase consistency, and reduce overall time through the approvals process.

The Australian Groundwater Modelling Guidelines (AGMG 2012) already exist at the federal

level. The DPE technical guidance is complementary to the AGMG while incorporating elements from other jurisdictions, international standards, scientific organisations, and more recent concepts. The new guidance is principally intended for groundwater modelling projects of low to medium technical complexity in low to medium sensetivity environments. However, it is still usful for all modelling projects.

The guidance is inspired by and follows the overall sequence of the AGMG with a focus on elements needed to develop the Groundwater Impact Assessment required by NSW state regulations. Amongst other elements, predictions required by the AIP include:

- Details of potential water level/pressure drawdown or quality impacts on nearby water users and groundwater dependent ecosystems
- Details of potential for increased saline or contaminated water inflows to aquifers and highly connected river systems
- Details of the potential to cause or enhance hydraulic connection between aquifers

The guidance helps Major Project proponents develop groundwater models that are technically robust, fit for purpose, meet AIP requirements, and consistent with Secretary Environmental Assessment Requirements (SEARs) and/or Conditions of Approval (CoA) that relate to the water related aspects of the project. The guidance also provides DPE hydrogeologists with checklists and a framework to streamline the review process.

ASSESSMENT OF CUMULATIVE GROUNDWATER IMPACTS – WHERE OUR PAST, PRESENT, AND FUTURE CONVERGE

Rachael Peavler[1], **Fabienne d'Hautefeuille**[2], **John Paul Williams**[2], **Hisham Zarour**[3], **Robert Brownbill**[2], **Kelly Greaser**[1], **George Fennemore**[1], **Abigail Lovett**[4]

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Aims

Human interference with groundwater must carefully balance benefits and risks. Regulations regarding water management in New South Wales (NSW) include the Water Management Act 2000 (WMA) and the Aquifer Interference Policy (NOW 2012). These regulations require proposed projects to include an assessment of cumulative impacts of their activity on the wider water resource. A standard definition of cumulative impact includes past, present, and reasonably foreseeable future actions. Consequently, a proposed Major Project (SSD[1] or SSI[2]) requires identification of the spatial and temporal extent of the impacts, plus impacts from other projects that affect the same environment as the proposed project.

The Water Division in the NSW Department of Planning and Environment (DPE Water) recently commissioned the Groundwater Modelling Toolbox (GMT) Project to provide applicable and targeted information to improve the planning, implementation, and reporting of groundwater models developed in support of project applications in the State. The primary objectives of this presentation focus on cumulative impact assessment approaches are to enhance knowledge of cumulative impacts of Major Projects and present practical approaches to assess them.

Methods

To meet these objectives, the presentation includes:

- NSW water management statutory requirements
- theoretical background and framework for water resources cumulative impact analysis
- case studies on cumulative impacts in NSW
- a brief account of the regulatory basis for cumulative impact assessment in other geographies
- a summary of best practices applied to model development, reporting, and long-term monitoring and mitigation.

Results

Due to the complexity and scale of cumulative impacts, the potential for cumulative impacts should be considered during project design using a mapping exercise (Figure 1). Collaborative planning during project design is critical to incorporate current and potential future developments into a cumulative impact analysis. A qualitative risk assessment conducted during conceptual model development may assist navigating the complexities and scale for cumulative impact analysis.

The basis for assessing cumulative impacts is well established in policies and regulations across the globe. There is consensus that water resources must be managed at a large scale to ensure the limited resources are not depleted and quality is preserved. Due to the complexity and scale of cumulative impact assessments, numerical models are commonly used to assess and predict impacts from proposed projects. Examples of best practices are provided regarding the spatial and temporal scale for numerical models, developing the model approach, model platforms, resolving inconsistencies between models, reporting, and reviews.

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[1] SSD: State Significant Development, mainly mines and quarries.

[2] SSI: State Significant Infrastructure, mainly metropolitan Sydney transport network.

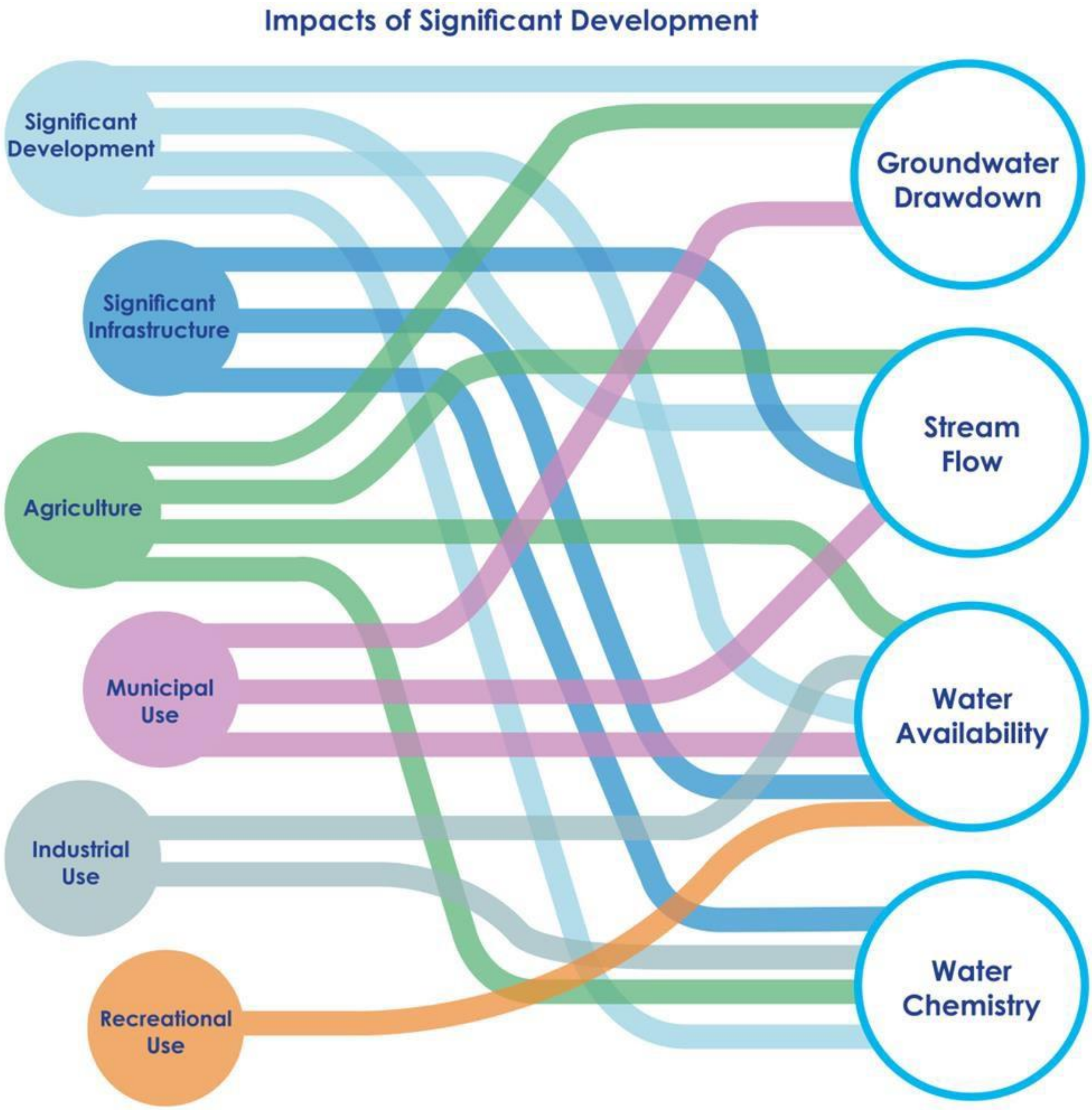

Figure 1: Conceptual map of cumulative impact analysis for State Significant Development (SSD) and State Significant Infrastructure (SSI) projects, collectively known as 'Major Projects'.

Given the predictive nature of cumulative impact assessments and inherent uncertainty, monitoring supplants model analyses and predictions. Operational monitoring programs are discussed. These programs are typically detailed in a monitoring plan and adopted as operating conditions in the water licence or project conditions of approval. For projects in which monitoring results indicate impacts have occurred, typical mitigation measures are discussed.

This presentation provides key recommendations to assist project proponents with planning their approach to predicting and managing the cumulative impact assessments required under the NSW planning approval and water licensing processes.

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WATER AND SALT BALANCE DURING ENVIRONMENTAL WATERING OF THE LOWER RIVER MURRAY FLOODPLAIN

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Environmental watering, implemented by artificially conveying fresh river water to the otherwise dry floodplain, is one of the basin-wide management strategies for the River Murray floodplain.
Field monitoring, laboratory experiments and unsaturated zone modelling were conducted to quantify the outgoing of environmental water via infiltration and evapotranspiration, the vegetation responses and salts migration due to artificial watering.
It was found that at the initial watering of 60 megalitres of fresh water, half of the water was stored in a 4.5-hectare jellybean-shaped pond and the other half was infiltered into the underneath alluvial soil. Recharge to the semi-confined aquifer via 6-m-deep Coonambidgal Clay was found to occur almost immediately after the formation of the pond, as indicated by the piezometric heads, groundwater temperature, electrical conductivity and chemistry. Numerical modelling suggests that the surface water pond persisted for 8 months, primarily due to water loss by evapotranspiration and infiltration, accounting for a ratio of 1:2, respectively. The subsequent top-up watering of 40 megalitres was predominately stored in the pond as the soil was saturated by the previous watering. The surface water pond lasted for 3 months, and the ratio of evapotranspiration to infiltration is 1:1. Instead of the surface water pond, the Coonambidgal Clay was found to be the long-lasting, effective environmental watering reservoir as the stored water can sustain the floodplain vegetation for years. This result of the study helps quantify the outgoing of the environmental water and can provide useful information to improve the efficiency of this floodplain saving strategy.

NOVEL SPATIAL-FEATURE ENGINEERING IN MACHINE-LEARNING TO EXPLORE CSG-INDUCED SUBSIDENCE FROM INSAR DATA

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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. The Office of Groundwater Impact Assessment (OGIA) has recently received an expanded remit to assess CSG-induced subsidence in the Cumulative Management Area (CMA). For monitoring subsidence as part of this assessment, OGIA adopted Interferometric Synthetic Aperture Radar (InSAR) – a powerful remote-sensing technique used for measuring ground surface deformation.

InSAR products, especially those with short wavelengths, have limited spatial coverage in cultivated areas due to the presence of vegetation. In the Surat CMA, the Condamine Alluvium is an area of CSG development where ongoing observations are needed to monitor CSG-induced subsidence. The area is also intensively cultivated, which poses a challenge for InSAR technology to provide coverage as good as outside those areas, as vegetation growth can disrupt the coherence of radar signals between acquisitions. Loss of coherence can make it difficult to generate interferograms and detect deformation.

A novel spatial-feature engineering method is applied, along with machine-learning, to interpolate InSAR data. This method involves Random Forest and Extra Trees methods with transformed coordinate features, which introduces a greater awareness of spatial relationships into the learning process, compared to using traditional coordinate features.

The interpolation clearly enables the identification of CSG-induced subsidence in the area of interest whilst removing spatially uncorrelated signals present in the raw data. As such, the method improves the understanding of spatial-temporal evolution of subsidence in low-density areas and addresses some of the main challenges of InSAR coverage in the area of interest.

BIOGEOCHEMICAL CYCLING OF IRON AND ASSOCIATED DIAGENESIS IN AN INTERTIDAL BEACH AQUIFER

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The freshwater-saltwater interfaces in coastal aquifers are dynamic biogeochemical reaction zones due to the mixing of two waters with distinct chemical signatures. At these interfaces, primarily the upper saline plume (USP) and saltwater wedge (SW), the groundwater-borne Iron (Fe) reacts with oxic seawater and undergoes an abiotic process named oxidative precipitation. This process typically involves numerous concurrent and interconnected reactions, and the resultant formation of Fe oxides can trigger additional biogeochemical processes. These processes include, but are not limited to, (i) the association (coprecipitation and adsorption) between dissolved organic matter (DOM)/dissolved phosphate (P), and particulate/colloidal Fe oxides; (ii) sulfate reduction and formation of Fe sulfide; (iii) reductive dissolution of Fe oxides by marine labile DOM. To understand the complex interactions between these processes, we use data obtained from porewater samples and sediment core samples along a beach transect perpendicular to the shoreline at Cowen beach in Moreton Island, Queensland, Australia. Combined analysis of porewater and sediment data revealed the formation and distribution of the Fe oxides in the intertidal area and the impact of the Fe oxides on porewater flow and subsequent salinity distribution within the USP. A conceptual model (Coupled Fe-P-S-OC) regarding to the Fe dynamics in the coastal aquifer, considering the aforementioned geochemical processes was raised and a 2-D reactive transport model was developed to simulate these processes. Numerical modelling locates the enrichment area of Fe oxides and Fe sulfide within the beach aquifer, and demonstrates the effect of tidal oscillation on the geochemical conditions of the beach aquifer and resulting temporal variations in the discharge of Fe. Overall, this research focuses on the transport (physical aspect) and transformation (geochemical aspect) of groundwater-borne Fe in the coastal environment, emphasizing the coastal aquifer's vital role in regulating terrigenous chemical fluxes and associated diagenetic processes.

COMPARATIVE DEWATERING MODELLING AND LESSONS LEARNT USING SEEP/W AND GROUNDWATER VISTAS

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Groundwater flow modelling is widely applied in the engineering industry to assess groundwater risks during infrastructure construction. Various modelling software, relying on finite difference or finite element solutions, offer different means to investigate groundwater numerically. This paper serves as a case study to compare the capabilities and limitations of two modelling softwares, SEEP/W and Groundwater Vistas, in assessing groundwater inflow and drawdown during the construction of a wastewater clarifier.

In this study, we developed a regional groundwater flow model based on a 3D geological model using Groundwater Vistas. Dewatering spears, with various abstraction rates and layouts were modelled as "Well" points to represent different dewatering designs proposed for each construction stage.

Additionally, we modelled the use of sheet piles as a "Horizontal Flow Barrier" to assess their effectiveness in reducing inflow and the magnitude and extent of drawdown. For comparison, a separate groundwater flow model was developed using SEEP/W, which takes advantage of its recent software development, directly incorporating the 3D geological model and the BUILD3D functionality. Although the problem was essentially the same, the modeller faced the challenge of adjusting the modelling approach to adapt to the model build environment of the software. Moving away from the traditional use of MODFLOW packages to represent boundary conditions in a numerical model, the modeller learned to shift the focus towards modelling the problem itself.

Modelling results are compared between the two models, and more importantly, insights and lessons are shared to enhance user experience and understanding of the two model build environments. We also discuss the limitations and capabilities of both software tools to provide better guidance for their practical applications in the industrial field.

SPATIO-TEMPORAL DEPENDENT INUNDATION RECHARGE IN GROUNDWATER MODELS: A CASE STUDY ON THE PIKE FLOODPLAIN, SA

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The river salinity and ecological health of the lower River Murray depend on the movement of water and salt in the floodplain. Inundation recharge to groundwater is crucial and can happen naturally or through artificial watering when the floodplain is submerged. The recharge rate depends on the area and depth of the ponded surface water, soil stratigraphy, groundwater level, and moisture content in the unsaturated zone, all of which change spatio-temporally.

Management of the river is informed by MODFLOW groundwater models, which usually treat recharge as a flux boundary (via USGS Recharge Package), without considering spatially variable relevant parameters. To improve the physical implementation of inundation recharge in groundwater models, four methods were evaluated:

1. Recharge Package, with a constant recharge rate applied to the inundated floodplain surface;
2. Recharge Package, and allowing the recharge rate to be changed spatio-temporally with the surface water depth, soil conditions and watertable;
3. River Package, considering the spatio-temporal dependent surface water depth and adopting a constant conductance across the floodplain soil;
4. River Package, similar to (3) but floodplain soil conductance varies with surface water depth, as the unsaturated floodplain soil tends to have higher moisture content and hydraulic conductivity with deeper surface water depth.

Method 1 is the most straightforward as it requires minimum data input. A recharge rate of 2 mm/day applied to the inundated surfaces can effectively achieve groundwater head estimations that agree overall well with the measured data. Groundwater heads and salt loads may be overestimated if the constant recharge rate or effective floodplain hydraulic conductivity is too high.

River Package effectively avoids excess recharge when the groundwater head equals the surface water head, even if the soil conductance is significantly overprescribed. Modelling results were more sensitive to the prescribed floodplain soil conductance while less so to the prescribed surface water depth.

COMBINING WEATHER FORECAST AND GROUNDWATER MODELLING ENSEMBLES TO QUANTIFY PREDICTIVE UNCERTAINTY UNDER CLIMATE CHANGE

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Predictive modelling includes assumptions about system variables in the future. In groundwater flow modelling often one of the main driving variables is the amount of rainfall. At the same time long-term weather forecasts and impact of climate change come along with high uncertainty. To overcome this problem, classic predictive modelling often uses a single “worst case” climate change scenario. This study presents a possibility on how weather forecast uncertainty can be included in predictive groundwater modelling. The aim of this approach is to propagate uncertainty from the weather forecast into groundwater predictive uncertainty analysis, by combining weather and groundwater parameter ensembles. Forty-eight different climate change scenarios, ranging from wet to dry scenarios, were available from the Department of Water for the study site in Western Australia. The upper and lower 90% interval and median were used to create an ensemble of normal distributed climate change scenarios between those bounds. Those scenarios were multiplied with local rainfall time series from monthly mean values of the model calibration period and randomly assigned to the predictive model ensemble. This led to predictions accounting for model parameter uncertainty and climate change uncertainty and provided more reliable model predictions.