Oral Abstracts

M-Z

WATER MONITORING FOR CLIMATE RESILIENCY

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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.).

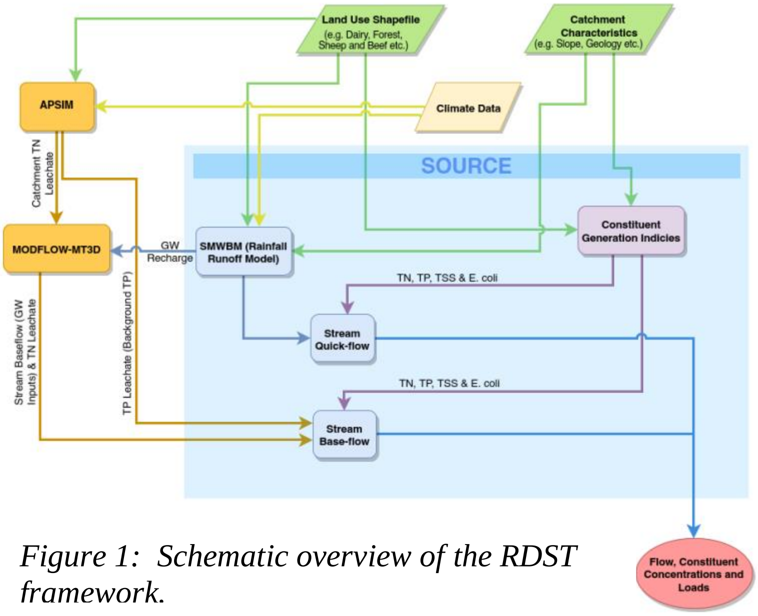

Figure 1: Schematic overview of the RDST framework.

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

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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.

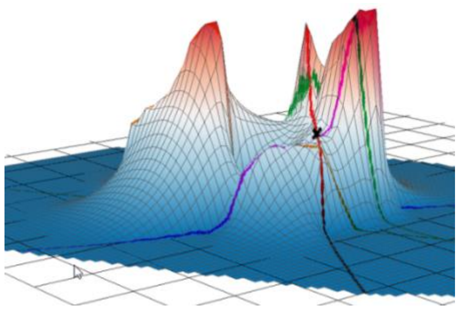

Figure 1. ERT survey 3D interpolation of basalt dyke.

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.

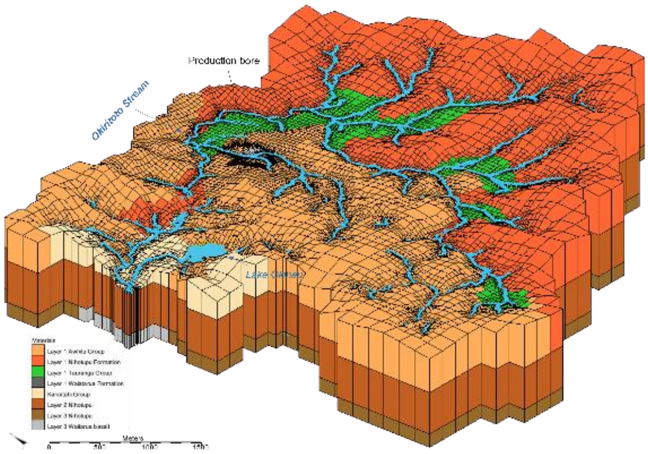

Figure 2. Groundwater model domain (3X vertical exaggeration).

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

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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

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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.

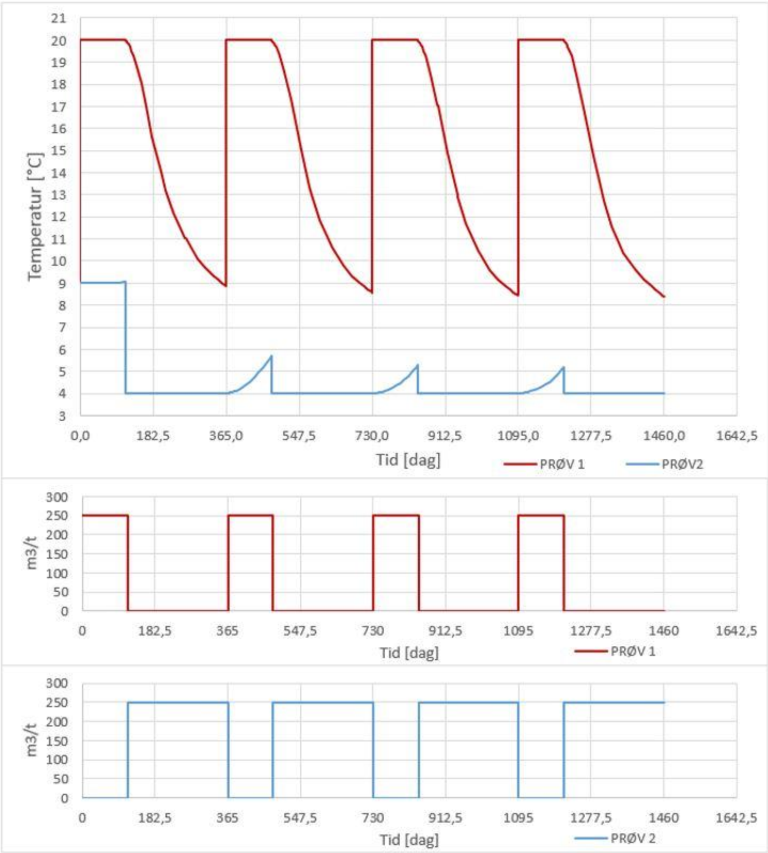

Figure 1; Simulated temperature variations of abstracted and injected groundwater and associated flow rates for one well-pair

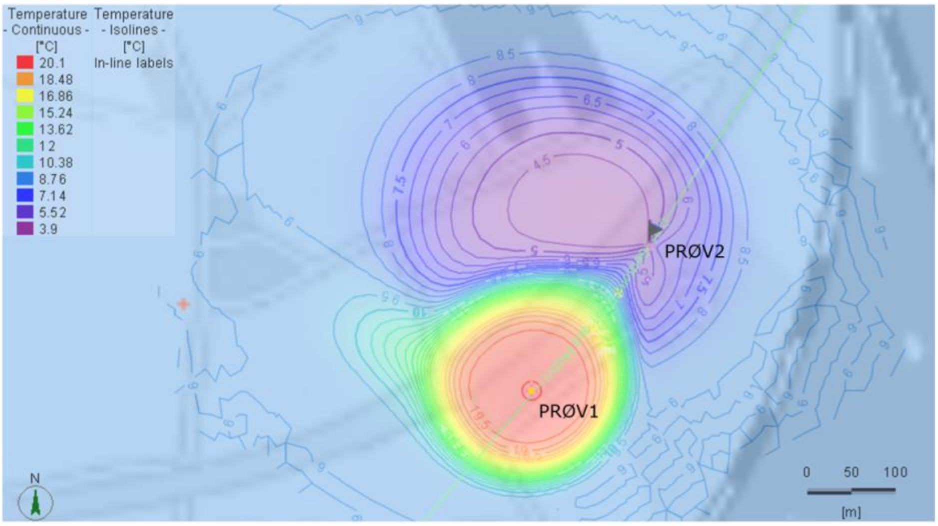

Figure 2; Simulated groundwater temperature of the targeted limestone aquifer after 3 years of operation.

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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[3]ESR

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.

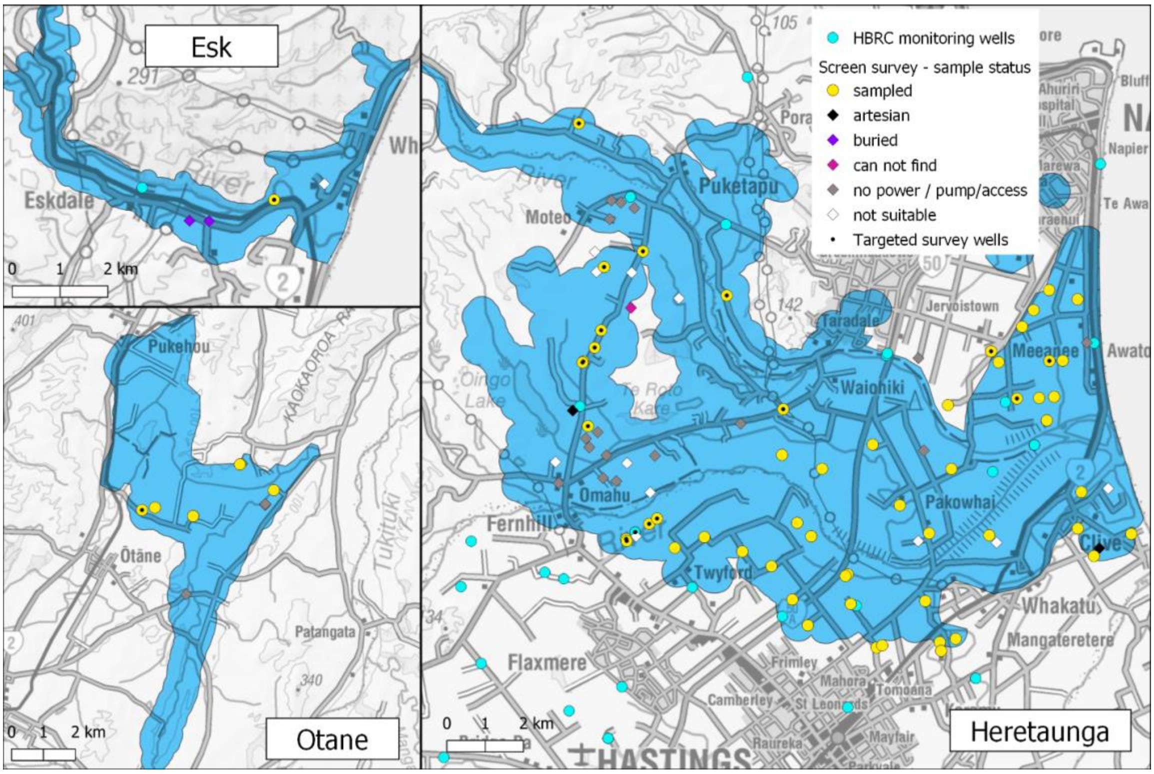

Figure 1: Distribution of locations visited during the screen survey and sampled for the targeted survey.

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

Moreau M[1], Cameron S[1], Harper S[2], Close M[3], Taves M[1], Sarris T[3]
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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

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[1] GNS Science, New Zealand

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.

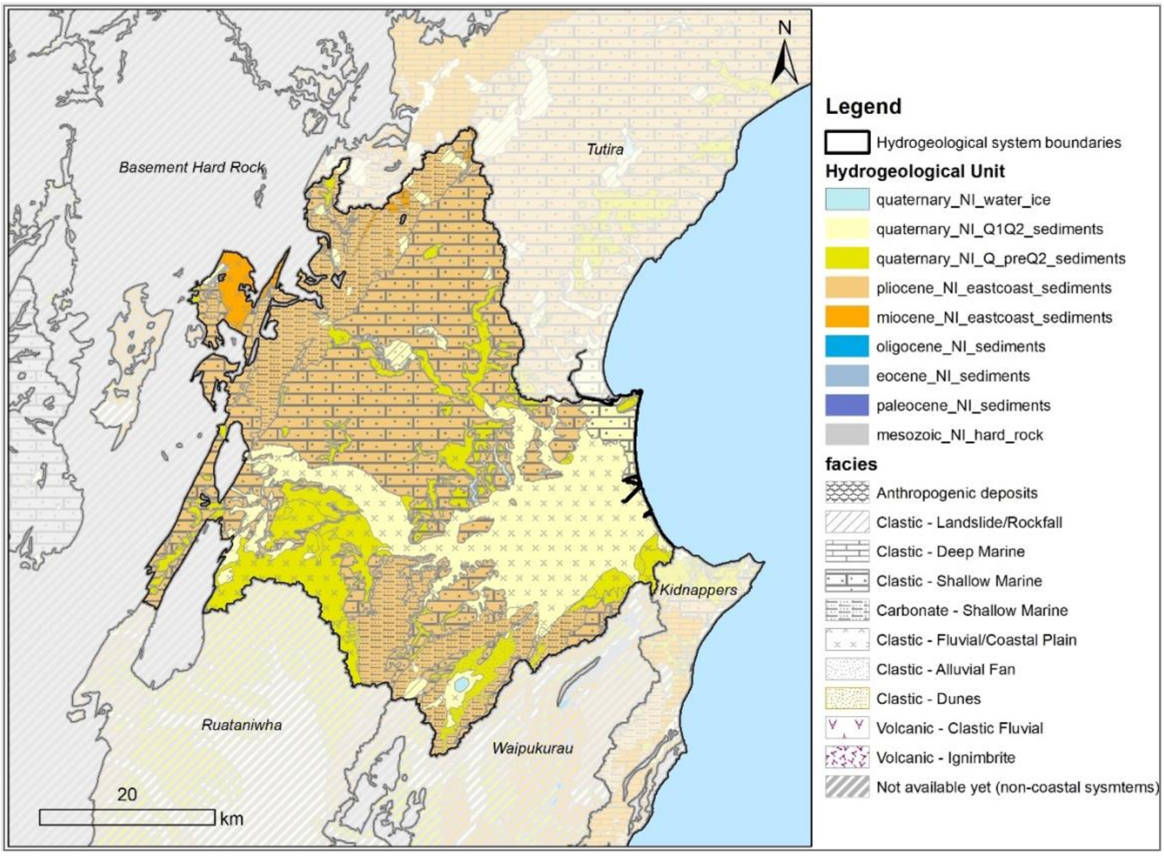

Figure 1: Hydrogeological units and associated depositional facies within the "Heretaunga Coastal System". Hydrogeological system were named as part of the mapping exercises. Coastal systems, names were based on geographical location.

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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.

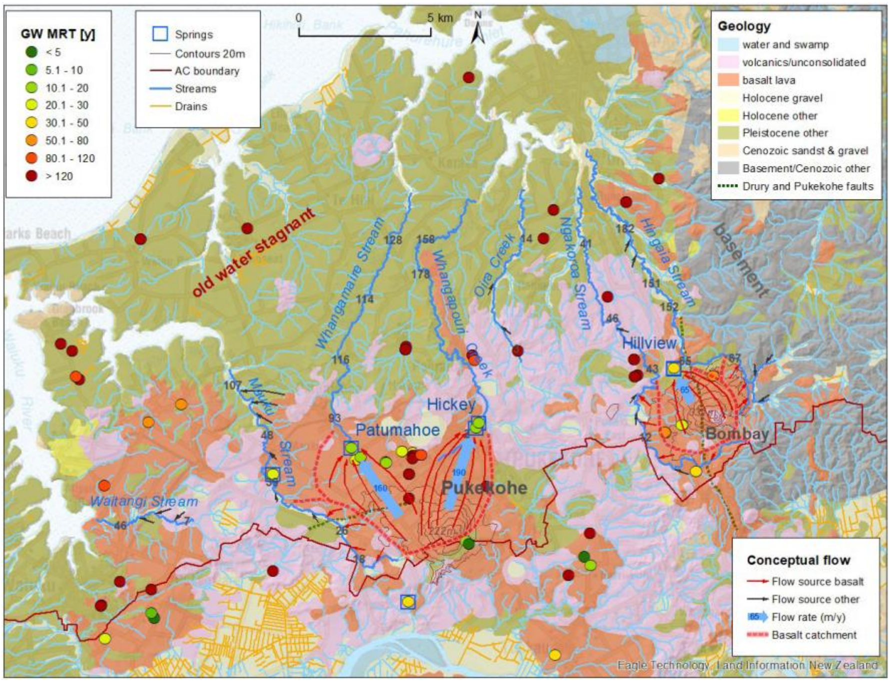

Figure 1: Groundwater dynamics and conceptual flow in the Pukekohe–Bombay area inferred from groundwater ages (MRT, circles) in conjunction with stable isotope and nitrate data (not shown). Active groundwater flow systems are shown in red arrows, flow rates are indicated by blue arrows of length proportional 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.

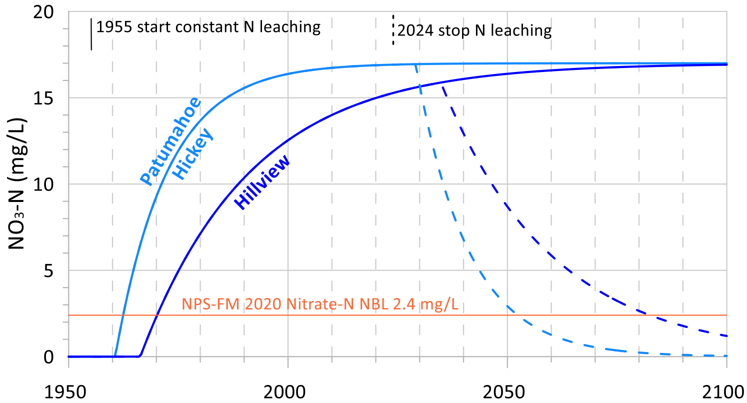

Figure 2. Response of nitrate concentrations for the main spring discharges from the Pukekohe and Bombay basalt lavas to the land-use scenario of start of constant nitrate loading at 1955 (full lines), followed by a theoretical discontinuation of nitrate loading in 2024 (dashed lines). Patumahoe and 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]

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[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

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[1] GNS Science, Wairakei, New Zealand
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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.

Murphy, G,[1]
[1] Pattle Delamore Partners Limited

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.

Tess Nelson[1], Kathryn Korbel[1], Grant Hose[1]
[1] Macquarie University, Sydney Australia

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

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

Rod Shaw,[1] Rebecca Nixon[1]
[1] Department of Climate Change, Energy, the Environment and Water

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

Paul Oluwunmi,[1] Catherine Moore,[1] Brioch Hemmings[1]
[1]GNS Science

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

Tomas Opazo,[1] John Doherty,[2]
[1] Flinders University
[2] Water Mark Numerical Computing

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

Lennie Palmer,[1]
[1] Riley Consultants Limited

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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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.

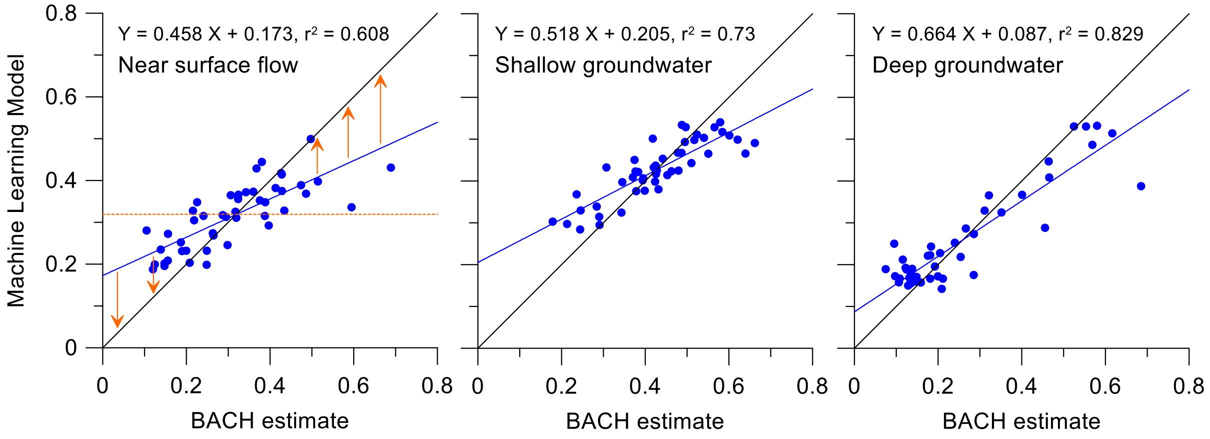

Fig 1: The ensemble model (XGBoost) consists of 150 mini-models estimating flow fractions using GIS data. The fitted regression lines of machine learning results on BACH estimate are shown in blue. The slope represents the sensitivity of the model.

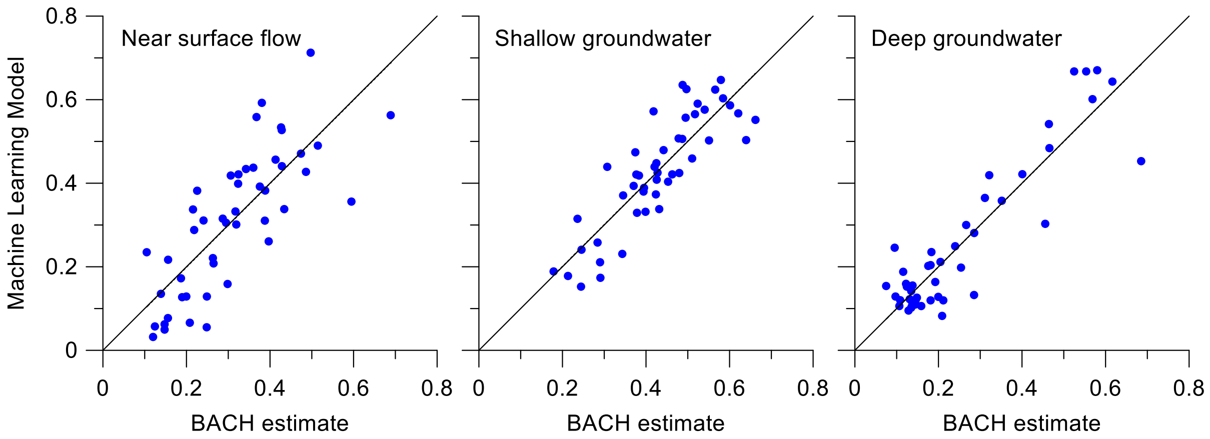

Fig 2: The scaled ensemble model.

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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.

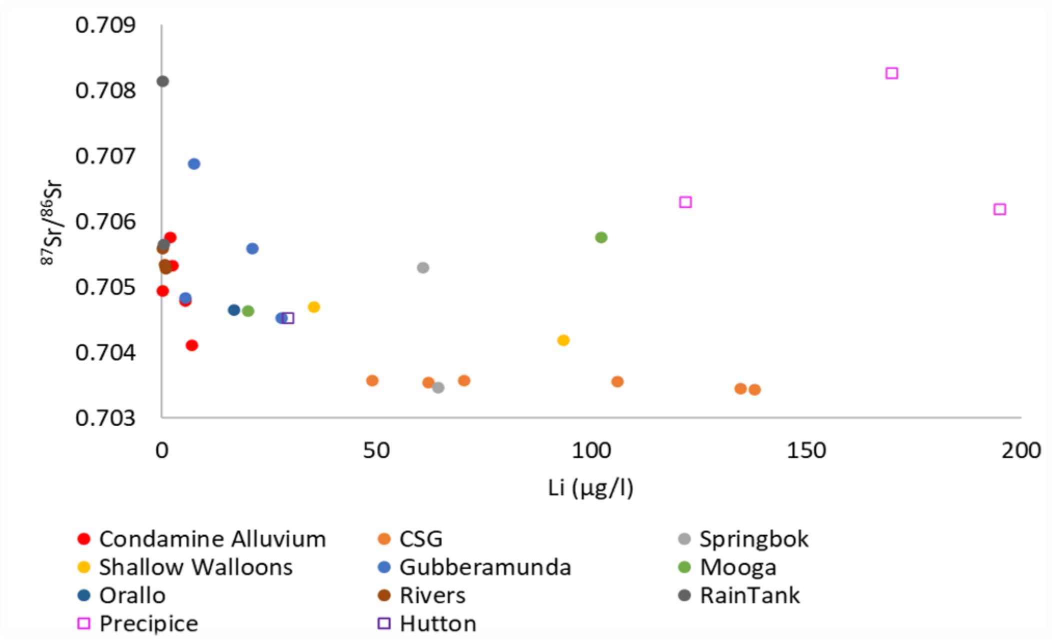

Figure 1: Groundwater, CSG production water, river and rain water $^{87}Sr/^{86}Sr$ signatures vs Li concentration.

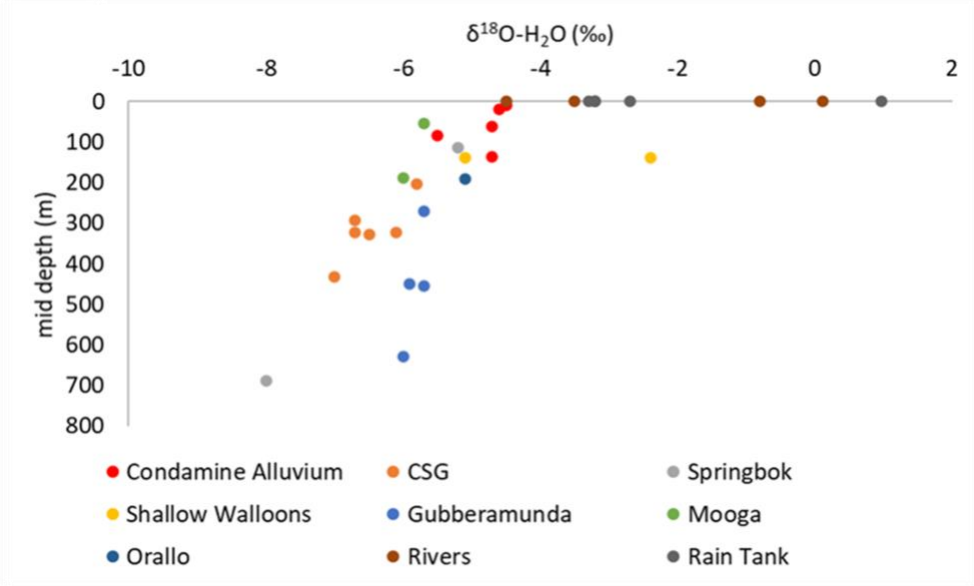

Figure 2: Groundwater, CSG production water, river and rain water $\delta^{18}O$-H_2O with depth.

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

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[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.

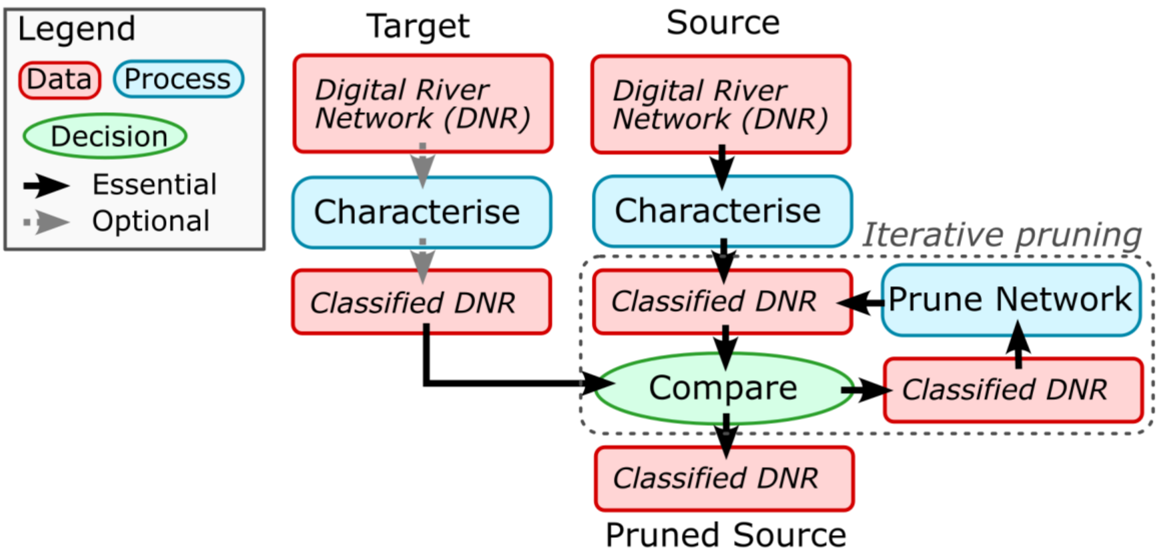

Figure 1: An algorithm for pruning a source network until it matches the characteristics of a target network.

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.

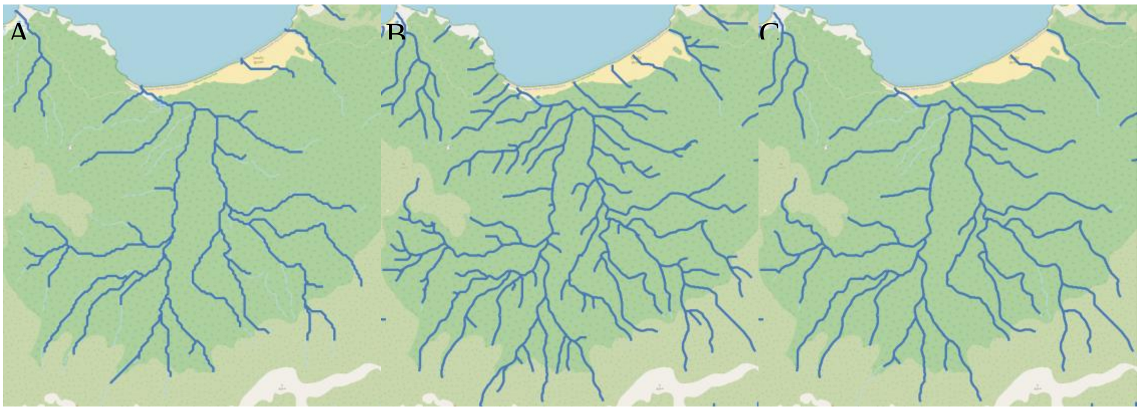

Figure 2: An illustration of the algorithm's ability to prune a source network to represent a target network more closely at Smokey Beach in Northern Raikora. A. NIWA's DN2, B. NIWA's DN3, C. NIWA's DN3 after iterative pruning to more closely resemble NIWA's DN2.

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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.

Rose Pearson[1], Matt Wilson[2], Cyprien Bosserelle[1], Alice Harang[1], Graeme Smart[1], Emily M. Lane [1]
[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.

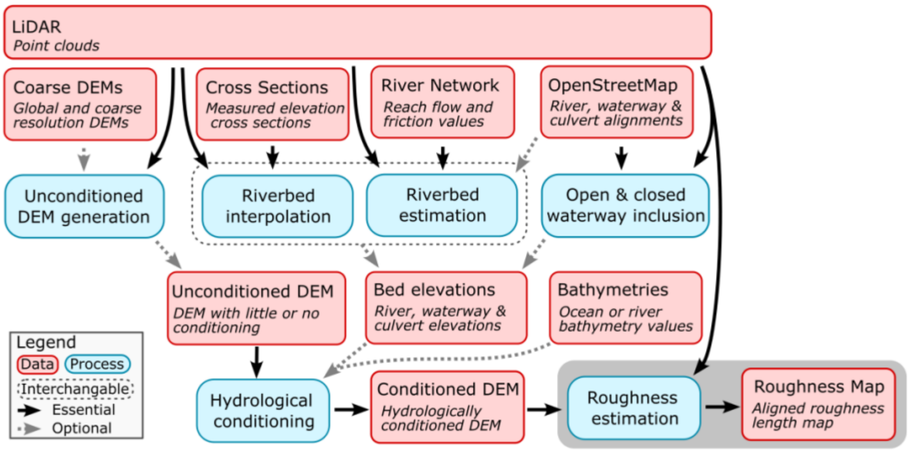

Figure 1: GeoFabrics is a multistage framework for producing hydrologically conditioned DEMs from a range of elevation data. REC stands for river environment classification (Snelder 2002), and OSM stands for Open Street Maps.

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.

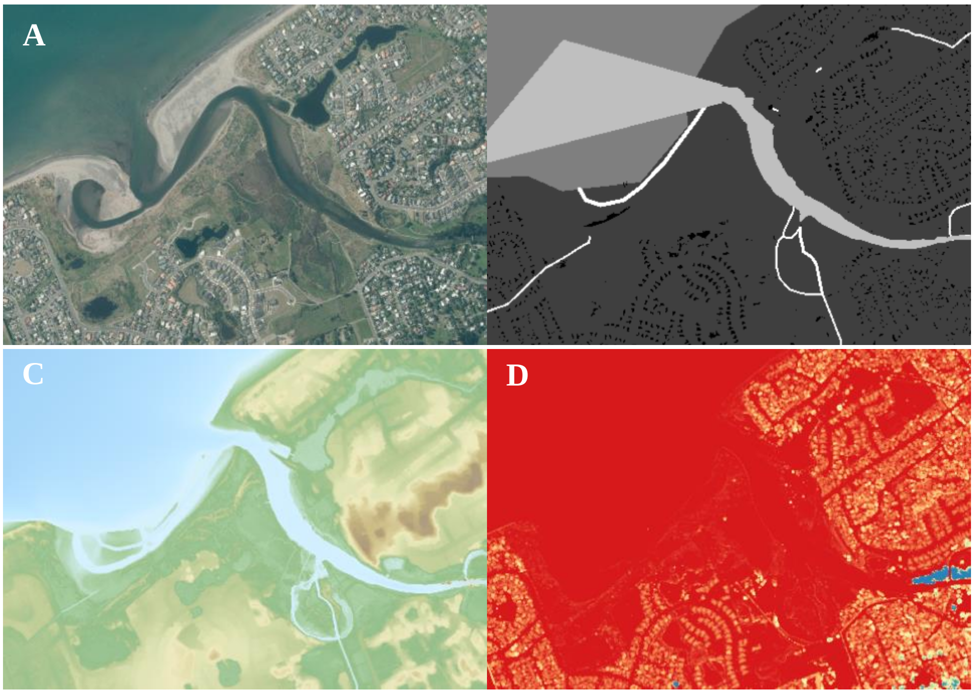

Figure 2: A roughness map and hydrologically conditioned DEM generated from the Wellington (2013-2014) LiDAR survey for the Waikanae River using GeoFabrics. A. Aerial image of the region, B. The data sources, C. The hydrologically conditioned DEM generated, D. The roughness map.

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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

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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)

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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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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).

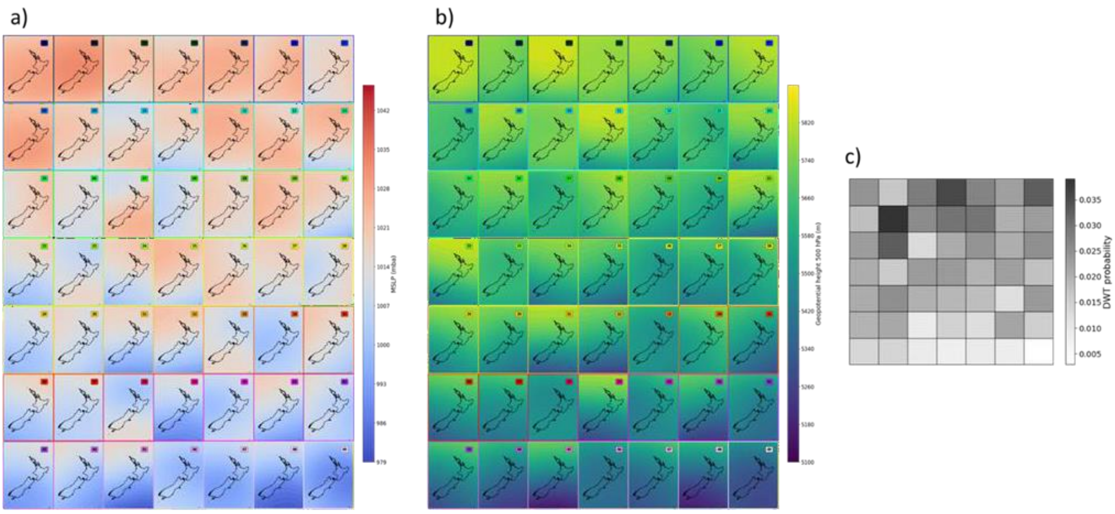

Figure 1: Composite patterns of MSLP (a) and 500 hPa geopotential height (b), and probability of occurrence of each DWT (c)

Acknowledgements

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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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[1] University of Canterbury

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).

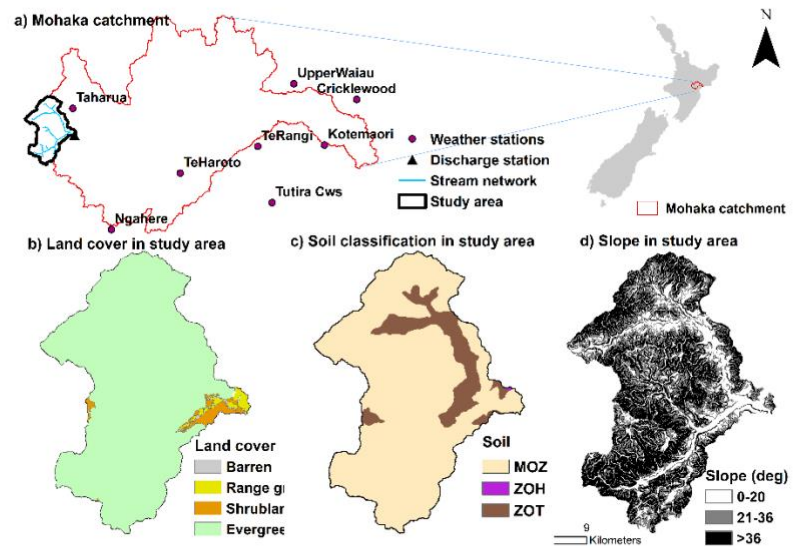

Figure 4: Top: Forested subcatchment study area within the Mohaka catchment showing streamflow network and nearby weather stations; Bottom: (a) land cover map, (b) the soil classification, and (c) the terrain slope.

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).

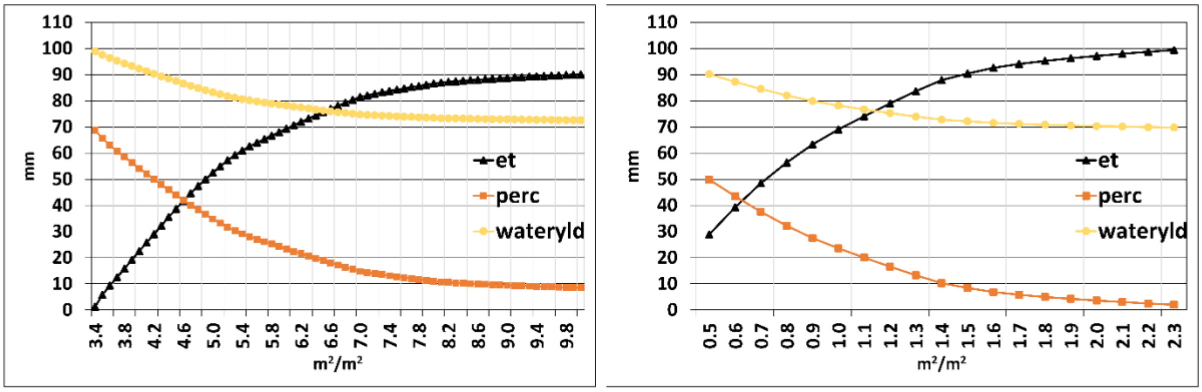

Figure 5: Sensitivity of water balance components evapotranspiration (ET), percolation (perc) and water yield (wateryld) to the variation of the maximum (left) and minimum (right) leaf area index.

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.

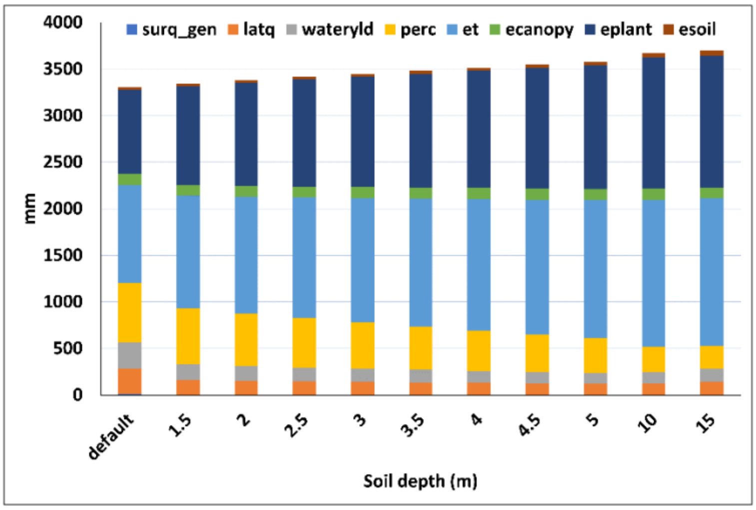

Figure 6: Water balance values for the actual rainfall scenario for different soil depths.

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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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[2] NIWA, Christchurch
[3] Rainfall.NZ

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.

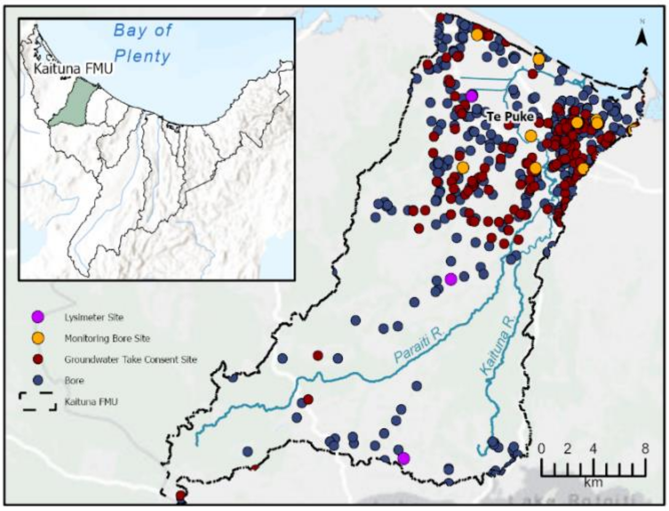

Figure 1: Bores and Lysimeter sites in Kaituna FMU.

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.

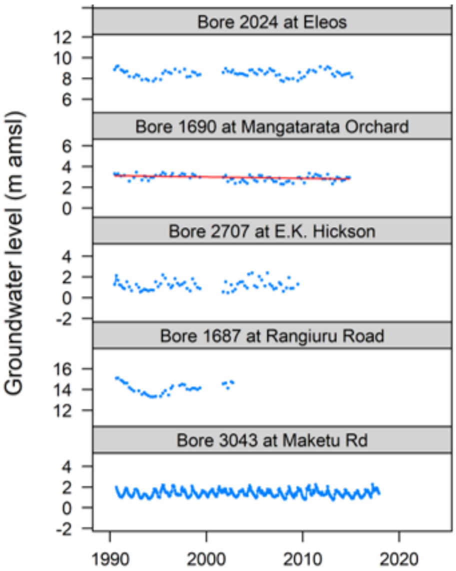

Figure 2: Time series plots of monthly averages of groundwater level for five sites analysed. Red line shows the trend for the sites where statistically significant (corrected $p < 0.05$) trends were identified.

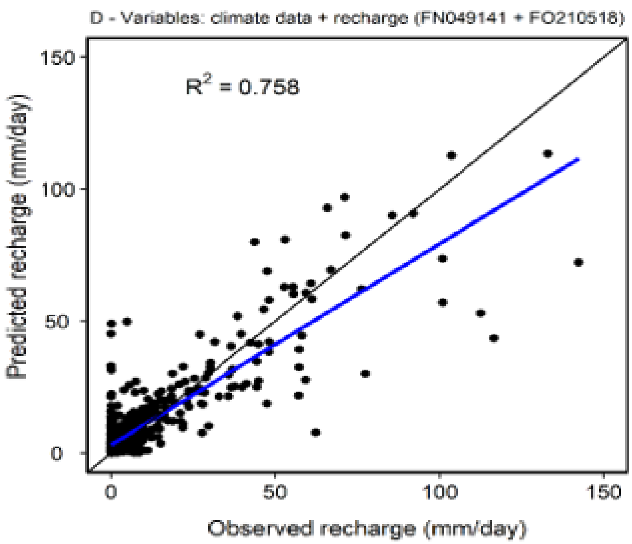

Figure 3:Observed versus modelled recharge using a multiple regression model with daily data at lysimeter site EL051775 using site specific data and recharges from nearby sites.

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

Rawlinson, Z.,[1] Kellett, R.,[1] Sahoo, T.,[1] Foged, N.,[3] Hemmings, B.,[1] Moore, C.,[1] Scadden, P.,[1] Tschritter, C.,[1] Herpe, M.,[1] Lawrence, MJF.,[1] Harper, S.,[2] Langley, A.,[4]
[1]GNS Science
[2] Hawke's Bay Regional Council
[3] Aarhus GeoInstruments
[4] Project Haus

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

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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

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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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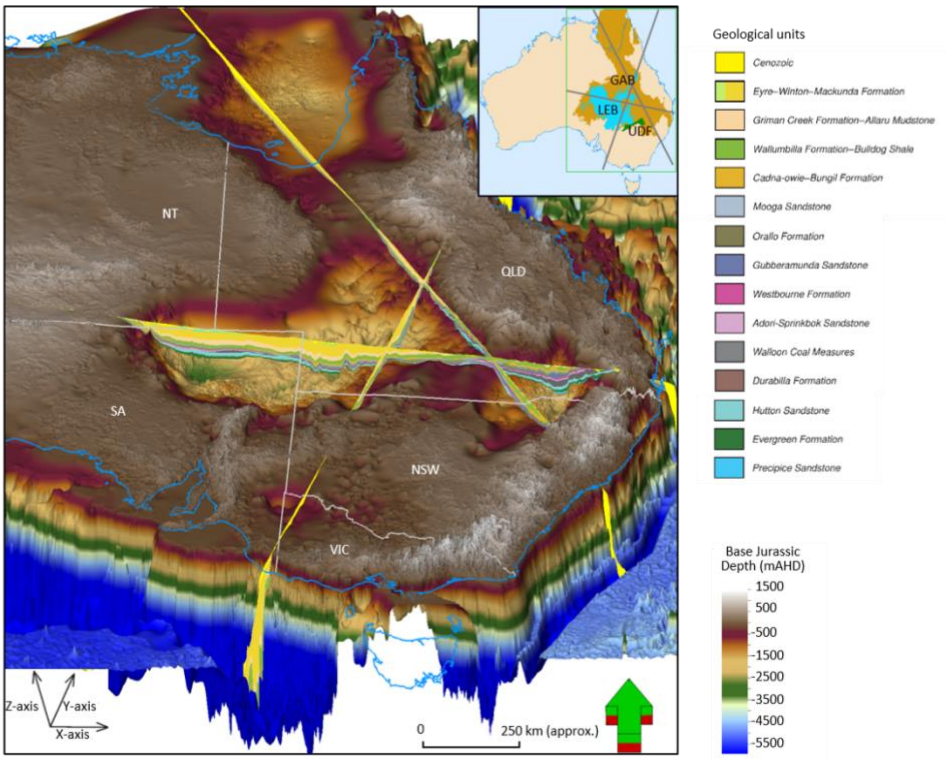

Figure 7. Three-dimensional hydrogeological model (Vizy & Rollet, 2023) showing the base of Jurassic surface (m AHD) for eastern Australia and cross-sections through the modelled hydrogeological units along three regional transects. The base of Jurassic surface corresponds to the base of the Great Artesian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

Guus Rongen,[1,3] Ben Throssel,[1] Kolt Johnsen[2]
[1] Pattle Delamore Partners Ltd.
[2] Auckland Council
[3] Delft University of Technology

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).

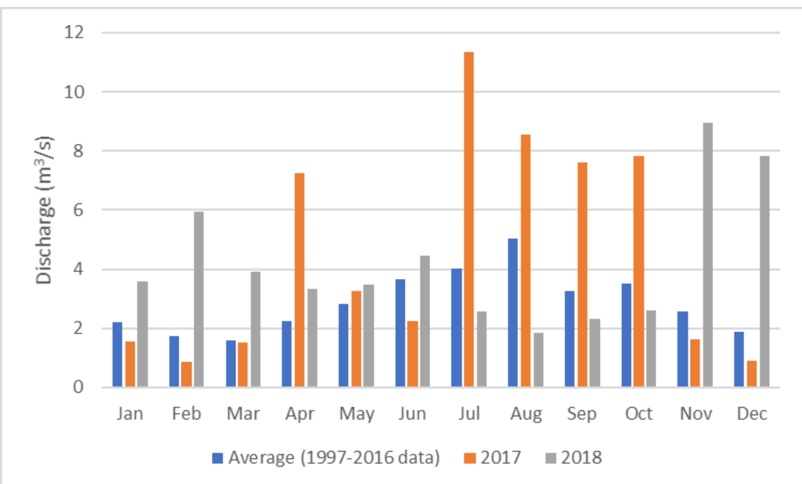

Figure 1: Monthly average discharge for the Selwyn River illustrating 2017 and 2018 against the longer term record

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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Institute of Environmental Science and Research Ltd. (ESR), New Zealand

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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[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*).

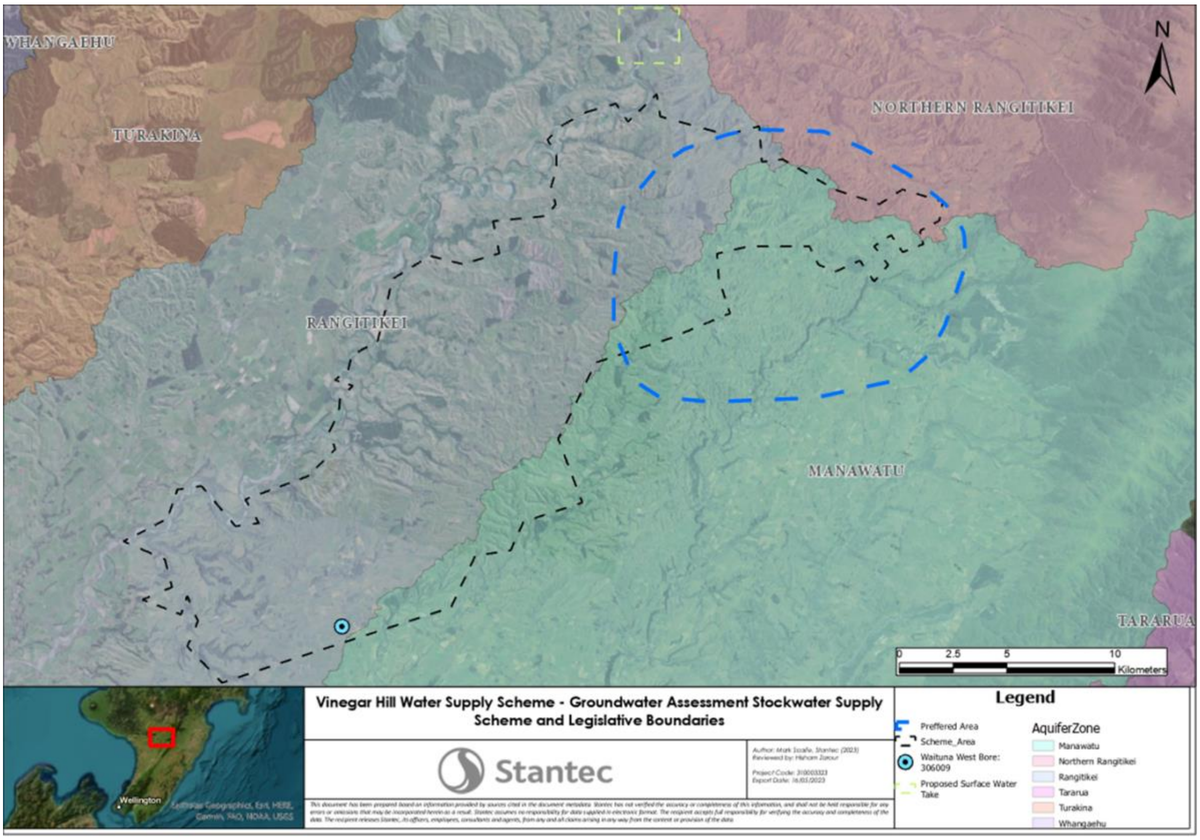

Figure 8: The extent of the Vinegar Hill Stockwater Supply Scheme, MDC's preferred bore location and regulatory boundaries.

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.

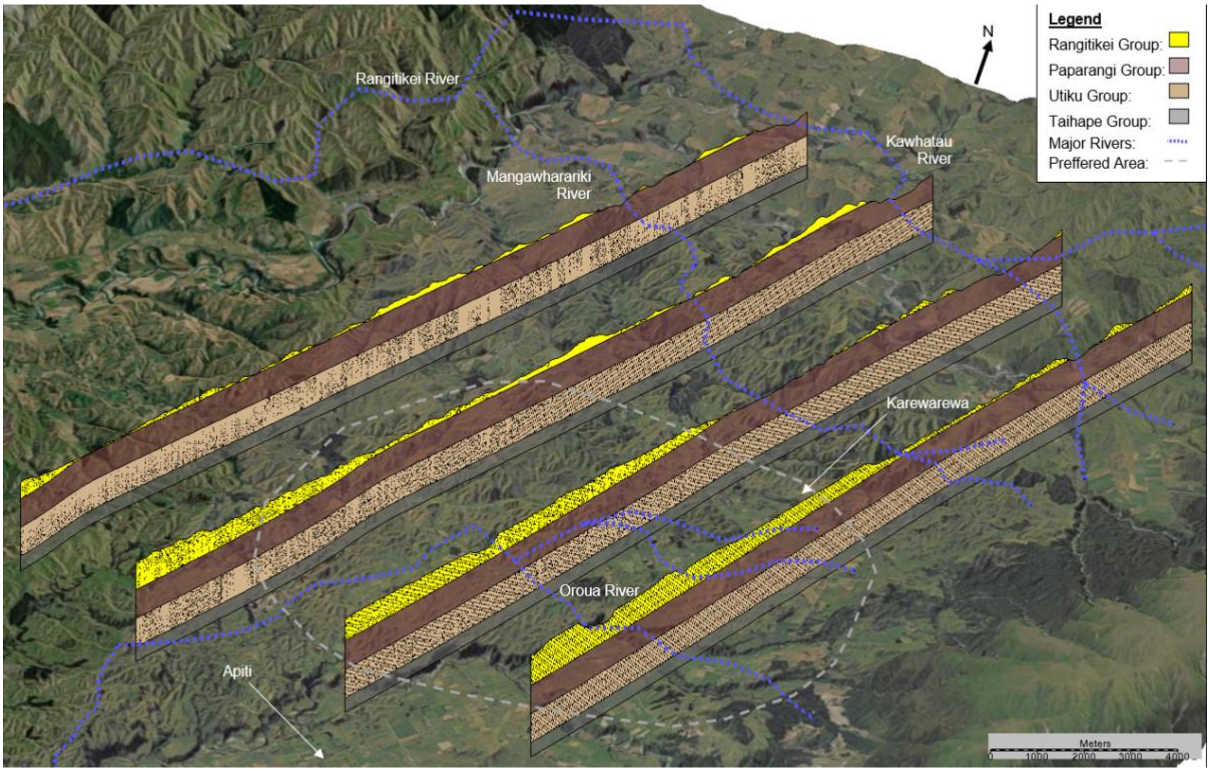

Figure 9: A series of cross sections cut through the geological conceptual model, 2×Vertical Exaggeration

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 Mangawhararariki 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.

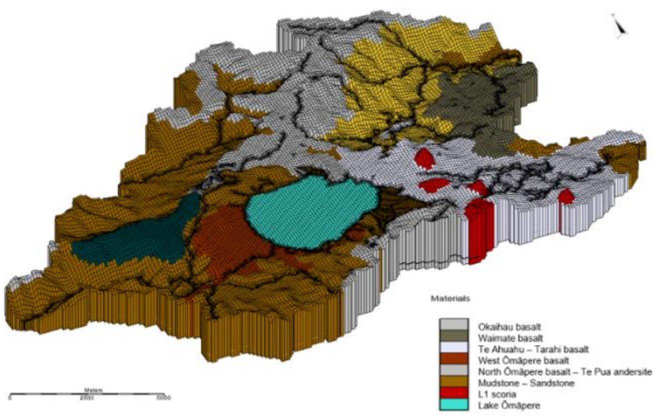

Figure 10. Numerical Groundwater Model of Lake Ōmāpere and surrounding catchments.

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.

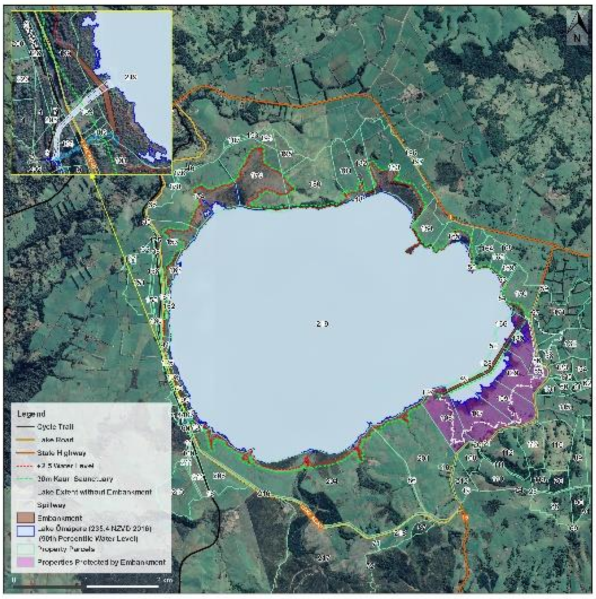

Figure 11. Lake Ōmāpere with 2.5 m water level increase indicated by red dash line.

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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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.

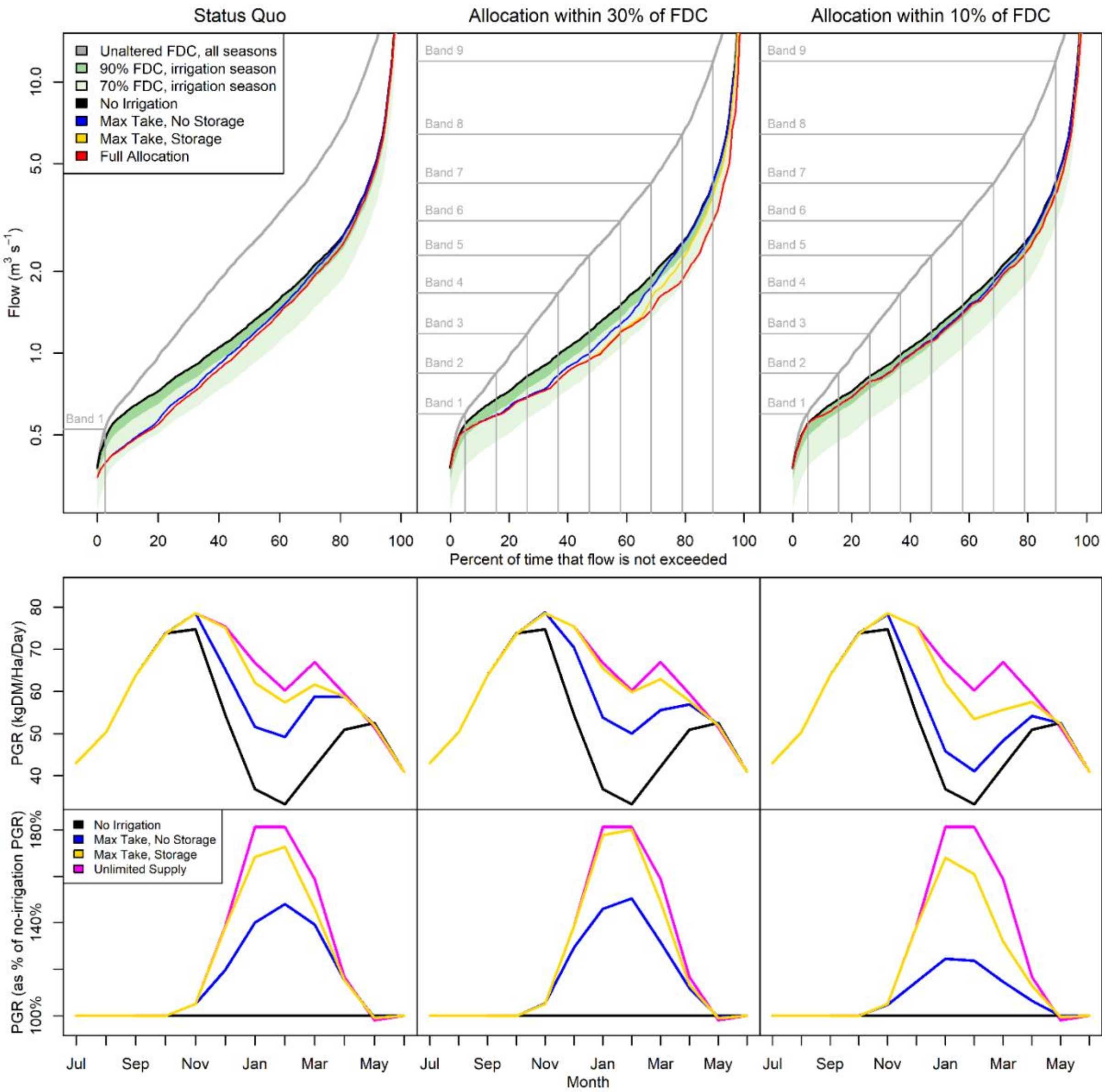

Figure 12: FDCs showing river flow alteration (upper row) and plant growth rate (PGR) (lower rows) for different allocation rules and irrigation strategies. Flow allocation bands are calculated from the all-time FDC. Resulting irrigation season FDCs are shown for each user strategy (No Irrigation; Max. 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

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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

Stanmore, E.,[1]
[1] WSP

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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[1] Lincoln Agritech

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.

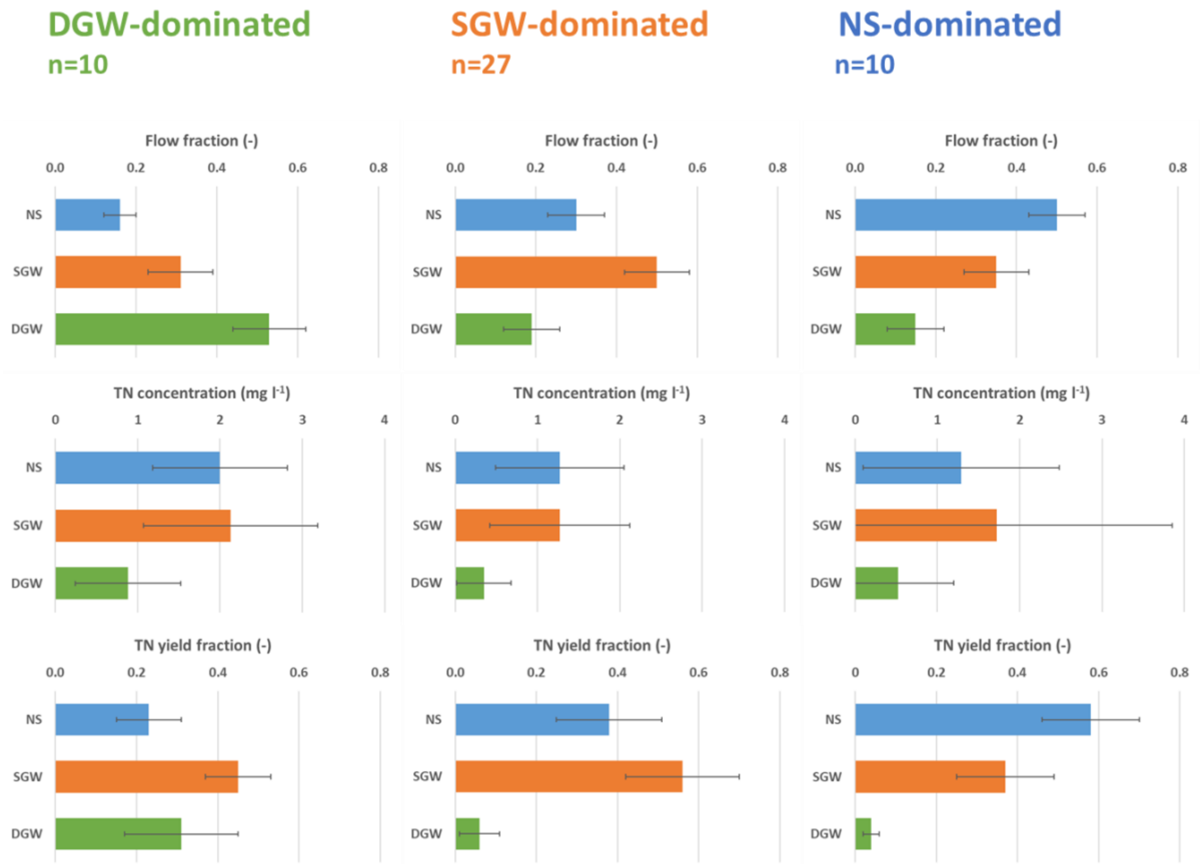

Figure 1: Vertical profiles of water flow contributions (top), TN concentrations (middle) and TN yield fractions (bottom) for DGW flow dominated catchments (left), SGW flow dominated catchments (middle), and NS flow dominated catchments (right). Based on long-term average BACH estimates (2006 – 2020).

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

Stewart, M.K.,[1] **Thomas, J.T.**[2]
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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.

4. References

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POWERING SAFE DRINKING WATER FOR AUSTRALIAN FIRST NATIONS REMOTE COMMUNITIES.

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Department of Climate Chnage, Energy, the Environment and Water.

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

Luke Sutherland-Stacey,[1] Andrew Peace,[1] John Nicol,[1] Celine Cattoen-Gilbert[2]
[1] Weather Radar New Zealand Limited
[2] Taihoro Nukurangi, National Institute of Water and Atmospheric Research (NIWA)

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

Swan, G,[1]
[1] Pattle Delamore Partners Limited

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

Mike Taves,[1] Yinjing Lin,[2] Matt Wilkins,[2] Wes Kitlasten,[1] Christian Zammit[2]
[1] GNS Science
[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

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[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.

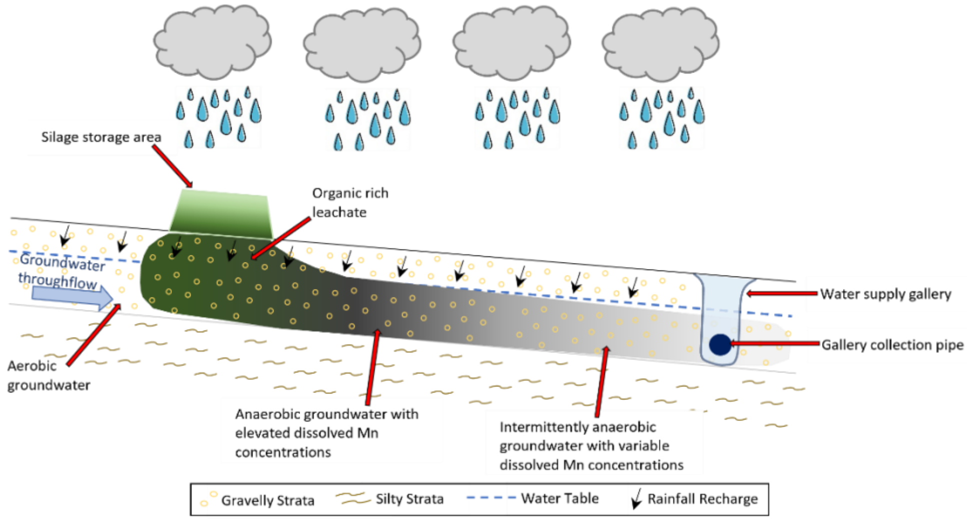
Methods

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]
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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]

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[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.

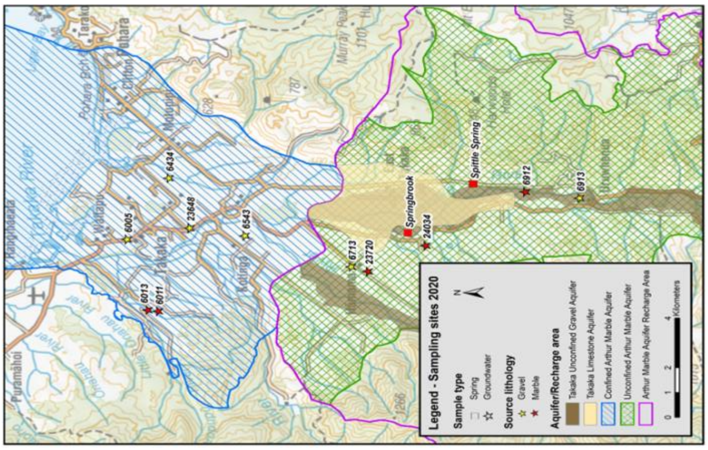

Figure 13 Location of sampling sites. Stars denote bore/well groundwater samples, squares denote Spring samples, Blue striped area confined Arthur Marble Aquifer, Green cross-hatched the unconfined Arthur Marble Aquifer. Pink line shows Arthur Marble Aquifer recharge area.

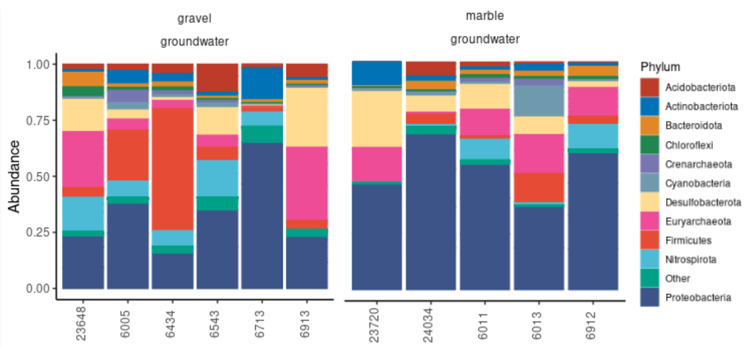

Figure 14 Phyla present across the gravel and marble aquifers.

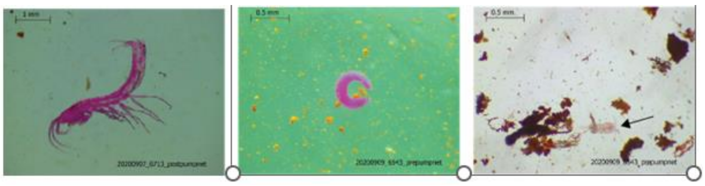

Figure 15 Example of the macrofauna (Stygofauna) present. Images from left to right are amphipod, worm, copepod.

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]
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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.

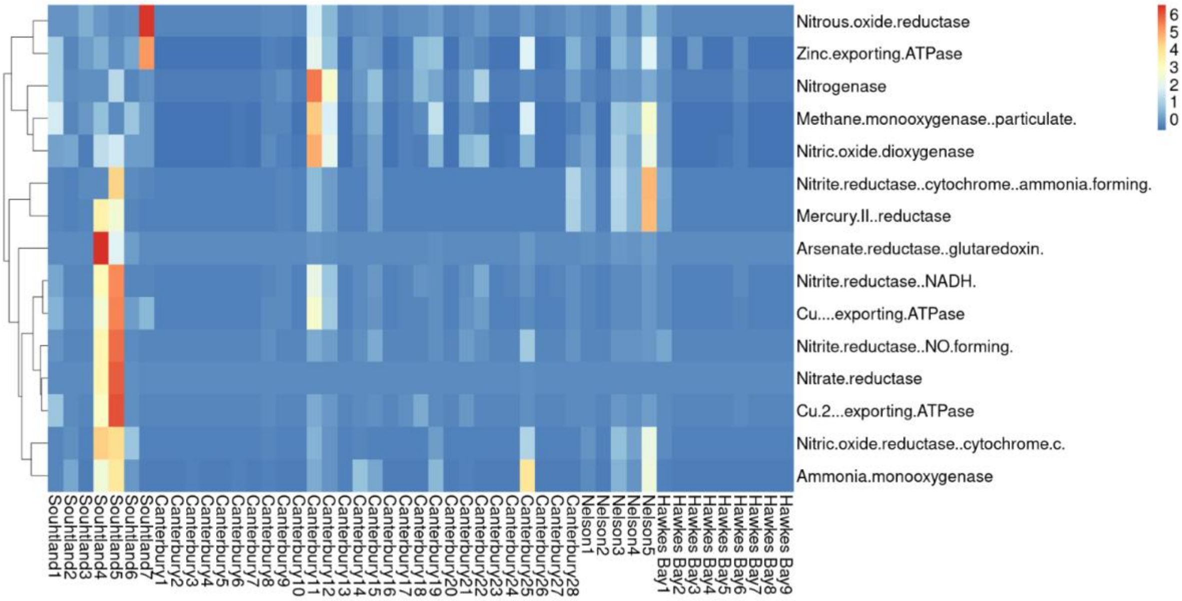

Figure 17 An example of the outputs from a PICRUSt2 generated heatmap of the selected gene markers across samples. Colours present a scaled index of the amount of genes identified in samples (blue less through to red higher number).

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INVESTIGATING PATHOGEN SURVIVAL IN GROUNDWATER

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

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.

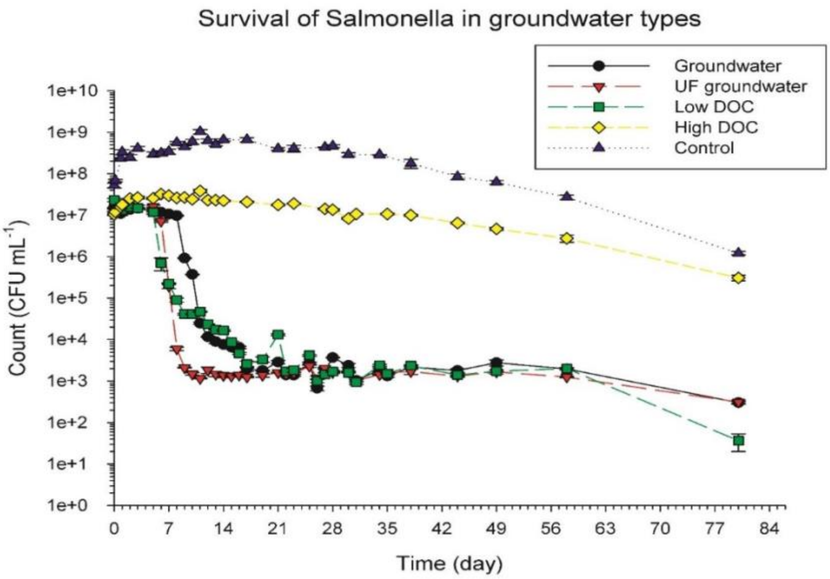

Figure 18 *Salmonella typhimurium* survival in four different groundwaters. The symbols are average (mean) counts (n = 3), lines are the standard error of the mean.

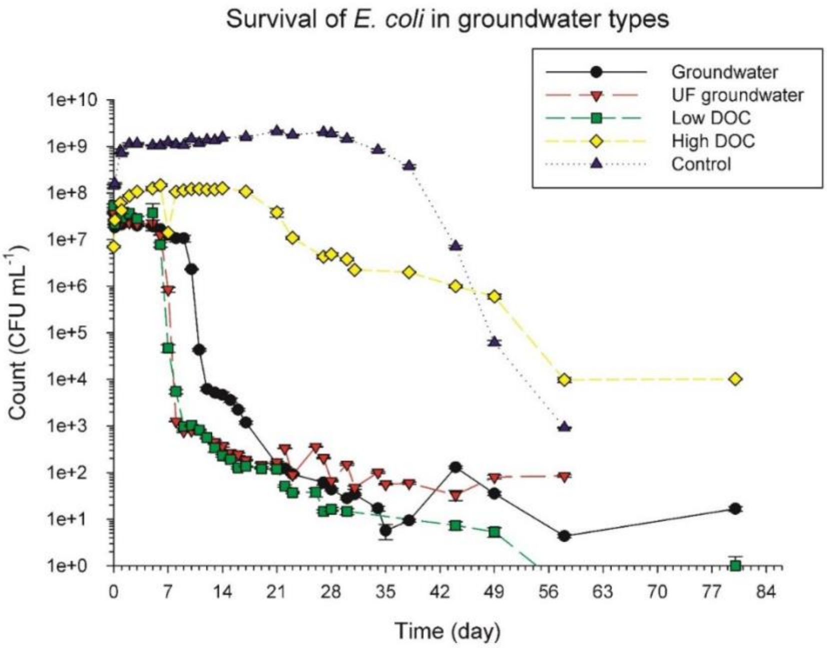

Figure 19 *E. coli* survival in the four different groundwater types over time. The symbols are average (mean) counts (n = 3), lines are the standard error of the mean. Control counts are included for comparison.

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

Julian Weir,[1] Joseph Thomas,[2] Andrew Fenemor[3]
[1] Aqualinc Research Ltd, Christchurch
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[3] Landcare Research, Nelson

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.

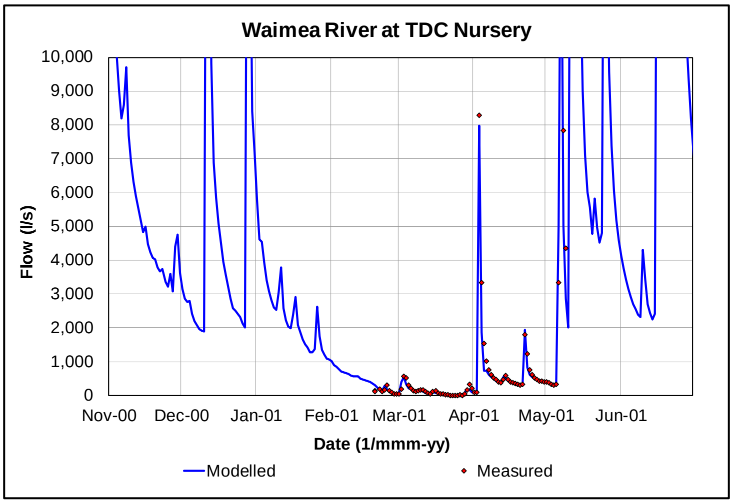

Figure 2: Example river flow calibration

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.

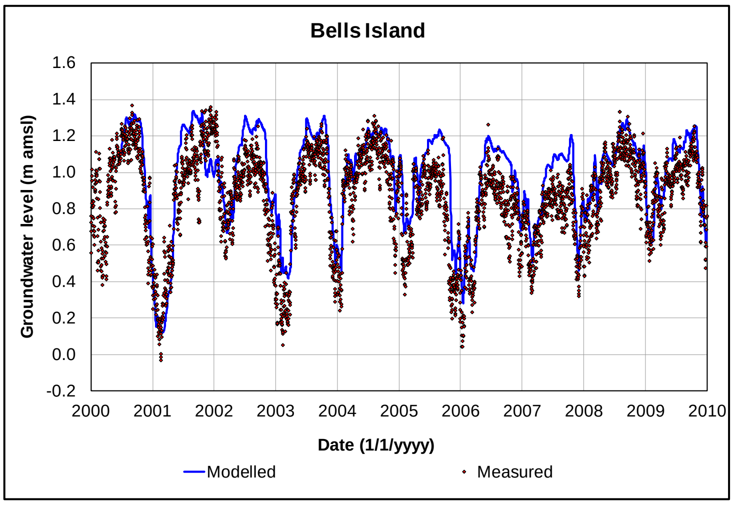

Figure 3: Example groundwater level calibration

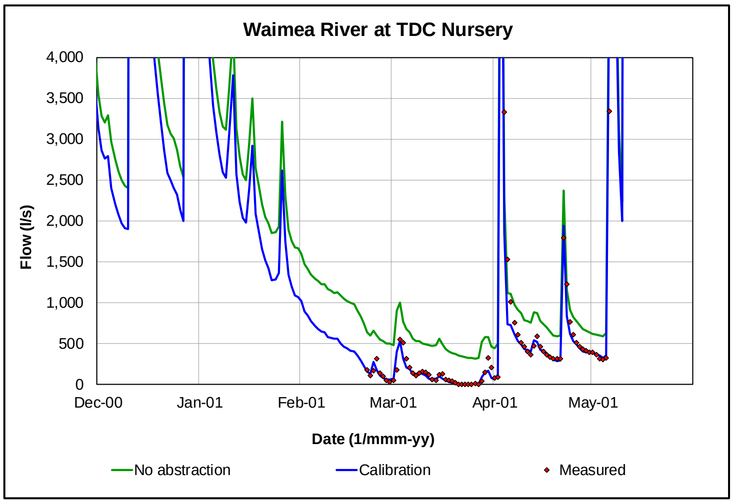

Figure 4: No abstraction scenario

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.

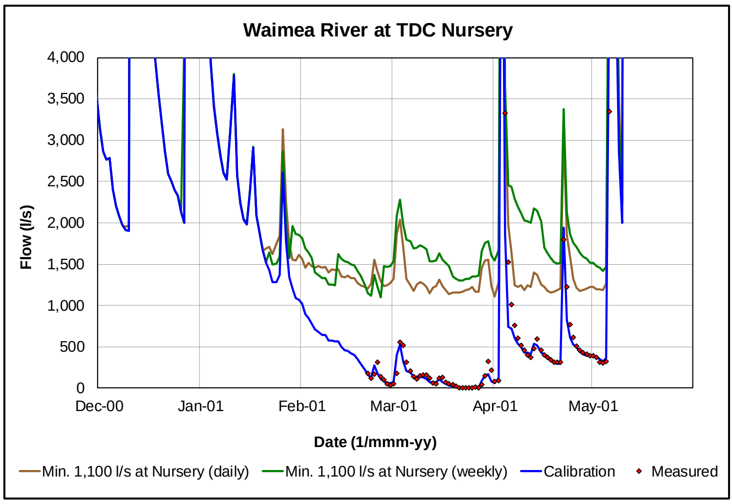

Figure 5: Dam release scenarios

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

P.A. White, M. Crundwell, M. Moreau
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).

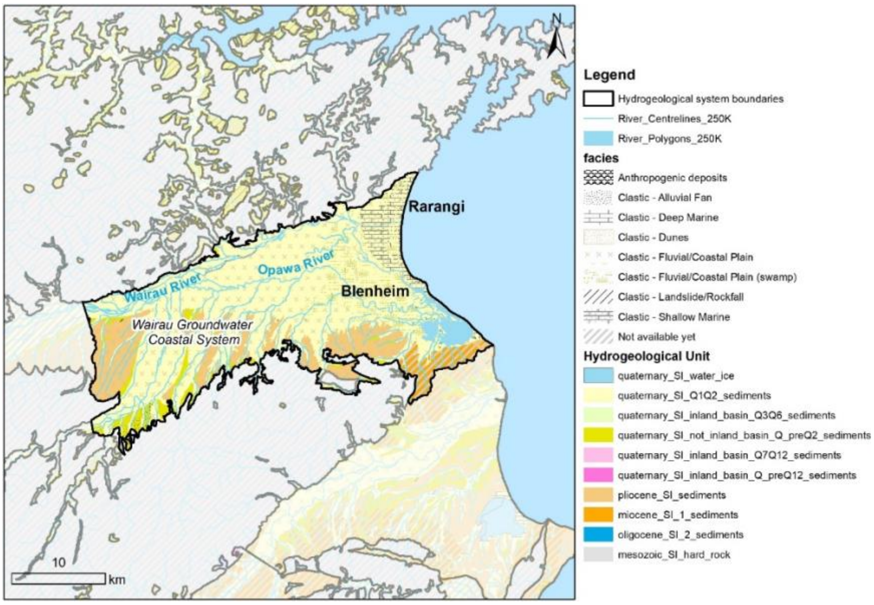

Figure 1. The boundary of the Wairau groundwater coastal system, South Island, New Zealand.

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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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

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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

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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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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

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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.

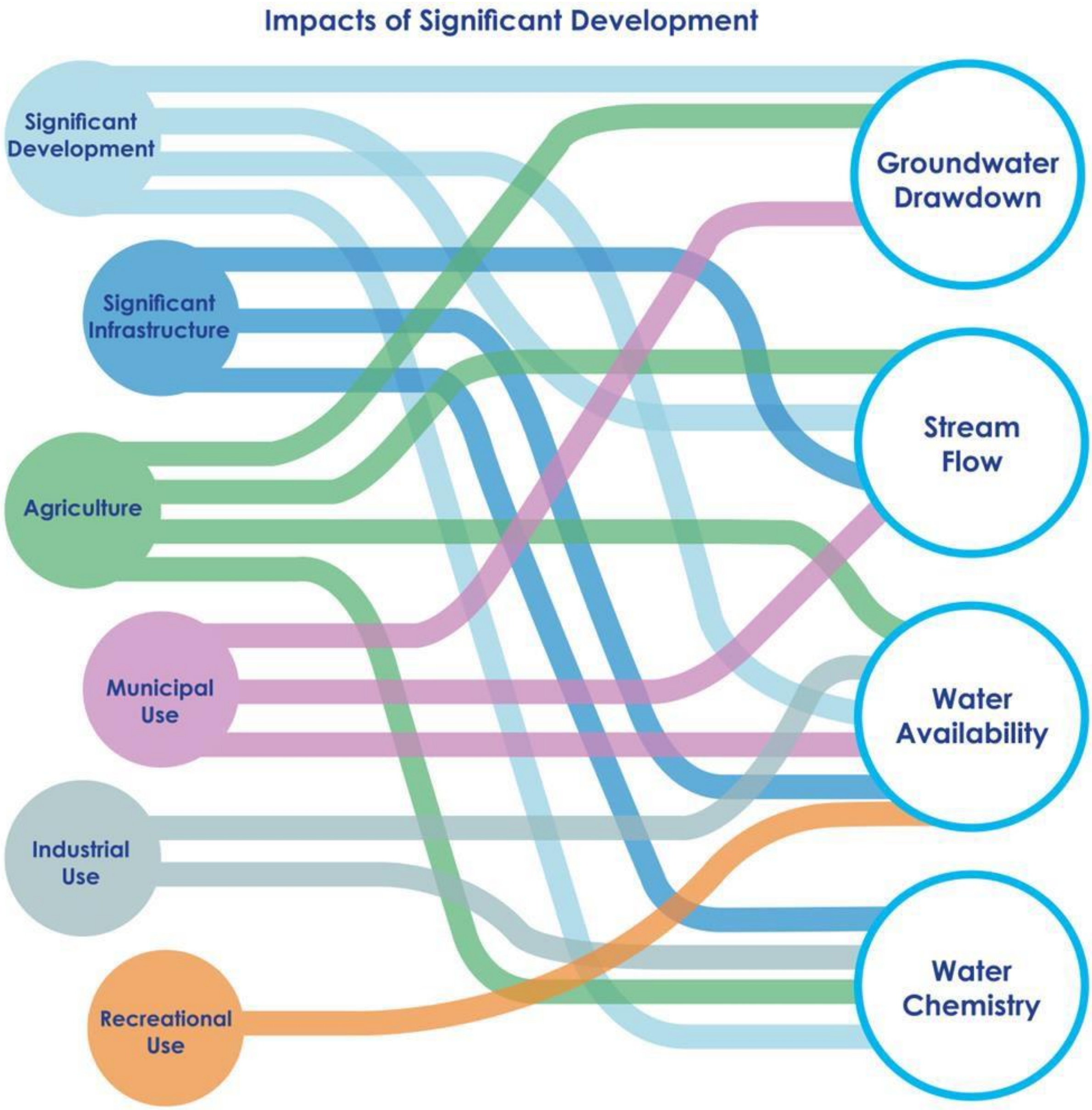

Figure 1: Conceptual map of cumulative impact analysis for State Significant Development (SSD) and State Significant Infrastructure (SSI) projects, collectively known as 'Major Projects'.

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.

References

DPE (2022): Cumulative groundwater impact assessment approaches. Information paper prepared for the Water Division, NSW Department of Planning and Environment as part of the Groundwater Modelling Toolbox Project.

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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.