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Oral Abstracts

WAINUI STREAM CATCHMENT ASSESSMENT

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Aim
Transmission Gully is a recently opened section of State Highway 1, north of Wellington. The Board of Inquiry decision for the construction of the highway contained off-set mitigation conditions, including one requiring the de-perching of the Wainui Stream culvert to enable fish passage into the upper catchment.

Whilst the de-perching of the culvert is a relatively simple exercise, providing fish passage into the upper catchment is complicated by the fact that the Wainui Stream loses much of its flow to ground across the alluvial fan, with surface flow being absent from the upstream ford before recommencing downstream of the of State Highway One (SH1). The proposed restoration plan, designed by Boffa Miskell (2021), is to capture and divert water to provide fish passage from the upstream weir to the SH1 culvert.

SLR Consulting was engaged by the Wellington Gateway Alliance to provide hydrological and hydrogeological assessments in support of this project, the aim being to address whether the proposed design will capture sufficient water to provide fish passage, and what effects the diversion of flow might have, particularly in relation to the Kapiti Coast District Council (KCDC) Public Water Supply (PWS) take for Paekakariki.

Method
In order to gain an understanding of the catchment hydrology, and thus the potential effects of the proposed restoration, we acquired and analysed the following data:

- Groundwater data;
  - From two barometric loggers we installed in boreholes located on the alluvial fan, downstream of the SH1 culvert and KCDC water treatment plant.
  - From KCDC's Public Water Supply wells.
- Flow data – Obtained from concurrent flow gaugings done over summer at sites upstream, downstream, and at the location of the SH1 culvert;
- Synthesised flow data, based on a NIWA station in the neighbouring Te Puka catchment;
- Turbidity data – Obtained from the KCDC Public Water Supply Wells; and
- Rainfall data – From monitoring sites within the Wainui Stream catchment.

Results
Preliminary results demonstrate the level of connectivity between the surface water of the Wainui Stream and groundwater levels, and the influence of the Paekakariki water supply take. Recent stream flow gauging shows how the flow regime changes over summer months, as a significant proportion of flow is lost to groundwater. Allowing for fish passage will reduce the quantity of water moving through the system. The likely impact on the Paekakarirki water supply is assessed.

IMPORTANCE OF SAMPLING FREQUENCY IN DETERMINING AIRBORNE MICROPLASTIC DEPOSITION FLUX

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Aim
Airborne microplastics (polymers < 5 mm in size) have emerged in recent years as ubiquitous atmospheric pollutants (Allen et al., 2022; Aves et al., 2022). However, data from the Southern Hemisphere, and remote regions in particular, are sparse. The aim of this study was to carry out a five-week sampling campaign at Mount John observatory near Takapō, New Zealand to assess for the presence, concentration and movement of airborne microplastics at a remote New Zealand site.

Method
Deposition collectors were installed in triplicate at Mount John observatory, and polymer composition subsequently confirmed via micro-Fourier Transform Infrared Spectroscopy. During the first week of the campaign, samples were collected every 24 hours. Samples were collected once per week during the final four weeks of the campaign, allowing us to investigate whether daily or weekly sampling frequency influences the number of collected microplastics.

Results
We obtained microplastic deposition fluxes of 100-200 microplastics (MP) m^{-2} day^{-1} when carrying out daily sampling. This decreased to 5-40 MP m^{-2} day^{-1} when carrying out weekly sampling, a result similar to that obtained from sampling in suburban Christchurch over 6-day sampling periods (Knobloch *et al.,* 2021). We conclude that sampling frequency is an important variable to consider when designing microplastic sampling campaigns and resuspension of particles is likely over longer periods. Previous studies, many of which used weekly sampling frequencies or longer (*Allen et al*., 2022), may have substantially underestimated atmospheric microplastic deposition fluxes.

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DUAL POROSITY MODELLING OF SEAWATER INTRUSION IN FRACTURED AQUIFERS

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Aim
Coastal regions are considered to be among the most vulnerable to the problem of groundwater contamination. Coastal aquifers are the source of water to more than one billion people around the world (Ajami 2021). Due to the continuous and increasing stresses on coastal aquifer resulting from over-pumping and climate change, seawater intrusion became very common in many coastal areas around the world. Many of those aquifers comprise fractured rocks, conduits and karst, especially around the Mediterranean. While numerous studies in the literature focused on modelling seawater intrusion in unfractured coastal aquifers, very few research was applied to fractured porous media. The aim of this study is to develop a new model for the simulation of saltwater intrusion in fractured aquifers.

Method
Several approaches were developed to model flow in fractured porous media. These approaches include Discrete Fracture Matrix (DFM), Discrete Fractured Network (DFN), Continuum Model (CM), and Dual Porosity (DP) (Teutsch and Sauter, 1998, Berre et al 2019). The DFM model is a middle way between representation of the fractures and the rock matrix, but requires a dense fractures network, with knowledge of fractures geometry. DFN model requires explicit discretization of the fractures/conduits, which is very difficult, especially for regional aquifers. The CM model assign a uniform equivalent value of hydraulic conductivity to the fractured porous media (i.e. Romanazzi et al 2015, Sebben et al 2015, De Fillippe et al 2016). This assumption fails to mimic preferential flow in fractured aquifers. Salt water intrusion is normally modelled either as a sharp interface or using variable density flow (VDF). The sharp interface assumes two immiscible liquids without mixing whereas VDF allows for diffusion and mixing, which enables better understanding of the intrusion process. Several studies explored the use of CM, DFN and DFM models with the VDF model. However, to the best of our knowledge the use of DP model with VDF remains unexplored. This study develops a DP model with VDF to simulate seawater intrusion in highly fractured rock. An advanced finite element code, based on DP and VDF, is developed using appropriate techniques for time integration and space discretisation. The benchmark Henrey's problem for seawater intrusion was used to test the developed model.

Result
The model is applied to the popular Henry's seawater problem. Accuracy of the developed code is verified against COMSOL multi-physics. Excellent agreement has been obtained between the code and COMSOL (Software for Multiphysics simulation). A sensitivity analysis is developed to understand the effect of parameters controlling the water and salt exchange between fractures and matrix on metrics characterizing the saltwater wedge and seawater intrusion.

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GROUNDWATER FLOW PATHS INTO WAIREPO ARM AND KELLANDS POND, UPPER WAITAKI MANAGMENT ZONE

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Aims
Wairepo Arm and Kellands Pond are two small lakes located south of Twizel on the south side of Lake Ruataniwha and the Ōhau canal (Figure 1). Intensification of land use in the lower Wairepo Creek catchment has resulted in degraded lake quality in Kellands Pond.

The lakes have been identified as vulnerable to nutrient enrichment in the Upper Waitaki chapter of Canterbury's Land and Water Regional Plan. The plan gives the lakes 'Lake Zone' status, which caps nutrient loss in the catchment upgradient of the lakes to prevent further water quality degradation.

The Upper Waitaki Zone Committee is looking at a more locally suited regime for management of the catchment. Because of this, the Upper Waitaki Zone committee recommended that Environment Canterbury investigate the movement of nutrients and water both into and within Wairepo Arm and Kellands Pond via groundwater and surface water.

This presentation summarises the investigation that was undertaken to better understand the interaction between groundwater and the lakes, and potential for groundwater to flow from the upper catchment to the lower catchment.

Methods
We started with a desktop review of existing data and previous work and in 2020 we installed eight shallow piezometers adjacent to Wairepo Arm and Kellands Pond and three monitoring wells in the wider catchment of the two lakes.

We undertook a piezometric survey across the catchment using the newly constructed piezometers and monitoring wells in addition to existing monitoring wells and some private wells. Furthermore, we surveyed water levels in Wairepo Arm and Kellands Pond, as well as several locations along Wairepo Creek, which flows into Wairepo Arm, to compare surface water elevations to groundwater levels and determine hydraulic gradients.

Results
Local groundwater levels surrounding Kellands Pond and Wairepo Arm rise and fall with the lake levels, demonstrating the close connection between groundwater and the lakes.

In the lower catchment, groundwater flow is predominately towards the north-east, from Wairepo Creek/ Willow Burn catchment towards Wairepo Arm. In the upper catchment groundwater flow is also towards the north-east, where groundwater flows towards the Ostler Fault and Wairepo Arm.

A groundwater divide is evident near well BZ15/5018. South of this divide, the groundwater direction is towards the south, towards the Ahuriri River and the Ahuriri Arm of Lake Benmore.

Groundwater in the upper catchment is likely to flow north towards the Ostler Fault where it flows into Wairepo Arm and Kellands Ponds. Any nutrients that make it into the groundwater in the upper catchment are likely to affect the two lakes.

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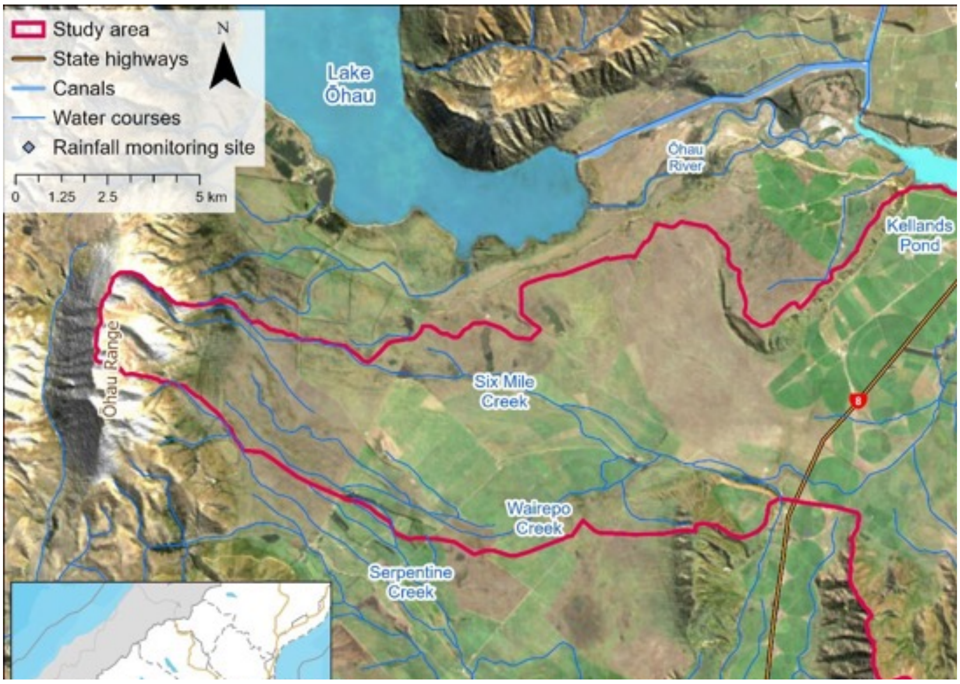

Figure 1: Location of the study area

RECYCLING OF END-OF-LIFE TYRES IN SEISMIC ISOLATION FOUNDATION SYSTEMS – ASSESSMENT OF POTENTIAL LEACHING

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Over 6.3 million waste tyres are produced annually in New Zealand (Tyrewise, 2021), leading to socioeconomic and environmental concerns. The 2010-11 Canterbury Earthquake Sequence inflicted extensive damage to ~6,000 residential buildings, highlighting the need to improve the seismic resilience of the residential housing sector. A cost-effective and sustainable eco-rubber geotechnical seismic isolation (ERGSI) foundation system for new low-rise buildings was developed by the authors. The ERGSI system integrates a horizontal geotechnical seismic isolation (GSI) layer i.e., a deformable seismic energy dissipative filter made of granulated tyre rubber (GTR) and gravel (G) – and a flexible rubberised concrete raft footing. Geotechnical experimental and numerical investigations demonstrated the effectiveness of the ERGSI system in reducing the seismic demand at the foundation level (i.e., reduced peak ground acceleration) (Hernandez et al., 2019; Tasalloti et al., 2021). However, it is essential to ensure that the ERGSI system has minimal leaching attributes and does not result in long-term negative impacts on the environment.

Aims

The overall aim of the portion of the study presented in this abstract is to provide an update on insights on subsoil/groundwater contamination due to the use of GTR in the ERGSI foundation system.

Method

Tests (Table 1) were undertaken to idenitfy the potential for the GTR:G mixtures to leach contaminants. Rigid-soft granular mixtures were prepared using a combination of uniformly graded round (G_{RND}) and angular (G_{ANG}) gravels and large (GTR_{LRG}) and small (GTR_{SML}) tyre rubber particles.

Test #	*Test media*	*GTR (% by volume)*	*Gravel (% by volume)*
1-3	$GTR_{LRG}G_{RND}$ (w)	40	60
4-6	$GTR_{SML}G_{RND}$ (w)	40	60
7-9	$GTR_{LRG}G_{ANG}$ (w)	40	60
10-12	$GTR_{SML}G_{ANG}$ (w)	40	60
13-15	GTR_{LRG} (w)	100	0
16-18	GTR_{SML} (w)	100	0
19-21	G_{RND} (w)	0	100
22-24	G_{ANG} (w)	0	100
25-27	G_{RND} (u)	0	100
28-30	G_{ANG} (u)	0	100
31	DI water (blank/control)	0	0

Leaching test media (left to right: GTR_{SML} 1.6 mm D_{50}, GTR_{LRG} 3.7 mm D50, G_{RND} 5.6 mm D_{50}, G_{ANG} 4.2 mm D_{50})

Table 1: Leaching tests undertaken in this study (GTR: granulated tyre rubber, G: gravel, LRG: large, SML: small, RND: round, ANG: angular, w: washed, uw: unwashed)

For each test, the required media were placed in 3 L wide mouth glass bottles and filled with 5 L (Tests #1-6) and 2 L (Tests #7-31) of DI water. For Tests #1-12 100g GTR and 355g gravel was used. The bottles were sampled periodically (Day 0, 1, 2, 4, 7, 10, 14, 17, 21, 24, and 28). pH and electrical conductivity (EC) of the leachate were recorded using a Hach HQ40d meter. Leachate samples were filtered (Millex® HA filter unit, 0.45 µm MF-MilliporeTM PVDF membrane, Merck Millipore), acidified and refrigerated until analysis. Components of interest analysed in the leachate included: TOC, Zn, Cd, Cr, As, K, P, Na, Mn, Fe, Ca, Mg, Al, Cu, and Pb. TOC was measured using a Shimadzu TOC high temp combustion analyser. Inorganic constituents were measured using Inductively Coupled Plasma – Mass spectroscopy (ICP-MS).

Results
pH of the leachate was relatively stable during the tests and there was no significant difference in the pH between the tests. Leaching from the GTR and G_{ANG} mixes caused the greatest increases in EC, with the larger surface area of GTR_{SML} causing increased leaching and, thus, the greater EC of the two mixes. TOC leached from GTR_{SML} (68.7 ± 18.4) was greater than that leached from GTR_{LRG} (25.4 ± 1.22 mg) (Figure 1). Greater amounts of TOC were leached out of G_{ANG} (washed: 4.21 ± 0.20 mg, unwashed: 4.01 ± 0.24 mg) compared to G_{RND} (washed: 0.63 ± 0.26 mg, unwashed: 0.55 ± 0.12 mg). Leaching of Ca, Na, Mg and K was attributed to the greywacke gravel (composed of feldspar minerals) and leaching of Zn (Figure 2) was attributed to the GTR. Zn was primarily leached from the GTR, with the higher surface area of GTR_{SML} leading to higher Zn levels (Test#4-6: 4.80 ± 0.56 mg, Test#10-12: 0.73 ± 0.04 mg) compared to GTR_{LRG} (Test#1-3: 0.95 ± 0.22 mg, Test#7-9: 0.12 ± 0.04 mg). The GTR also leached small amounts of Co (≤ 10^{-2}), Cr (≤ 10^{-3}), Ni (≤ 10^{-3}), As (≤ 10^{-4}), Cd (≤ 10^{-4}), Pb (≤ 10^{-4}).

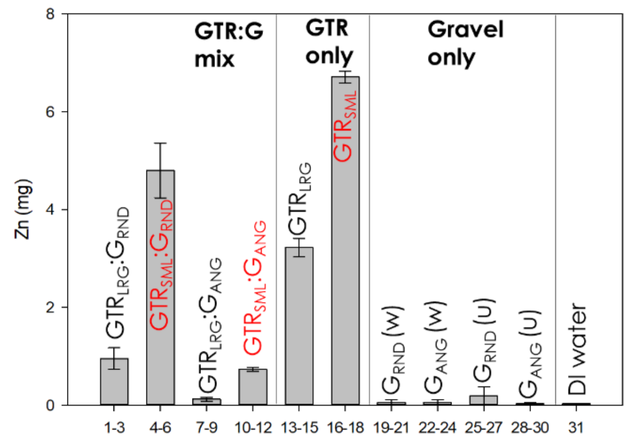

Figure 1: TOC (mg) of leachate

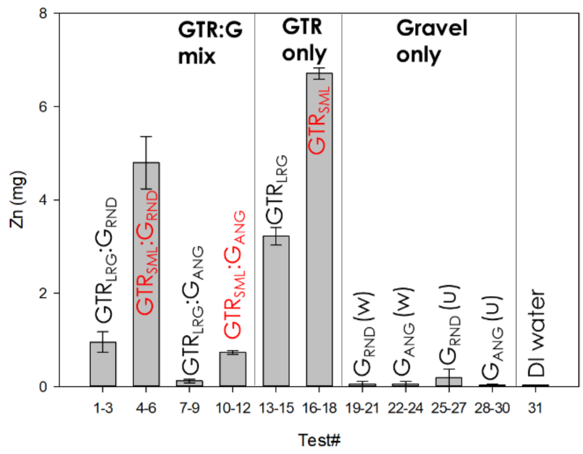

Figure 2: Mass of Zn (mg) in leachate

Key findings from this research show that leaching was dependent on the size of GTR and the gravel used. Greywacke is a variety of argillaceous sandstone that is made up of quartz, lithics, and minor feldspars, and these assorted minerals account for the various elements leached from it. In the presence of GTR, the levels of Na, Mg, and Ca in the leachate were increased, while the levels of As were reduced. Increased surface area of the angular gravel and the "raw" nature of those exposed broken surfaces allows for greater weathering of the minerals making up the G, leading to increased chemical leaching. The GRND showed consistently lower levels of most of the elements tested for (except for P). The naturally rounded nature of the gravel means that it has already undergone a period of weathering in the environment and the easily leached/weathered minerals will have already been lost from the gravel's surface. The washed GRND showed higher levels of elements in the leachate than the unwashed GRND, due to the washing and oven drying processes that the media was subjected to, drawing elements from within the gravel to the outer surface. The leaching data for these compounds, particularly for the smaller size fraction of GTR, provides the data required to develop a framework with specific design criteria for ERGSI foundation systems so that leaching to groundwater and surface water is minimised (e.g., pre-treatment, confinement of leaching materials).

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COMPOUND AND SEESAW EVENT OCCURRENCE ACROSS NEW ZEALAND: A MULTIVARIATE PERSPECTIVE

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Aims

Extreme weather events cause billions of dollars in damages globally. The relationship amongst variables within the hydrological cycle can play a significant role in the development of these events. As such, it is critical to identify how different parts of the atmospheric and terrestrial hydrological cycle interact to fully understand the controls of the causes and characteristics of these damaging extreme events. In particular, understanding the compounding nature of extreme events such as heat waves and droughts (compound events), and the co-occurrence of pluvials and droughts (seesaw or whiplash events) has emerged as a critical research objective.

While New Zealand is considered a cool climate, the country does experience strong drought episodes (Porteous and Mullan, 2013). Recent research has also revealed the relative impact of extreme temperature for the country (Harrington, 2021). With similar climates revealing increased risk to temperature extremes, and the role of land atmosphere interactions during these extremes (Dirmeyer et al., 2021), research into the interaction of hot and dry events in a New Zealand context is urgently required. Such work can be revealing for not only individual drought and heat wave events, but more importantly the interaction and compounding effects of these two events.

Drought and pluvial episodes are inherently interconnected due to the common driving hydroclimatic processes. With the potential for greater variability in these processes as a response to a warming climate, seesaw or whiplash events have similarly attracted increased attention (He and Sheffield, 2020). Similarly, there is also increasing evidence of the importance of atmospheric rivers to New Zealand's hydroclimatic variability, investigating the rapid transition between dry and wet land surface states will further help explore the impact of these events.

Methods

Here, changes to hydrometeorological event behaviour under a joint probability framework are investigated by asking questions on the co-variability and joint probability of occurrence amongst selected climatic and hydrological variables. Data were obtained from European Reanalysis 5th Generation Land Component (ERA5-Land). Daily total precipitation, maximum temperature and mean soil moisture were obtained for the period 1 January 1950 to 31 December 2021 for the New Zealand region. Standardised indices were then constructed for each variable (Standardised Precipitation Index; SPI, Standardsised Tempearture Index; STI and Standardised Soil Moisture Index; SSMI) for monthly to yearly (30,60,90,180,365 day) and sub monthly (1,3,7,10,21 day) accumulation periods. Gamma (SPI), normal (STI) and Beta (SSMI) parametric distributions were employed to standardise each variable.

A vine copula (Joe, 1994) was then constructed to obtain the joint probability distribution of the three standardised indices and build a multivariate index (Standardsied Multivariate Index; SMI), following the proecdure of Tootoonchi et al. (2021) for family and parameter selection, and goodness of fit testing. Families selected included Gaussian, Clayton, Gumbel, Frank and Joe copulas. In turn, the multivariate index was then employed to discover the historical compound and seesaw event occurrence for the first time across New Zealand.

For each grid cell, seesaw events were examined using the methodlogy of He and Sheffield (2020), by defining a seesaw event as a drought (-1 SMI-30) which was followed by a pluvial (+1 SPI-30) within a one month window. Compound events were defined for each grid cell as all days where -1 on the SMI-30 index was met or exceeded. Trends were then examined using a Mann-Kendall test.

Results

Increased compound event occurrence over the 1950-2021 period is found across much of the North Island and upper South Island, but in particular across the Waikato region (Fig. 1). Decreased event occurrence is found along the Canterbury coast, Central Otago and Southland.

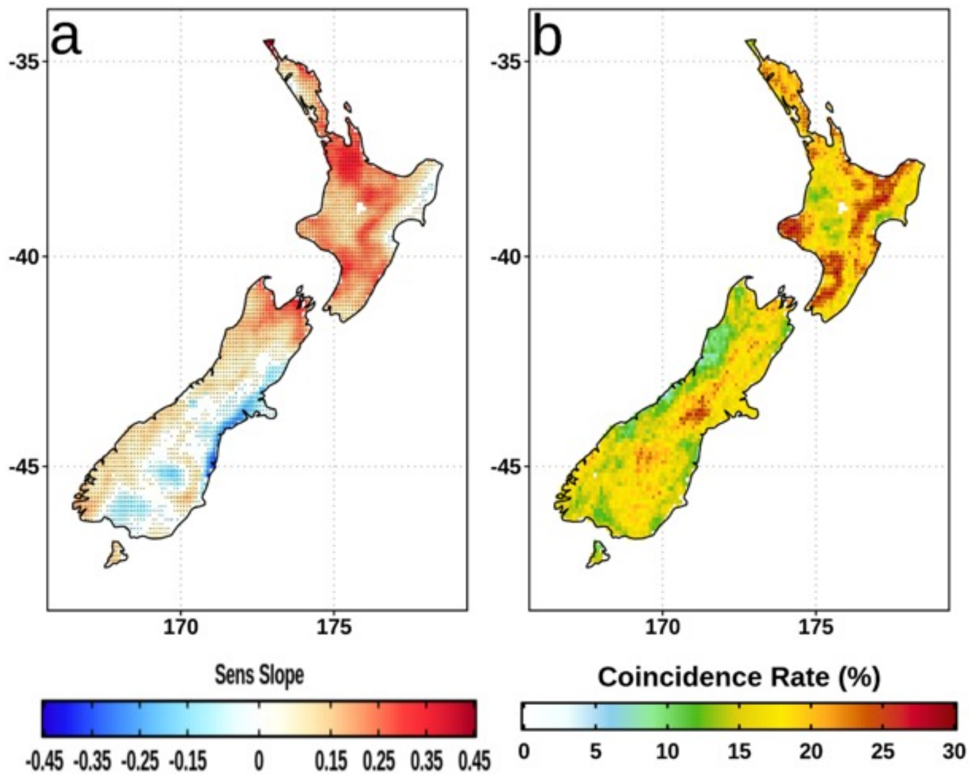

Figure 1: Sens slope (Sen, 1968), identifing trends in compound event occurrence across New Zealand (a) and (b) seesaw event occurrence across New Zealand. Both (a) and (b) are derived from data spanning 1950-2021. Compound events were identified for each day, at each grid cell, if -1 on the SMI-30 was met or exceeded, while seesaw events were calculated using the methdology of He and Sheffield (2020), with a one month delay between droughts (-1 SMI-30) and pluvials (+1 SPI-30).

Statistically significant occurrences (compared to a Poisson-based process) of whiplash events occur across the Mackenzie Basin, Kāpiti Coast, Taranaki and Bay of Plenty (Fig. 1). Patches of significant event occurrence occur across Northland and Auckland, but are not as widespread in agreement across grid cells. Low event occurrence occurs across the west coast of the South Island. Collectively, the multivariate approach adds new dimensions to our understanding of the generation and duration of compound and seesaw events, with the results also providing one of the first looks for New Zealand at these damaging hydrometeorological events.

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THE FIFTH REVISION OF THE HUTT AQUIFER MODEL: AN UPDATE ON AN UPDATE

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Aims

The Waiwhetū aquifer beneath the Lower Hutt Valley is a critically important source of water for Wellington, providing 40-70% of the capital's drinking water from abstraction wells located at the Waterloo and Gear Island wellfields. Abstraction of groundwater from the Waiwhetū aquifer is constrained by depletion effects on Te Awa Kairangi/Hutt River and mitigation of saline intrusion risks from Te Whanganui-a-Tara/Wellington Harbour.

The fifth revision of the Hutt Aquifer Model (HAM5) is intended to provide water suppliers (Wellington Water) and water resource managers (Greater Wellington Regional Council) with a suite of tools for understanding groundwater flow and solute transport in the Waiwhetū aquifer and enable robust modelling approaches to support decision-making.

HAM5 is a revision of previous groundwater models of the region, including HAM3 (Gyopari, 2014) and HAM4 (Gyopari, 2018). The unexpected detection of E.coli in raw water from the Waterloo Wellfield in late 2016 indicated that further assessment of the underlying hydrogeological conceptual model was necessary. This, combined with the need for additional work to support wellfield planning, resilience, and operations, resulted in significant field investigations in 2020-2021. These investigations have yielded information that directly support the revision of the Hutt Aquifer Model, including detailed aquifer testing and ongoing groundwater level monitoring across the Lower Hutt Valley.

To meet the objectives of Wellington Water and GWRC, HAM5 is being developed within a framework comprising the following three stages:

- A Database model
- Predictive scenario analyses
- Operational tools.

The Database Model (the focus of this abstract) is a history-matched numerical groundwater model that acts as the foundation for subsequent simulations. This is described in further detail in the following section.

Predictive scenario analyses will be used to guide decisions regarding wellfield redevelopment and resilience under uncertainty with respect to changes in climate, hydrological conditions and water demand.

Operational tools will unlock the results of groundwater modelling and predictive scenario analysis for water suppliers and resource managers and will be developed following the Database model and prediction stages.

Methods

The Database Model is three-dimensional, transient numerical groundwater model developed using the MODFLOW 6 simulator and implemented with FloPy programming tools (Bakker et al., 2016). This enables a flexible approach to groundwater model development. The basis of the aquifer properties is a three-dimensional hydrostratigraphic model (Begg, 2021) generated from extensive historic bore logs as well as information from recent field investigations.

Groundwater-surface water interactions have been modelled using the RIV package of MODFLOW 6 (Langevin et al., 2017), with river water levels derived from relationships between flow of the Hutt River / Te Awa Kairangi at Taita Gorge and water levels from hydraulic modelling undertaken as part of the RiverLink development (DamWatch Engineering, 2022). Inputs for other waterways in the Lower Hutt Valley (Waiwhetū and Ōpahu Streams) have been derived from other existing hydraulic models.

History-matching (or calibration) to long-term observation records maintained by GWRC and Wellington Water has been undertaken in the first instance using PEST_HP (Doherty, 2017), with further uncertainty analysis performed with PEST++ (White et al., 2020) and PyEMU tools (White et al., 2021) implemented on cloud technology. The history-matching strategy incorporates the use of spatial pilot points for aquifer properties and rainfall recharge, linear pilot points for riverbed conductance and global multipliers on other boundary conditions such as groundwater abstraction.

As part of the predictive scenario analysis component of HAM5, boundary conditions will be varied according to projected changes in sea level, river morphology and hydrological conditions adopted from other modelling studies and adapted for groundwater modelling inputs. This will provide information about the relative effects in groundwater dynamics caused by changes in the Lower Hutt Valley, with a particular focus on stream depletion and saline intrusion risks.

Results

The results of the history-matching indicate good agreement with absolute hydraulic head observations, vertical head differences and observed fluxes in waterways. Groundwater flow dynamics are generally consistent with those observed over a range of time periods, from 7-day periods to seasonal/annual variability.

In this presentation, we will present the results of the Database Model and preliminary findings from the initial stages of predictive scenario analyses.

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INFLUENCES OF ANTARCTIC OZONE DEPLETION ON SOUTHERN OCEAN AEROSOLS

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Aims
The Southern Ocean is often identified as a pristine aerosol environment, being distant from anthropogenic sources. We investigate anomalies in aerosol loading over the Southern Ocean due to stratospheric ozone depletion in historical simulations performed for the sixth Coupled Model Intercomparison Project.

Method
We explore direct influences of ozone depletion on aerosols via enhanced ultraviolet-induced production of oceanic dimethyl sulfide (DMS), and indirect influences via changes in the Southern Hemisphere westerly jet, which impacts wind-driven aerosol fluxes.

Results
We identify wind as the key driver of change for austral summertime aerosol, leading to increases in aerosol optical depth of up to 24% compared with the pre–ozone hole era. In contrast to previous studies, direct impacts on aerosol from ozone depletion and enhanced ultraviolet fluxes are less obvious. Our results show that the Southern Ocean summertime aerosol environment cannot be considered to be representative of pre–industrial conditions because stratospheric ozone depletion has indirectly increased marine aerosol fluxes.

WATER VELOCITY PROFILES WITH SURFACE WIND INTERACTIONS

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Aims
Surface velocimetry techniques are growing in popularity for river flow measurement. Typically, surface velocities are measured from imagery (e.g. Detert et al., 2017; Cao et al., 2020; Schweitzer & Cowen, 2021) or Surface Velocity Radar (SVR) (e.g. Welber et al., 2016). However, to calculate discharge requires the conversion from surface velocity (us) to depth averaged velocity (U) using acoefficient α (alpha), where $\alpha = U/us$. There are multiple ways to estimate α, with the optimal method depending on channel characteristics and data availability (Biggs et al., 2021). Typically, α is evaluated for a site using reference measurements of discharge and surface velocities, or from extrapolated velocity profiles, then applied to the site for higher discharges where instream measurements are not possible. It is also possible to develop a stage-alpha rating curve if alpha is not consistent at a site (Biggs et al., 2021). This enables more accurate estimation of alpha from extrapolation of the stage-alpha curve beyond the range where in stream measurements are possible, increasing the accuracy of high flow measurements. If instream measurements are not possible, then alpha can also be estimated from hydraulic parameters by assuming that the time averaged velocity profile follows a logarithmic (or power law) profile (Smart & Biggs, 2020; Biggs et al., 2021). These methods are a significant improvement from using a default value for alpha of ~0.857 for natural channels and 0.90 for smooth artificial channels (e.g. Rantz, 1982), however further work is required to account for the effect of surface wind on velocity profiles and alpha.

The 'velocity profiles and surface wind' project aims to address this knowledge gap through a combination of empirical measurements and theoretical analysis.

Methods
To achieve the aim four high resolution data sets were analysed, with twocomprising laboratory flume measurements (Cameron et al., 2019; Akbarpouret al., 2020) and two comprising field measurements. Flume measurements investigated velocity profiles at a range of flow conditions over hexagonally packed spherical roughness elements. The first dataset provided high resolution velocity profiles measured with stereoscopic particle image velocimetry, while the second dataset provided velocity profiles measured with an acoustic

doppler velocimeter, and surface velocities measured with large scale particle image velocimetry. Field measurements were conducted in two hydro-power canals in New Zealand, with the most comprehensive measurements occurring in the Tekapo Canal (Figure 1), where an up-looking ADCP benthic lander, climate station, and wind tower were deployed for 36 days to record velocity profiles at a range of wind and flow conditions.

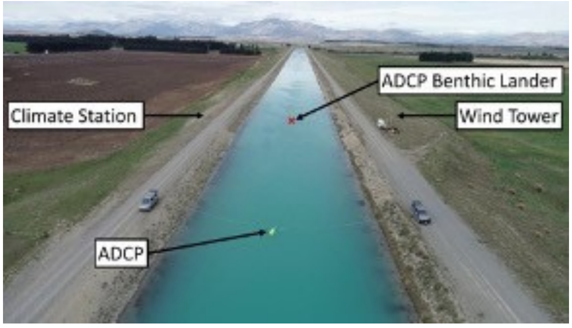

Figure 1: Field measurements of velocity profiles and wind in theTekapo Canal, New Zealand.

The wind tower was 5 m tall and consisted of three Campbell Scientific CSAT3B Sonic Anemometers (Figure 2: Left). The ADCPbenthic lander consisted of a Nortek Signature 1000, Nortek Aquadopp, and a battery (Figure 2: Right). Complementary measurementsof surface velocities were made using nadir (down-looking) aerial imagery from drones on three occasions, with tracer particles addedfrom an aerial tracer particle distribution system (Biggs et al., 2022). The wind tower provided vertical profiles of wind velocities andturbulence, which were used to investigate the effect of wind (and shear stress) on water velocity profiles. Data analysis focused onmeasurement periods when wind was blowing directly up or down the canal, to minimise turbulence due to localised topography (i.e. the canal berms). Phase averaging techniques were then used to analyse the velocity profile data based on wind characteristics.


Figure 2: Left: Wind tower with 3x CSAT3B Sonic Anemometers. Right: Up-looking ADCP benthic lander.

Results

The analysis of results is ongoing, however preliminary findings indicate a direct link between velocity profile shape and wind characteristics. Detailed results and theoretical analysis will be presented at Hydrometsoc22.

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PROPOSED FRAMEWORK FOR RIVER FLOW MANAGEMENT TO SUPPORT IMPLEMENTATION OF THE NPS-FM

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Introduction
Local authorities must prepare regional plans and action plans that give effect to the National Policy Statement for Freshwater Management 2020 (NPS-FM). River flows are an essential consideration for all 15 NPS-FM policies and many of its associated values. The Te Mana o te Wai hierarchy of obligations set out in the NPS-FM prioritises first the health and well-being of water bodies and freshwater ecosystems, second health needs of people, and third the ability of people and communities to provide for their social, economic, and cultural well-being. This hierarchy of obligations is relevant to all aspects of freshwater management and therefore presents new challenges for river flow management. In this talk we present a proposed framework intended to facilitate river flow management approaches that will achieve environmental flow regimes that will support environmental outcomes defined under the NPS-FM.

Methods
The proposed framework depicted in Figure 1 consists of nine steps that join together to form a transparent approach for linking environmental flow regimes to ecosystem states through controls on flow-altering activities and the application of adaptive management. The framework starts with six prerequisits to defining environmental flow regimes, explicitly includes consideration of the foreseeable effects of climate change, incorporates a loop for monitoring and adaptive management, and ends with controls on flow-altering activities. We outline how this framework can be operated in a manner consistent with the Te Mana o te Wai hierarchy of obligations and give effect to the NPS-FM by mapping each flow-related NPS-FM clause to a step in the framework.

Provision of a general framework, rather than prescriptive instructions for technical methodologies, is consistent with the NPS-FM because it allows for flexibility in setting in-stream values and the methods used to give effect to its objectives and policies. It is important to recognise that the proposed framework does not preclude the intentional integration of participatory approaches or the inclusion of diverse stakeholders and iwi partners in flow management decisions. The proposed framework does not set any limitations on methodological approach used to describe desired states, flow-ecology linkages, cultural values, or cultural attributes. Adopting the framework should therefore encourage selection of a combination of scientific methods (e.g., monitoring, trend detection, water accounting, ecological models), mātauranga Māori, planning processes (e.g., tangata whenua and community engagement), and consenting mechanisms (e.g., restrictions within consents) to give effect to river flow management aspects of the NPS-FM.

Conclusions
It is intended that the predefined alignment of flow-related NPS-FM clauses to the various steps within the framework will assist regional councils to demonstrate how they have adapted existing methods or adopted new methods as they transition their river flow management processes to be consistent with the updated requirements of the NPS-FM.

We recommend that the proposed approach be tested and refined with regional councils and tangata whenua through a participatory process to increase its credibility and legitimacy. We recommend co-development is required to clarify interpretation, application, and evaluation of the Te Mana o Te Wai hierarchy with respect to river flow management within the proposed framework, and to clarify the implications of the Te Mana o Te Wai hierarchy for existing water take limits.

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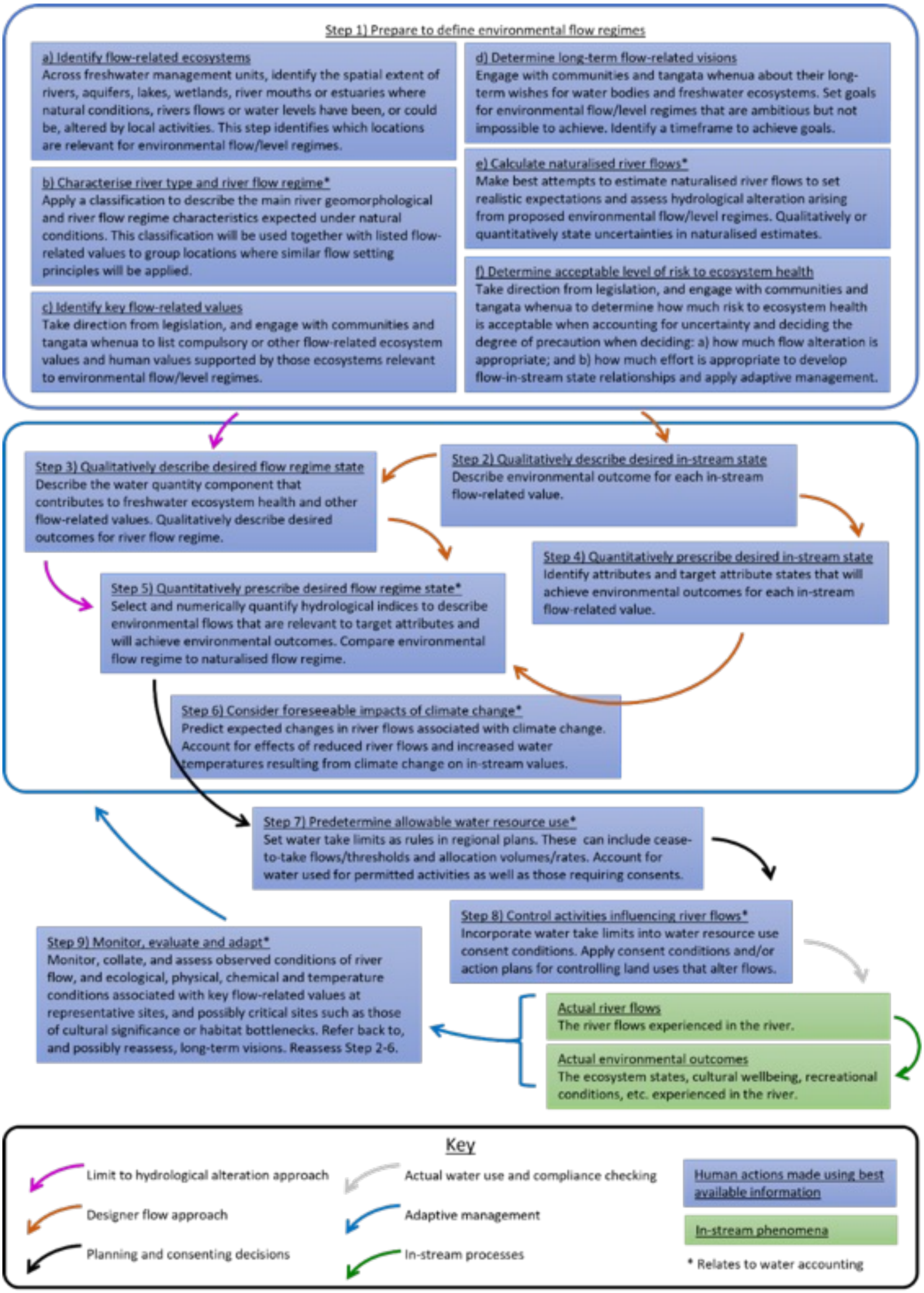

Figure 1: A depiction of 9-steps that comprise the proposed framework for river flow management.

CLIMATE CHANGE AND LOCAL HUMAN ACTIVITIES HAVE ALTERED RIVER FLOW REGIMES IN CANTERBURY

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Introduction
Many aspects of river flow regimes are considered important for river flow management due to their influence on ecological, cultural or social values. River flow regimes are driven by interplay between climate conditions and local catchment characteristics. Climate conditions are important because they determine precipitation and evaporation. Catchment characteristics are important because they influence water fluxes, but these fluxes are also influenced by anthropogenic activities such as abstraction, damming, diversion, landcover change and drainage modification.

Methods
This work demonstrates a systematic approach to quantifying temporal changes in river flows associated with water management practices whilst accounting for temporal patterns in climatic conditions. Median seasonal flows were investigated as they relate to flow management and environmental flows. River flow time-series were obtained for gauged catchments across Canterbury, Aotearoa-New Zealand and matched to climate data for each catchment from NIWA's Virtual Climate Station Network (VCSN). Statistical models were trained to predict river flows that would be expected given concomitant and antecedent weather conditions. Models were trained to data from an early period within each flow record, and therefore included the likely effects of any flow altering anthropogenic activities operating on-average over that period. Residual flow time-series were calculated by subtracting model predictions from observed values beyond the model training period. Residual flows represent deviation in observed flows away from those that would have been expected. Trend analyses were applied to quantify the confidence with which it can be stated that each flow time-series has been decreasing in absolute terms firstly whilst including climatic influences, and secondly whilst accounting for the likely effects of inter-annual changes in climatic conditions. This study was therefore able to assess the degree to which trends in river flows could be attributed to changes in climate versus local anthropogenic activities.

Results
Trends were assessed for a period that started immediately after a change in regulatory regime in 1991 and ended in 2020, that coincided with increases in water abstraction and changes in water management practices. Trends in observed summer conditions indicated that rainfall was stable, temperature increased, and flows decreased for many sites during the assessed period. Models representing flow as a function of rainfall and temperature were trained and tested using cross-validation for an earlier baseline period. Predictions for the 1991–2020 period made with the models were used to account for the effect of change in climate. The difference between predicted and observed flows were attributed to changes in local activities. Decreases in summer flows were partially associated with changes in climate, but changes in summer flows in several catchments were also associated with local activities. The findings indicate changes to both climate and local activities have combined to alter flow regimes, suggesting that hydrological impacts of local activities should be considered alongside climate change when making river flow management decisions.

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SHALLOW GROUNDWATER HYDROGRAPHS CLASSIFICATION IN URBAN ŌTAUTAHI / CHRISTCHURCH

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Aims

Monitoring fluctuations in water levels at the water table is essential as shallow groundwater is present under many coastal cities and settlements (Bosserelle et al., 2022). The field of urban hydrogeology considers a complex environment where groundwater interacts with surface water, infrastructure and drivers such as rainfall recharge and ocean variations. Despite the importance of protecting coastal urbanised areas from flooding, the effects of groundwater rise due to climate change-induced sea-level rise are rarely investigated. This research supported the identification of current shallow to very shallow groundwater and the hydrographs classification in the coastal urban context can inform environmental monitoring for cities worldwide (Bosserelle et al., In Preparation).

Method

Classifying the hydrographs of the shallow urban groundwater system of Ōtautahi provides an opportunity to explore the relationship between water levels, natural and anthropogenic stressors. Both methods of clustering and cross-correlation were used on time series data from a dense groundwater monitoring network with high temporal resolution.

Results

We found that the hydrographs are generally spatially distributed and that patterns, trends, clusters and outliers can be detected to obtain information on a large group of monitoring wells. However, it is difficult to automate the classification of groundwater hydrographs in Ōtautahi, due to their locations in an area of similar geomorphology, geology or climate type. The statistical time series analysis indicated water table depth was a useful means of classifying the groundwater system because it is spatially correlated to low variation in levels and provides an adequate correlation to the clustering results. However, the most useful and important feature for classifying hydrographs was the distance to tidal rivers. We anticipate that these findings will contribute to an improved design of the groundwater monitoring network, particularly to further investigate the effects of rising sea levels on the modified subsurface because longer time series analysis is needed for the impact assessment of sea-level rise.

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CASCADING MODEL SYSTEM FOR NATIONAL FLOOD ASSESSMENT

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Aims
The MBIE Endeavour programme Mā te haumaru ō te wai aims to develop consistent flood hazard maps for the whole of Aotearoa New Zealand. To acheive this goal, a workflow, similar to a cascading flow down a catchment, was developed . The workflow is composed of hydrological and hydrodynamics models that are used at an increasingly higher resolution to capture the key mechanisms and features of flooding in the developed parts of catchments.

Method
The flood modelling workflow is not only used to simulate flow but also includes automated DEM conditioning, preparation of model files, and format conversion between different models.

Starting with a design or historical storm, runoff and flow routing of streams and rivers on the “steep” part of catchments are simulated using the NIWA TopNet model (McMillan et al. 2016). The model was modified to include a physcially realistic soil conductivity formulation to produce overland quick flow runoff without requiring model calibration. This allows the flow simulation to be accurate even in catchments where flow monitoring is nonexistent and provides a consistent model response between gauged and ungauged catchments. . The hydrological calculations are significantly faster than the hydrodynamics and run a short climatology of the catchment to identify representative base flow and soil/groundwater conditions. Running the hydrodynamics model on the steep part of the catchment would be computationally very expensive due to the “waterfall” effect (where the model tries to resolves very fast flow of waterfalls). Instead, the hydrological model provides realistic boundary conditions for the hydrodynamics model in the developed part of the catchment. .

Flood inundation is simulated using the BG_FLOOD Hydrodynamics model (Bosserelle et al. 2022). The model is an open-source GPU capable flood/inundation model using modern a shock capturing St Venant solver. The model uses a quadtree type mesh that is well suited for GPU computation and allows iterative refinement of the mesh. The hydrodynamics model is run in two phases. Once with a low uniform resolution to coarsely-but-quickly capture the expected inundation extent. The coarse assessment of flow depth and speed is then used to identify target areas where the finest resolution is required (e.g. flow constrictions, potential breaches) (Figure 1). The model is then run with an adapted mesh that captures these features.

Results
The cascading model system is demonstrated using a case study in the Waikanae catchment.. The model is validated using recorded flow data and post-flood high water marks collected by the local council from the 2005 Waikanae flood. Both the hydrological and hydrodynamic models validate well against them. This system will be expanded to model catchments all around Aotearoa.

Figure 1. Refined block quadtree created by BG_FLOOD. The colour shading is the catchment topography where each pixel represents a model cell, the black lines represent the extent of a block of 16x16 model cells.

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AVERAGE CIRCULATION CONIDTIONS THAT PRECEDE RIVER FLOODING IN EASTERN CATCHMENTS OF NEW ZEALAND

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Aims
With two-thirds of Aoteaora New Zealand's population residing on large river flood plains, the social and economic impact of river flooding is significant (NIWA, 2021). Historic and recent events in Gisborne and Canterbury, as well as other areas in Aotearoa, illustrate the need for better understanding of what influences river flooding in order to better manage and reduce the hazard, especially in a changing climate. Existing research has identified that New Zealand's location in the Southern Hemispere middle latitudes, along with its extremes in topography, results in many different local weather and large-scale climate patterns that can lead to flooding, with strong variations by region (Smart & McKercher, 2010). Flood generating mechanisms have been widely studied in the West Coast of the South Island, with floods mainly a result of moist westerly airstreams intersecting the Southern Alps and trough regimes, which can trigger intense moisture transport in the form of "atmospheric rivers" (Kingston et.al, 2021). However, these drivers of western South Island River flooding are unlikely to be related to catchments on the eastern side of New Zealand due to lower elevations and smaller catchments. Some interannual fluctuations in large-scale circulation, such as those associated with La Nina, have also been found to enhance flooding in some eastern catchments but the precise synoptic circulation that delivers the moisture (and resultant heavy precipitation) remains largely unknown (Freeman, 2008). Therefore, understanding what drives regional river flooding in eastern catchments is crucial to understand New Zealand's current and future flood risk. This reseach aims to determine the large-scale and regional atmospheric circulation patterns associated with river flooding in catchments on the eastern side of New Zealand. The main objectives are to enhance our understanding of flooding using a range of flood frequency analysis methods and to identify the average atmospheric circulation patterns that have lead to historical high rivers flow with a magnitude greater than a 1-in-5 year flow.

Methods
Eleven catchments in six regions are used in this study: 1) the Bay of Plenty (Otara and Waioeka Catchments); 2) Canterbury (Selwyn and Hurunui Catchments); 3) Gisborne (Waimata, Te Arai, and Hikuwai Catchments); 4) Wairarapa (Waingawa and Ruamahanga Catchments); 5) Marlborough (Wairau Catchment); and 6) Northland (Waitangi Catchment). The catchments were selected after successful river flow data acquisition and consultation with the relevant councils. The catchments selected were required to be subject to frequent and damaging floods, have a complex environment, low groundwater recharge, and have available flow data from at least 1979. Mean hourly flow data were collected from the councils and daily maximum flow values were generated using the statistical programme Rstudio.

An analysis of the recommended flood frequency methods provided by New Zealand Councils and international governments was carried out to assess the robustness of flood frequency methods for the various New Zealand catchments. New Zealand Council recommendations varied by region based on the catchment, and the methods recommended included the Log Pearson Type III (LP3), Gumbel, Genralised Extreme Value (GEV), and Peaks Over Threshold (POT). International recommendations suggested the use of multiple methods to determine the most reliable based on the modelled and observed value fit. For this study, it was determined that the LP3, Gumbel, and POT methods were best suited for defining 1-in-5 year river flows. The flood frequency analsyis (FFA) was completed in Rstudio and the results were examined individually for each catchment to determine the best suited FFA method for each catchment. An appropriate 1-in-5 year magnitude was selected based on the results and all historical flows that exceeded the 1-in-5 year flood magnitude were examined, creating a robust dataset of up to 15 historical high river flow events.

The European Centre for Medium-range Weather Forecasts (ECMWF) fifth generation atmospheric reanalysis ERA5 (Hersbach et al., 2020) data set was used to identify the anomalous atmospheric circulation pattern during the three days prior to an observed high river flow. Particular variables of interest were mean sea level pressure (to identify the location and intensity of high and low pressure systems), near-surface temperature (2 m), near-surface dew point temperature (2 m), vertically integrated water vapour flux, and near-surface wind (10 m). The concurrent phases of large-scale modes of climate variability were also investigated using standard climate indices for the El Niño-Southern Oscillation, Southern Annular Mode, and Madden-Julian Oscillation. The anomalous conditions leading up to all high river flows above the 1-in-5 year threshold were composited to examine the most common atmospheric circulation patterns and moisture transport pathways.

Results

The flood frequency analysis determined there are high amounts of uncertainty in our current definitions of flooding in all 12 catchments. The 4 FFA methods generated different flood magnitudes for all catchments except for the Selwyn River in Canterbury. Not one single FFA method was identified as the most reliable, however the Gumbel method was identfied as the most robust for the East Coast catchments. These results suggest improvements in New Zealand's flood frequency methods are required to improve the certainty around flood magnitudes.

Interim results for the Hurunui Catchment in Canterbury (Figure 1) indicates historical floods that exceeded 970m3/s occurred when there was a deep low pressure system just west of the North Island combined with a strong high pressure centre south of the South Island. In this case, strong poleward moisture transport out of the tropics (near Fiji) within the warm sector of the cyclone occurred, which was then steared easterly between the cyclone and high pressure to the south to directly intercept the Hurunui Catchment.

Results for the other five catchments will also be presented in this talk, along with connections to large-scale climate patterns.

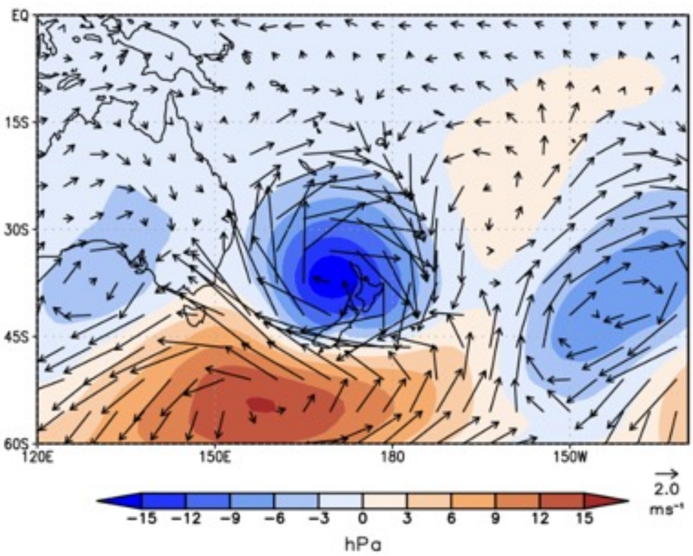

Figure 1: Anomaly composite of mean sea level pressure (shaded) and 10-m wind (vectors) during the 3-days leading up to and including the (13) 1-in-5 year high river flow events (events that exceeded 970m3/s) for the Hurunui River Catchment. Yellow circle denotes the location of the Hurunui Catchment.

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N-WISE IRRIGATION – FIELD TESTING

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Aims
N-loss to water from the majority of NZ's irrigated area must be reduced to meet water quality criteria. There are multiple ways in which a farm's N-loss to water can be reduced, one of which is improving irrigation practices to reduce the risk of drainage.

A recent desk-top pilot study (Bright et al, 2018) provided 'proof of concept' that radically changing irrigation management strategy on case-study dairy farms in Canterbury would, on average, achieve a 27% reduction in N-loss to water. The irrigation management strategy recommended by this study balances the risk of pasture production loss against the risk of N-loss to water. This we refer to as "N-Wise Irrigation".

Development of N-Wise Irrigation strategies was based solely on computer modelling of irrigation management, drainage losses, pasture production and N-loss to water. The overall aim of the current project is to answer the question "does N-Wise Irrigation significantly reduce the risk of N-loss to water without significantly raising production loss risks, even when water supplies are unreliable?"

Our method for doing so is to conduct plot-scale field trials on a commercial dairy farm. The farm is located in Selwyn District, located predominantly on a Lismore soil (because of the prevalence of dairy farms in Canterbury on this soil type).

Method
The field-plot trial is designed to measure pasture production and N-leaching losses under three irrigation management strategies and two water supply reliabilities – six treatments in total.

The plots are located on an irrigated dairy farm in an area that is separate from the farm's normal irrigation schedule, but in every other way is managed in a business-as-usual way. In particular, it is subject to the same fertiliser and grazing regime as the rest of the irrigated area.

The irrigation management strategies are:
- Current Good Management Practice – minimal production loss risk, relatively high N-loss risk.
- An N-Wise Irrigation strategy that balances production loss and N-loss risks.
- An irrigation strategy for which there is minimal N-loss risk and relatively high production loss risk.

The two water supply reliabilities are:
- 100% (a typical groundwater security of supply.
- 80% (representative of the low-end of current security of supply from river sources in Canterbury.

There are 3 replicates of each treatment. Treatments were randomly assigned to each of 18 plots that are 12 metres long by 3 metres wide.

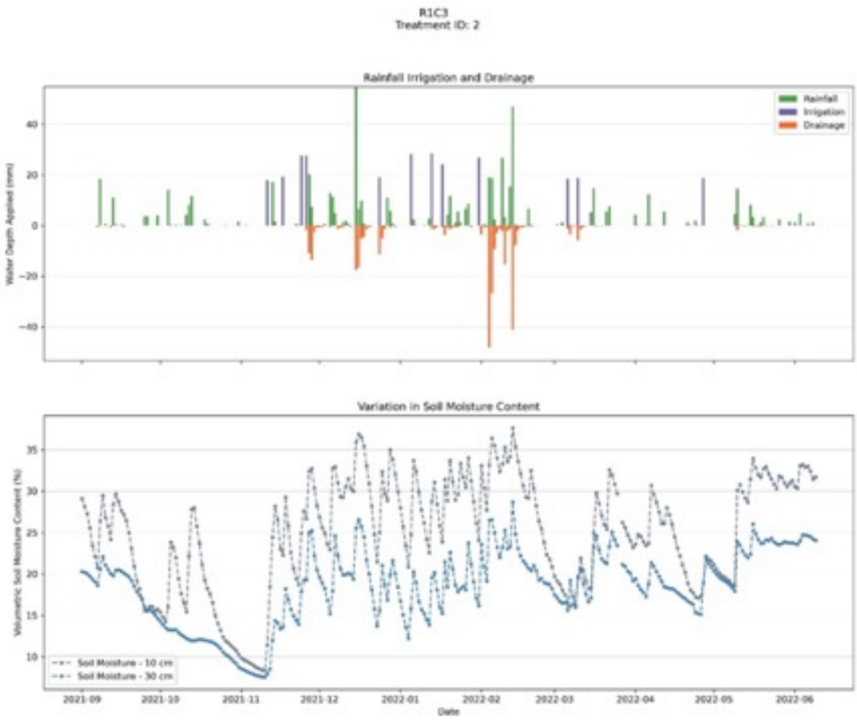
Each plot can be irrigated independently of the rest. A strip-lysimeter 10m long by 0.4m wide has been installed in each plot, along with soil moisture and irrigation application depth monitoring equipment. A climate station and duplicate rain gauges have been installed. Thus all aspects of the water budget can be measured for each plot.

Drainage samples are taken on a volume proportion basis and sent to a laboratory for chemical analysis. In addition to this, drainage water EC is continuously monitored to provide the basis of interpolating between water sample analyses, and to provide a degree of data redundancy.

We have a significant degree of remote monitoring/control and data redundancy built into our monitoring systems. This has already proved its worth.

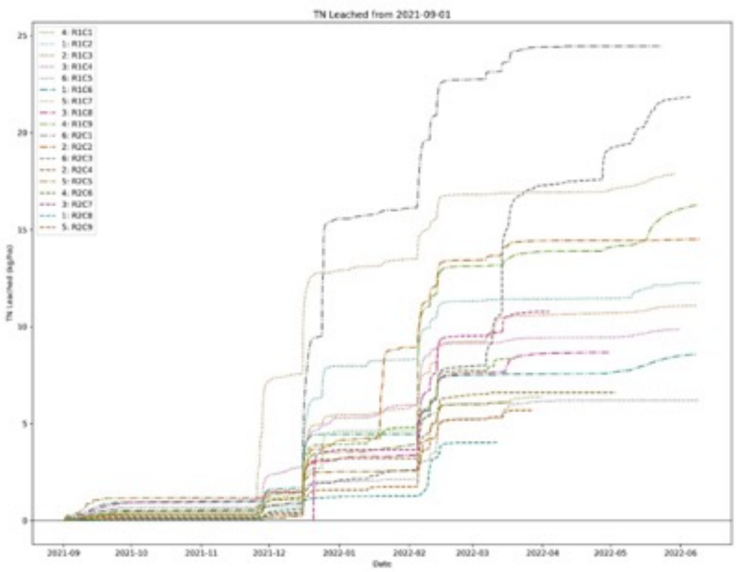
Results

The time-series graphs below illustrate the nature of the data that has been collected to-date.



Because of the amount of rain received through January and much of February, soil water content in the topsoil did not often drop below the nominal field capacity of 25% v/v and only approached the trigger level of 15% v/v for GMP irrigation on a couple of occasions. Thus, there was no opportunity to apply the designated irrigation treatments.

It is evident from the figure below that there are considerable differences between the field plots in terms of the mass of TN leached from the soil during the year. These aren't attributable to differences in irrigation amounts, they illustrate the effects of spatial variation in soil properties and topography.



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AGILE, ADAPTIVE WATER ALLOCATION POLICY

John Bright,[1] **Jane Alexander,**[1] **Julian Weir**[1], **Andrew Dark**[1]
[1] Aqualinc Research

Aims
Many operative groundwater allocation policies set a fixed limit on the annual water take volume, and restrict the rate of take from bores "close to" rivers. The restriction on groundwater takes is based on the restriction regime applied to surface water takes from the relevant river.

Monitoring data shows that for some significant lowland river/stream systems this isn't sufficient, and modelling has shown that it will not be sufficient under project changes in climate.

Our hypothesis is that more agile water allocation policy is needed to enable timely, low transaction cost adaptation to climate change and climate variability.

We are using computer simulation models to explore what agile water allocation might need to look like to maintain stream-flows and water levels in the Selwyn-Waihora water management zone, as a cast study.

Methods
Four climate change projections out to ~2100 were obtained from NIWA (daily climate data from a 'mid-range' GCM driven by 4 RCP's)

Irrigation demand and land-surface recharge (LSR) were modelled, using IrriCalc, from 1972-2100 for each of the VCN grid squares covering the study area– assuming current water allocation rules.

In parallel with this, mean daily river flows for the Waimakariri, Selwyn and Rakaia rivers (where they exit the foothills) were modelled for each of the 4 projected climates by NIWA and Ecan – these are key inputs to the detailed modelling that follows.

Calibrated Eigen Models were used to simulate daily streamflow and groundwater levels for the past (20 year hindcast) and future 20 year periods centred on 2040 and 2090.

Key flow and level statistics were calculated for each time period.

We then developed alternative allocation policies with the goal of significantly improving stream health, relative to the recent past, and maintaining improvements under future climate scenarios. The ability of each alternative policy to meet the goal was then tested by simulating its application using Eigen models. This enabled a large number of options to be tested quickly.

The most promising approaches were selected for more detailed analysis. We are using the Selwyn Waihora Integrated Groundwater–Surfacewater (SWIGS) flow model for this detailed analysis.

Results
If the current allocation policy is retained then the mean annual low flow for the Waikirikiri Selwyn River at Coes Ford is projected to reduce by up to 18%. The range of reductions is shown in the following table.

RCP	2040's	2090's
2.6	-3%	-5%
4.5	-5%	-13%
6.0	-9%	-17%
8.5	-18%	-18%
Percentage Change is relative to MALF during hindcast 20 year period		

The policy response options may be categorised as follows:

- Policies that reduce demand
  - Reduce the annual volume limit on groundwater takes, no year-to-year variation.
  - Vary the annual volume limit on groundwater takes based on prior year(s) LSR.
  - Shift groundwater takes onto surface water supplies.
  - Vary the maximum daily rate of take based on prior year(s) LSR – mimics restrictions on surface-water takes.
  - Vary the maximum daily rate of take based on river flows – mirroring surface water restrictions

- Policies that enhance groundwater recharge
  - Increase irrigated area
  - Managed aquifer recharge
  -

To-date we have examined the effectiveness of policies that reduce demand.

Our analysis shows that, for this groundwater-surfacewater flow system, policies that reduce annual volume limits in response to reductions in LSR can be effective at maintaining MALF out to 2100, providing they're carefully designed. However there are several years where low-flows have been, or are projected to be, very low under current policy, and the alternative policy is unable to prevent this. Having the agility to manage takes in response to year-to-year variations in climate is as important as adapting to a changing climate.

We find that groundwater take policies that reduce the daily rate of water take for all abstractores are more effective in maintaining lowland river/stream flows than annual volume-based limits.

In particular, restricting the daily rate of all groundwater takes on the same basis as the restriction of surfacewater takes is very effective.

Under this time of policy, groundwater supplies would be very much more reliable than they are now, becoming similar to surface water supply reliability.

We cannot eliminate the cumulative effects on streamflows of groundwater abstraction. These effects adversely impact surface water take supply reliability. To avoid this it may be necessary to set the cease-take-flowrate for groundwater takes at a higher level than that for surface water takes.

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CONDENSATION NUCLEI OFF THE WEST COAST OF THE NORTH ISLAND, NEW ZEALAND.

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National Institute of Water & Atmospheric Research Ltd

Aims
Condensation nuclei are very small hygroscopic particles or aerosols upon which water vapour can condense to form a liquid. They range in size from 0.001 micrometer (μm) to 0.1μm in diameter. By comparison a human hair is around 50μm. Water requires a non-gaseous surface to make the transition from a vapour to a liquid. The particles continue to coalesce until they are large enough to become cloud or rain droplets. The size and number of particles is important in determining the effect they have on atmospheric conditions.

In the marine atmosphere, conventional wisdom says that the smaller nanometer (nm) sized particles originate from atmospheric oxidation of precursor gases to form secondary aerosols. They come from natural and anthropogenic sources such as dimethylsulfide, methanesulphonate and sulfur dioxide, and oxides of nitrogen; in a process known as gas-to-particle conversion. This particle size dominates the number distributions. The larger micrometer sized aerosols originate from natural and anthropogenic sources and include dust or clay; soot from fires, combustion engines and factories; sea salt from wave spray; and sulphates from volcanoes. The larger particles can interact with CN of gaseous origin. This particle size dominates the volume and mass distributions (Ayers et al, 1997).

CN are important because the variation in concentration, source and size contributes to weather and climate predictions at local, regional and global levels. Atmospheric aerosols influence the world's climate in two main ways: direct forcing and indirect forcing (Boucher et al, 2013). The direct forcing mechanism is where aerosols reflect sunlight back into space, thus acting to cool the planet. Conversely, aerosols of a sooty nature absorb some of the sun's energy, which can lead to local atmospheric heating and changes in stability and convective patterns in nearby regions. The indirect effect is where aerosols act as additional cloud condensation nuclei that can cause clouds to be more reflective and longer lasting.

This talk focuses on CN measurements recorded off the west coast of the North Island of New Zealand during eight voyages from Picton (New Zealand) to Osaka (Japan) by the bulk carrier Transfuture 5 between 2006 and 2013 and the transportation of aerosols of anthropogenic source into this region.

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CAN DEEP LEARNING ADD CONTEXT TO TRADITIONAL WEATHER AND CLIMATE MEASUREMENTS? – A CASE STUDY

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For several years, NIWA has increasingly been investigating and applying solutions, based on Artificial Intelligence (AI), to practical science problems. Using AI Deep Learning we have been able to resolve several meteorological and hydrological challenges such as: instantaneous measurement of total discharge in low-flow, weedy streams; automatic detection of anomalies in incoming data from the climate monitoring stations in our climate network, and real-time invasive species detection and mapping for freshwater and marine biosecurity programmes. In this presentation, we will look at another application, a case study, that could potentially be developed further.

Aims
In 2019, NIWA built and installed two alpine weather monitoring stations, for a client wanting to assess how the local weather affects visibility. Consequent aims were to:

- Electronically record weather/climate data, at each of the two high-altitude stations, using standard sensing instruments.
- Use cameras to periodically record an image of the fixed view from each station, over a period of approximately two years, to provide continuous visibility information during daylight hours.
- Analyse each recorded image to determine what percentage of this period might have provided satisfactory visibility for a human observer.

Method
To invoke the visibility assessment:
- We defined six classes of visibility: clear sky, broken cloud, overcast, reduced visibility, poor visibility, and whiteout.
- As manual classification was impractical, we decided to use an AI Deep Learning method to automatically classify each of the images, as a post process.
- We trained a classifier to predict which class each image might belong to (figure 1).
- We fed batches of images into our trained classifier, filed the classified output data in a spreadsheet table and derived our conclusions from it.

Results
Over two years, we collected 54,000 images at various frequencies (5, 10 and 30 minutes) and at two resolutions. For each of the two sites:
- We defined the overall 'visibility acceptable' to be the percentage of all images that had been classed as clear sky, broken cloud, or overcast.
- We defined the overall 'visibility not acceptable' to be the percentage of all images that had been classed as poor visibility and whiteout, but also included the marginal class, reduced visibility, in this category.
- We tallied the 'visibility acceptable' percentage in two ways - by class and by day.

In the presentation we will reveal what we found. This case study touches on aspects of standard manual climate observations that preceded the introduction of Automatic Weather Stations. These observations were made by human observers who would manually record visibility, present weather, cloud type, height and percentage cover. In the presentation we will take a brief look at the uncertainties involved and at new technology that would enable us to make aspects of observation automatically, in real time, at sub-second frequencies.

Figure 1: A monitoring station showing the camera recording the still images that were manually downloaded and classified by the Deep Learning algorithm as a post-process.

TRIALLING AN IN-STREAM WOODCHIP DENITRIFYING BIOREACTOR AS AN EDGE-OF-FIELD N-MITIGATION PRACTICE

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[1] DairyNZ
[2] Institute of Enviornmental Science and Research Ltd. (ESR)

Aims

The aim of a woodchip denitrification bed is to intercept shallow drainage water and treat it of reactive nitrogen (Schipper et al., 2010). Conceivably, if such beds were strategically positioned within the agricultural landscape they could function as an edge-of-field, end-of-pipe, nitrate-mitigation practice and assist with addressing the challenge of 'farming within [nutrient] limits'. A handful of experimental woodchip denitrification bed field trials have been completed in New Zealand (NZ) to date, where the focus has been on interception and treatment of subsurface tile drainage (Hudson et al., 2019; Goeller et al., 2019; Rivas et al., 2020; Pratt, 2020). Results from those trials have been mixed and it remains for a reliable assessment to be made of whether woodchip denitrification beds offer a viable (i.e., practicable and cost-effective) nitrate-mitigation option for the NZ farm-scape.

In this work we present the results from a woodchip denitrification bed trial we are conducting on a working dairy farm in the Barkers Creek catchment, South Canterbury. Some key differences of the denitrifying bioreactor we are testing compared to others so far examined in NZ are: i) its placement within an open drain, and ii) the scale of the treatment system. After facing a set of complications, delays and false starts imposed on us by an ever-changing physical and economic climate, we started proper operation of the bioreactor in November 2021. We have been monitoring its performance since then. Beyond the single objective of nitrogen removal, our study aims to evaluate ancillary water treatment benefits offered by the bioreactor; pollution-swapping effects, and the cost-effectiveness of N-removal.

Method

The in-stream woodchip bioreactor we are testing copied design concepts that were first explored by Robertson and Merkely (2009). A schematic design is shown in Figure 1. The bioreactor is set in the base of an artificial drain, which it partially dams. Water within the farm drain comprises a combination of natural groundwater spring flows and piped tile drainage. The bioreactor itself comprises 430 m3 of pine woodchip sealed within EPDM rubber membrane. Inlet and outlet pipes permit flow of drain water through the woodchip, driven by the head of dammed water. The size of the bioreactor was determined from consideration of the hydraulic regime of the drain flows; seasonal temperature; expected nitrate concentrations and denitrification rates, as well as construction costs. It was optimally designed to treat an average flow rate of 6 L/s and drain water containing 6 mg N/L. Details of the design strategy can be found in Sarris and Burbery (2019).

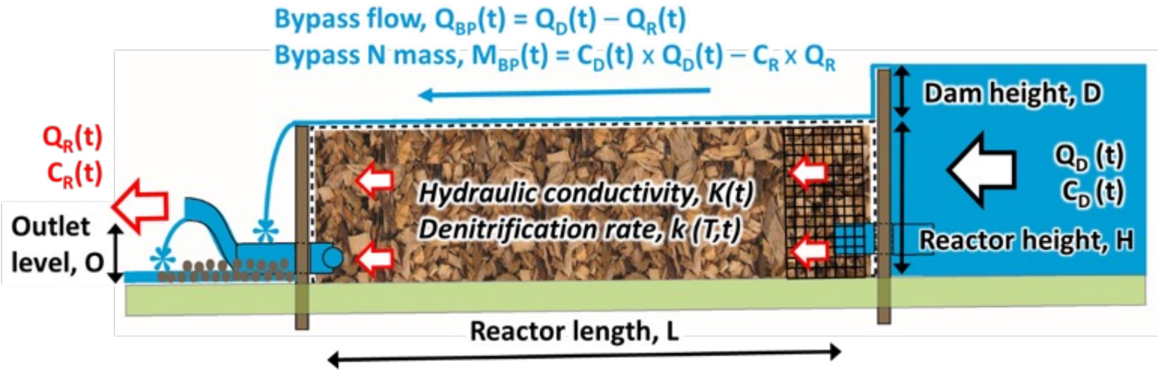

Figure 1: Schematic of the in-stream woodchip denitirifying bioreactor under trial. As-built dimensions were length L = 75 m, height H = 1.5 m, dam height D = 0.5 m and woodchip volume V = 430 m3.

Construction of the in-stream denitrifying bioreactor took place in stages, between the years 2017 and 2021. Over this time, the hydrological function of the drain on which the bioreactor was positioned changed and it was not until November 2021, following some remedial actions, that 'normal' flow conditions at the site resumed to the state for which the bioreactor had been designed to address. By that time much of the labile dissolved organic carbon from the woodchip had already been exported from the bioreactor.

The bioreactor is instrumented with water level, flow and water quality sensors (including a TriOS OPUS optical nitrate sensor and YSI Exo multi-parameter sonde) that make measurements up-stream, down-stream and within the bioreactor, at a frequency of 8-times/day. Automated monitoring is complemented by monthly manual water quality sampling and flow checks. At those events, speciated nitrogen in both influent and effluent water is measured, as are concentrations of phosphorus, sulphate, iron, manganese, dissolved greenhouse gases (CO2, CH4 and N2O), and the indicator pathogen Escherichia coli.

Results
Since December 2021, flows through the woodchip bioreactor have varied between 3.1 and 8.5 L/s (average 6.3 L/s). Nitrate concentrations in the drain water subject to treatment have ranged between 3.6 and 6.0 mg N/L (average 5.1 mg N/L). The in-stream bioreactor has proven effective at reducing nitrate, having removed between 0.53 and 1.7 kg N/day (average 1.3 kg N/day). In the 6 months between December 2021 and June 2022 it mitigated a total of 258 kg of nitrate-nitrogen. There is clear evidence that N-removal is sensitive to temperature. The observed rate of nitrate removal is almost half the rate Sarris and Burbery (2019) predicted it would be, based on their review and analysis of published rates in the scientific literature. This disparity highlights more practical field-trials of woodchip denitrifying bioreactors are needed in NZ to reliably evaluate their effectiveness and inform predictive N-mitigation models.

Water quality monitoring data collected so far indicate the woodchip bioreactor is also acting to attenuate dissolved reactive phosphorus (between 3 and 22 g/day), total phosphorus (between 6 and 29 g/day) and ammoniacal nitrogen (between 3 and 35 g/day) in the drain water. Escherichia coli counts in the bioreactor effluent have been consistently lower than counts in the influent, suggesting some attenuation. Whilst it remains for mass fluxes to be calculated, relative concentrations of dissolved greenhouse gases in treated and untreated drain water show operation of the bioreactor is leading to some production of both N2O and CH4. Performance monitoring of the in-stream bioreactor continues.

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HIGH-FREQUENCY VARIABILITY IN THE SOUTHERN HEMISPHERE: OBSERVATIONS AND CMIP6 MODELS.

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[1] Victoria, University of Wellington/Te Herenga Waka

Aims
In this study, we explore linkages between the monthly mean 500hPa height field (Z500) and its high-frequency variability over two-eight days as a proxy for SH storm track activity. We compare results from ERA-5 reanalyses with a set of twenty models from the CMIP6 project to diagnose model biases.

Methods

We apply Maximum Covariance analysis to identify leading modes of co-variability between the Z500 mean and high-frequency variance anomalies on monthly and sub-monthly timescales. We also calculate covariance with indices of large-scale variability (Southern Annular Mode (SAM), El Niño-Southern Oscillation (ENSO) and Zonal Wave 3 (ZW3)). The normalised first Principal Component (PC) of the mean Z500 anomalies was used to define a SAM index (SAMI), as outlined in Fogt & Marshall (2020) [1]. The Southern Oscillation Index (SOI) was used to quantify ENSO, collected from NOAA (url: https://www.cpc.ncep.noaa.gov/data/indices/soi). The index formulated in Goyal et al, 2022 [2] characterises ZW3, with data retrieved from the author. For CMIP6 model output, we quantify base state biases and perform the same MCA and covariance analysis procedure as on the ERA-5 reanalyses. Model indices were calculated using the same methods outlined for ERA-5 with data retrieved from the model output.

Results

We find large-scale circulation patterns emerge as prominent modes of co-variability in ERA-5 reanalyses, particularly SAM and ENSO. The seasonal cycle plays a prominent role in explaining variability in both SAM and ENSO interactions with the storm track. We find that despite a broadly linear response, both SAM and ENSO teleconnections present additional complexities and non-linearities. Despite strong ZW3 signals in the mean height field, links to the high-frequency variance field remain unclear. Generally, the three large-scale variability modes investigated emerge from the CMIP6 model output in the leading MCA modes, however, models tend to poorly represent the asymmetrical component of SAM. Figure 1 shows an example of MCA patterns obtained from ERA5 and a selection of CMIP6 models.

The presentation will cover aspects of observed mean flow-storm track interactions, and the strengths and weaknesses of climate model representations of those patterns and interactions.

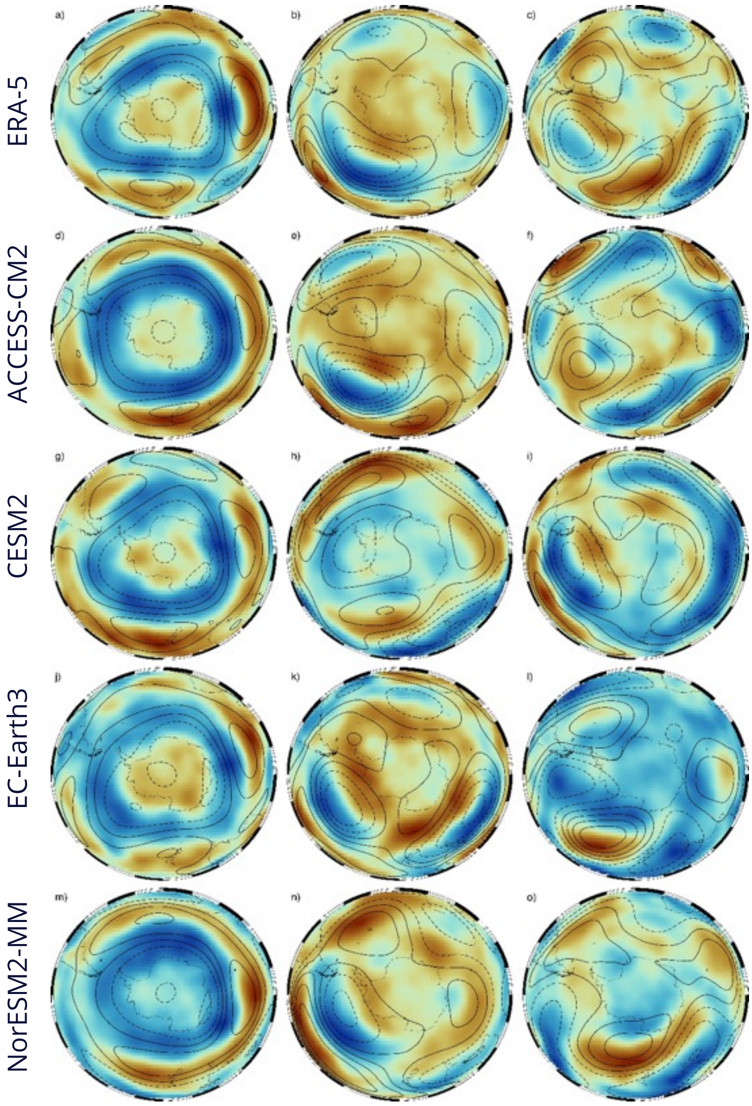

Figure 1: Leading three singular vectors of mean Z500 and high-frequency variance fields from MCA on a monthly timescale, a-c) ERA-5, and a sub-sample of CMIP6 model output, d-f) ACCESS-CM2, g-i) CESM2, j-l) EC-Earth3, m-o) NorESM2-MM. The mean Z500 field anomalies are indicated by the contours, positive contours solid and negative dashed. The associated storm-track anomalies are shown as the colour fill, blue indicating increased high-frequency variance and brown showing decreased variance. Units are dimensionless so intervals indicate relative magnitude only.

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CONVECTION-PERMITTING ENSEMBLE WEATHER PREDICTION

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[1] NIWA, Wellington

Aims
NIWA has been trialling a convection-permitting ensemble numerical weather prediction system over New Zealand for the past two years. This system has provided increased confidence to NIWA's Forecasting Services Team when issuing forecast guidance. Forecasting the location and timing of precipitation is challenging, especially at higher resolution as individual convective cells begin to become resolvable. At longer lead times, the goal of predicting the exact location and timing of precipitation becomes more and more unrealistic, at which point a probabilistic forecast becomes much more valuable. While computationally expensive, ensemble prediction systems are an ideal tool for providing such probabilistic forecasts.

Here we assess the skill of NIWA's ensemble prediction system over a 12-month period focussing on the resolution and reliability of its precipitation forecasts. In addition, the value of the system during severe weather events will be shown through a case study of the August 2022 extended heavy rainfall event in the Tasman/ Marlborough districts (Figure 1).

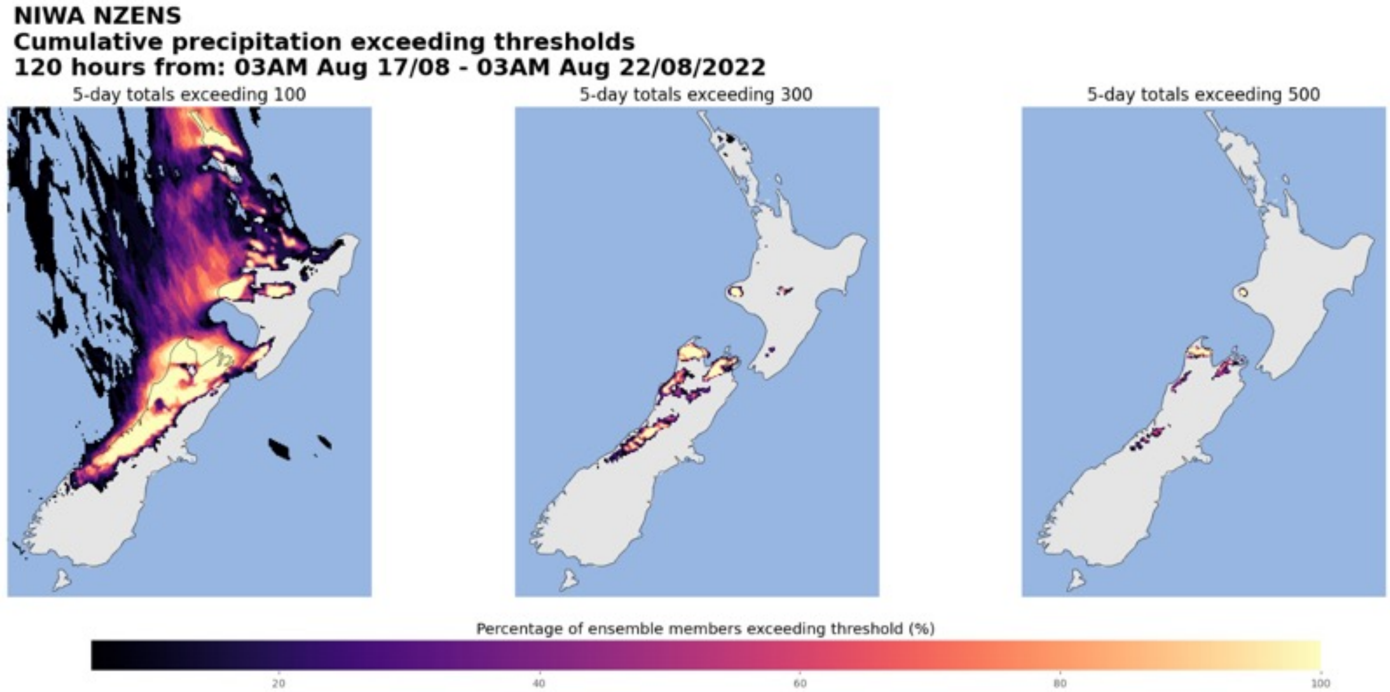

Figure 1: Probability of predicted 5-day rainfall accumulation exceeding the 100mm, 300mm and 500mm thresholds based on a forecast initiated on the morning of August 17th, 2022. Such a prediction provides high confidence in the forecasts of heavy rainfall given in the Tasman and Marlborough districts.

Method
NIWA's New Zealand Ensemble (NZENS) is an 18-member ensemble numerical weather prediction (NWP) system. At its core is the Met Office Unified Model configured with the RA1-M convective-scale science package (Bush et al., 2021) and the system forecasts out to a lead time of 120 hours with surface and pressure level outputs available at hourly resolution. NZENS operates with a horizontal resolution of 4.5km and covers all of NZ's land mass and its coastal waters. Initial conditions and lateral boundary conditions are derived from each member of the UK Met Office MOGREPS-G global ensemble forecasting system as described in Allen et. al. (2020) and references therein. Over the past two-year period, the ensemble has been run twice per day, although more recently this has been increased to four times per day.

The skill of the NZENS precipitation forecasts has been validated against rain gauge observations for the most recent calendar year. This has been done using a variety of verification metrics to assess the different qualities of the ensemble system. These metrics include RPS (rank probability score), ROC (relative operating characteristics), spread/skill ratio and tools such as the reliability diagram and rank histogram. The majority of these metrics have been assessed for different regions of New Zealand at the hourly scale at a range of rainfall rate thresholds.

Results

Verification of precipitation forecasts from NZENS are positive and show that the model is performing well. Figure 2 shows reliability diagrams for two different climate regions of NZ for the 1 mm/hr rainfall threshold. For shorter lead times, the reliability is good for both regions, although there is a tendency to overpredict, particularly at higher probabilities. At longer lead times, forecast reliability deteriorates quicker in the north of the North Island than on the southwest of the South Island.

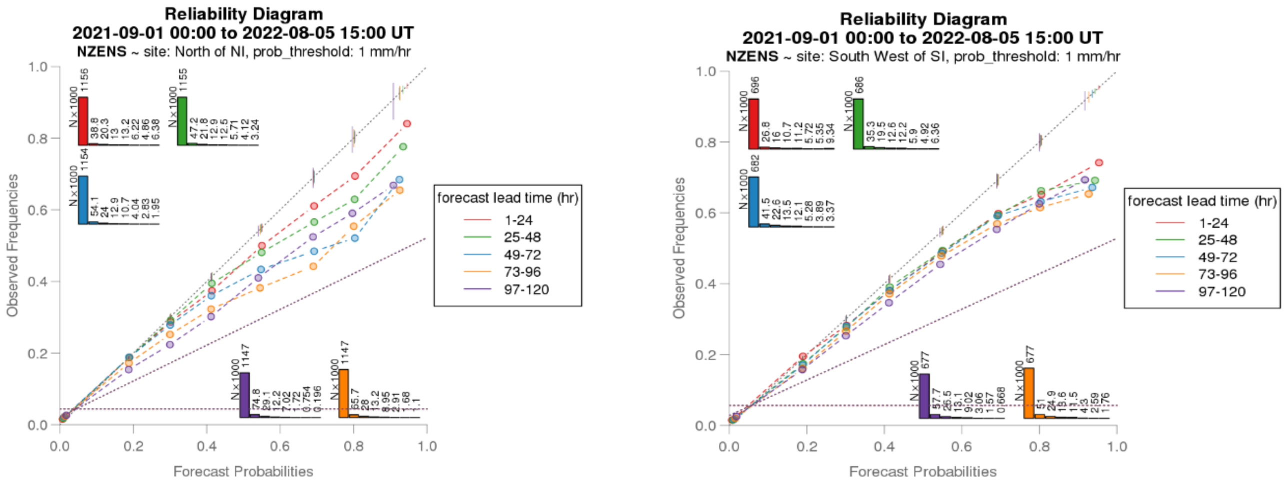

Figure 2: Reliability of NZENS precipitation forecasts when compared against rain gauge observations. A total of 95 gauges covering the north of the North Island are included in the left panel and 56 gauges covering the southwest of the South Island in the right panel. Perfectly reliable forecasts follow the 1:1 line, while the dotted line represents a forecast with no skill.

Figure 3 compares the forecast skill of the ensemble mean against a measure of the ensemble spread. Ideally, the magnitude of the variability will be similar to the root mean square error of the ensemble mean showing that the spread in the ensemble is wide enough to encompass the truth. Figure 3 shows that as the number of members in the ensemble increases, the forecast skill also increases, although with diminishing returns. Interestingly, the variance of the ensemble stays relatively constant, and for NZENS, even with 18 members, the spread/skill ratio does not reach unity.

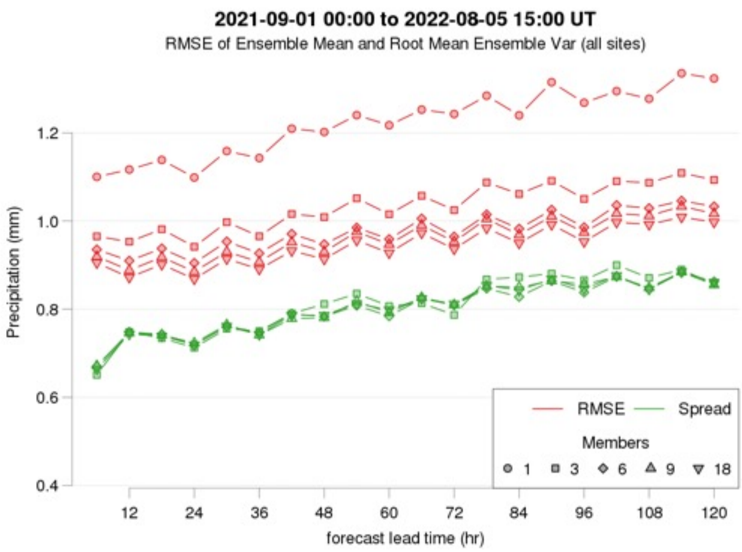

Figure 3: Comparison between precipitation forecast skill and spread for ensembles ranging in size from 1 to 18 members. The smaller ensembles were created by sub-sampling the full 18-member ensemble.

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FLOODS IN UNGAUGED RIVERS: IMPROVING QUICK AND SLOW FLOW PATHWAY PARTITIONING IN A HYDROLOGICAL MODEL

Cattoën, C.,[1] **Dean, S**,[2] **Shiona, H.**[1], **Shankar, U.**[1]
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Aims

The cost and impact of flooding in Aotearoa New Zealand is considerable. Over the last 50 years, half of the natural hazards reported in the Insurance Council of NZ database relate to flood events with an estimated cost of over $160M per year. To increase resilience, the 5-year MBIE Endeavour programme Mā te haumaru ō te wai aims to develop consistent flood hazard maps for the whole of Aotearoa. However, generating reliable flood maps relies on a complex cascade of models, including a hydrological model that can provide accurate river flood estimates in steep terrain and ungauged rivers at national scale. Without model calibration and using only nationally derived parameters, modelled flood peaks highly depend on the correct partitioning and pathway representation of quick (surface) and slow (underground) flows. Here, we assess different model parametrisation and process conceptualisation approaches to understand and improve flood estimates, without performance deterioration outside of events, in a semi-distributed hydrological model.

Method

We use TopNet (Clark et al. 2008), a semi-distributed hydrological model, based on TOPMODEL concepts of runoff generation controlled by sub-surface water storage (Beven et al. 1984). TopNet combines a water balance model within each sub-catchment, with a kinematic wave-routing algorithm (Goring 1994). The hydrological model provides natural flow information for all of Aotearoa and replicates the environmental diversity of NZ catchments.

We consider four versions of TopNet with different parametrisation and/or conceptualisations:

i) The Calibrated model: calibrated using traditional techniques for high flow performance;
ii) The Uncalibrated model: parameter settings used in all uncalibrated modelling efforts (McMillan et al. 2016);
iii) The Clark model: parameter settings published in Clark et al. (2008);
iv) The Ki model: parameters and conceptualisation modified to allow for an effectively shallower, soil layer that can generate infiltration excess runoff using physically realistic values for saturated hydraulic conductivity. Ki values are based on Clapp-Hornberger estimates, available for soil type in the Fundamental Soil Layer national database. Large downslope saturated hydraulic conductivity values are kept for drainage and baseflow conceptualisations, which differ from previously unsuccessful trials of using realistic saturated soil conductivities, such as Ki, in TopNet (Woods et al. 2009) and (Ibbitt et al. 2009).

We assess 10-year simulations in the Waikanae catchment, from 1995 to 2005, and present summary statistics with long-term and event-based hydrological signatures, as well as a close look at model performance during the largest flood event to date on the 5th-6th of January, 2005. We use daily 500m resolution interpolated VCSN rainfall with station-based disaggregation that includes NIWA and council rain gauges.

Results

Long-term statistics of hydrological signatures inform us about model representation of specific hydrological behaviours (e.g. flood magnitude representation, proportion of slow flow response, overall proportion of runoff from rainfall). The error relative to the observed signatures is presented graphically in Figure 1. Analysis of the observed flow relationship with rainfall suggests that infiltration excess plays an important role in flood peaks in Waikanae. Overall, the Ki model has the best quickflow generation process representation but with a drainage that is still a little too large although an improvement over the Uncalibrated model. The Calibrated model is predominantly a single flow model using soil storage to produce a fast interflow-like response, but with poorer baseflows in general, while the Uncalibrated model is a single flow aquifer-dominant model that produces good baseflows but cannot produce good flood peaks (Figure 2). The Clark model is a two-flow model (fast and slow using 3 storage components), but for Waikanae at least, too much water is stored in the soil layer, during and outside of floods, and it likely loses too much water to evaporation. The Ki model is also a two-flow model that produces fast surface flow and a baseflow like the Uncalibrated model, while avoiding the compromises of the Clark model. We suggest that all this evidence makes the Ki model the best in overall performance for the Waikanae catchment. However, the Ki model suffers from conceptual shortfalls by using different values for saturated conductivity within the soil layer equations. This could be addressed in further work by combining a macropore flow bypass (by allowing a proportion of infiltrating rainfall to bypass the soil store) and an extra subsoil layer to represent proper interflow, allowing clear separation of the baseflow responses and recession shapes. Allowing three flow pathways to contribute to a flood peak may be the only way to build a model that can be expected to do both flood and baseflows more generally across different catchment types with a consistent physically-based conceptualisation.

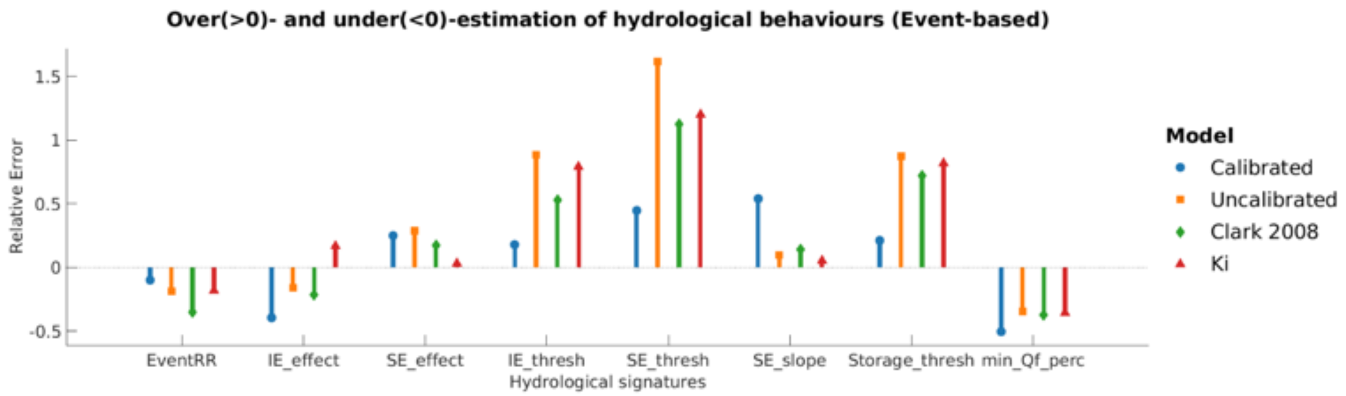

Figure 5 Relative error in event-based signatures over a 10-year period.

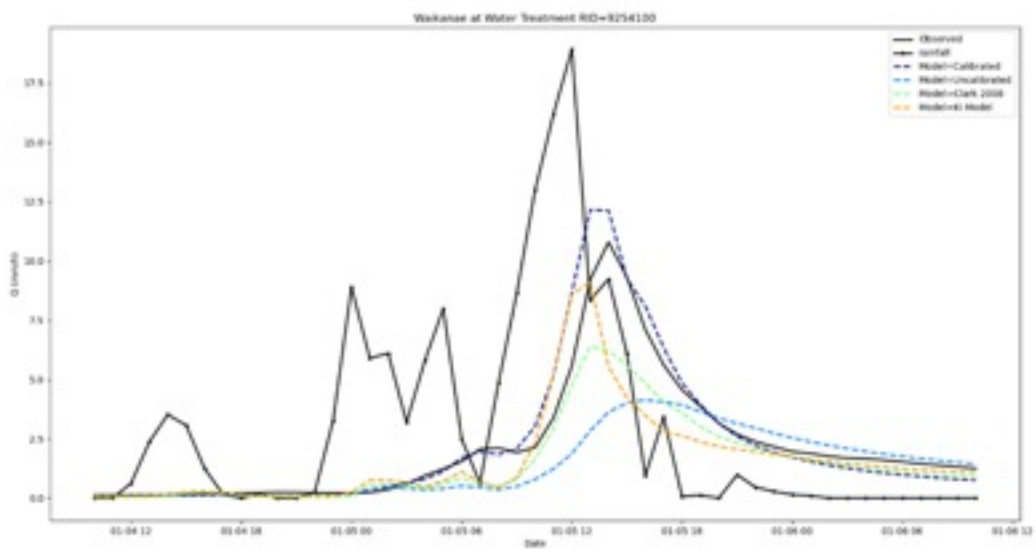

Figure 2: Catchment average rainfall, observed flow at Water Treatment, and for four different TopNet models

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A BAYESIAN FRAMEWORK FOR MAPPING THE PROBABILITY OF GROUNDWATER INUNDATION UNDER SEA LEVEL RISE SCENARIOS

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Alarming decade-to-century rises in global mean sea levels are projected by the Intergovernmental Panel on Climate Change (IPCC). Under high emissions scenarios, global mean sea level could rise by 1.0 m above 2000 levels by 2100 (IPCC, 2021). Moreover, we are now committed to a minimum sea level rise (SLR) of 274 ± 68 mm, regardless of mitigation measures or climate change pathway (Box et al., 2022). This will have profound impacts on low-lying coastal regions.

An often-overlooked impact of SLR are rising groundwater levels and the emergence of groundwater at the surface (that is, groundwater inundation). As sea levels rise, hydraulically connected groundwater levels will rise and eventually break out at the ground surface, potentially before surface flooding occurs (e.g., Rotzoll and Fletcher, 2013). This represents a hidden natural hazard to vulnerable communities that will lead to severe economic and social damages, such as road and property flooding, and reduced capacity of storm and wastewater networks (e.g., Cox et al., 2020).

Given these potential impacts, groundwater rise and inundation mapping will be an essential tool for supporting decisions on how to manage and communicate the impacts of SLR on coastal aquifer systems. Furthermore, mapping products will require modelling techniques which acknowledge the inherent spatial and temporal uncertainty of the system simulated, this being an essential component of risk-based decision making (e.g., Freeze et al., 1990).

Aims
Under IPCC scenarios of SLR, we therefore aim to map the spatial and temporal probability of groundwater rise and inundation within a Bayesian framework to support decision-makers. We present this framework for a real-world case study (South Dunedin, New Zealand), where the uncertainty of groundwater level rise and inundation predictions are robustly quantified. Although currently local in scale, the framework is widely applicable and can be deployed for other coastal regions where decision-support models are needed. The modelling workflow will be made available as a Jupyter notebook upon publication, to ensure transparency and reproducibility (Jupyter, 2016).

Methods
The presented Bayesian framework involves four main components: 1) early uncertainty quantification to assess prior parameter and corresponding prediction uncertainty to resolve any conceptual model inadequacies, 2) running a strategically designed history matching process to condition model parameters pertinent to the predictions of interest, 3) Monte Carlo sampling of climate change and SLR parameters to explore history matching constrained predictive distributions of groundwater levels, and 4) the production of maps assessing groundwater rise and susceptibility to groundwater inundation according to selected exceedance probability levels.

Results
The spatial and temporal probability of groundwater levels exceeding the groundwater model top is shown for an example IPCC scenario (Figure 1). Under high emissions scenario SSP5-8.5 (medium confidence), the simulated susceptibility to groundwater inundation appears low and relatively constant for the 2030-2050 timeframe. It is, however, possible to distinguish zones which appear to be more susceptible to groundwater inundation in this timeframe. Due to dramatic SLR associated with the SSP5-8.5 scenario, a sharp increase in the probability and spatial extent of groundwater inundation is then apparent for the 2070-2100 timeframe. As expected, the highly susceptible areas generally tend to coincide with low-lying open areas, and where there is absence of drainage.

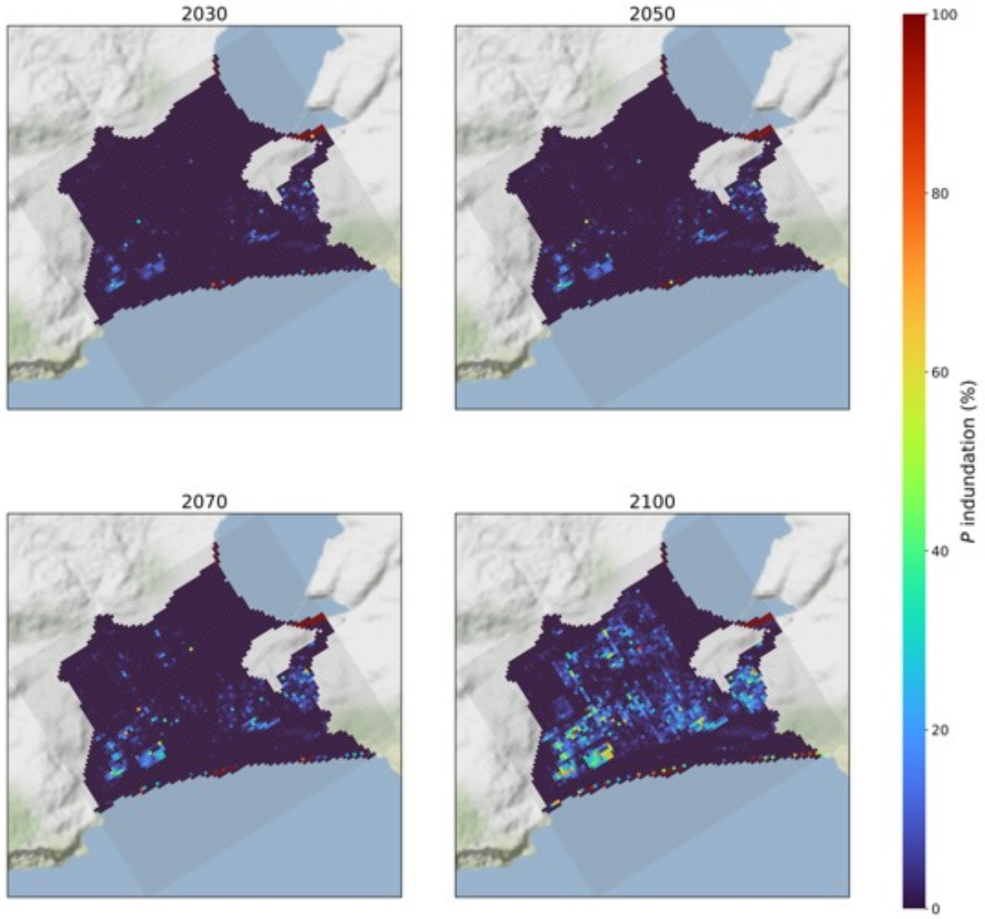

Figure 1. The projected spatial extent of the probability for groundwater levels exceeding the model top (that is, groundwater flooding or inundation) due to SLR and climate variability. Projected probability of groundwater inundation for 2030, 2050, 2070 and 2100 based on the IPCC SSP5-8.5 [medium confidence] scenario.

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A LOW-COST OPEN-SOURCE CLARITY SENSOR

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Aims

Extending the monitoring network of suspended particulate matter (SPM) in freshwater systems for research, national monitoring and citizen science initiatives has long been hampered by both cost and calibration issues. Measurements of SPM require collection of samples and laboratory analysis, a time consuming and expensive process (Davies-Colley et al., 2014). As a means of rendering catchment-scale monitoring more affordable, proxy optical measurements of turbidity are often used instead.

At many monitoring sites, good correlations between turbidity, clarity and suspended mineral sediment (Ballantine et al., 2014) have been established. Therefore, turbidity and clarity are useful surrogate measurements for suspended mineral sediment, with the important caveat that these correlations cannot be extended to other locations as SPM is a function of local terrain conditions and precipitation regime (Hicks et al., 2011). Variable constituent components of mineral sediment and organic matter will also influence site correlations due to their diverse behaviours in scattering and absorbing light (Bright et al., 2020) (Davies-Colley et al, 2014). Different turbidity sensors show different responses to SPM matrices even following calibration to the same standards (Davies-Colley et al., 2021). This issue is compounded by the fact that measures of turbidity are not SI units but are rather set to an arbitrary standard (Davies-Colley & Smith, 2001).

Turbidity sensors are usually expensive to purchase, costing several thousands of dollars, therefore limiting the ability of any monitoring group or agency to construct dense intra-catchment networks necessary to characterise the temporally dynamic, spatially heterogenic nature of erosion or pollution processes. To address this there have been numerous studies that seek to build low-cost turbidity sensors; however, in this quest a key obstacle has been calibration of the sensor. Calibration generally requires access to expensive standards and solutions, or comparison to an expensive commercial turbidimeter.

Method

To address this problem, a low-cost open-source sensor ($450NZD) measuring 563nm signal attenuation at 180° incidence (nominally called a 'clarity' sensor to distinguish from turbidity as a standard) is being developed. The sensor is designed to be calibrated to local observations of visual clarity and provides a novel measurement technique: four different path lengths. As light attenuation is a function of mineral and organic matter in suspension, and the path length over which attenuation is measured, the use of four different path lengths is proposed to achieve two different goals: (1) a large measurement range; and (2) a method to detect sensor drift due to fouling.

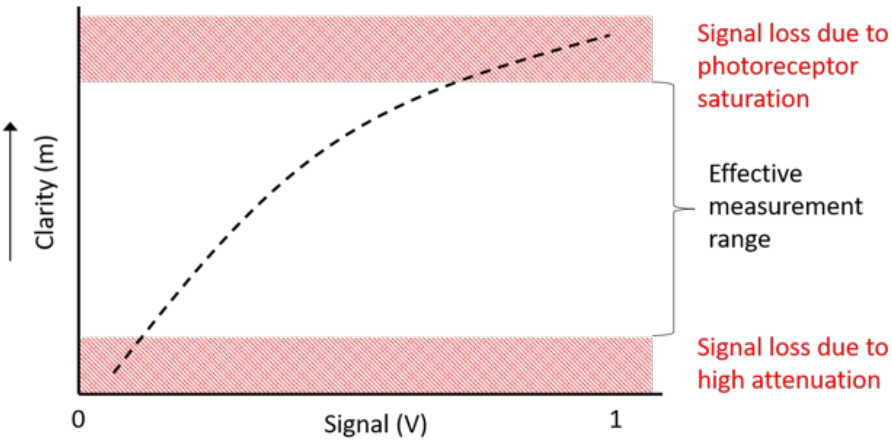

Figure 1: Theoretical response of an optical attenuation sensor showing signal loss

Goal 1 is straightforward, the shorter the path length the less sensitive the path is to turbid water conditions. The design of an optical attenuation sensor presents challenges when clarity is high or low, due to over-saturation of photoreceptors or complete attenuation of emitted light, respectively (Figure 1). Combining four different path lengths can overcome these challenges. For example, a short path length may be saturated when stream water is relatively clear; however, a longer path length will experience more attenuation and hence will provide an effective measurement.

Goal 2 is more challenging, but potentially more important. If all environmental factors remain constant, then the only difference in measured signal strength between paths will be due to the difference in path length. This should hold true for conditions where biofouling of the sensor occurs, therefore comparing the average of the path signal strength with the average of the difference in path signal strength will give two comparative readings, an indication of sensor drift due to fouling, and a (potentially) fouling-corrected trace.

This sensor is part of a wider PhD programme investigating the application of clarity sensors to construct dense catchment networks that can determine water clarity heterogeneity, of interest at the Aotearoa New Zealand national scale to inform sediment load reduction targets. The research is designed to enable community groups and citizen scientists to collect SPM time-series data.

Results

The research follows open-hydrology principles (Hall et al., 2022). The clarity sensor is built on the Adafruit Feather M0 platform with supporting hardware purchased through hobbyist electronic retailers, home hardware stores and online retailers. The sensor head is built with a mix of nylon selective laser sintering (SLS) and ABS fused deposition modelling (FDM) 3D printing techniques. Nylon SLS is an expensive 3D printing medium, but ensures critical submerged parts achieve high precision and remain watertight. The less expensive FDM can be substituted, though the sensor housing components may not achieve the same precision and waterproofing standards. The unit has low power consumption, with a 2W 6V solar panel to ensure longevity during extended deployments. Remote communication can be maintained via LoRa 915Mhz onboard the Adafruit to a Wifi ESP32 gateway, enabling real-time data to be streamed to webpages.

A public GitHub repository (https://github.com/EdFClayton/Clarity-Sensor) has been established to share materials list, 3D print designs, PCB designs, build instructions and program code.

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QUANTIFYING TIMESCALES OF SEAWATER-GROUNDWATER INTERACTIONS IN HETEROGENEOUS ALLUVIAL DEPOSITS

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Rising sea levels and growing populations put coastal groundwater under increasing pressure worldwide. One challenge for groundwater management is the unobserved nature of groundwater flow and solute transport processes in aquifers. This is especially true in heterogeneous environments where geological variations influence hydrologic processes in a range of environments (e,g, Kreyns et al., [2020]). Alluvial deposits form important aquifers in New Zealand and worldwide. These deposits can be characterized by small highly conductive channels embedded in a less permeable matrix.

We hypothesize that this aquifer structure causes notable departures in the behaviour of alluvial coastal aquifers from the idealized homogeneous case. To test the nature and scale of these effects, we have used numerical modelling. First, we developed an ensemble of [3]D synthetic alluvial aquifer models (Pirot et al., [2015]). Then, we simulated salinity distributions and the position of the freshwater-seawater interface using SEAWAT (Guo & Langevin, [2002]). Using [3]D models allows us to capture alongshore mixing and flow paths not captured by cross sectional models. We analysed how the interface responded during initial aquifer salinization, equilibration, and then after an increase in the offshore head, approximating future sea level rise. This allowed us to assess how heterogeneity affects the size and shape of the mixing zone between fresh and saltwater, and how quickly it responds to external forcings.
These results will form the basis of further work modelling the behaviour of alluvial coastal aquifers under pumping and managed aquifer recharge. Furthermore, the influence of heterogeneity on the characteristics and behaviour of offshore freshened groundwater systems likely to exist in alluvial deposits around New Zealand will be explored (Morgan and Mountjoy, [2022]).

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FACTORS INFLUENCING THE DISTRIBUTION OF STYGOFAUNA IN GROUNDWATER SYSTEMS.

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Background & Aims
Groundwater biodiversity is invisible to most people outside the field of groundwater ecology. Microbes densely colonize groundwater and there are also many stygofauna species present. The difficulty in assessing the true diversity of groundwater life is primarily due to a low sampling effort. Groundwater represents the largest reservoir of liquid freshwater on Earth, but groundwater ecologists have only explored a minor fraction of it.

In 1994 the first edition of "Groundwater Ecology" by Janine Gibert, Dan L. Danielopol and Jack A. Stanford was published. Since that time there have been major developments in this field and a new edition, entitled "Groundwater Ecology and Evolution" edited by by F. Malard, C. Griebler, and S. Rétaux is currently being prepared. We have contributed to some of the book chapters in the new edition and this presentation summarises the current knowledge concerning factors that influence the distribution of stygofauna in groundwater systems. The factors are discussed and illustrated using research from New Zealand groundwater systems.

Results: Key factors influencing Stygofauna distribution
The size of voids, their interconnectedness, and their hydrological connections to the surface environment are three key physical variables controlling the number of species in groundwater stygofaunal communities. Hydrological connection to the surface may in turn exert a major control on three other key variables, the availability of dissolved oxygen (DO) and organic matter (OM), and thermal variability. These six integrative features probably account for the largest proportion of variance in groundwater stygofauna richness and composition among localities within a region.

There are some interactions between these factors that can influence the abundance of stygofauna. For example, reduced thermal variability of deeper subsurface environments may select for a low thermal tolerance of species, which may in turn constrain their dispersal along spatial temperature gradients. Increased OM supply to groundwater enhances the complexity of food webs and diversity of organisms present, with DO depletion due to microbial aerobic respiration affecting the survival of many stygofauna species.

These six factors are discussed and illustrated with examples from the international literature and from New Zealand research sites.

INVESTIGATING GROUNDWATER SOURCES TO A COASTAL LAGOON USING HYDROGEOCHEMISTRY AND NUTRIENT ANALYSIS

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Aims

Groundwater discharge to coastal waterbodies has been increasingly recognised as having an important role in contaminant transport and ecological functioning. Groundwater often has high concentrations of solutes such as nutrients, so even where groundwater discharge rates are low, groundwater-derived contaminant loads may be high. In brackish environments such as coastal lagoons, inputs of fresh groundwater may serve vital ecological roles for the flora and fauna in these water bodies. Improving the understanding of groundwater discharge sources can assist with contaminant and water allocation management in catchments, while informing restoration efforts in coastal waters. This study aims to resolve groundwater sources to a large (~150 km^2), shallow, eutrophic coastal lagoon in Canterbury, New Zealand – Te Waihora/Lake Ellesmere. Te Waihora has seen a significant degradation of water quality in recent decades, and it is now at the centre of large-scale multi-stakeholder restoration efforts. This study seeks to inform management of this culturally important site by shedding light on groundwater sources and their contribution to nutrient transport to the lagoon.

Methods

We carried out a hydrochemistry sampling campaign in several source waters in and around Te Waihora: the lagoon surface water, shallow porewater on the lagoon margins, groundwater wells of varying depths, and springs. We collected 40 samples in November-December 2020 and analysed these for major ions (Ca^{2+}, Mg^{2+}, Na+, K+, Cl-, SO_4^{2-}, NO_3-), dissolved trace metals (Fe, Mn), water isotopes ($\delta^{18}O$ and δ^2H), and nutrients (N and P suites).

We took five surface water samples from Te Waihora spatially distributed around the lagoon by boat on a moderately windy day, ensuring well-mixed conditions. We collected 14 porewater samples using stainless steel drive-point mini-piezometers installed to a maximum depth of 0.75 m within 750 m of the lagoon's water edge. We sampled existing groundwater wells mainly on the northeastern to southwestern inland margins of the lagoon (n = 14), as well as five wells on Kaitorete Spit, the permeable gravel barrier that separates the lagoon from the sea. Well screen depths ranged from 0.5-90.5 m below ground with samples taken from the surface aquifer, as well as confined Aquifers 1-3. Water quality parameters (dissolved oxygen, specific conductivity, temperature, pH, oxidation-reduction potential (ORP)) were measured through a flow cell while sampling. Two spring samples were also taken as grab samples.

Results

In general, groundwater chemistry split into two distinct groups: (1) samples from the inland margins (i.e., Canterbury Plains side) of the lagoon and (2) samples from the permeable barrier. Overall, inland groundwater samples reflected a combination of mainly alpine river recharge (particularly samples from greater depths) and shallow land surface (rainfall) recharge. This group of samples was dominated by $MgHCO_3$ water types and lower δ^2H:$\delta^{18}O$ ratios. Samples collected on the barrier were dominated by NaCl water types and higher δ^2H:$\delta^{18}O$ ratios. The barrier samples reflected locally derived rainfall recharge as the main source of groundwater recharge, as well as seepage from the lagoon. Lagoon surface water and groundwater on the barrier showed a strong influence of seawater, with several ions (e.g., SO_4^{2-}, Na^+, Cl-) correlating with seawater dilution lines. Samples from the lagoon surface water and several lagoon margin porewater samples on the barrier reflected evaporative effects in the chemistry, resulting in higher concentrations of some ions (e.g., Mg^{2+}) and depleted δ^2H:$\delta^{18}O$ ratios.

Overall, our results showed elevated dissolved reactive phosphorus (DRP) and low nitrate (NO_3^--N) in shallow groundwater samples at the margins on the lagoon. We found evidence of anoxic conditions in porewater samples with elevated dissolved Fe, Mn, NO_2^-N and NH_4^+. This sampling suggests that reactive phosphorus may be mobilised in the shallow anoxic sediments at the lagoon margins. Meanwhile, the anoxic conditions and low nitrate concentrations compared to regional groundwater and river concentrations suggest potential denitrification occurring in the shallow sediments before groundwater discharges to the lagoon. These results highlight the importance of managing tributary-derived nutrient inputs to the lagoon. The findings also underscore the importance of balancing wetland restoration with limiting conditions for phosphorus release to shallow groundwater.

IDENTIFYING WELLBEING ASPIRATIONS FOR ASSESSING THE IMPACTS OF CLEAN WATER TECHNOLOGIES IN AOTEAROA NEW ZEALAND

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Context

Wellbeing Governance is a socio-political driver of change that aims to improve the impacts of decisions on the wellbeing of people and their ecosystems. A key challenge in implementing Wellbeing Governance is the alignment and prioritization of aspirations amongst stakeholders as wellbeing is a normative concept that differs between societal groups (Organisation for Economic Co-Operation and Development, 2011). Common factors influencing aspirations include cultural values and development priorities (Fioramonti et al., 2019). Global frameworks can support large-scale change and connect national goals, but effective implementation and operationalising must consider place-based wellbeing aspirations of local stakeholders (Ormsby, 2018, United Nations, n.d.).

In Aotearoa New Zealand, the Government has committed to Wellbeing Governance in partnership with Tāngata Whenua. Enhanced wellbeing outcomes are sought through implementation of the Living Standards Framework alongside He Ara Waiora, Fonofale and Children's Commissioner's Wellbeing Wheel. Wellbeing is the goal of national fiscal policy and is being introduced into national and regional policies (Parliamentary Commissioner for the Environment, 2021).

Uptake of Wellbeing Governance and commitment to sustainable development is driving demand for technologies that can achieve integrated environmental, social, and economic benefits (Vörösmarty et al., 2018). However, there are challenges with the holistic evaluation of such technologies due to current limitations of sustainability assessment methods and decision-making tools. Key challenges include the bridging knowledge bodies, recognition of cultural values, and the operationalising and implementation of global goals at local levels (Reid et al., 2005).

The core wellbeing concept in the National Policy Statement for Freshwater Management is Te Mana o te Wai, an earth-oriented principle (i.e., prioritises ecosystem wellbeing), that outlines a hierarchy of obligations and principles for managing freshwater (New Zealand Government, 2020).

Aims

This paper will describe the first phase of a PhD project that seeks to embed Te Mana o te Wai and wellbeing at the heart of the selection of Clean Water Technologies (CWT) through the development of a Wellbeing Approach (comprised of a framework and supporting methodology) that:

- Is co-informed by Western science and mātauranga Māori;
- Aligns with international and national wellbeing and sustainability aspirations; and
- Considers stakeholder cultural values.

Phase one is developing a Wellbeing Assessment to generate a regional understanding of stakeholder perspectives on wellbeing and sustainability aspirations, and cultural values, for selection of CWT. Findings from this assessment will inform subsequent research phases that include environmental impact assessment and development of the decision-making framework (the Wellbeing Framework).

CWT are sustainable technologies that clean wastewater such as treatment filters and stormwater treatment systems using an approach that connects to ecosystem wellbeing. These technologies offer solutions to reduce the impacts of human activities and protect and enhance the wellbeing of water.

Method

A mixed-method and cross-cultural methodology has been developed for the research. He Awa Whiria framework (Figure 1) guides the inclusion of mātauranga Māori alongside Western science, and the cross-cultural methodology for the research (Macfarlane and Macfarlane, 2018). Primarily, the research shall engage with the knowledge bases of Western science and mātauranga Māori.

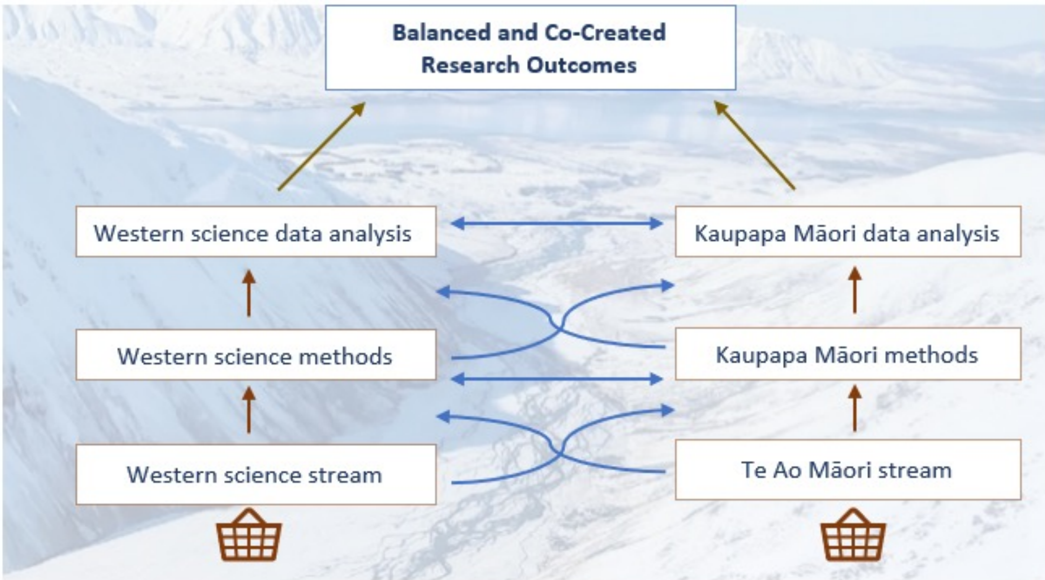

Figure 1: He Awa Whiria Framework. Modified from (Wilkinson et al., 2020)

Data shall be collected through literature review and surveys, and the process will be iterative and inductive in line with Straussian Grounded Theory (Sbaraini et al., 2011). Target populations for the surveys are freshwater stakeholders in Te Waipounamu, and representation will be sought across societal groups (Figure 2).

Figure 2: Target Societal Groups for Survey Participation

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NEW ZEALAND 3D HYDROGEOLOGICAL MAP: THE WAIRAU PLAINS COASTAL GROUNDWATER SYSTEM

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Aims

The "National Aquifer Characterisation by System" project is a GNS Science-led collaboration to develop the first 3D hydrogeological map of New Zealand. Hydrogeological maps are resource management tools that integrate geology, aquifer properties, and groundwater quality and quantity information (Gleeson et al. 2014). These maps will characterise our geologically-complex aquifer systems at a national scale, providing digital resources in a consistent template for evaluating aquifers according to the 2.5D Hydrogeological-Unit Map (HUM) framework of White et al. (2019). The project is funded by the New Zealand Ministry of Business, Innovation and Employment Strategic Science Investment Fund (contract C05X1702) through GNS's Groundwater Programme and is led by Stewart Cameron.

Our preliminary hydrogeological mapping and characterisation of New Zealand Quaternary coastal groundwater systems indicates deep gravel aquifers that were deposited during periods of cold glacial climate are present where there is a long history of tectonic subsidence. This includes regions like Canterbury where there has been widespread subsidence of the continental platform for millions of years (Kominz 2006), and tectonically active half-grabens like the Hutt Valley (Wellington) and the Wairau plains Marlborough), where the history of subsidence is more recent and localised (Crundwell and White 2021).

The groundwater resources that are currently used by the Marlborough District community are largely sourced from natural springs and shallow boreholes, and very little is known about the deep groundwater system beneath the Wairau plains. Because there is a paucity of deep boreholes in the Wairau plains, it is necessary to develop sedimentary facies and hydrological properties models for the deeper sedimentary facies, using the principles of "sequence stratigraphy" (Crundwell and White 2021).

Method

Three inputs are needed to develop a 3D sedimentary facies and hydrological properties model for a coastal groundwater system:1) a calibrated global sea level curve; 2) the local net subsidence rate (i.e., the sum-total of near and far-field Quaternary tectonic deformation); and 3) sedimentary facies information derived from borehole lithological descriptions and the analysis of microfossils in borehole samples. A calibrated sea level curve is essential, and only one of the other components is needed to develop a working model. For example, when there is no sedimentary facies information, subsurface sedimentary facies can be modelled using the sea-level curve and the local net subsidence rate. When the subsidence rate is unknown, sedimentary facies information from shallow boreholes can be used to estimate the subsidence rate and use it to model the deeper sedimentary facies. And when there are no local subsidence or sedimentary facies data, different subsidence rates can be used to develop hypothetical groundwater models for evaluation using other types of data.

Results

The geomorphology and geology of the Wairau plains indicate the coastal groundwater system is associated with a tectonically active half-graben with a relatively long history of Quaternary subsidence. This supports the use of the sequence stratigraphic method to model deep sedimentary facies in the coastal groundwater system.

Because the local subsidence rate is unknown and sedimentary facies information is largely limited to borehole lithological descriptions, several hypothetical sedimentary facies and hydrological properties model have been developed for the Wairau plains based on different subsidence rates. The best fit model is shown in Figure 1. It is based on the inferred sedimentary facies of borehole P28w–4047 near Rarangi, the only deep borehole near the coast that penetrates to basement. The model relates primarily to the Rarangi area (north-eastern Wairau plains) on the northern side of the Wairau Fault, and it assumes a local subsidence rate of -0.2m/kyr. No samples were collected when the borehole was drilled (i.e., the sedimentary facies are inferred from the lithological borehole descriptions, and they are not constrained by paleoenvironmental data derived from the analysis of microfossil samples) and in this respect, the model is poorly constrained. Despite the uncertainties, the model indicates there are alluvial fan gravels of MIS-6 penultimate glacial age (134–151 ka) beneath the Wairau plains. The potential of these deep gravels as a groundwater resource has not yet been tested, but our modelling indicates the hydrological properties of the alluvial fan gravels are good when sea-level was very low and the rivers that deposited the gravels were highly energetic.

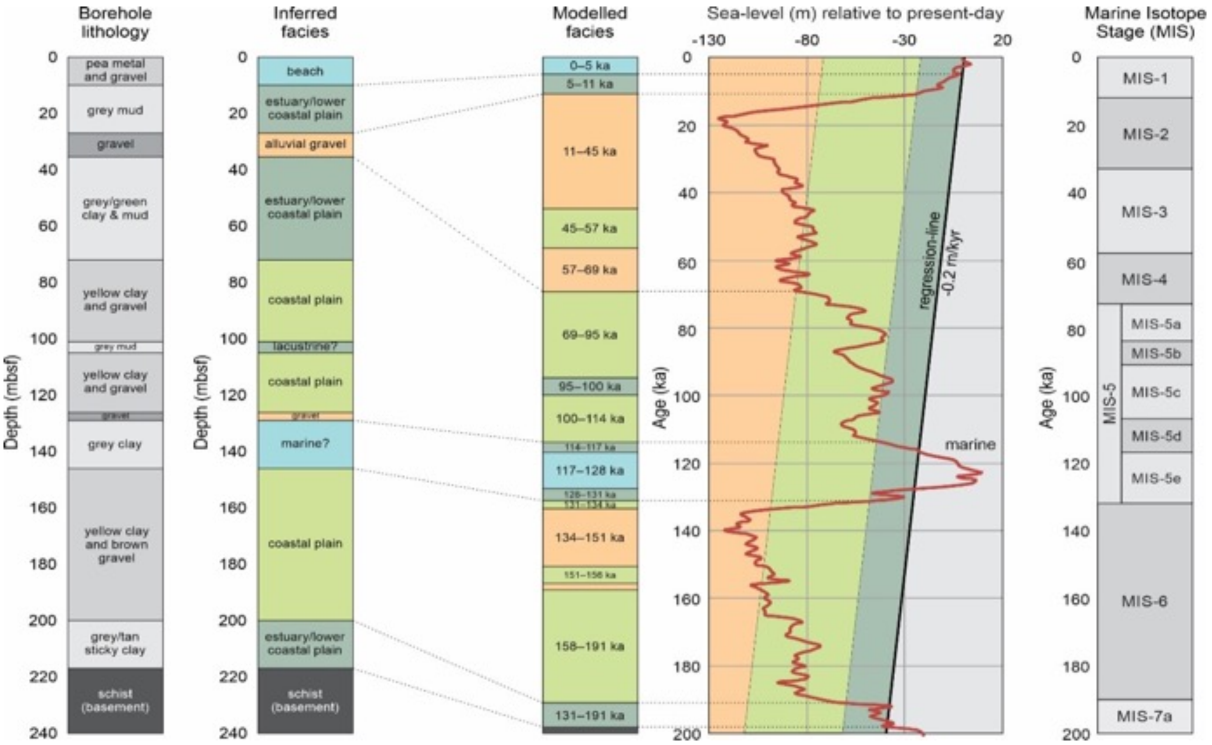

Figure 1: Best fit model for sedimentary facies beneath the Wairau plains, near Rarangi (based on borehole P28w–4047 and a local subsidence rate of -0.2 m/kyr).

The use of the sequence stratigraphic method to model the distribution and quality of sedimentary facies in New Zealand coastal groundwater systems is currently limited by the paucity of Quaternary subsidence data and the absence of samples from most groundwater boreholes. To advance our understanding of coastal groundwater systems on a national scale, it is important to collect and achieve samples from new groundwater boreholes, especially samples of fine-grained sediments.

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MODELLING FRAMEWORK TO ESTIMATE FRESH GROUNDWATER OCCURRENCES AND VOLUMES BELOW ATOLLS

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Freshwater lenses are important fresh groundwater resources at Small Islands Developing States (SIDS), especially during droughts. During the last decades, sustainable groundwater management has become a pressing issue due to a changing climate, population growth, and unsustainable groundwater extraction. Furthermore, sea level rise will have an irreversible impact on these lenses and their ability to supply enough fresh water for domestic and agricultural use. Previous studies show that the occurrence of fresh groundwater at small islands depends on many factors like hydrogeological composition and permeability, topography, size and shape of the island, drainage characteristics, vegetation, land use, and meteorology. The way these factors interact and determine the fresh groundwater volumes at small islands over time can be estimated by groundwater modelling. The accuracy of the estimation depends on model conceptualization, accuracy of the parameter values and scenarios for climate change, sea-level rise and socioeconomic developments/ human activities. We used a MODFLOW/SEAWAT based toolbox, iMOD-WQ, to set up a detailed variable-density groundwater flow and coupled salt transport model of the Laura freshwater lens on Majuro atoll (Marshal Islands) to explore which factors are the most sensitive in controlling the volume of the freshwater lens over time. Based on the findings of this Laura lens modelling as well as previous studies, we set up a generalized conceptual modelling framework using global datasets which contain the most important factors determining the freshwater lens occurrence. Although data for most SIDS is scarce, the geological characteristics of atolls show large similarities which helps to schematize a general hydrogeological composition of an atoll. Within this modelling framework, the key factors that determine the freshwater lens volume can easily be adapted once actual local data is available (e.g. thickness of the Holocene layers, hydraulic conductivities, recharge, shape of the island). The modelling framework is set up using python and uses the python package Snakemake as a workflow manager. It applies the extensive capabilities for pre- and postprocessing of data and model building of the iMOD-python package and has version control (using Git). The robust and flexible modelling framework provides a quick estimate of the freshwater lens occurrence and volume while it can be easily adapted to the local situation with new data. The modelling framework opens a wide range of possibilities for both site specific and general estimations of freshwater lens volumes. This framework forms the base towards more effective and sustainable fresh groundwater management.

MULTIYEAR DROUGHT IMPACT (2018-2019-2020) ON THE GROUNDWATER SYSTEM OF THE DUTCH SANDY AREA

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Aims

In large parts of Europe, 2018 is known as an extremely dry year. In the Netherlands this 2018 drought caused over 1 billion euros of damage to different sectors like agriculture, shipping, and buildings and unrecoverable damage to nature. A large part of the damage was due to extreme low groundwater levels, large soil-moisture deficits and many streams stopped flowing due to an affected run-down groundwater system. While the groundwater system was recovering from this extreme drought, two consecutive extreme dry years (2019-2020) followed and enhanced the impact on the water system. This multiple drought showed clearly the vulnerability of the current groundwater system for droughts and change to a more climate robust water system to withstand future events is required.

Method

A large research was conducted for the Dutch sandy area, which covers more than half of the Netherlands, to analyze the impact of this multiple drought on all aspects of the water system (soil moisture, groundwater levels, groundwater discharge and stream flow) and agriculture and groundwater dependent nature. The research was followed and guided by over 100 stakeholders of ministries, water boards, provinces, drinking water companies, nature conservation and agricultural organizations. For this research we used different types of available data and analysis methods like: satellite images (NDVI, NDWI), times series analysis of groundwater levels, stream discharges and soil moisture, detailed 1D vadose-saturated zone modeling (SWAP) and large-scale modeling of the entire sandy area using our integrated nationwide groundwater and surface water model (MODFLOW-METASWAP-MOZART). We combined the different data analyses and modeling results to understand the propagation of the drought through the water system, address spatial differences due to different area characteristics and to formulate operational ad-hoc measures and structural solutions to mitigate drought. A nice example is the detection of agricultural irrigated fields and quantification of extracted groundwater via the combination of satellite imaging and groundwater modelling.

Results

We concluded that during a drought operational measures are limited to restricting surface and groundwater abstractions and a structural change of the entire water system is required to mitigate a drought. Already under normal meteorological conditions, the water system is far from robust and conflicting water interest between agriculture, drinking water abstractions and nature which act in the same spatial space is the major task to make the water system future proof. The most striking results and guidelines for such a huge water transition will be presented.

ESTIMATING THE COST OF THE JULY 2021 BULLER FLOODS ATTRIBUTABLE TO CLIMATE CHANGE

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Aims

Heavy rainfall from the 15th to the 18th of July 2021 caused significant flooding within Westport. Following the flood, 23% of the town's housing stock required repair to be habitable. Insurers have paid out over $85 million in claims to date. With New Zealand having already warmed by about 1.1 degrees above preindustrial temperatures as a result of human-induced climate change, it is broadly understood that both the intensity and frequency of such heavy rainfall events have likely increased. Here we assess different methods for estimating how much of the costs associated with the event might reasonably be attributed to anthropogenic emissions of greenhouse gases.

Method

We use the new Buller flood model developed by the MBIE Endeavour programme Mā te haumaru ō te wai to run with a new gridded observational rainfall product as input and validated with in-situ measurements of flood depths for the July 2021 event. We then use a range of methods developed by the Endeavour programme Whakahura: Extreme Events and the Emergence of Climate Change to remove the contribution to the rainfall intensity that might be considered attributable to climate change (Stone et al. 2022), creating a 'counterfactual' rainfall event. This is used to simulate a counterfactual, or 'naturalised', flood as though there had been no anthropogenic emissions of greenhouse gases.

Using a building damage model for the 2021 Westport flood event we estimate direct economic costs from both the actual flood and the naturalised flood, and thus an associated attributable cost that is the difference between the two. We compare this to the attributable cost estimated from a previously published methodology based on the fraction of attributable risk (FAR) associated with the rainfall event (Frame et al. 2020). We also consider how climate change will contribute to changing the cost of the same flood over the next 30 years.

Results

The results of this analysis are not yet fully complete for the Buller flood. Instead, we present here flood maps estimated by applying these methods to the Waikanae flood of January 2005 as indicative of the effect climate change can have on increasing flood depth and extent. (Figure 1)

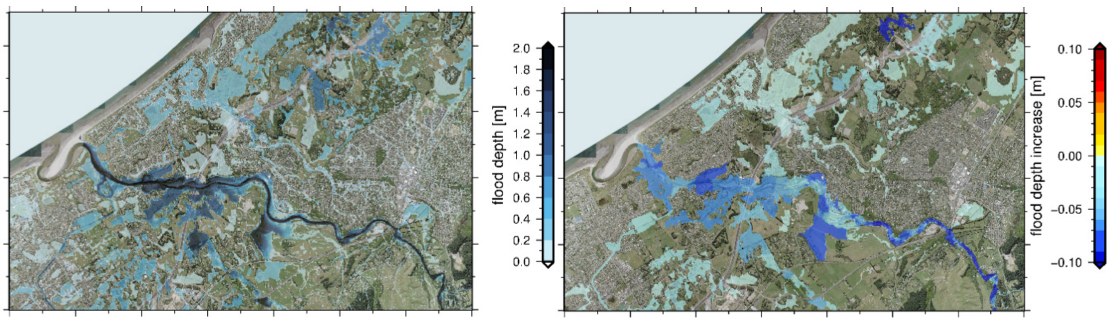

Figure 1. Flood depth predicted by the BG-FLOOD model when using observed rainfall as input (a) and the difference in flood depth when using counterfactual rainfall, where the effect of climate change has been removed (2).

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DERIVING TRANSMISSION LOSSES FROM EPHEMERAL RIVERS USING SATELLITE IMAGERY AND MACHINE LEARNING

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Aims
Transmission losses are the loss in the flow volume of a river as water moves downstream. These losses provide crucial ecosystem services, including groundwater recharge, particularly in ephemeral and intermittent river systems. We present a novel framework to quantify transmission losses in ephemeral rivers from satellite imagery and reconstruct their hourly time series using machine learning.

Method
Transmission losses can be quantified at many scales using different measurement techniques. One of the most common methods is differential gauging of river flow at two locations. However, differential flow gauging is labour-intensive, especially to gather high time resolution data. An alternative method for ephemeral rivers is to replace the downstream gauging location by visual assessments of the wetted river length on satellite images. We used this approach to estimate the transmission losses in the Selwyn River (Canterbury, New Zealand) using 147 satellite images collected between March 2020 and May 2021. The location of the river drying front was verified in the field on 5 occasions and seven differential gauging campaigns were conducted to ground-truth the losses estimated from the satellite images. The transmission loss point data obtained using the wetted river lengths and differential gauging campaigns were used to train an ensemble of random forest models to reconstruct the hourly time series of transmission losses and their uncertainties.

Results
Our framework proved to be an efficient approach to quantify transmission losses from ephemeral rivers. The method has the advantage of requiring less fieldwork and generating more data than traditional methods like differential flow gauging, at a similar accuracy. Our results show that the Selwyn river transmission losses ranged between 0.25 and 0.65 m3/s/km during most of the 1-year study period. However, shortly after a flood peak the losses could reach up to 1.5 m3/s/km. Furthermore, studying the relationship between the transmission losses and the river stage/discharge enabled us to improve our understanding of the Selwyn River interactions with groundwater. We believe that the generated transmission loss time series provide a valuable dataset to support further research efforts, especially the development of physically based models. Moreover, the presented framework has the potential to help water management in this catchment and beyond by providing an approach to simulate the transmission losses, groundwater recharge and wetted river length. Our framework is easily transferrable to other ephemeral rivers and can be applied for longer time series. This could provide important information at relatively low cost.

METSOC 50TH ANNIVERSARY ORAL HISTORY PROJECT

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Aims
In early 2021, a subcommittee of the Meteorological Society of New Zealand (MetSoc) was formed to prepare for the 50-year anniversary in 2029 of the foundation of the society. It was resolved that the main thrust of the subcommittee's work should be a collection of interviews with notable members of the society; this work has been given the provisional title of MetSoc 50th Anniversary Oral History Project (MSOHP). This paper discusses the progress of this work so far.

Method
The members of the subcommittee tasked with carrying out the MSOHP are Ciaran Doolin, Sylvia Nichol, Katrina Richards, and Jim Salinger.

In 2021 an email was sent to MetSoc membership describing the project and asking for suggestions of members to be interviewed. There was an enthusiastic response and numerous individuals were suggested as potential subjects. From this feedback the subcommittee compiled a list of potential interviewees, and then endeavoured to arrange these individuals in order of priority. The main concern of the subcommittee is ensuring that the more elderly or unwell individuals are interviewed first – this sense of urgency was reinforced earlier this year when an elderly member that the subcommittee had been in contact with to arrange an interview sadly passed away.

Subcommittee members have been exploring options for training in the methods of oral history. This year Ciaran Doolin and Sylvia Nichol attended the two-day oral history workshop run by National Library of New Zealand. Both found these workshops to be very edifying, and the written resources they obtained have been circulated amongst the subcommittee and are proving useful in guiding the project. Funding for their attendance at the workshop was from the Jack Ilott Oral History Education Operating Fund. It is hoped that the other subcommittee members will be able to attend a workshop soon.

Given the ongoing challenges with the COVID-19 pandemic, the subcommittee has been experimenting with conducting interviews via an online platform like Zoom or Teams. The subcommittee has approval from the committee to purchase quality headsets for interviewees if they do not already possess one, to ensure high-quality sound recording. If an interviewee wishes to proceed face-to-face then recording equipment will be hired from National Library.

Results
Interviews with the first subject began in May 2022. These were conducted via Teams, which served as a test case for conducting interviews remotely. The subcommittee developed the interview questions in advance and sent them to the interviewee, who returned brief written answers which proved very useful in guiding the interview. The interviewer, Ciaran Doolin, spent considerable time researching further biographical information about the interviewee in preparation for the interview. A consent form was prepared for the purposes of the interview, following the recommended format of National Library.

The subcommittee is happy to report that the first interview went without incident: the sound quality was excellent and the content fascinating. There are several other interviews scheduled for the coming months. If the outcome of the first interview is anything to go by, then we can expect many more interesting insights, reflections, and anecdotes to come from those who built MetSoc into the organisation it is today.

DOES THE SOUTHERN HEMISPHERE WESTERLY JET RETURN TO NORMAL UNDER NET-NEGATIVE GHG EMISSIONS?

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Aims

The Southern Hemisphere westerly jet (the jet) is a major feature of tropospheric circulation, with impacts on the New Zealand climate. Over recent decades, stratospheric ozone depletion and increased greenhouse gas forcing have led to a poleward shift and strengthening of the jet1,2. While the ozone hole is expected to recover during the twenty-first century3, future forcing due to greenhouse gases is less certain, depending on the degree to which humanity reduces its emissions in response to climate change. Studies assessing future jet changes have to date utilised moderate-to-high emissions scenarios4 or only tier-1 experiments5, without isolating the greenhouse gas influence. In the event that emissions turn net-negative, and greenhouse gas forcing drops from peak levels, some aspects of the climate system are expected to be quickly reversible, while others exhibit significant hysteresis6,7. Here, we use results from an ensemble of climate models to examine whether the changes to the jet caused by greenhouse gases are reversible on human timescales.

Method

We analysed results from CMIP6-era earth system models participating in ScenarioMIP and Carbon Dioxide Removal MIP8,9. We first assessed SAM index, meridional temperature gradient, jet position, and jet strength in the idealised 1pctCO2-cdr experiment, in which carbon dioxide concentrations are increased at one percent per annum for 140 years, then decreased symmetrically for the following 140. This yielded a signature of greenhouse gas influence under positive then negative emissions. We then applied the same analyses to emissions scenarios with net-negative emissions: SSP1-1.9, SSP1-2.6, SSP4-3.4, and SSP5-3.4-over and looked for this same signature.

Results

Increased carbon dioxide concentrations have a clear impact on the Southern Hemisphere Westerly jet in CMIP6 models, causing a poleward shift and intensification. Under net-negative emissions, these changes exhibit hysteretic behaviour due to inertia in the climate system, but they are largely reversible on decadal timescales. Under more realistic experiments that include changing concentrations of other climate forcing agents, the GHG signal is less apparent but still detectable. Detecting a “return to normal” of the jet in these scenarios is complicated by the confounding influence of stratospheric ozone recovery (which is handled differently by models with and without interactive chemistry10), ozone being the dominant driver of SAM in Austral summer11,12.

These projected, reversed shifts in the jet have implications for New Zealand climate, leading to cooling, wetting, and stronger winds, particularly during summer in the south-west13–15. Extending such model experiments for longer time periods would aid in understanding the conditions necessary for a return to normal of the jet.

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DEVELOPMENT OF CLIMATE INPUTS FOR HYDROLOGICAL MODELS

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Aim
As part of the MBIE-funded Critical Pathways Programme, Lincoln Agritech has developed several sub-catchment scale hydrologicalmodels of the Piako headwaters and Waiotapu catchments. Both of these catchments feature stark gradients in topography. For example, the Piako headwaters range from approximately 500 m elevation to circa 30 m elevation at Kiwitahi. Like most lowly populated areas of New Zealand, few if any climate stations are available to provide climate inputs into hydrological models. Those sites that do existcurrently are either located outside the catchment or at the lowest points within the catchments. While several historical sites have been maintained within the catchments at higher elevations, these are not contemporaneous with our study period. Analysis of historical higherelevation precipitation data and preliminary modelling suggested water balance errors were likely occurring in our study catchments (when using readily available climate datasets) due to orographic effects and incorrect climate inputs. Using climate inputs from publiclyavailable data, our models failed to produce realistic cumulative discharge volumes due to failure to reproduce either peak flows, baseflow or both. Climate inputs that adequately describe spatial and temporal patterns at the local scale are needed to be able to realistically describe flow and nutrient transport in these hydrological models.

Generally, in hydrological models, climate inputs are taken as the "truth". This often means that while many parameters affecting hydrological conditions are optimised for observations, climate inputs are fixed. For small catchment and sub-catchment scale models, those spanning several tens of km2 (Stenger et al. 2019), it may not be possible to fit model outputs to observation data when usingreadily available climate datasets while at the same time using realistic hydrological parameters. The adoption of unrealistic hydrologicalparameters during model optimisation may indicate that the catchment water balance is wrong. Errors in catchment water balance, can, in turn, suggest that the climate inputs for the model are insufficient to describe the actual patterns of precipitation timing and intensity in a catchment. To improve our ability to replicate the catchment water balances we have developed higher resolution climate inputs that realistically describe observable spatial and temporal patterns, with a principal focus on precipitation.

Method
Although several existing datasets provide interpolated climate inputs, these can be either costly to purchase, too coarse in resolution, or both. Further, while in areas of low elevation changes, simple interpolation of climate sites may prove sufficient, we have found that in our two study catchments, orographic effects, not captured in coarse resolution datasets can have significant impacts on the hydrological cycle.

To gain a better understanding of both the spatial and temporal dynamics of the climatic conditions present in our study catchments, wedeployed a number of in-catchment weather stations at a range of elevations across the study sites for approximately two years. Notsurprisingly we identified orographic effects in the precipitation observations that are not captured in the publicly available low elevation weather stations or the coarser resolution interpolated datasets.

Unfortunately, two years' worth of data is insufficient to develop robust hydrological models that adequately describe both flow and transport. To extend our weather station data (precipitation, temperature, RH, wind speed, wind direction and solar radiation) to a length of time useful for hydrological models, we developed a spatiotemporally interpolated dataset using random forest regression models using the packages mice (van Buuren and Groothuis-Oudshoorn, 2011) and caret (Kuhn, 2008) in the interpretive language R. The Rpackage mice has been used to infill temporal gaps in training site records, while caret has been used for spatial interpolation on a dailybasis. Inputs to the random forest models included many publicly available climate and spatial datasets (such as precipitation, solar radiation, catchment discharge, elevation, and spatial coordinates) and used the repeated cross-validation method of splitting the dataset during training.

Results
The regression models that we have developed, produce spatially scalable outputs at a daily timestep for the period 2001 to 2022. Effectively the models enable the prediction of climate variables at any combination of spatial location (x, y, z) and day within thistimeframe. Not surprisingly, the model results show much greater spatial variation in precipitation than the other climate variables, perhapssuggesting

that for studies such as ours, rain gauges may be sufficient. The precipitation results capture both the expected or observed orographic effects (Figure 1) and compare favourably to climate stations excluded from the model development. While the random forest method does not lend itself to extrapolation, e.g. forecasting, it is still useful for hindcast models. Further, when used as climate forcing in our hydrological models we can optimise model outputs using realistic hydrological parameters and can match peaks baseflow and cumulative discharge volumes.

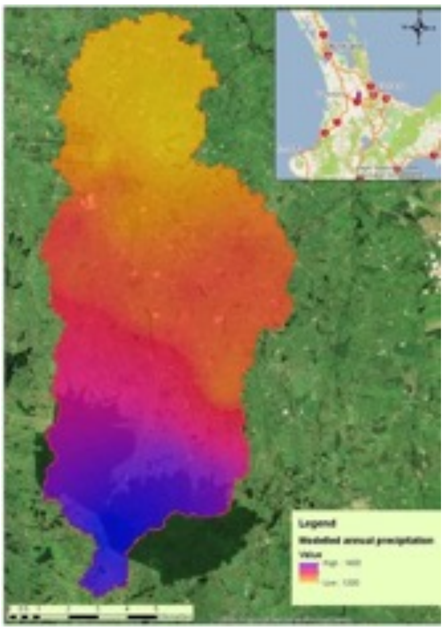

Figure 1 Simulated annual average precipitation

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ENABLING PRIMARY MARINE ORGANIC AEROSOL AS A SOURCE OF ICE NUCLEATING PARTICLES IN THE NZESM

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Aims
The problem that this work aims to address is the shortwave radiation bias over the Southern Ocean (SO). In climate models, the downwelling shortwave radiation at the top of the atmosphere is significantly lower than in observations (IPCC, 2013). This bias has been linked to a deficit in supercooled liquid over the SO in models (Fan et al., 2011).

This deficit in supercooled liquid could be caused by using parameterisations of ice nucleation tuned to northern hemisphere observations, where mineral dust is much more prevalent. In the pristine atmosphere over the SO, however, primary marine organic aerosol (PMOA) is in fact the dominant source of ice nucleating particles (INPs) (Vergara-Temprado et al., 2017; Zhao et al., 2021).

PMOA has recently been implemented in the UK Earth System Model (UKESM1) (Mulcahy et al., 2018), from which the New Zealand Earth System Model (NZESM) is derived. The purpose of this work is to allow PMOA to function as a source of INPs within the NZESM. This will be an extension to earlier work by Varma et al. (2021), which enabled dust particles to function as INPs in the NZESM.

Method
Because the NZESM has no explicit INP functionality, Varma et al. (2021) instead replaced the globally uniform heterogeneous freezing temperature with a three-dimensional distribution that is a function of the dust number density. This increases the freezing temperature for high dust densities, mimicking the function of dust INPs.

A similar approach will be used in this work, but with PMOA. Different parameterisations of INP number density for PMOA exist in the literature, representing PMOA INPs as a function of temperature and total organic carbon mass concentration (Wilson et al., 2015) or temperature and sea spray aerosol mixing ratio (McCluskey et al., 2018). These will be implemented within the NZESM and assessed for their ability to reduce the shortwave radiation bias over the SO.

Results
We will present a review of the available methods for representing PMOA in climate models, a description of the implementation of a selection of these methods in the NZESM, and preliminary results of NZESM simulations including PMOA.

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ARE NITRATE LOSS MITIGATIONS IMPROVING WATER QUALITY? NITRATE LOSS MITIGATION EFFECTIVENESS MONITORING DESIGN FOR GROUNDWATER

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Aims
Aotearoa New Zealand has made and is continuing to make significant investments in planning processes and on-the-ground actions to reduce diffuse nitrate discharges to freshwater bodies. Investment in monitoring systems to evaluate the effectiveness of this investment has been limited to date.

Existing freshwater monitoring networks, in New Zealand and overseas, are designed to yield information on the state and trend of freshwater but are not designed, and have often proven ill-suited to, robustly establishing cause-effect relationships between improvement actions (e.g., on-farm nitrate loss mitigations) and their effect (e.g., reduced contaminant loads in spring-fed streams).

Time lags, attenuation and other uncertainties and complexities that may vary across different components of freshwater systems (e.g., shallow groundwater, rivers, lakes) make the measurement of freshwater improvement challenging. As a result, we often have limited evidence to determine the extent to which specific policies or land management actions result in improvements in the aquifer, river or lake quality. Unless we change how we monitor freshwater, we will not be able to report robustly on the actual benefits of the vast amount of effort and resources we are currently investing in freshwater quality management.

The aim of the overall Our Land and Water Mitigation Effectiveness Monitoring Design programme is to develop a methodology and applications which help end-users (i.e., all groups involved in freshwater improvement actions, including councils, iwi, co-governance entities and catchment groups) to robustly monitor the effectiveness of land mitigation and land management actions in improving the health of our freshwater bodies.

This paper presents the methodology we have developed to build a groundwater quality monitoring network design tool, which is one element of the broader programme. The purpose of the tool is to evaluate the power of a given monitoring network to detect whether nitrate loss mitigations have resulted in lower groundwater nitrate concentrations at a user-defined level of statistical confidence.

Methods
The following variables are key for nitrate mitigation effectiveness monitoring design:

- Temporal variability in nitrate concentrations
- Spatial variability in nitrate leaching loads and concentrations
- Lag times between land use mitigations and detectable arrival at the measurement point
- Flow paths between nitrate source areas and freshwater receptors and compliance monitoring points

Statistical power analysis is used to determine the sampling frequency and duration required to detect a given reduction in nitrate inputs (e.g. 15%) to a hydrological system based on temporal variability in nitrate concentrations.

The spatial variability of nitrate leaching rates is a key variable in determination of the spatial density of groundwater monitoring points required to obtain a representative sample for a given level of statistical confidence. We evaluated the spatial variability in nitrate leaching rates associated with soil and land use variability via analysis of modelled nitrate leaching layers and the integrating effects of groundwater monitoring wells under pumped and un-pumped sampling conditions. We also evaluated the spatial variability in nitrate leaching rates for a given land use (e.g. Dairy Farm) and explored the effects of soil mapping resolution on inferred sampling density requirements.

A set of lag time typologies were developed through statistical analysis of regional groundwater age tracer databases to generate the time lag input to the monitoring duration evaluation tool.

A groundwater flow path mapping tool is being developed to estimate flow paths between nitrate sources and receptors/nitrate limit monitoring sites. Version 1 of the tool uses data generated by the National Water Table model (Westerhoff et al, 2019) for flow path mapping coupled with geometric monitoring well recharge areas and spatial and temporal nitrate variability data to explore the extent to which a user-defined monitoring network meets the monitoring goals (e.g., detect effectiveness of nitrate mitigations within 10 years with 80% confidence). Version 2 of the tool will incorporate locally generated flow path data (e.g., groundwater model outputs, groundwater contours derived from piezometric surveys) to incorporate best local information into the tool.

The tool development will be completed in 2023.

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CLIMATE-SHOCK RESILIENCE AND ADAPTATION: INCORPORATING CLIMATE RISK IN WATER MANAGEMENT DECISION MAKING

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Aims

Climate change has increased the frequency and severity of extreme weather events such as droughts and floods and this will worsen as greenhouse gas discharges to our atmosphere continue.

Having been historically 'water-rich', New Zealand is not well-prepared to cope with a future that will involve more drought and higher soil moisture deficits in some areas (Hendy et al., 2018). For example, much of the irrigated area is still operated on a run-of-river basis, a model extremely vulnerable to drought, particularly given growing environmental obligations and the associated increase in low flow water take restrictions.

Proactive near-term risk management and adaptation to climate change requires better knowledge of the risk associated with multiple extreme events to occur within a compressed period over the next 10 years. The 10-year time horizon is important both to identify near-term adaptation actions and to highlight the urgency of adaptation. The likelihood of adaption actions being implemented based on climate change projections several decades into the future is significantly reduced by the social discount rate (how much values decline as we look to the future) [Walsh, 2019].

The aim of this project is to test two hypotheses:

- The compounding effects of increasingly frequent and severe weather events on farm financial resilience in a changing climate will, over time, cause a significant adverse impact upon primary sector productivity and the rural economy. The risk of these impacts can be reduced by identifying vulnerability and resilience factors and providing adaptation guidance for farming systems and their financial management.

1. The incorporation of information on the impacts of climate change-amplified adverse events on the natural environment and primary sector economy into a water allocation decision-making process would change the outcome. Decision-making tipping points will be encountered at which the severity of cumulative primary sector impacts changes the relative values society and decision makers place upon in-stream values and the primary sector economy. Identification of key indicators for the tipping points could be used to develop an adaptive allocation framework which optimises the balance between primary sector resilience and protection of environmental and cultural values.

This paper presents the methodology for our research in relation to Hypothesis 2.

Methods

The main components of our methodology, which were developed for a north Canterbury case study area, were:

1. Determine types and scales of climate and river flow events that cause significant primary sector impacts via a farmer workshop. The identified events are referred to as Noteworthy Events.
2. Detrend the historic daily flow record from a representative alpine river for the case study area (the Waimakariri River).
3. Generate a large suite of 10-year climate and river flow time series data sequences which include Noteworthy Events. These sequences are referred to as Storylines.
4. Build climate probability tool (referred to as the Infinite Improbability Drive) to estimate the probability of every climate Storyline under present day climate conditions.
5. Build Stochastic Weather Generator to create a realistic set of weather data realisations for any given Storyline.
6. Modify and extend the BASGRA pasture growth model to generate pasture growth time series data for every Storyline.
7. Develop a habitat-based stream health model.
8. Develop a farm and rural economy health model.
9. Evaluate primary sector climate change adaptation and resilience options and incorporate options into farm and rural economy health model.
10. Input pasture growth and river flow time series Storyline data into the stream health model and the farm and rural economy health model respectively using a standard set of water take limits (derived using typical approaches which ignore climate change).
11. Apply a range of Environmental Flow Regime options to the river flow storylines and generate associated pasture growth time series for run-of-river irrigated land.
12. Use a Multi criteria decision analysis (MCDA) method to generate an aggregated score for each Storyline under the range of Environmental Flow Regime options.
13. Undertake sensitivity analysis for MCDA scoring system inputs
14. Define optimal Environmental Flow Regime for a combined suite of Storylines reflecting a range of probabilities, with and without farm adaptation and resilience options, based on MCDA scores.
15. Use results to evaluate research hypothesis 2.

Implementation of the methodology will be completed and the full results of this research published in October 2022.

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INVESTIGATION INTO THE SOURCES OF VARIABILITY IN INTENSE RAINFALL AND FLASH FLOODS IN THE SOUTH WEST OF THE UK

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Aims

Europe as a whole is undergoing a period of greater flood frequency 'flood rich period' (Wilby et al., 2008), yet there is historical evidence of a much greater flood frequency in the past. Flash floods occur locally due to atmospheric instabilities and convective circulation which result in high-intensity short duration rainfall (Marchi et al., 2010). Due to the rapidity with which they occur, the hazards and dangers to life from flash floods can be greater than floods of longer duration because warnings cannot always be issued as evidenced recently in central Europe.

Across the UK and particularly in the South West flow and river gauging records started in the mid to late 1900s, so flood events in the past have not been recorded. Using historical records of flood events provides essential information on the frequency and severity of the high intensity extreme rainfall events which led to floods (Williams and Archer, 2002). This study is based on an extensive and innovative database of historical flash floods in the South West of the UK compiled by D. Archer from newspaper records, BHS Chronology of British Hydrological Events (CBHE) and British rainfall records. The Archer database (Archer, 2016) includes flood events from 1286 until 2012, providing a wealth of data on historical floods which allows the recent flash flood events to be put in historical context.

Methods

The project makes use of a database of historical chronologies of floods in the South West of the UK compiled by David Archer from newspaper records and archives. The database includes floods from 1630 to 2012, with descriptions of their location, severity, impact and associated weather data.

Using this unique historical chronology of flash floods in Devon and Cornwall since the 13th century, a multivariate investigation was conducted. Datasets of UK synoptic atmospheric conditions were obtained, notably the Lamb Weather Type dataset and the Central England Temperature dataset. Additional coarse resolution data was obtained on the North Atlantic Oscillation (NAO), the Atlantic Multidecadal Oscillation (AMO), the East Atlantic Index (EA), the Polar Index (Polar) and the Scandinavian Index (SCA). Localised precipitation data was obtained for the South West of the UK, as well as local Sea Surface Temperature (SST) data for the South of the UK.

Four of the largest and most damaging flood events in Devon and Cornwall were analysed in greater detail to assess any atmospheric conditions which led to their formation. The database of flash floods was analysed spatially to assess the vulnerability of certain locations to repeated flood events in the past few centuries, some towns suffering from more than 24 flooding events since 1770.

Results

The daily airmass flow direction parameter from the UK Synoptic Atmospheric Dataset was found to be different for convective and non-convective flood events as identified in the record by instances of thunder and lightning. The overall airmass flow direction on convective flood events was found to be Easterly, contrasting to reference periods which had an overall Westerly flow direction.

On monthly scales the summer convective flood count in any month was found to be modelled by a multivariate Poisson regression of AMO (one-unit increase in AMO was found to increase the monthly flood count by 2.19) and localised SSTs (one-degree increase in SST was found to increase the monthly flood count by 1.15). A principal components analysis was conducted on average summer conditions and the first component was found to explain the difference between the AMO and SST compared to the NAO.

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PREDICTING NATURALIZED CATCHMENT CONDITIONS USING ENSEMBLE MACHINE LEARING TO INFORM OTAGO'S LAND AND WATER PLAN

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Aim

The Otago Regional Council has the aim to develop a new Land and Water Plan (LWRP) giving effect to the 2020 New Zealand National Policy Statement for Freshwater Management. A key component of this aim is to set default limits on water quantity for Otago streams of Strahler order 3 or greater. The objective of this study is to generate estimates and uncertainties of hydrological statistics using and comparing different ensemble machine learning methods. Our presentation will the compare supervised ensemble machine learning workflow used in determining default catchment minimum flows and default minimum allocation rates for assisting in managing water resources sustainably and make informed decisions for preparing the LWRP.

Method

To inform the LWRP, we use a two-step approach involving machine learning and limit setting. Two supervised ensemble machine learning methods are evaluated for this purpose: the Random Forest Regressor (Breiman, 2001) and the Gradient Boosting Regressor (Hastie et al., 2009) available from the Scikit-Learn toolbox (Pedregosa et al., 2022). Both ensemble machine learning algorithms require feature aggregation (populate data cube with mutually informative catchment characteristics), feature selection (identify mutually informative features based on the application of learn heuristics), feature prediction (randomly shuffling and splitting the aggregated features with 80% used for training and 20 % for independent testing) and estimating hydrological statistics at catchment locations across the Otago region (figure 1). Primary challenges in aggregating features included identifying gauging stations with suitable periods of record (e.g., spanning a minimum of 5 years with at least 11 months of daily time series) and are not affected by engineering projects (e.g., dams, diversions, or substantial abstractions). Catchment characteristics were available from the FWENZ (Freshwater Environments of New Zealand; Leathwick et al. 2011) database describing various characteristics of the catchment upstream of each gauging station (e.g., annual potential evapotranspiration of catchment, catchment rain days greater than 10 mm/month, coefficient of variation of annual catchment rainfall, percent annual runoff volume from catchment area with slope > 30° percent, average elevation in the upstream catchment, catchment average particle size, catchment average slope, and catchment area).

Limits setting is undertaken differently for mean flows less than or equal or greater than to 5 m3/s. For mean flows less than or equal 5 m3/s the default minimum flow is assigned as 90% of the naturalized 7-day MALF with the allocation rate assigned as 20 % of the naturalized 7-day MALF, whereas mean flows greater than 5 m3/s are assigned as 80% of the naturalized 7-day MALF with the allocation rate assigned as 30 % of the naturalized 7-day MALF. If after subtracting the catchment abstraction from the default allocation rate results in a negative value, then the catchment is designated as over-allocated and if the result is a positive value the catchment is designated as under-allocated. We calculate and compare these conditions based on models with no hyperparameter tuning and hyperparameter tuned models. In addition, we compute quantile models associate with the Gradient Boosting Regressor to evaluate the likelihood for default allocation conditions given decile conditions.

Results

Independent testing of the Random Forest Regressor and Gradient Boosting Regressor models demonstrated generalizability of each method supporting their usefulness as predictors of naturalized catchment Mean and MALF across the Otago region (Figure 2). Also, three untuned quantile GBR models were developed providing hydrological prediction uncertainty in the Mean and MALF at 10, 50, and 90th percentiles, and nine tuned quantile models providing hydrological prediction uncertainty at 10, 20, 30, 40, 50, 60, 70, 80, and 90th percentiles (table 1). This information was used to compute likely default minimum flow and primary allocation limits, expressed as % of naturalized 7-day mean annual low flow, for maintaining flow regimes that present a low risk of more than minor effects on ecosystem health, including their instream habitat, species and their interrelationships, and fisheries economic values. Lastly, these quantiles were used together with total catchment abstractions to determine the likelihood of limit setting on over/under catchment allocation for future policy decisions.

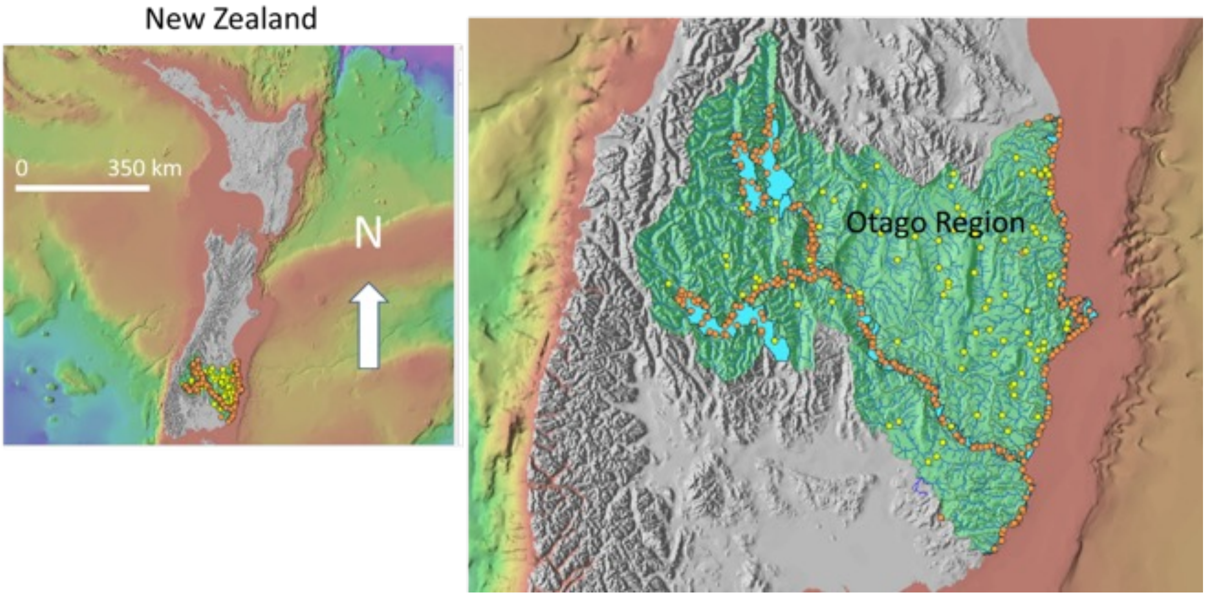

Figure 1: Otago catchment gauge locations used in training and testing the ensemble machine learning methods. Yellow dots are catchment training sites and orange dots are catchment prediction sites.

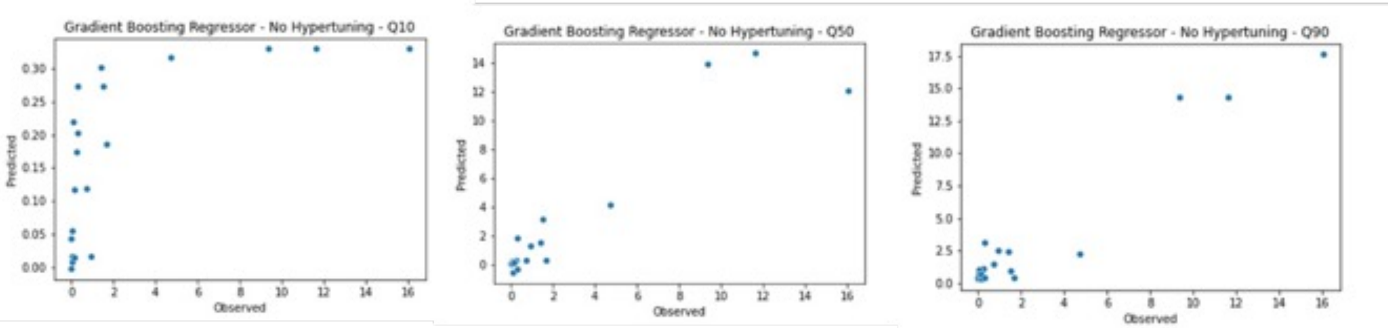

Figure 2: Independent testing of the untuned Gradient Boosting Regressor method. Quantile models for 7-day Mean Annual Low Flow following single random subset: 10th percentile (Q10): training score: -0.09, test score: -0.23 (poor), 50th percentile (Q50): training score: 0.99, test score: 0.85 (very good), and 90th percentile (Q90), training score: 0.96, test score: 0.91 (excellent). One to one correspondence reveals unbiased predictions with respect to the observations.

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BETTER CHARACTERIZATION OF ALLUVIAL AQUIFERS BY ASSIMILATING HELICOPTER ELECTROMAGNETIC AND BORE INFORMATION USING MACHINE LEARNING

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Aims

In accordance with the National Policy Statement for Freshwater Management 2020 (NPS-FM), the Otago Regional Council (ORC) is preparing to draft new Land and Water Regional Plan (LWRP). The LWRP will give effect to the requirements of the NPS-FM and other relevant national and regional legislations. A key component of this plan will be to set limits on water quantity for meeting NPS-FM requirements. To meet this challenge in the groundwater realm, we develop and apply a helicopter electromagnetic machine learning workflow for transdisciplinary characterization of alluvial aquifer systems and informed sustainable groundwater and ecosystem management. Transdisciplinary interpretation is defined as interpreting shared meaning among different geophysical and groundwater modalities by forming a single interdependent data product. In this study, examples of geophysical modalities include electrical conductivity, whereas hydrogeophysical modalities include hydraulic conductivity, lithology, aqueous chemistry, redox and others. Our objective is to use multimodal machine learning (MML) to assimilate mutual information in hydrogeophysical modalities for simultaneous subsurface characterization and mapping of all alluvial aquifer system features and their uncertainty.

Method

The MML workflow involves four steps: feature aggregation, feature selection, feature prediction, and feature clustering. Feature aggregation involves populating a data cube with mutually informative observations. Feature selection involves identifying mutually informative features based on the application of learn heuristics, Feature prediction involves randomly shuffling and splitting the aggregated features (for example, 80% for training and 20 % for testing) and predicting at locations using a competitive learning algorithm. Lastly, feature clustering involves grouping statistically meaningful features across the MML network to identify hydrogeophysical units (HGUs).

Results

Two regional case studies are presented in which the traditional (interdisciplinary) geophysical exploration approach is compared to results obtained using the MML (transdisciplinary) approach In the first study, the traditional approach relies on inverted Glass Earth layer resistivity models to subjectively identify groundwater prospects in the Ida Valley (Wilson and Rekker, 2012). Application of the MML highlights differences in interdisciplinary application at the Moa bore on the western side of the Ida Valley to the transdisciplinary application at the C-2017 bore on the eastern side of the Ida Valley. For example, using the interdisciplinary approach is limited to identifying highly resistive locations assumed to be coarse water bearing sediment in apparent resistivity slices to a maximum of 30 m. Of the 5 bores drilled only the moa site produced water. In the Moa case, the eastern half of the valley was not previously considered a groundwater target because of the low resistivity from the surface to maximum depth of 30 m. In fact, the transdisciplinary interpretation extends the utility of resistivity data to estimate subsurface lithological properties (gravel, sand, silt, clay, bedrock) and depth to aquitards and aquifers (Figure 1). At this location, the aquitard comprises silt and clay that extends from the surface to a depth of about 110 m where it transitions to a gravel-sand aquifer to 140 m below which is bedrock. Similarly, the MML approach assimilates information in hydrogeophysical properties and simultaneously predict alluvial aquifer properties and their uncertainty to depths of 160 m across the Ida, Pisa, Manuherikia, Maniototo, and Strath Taieri catchments. We also demonstrate the ability of the proposed approach to identify sets of stochastic hydrogeophysical units (also called HGUs) characterizing for which we present average HGUs across the Otago region (Figure 2). Each hydrogeophysical unit is uniquely described by a set of statistics for properties that include resistivity, lithology (e.g., gravel, sand, silt, clay, bedrock fractions), hydraulic properties (e.g., hydraulic conductivity and water levels), system components (e.g., aquifer and aquitard), aquifer chemistry (e.g., specific conductivity, O2, temperature, pH, Br, Cl, NO3, etc.). This set of HGUs provides a conceptual subsurface model that includes a full set of stochastic properties at each prediction location in bores across Otago. We extract average HGU values and present regional distribution of average clay, bedrock, hydraulic conductivity, water level, and nitrate concentration to depths of 160 m across the Otago region. Because the new approach introduces HEM measurements as part of the model, the presentation of other independent sounding data to the model predicts all features simultaneously. Whereas this model is trained on local information for predicting alluvial aquifer characteristics across Otago, the model can readily assimilate information from hydrogeophysical features from other regions thereby extending predictions across multiple regions and/or New Zealand.

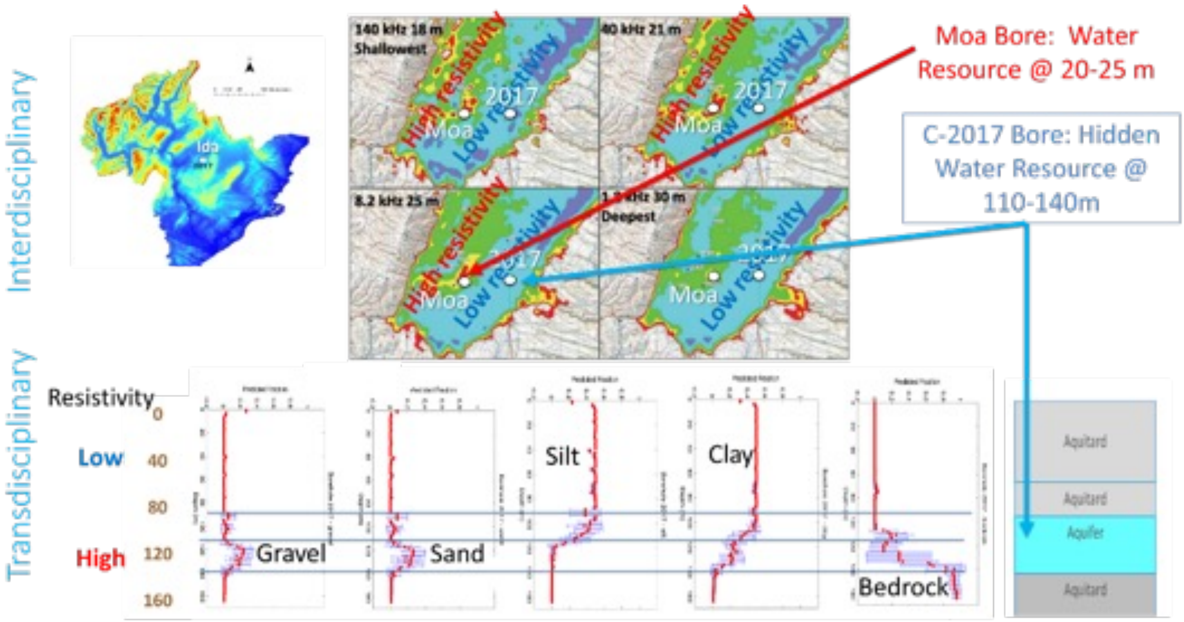
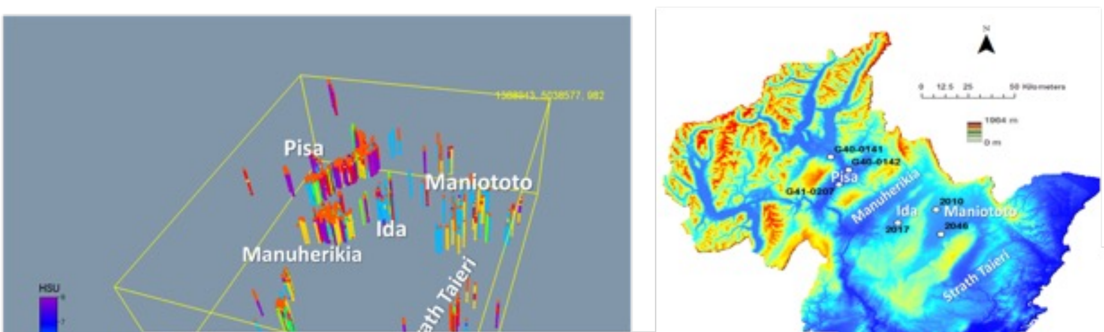


Figure 1: Comparison of traditional interdisciplinary (upper) and transdisciplinary (lower) aquifer results at Ida Valley, Otago NZ. See following figures for other outcomes available as part of the transdisciplinary results.



Hydro-stratigraphic Unit (HSU)	N	Resistivity, ohm-m	Gravel	Sand	Silt	Clay	Bedrock	Ks, m/d	aquifer	aquitard
1	27616	5570	0.72	0.22	0.01	0.04	0.02	126.88	0.94	0.04
2	16703	752	0.64	0.15	0.01	0.20	0.00	232.15	0.79	0.21
3	39168	3533	0.05	0.10	0.19	0.65	0.00	58.82	0.15	0.85
4	4689	154	0.22	0.20	0.00	0.53	0.05	1.68	0.41	0.53
5	7388	250	0.22	0.04	0.00	0.67	0.07	0.05	0.26	0.67
6	21955	2699	0.04	0.06	0.17	0.49	0.24	53.20	0.10	0.66
7	1477	223	0.05	0.31	0.00	0.00	0.64	5.17	0.36	0.64
8	33059	43895	0.01	0.00	0.00	0.00	0.99	0.05	0.01	0.99

Figure 2: Regional distribution of predicted average hydrogeophysical units (HGUs), Otago, NZ.

Acknowledgement

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DYNAMICAL DOWNSCALING OF CMIP6 CLIMATE MODELS: EXPERIMENTAL DESIGN AND HISTORICAL EVALUATION

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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 where 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 experimental design of the ensemble is presented, consisting 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 are also 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.

A preliminary model evaluation is presented targeting the first complete historical simulations from the regional ensemble. We explore several “added value” evaluation metrics to quantify the extent to which the downscaled simulations improve on the raw output from the host GCM, assessed relative to observational products. Significant added value is demonstrated for a range of variables, in both the mean and extremes of the distribution. The enhanced spatial resolution and updated model configuration/physics used in this round of dynamical downscaling require significant computational investment. In total this exceeds 10 million CPU core hours of computation, approximately an order of magnitude larger than that used in NIWA’s previous round of dynamical downscaling for CMIP5.

NARRATIVES, SOURCES OF KNOWLEDGE, CULTURES, AND INTENTIONALITY: IMPACTS ON NATURAL RESOURCES, HAZARDS, AND ENVIRONMENTS

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Context
Choices, decisions, and actions relevant to the science, management, and policy of complex systems and issues involves much more than the matters of fact investigated by hydrologists and other disciplinary scientists. This presentation explores some of the issues that affect the use of scientific facts in decision making, and that may also influence choices made in the conduct of science.

Community perceptions
Socio-cultural processes, interactions with nature, community histories and habits, legacies of place or of experiences, reflect and affect community perceptions (1) of the value of ecosystem services (material and non-material services) and (2) of ecosystem risks and hazards. These community perceptions strongly influence behaviors and policy and management decisions across scales of governance (from the individual to the group and beyond). They impact how natural resources, hazards, and environmental issues are managed or addressed. These perceptions may be relatively unconscious or more explicit; they are shaped by existing biases, beliefs, heuristics, and values (BBHV; including social and moral norms; Glynn et al., 2017, 2018; Walker et al., 2018). The perceptions often emerge in the form of transmitted narrative expressions and behaviors (Helgeson et al., 2022).

Different sources of knowledges
The perceptions (and ensuing decisions and actions) are also shaped by the interplay and differential acquisition of different sources of knowledge (conscious or innate), an interplay modulated by social and biophysical contexts and by a wide diversity of valuation processes (Glynn et al., 2022a, 2022b). Knowledge and values may be recently socially transmitted through recent interpersonal interactions, or may be the result of more permanent (slower-changing) shared sources of knowledge and values: examples include culturally embedded knowledge, place-based knowledge, or boundary-object forms of knowledge such as scientific knowledge. For individuals and over shorter time periods, knowledge and value may also develop tacitly, from repeated experience. Different groups and communities hold differing perceptions and valuations, that can complement and/or confound scientific information and knowledge. When conflict arises, it may (or may not) resolve through adaptive governance processes, or through changes in how the community or group weights different knowledge and values.

Findings
We present thought examples and findings based on our experiences and case studies from New Zealand, Germany, and the USA. To wit, Figure 1 below shows the thought processes, sources of knowledge, and decisions that might be taken by a town manager or a resident of a town when confronted with a possible need to evacuate the town due to an impending hurricane. More generally, we suggest that having a greater understanding and a framework for thinking about the sources of knowledge, BBHV and norms, inherently adopted by communities and individuals – and their timescales of change – is important for improving how societies address natural resource, hazards, and environmental issues.

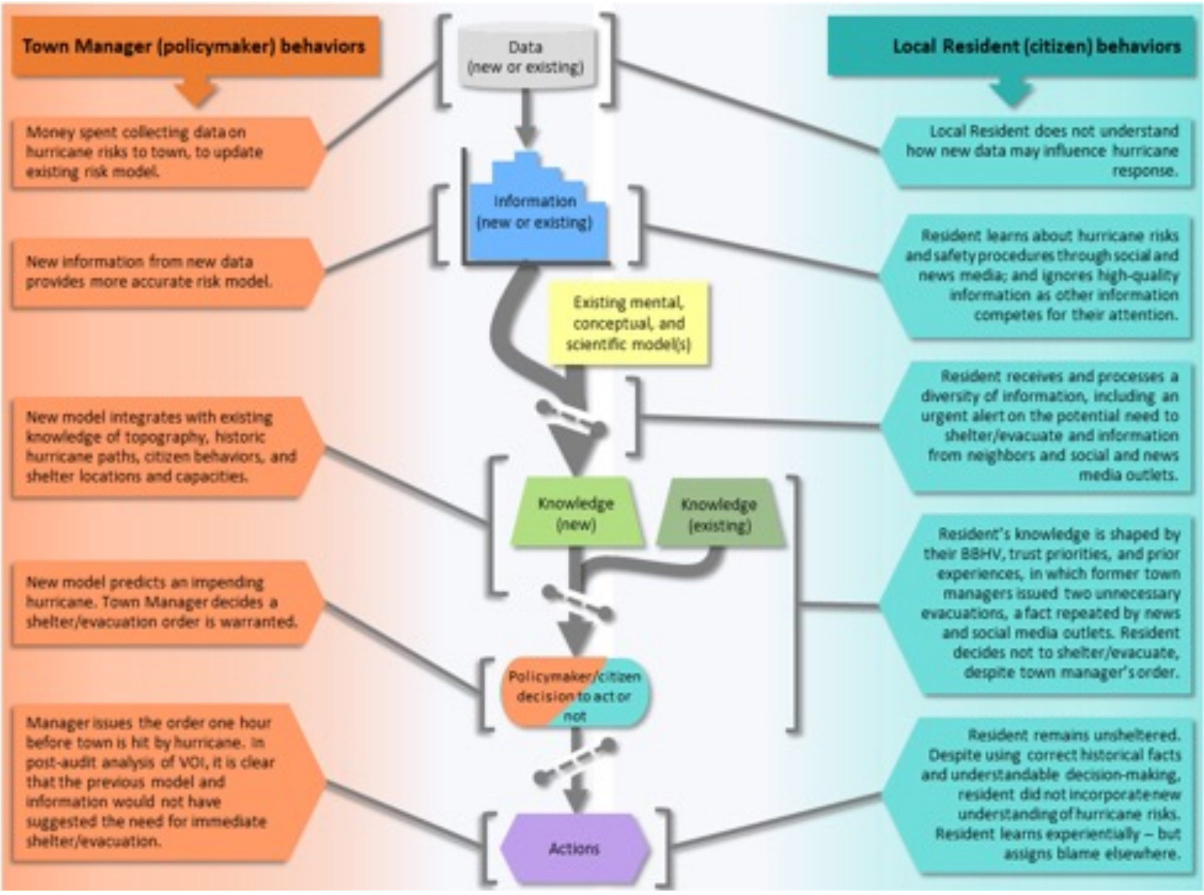

Figure 1: Differences in DDP perceptions and decision making for two different actors – a town manager and a local resident – confronted with different knowledge sources, and different roles and decisions, relating to a well perceived hazard, a hurricane in this example (from Glynn et al., 2022b).

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ETEOROLOGY AND THE POST QUAKE FARMING PROJECT

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Abstract
The Post Quake Farming Project is a programme undertaken by several research entities to support the recovery of farming businesses and future land use decisions in the area of North Canterbury affected by the 2016 Kaikoura earthquakes. The programme is jointly funded by MPI through the Earthquake Recovery Fund, with significant contributions from Beef+Lamb NZ, Environment Canterbury and NIWA.

NIWA's role was to install a meteorological station at 12 farms within the affected area; the basic aim is to identify microclimate areas on the farms that may allow diversification from mainly sheep and cattle farming into possible horticultural crops. Plant & Food Research carried out an intensive study aimed at identifying changes in soil types over each farm.

The stations were installed in late June/early July this year with a plan for them to be on site for at lest 5 years. Data is transmitted via Neon to our Aquarius data base and each farmer can log-in through a webportal to view up-to-date data in numeric or graphical form.

This talk will describe the initial data collected to date and comment on various climate features showing up in the data.

Map view indicating the meteorological station sites.

MODEL BIAS CORRECTION TO ASSESS IMPACT OF CLIMATE CHANGE ON FUTURE HYDROPOWER CAPACITY

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Aim
With the shift to 100% renewable energy in Aotearoa-New Zealand, there is increasing interest in the capacity and variability of hydro-power generation under future climate change. This research aimed to model the present and future hydro-power generation capacity of New Zealand using the TopNet surface water module (Clark et al 2008) and snow model (Clark et al 2011) from the New Zealand Water Model (NZWaM).

Method
Observed hydropower generation capacity data was provided by the Hydrological Modelling Dataset (HMD), referred to as the Power Archive (Electricity Authority 2018a,b). This dataset provided harmonised daily run-of-river hydrological flows and hydropower inflows at 35 locations since January 1932. This dataset represents 12 current and potential future hydropower schemes across New Zealand (a total of 36 stations) with 5 schemes in the North Island (19 stations) and 7 schemes in the South Island (17 stations).

A GCM-specific simple bias correction proceedure was developed for the TopNet surface runoff model represent the hydrological characteristics of the HMD dataset (runof river flows and total natural inflows to hydro-power storage lakes) for the different time scales of interest (weekly, monthly, seasonal, annual). To measure the effect of climate change on the river flows or lake inflows, model simulation data for a baseline period (mid-1986 to mid-2006 (see Figure 1)), were compared with four future time periods: 2021–2041, 2031–2051, 2041–2061, and 2051–2071. Data from six climate models were used to represent future climate change (CESM1-CAM5, GFDL-CM3, GISS-E2-R, BCC-CSM1.1, and NorESM1-M).

Results
Use of precipitation bias correction (based on water balance approach with a snow accumulation and melt threshold adjustment (of up to -2 degrees), improved model ability to generate average conditions (< 5% error for average inflows) but did not improve the ability of the model to simulate the correct timing of the flow regime. However, analysis of the daily average precipitation and inflow indicates that the seasonal pattern of inflows matched that of precipitation. This result was consistent for all the modelled hydro-lake inflows.

Key findings for modelled future hydro-electric generation capacity indicates that:
- North Island annual hydro generation at the low flow 5%'ile (per modelled 20 year periods) may increase by up to 10%.
- South Island annual hydro generation at the low flow 5%'ile is projected to increase by c.16%.
- Future variability of the annual generation 5%'ile in South Island for the 2051–2070 period, was twice that of the hindcast period.

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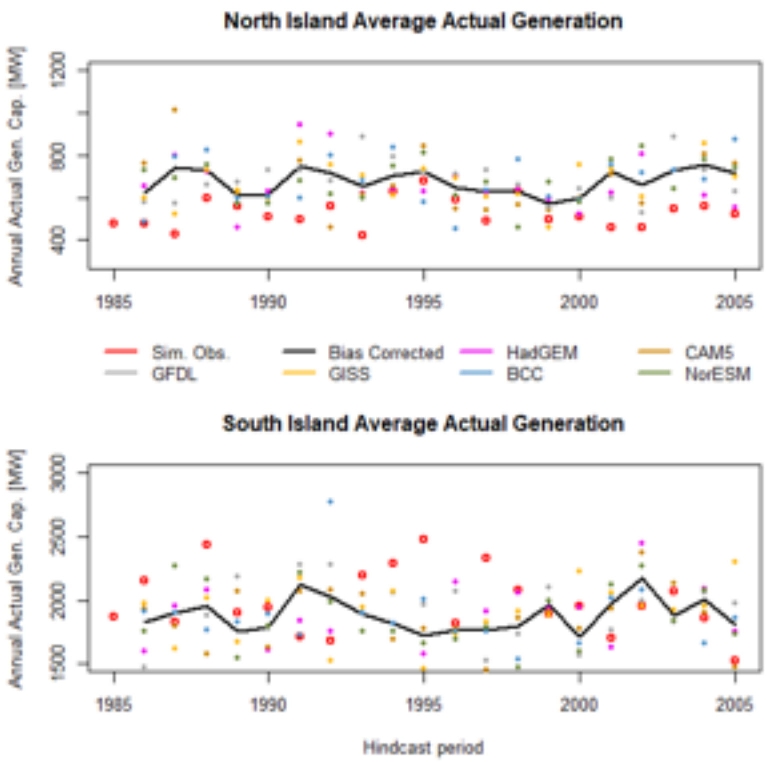

Figure 1: Comparison of simulated annual-average generation between HMD dataset and hindcast bias-corrected CMIP5-driven for 1985-2006.

North Island (top panel) and South Island (bottom panel) plots show: HMD dataset (red circle); TopNet flows driven by HadGEM-ES (magenta), CESM1-CAM5 (black), GFDL-CM3 (grey), GISS-E2-R (gold), BCC-CSM1.1 (blue), and NorESM1-M (dark green). [Actual generation capacity is based on conversion of natural inflows to power generation for the following system: North Island : Waikato-Wharkaremoana, South Island: Cobb-Waitaki-Clutha-Manapouri/Te Anau].

DYNAMIC SEDIMENT TRANSPORT ROUTING MODEL

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Aims

Fine sediment is one of the most pervasive and significant contaminants in aquatic systems, contributing to degradation of both ecosystem health and amenity values. New Zealand's National Policy Statement for Freshwater Management (NPS-FM 2020) requires regional councils and unitary authorities to manage the impacts of sediment on ecosystem health in rivers and downstream receiving environments. Therefore, models are needed that can reliably predict fine sediment and its relevant attributes at different locations within the catchment, and at sufficiently high frequency to define dynamics during flood events.

Sediment routing models will be useful for catchment erosion-sediment management when coupled with dynamic erosion process models to track sediment from upstream sources (e.g., hillslope sources, bank erosion and gullies) through to sinks (or the sea) (Schmitt et al. 2016; Czuba 2018). The aim of this study is to develop a new sediment routing with a capability of modelling fine sediment deposition and re-entrainment at high frequency throughout the river network. These high frequency sediment data may provide valuable information for designing efficient sediment management measures and reduce fine sediment supply to downstream aquatic ecosystems.

Model outline

To route fine sediments with different size fractions throughout the river network, the advection-diffusion relationship describing conservation of sediment mass for suspended particles subjected to diffusion, mixing, dispersion, and advection with point erosion sources is used:

(kg/m2/s) (1)

Where C is sediment concentration (kg/m3), h is water depth (m), q is unit discharge (m2/s), is the time steps (s), is the distance steps (m), E is fine sediment re-entrainment from riverbed (kg/m2/s), D is deposition (kg/m2/s), Kd is the longitudinal dispersion coefficient (m2/s), and i represents the ith sediment size fraction class.

The deposition rate (D) of sediment in size class i can be determined by:

(kg/m2/s) (2)

Where is base to average sediment concentration ratio calculated using the Sediment concentration profile measurements through the water column, v is settling velocity (m/s), and c is Sediment concentration.

The re-entrainment rate (E) for size class i is given by equating the stream power available in a column of water to the power expended to lift the sediment:

(kg/m2/s) (3)

Where F is effective fraction of excess stream power in sediment removal, h is water depth (m), ki is the fraction of water depth through which fine sediment is lifted, is stream power (W/m2), Ωoi Threshold stream power for fine sediment of size class i (W/m2), ρs is sediment density (kg/m3), and ρ is water density (kg/m3).

The output of the routing model is sediment concentration together with the erosion and deposition rate within bins of particle size at high frequency (i.e., 1 hour or less time steps) for the whole river network within a catchment.

Model applications

The conceptual framework of the model in a stationary state (i.e., sediment concentration changes only through time and not space) has been calibrated and validated using data from the Ōreti River at Wallacetown (Haddadchi & Rose 2022). We intend to further develop the model to represent SSC changes through time and space. This improved model will be tested in the Manawatū River located in the lower North Island of New Zealand (Figure 2). Data from eight monitoring sites in the catchment will be used for calibration, including three sites with specific data on several sediment metrics including continuous records of sediment concentration from MWLR's MBIE-funded STEC programme (Davies-Colley et al. 2021). Monitoring sites cover rivers with different sizes from tributaries with stream order 5 (e.g., Pohangina at Mains reach and Makuri at Tuscan Hills) to main-stem river sites of stream order 7 (Manawatū at Teachers College).

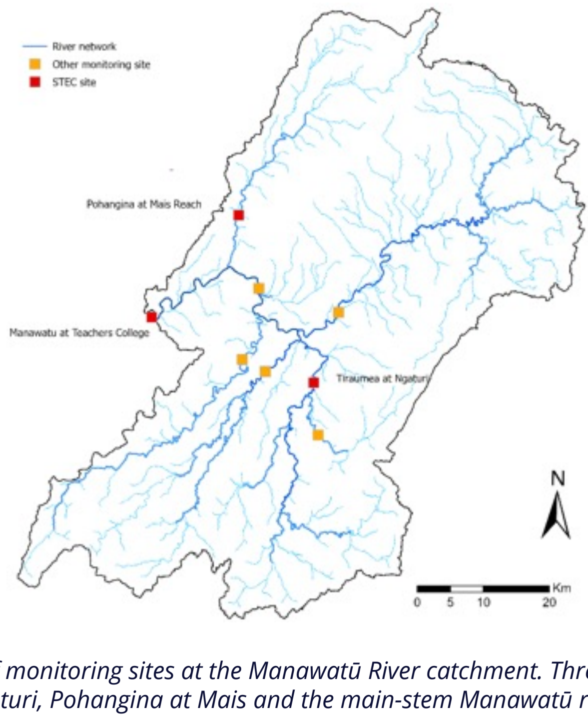

Figure 2. Map showing the location of monitoring sites at the Manawatū River catchment. Three STEC sites which were more intensively sampled: Tiraumea at Ngaturi, Pohangina at Mais and the main-stem Manawatū river at Teachers College.

Impact of fine sediment on rivers can be quantified with the three fine sediment attributes of: suspended sediment concentration, river bed fine sediment deposition, and visual water clarity. The routing model outlined here provides a direct estimate for two attributes of concern: suspended sediment concentration and fine sediment deposition for different particle size classes at any user-defined time frequency during the flood events. Since visual clarity depends on fine sediment concentration and size gradings of sediment (Davies-Colley & Smith 2001), continuous estimates of visual clarity can be determined using a separate sub-model by relating sediment concentration to visual clarity taking particle size class distribution into consideration.

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WAIKATO GROUNDWATER QUALITY AND MANAGEMENT RESPONSE EFFICACY

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Aims

This work characterises groundwater quality in the Waikato region including state and trends. It also describes pressures, implications for use and factors affecting the efficacy of management response.

Method

Monitoring enables changes in groundwater quality state and trends to be identified. It also reflects the efficacy of management of this resource and provides information for future policy development. The state of groundwater quality in the Waikato for the five years to the end of 2020 and trends over an 18-year period from 2003 to 2020 were recently reported (Hadfield, 2022). Information was derived from data collected from a regional network of 110 state of environment (SOE) wells, including 10 wells which are part of the National Groundwater Monitoring Programme. Less frequent data was also collected from a network of 80 'Community' or rural school water supply wells.

Results

Groundwater quality in the Waikato region is highly variable, reflecting the diversity of hydrogeologic settings and hydro-chemical conditions. The impacts of land-use activities are clearly evident and water quality guidelines are commonly exceeded.

Groundwater is extensively used in the Waikato region for purposes including drinking water supply, irrigation, stock water and industry. It also importantly sustains surface water flows and influences its quality. Progressive land-use intensification threatens the quality of groundwater and its long-term sustainable management.

The primary issue in respect to manageable groundwater quality is nitrate contamination. Nitrate commonly exceeds the drinking water guideline, with medians for 2016-20 being over the maximum acceptable value at 11% of the SOE monitoring network sites. The highest concentrations are associated with market gardening and dairy farming activities. These account for all exceedances, except for one point-source location related to effluent from a woolshed. Areas with highest concentrations are the basalt aquifers of Pukekohe and Pukekawa and parts of the alluvial aquifers of the Hauraki Plains and Hamilton Basin. Areas of relatively low intensity land-use activity such as Coromandel Peninsula, by contrast, have noticeably lower nitrate-N concentrations.

Other anthropogenic contaminants of concern include pesticides and emerging organic contaminants (EOCs). Data from 2020 shows pesticides detected at 22.5% of SOE wells with 2.5% exceeding the drinking water guidelines. EOCs were detected at 91% of SOE sites sampled in 2018 and many of these have no guideline values.

Naturally occurring determinands, which are routinely monitored and exceed health guidelines, include arsenic and manganese. Median results exceed maximum acceptable values for arsenic at 5.48% and manganese at 4% of the SOE wells monitored.

Sub-regional differences reflect the varied hydrogeologic settings. Relatively large inter-quartile concentration ranges for bicarbonate, calcium and hardness in the Coromandel and Waipa catchment areas, for example, reflect the presence of some shelly sediments in the former and limestone in the latter. The prevalence of relatively higher sodium, chloride and conductivity in the Coromandel area reflects the coastal influence.

Groundwater quality trends are mixed with rates of change correlated with concentration. Although there are similar numbers of nitrate-N increases and decreases regionally (~31%), the trends vary substantially sub-regionally. Nitrate-N increases predominate in the northern basalt aquifers (~two thirds) along with many other major ions. This contrasts with a similar proportion of decreases (~69%) in nitrate-N and other major ions in the shallow monitoring wells of Hamilton Basin. Other areas are more balanced although there are more increases (37%) than decreases (~22%) in nitrate-N concentration trends in the Hauraki area. Data from the Community supply network indicates that nitrate trends at these wells are predominantly increasing.

Nitrate concentrations decrease with depth. Shallow groundwater may have a range of nitrate concentrations influenced by factors such as land-use and redox conditions. The latter were categorised into aerobic, anaerobic (characterised by nitrate absence), mixed and indeterminate conditions. The mixed category can have high nitrate concentrations while including some anaerobic characteristics, such as notable iron and manganese concentrations. Investigation has shown these often reflect wells screened across both aerobic and anaerobic zones. Wells with indeterminate redox character may have older groundwater or be largely devoid of land-use influences. There are several key determinands, such as nitrate, calcium, magnesium and sulphate, which have higher concentrations in younger groundwaters, particularly the last ~50 years. These increases infer anthropogenic rather than geogenic influences.

There are marked contrasts in the efficacy of groundwater quality management initiatives in the Waikato region (and nationally). Work in the Lake Taupo catchment has been effective in preventing widespread dairy conversion and considerably reducing pressures on water quality. This was predicated by an economic impact assessment based on modelling by Fairgray, McDermott (2001). It indicated that the loss of value resulting from degrading water quality (for example, through losses in the tourism industry) would be large compared to possible gains from land-use intensification. The ability to manage nitrogen at a property scale meant that the ingredients for policy efficacy were readily implemented.

By contrast, the National Policy Statement for Freshwater Management (NPSFM) specifically requires that, for the Pukekohe vegetable growing area, its importance for the domestic supply of vegetables and maintenance of food security for New Zealand must be considered (MfE, 2020). This area coincides with the most degraded groundwater quality in the region. Where declining trends in water quality are evident, this suggests that either policy is not designed to maintain standards (no longer possible under the NPSFM), or that one or more components of policy efficacy are lacking.

An increase in overall cow numbers in the Waikato of 43% from 1.28 M to 1.82 M over the period 1990 to 2019 (Statistics New Zealand, 2021) inevitably increases pressure on the environment. This may variably prevent improvements in water quality despite management intentions and underpinning science. The relative benefits to land users of different activities are often tilted by the presence of external costs (i.e. where the costs of an action’s environmental effects fall on others). Externalities are a key rationale for policy intervention, and policies need to be designed to address this if they are to be economically efficient (Baumol and Oates, 1988). For example, while dairy farming may return higher profits per hectare than forestry, once externalities are taken into account, they are more similar (Monge et al., 2017). Further consideration of the international impacts of, for example, imported animal feed should also be taken into account with respect to climate change. Ultimately the efficacy of water quality management initiatives is dependent not only on robust science information but also economic and social factors.

MODELLING INUNDATION IN AOTEAROA: A NEW TOOL TESTED ON THE BULLER RIVER FLOODING

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[1] National Institute of Water and Atmosphere Research

Aims

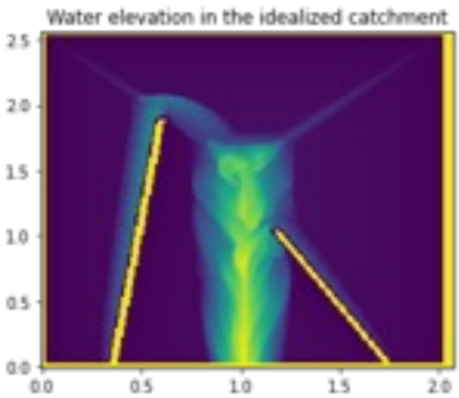
One central objective of the Endeavour project “Ma te haumaru ō te wai: Increasing flood resilience across Aotearoa” is to produce a flood mapping system for the country. This objective requires the development of a large variety of procedures, methodologies, but also new tools. A new GPGPU-enabled numerical shallow water code BG_Flood has been developed. This code will be presented and illustrated on recent floods of the Buller River.

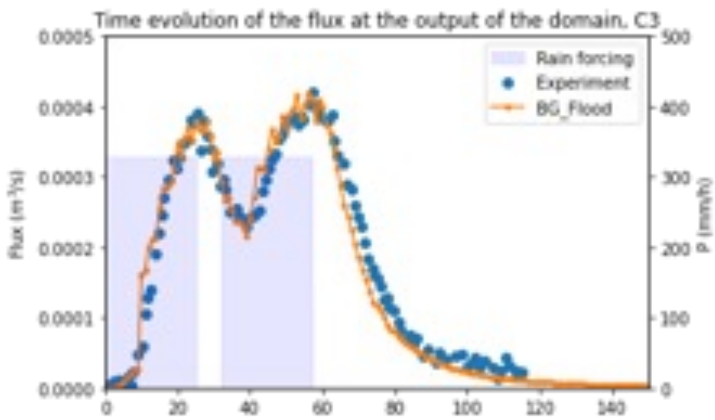
Method

The solver BG_Flood is an open-source GPU-powered software, solving the shallow water equations on complex topography. It allows for a wide range of configuration by enabling multiple forcings relevant to inundation: river discharge, tidal forcing and storm surge, tsunami propagation, and rain on grid. The numerical domain is built up from an adaptative quad-tree mesh which allows for higher resolution where required depending on the forcings (i.e. rain map, discharge input), the topography, area of interest (i.e. populated area) or physic properties (i.e. high velocities). Together with the use of Graphic Processing Units (GPU), it enables efficient modelling of large domains. As part of the national flood maps workflow, a Digital Elevation Model (DEM) and roughness map (of different resolution if needed) is specified from the geofabrics suite, and the model is then driven with time-varying boundary conditions including discharge (i.e. river flow) from TopNet software, a time varying rain map from the design storm process and a downstream water elevation (i.e. tide).

Results

This code has been validated on classic literature experiments. It is now tested as part of the national flood map workflow on the Buller River, located on the West Coast of New Zealand. As the July 2021 as been well documented with flood measurement along the Buller plains, this event is reproduced to validate the code on a river driven inundation configuration. A comparison the flood observation of July 2021 is presented.





This open-source model is available at: https://github.com/CyprienBosserelle/BG_Flood/.

FUTURE CHANGES IN DRY AND WET EXTREMES HIDDEN WITHIN ANNUAL RAINFALL SIGNALS: A NEW ZEALAND CASE STUDY

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[1] Te Aka Mātuatua School of Science, University of Waikato, Hillcrest Road, Hamilton 3216, New Zealand.
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Aim
Understanding how the statistical properties of daily rainfall will respond to a warming climate requires ensembles of climate model data which are much larger than those typically available from existing model experiment frameworks (e.g. the SSP-RCP simulations from CMIP6). These ensemble size constraints often result in regional climate change assessments restricting their focus to annual- or seasonal-mean rainfall projections.

Methods
Here, we make use of multi-thousand member ensembles of regional climate model output from the Weather@ Home project to resolve explicitly how the wettest and driest days of the year over New Zealand will respond to simulations of a +3°C world, relative to a +1°C world (comparable to today's climate).

Results
By developing a novel framework to disentangle changes during the wettest and driest days of the year separately, we show that many regions which show no change in annual mean rainfall are in fact experiencing substantial changes in the amount of rain falling during the wettest and driest spells and these are cancelling each other out in the annual mean. Exploring these changes through the lens of drought risk, we find many agricultural regions in New Zealand will face robust increases in the frequency of low-rainfall extremes in a warmer world.

CO2: A HIDDEN DRIVER OF GLOBAL DECLINES IN FRESHWATER QUALITY?

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Aims
In this talk I discuss the potential for carbon dioxide to have caused historic and ongoing freshwater quality deterioration, primarily through priming of harmful algal blooms (HABs) and pH effects on bacterial communities.

Method
Idealised freshwater quality simulations were performed in PHREEQC 3.0 across atmospheric CO2 of 200 – 400 ppmv. Initial solutions included 1 g L^{-1} HFO (diffuse layer model of Dzombak and Morel (1990)), 1 mg L^{-1} P and 5 mg L^{-1} Fe. Additional boundary conditions (e.g. T) are not explored here, but are expected to amplify CO_2 dissolution (and accompanying pH shifts) in temperate settings (results presented only for 25 °C; 1 atm).

Results
Equilibrium surface water chemistry was modelled based on a range of initial alkalinity values (12.5 to 100 ppm HCO_3^- equivalent) with initial pH = 6, and pe = 4 . Simulations place water in contact with sediment containing hydrous ferric oxide (HFO) and then evaluate the proportion of Fe and P ions attached to the HFO surface via surface complexation reactions.

Preliminary results suggest that seemingly minor changes in pH (0.1 – 0.2 units) can induce small (up to 4%), but potentially non-trivial changes in trace metal (Fe) bioavailability from pre-industrial (280 ppm) to future (500 ppm) CO_2 levels (Figure 1). Changes in metal and P binding by iron oxides can be pronounced due to the steep relationship between HFO surface charge and pH across the adsorption edge (i.e. between pH ~6 and 5) associated with protonation/deprotonation reactions at iron oxide surfaces in sediments. Increases in positive surface charge, in turn, lead to the displacement of adsorbed cation micronutrients (Fe^{2+}, Mn^{2+}, Cu^{2+}, Ni^{2+}, Co^{2+s} etc..), but enhanced retention of orthophosphate (HPO_3^{2-}/$H_2PO_3^{2-}$) and other anions.

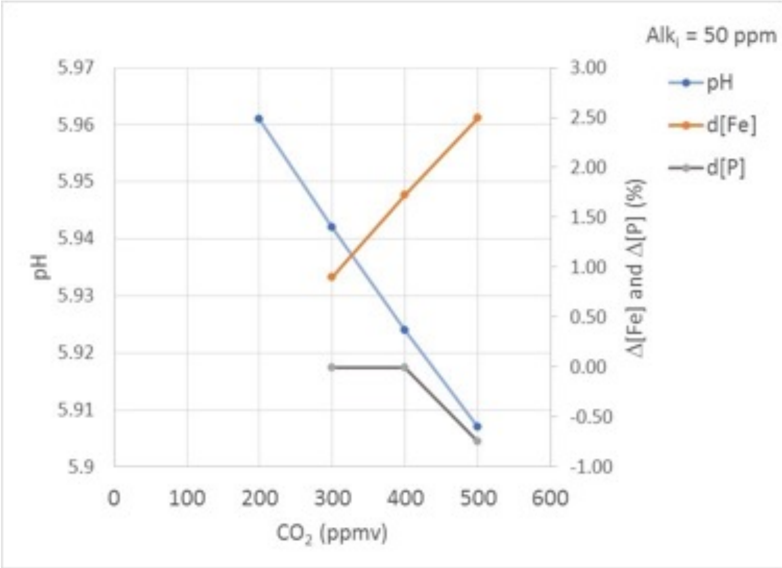

Figure 1 Results of surface complexation modelling of Fe and P adsorption on hydrous ferric oxide (HFO) for an initial alkalinity of 50 ppm HCO3- and atmospheric CO2 values between 200 and 500 ppmv. □ [Fe] and □[P] report the % change in dissolved concentrations relative to pH 6 based only on changes in surface charge.

Additionally, the effect of changing atmospheric CO_2 levels on mineral solubility, while not considered here, represents another potentially major source of Fe and adsorbed nutrients originating from sediments. Initial simulations based on $NaHCO_3$ composition (HCO_3- set at 50 and 25 ppm) showed progressively undersaturated conditions for amorphous iron hydroxide ($Fe(OH)_3$ a) of -0.1 to -0.15 SI units (50 ppm HCO_3- scenario). This indicates a larger and more significant feedback on dissolved Fe concentrations, as well as the accompanying release of previously adsorbed species (such as P). However, the sensitivity of Fe oxide dissolution to atmospheric CO_2 needs to be explored using real-world water chemistry data, due to the effect of bulk water composition on mineral solubility.

Emerging data support a role for Fe in priming cyanobacteria and HABs (Dengg et al., 2022), in addition to known pH effects on microbial community structure (Lauber et al., 2009). Taken together with the emerging data on micronutrients, these results point to a subtle, but potentially measurable impact on primary producers. Vulnerable systems are predicted to consist of mid-to-high latitude and alpine lakes and streams, particularly in regions with low carbonate or groundwater inputs.

Forward modelling of CO_2 and T shifts suggest a further 1-4% increase in dissolved Fe, and a negligible -0.1% decline in dissolved P between atmospheric CO_2 concentrations of 300 to 400 ppm (surface complexation only). While, these results are far from definitive they point to a mechanism for global atmospheric forcing of water quality regardless of proximity to emission sources. Characterising NZ freshwater alkalinity should therefore be a priority for regional authorities aiming to manage nutrient inputs to pristine and mesotrophic water bodies.

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ON SITE WASTEWATER TREATMENT EFFECTS: TRYING TO IMPROVE CERTAINTY IN AN UNCERTAIN WORLD

Ross Hector,[1] **Helen Rutter**[1]
[1] Aqualinc Research Limited

Increased focus on drinking water and protection of drinking water supplies as a result of recent events (Havelock North), has led to a far more conservative approach to assessing new or existing discharges within protection zones (source water risk management areas) for community drinking water supplies. Onsite wastewater treatment systems (septic tanks etc) are examples of such discharges. Uncertainties associated with these systems and the environment they discharge into means that assessment of the impacts of these systems on drinking water supplies is very difficult.

Field assessments, for example test pits, soil texture assessments and groundwater level measurement, may be able to reduce the uncertainty, however field measurements are often not possible or inconclusive, and may not represent the natural variability of the environment.

To be ultra-conservative we would always need to assume the "worst-case" with regard to contaminant transport, thus limiting the activities of landowners. With increased measurement and investigation, we can possibly move away from "worst case" assessments. This presentation will outline the investigations carried out at one site, and the approach to reducing uncertainty, in the situation where an onsite wastewater treatment system was to be installed within a community drinking water protection zone.

We need to continually determine whether there are improvements in the way that we can approach such issues, utilising new science and technologies as they emerge. Underlying any investigation is the need to ensure that human health is not put at risk, but that is balanced against a realistic assessment of the risks.

AN ASSESSMENT OF GEOHAZARDS AT GUNNS CAMP, FIORDLAND, FOLLOWING THE FEBRUARY 2020 STORM EVENT

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Aims

Between February 2 and 4, 2020, a warm northwesterly front brought heavy rain to the wider Fiordland area, with Milford Sound recording over 1,000 mm of rainfall during this 72-hour period. As a result, Gunn's Camp, a popular holiday location in Fiordland National Park, was severely damaged by a debris flow from an upslope gully and flooding from the adjacent Hollyford River (Figure 1). Analysis of local rainfall gauge data suggested the 72-hour rainfall associated with the February 2020 storm corresponded to a greater than 250-year annual recurrence interval (ARI) rainfall event at the site. The camp has remained closed since the storm event, but may be rebuilt or relocated depending on debris flow and flood risks. The aim of this study was to characterize the geohazards associated with the site (debris flow, flooding, and bank erosion), perform a risk assessment for the subject geohazards, and provide potential risk mitigation options to reduce the impact of future events.

Figure 1: Extent of Debris Flow and Bank Erosion after the February 2020 Event (source: https://www.odt.co.nz/regions/fiordland/minister-views-damage)

Method

An in-field assessment was performed including a site walkover, unmanned aerial vehicle (UAV) flyover, and helicopter flyover to observe and map features such as slope gradients, erosional features, depositional features, source materials as well as the general geology and geomorphology. The return period of the February 2020 debris flow was assessed using historical aerial imagery and frequency-magnitude estimation relationships of past debris flow events (Jakob, Holm, & McDougall, 2016). The return period of the flooding and bank erosion was assessed using historical aerial imagery, publicly available web videos recorded during the storm event, and the National Institute of Water and Atmospheric Research's (NIWA's) high intensity rainfall design system (HIRDS).

The risk assessment was performed using a method developed by GNS Science for Department of Conservation (DoC) Backcountry Huts and Camp Sites (Hancox, 2008). This method involved a geological hazard evaluation, qualitative risk assessment following Australian Geotechnical Society guidelines (AGS,2000), and priority rating in relation to all other backcountry huts across New Zealand.

Results

It was found that the debris flow was initiated by a relatively small landslide in the upper reaches of the catchment. It is possible that evacuated material from this failure formed a temporary landslide dam towards the head of the gully. Water impounded behind this small failure was likely released over a short period of time in a dam-breach and, with the large distance of travel along the main channel between the failure catchment area and accumulation area, a large volume of soil was entrained into the debris flow. Flow velocities towards the head of the fan apex appeared to have been very high, before reducing downslope towards the site as the debris flow became non-channelised. Based on the damage evident to some of the structures, velocities may still have been 8 to 10 m/s as the debris flow passed through the northern part of the camp. The debris flow event was estimated to have had a volume between 25,000 and 50,000 m3, a debris height in the vicinity of the camp up to approximately 1.5 m, and an ARI between 100 and 500 years.

It was estimated that the Hollyford River reached a peak flow rate on the order of 500 to 1,000 m3/s during the February 2020 storm event, with a depth of approximately 5 m in the deepest part of the channel and over 1 m in depth above the Gunn's Camp floodplain. The average flow velocity appeared to be on the order of 3 m/s in the middle of the channel, and less than 1 m/s second on the floodplain. During the storm event, structures at the camp were not swept off of their foundations due to the Hollyford River overtopping its bank, but it was estimated that approximately 8 m of lateral bank erosion occurred adjacent to the camp. Since 1939, the western bank was found to have migrated east between 10 to 80 m in the vicinity adjacent to the camp, resulting in an annualized erosion rate between 0.1 and 1 m per year. Projecting the impacts of climate change, the flooding and bank erosion associated with the February 2020 event was estimated to have an ARI of 100 years.

Using the GNS Science Backcountry Huts and Camp Sites risk assessment method, the debris flow hazard was categorized as a "high risk" to the camp buildings, and the hydrotechnical hazard (flooding and bank erosion) was categorized as a "moderate to high risk" to the camp buildings.

In addition to the alternatives of doing nothing (which was not recommended) or relocating Gunn's Camp to an appropriate new location, the following potential engineered risk mitigation options were provided:

Construction of a deposition area upslope of the camp to allow potential future debris flows to accumulate.

Construction of a deflection bund upslope of the camp to limit potential future debris flows to avulse the slope above the camp.

Construction of erosion protection works (such as the placement of armour stone) along a suitable length of the Hollyford River's bank.

Construction costs for these works were estimated to be between $500,000 and $1.5 million.

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IMPROVING STOCHASTIC MODELLING WORKFLOW VISUALISATION, INTERROGATION AND INTERACTION

Brioch Hemmings[1], **Catherine Moore,**[1] **Wes Kitlasten**[1], **Lee Chambers**[1], **Phil Scadden**[1]
[1] GNS Science

There is a growing appreciation that the use of numerical modelling to support decision-making benefits from, or even requires, model uncertainty quantification. Unfortunately, this can often involve complex modelling workflows and complicate the visualisation and interrogation of the numerical model outputs. Ultimately, this can separate those involved in the decision making process from the information provided by the modelling workflow.

If the stakeholder in a modelling study does not understand the information provided by the process, or if that information is, through oversimplification, incomplete or inaccurate, their subsequent actions may be inaccurate, inappropriate, and poorly communicated. Consequently (and somewhat ironically), this understanding gap can mean that the efforts to improve the robustness of modelling studies, through the use for stochastic methodologies, can undermine the trust in the modelling outputs and the decisions that they inform.

Aims
We aim to develop tools that support user interrogation and interaction with stochastic modelling workflows. These tools must mesh with prediction specific modelling frameworks that quantify and express model uncertainty. They need to be able to convey diverse and complex results from a variety of models. They also need to be relatively easy to construct and must not require additional specific computational specialties for the end user.

Methods
We develop a variety of example tools for visualisation, interaction and interrogation of stochastic groundwater modelling workflow results, through combining open-source, python libraries and cloud-based server solutions. These tools can be by run by users from their browsers, without any requirement for specialist software or computational expertise.

Results
We demonstrate examples of these interaction and visualisation tools that give the power to interrogate, visualise and explore complex stochastic workflows at various stages in a modelling study, to a range of end users (e.g. Groundwater emergence mapping in South Dunedin, Figure 1.). The examples provide a starting point for standardising and generalising (where possible) the roll-out of visualisation tools, often within complex workflows, to improve trust and uptake in the use of robust modelling methodologies in decision support.

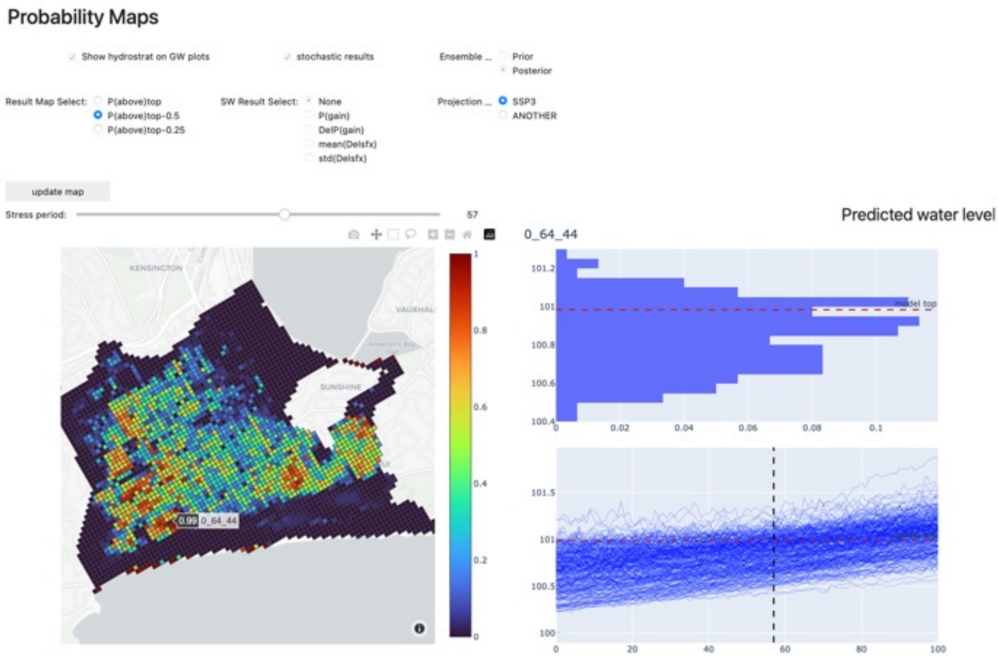

Figure 1: An example model interaction tool, providing a means to explore model prediction of groundwater emergence in South Dunedin in a changing climate, under uncertainty.

AQUIFER MAPPING PROJECTS USING AIRBORNE TIME-DOMAIN ELECTROMAGNETICS: OVERVIEW AND UPDATE

Cameron, S.,[1] Frances, J.,[2,3] Pasco, B.,[2,4] Rawlinson, Z.,[1] Kellett, R.,[1] Westerhoff, R.,[1] Worts, C.,[1] Reeves, R.,[1] Herpe, M.,[1] Clarke, D.[1]
[1] GNS Science
[2] Aqua Intel Aotearoa (AIA)
[3] Saphron
[4] Tetra Tech Coffey

Aims
The demand for water to provide for economic growth has increased in all regions of New Zealand. Better understanding of the nation's groundwater systems will inform and support sustainable water use and regional economic development alongside the objectives of Te Mana o te Wai in a setting of climate change and agricultural intensification.

Aqua Intel Aotearoa (AIA) is a collaboration between Kānoa REDIU (the delivery arm of the Provincial Growth Fund) and GNS Science. AIA is undertaking projects in four regions (Northland, Gisborne, Southland, and Otago) to better understand the hydrogeological complexity in those regions, which will inform subsequent studies of sustainability of groundwater use. Greater Wellington Regional Council (GWRC) and Hawke's Bay Regional Council (HBRC) are undertaking similar projects in their regions.

Method
Airborne time-domain electromagnetic (Airborne TEM) is an aerial geophysical surveying method that yields information on subsurface electrical resistivity down to about two hundred metres depth depending on a range of factors that include geology, aquifer salinity and the survey design (Sørensen and Auken, 2004; Rawlinson et al., 2020; Rawlinson et al., 2021a). Airborne TEM surveying can provide greater certainty than traditional methods on the characteristics and extent of groundwater systems based on interpretations of resistivity models.

Results to date*
As part of the Hawke's Bay 3D Aquifer Mapping Project, 8000 km of Airborne TEM was collected in early 2020 over the Heretaunga Plains, the Ruataniwha Plains and the Otane and Poukawa Basins. Resistivity models have been developed and hydrogeological interpretations of the three survey areas are being undertaken (Rawlinson et al, 2021a; Rawlinson et al, 2021b).

SkyTEM Australia has been contracted by AIA to undertake Airborne TEM surveys this summer in Northland, Gisborne, and Southland; and by GWRC to survey an area in the Wairarapa in early 2023 with similar specifications. Figure 1 summarises the locations of the proposed and existing airborne TEM surveys in New Zealand.

An overview and update of the 2022-23 surveys will be provided, including objectives, survey design, flight details, timelines, stakeholder involvement and communications.

* Early August 2022

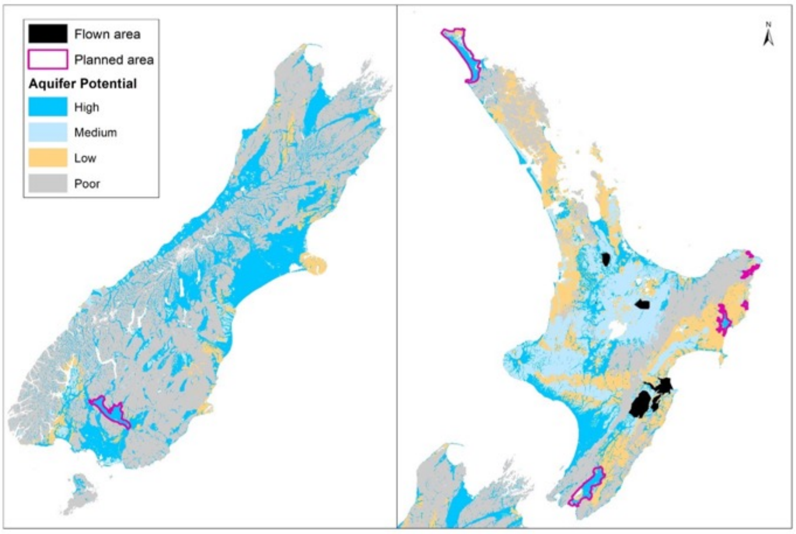

Figure 1: Location of flown and planned Airborne TEM survey areas. Mapped on the aquifer potential map (Tschritter et al., 2017)

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MASS MOVEMENT SEDIMENT DELIVERY AND MOBILISATION IN ALPINE CATCHMENTS

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Aims

This research investigates the cascading effect of mass movement sediment input to alpine catchments and the understand the potential for evolution identified at the relatively localised mass movement-channel interface to become a larger catchment-scale process. The aim of this study is to explore the hydrogeomorphic controls on post-sliding mobilisation of sediment, and the effect of such controls on downstream morphology and the thresholds at which this change occurs.

Method

Six alpine catchments within the Mount Aspiring region of New Zealand's South Island were investigated, employing a combination of satellite imagery and Unmanned Aerial Vehicle (UAV) surveying, alongside hydrological data processing. Sites include the Dart River/Te Awa Whakatipu, Rees River/Puahiri, Shotover River/ Kimi-ākau, Matukituki River, Wilkin River, Young River and Siberia Stream. Satellite imagery of mass movement sites and 1 km downstream reach lengths were collated over available temporal ranges (2005 onwards), allowing for the mapping of channel morphology (bank and bar area/formation) and landslide morphology (toe formation and scar area) to be identified and assessed over each temporal snapshot. At the finer scale 3D UAV surveying of sites presenting the greatest sediment reworking and evolution in the Dart River/Te Awa Whakatipu, Rees River/Puahiri, Wilkin River and Siberia Stream was undertaken. UAV surveying facilitated the analysis of previously identified patterns of erosion and accretion at significant locations in addition the finer scale analysis of the thresholds controlling such processes. Underpinning this multiscale surveying the extraction of environmental thresholds from available hydrological data, largely comprised of discharge and rainfall monitoring, aided in the justification of emerging behaviours. Namely, high volume rainfall and discharge events, and the role of antecedent conditions using an antecedent precipitation index (API) and sediment mobilisation capacity were identified. Analysis in this form was additionally supported by known mass movement and channel activity.

Results

Morphological change across catchments at the satellite image scale reflects the variability in catchment processes and the scale of control exerted by individual mass movement sites. Overall, the Dart River/Te Awa Whakatipu, Rees River/Puahiri, Wilkin River and Siberia Stream present frequent reworking, evident in shifts between single and multiple channel presence and active reworking of in-channel features. In contrast the Shotover River/ Kimi-ākau, Matukituki River, and Young River returned a greater stability in channel form with little evolution identified. Preliminary analysis of satellite imagery denotes a threshold boundary between the longitudinal evolution of sediment slugs post sliding, and the total reworking of channel material – evidence of which is clearest where activity is greatest. Within active catchments the presentation of channel morphology change varied, reflecting the control of specific thresholds in individual catchments (Figure 1). The Dart catchment reflected a greater control of sediment delivery and landslide dam reworking following mass movement evident in a significant decrease in feature area between 2015 and 2019. In contrast the Rees and Wilkin catchments reflect minimal shift in channel form area, however present high lateral mobility and channel migration in image analysis. Of note is the combination of both generalised behaviours of the Siberia Stream, in which both sediment input and channel reworking appear evident. As such there is a need to assess the conditions producing these individual responses to better categorise the potential post-sliding response of catchments presenting similar conditions.

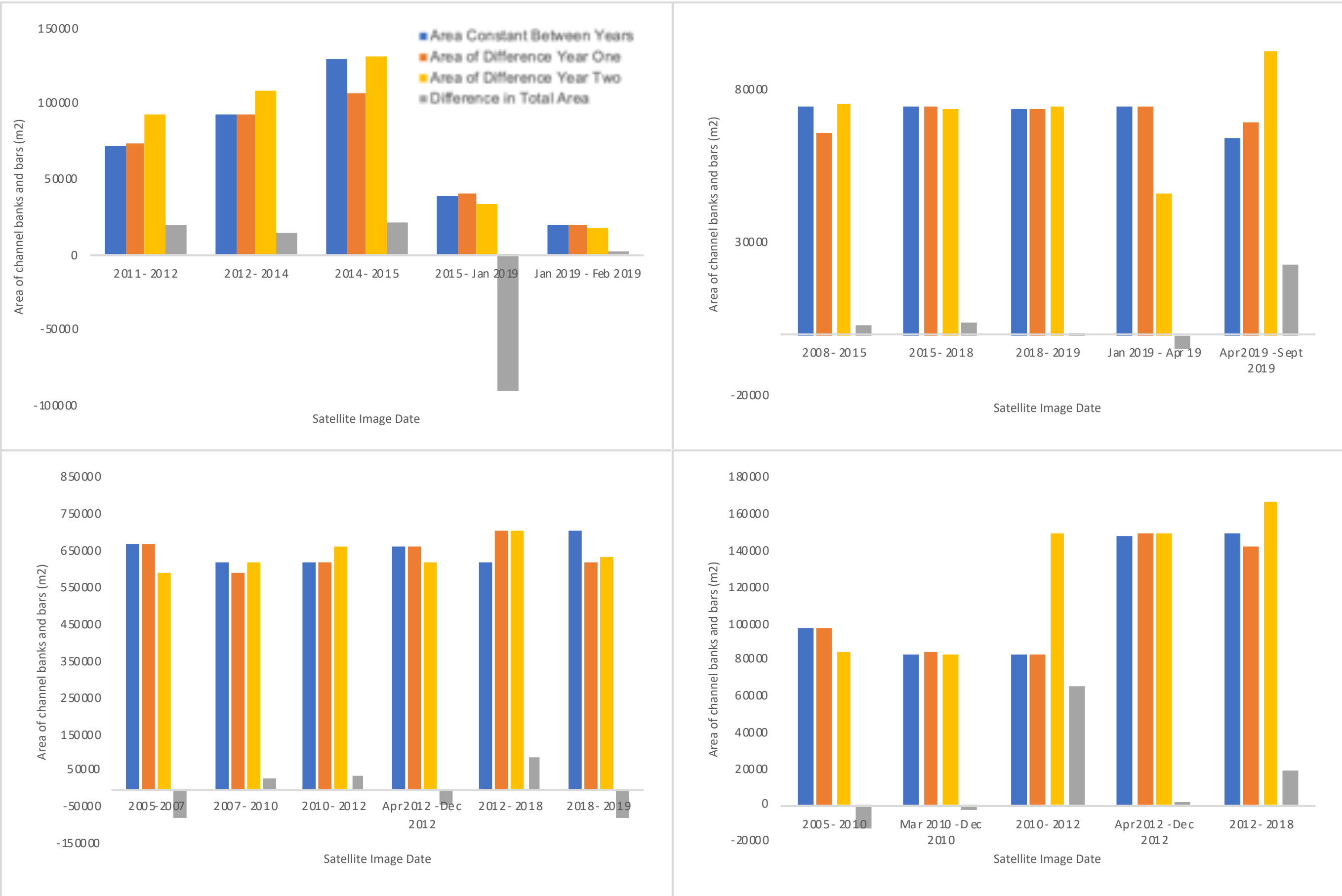

Figure 1: Area breakdown of bank and bar channel morphology between available satellite images, in clockwise direction Dart River/ Te Awa Whakatipu, Rees River/Puahiri, Siberia Stream and Wilkin River.

Following on from these results, the catchment specific analysis of prevailing conditions is to be conducted in order to identify the thresholds at which equilibrium is overridden, and sediment evacuation occurs on a scale detrimental to downstream channels. Higher order analysis of hydrological data suggests a separation of thresholds, in which high volume discharge and rainfall events occur frequently with little identifiable effect on channel morphology, and present little overlap with events presenting the greatest control of antecedent conditions. Extraction of the five highest daily discharge and API events across local monitoring stations presented overlap in the Matukituki catchment alone, in which two of the five events co-occurred. Sediment transport capacity is predicted to produce a transport ability decreasing as sediment size increases, reflecting patterns similar to high volume discharge events in which the greatest capacity reflects relatively low morphological impacts, whilst the frequent occurrence of median grain size mobilisation with incur the greatest impact on channel evolution.

LIDAR OBSERVATIONS OF SPATIOTEMPORAL CONTRASTS IN CLOUDS AND AEROSOLS (LOSTECCA) ON THE SOUTH ISLAND NZ

Julian Hofer[1], **Patric Seifert**[1], **Ben Liley**[2], **Osamu Uchino**[3], **Isamu Morino**[3], **Tetsu Sakai**[4], **and Tomohiro Nagai**[4]

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Aims

The presented study investigates the efficiency of heterogeneous ice formation in natural clouds over Lauder, New Zealand (45° S, 170° E). Aerosol conditions in the middle troposphere above Lauder are subject to huge contrasts. Clean, pristine airmasses from Antarctica and the Southern Ocean arrive under southerly flow conditions while high aerosol loads can occur when air masses are advected from nearby Australia. This study assesses how these contrasts in aerosol load affect the ice formation efficiency in stratiform midlevel clouds in the heterogeneous freezing range (-40 - 0°C).

Method

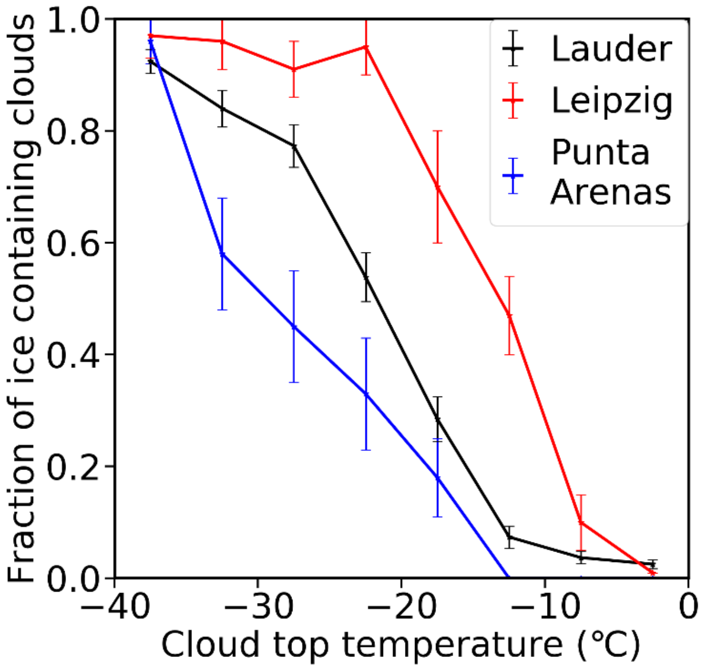
For this purpose, an 11-year dataset was analyzed from a dual-wavelength polarization lidar system operated by National Institute of Water & Atmospheric Research (NIWA) at Lauder (45.04° S, 169.68° E, 360 m a.s.l.). These data were used to investigate the efficiency of heterogeneous ice formation in clouds over the site as a function of temperature as in previous studies (Seifert et al., 2010, Kanitz et al., 2011). Trajectory-based tools (Radenz et al., 2021) and model data (CAMS-MACC aerosol reanalysis (Copernicus Atmospheric Monitoring Service - Monitoring Atmospheric Composition and Climate)) are used to relate this cloud dataset to the aerosol load and the air mass sources.

During November 2022, a joint LOSTECCA/go-South measurement campaign dedicated to the characterization of clouds as well as cloud-relevant aerosol properties will be conducted near Pahia, New Zealand (46.31° S, 167.71° E, 10 m a.s.l, Stratmann et al., 2022). Its vicinity at the southern tip of New Zealand allows to observe pure marine aerosol when air masses approach from the open Southern Ocean. However, also long-range transport from Australia is expected to take place in the free troposphere over the South Island of New Zealand, especially in the envisaged springtime period of the campaign. The pristine and Australia influenced (biomass burning, Aeolian dust, urban haze) datasets can be contrasted to each other using equipment of TROPOS, as it was used for previous mixed-phase cloud studies (Seifert et al., 2010, 2015; Kanitz et al., 2011). As for LOSTECCA/ground-based remote sensing, a multiwavelength-polarization lidar PollyXT (Engelmann et al., 2016), a Halo-Photonics Streamline XR Doppler lidar, an RPG-HATPRO microwave radiometer, and a CIMEL Sun photometer will be operated. During the campaign, the remote sensing equipment of the LOSTECCA project will be accompanied by ground-based and airborne in situ observations of aerosol and cloud microphysical properties. The combination of the in situ and remote sensing instruments will allow to infer relationships between atmospheric dynamics and cloud microphysical properties, as well as on the role of local, marine or long-range transported aerosol on the observed cloud properties.

Results

The Lauder cloud dataset was put into context with lidar studies from contrasting regions such as Cyprus, Germany, and southern Chile (Fig. 1). Strongest similarity of the dataset was found with the one from Punta Arenas (Kanitz et al., 2011). Both of these sites are subject to generally low free-tropospheric aerosol loads, which suggests that the low ice-formation efficiency at these two sites is related to low INP concentrations. The enhanced lack of ice-containing clouds at T<-20°C over Punta Arenas compared to Lauder is likely caused by enhanced formation of supercooled liquid water layers within gravity waves in the lee of the Andes mountains (Radenz et al., 2021). The similarity of the Lauder dataset to the Leipzig dataset at T>-5°C can be explained by the contribution of local aerosol to the ice formation efficiency. Similar indications were found for Punta Arenas in the studies of Radenz et al. (2021) and Gong et al. (2022).

From the LOSTECCA/go-South measurement campaign 2022, two measurement scenarios are planned to be investigated. First, the occurrence of supercooled cloud systems and second, clear-sky conditions suitable for full tropospheric aerosol characterization. The first scenario will produce the data required for creating a PollyXT-based mixed-phase cloud statistics similar as shown in Fig. 1. The second scenario will be the basis for closure studies with the vertically resolved in situ measurements of aerosols, cloud-condensation nuclei and ice-nucleating particles.



At the conference, first insights in the results obtained with respect to the two focus scenarios will be presented. Fig. 1: Frequency of occurrence of ice‐containing clouds as a function of cloud top temperature for Lauder (blue, 2009-2020, this study), Leipzig (red, Seifert et al., JGR, 2010), and Punta Arenas (black, Kanitz et al., GRL, 2011). The error bars represent the statistical significance.

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Acknowledgments

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STRUCTURAL PROTECTION FROM FLOODING DIFFERENCES IN APPROACHES ACROSS THE DITCH

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[1] Cardno Now Stantec

Aims
Stop banks, known as levees in Australia, are a form of structural protection from flooding and are commonly used around the world. Despite being close neighbours, New Zealand and Australia adopt widely different approaches to the strategy behind the implementation of structural protection from flooding. This topic aims to outline key differences in strategy between the neighbouring countries behind structural protection from flooding and consider potential for learnings from across the ditch.

Methodology
Historically, the inherit strategy behind the protection from flooding is vastly different between the south-pacific neighbours. The historic approach in New Zealand across the floodplain is to build stop banks along the entire length of river systems. The purpose of stop banks is to provide a level of protection for both townships as well as farmland from flooding. Noting that a lower standard of protection is often warranted for farmland.

The Australian approach to using structural protection is normally focussed on bunding around or along the river side of a significant township or infrastructure only. The strategy behind this approach is to provide a level of protection for the township or infrastructure only.

While our locations in the world are similar, Australia and New Zealand are polar opposites in terms of geology. Australia is one of the oldest continents in the world and as a result our landscape has spent millennia evolving and adjusting resulting in relative stability. Australia soil has naturally degraded and the nutrient density reduced over time. This process has been accelerated since European settlement. The nutrient scarcity in our soils means that our farmers place a high value on the fine sediment nutrients carried by flood waters. Historically, these sediments have created some of the richest farmlands of the continent across the floodplains.

New Zealand is one of the world's younger countries in terms of geologic. The river systems and floodplains of New Zealand are evolving, with gravel aggradation a significant issue in many systems across the country. With the evolving landscape and relative youthfulness of the soils, New Zealand farmers historically place a lesser value on the nutrients of floodwaters and would hence would prefer to have farmland protected from the potential damage to stock, crops and assets.

Structural protection from flooding is not a low-cost solution. The capital expenditure of design and construction combined with the perpetual maintenance costs require ongoing funding. Qualitative and quantitative assessments of the benefits of structural protection from flooding previously undertaken in both Australia and New Zealand will be shared.

Despite the variance in strategy across our nations, the value on community safety is common. Structural protection is designed to provide a level of protection from flooding for our communities. However, inherently these measures can provide a false sense of security. Communities are commonly reported to believe that they are immune to flooding as a result of the protection provided by the structural arrangement. The false sense of security can often result in the magnification of impacts of flooding in the event of either: overtopping of the structural measure or failure of the stop bank due to erosion or other mechanisms.

In Australia, the industry widely acknowledges and mitigates the impacts to areas outside of the protected zone where increases to peak design flood levels occur, due the implementation of structural protection.

The confinement of floodwaters to within bank areas is by definition an alteration to the natural riverine processes. The concentration of flows inherently results in magnification of scour and erosive potential of flood waters. Interestingly the Australian approach to structural protection from flooding may be more aligned with the values of Te Mana o te Wai. Where the health of the river comes first.

Consideration of reduction in areas of the floodplain protected could not be achieved as a short-term outcome. This would involve strategic long-term planning and stakeholder engagement. The process would present some significant challenges. The most notable challenge would be in areas of reduced level of protection relative to that provided by the historically established stop banks.

Results
There is potential for the flood risk management industry in Australia and New Zealand to step back from historically accepted approaches and consider whether there are any pertinent learnings to the strategy behind structural protection from flooding either side of the ditch. Evaluation of alternative approaches need to consider economic, social and environmental factors to ensure that the net benefits are commensurate with the cost of protection.

OPTIMISING METHODS FOR SAMPLING GROUNDWATER ECOSYSTEMS FOR ENVIRONMENTAL ASSESSMENTS AND MONITORING IN AUSTRALIA

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Major developments that impact aquifers require assessments of potential impact as part of the approvals process. Regulatory authorities across Australia vary in terms of their requirements and processes for assessing impacts to groundwaters and their dependent ecosystems and in terms of requirements for post-approval monitoring. While there are several robust and effective state-based methodologies for sampling groundwater ecosystems, there are no standardised sampling approaches. Microbial assemblages, in particular, are seldom considered in Environmental Impact Statements (EISs) despite their importance in biogeochemical processes. The analysis of DNA shed in the environment, termed 'environmental DNA' (eDNA), is a powerful, rapid, non-invasive and potentially cost-efficient tool that may address many of the challenges associated with characterising groundwater microbial and stygofauna communities.

Aim
The aim of this study was to evaluate methods for sampling stygofauna and microbial communities in groundwater, including assessing the suitability of eDNA-based approaches for use in routine monitoring and assessment of groundwater biota. Specifically, the study sought to explore associations between groundwater quality and the composition of stygofaunal and microbial assemblages and assess the effectiveness of various sampling protocols and the likely feasibility of metagenomic approaches for routine groundwater biomonitoring.

Method
Sites in alluvial and fractured rock aquifers across NSW, Australia were sampled using a suite of different approaches. Samples of groundwater were collected using 'traditional' net and bailer methods, as well as sampling with a motorised pump. Samples were analysed for stygofauna using morphological analyses (with microscopy), and microbes (prokaryotes) and higher organisms (eukaryotes-stygofauna) using eDNA. Water quality and site attributes were also recorded.

Result
Stygofauna collection using bailers and 63-μm and 150-μm mesh nets generally did not collect the full diversity of stygofauna present at a site. A combination of pre-purge sampling (using nets or pump) and pumping of at least 150 L of groundwater is necessary to maximise the diversity of stygofauna collected and the representativeness of those samples with respect to the diversity and relative abundances of fauna in the aquifer. Although not expressly tested, the outcomes of this study are consistent with existing sampling guidelines that require multiple samples from a site, and samples from multiple sites, to adequately characterise the stygofauna within an aquifer.

Prokaryote and eukaryote communities in bores were different to those in the surrounding aquifer, with results indicating purging by pumping at least three bore volumes is necessary before collecting samples for eDNA and water quality analyses. The eDNA results indicated no significant difference in biotic communities collected immediately post-purge (30 L pumped) and after pumping 180 L. However, for stygofauna, eDNA did not always identify the known richness at each site. Therefore, a combination of traditional 'whole-organism' analysis (with microscopy) of stygofauna is recommended in addition to eDNA, where thorough assessment of stygofauna is required.

Prokaryote (microbial – Bacteria and Archaea) communities were further characterised by assigning putative functional capabilities to each taxon using the FAPROTAX program. Analysis of communities in terms of their inferred functional profile highlighted differences between those based on DNA assemblages. However, functional-based analyses did not show a clear separation by sample volume.

From this study, we provide recommendations for sampling groundwater to efficiently collect the maximum diversity of stygofauna and characterise biotic communities using eDNA, with a view to metabarcoding analysis of eDNA being used as a tool for routine survey and monitoring of groundwaters that may be impacted by extractive industries.

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

NATIONAL SURVEY OF GROUNDWATER BACTERIAL DIVERSITY: INSIGHTS INTO RELATIONSHIPS BETWEEN MICROBIAL BIODIVERSITY AND GROUNDWATER CHEMISTRY

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Aims
This paper presents the first results from an ongoing monitoring project investigating the diversity and functions of microorganisms within groundwater ecosystems.

Groundwater delivers essential ecosystem functions including water purification through removal of contaminants and pathogens, biogeochemical cycling, and the maintenance of hydraulic conductivity, and also has cultural or spiritual values (Griebler and Avramov, 2015). It supports both subterranean and surface-water ecosystems and provides up to 80 % of base-flow to rivers (White et al., 2015).

Ecosystem services are a direct result of the biodiversity present in an environment and the biological processes they perform (Griebler and Avramov, 2015). Identification of microbial functional genes can even be used to predict groundwater contamination (He et al., 2018). Despite the clear importance of groundwater, little is known about the biodiversity of Aotearoa New Zealand groundwater ecosystems, and the impacts of abstraction, land use change, climate change, or contamination on biodiversity and ecosystem services are unknown.

This monitoring project aims to create an Aotearoa New Zealand-specific health index of groundwater ecosystems, to predict water quality and contamination, and to capitalise on the beneficial microbes performing essential ecosystem services. Policy makers may use the results to inform decision making on groundwater ecosystems and their management.

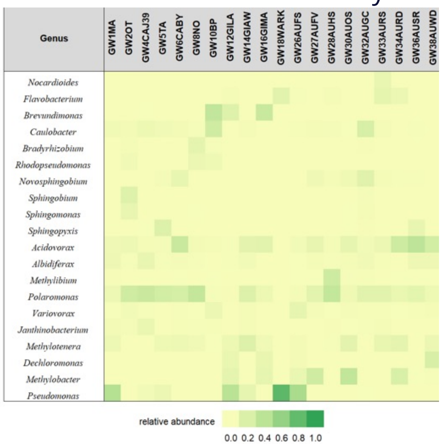
Figure 1: Sampling locations.

Method
Groundwater samples (n=40) were collected from 27 aquifers across the country (Figure 1). Duplicate samples were used for either standard water chemistry analysis (National Environmental Monitoring Standards, 2019) or for the extraction and sequencing of microbial DNA, following filtration through a 0.1 μm filter. DNA was successfully extracted from 37 samples; 20 samples were subjected to metagenomic analysis of all genes, while 17 samples were classified according to 16S rRNA marker genes. Statistical analysis identified correlations between environmental parameters and microbial diversity and/or function.

Results

Chemistry: A wide range of environmental parameters were measured for different samples, with 25 collected for at least half of all samples. Of particular concern were concentrations of phosphorus, nitrate, ammonia, and manganese, which were above the acceptable guidelines for drinking water or the National Policy Statement for Freshwater Management (NPS-FM) in many samples. One sample showed possible signs of saltwater intrusion, with 14/22 measured parameters being significantly different from the median of this dataset, and more similar to seawater than groundwater.

Taxonomy: Analysis of the microbial diversity within aquifers indicated that there was a core set of bacterial genera which were present in the majority of samples but at a low abundance. Many microbial communities were dominated by one or two genera which were observed in only a few other samples (Figure 2).



Functions: Microbial communities within groundwater samples display a range of metabolic pathways with the capacity to degrade many environmental contaminants. For example, the potential for nitrate reduction was common across samples, but full denitrification to dinitrogen gas was much rarer (Figure 3).

Associations between environmental parameters and diversity: Concentrations of parameters such as silicon, iron and sulfate may drive the taxonomic diversity of microbes within these systems, in conjunction with the availability of nutrients and essential elements. More samples with more consistent measurements of parameters are necessary to better refine correlation studies.

Figure 2: Relative abundance of bacterial genera within the groundwater samples.

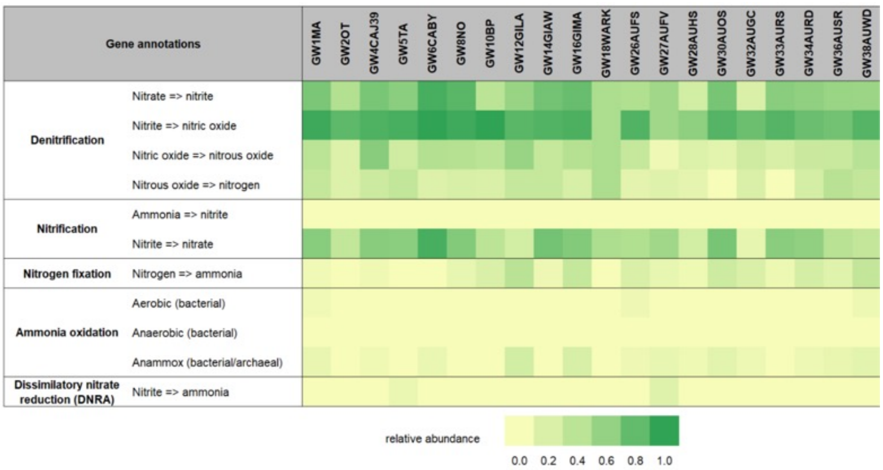


Figure 3: Relative abundance of genes involved in nitrogen cycling within groundwater samples.

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YAKAMA NATION MANAGED AQUIFER RECHARGE PARTNERSHIP

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[1] Wallbridge Gilbert Aztec, WGA

Aim
Wallbridge Gilbert Aztec (WGA) is carrying out a technical review of the Yakama Nation's Draft Managed Aquifer Recharge (MAR) Plan in the Toppenish and Simcoe Basins, Washington, USA.

The Treaty of 1855 established the Confederated Tribes and Bands of the Yakama Nation and the Yakama Reservation. The Yakama Reservation consists of 1.3 million acres, which includes a significant portion of the Yakima River and Klickitat River Basins. Over half of the Reservation is classified as semi-arid and water supply is limited.

The MAR Plan summarizes current and future groundwater resource management concerns and identifies goals for restoration of hydrologic processes in the lower Toppenish and Satus Basins. Based on the resource needs, a suite of MAR projects has been identified to address current and future resource concerns and to attain water supply goals. Unlike many other MAR projects, the Yakama Nation is working to manage and implement aquifer recharge at the catchment scale.

Method
The project is located west of Toppenish, Yakima County on the Yakama Nation, Washington, USA. For the past few years, several open irrigation canals have been used to kick start the Yakama Nation's MAR programme with a focus to improve shallow groundwater storage in order to enhance annual storage and improve the security of supply for downstream spring-fed streams. WGA staff have been on site to observe and review the operating MAR scheme. We are now working in partnership with Yakama Nation to investigate the potential options for the design of a MAR plan to achieve the desired outcomes from the project.

The MAR programme is intended to address the following current and future resource needs:

- Provide climate change resilience
- Slow over-extraction of deep basalt aquifers
- Restore recharge processes that have been disrupted by development, channelization, grazing and agriculture
- Develop intentional conjunctive use of groundwater and surface water to address water resource needs for fish, wildlife and irrigation
- Address reduced recharge due to water conservation on the Wapato Irrigation Project

Results
The presentation will provide a background on the hydrogeology of the study area, the MAR project and initial considerations on potential options for the Yakama Nation's MAR programme to extend the MAR from the current simple network to a full catchment scale MAR project.

TOWARDS A BETTER UNDERSTANDING OF CLOUDS AND THEIR HEMISPHERICAL DIFFERENCES BY ANALYZING CLOUD IMAGES

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Aims

Cloud images recorded in New Zealand and Germany are analyzed with the aim to better understand hemispherical differences of cloud parameters. Cloud cover is determined by images from a Hemispherical Sky Imager (HSI) system and eventually compared with satellite and model data.

Along with cloud type, the cloud cover is an important parameter that influences the solar radiation at the ground and may be incorrectly represented in current climate models for the southern hemisphere [Zelinka et al., 2020]. Therefore, the ground measurements of cloud cover will be compared with both satellite data and model data to validate the models.

The understanding of the determined differences in cloud cover will improve our understanding of clouds and their impact on climate in general.

Method

A Hemispherical Sky Imager (HSI) system of the Institute of Meteorology in Hannover, Germany (52.39° N, 9.70°E) is used to take high-resolution images of the upper hemisphere since 2009. An identical system has been deployed at NIWA in Lauder, New Zealand (45.04° S, 169.68° E). Images are taken every 1-10 minutes since 2009. In addition, during a 3-week campaign in Invercargill (46.41° S, 168.35 °E) images will be recorded every minute in November 2022. From these images, information on the state of the sky and the surrounding area can be obtained (Kawanishi, 2010; Tohsing et al., 2013, Seckmeyer et.al.,2018), such as, in particular, the cloud cover, cloud type, the general weather situation, shading by obstacles (Schrempf et al., 2017), and surface structure.

Image processing algorithms calculate the total cloud cover by determining whether a cloud is present in each pixel based on the measured RGB channels (red, green, and blue). The haze index, described by Werkmeister et al., (2015), is an improved version of the sky index of Yamashita et al. (2004) and is used for this study.

The dataset generated during the measurement campaign in Invercargill shall be compared with the ground and airborne measurements of the Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, and the National Institute of Water and Atmospheric Research (NIWA), Wellington. In particular the results will be useful for the validation of the model results.

Results

It has been found that differences in biologically weighted irradiance up to a factor of 2 were already observed in summer 1990-1991 between the northern and southern hemisphere. Most of the differences were first attributed to the different ozone levels [Seckmeyer and McKenzie, 1992], although later it became clear that differences in cloudiness also play a major role for the hemispherical differences in UV-radiation. A Comparison between Garmisch (47.48° N, 11.07 °E) in southern Germany and Lauder (45.04° S, 169.68 °E) in New Zealand showed that clouds can reduce the monthly mean erythemal-weighted UV radiation in Garmisch by 24-44%, while in Lauder the reduction was found to be only 10-29% [Seckmeyer et al.,2008]. Furthermore, it has been shown that the differences in cloudiness between Northern and Southern Hemisphere are even higher in the winter than summer months [Seckmeyer et al., 2018].

The results may help to quantify possible errors of the cloud models so that they can be optimized in the future. Thus, climate models may be improved with respect to the prediction of clouds and their climatic impact in the Southern Ocean region. Preliminary results from the November campaign may be presented as well.

Acknowledgments

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FLOOD HAZARD FORECASTING BY INTERPOLATING EXISTING INUNDATION AND HAZARD MAPS

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Aims

Real-time hydrodynamic modelling is often employed to forecast flood extent, depth and hazard rating. However, conducting real-time hydrodynamic simulation is challenging due to the time-consuming processes of input data preparation, numerical computation, and post-processing/reviewing model results. We proposed an alternative to forecasting inundation depth, extent, and hazard rating by interpolating existing flood inundation and hazard maps derived from a library of reference flood events.

Method

The proposed flood hazard interpolation method is an update to a similar approach that was first adopted for the Karamea River flood model (Chiaverini, A., 2016). Compared to the previous interpolation approach, the proposed method requires a library of referencing flood events following the uniform distribution and a spatially discretized interpolation algorithm that implicitly incorporates the flooding mechanism at any given location.

We consider 100 scenarios of reference flood events based on historical and synthetic events to build the library of pre-computed flood maps. Flood characteristic parameters that will be forecasted, such as peak flow, peak sea level, the timing of the peaks, and 5-hour averaged peak flow, are compared to the corresponding parameters of the reference flood events in the look-up library. Flood maps of the most similar reference events to the forecasted event are then interpolated to forecast flood hazards.

This flood forecasting method was developed for Westport, where flood hazards can be a result of either high flows in the Buller River, extreme sea levels in the Buller Bay, or, on many occasions, a combination of both. Each reference flood event consists of a flow hydrograph and a sea level time series that were extreme historical events extracted from existing hydrometric data or synthesized to cause flooding in Westport. The library of reference events was developed iteratively with performance feedback from the interpolation process.

Results

We present the detailed method for creating the reference flood library, data assimilation for time series, and the preliminary evaluations of the interpolation performance. We discuss challenges and recommendations for the development of flood scenarios for use in real-time inundation forecasting applications.

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2022 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 is 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 2021-2022 are given below:

Hydro-geofabric (national-scale spatio-temporal database of hydro-geological data)
- Identification of potential groundwater catchments using models with a-priori parameterization (with GNS)
- Provided public access to surface-water hydro-geofabric data
- Development of a 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 EWT model in HydroDeskNZ
- One way coupling TopNet-EWT using land surface recharge scenario

Groundwater module
- A-priori parametrization of TopNet-GW at national scale
- Development of an initial national scale MODFLOW 6 groundwater model (aligned with Te Whakaheke o Te Wai)

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

THE IMPACT OF CLIMATE AND SOIL DATA INPUT UNCERTAINTY ON HYDROLOGICAL MODEL PERFORMANCE

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Aims
The New Zealand Water Model (NZWaM) project seeks to develop a versatile hydrological modelling framework coupling climate, land surface and underground processes. For reliable application and decision-making, model validation should keep pace with evolving knowledge and spatial data sets relating to temporally dynamic natural systems. The NZWaM structure allows the input of environmental data across varying spatial resolution, providing an iterative process of model refinement, evaluation, and diagnosis. The model benchmarking process (i.e., systematic evaluation and diagnostic processes) enables the reliability and plausibility of model performance to be tested. Here we objectively compare outputs of the NZWAM from differing input assumptions as such comparisons are rarely accounted for as part of conventional uncertainty analysis. This process of benchmarking is undertaken by varying rainfall and soil hydraulic properties into the NZWaM at key locations throughout New Zealand with the following aims;
- develop tools and automatic processes to assess the impact of field observation on landscape hydrological understanding
- assess NPS-FW (National Policy Statement Freshwater) driven policy options to guide implementation at regional scale

Method
To develop a consistent national scale hydrological output, we use an a-priori parametrised hydrological model, TopNet (Clark et al. (2008), Booker and Woods (2014), McMillan et al. (2016)) flexible enough to represent a wide range of environmental conditions, and complex enough to represent the integration of natural and anthropogenic processes, the later not being present here. Various input parameters are compared between operational data sets and newly compiled augmented datasets. Our analysis focuses on testing the impact of rainfall and soil information on the ability for one of the NZWaM hydrological model suite to generate accurate hydrological simulations.

Precipitation uncertainty is explored using the Virtual Climate Station Networks (VCSN) precipitation products (Tait et al. 2006). Here we assess the impact of spatial resolution and observation density, within a specific gridded climate product, on the accuracy of hydrological simulations. At least two gridded rainfall products; the operational VCSN generated on daily basis based on NIWA's national Climate Data Base (CliDB) (5000 m grid) and an Augmented VCSN of 500 m2 resolution which includes rainfall measurements from local authorities combined with ClidB. Those two products represent the endmembers of the VCSN products available to drive hydrological models in New Zealand).

Soil information source uncertainty is assessed by using soil information used to drive hydrological models in New Zealand. Those are the national Fundamental Soil Layer (FSL) (Hewitt 1993) and the newly developed Soil Map (S-Map) (Lilburne et al. (2018), McNeil et al. 2018). Assessments are carried out across catchments where both datasets are available.

Hydrological metrics tested for each rainfall product are the % error for low, mean and high flow. Tested hydrological parameters for the soil data sets are estimates of low flow, groundwater recharge and depth shallow groundwater depth.

Results
Hydrological flow outputs of NZWAM are compared a-priori to demonstrate that the source of spatial information is vital for reliable estimates of national and regional hydrology. We investigated two regions with an uncalibrated model to test the source of the uncertainty of gridded rainfall products and soil hydrological data.

The Augmented VCSN product improved the a-priori estimates of climate data driven flow at low, mean and high flows. Although, improvements in estimates of hydrological metrics are not equal at a given site and vary between the benchmarked hydrological metric and location. Improvements in flow estimation appear to be related to the density of measured data in the climate network, which has a greater impact at higher elevation than at lower elevation. Sites with no measurable improvement in a-priori flow estimates flow estimates correspond with no change in network density.

Hydrological benchmarking is important to test the predictive ability (% error) of hydrological models at a range of flow statistics. We demonstrate where, when and to what scale input data effects model outputs, with implications for water resource management issues. Future work may justify a data worth approach to hydrological and climate network design, enabling the targeted collection of data at selected locations. This approach may prove to systematically reduce reliance on model calibration and ultimately reduce hydrological simulation uncertainty using a-priori parameterised hydrological models. Overall, an increase in the resolution of hydrological input and process control data tends to improve ability of NZWaM to reproduce hydrological characteristics in the study locations using a-priori parametrised hydrological model.

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DETERMINING SOURCE PROTECTION ZONES FOR HETEROGENEOUS AQUIFERS: INSIGHTS FROM COMPARING COMPLEX AND SIMPLE METHODS

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Aims

The insights described in this presentation have emerged from our work on the delineation of source protection zones (SPZ) in highly heterogeneous aquifers. Sarris et al. (2021) demonstrated how categorical simulations of heterogeneous hydraulic conductivity can be used within a stochastic framework to provide a probabilistic description of source protection area. Our efforts to apply this methodology have highlighted several issues that suggest that the overall aim of developing a simple method for SPZ delineation may be challenging.

Method

In this presentation we compare results from complex stochastic flow and transport simulations, simple homogeneous models, and existing analytical expressions. As case study we use the existing drinking supply wells in West Melton located Canterbury's Selwyn District.

The development of the fine scale, heterogeneous stochastic flow and transport results has been presented earlier by Sarris et al. (2021). Each realisation is parameterised in MODFLOW6 so that the prior knowledge of the effective, large scale flow characteristics of the aquifer are honoured. Homogenous simulations are based on the same grid, using the aquifer effective properties to parameterise the numerical flow model.

In both cases conservative transport of pathogens is undertaken using Modpath7, using both forward and backward particle tracking. For forward particle tracking four particles are realised in each surface model cell and are tracked for one year or until they reach the well boundary. For backward particle tracking, 10,000 starting particles are randomly distributed within the pumping well cell and are tracked for one year or until they reach the surface layer. The numerical results are compared with the analytical expressions used in the provisional community drinking-water protection zones for unconfined or semi-confined aquifers from ECan's LWRP Schedule 1 (Environment Canterbury, 2018).

Results

A comparison of the corresponding homogeneous source protection zone with a probabilistic protection zone (for a specific lithology categorisation scheme and facies conductivity assignment method) is shown in Figure 1, where the porosity and anisotropy of the homogeneous model are varied. Using the expected hydraulic conductivities based on the aquifer effective properties (i.e. vertical anisotropy of 10) in the homogeneous model failed to produce any particles that reached the pumping well; the low vertical conductivity meant that particles could not easily travel downwards. In order to compare with the probabilistic protection zone, both the anisotropy and porosity must be decreased significantly.

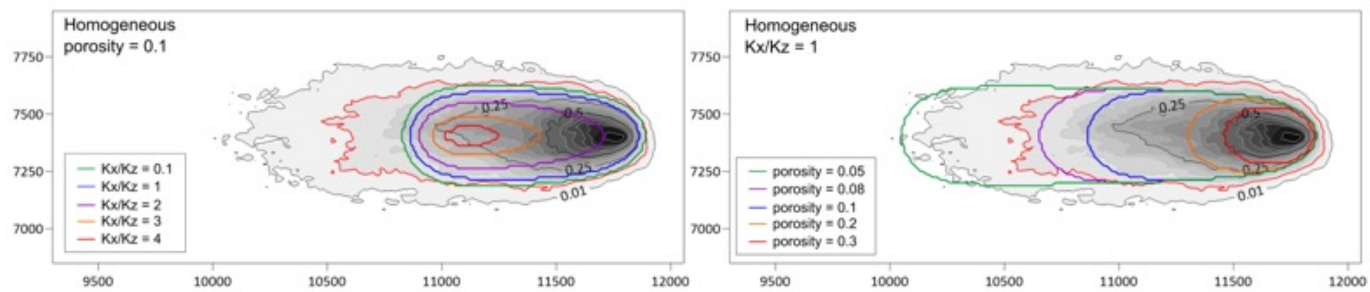

Figure 1: Homogeneous protection zone compared to a heterogeneous probabilistic source protection zone. The anisotropy and porosity of the homogeneous model are varied. The outer and red contours of the heterogeneous SPZ represent 1% and 5% probability respectively.

Figure 2 compares a set of probabilistic source protection zones for varied well depth against the provisional group or community drinking-water protection zones for unconfined or semi-confined aquifers from ECan's LWRP Schedule 1. Our results suggest that the degree of protection offered by deeper pumping wells may often be overstated, and instead other factors such as the pumping rate have a much greater influence.

Figure 3 demonstrates that the method of backward tracking particles to the top of layer 1 does not produce the full extent of the probabilistic source protection zone. The majority of particles in the forward tracking simulation terminate on the upper face of the pumping cell, whereas in the backward tracking simulation particles are typically distributed throughout the pumping cell and most do not reach the top of layer 1. Using starting particles randomly distributed on the surface of the cell (rather than within) does not make any significant difference. These results will be elaborated on, and their significance discussed in the presentation.

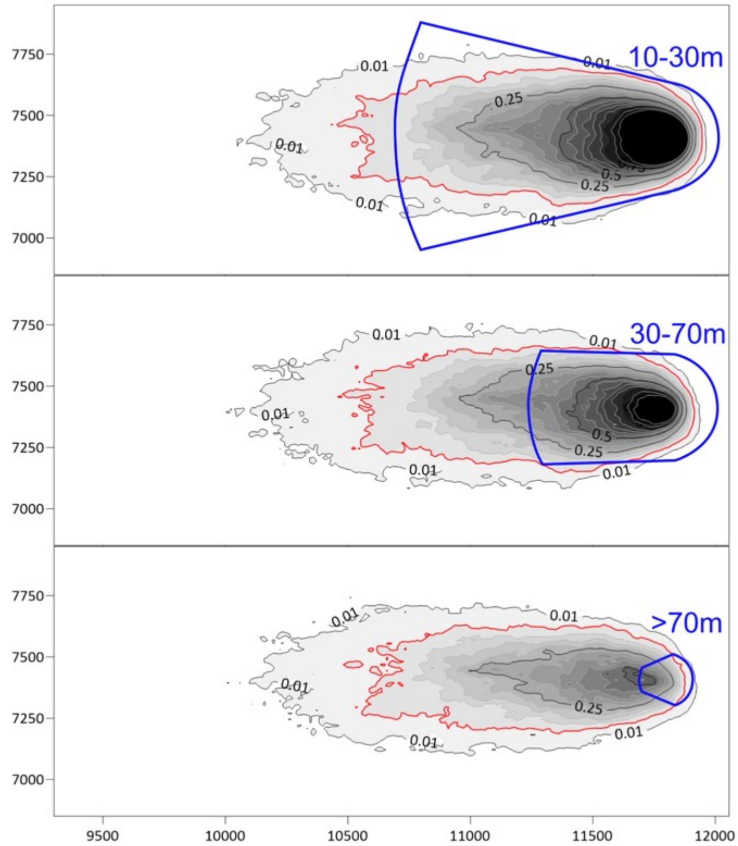

Figure 2: Probabilistic source protection zones for varied pumping well depth compared with the provisional group or community drinking-water protection zones for unconfined or semi-confined aquifers from ECan's LWRP Schedule 1.

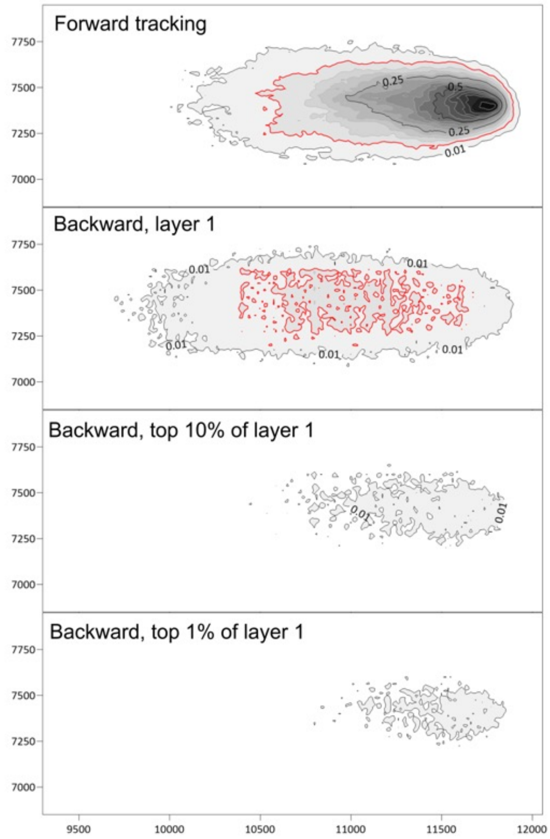

Figure 3: Probabilistic source protection zones for a heterogeneous aquifer, using forward and backward tracking.

Acknowledgments
This work is part of the MBIE-funded 'Te Whakaheke o Te Wai (The Pathways of the Waters)' programme led by GNS.

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A MICROBIAL RISK ASSESSMENT TOOL TO PROTECT DRINKING WATER WELLS: CASE STUDY AND DEMONSTRATION

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Aims

The recent delineation of source protection zones for drinking water supply wells has prompted consideration of the risk from a range of activities within these zones. The Microbial Risk Assessment (MRA) tool (funded by Envirolink Tools) addresses a range of land use activities that might occur within a source water risk management area (also known as a source protection zone) and for the drinking water wells being pumped at a range of rates equivalent to domestic, small town and municipal uses.

Methods

A modular approach is used that determines the loading of microbes from a particular land use and degree of removal if appropriate; components include transport and removal through the soil, vadose zone, and through the groundwater system to the pumping well. This tool determines the relative microbial risks associated with the following land use practices:

Onsite wastewater management systems, both multiple individual and community size systems (previously known as septic tanks)

- Dairy farming
- Sheep and beef farming
- Wildfowl
- Stormwater systems
- Animal effluent/manure application to land.

Results

Norovirus was chosen as the most suitable viral pathogen for the MRA tool with regards to the human related land use scenarios. Campylobacter was considered the most appropriate organism to be used for agriculture related land use scenarios due to its widespread prevalence in animals, and the high rate of infections within the NZ population. E coli was included for all land-use scenarios as an indicator of faecal contamination and because of its use in regulatory standards.

The MRA tool has been developed for a range of hydrogeological settings found in NZ. Aquifers can be very heterogeneous, and hydraulic properties can vary over several orders of magnitude, even if measured at wells in close proximity to each other. The contaminant transport and pathogen removal within the aquifer are therefore addressed in a stochastic framework. The soil and vadose zone model also incorporate uncertainty by using probability distributions for various model parameters. The development of the tool and the assumptions used in the simulations for all the scenarios were presented at the 2021 NZ Hydrological Society conference. This presentation focuses on the user interface and how the tool is used for real world problems.

The MRA tool is comprised of a user interface in which the user is able to specify all relevant input such as land use scenarios, climate, distance from the pumped well, soil/vadose zone/aquifer depth and type. Outputs are in the form of probable ranges of contaminant concentrations at the well from multiple overlapping sources, along with the probability of exceeding the pathogen specific maximum acceptable concentration, from a human health risk perspective. The tool provides a rapid and simple analysis of the microbial risks in any selected context, so that the entire spectrum from risk averse to risk tolerant solutions can be considered. This presentation will provide a step-by-step overview of a case study with multiple land uses and pathogens.

OBSERVED MOUNTAINSIDE TEMPERATURE LAPSE-RATES

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Aims
The aim of the project is to measure temperature up the sides of mountains for future comparison to commonly used lapse rates.

Method
On four different mountainsides, ten temperature sensors were installed at ~100 m elevation intervals. All mountains are in the Canterbury region: Mt Philistine, the Broken River Ski field, Mt Potts and Mt Hutt (Figure 1).

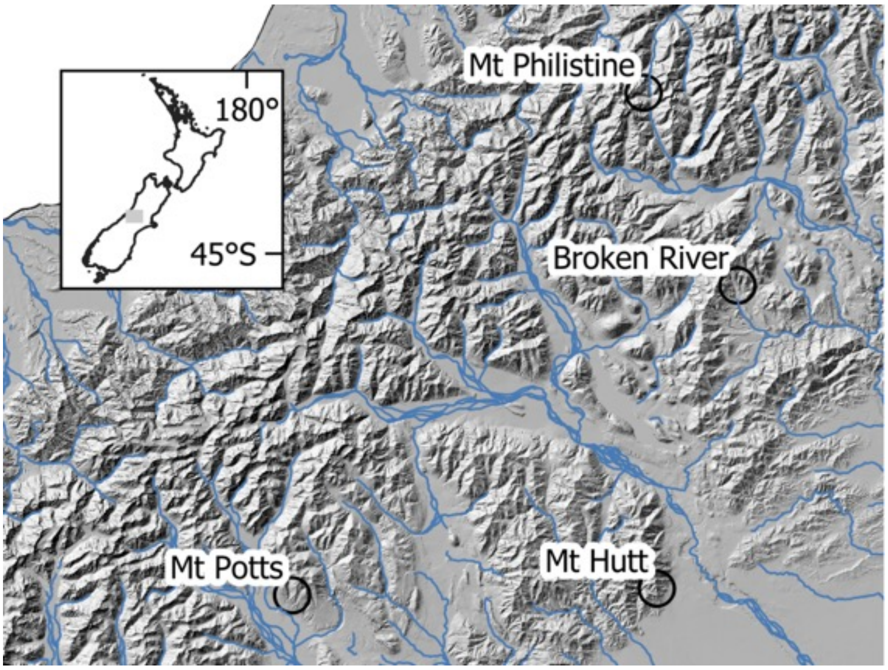

Figure 1. Location of the four mountain temperature measurement transects

The temperature sensors for Mt Hutt and Broken River Ski Field were operating by October 2021, Mt Potts, and Mt Philistine were operating by December 2021.
The intention is to continue the measurments for several years.
Temperature is logged at 30 minute intervals. Data are downloaded on-site every 6 months.
For each mountain the average lapse rates of the daily minimum, mean and maximum temperatures have been calculated.

Results
A summary of the lapse rates measured at each mountain is provided in Table 1. These early results indicate that the lapse rates are different on each mountain, with high variability. From this preliminary data it appears that, generally, the daily minimum temperatures have a smaller lapse rate than the daily mean, which is smaller than the daily maximum temperatures.

Table 1. Mean daily lapse rates (°C/km) for the four mountains based on measurements taken so far. Uncertainties are ± 2 standard deviations

	Daily Minimum	Daily Mean	Daily Maximum
Mt Philistine	-3.8 ± 8.6	-5.7 ± 4.4	-9.5 ± 7.2
Broken River Ski Field	-2.6 ± 7.0	-3.9 ± 6.0	-5.6 ± 5.4
Mt Potts	-6.3 ± 3.0	-6.9 ± 2.6	-6.8 ± 5.4
Mt Hutt	-3.8 ± 4.6	-4.9 ± 4.2	-6.7 ± 6.2

Figure 2 provides an example of the daily variation in lapse rates as measured at the Broken River Ski Field transect. The lapse rate changes considerably from day to day with frequent positive lapse rates through autumn and winter.

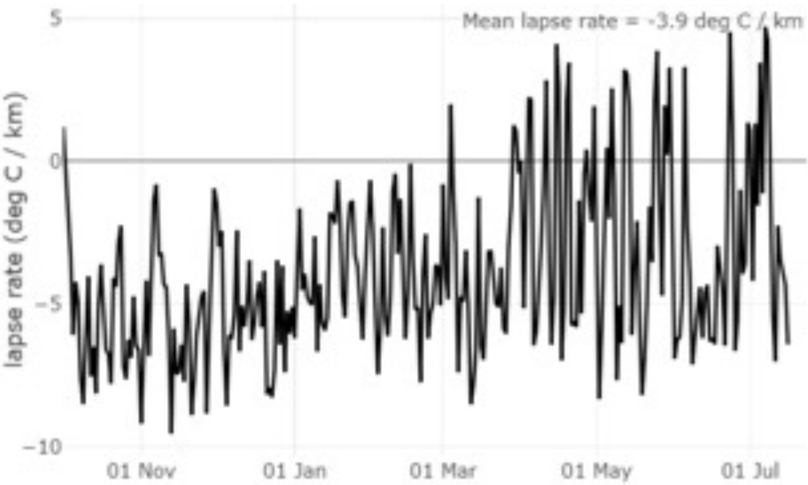

Figure 2. Lapse rates of mean daily temperature at Broken River Ski field.

The International Standard Atmosphere average lapse rate is defined as -6.5 oC/km (ISO 2533:1975)

In New Zealand, efforts to improve existing gridded temperature data in New Zealand mountain regions have used -5 oC/km for interpolation of climate station data (Tait and Macara, 2014). The measurements taken so far indicate that use of single lapse rates for daily interpolation of climate station data in the New Zealand mountains will provide a poor estimate of the actual temperature.

It is anticipated that with further measurements over several years that a valuable data set will be available to enable determining the uncertainty of various temperature interpolation schemes, and will enable exporation of methods for improvement.

Details of the sites and summary graphs of the lapse rates are avaiable at https://apps.rainfall.nz/MountainTemperature/

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DESIGN METHODOLOGY FOR CULVERTS WITH FISH PASSAGE

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Introduction

Fish passage requirements for culverts were introduced as part of the Freshwater Fisheries Regulation in 1983 and its enforcement has been a responsibility of DOC. Under the RMA (1991), control of the environmental effects of culverts became the responsibility of Regional Councils. In practice, the impact of the above on culvert design was relatively small. Guidelines for fish passage at culverts continued to focus primarily on the swimming characteristics of fish. Engineering design guidelines for achieving culvert hydraulics that support passage of New Zealand native fish were not well defined and lacked measurable design criteria. The introduction of the New Zealand Fish Passage Guidelines (Franklin et al., 2018) aimed to fill this gap. The guidelines included an approach for obtaining suitable hydraulic parameters for meeting fish passage. However, in practice, the approach did not provide clear quantitative design requirements that can easily be included in a design methodology. As a result, confirming that a culvert design meets fish passage requirements, particularly the new National Environmental Standards for Freshwater 2020 (NES-F), is difficult. To better align the Fish Passage Guidelines with the new policy requirements set out in the NES-F and the information required for quantitative design, NIWA is currently in the process of updating the document. In support of the updated Fish Passage Guidelines, this paper reports on a methodology for detailed design of culverts with fish passage.

Typical Culvert Design Methodology without Fish Passage
Run-off from the catchment upstream of the culvert yields the design flow rate for that culvert for particular design storm events. High level flow rate estimates can be obtained using the rational method or the SCS curve number method. More detailed estimates can be obtained through software EPA SWMM which includes various infiltration methods for taking into account the impact of the soil on the run-off. For the design flow, the culvert hydraulics are modelled in software such as HY-8 or HEC-RAS to determine the culvert size. Input parameters include the downstream stream characteristics obtained from the field and the culvert parameters (size, shape, roughness, gradient and length). The model is iterated until a culvert size is found that meets the head-water requirements for all design events (e.g. head-water to be below soffit during 10yr ARI event and 500 mm freeboard below road verge during 100yr ARI event). The culvert size yields the cross-sectional average velocity at the downstream end of the culvert which informs erosion countermeasures and channel stability measures if required.

Proposed Culvert Design Methodology including Fish Passage
The proposed culvert design methodology adds the requirements related to fish passage to the head-water requirements during the iterative modelling steps to obtain a suitable culvert size. The fish passage requirements are based on water depth and velocity thresholds that allow fish to pass through the culverts between a minimum and maximum design flow rate for which fish passage should be possible.

For single cell culverts, the maximum flow rate for which fish passage should be possible is set to half of the 2yr ARI flow rate. One half of the 2yr ARI event provides a reasonable approximation of the mean annual flood flow, which in small wadable streams is roughly the bank-full flow. Based on information provided by freshwater biologists, native fish migration is likely to occur predominantly up to the bank-full flow. If a measured dry weather flow is available for the stream, it can be used as the minimum flow rate. Using the base flow and the half of the 2yr ARI flow as the design events for fish passage means that the velocity inside the culvert is suitable whenever fish migration is most likely to be occurring. If the base flow is not known, or the stream is ephemeral, a flow rate less than half of the 2yr ARI flow is used to confirm the range of flow rates for which fish passage is possible.

For multi-cell culverts, the procedure is more complicated, as fish passage may be possible in one of the secondary culverts, but not in the primary culvert or vice versa. If the multi-cell culvert has been designed for fish passage to occur during low flows in the primary and in a secondary culvert during high flows, then it must be confirmed that there is a flow rate for which both the primary and secondary culvert yield suitable fish passage conditions. This guarantees that within the range of flows which require fish passage, there is not a flow rate for which fish passage is not possible.

A typical value for the minimum depth threshold is 150 mm (Franklin et al., 2018). The value for the maximum velocity threshold must be based on the swimming capabilities of the fish expected to be present in the area. Franklin et al. (2018) presents a summary of currently available data on swimming velocities for New Zealand native fish species. The swimming velocities enable a comparison to be made with water velocities in the culvert. The swimming velocities must exceed the culvert water velocities by an amount that when multiplied by the duration that the fish can maintain the given swimming speed, the resulting distance is greater than the length of the culvert.

The typical culvert design yields an estimated cross-sectional average (1D) velocity. This estimate is suitable for design of downstream erosion protection, which is based on 1D equations. However, when assessing fish passage, it is important to account for the reduced velocities around the wetted perimeter of the culvert that fish can take advantage of to migrate. The distribution of the cross-sectional velocity in a culvert depends on its shape, wall/bed roughness, and water depth. Zhai et al. (2014) developed a methodology for determining the velocity distribution within a culvert cross-section based on physical and numerical experiments.

HY-8, the culvert evaluation software by USDoT FHWA (United States Department of Transportation Federal Highway Administration), includes a feature that uses the methodology by Zhai et al. (2014) and the calculated maximum cross-sectional average velocity in the culvert, to calculate depth-averaged velocities within a vertical slice of the culvert as a function of distance from the culvert wall. As input for its evaluation of fish passage, the software requires the minimum and maximum flow rates for which fish passage should be possible, the maximum threshold velocity for the flow within a vertical slice that allows fish to pass, and the minimum threshold depth for the flow within a vertical slice that allows fish to pass.

Results from HY-8 for an example single-cell 1.5 m square box culvert with 375 mm embedment are presented in Figure 1. The high flow results correspond to the 50% of the 2yr ARI flow rate. The base flow was not known and was set to 10% of the 2yr ARI flow rate. The maximum threshold velocity was set to 0.25 m/s for this example and the minimum threshold depth to 150 mm. Figure 1 shows that at the low flow rate, the 0.30 m nearest to the culvert wall would reasonably accommodate fish passage. At the high flow rate, the 0.19 m closest to the culvert wall would reasonably accommodate fish passage. It is assumed that if the distance from the wall, where fish passage is accommodated, is greater than the minimum depth threshold, then the culvert design would be considered passable.

Parameter (units)	Value	Value	Value	Value	Value	Value	Value	Value	Value
Low Flow Results									
Distance from wall (m)	0.00 - 0.04	0.04 - 0.08	0.08 - 0.11	0.11 - 0.15	0.15 - 0.19	0.19 - 0.23	0.23 - 0.26	0.26 - 0.30	0.30 - 0.34
Slice Average Velocity (m/s)	0.02	0.05	0.13	0.18	0.20	0.22	0.24	0.25	0.26
Slice Depth (m)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Threshold	Threshod Met	Threshod Met	Threshod Met	Threshod Met	Threshod Met	Threshod Met	Threshod Met	Threshod Met	Too Fast
High Flow Results									
Distance from wall (m)	0.00 - 0.04	0.04 - 0.08	0.08 - 0.11	0.11 - 0.15	0.15 - 0.19	0.19 - 0.23	0.23 - 0.26	0.26 - 0.30	0.30 - 0.34
Slice Average Velocity (m/s)	0.02	0.06	0.15	0.20	0.23	0.25	0.27	0.28	0.30
Slice Depth (m)	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Threshold	Threshod Met	Threshod Met	Threshod Met	Threshod Met	Threshod Met	Too Fast	Too Fast	Too Fast	Too Fast

Figure 1: HY-8 Low Flow analysis results table

Conclusions

The proposed culvert design methodology is based on a detailed analysis of the hydraulic parameters of the flow in the culvert, and compares these with the threshold parameters required for fish passage, to ensure that the culvert design accommodates fish passage for the range of flow rates during which fish migration is expected. The methodology adds the fish passage requirements to the head-water requirements during the culvert design process that yields a suitable culvert size. The next step is to add the requirements related to the continuity of geomorphic processes to the design methodology as well.

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CONSIDERATIONS FOR NATIONAL SCALE MODEL OF GROUNDWATER AGE

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Physically based numerical groundwater models provide essential tools to help inform resource management decisions by extending our understanding of groundwater systems beyond direct observations. We present a national-scale model of groundwater age, origin and flow paths for New Zealand developed as part of the Te Whakaheke o Te Wai Project (Figure 1), to support the effective management of water resources at a national scale. This national scale model is also used to inform the boundary conditions and properties of smaller models tailored to address specific water management issues. NIWA have also adopted this model in their national hydrologic modelling platform (NZWaM).

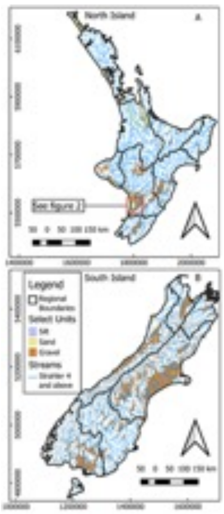

Figure 1 Map of New Zealand showing Strahler order 4 streams and above, regional boundaries, and hydrogeologic units of interest in this study (silt, sand, and gravel)

Aim

The development of this national scale model requires consideration of properties and processes spanning orders of magnitude in both time and space. The simplification of real-world properties and processes to facilitate efficient computation is an inevitable component of modelling and is especially so at this scale. At the same time the model design needs to avoid too much simplification which can induce a systematic bias in parameters and any predictions that depend on these parameters. Determining the appropriate level of simplification to include in groundwater models remains a challenging issue and depends on the intended use of the model and the availability of data.

The aim of this study is to explore appropriate levels of model structure, parameter and process simplification for the type of predictions that will be made using this national scale model.

Method

One of the most fundamental techniques for simplifying processes and properties in numerical groundwater models is the subdivision of the model domain into discrete volumes with representative properties ("representative elemental volume" or REV; the volume within which properties are assumed to be constant to facilitate numerical modelling). This requires heterogeneous and potentially scale dependent properties (e.g., hydraulic conductivity, porosity) within each REV to be represented by a single value in each cell. Complex processes (e.g., stream-aquifer interactions) also need to be conceptualized and simplified in a way that allows them to be effectively represented over the entire cell.

Model discretization provides the underlying structure to support the parameter representation (parameterization) of hydraulic properties. It also imposes a limit on the level of parameterization a numerical groundwater model can accommodate for history matching and predictions. Coarse discretization can reduce the computational burden and may ease the parameter estimation and inversion process, but it also increases the potential for structural deficiencies caused by homogenising processes and properties over larger areas which can bias model results (e.g., Knowling et al., 2019).

Numerical experiments are used in this national model development to explore these important parameter and process simplification considerations and challenges that arise when developing a national scale groundwater model including: 1) trade-offs between model resolution and computational burden, 2) upscaling of hydraulic properties to an REV, 3) representation of local processes over a large REV (e.g. upscaling stream-aquifer interactions), 4) representation of high variations in permeability (e.g. bedrock – aquifer contacts which typically form model boundaries in "traditional" groundwater models), 5) large changes in topography (e.g. Southern Alps rising 3,700 km from sea level over 30 km and/or deeply incised streams), and 6) limited subsurface data makes characterization of the groundwater system difficult, especially in areas with complex topography and geology like Aotearoa/New Zealand.

These numerical experiments adopt a paired simple-complex model analysis, using the "iterative ensemble smoother" method for history matching to results from a stochastic realization of a complex model. Using this approach, we can establish a "synthetic truth" to test the implications of model simplifications (e.g. Doherty and Christensen, 2011).

Results

Of these numerical experiments, we focus our presentation here on the impact of vertical simplification on the model's ability to make predictions of groundwater age, where these vertical discretisations are depicted in Figure 2. Our results show that vertical simplification can decrease the model's ability to accurately predict groundwater age.

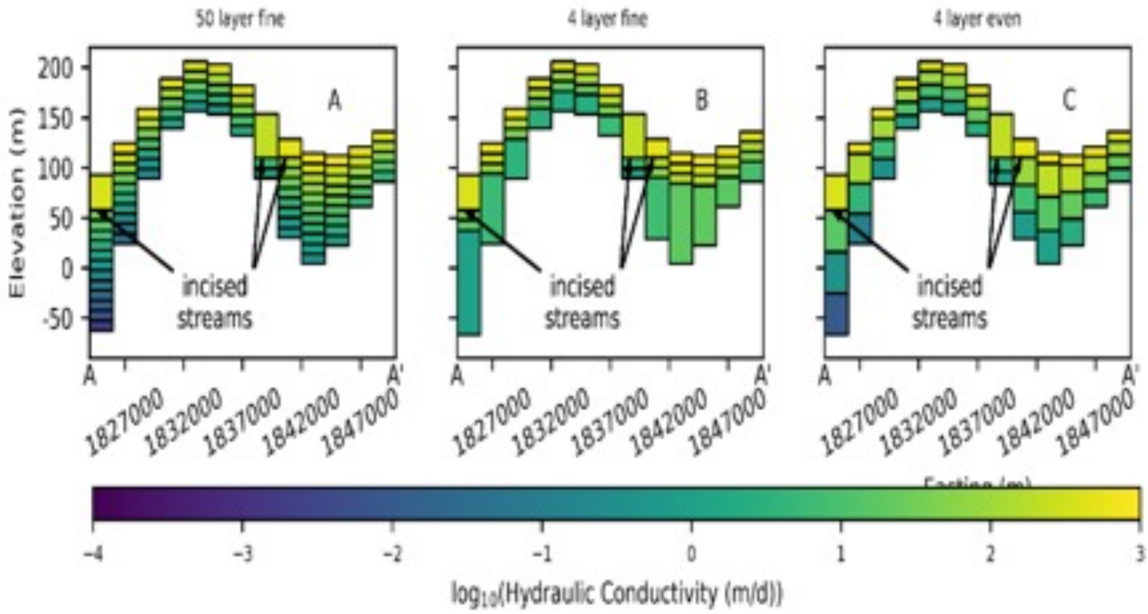

Figure 2. For a selected cross section of the national model we compare the discretization and upscaled hydraulic conductivity values (log(K)) for a (A) 50-layer model, (B) 4-layer model with fine upper discretization, (C) 4-layer model with evenly distributed deeper layers.

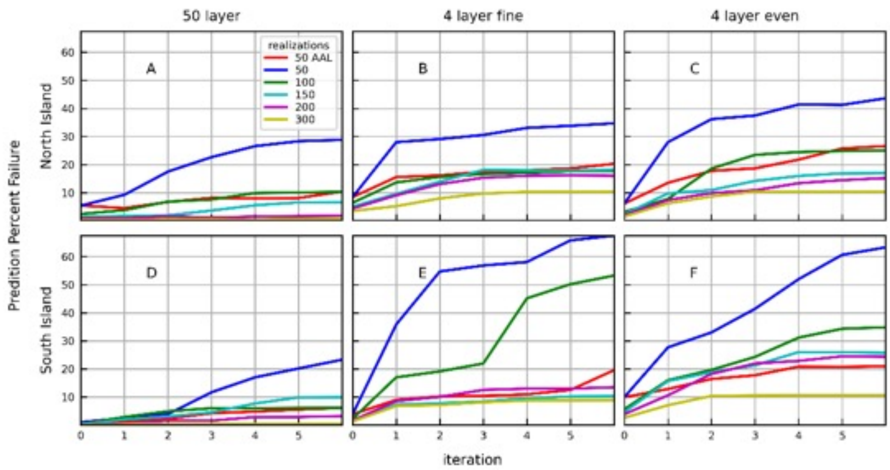

Figure 3. Percent failure (Pf) by iteration, ensemble size, and model structure for predictions (unweighted observations). Ensemble sizes are indicated by colours.

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MODELLING GROUNDWATER AND SURFACE WATER INTERACTIONS IN THE NEW ZEALAND WATER MODEL (NZWAM)

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Effective management of water requires consideration of both groundwater and surface water systems. In order to facilitate effective management decisions, models need to be numerically efficient while still effectively representing the important aspects of the system being modelled. Modern numerical models can simulate a variety of processes that impact the health and availability of water. However, discrepancies in temporal and spatial scales often provide formidable obstacles for successfully coupling surface water and groundwater models. In addition, differences in conceptualization of flow and storage processes can result in inconsistent representation of various components across the various models.

TopNet (Clark et al., 2008) is a catchment-based model of New Zealand that focuses on surface processes. TopNet is based on the TopMODEL developed (Beven, et al., 2021). Groundwater recharge from the surface is estimated and TopNet-GW represents regional groundwater flow in a conceptual way. However, subsurface hydrogeology is not well represented and groundwater flow is not explicitly simulated.

MODFLOW is the most widely used groundwater modelling software in the world. A national scale groundwater model of New Zealand was recently created for Te Whakaheke o Te Wai using MODFLOW 6. This model routes excess groundwater to nearby streams and simulates channel flow but lacks the ability to simulate processes such as overland flow, soil storage, and evapotranspiration.

Aim

Versions of fully integrated groundwater-surface water modelling software exist (e.g., Davidson, et al., 2018; Maxwell and Miller, 2005; Regan, et al., 2022). These fully integrated models ensure conservation of mass between all components of the model with each time step. However, they often suffer from numerical instability and/or excessively long simulation times making them impractical for history matching and decision support. In addition, proper parameterization of these models requires a high level of expertise and a significant amount of work.

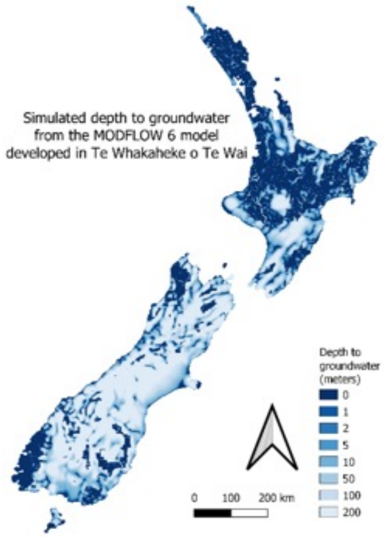

Figure 1 Depth to groundwater from the national scale model developed in Te Whakaheke o Te Wai.

The aim of this study is to demonstrate approaches for coupling of the existing national scale TopNet model and the national scale MODFLOW 6 groundwater model recently developed in Te Whakaheke o Te Wai within HydroDeskNZ, the user interface for the NZWaM project. Emphasis is placed on describing the conceptualization of processes and potential errors arising from associated approximations, the passing of information between the two models, and the computational burden imposed by the coupling methods.

Method

We perform "loose coupling" between the national scale TopNet and MODFLOW models by using estimates of groundwater recharge from TopNet as inputs for land surface recharge in the MODFLOW model (Figure 2). This provides a computationally efficient way to link two existing models. We compare these results to MODFLOW simulations using other estimates of groundwater recharge (e.g., Westerhoff et al., 2018). Simulated streamflow and groundwater head are compared between the different recharge options in the model.

MODFLOW 6 includes an "Application Programming Interace" (API) developed using the "Basic Model Interface" (BMI), which allows models with different source code to interact without modifying the original source code (Hughes et al., 2022), so long as each model adheres to the appropriate interface requirements. Work is underway to tightly couple TopNet with MODFLOW for a case study in New Zealand. We discuss conceptualization and technical challenges associated with this coupling.

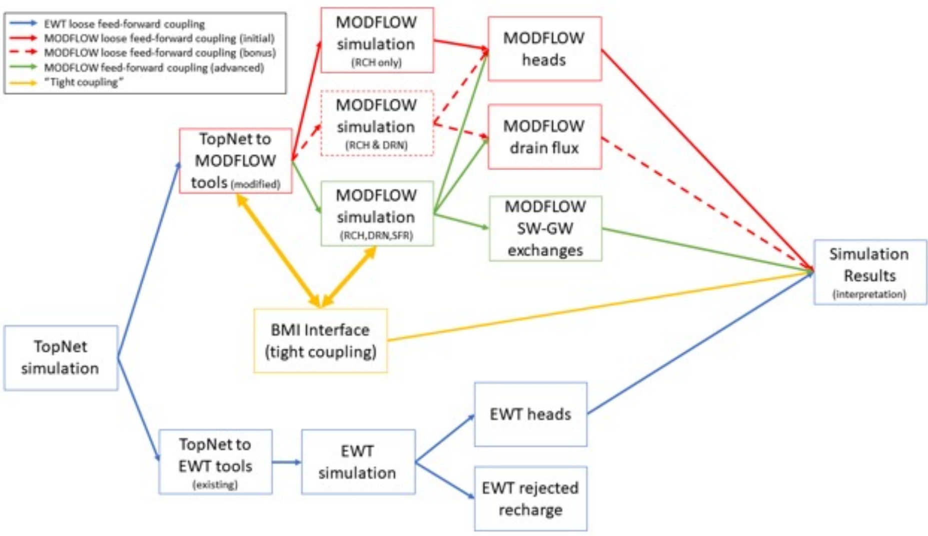

Figure 1 Comparison of different approaches for TopNet-MODFLOW and TopNet-EWT coupling.

Results

We present a "loosely coupled" TopNet-MODFLOW model for New Zealand. We compare simulated water level, streamflow, and groundwater-surface water exchanges to results from simulations using other estimates of recharge, as well as results from TopNet-Groundwater. We discuss computational and conceptual challenges associated with creating a tightly coupled TopNet-MODFLOW model using the BMI.

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MĀ TE HAUMARU Ō TE WAI: INCREASING FLOOD RESILIENCE ACROSS AOTEAROA

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Aims

Mā te haumaru ō te wai: increasing flood resilience over Aotearoa is a five-year MBIE-funded Endeavour programme which will provide accurate, nationally consistent flood hazard and risk information to stakeholders including central, regional, and local government, and iwi. The programme is also working with these stakeholders to better understand the issues that Aotearoa faces and to ensure robust flood adaptation decisions are being made. This is vitally important as the combined pressures of climate change (Hirabayashi et al., 2013), housing shortages and aging flood infrastructure (Te Uru Kahika, 2022) means that there are critical flooding decisions that need to be made in the near future.

This programme consists of four research aims with two overarching themes: Mātauranga Māori; and Uncertainty (see Figure 1). The research aims cover the flood hazard (i.e. where inundation occurs, both under the current and future climates), the flood risk (what gets wet and the impacts of that), societal vulnerability (how communities cope with flooding – especially repeated flooding) and how to use this information to make Aotearoa more flood resilient – especially under climate change and other pressures.

Figure 1: A schematic diagram of the four research aims and two themes showing how they interconnect.

Method
Rather than simply providing flood maps, our programme is focussed on creating a semi-automated system for flood modelling and is based on a philosophy of continual improvement. There are many reasons why automating the system as much as possible is important. We currently do not have LiDAR for all of Aotearoa, but new LiDAR needs to be incorporated into our modelling as quickly and efficiently as possible as it becomes available. Furthermore, Aotearoa stradles two tectonic plates, meaning that seismic activity can drastically change the topography. The February 22, 2010 earthquake quite literally changed the flood hazard landscape in the Flockton Basin (Hughes et al., 2015). Furthermore, as the effects of climate change play out, the continual improvement approach will allow the models to adapt and remain current.

Continual improvement is also vital aspect to the work. Figure 2 shows the basic outline of the system from underlying datasets through to national map. Future iterations will build on earlier versions and be able to incorporate additional details such as improved representation of groundwater and flood defences. Increases in computational power will also allow higher resolution and a greater range of scenarios to be modelled.

The system is based on fluvial and pluvial catchment scale modelling and a design storm concept that can be adjusted to account for climate change effects. The results will be incorporated into national scale flood hazard layers.

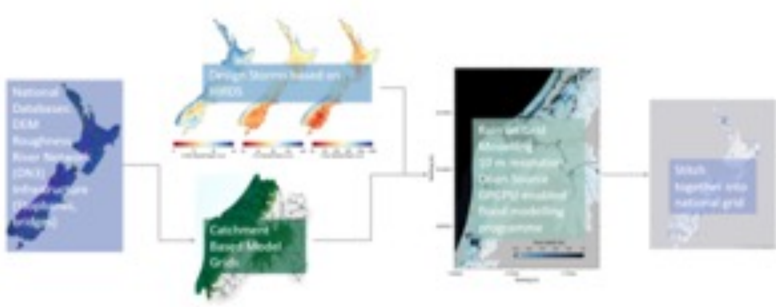

Figure 2: The basic workflow of the flood mapping system.

Results
We are now two years into this five-year programme and the flood mapping system is at the point where we are starting to apply it beyond our prototype regions to assess flood risk in other areas. This work will inform the other aspects of the programme and result in consistent flood maps across Aotearoa, providing underlying information for places where the flood hazard has not yet been assessed. The flood mapping, however, is only the start of the process, and the work of the other research aims is vital in ensuring that these outputs are presented and used in ways that do lead to increased flood resilience for the future.

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

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Groundwater-surface water interaction in the Upper Taieri Scroll Plain, Otago

Aims
Interaction with groundwater can significantly impact the hydrology, water quality, and ecology of wetlands and rivers. The aim of this research is to further understand the magnitude and temporal/spatial dynamics of groundwater-wetland-river interactions in the Upper Taieri Scroll Plain (Scroll Plain).

The Taieri is the 4th longest river in New Zealand, and it has significant ecological, cultural, and economic values. The Upper Taieri contains the Scroll Plain wetlands complex that hold unique landscape and biodiversity values of international, national, and regional significance. These wetlands are likely to experience interaction between groundwater and surface water that can impact their hydrology, water quality, and ecology. However, despite this importance, there is currently only sparse information about groundwater in the Scroll Plain.

The study focuses on monitoring groundwater and river levels, quality, and geochemistry in the Scroll Plain. Groundwater and river levels are monitored every five minutes using pressure transducers. Water physicochemical parameters and nutrients (temperature, pH, Electrical Conductivity, Dissolved Oxygen, nitrate, nitrite, and Chlorophyll A) are collected in the field monthly using handheld meters and flow cells. Water geochemistry (major anions & cations) and nutrients are analysed in the laboratory. The main objectives of the project are:

Assessing the impact of river levels on groundwater levels in the wetland

Delineating the sources of recharge in the catchment

Determining the hydrogeological parameters (hydraulic conductivity, Transmissivity, Storativity) for the area

Method
Groundwater levels and quality are monitored in 12 bores located in four sites across the Scroll Plain. River levels in the Taieri are monitored in three locations near the bore sites. Each site has a transect of three shallow bores (4-6m deep) situated near the river, within the flood zone, and above the maximum flood level. The sites are situated on different land uses across the Scroll Plain (dairy, sheep & beef, deer, and a sheep/beef block recently converted to conservation land).

The bores were installed using the lost cone method, which provides some lithological information but not a complete bore log. Nevertheless, some useful insights were obtained, with observations of some fine-grained layers (silt, silty sand) and layers of medium/coarse gravels and pebbles. The water table is shallow, ranging between approximately 0.80 and 2.5m below Measuring Point, with shallower water table closer to the river.

Results
The sites were installed in June 2022, hence, this paper only covers the initial monitoring results. The geochemistry data shows that the river water chemistry is similar across the three sites, with a composition of approximately 55% bicarbonate/alkalinity and 40% chloride. Conversely, the groundwater chemistry has shown different spatial patterns. A Piper plot shows that groundwater chemistry in the outer bores (i.e. those situated furthest from the river) is dominated by sulphate and chloride, while the sites nearer the river are dominated by bicarbonate/alkalinity. For the cations, the composition is much more similar across most sites, with approximately 50% sodium/potassium, 30% calcium and 20% magnesium. Dissolved oxygen concentrations vary across the sites, with higher concentrations measured in the outer bores. The bores near the river generally have lower Dissolved Oxygen concentrations, suggesting more anoxic conditions. These sites also had the lowest nitrate concentrations and higher arsenic concentrations, that can be associated with reducing environments.

DRY-CALM-CLOUDY YEARS IN AOTEAROA'S ENERGY FUTURE

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Aim
With hydroelectricity providing 55% of NZ electricity, there have been 'dry years' when low autumn inflows result in low hydro storage for the critical winter period. The Ministry of Business, Innovation and Employment (MBIE) seeks to address this problem with the 'NZ Battery' project, exploring in particular pumped hydro storage. As a contribution to that work, we explore how the problem may changing a future with much more renewable energy from wind and solar generation. What are the risks and implications of a future dry-calm-cloudy year?

Method
To characterise past climate and evaluate the potential of the three alternative types of generation, we used the following sources of historical information:

- Hydro: The Hydrological Modelling Dataset (HMD) of historical stream and river flows into hydro lakes, from the Electricity Authority (EA).
- Wind: Reanalysis of data from a very high-resolution NZ Convective Scale (weather) Model (NZCSM), together with wind generation data for 2018–2020 from the EA.
- Solar: Pyranometer (solar irradiance) data from the NIWA Climate Database, collated and quality-controlled into time series for 18 climate zones to represent NZ climates.

Projected hydro, wind, and solar generation came from six General Circulation Models (GCMs) that, of the 41 in the IPCC AR5 model archive, were previously found (MfE, 2018) to represent NZ climates well. The six models had been dynamically downscaled over NZ for the four IPCC AR5 Representative Concentration Pathways (RCPs) from 2021 to 2070, and for past greenhouse gas concentrations from 1981 to 2005 (from which 1986–2005 forms the 'hindcast'). For hydro, the climate model ensemble was coupled with NIWA's TopNet hydrological model to simulate natural inflows at HMD dataset locations under past and future conditions. Scenario analysis was in three stages:

- For each type of generation, the hindcast generation potential was compared with historical data and bias-corrected if needed.
- Patterns of change from past to future climate scenarios were described in terms of their effects on potential power generation.
- The current and future correlations between the potential for hydro, wind and solar energy generation were assessed, and the implications for pumped hydro storage considered.

Results
Hydroelectricity:

- South Island hydro generation capacity is more than three times that of North Island.
- North Island summer hydroelectricity generation has been stable over the period from 1972- 2017, while the South Island summer generation decreased after 1984.
- North Island winter flows diminished over the hindcast period, while South Island winter flows increased.

Future outlook for hydroelectricity:

- North Island annual hydro generation at lowest 5% may increase by up to 10%.
- South Island annual hydro generation at lowest 5% is projected to increase by about 16%. Variability in the lowest 5% of South Island annual generation doubles from the hindcast period to 2051–2070.

Wind power:

- Installed wind capacity is about 1 gigawatt-peak (GWp). Another 2 GWp is consented, with nearly 2 GWp more proposed. We assumed these, plus 5 GWp offshore, for a total 10 GWp.
- Of the present 1 GWp, 90% is in the North Island, and for the 10 GWp it would be similar. The overall pattern of wind generation for NZis lower in autumn and higher in spring, similar to that of hydroelectricity. Both the seasonality and year-to-year variability of wind is relatively less than for hydro.

Future outlook for wind power:

- All GCM models and RCPs show a modest (5-10%) increase in spring generation, stronger in the South Island.
- Small (<5%) decreases in summer and autumn are predicted in most models, while winter generation has a comparably small increase.
- Future changes in projected total wind capacity are very much less than the uncertainty in how much of that capacity will be built in future wind farm construction.

Solar energy:
- Solar power accounts for less than 0.3% of NZ generation at present, but it is expected to reach 2% within the next two years and continue to grow.
- Solar generation is two to four times higher in summer than in winter, so it will add relatively little to winter hydro and wind generation.
- Countering the previous point, abundant solar generation in summer would mean that hydro storage could be maximised going into autumn.
- Solar photovoltaic generation is expected to be widely distributed, probably in approximate proportion to population and associated demand, and the resulting solar power will be much less variable year-to-year than either hydro or wind power.

Future outlook for solar energy:
- The downscaled Coupled Model Intercomparison Project 5 (CMIP5) models in hindcast mode closely match the distribution of measured daily solar radiation when both are applied to the putative future distribution of solar panels. This gives us confidence that the future projections of solar generation are representative.
- All models and RCPs show small and inconsistent changes in solar generation from hindcast amounts.

Linear correlations of the expected power output of the three forms of generation were explored at monthly and weekly time scales, and between islands, in both hindcast and future projections. Most important for national power generation was a positive correlation (R ~0.6) between the two largest future renewable supplies, South Island hydro and North Island wind. It applies to both total generation and year-to-year differences from mean seasonality, indicating that dry months are also somewhat less windy.

Though the most variable on short time scales, solar energy is the least uncertain, especially with distributed systems. It will be the main source of surplus generation for hydrogen or pumped hydro. The correlations vary between models, and between hindcast and future scenarios for four different RCPs, but there is no clear expectation that future correlations will differ from present.

Residual		Wind		Solar	
		N	S	N	S
Hydro	N	0.05 – 0.19	-0.09 – 0.07	-0.43 – -0.34	-0.27 – -0.18
	S	0.53 – 0.63	0.35 – 0.48	-0.11 – 0.01	-0.17 – -0.02
Wind	N			0.05 – 0.14	0.17 – 0.32
	S			0.15 – 0.23	0.17 – 0.31

Table 1: Correlations between residual variation in hindcast monthly generation show the extent to which any month is wetter or drier, windier or calmer, and clearer or cloudier than usual.

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SOURCE WATER RISK ASSESSMENT AND MANAGEMENT: A PRACTICAL IMPLEMENTATION

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Aims

The development of Source Water Risk Management Plans (SWRMP) is now legally mandated for all registered water suppliers under the Water Services Act 2021. Understanding and managing risks to drinking water sources (and accordingly, risks to the health of people who consume those resources) are part of the hierarchy of obligations under Te Mana O Te Wai (NPS-FM, 2020). Although there is some practical guidance for the delineation of Source Water Risk Management Areas (SWRMA) (Rutter & Moore, 2021) and SWRMP development as part of the legislation, the practice is still emerging. Particular challenges include multiple raw water supplies, effective processing and analysis of existing data resources and variability in the spatial, temporal characteristics and human health effects of potential contaminant sources. In addition, the SWRMPs are required to support operational risk management and be 'living' documents, that can be updated according to changes within the catchment.

Tonkin & Taylor (T+T) have been working with our clients to provide a robust, defensible and scalable methods for the development of SWRMP across multiple water supplies and regions. In this case study, we describe the development of SWRMP for Waimakariri District Council (WDC), who operate twelve primary water supplies in their rohe. Working closely with WDC, we have developed a methodology that encompasses data capture and analysis of identified hazards, catchment risk assessments and steps for developing SWRMPs.

Method

Before hazard identification can be undertaken, the catchment area of the water source, known as a SWRMA, must be delineated. These areas can be developed using various analytical and numerical tools depending on a range of factors including data/model availability and water source characteristics.

For the Waimakariri SWRMAs, we have adopted the Waimakariri numerical groundwater model (Etheridge & Hanson, 2019) that was developed by Environment Canterbury (ECan) and has been subject to peer review. The Waimakariri numerical model included a significant uncertainty component, undertaken in conjunction with GNS, which produced an ensemble of model realisations that could be used for subsequent predictive analysis. T+T used this model ensemble as the basis for delineating the SWRMA, including the use of particle tracking for delineation of the intermediate SWRMA2, which is defined by a 1-year time of travel. The use of python scripting tools such as FloPy, has enabled the efficient implementation of the approach across multiple water supplies and model realisations. Several water supplies were conjunctive takes with a significant surface water component to the groundwater source. Here, geospatial analysis was also undertaken using a scripting environment to ensure reproducibility and accuracy.

Identification of hazards within a water source catchment is a technical challenge. Hazard data were assimilated into Catchment Risk Assessments (CRA) which form an integral part of understanding the risks to a water source. These assessments comprise desk-based components and site visits of the immediate source water areas (SWRMA1 and part of SWRMA2). CRA rely on a detailed understanding of the historic, current and future activities in the catchments which may pose a risk to the water source through deterioration of water quality from potentially contaminating activities. For each water source, a conceptual hydrogeological model was developed to identify the pathways for potential contaminants to enter into the water source; either into an aquifer or directly into surface water.

For the Waimakariri SWRMAs, data sources included a review of land use mapping, aerial imagery, ECan publicly available data (such as discharge consents, bores and wells data), Listed Land Use Register and maps of WDC wastewater and stormwater infrastructure. The project presented some data sharing challenges and required handling thousands of different datapoints across the District. The digital data were uploaded to an interactive ArcGIS viewer so that potential contaminant sources could be assigned to specific categories and georeferenced so other assessments could utilise the data.

Further detailed assessments included a screening-level quantitative risk assessment, modelling the potential concentrations of E. coli from sources of microbial pathogen contamination within the catchment that could reach the drinking water supplies. E. coli is a widely accepted indicator for faecal contamination in drinking water sources and is used as a proxy for wastewater discharges from septic tanks and livestock effluent.

Once hazard data had been assimilated and the conceptual hydrogeological understanding had been confirmed, each potential contaminant source was identified and rated based on a qualitative risk rating. Groups of contaminant sources were initially assessed for two scenarios: (i) an unmitigated, and (ii) a mitigated source-based qualitive risk assessment. The mitigated assessment draws on the current monitoring and management controls undertaken by WDC. Further risk management and the implementation of controls (solutions) to reduce or eliminate risks were undertaken. These source water risk management solutions are targeted to the risks characterised in the risk assessment for each water supply, which allow the development of a targeted SWRMP by WDC.

Results
Overall, T+T has developed twelve Catchment Risk Assessments for WDC, including ten groundwater sources, and two conjunctive (groundwater and surface water) source water supplies. The assessments provide a transparent and tangible overview of the potential hazards identified within the defined SWRMA2.

Identified hazards for each water source were grouped based on land use types and proximity to the water source supply. Hazards were assigned a risk rating, based on a likelihood and consequence risk matrix, designed to integrate with WDC's existing risk classification system so that they could be readily employed by WDC operational managers. This resulted in the development of concise water source-specific risk assessment data sets for each water supply. These data sets have been used in the creation of SWRMP by reviewing the residual risks to each source water supply and developing management solutions in partnership with WDC. The risk management solutions, both targeted and generic, were divided into operational and non-operational categories to allow WDC operational managers to make appropriate decisions and take actions for the future management of the source waters.

This risk management forms part of the SWRMP which supports the long-term multi-barrier approach to understanding the health and well-being of the source water. It is a live document with proactive monitoring strategies designed to trigger specific actions when new risks are identified in the catchments. Therefore, T+T are implementing a customised dashboard for WDC that is designed to present a summary of the data for each water source. The dashboard created using ESRI ArcGIS tools, will be a user-friendly, interactive tool that includes near-real time charts and infographics to provide a live snapshot of the risk status of each water source. The final deliverable comprises the dashboard and many reports generated by this complex work package, enabling WDC to create the statutory SWRMPs for their water supplies. This will provide WDC with a critical Water Services Act compliance tool for the active future management of their water supply source waters.

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IS CLIMATE CHANGE EVIDENT IN WELLINGTON RAINFALL RECORDS

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[2] Wellington Water Ltd

Aims

As a result of climate change, temperatures are expected to increase. Warmer temperatures mean that more water vapor will enter the atmosphere, while also increasing the air's ability to hold moisture. This may result in changes in rainfall that are often amplified in runoff.

As part of a wider project to better understand the spatial and temporal variability of rainfall across the Wellington Region, potential future changes in rainfall in response to predicted warming were assessed. This included an analysis of any trends in the historic rainfall data to quantify any effect of climate change to date.

Methods

Records from six rain gauges throughout Wellington were used to identify any trend in annual and seasonal rainfall maxima. The sites were selected based on record length (including consideration of gaps) and the quality of the data. Two sites have over 100 years of record – Kaiwharawhara Stream at Karori Reservoir and Wainuiomata River at Wainuiomata Reservoir. The other four sites have records between 50 and 80 years in length. A long-term record for Kelburn was formed by combining data from two gauges at the same location. The six sites are well distributed across the Wellington stormwater catchments.

Data from each site was converted into daily totals from which annual, seasonal and monthly rainfall maxima were obtained. Regression analysis is used to determine whether there was any overall trend in rainfall over time and the strength of any relationship.

Results

Any effects of climate change are yet to be observed in Wellington's rainfall. Variability in Wellington's rainfall appears to be influenced by various shorter period climate indices (e.g. SOI and SAM). There are no consistent trends in annual rainfall or annual maxima across Wellington and the frequency of large events has also not changed. While two of the six sites showed a significant, although weak, positive relationship the other four showed either no change or a negative trend.

Similarly, there is a lack of any consistent trend or correlation when looking at seasonal rainfall and monthly maxima. While some sites suggest seasonal rainfall is increasing, others appear to be decreasing. Few of these relationships are significant.

Therefore, at this point there appears to be no consistent trend of increasing rainfall in Wellington over the past 100-years. It is likely that storm passage, topography and orographic enhancement are stronger controls on rainfall than temperature.

WHEN IT RAINS, IT POURS: AN IDENTIFIED RELATIONSHIP BETWEEN WET DAY FREQUENCY AND PRECIPITATION INTENSITY

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Aims

Understanding precipitation is essential for quantifying weather and climate related risks. Precipitation distributions and how they might change due to climate change are of particular importance in extreme events. Wet day intensity (how much it rains) and wet day frequency (how often it rains) are commonly used independently to evaluate the simulation of precipitation within numerical weather prediction models, reanalyses and climate models. In this work, wet day intensity distributions were grouped by areas of similar wet day frequency across reanalyses, satellite and gauge datasets. Using ERA5 output, correlation with a range of extreme precipitation metrics and the potential drivers for this relationship were also assessed.

Method

Wet day frequency was derived where a period was marked as precipitating if the accumulated precipitation was greater than a 1 mm/day threshold and non-precipitating otherwise. Precipitation intensity data was then aggregated into regions where the wet day frequency was the same. For these regions, precipitation was grouped together to derive cumulative precipitation intensity distributions. As for the wet day frequency, a 1 mm/day equivalent threshold was applied such that only wet days were considered. This methodology produces a new framework for analysing precipitation that links spatially disparate regions together.

Results

When grouping precipitation into regions of similar wet day frequency, regardless of geographical separation, there is a strong correlation with wet day intensity distributions (Figure 1). These wet day frequency regions are also more physically coherent than regions based on geographical location. We find the coherent relationship between wet day frequency and intensity is partially explained by wet day frequency regions having similar vertical velocity and convective available potential energy distributions (Figure 2). These represent dynamic and thermodynamic processes which partially indicate how conducive wet day frequency regions are to large-scale and convective precipitation. Our results show we no longer need to consider wet day intensity and frequency separately, providing a new perspective for understanding precipitation in a changing world.

References

McErlich, C., McDonald, A., Schuddeboom, A., Vishwanathan, G., Renwick, J., & Rana, S. (2022) Identification of the relationship between wet day frequency and precipitation intensity distributions. Nature Geoscience (In review)

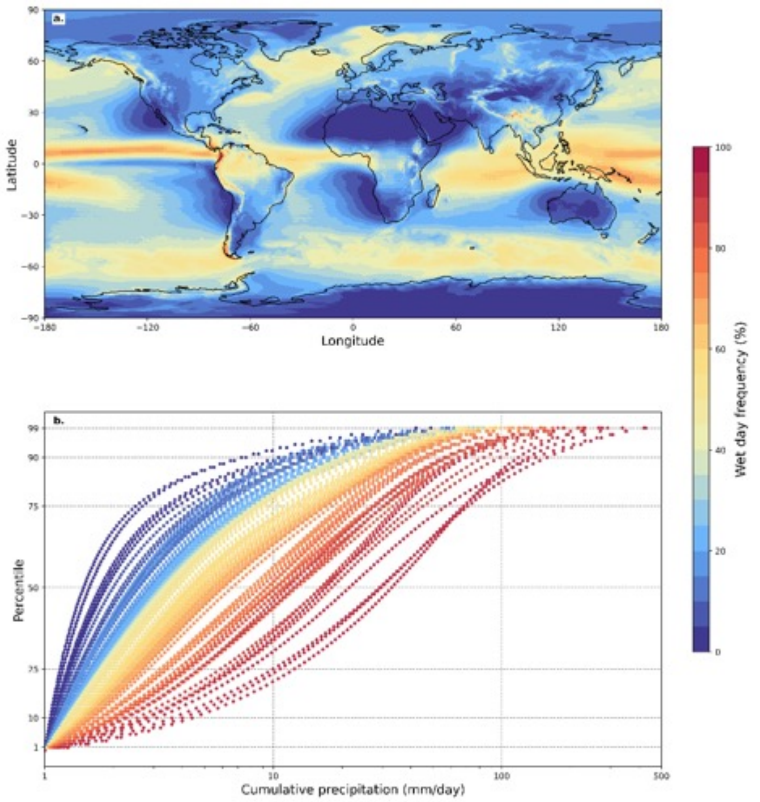

Figure 1: ERA5 total precipitation output between 1980 - 2019 showing a) the geographic distribution of wet day frequency above a 1 mm/day threshold and b) distributions of wet day intensity showing cumulative precipitation values for aggregated regions corresponding to each percentage of the wet day frequency shown in (a). Here precipitation is displayed using a logarithmic scale.

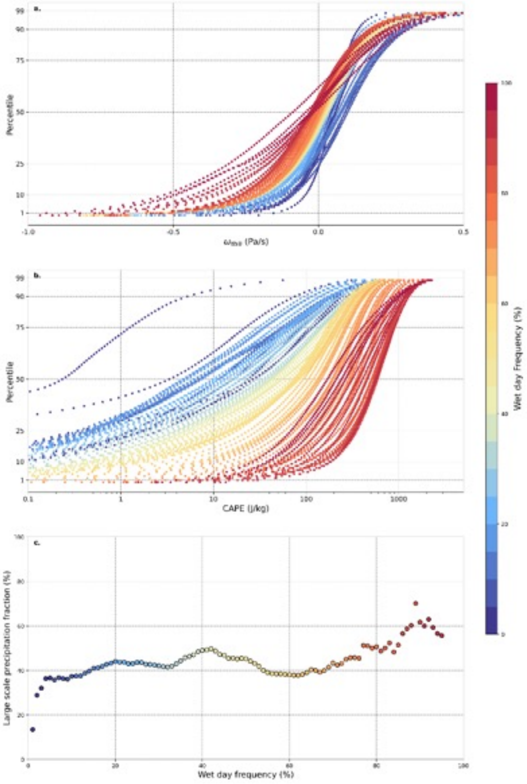

Figure 2: a) Distributions for vertical velocity at 850hPa for all days grouped based on wet day frequency. b) Distributions for CAPE for all days grouped based on wet day frequency. c) The amount of large-scale precipitation as a fraction of the total precipitation. At each point the remaining fraction corresponds to convective precipitation.

THE RELATIVE INFLUENCE OF CLIMATE, LANDSCAPE STRUCTURE, AND FOREST HARVEST ON CATCHMENT SUSPENDED SEDIMENT EXPORT

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The relative and interacting influences of catchment structure, climate variability, and forest disturbance on water and sediment export are poorly understood but requisite for informed forest management decisions.

Aims
Here we investigated how rainfall and snowmelt dynamics, landscape structure, and forest harvesting influenced streamflow and suspended sediment export across six adjacent catchments in the Tenderfoot Creek Experimental Forest (TCEF; Little Belt Mountains of Montana, USA).

Methods
We quantified catchment cumulative suspended sediment export across a 16-year data record. Five years into the study, access roads were installed and 30–40% of the lodgepole pine forest was harvested across two of the six catchments. We compared each catchment's annual suspended sediment export to metrics of landscape and stream network structure derived from spatial analysis of 1m LiDAR data, and annual climate characteristics.

Results
We found significant correlations between sediment export and landscape metrics that relate to hydrologic processes and the potential for sediment mobilization or deposition ($r2=0.75–0.98$, $p<0.05$). The strength of correlations between these metrics and sediment yield became stronger during years of higher precipitation and increased snowmelt intensity. Annual differences in sediment export were strongly related to annual snowmelt intensity ($r2=0.88$, $p<0.001$) and mean catchment hydrologic response times. Although all catchments exhibited increased streamflow and sediment export from the drier pre-treatment period to the wetter post-treatment period, the harvested catchments responded disproportionately with increases in streamflow of 25–75% and increases in sediment export of 140–175%. Prior to harvest, these two catchments exhibited the lowest sediment export of the six, likely due to differences in landscape structure and organization. Our results indicate that differential sediment export across catchments can occur as a function of climate, landscape structure, and disturbance magnitudes. This suggests that similar management strategies can result in different water and sediment export dynamics that persist for years depending on catchment characteristics and climate dynamics following disturbance.

UV CHANGES DUE TO DAILY AND SEASONAL VARIABILITY IN OZONE

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Extended Abstract
We discuss implications for New Zealand of results from our recent paper (McKenzie et al., 2022) that shows the measured relationship between ozone and UV radiation is in excellent agreement with calculations for several different biological weightings. These sensitivities are usually expressed in terms of what's called a 'Radiative Amplification Factor' (RAF), which is just the percentage increase in UV that results from a one percent reduction in ozone.

The study uses data from spectrometers developed by NIWA at Lauder, which have been deployed around the world. The four global NDACC sites used in the study are widely-spaced geographically, two in each hemisphere: two at tropical latitudes (the high -altitude Mauna Loa Observatory in Hawaii (20°N), and Alice Springs, Australia (24°S)), and two at mid-latitudes (Boulder Colorado (40°N), and Lauder New Zealand (45°S).

The relationships between UV and ozone could be deduced without recourse to any other data sets. Statistics of the measured spectra themselves are used to remove effects of clouds and aerosols. The spectra are also analysed to retrieve the amount of atmospheric ozone, which is shown to be in good agreement with ozone data from other sources.

Because the sun elevation angle is such a strong determinant of the amount of UV radiation transmitted to the Earth's surface, we first sorted the data by Solar Zenith Angle (SZA = 90 - Solar Elevation Angle). We then looked at the subset of clear-sky data for each SZA (Figure 1).

The results for Lauder were particularly interesting, where about 18,000 clear-sky spectra were identified over the multi-year observation period from 2006 to 2022. As at other mid-latitude sites, there's a strong seasonal variation in ozone, with a spring maximum and autumn minimum. This seasonal variation is large enough at Lauder to impart a marked asymmetry in UVI between the spring and autumn equinoxes, as shown in Figure 1.

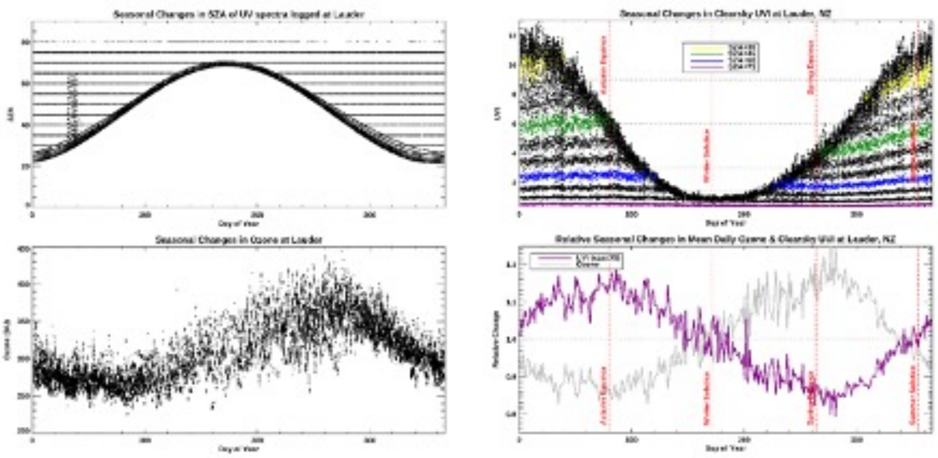

Figure 1. Upper left: SZAs of logged clear sky spectra obtained over the multi-year data analysis period. Lower left: Retrieved ozone amounts showing the much higher variability in winter and spring. Upper right: Clear-sky UVI as a function of day of year from spectra obtained over the multi-year data analysis period. Lower right: Retrieved mean UVI for SZA=75 and corresponding retrieved mean ozone amounts for each day of the year.

The most obvious feature is the huge summer-winter contrast. At mid-summer the peak UVI exceeds that at mid-winter by more than a factor of ten, due mainly to the shorter light path through the atmosphere when the Sun is high in the sky (i.e., when the SZA is smallest). But, following the coloured points across the plot, it is clear that UVI values near the autumn equinox are also much higher than for the spring equinox for the same SZA. At Lauder's latitude of45°S, data are available throughout the year only for SZAs greater than 67 degrees.

Outside the midday period, data are acquired mainly at 5-degree steps in SZA, and for each of the larger SZAs - when data are available year-round - there are more than 2000 clear sky spectra: several for each day of the year. The lower right panel on Figure 1 shows the near-perfect anti- correlation between the resulting average ozone and the corresponding average clear-sky UV for any day of the year. For the SZA shown (75 degrees), the mean UVI is about 50 percent greater in autumn than in spring, and those differences become larger for smaller SZAs.

Looking at individual spectra, you can see that because of the additional day-to-day variability in ozone, differences can be substantially larger than those mean seasonal changes. The plot below (Figure 2, left panel) shows that on some days the peak UVI in autumn can exceed that in spring by more than a factor of two, with UVIs ranging from less than 0.7 to greater than 1.4 times the mean.

From a human health perspective, it is fortuitous that the UVI is relatively low in spring compared with autumn. In spring, following the sustained period of low UV over winter, our pallid skins are more sensitive to UV damage. As we emerge from the low UV winter climate, we are not immediately subjected to the highest UVI for any given SZA. The higher ozone amounts have the effect of protecting our skins during the season of most-rapid increases in UVI. It's only in autumn after our skins have had a chance to acclimatise and adapt (by tanning) over summer that the highest UVI for any SZA occurs.

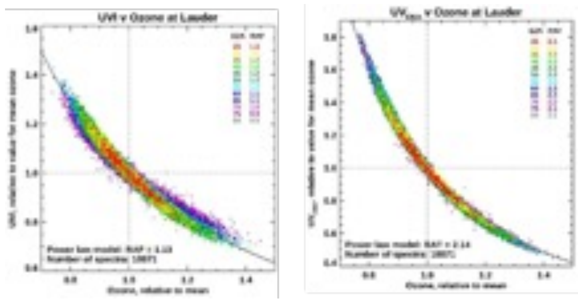

Figure 2. Left panel: Relative changes in clear-sky UVI for the SZAs shown as a function of ozone. Right panel: Relative changes in clear-sky DNA-damaging UV for the SZAs shown as a function of ozone.

Could those lingeringly high UV irradiances in autumn also help us synthesise sufficient levels of vitamin D to sustain us over the winter period when little vitamin D is produced? The seasonal difference in the radiation that leads to the production vitamin-D is even larger than for UVI.

There may be even wider biological implications. For DNA-damaging radiation (Figure 2, right panel), which is more than twice as sensitive to ozone for larger SZAs, the peak UV in autumn can exceed that in spring for the same SZA by a factor of four, as shown below, with DNA-damaging UV ranging from 0.45 to greater than 1.8 times its mean.

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McKenzie, RL et al. 2022. Relationship between ozone and biologically relevant UV at 4 NDACC sites . Photochemical & Photobiological Sciences, 91: DOI 10.1007/s43630-022-00281-5.

USING VERIFICATION METHODS TO EVALUATE WRF PRECIPITATION FORECASTS AT DIFFERENT RESOLUTIONS AND ENVIRONMENTS.

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[1] MetService

Aims
Quantitative Precipitation Forecasts (QPFs) are crucial guidance for forecasters and decision makers. The grid resolution of models is important for depicting realistic rainfall, especially for complex terrain, as is typical in Aotearoa New Zealand. Higher resolution forecasts may give more realistic looking rainfall patterns, but it is not a given that they are more accurate than lower resolution forecasts. There is often discrepancy in modelled rainfall rates between resolutions. Through objective assessments of their performance in different conditions this research aims to improve confidence in operational implementation of high-resolution models. Point based verification methods tend to punish higher resolution models, doubly penalising them for what may be small errors in the placement of rainfall. Here a spatial based verification method is employed, Fractions Skill Score (FSS).

Method
FSS were used to study the sensitivity of the Weather Research and Forecasting (WRF) model QPF to different resolutions. The model QPF was verified against a combination of rain radar, satellite precipitation products and rain gauges. Skill scores were calculated for different resolution models over the domain of New Zealand, and sub-domains of New Zealand where different rain processes typically dominate; Auckland, Marlborough, and Westland. Four severe weather events were selected as case studies, to further explore precipitation processes such as convection, orographic enhancement and local flow effects.

Results
In summary, this research found FSS improvements in increasing resolution from 8 km to 4 km for the WRF models. Clear improvements could not be found down to 1.5 km or 500 m resolution, but this should be further investigated, as there are limitations to the FSS. The FSS was found to be lower in more convective regimes, and higher for orography driven rain. The 4 km ECMWF WRF scored the best overall, especially so over Auckland. The sub-domains of New Zealand performed very differently. For all resolutions and all hours of rainfall accumulation, Auckland scored the lowest, and Westland the highest. This is due to the different processes driving precipitation in these areas, and the related temporal and spatial scales of the precipitation.

MODELLING THE HAZARD AND RISK FROM LANDSLIDE DAM OUTBURST FLOODS IN THE WEST COAST REGION, NEW ZEALAND

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[2] GNS Science

Aims
Earthquakes can trigger a cascade of secondary hazards that can be more damaging than the initial shaking. One of these hazards is landslide dams, which form when debris from a landslide blocks a river, impounding a lake and flooding upstream areas (Costa & Schuster, 1988). These natural dams are often unstable and can fail soon after formation, sending a large flood wave downstream that can exceed hydrometeorological floods (Fan et al., 2021). Landslide dams are more likely to fail during heavy rainfall, which is common on the West Coast of New Zealand (Korup, 2002, 2005). Increased high precipitation and storm events as a result of climate change may therefore increase the hazard form landslide dam outburst floods.

The aim of this research is to develop a simple method to evaluate the potential for landslide dams to form at a regional scale, and to model the potential outburst flooding from selected high hazard sites. This will allow for greater understanding of landslide dam outburst flood hazard resulting from large earthquakes and precipitation events, providing a method that can be applied elsewhere in New Zealand and globally. The project has 3 key objectives:

- Develop a regional model to identify potential locations where landslide dams could form;
- Model the resulting outburst floods from scenario landslide dams at identified high hazard locations in key catchments using HECRAS; and
- Identify at-risk locations, people and infrastructure in the West Coast Region.

Method

We developed a model to assess the potential for landslide dam formation on a regional scale by combining valley width and local relief, and apply it to observed landslide dam locations in North Canterbury following the 2016 Kaikōura earthquake. Valley width is a critical metric for landslide dam formation as both valley width and landslide volume are required to determine if valley blockage will occur (Hermanns et al., 2011; Tacconi Stefanelli et al., 2016). Valley width is a variable that can be measured, while local relief acts as a metric for valley steepness. We then applied this model to the West Coast Region, including calculations of upstream area and proximity to the Alpine Fault to determine both where landslide dams might form, and which of those locations could sustain particularly large, hazardous lakes. From this, we identify 4 high hazard locations where valley width is particularly narrow and local relief especially high, whilst the upstream area suggests a potential for a large lake to form in the event of a landslide dam. Most importantly, these 4 sites all threaten a variety of downstream infrastructure, including a key state highway, productive farmland, and isolated rural communities. Consequently, we apply a series of scenario dambreak floods at these key sites to assess the downstream exposure to an outburst flood. Outburst flood modelling was undertaken using HECRAS with two scenario dam heights of 10 m and 50 m, which correspond to plausible average and high hazard landslide dam heights, in order to determine the downstream extent of flooding and the exposure of lifelines and communities.

Results

We show that in excess of 98% of observed landslide dams in the Kaikōura earthquake formed in locations where local relief is equal to or exceeds local valley width, providing a simple threshold to evaluate hazard. In total, 1500 km (or 72.5%) of river in North Canterbury lie above this threshold, resulting in 228 observed landslide dams at a rate of 1 per 6.6 km. Applied to the West Coast Region, we show that >10,500 km (45.4%) of order 2 or greater streams sit above this threshold and therefore have the potential for landslide dams to form in a future Alpine Fault earthquake. Using a conversion rate similar to that observed in North Canterbury, this could amount to >1500 landslide dams across the West Coast Region. This suggests landslide dam hazard following an Alpine Fault earthquake is likely to exceed that witnessed in the 2016 earthquake, and may even exceed that witnessed in the 2008 Wenchuan earthquake, one of the most significant landslide dam forming events in recent history (Fan et al., 2013; Zheng et al., 2021). Outburst flood inundation models of 4 key sites in the Whataroa, Haast and Hokitika catchments for landslide dams with 10 m and 50 m dam heights demonstrating downstream lifelines and utilities are particularly exposed to outburst flood hazard. This research has demonstrated a simple approach for evaluating landslide dam formation potential regionally. This may allow for more awareness of outburst flooding impacts on communities and lifelines downstream, particularly with climate change increasing heavy rainfall events and increasing awareness of a future Alpine Fault earthquake. This can enable greater understanding of the secondary impacts of landslide dams and outburst flooding from future earthquakes and storm events in New Zealand and globally.

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AOTEAROA NEW ZEALAND'S 21ST-CENTURY WILDFIRE CLIMATE

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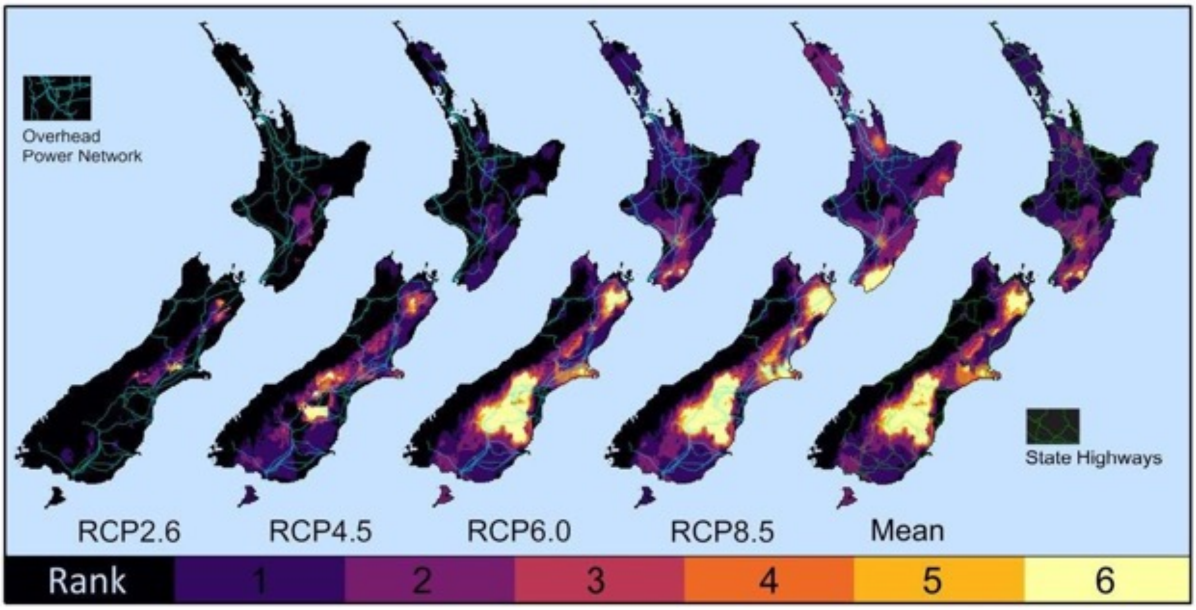
Wildfire is a highly variable natural phenomenon, yet despite this, climate change is already making wildfire conditions measurably worse around the world; however, detailed knowledge about Aotearoa New Zealand's wildfire climate is currently limited. This study blends weather observations with regional climate model projections to assess Aotearoa New Zealand's 21st-century wildfire climate.

We find that in the 21st-century, the emergence of a new – more severe wildfire climate will occur. Detailed analysis of observed and simulated wildfire weather finds that 'very-extreme' wildfire weather conditions matching the levels observed in Australia's 2019/20 'Black Summer' bushfires are possible in regions formerly unaffected. While the extent of emergence is dependent on future emissions, the frequency of very-extreme conditions for the areas affected can occur at any time and is independent of projected 21st-century climate changes. Our findings have significant implications for many rural fire authorities, forest managers and investors, and climate mitigation and afforestation programmes.



Areas projected to experience emergence in the season length of wildfire weather risk up to the specified wildfire rank severity from 2005–2020 levels in the 21st century. Shaded areas also include all wildfire ranks below, for example, if rank six has emerged, ranks one through five will also emerge.

Melia, N., Dean, S., Pearce, H. G., Harrington, L., Frame, D. J., & Strand, T. 2022. Aotearoa New Zealand's 21st-century wildfire climate. Earth's Future, 10, e2022EF002853. https://doi.org/10.1029/2022EF002853

APPLICATIONS FOR AI DOWNSCALING OF SUB-SEASONAL FORECASTS: HIGHRESOLUTION DROUGHT PREDICTIONS AND RIVER FLOW FORECASTS

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Aims

A new sub-seasonal forecasting model that uses Artificial Intelligence (AI) to downscale weather parameters has been operationalised at NIWA. Several applications of the so-called NIWA35 forecasting system are being developed. Here we describe NIWA35 and its potential for use in creating derived applications such as drought and river flow forecasting.

The New Zealand Drought Index (NZDI) is a climate data-based indicator of drought and is dependent on four commonly used climatological drought indicators: the Standardised Precipitation Index (SPI), the Soil Moisture Deficit (SMD), the Soil Moisture Deficit Anomaly (SMDA), and the Potential Evapotranspiration Deficit (PED). Initially, the NZDI was used only for monitoring drought, but now we want to develop a high-resolution (5 km) sub-seasonal ensemble forecast (1-5 weeks) of the NZDI that is driven by artificial intelligence (AI) with daily updates. Having advance warning of possible dry spells will make a big difference to farmers' planning and decision making, particularly as drought risk is forecast to increase in the future across New Zealand (Sood and Mullan, 2020).

Knowledge about future river flows can be required for flood warning purposes during times of high flow and water availability purpose in times of low flow. Physically-based rainfall-runoff models can be used to forecast flows across ungauged sites, and machine learning approaches can be used to forecast river flows where flow observations are available, but in either case weather forecast information such as that produced by NIWA35 is required as input.

Method

Due to the computational expense of running large ensembles of global sub-seasonal forecasts, model resolutions are typically of the order of 50 km – which does not provide the detail required for local-level decision making. Statistical methods have traditionally been used to enhance the resolution of the forecasts. Such methods are computationally inexpensive but unable to resolve the non-linear dynamics of precipitation over New Zealand associated with the country's complex terrain.

AI is used to enhance the resolution of numerous prognostic fields from NCEP-GEFS sub-seasonal ensemble forecasts from 50 km to 5 km. The perfect prognosis approach to downscaling was implemented (Renwick et al., 2009, Maraun and Widmann, 2018), which involves deriving empirical relationships between reanalysis (e.g. circulation fields, temperature, humidity) and the surface weather parameters of evapotranspiration (PET) and rainfall. The enhancement follows a downscaling technique (Rampal et al., 2022) that utilises convolutional neural networks with a gamma loss function from a Bernouli-gamma distribution.

Our high-resolution rainfall and PET forecasts are combined with the initial soil-moisture conditions in a water balance model to forecast SMD, SMDA, and PED. Combined with the Standardised Precipitation Index (SPI) from our precipitation forecasts, these variables are used to create a ensemble forecast of NZDI.

Various machine learning techniques can be used to forecast river flow from antecedent weather, forecasted weather, and possibly antecedent river flow. Strategies for flow forecasting include direct forecasting at 1 to n (e.g., 35) day outlooks, and recurrent forecasting where the forecast for tomorrow is used to forecast for the day after tomorrow.

Results

When evaluated on hindcasts, our AI-based model dramatically reduces biases in both forecast rainfall and PET. The model can resolve detail which matches orographically forced rainfall patterns, including the enhanced rainfall on the western side of the Southern Alps and rain shadow in the

Canterbury, shown in Figure 1. North Island geographical features which orographically enhance such as Taranaki Maunga, Tongaririo, and the Tarauras are also clearly seen in Figure 1.

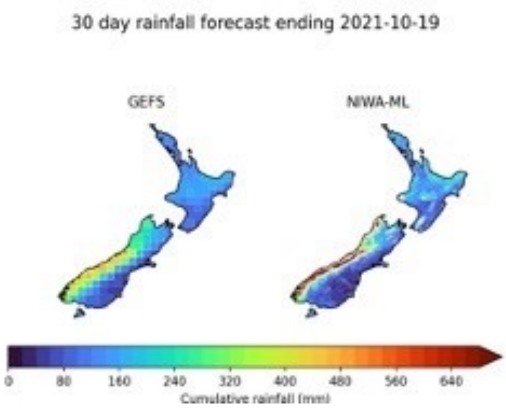

Figure 1: Side-by-side comparison of dynamical NCEP-GEFS 30 ensemble mean rainfall (left) and NIWA35 downscaled ensemble mean rainfall (right).

By creating a climatology of NIWA's Virtual Climate Station Network (Tait et al., 2006), SPI parameters can be derived and applied to theforecast rainfall. Initial results show good spatial correlations between forecast and observed SPI, shown in Figure 2.

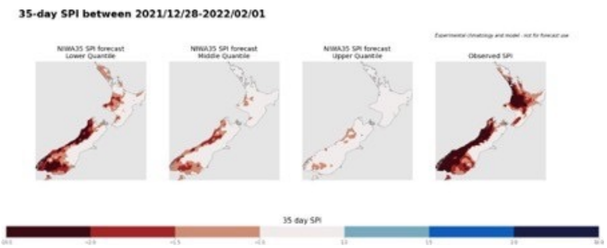

Figure 2: (left three plots) NIWA35 lower, middle and upper quartile 35 day SPI forecast. (right) Observed SPI in the VCSN.

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THE AUGUST 2022 ATMOSPHERIC RIVER WAS ONE OF THE STRONGEST COLD SEASON ARS IN RECENT HISTORY[TEXT WRAPPING BREAK]

Meyers, T. [1], **Noll, B.**[2], **Gibson, P.**[1], **Carey-Smith, T.**[1], **Turner, R.**[1], **Brandolino, C.**[2], **Fedaeff, N.**[2]
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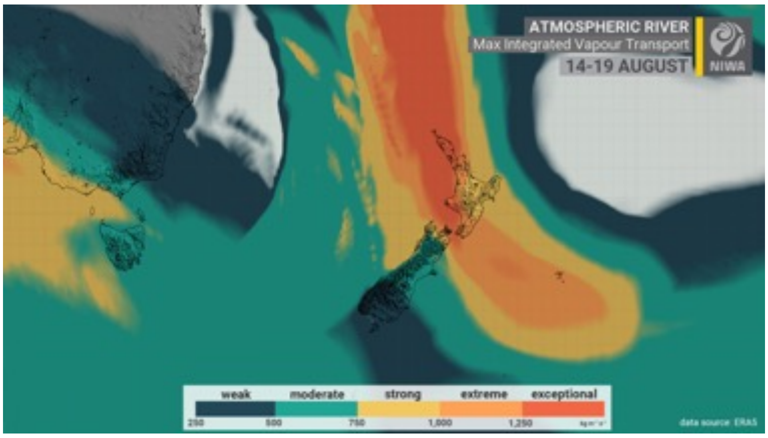

Figure 1: The atmospheric river that impacted New Zealand during 16-19 August 2022. Values are maximum integrated water vapour (IVT) over that timeframe, with the scale adapted from (Ralph et al., 2019).

Aims

Atmospheric rivers (ARs) are a normal feature of Aotearoa New Zealand's (NZ) climate; at any given point in time, there are around four or five ARs active in the Southern Hemisphere (Payne et al., 2020). In Nelson, over 60% of the normal annual precipitation is due to ARs (Prince et al., 2021). However, ARs can also be destructive, as in the case of the 16-20 August 2022 Nelson flooding, and are responsible for a disproportionate amount of extreme precipitation events in New Zealand (Kingston et al., 2016, Prince et al., 2021, Shu et al., 2021). Around 75% of extreme precipitation (Prince et al., 2021) in Nelson is caused by ARs, although they account for higher than 90% of extreme precipitation for parts of the West Coast.

The 16-20 Aug 2022 was very anomalous for winter in NZ, and was an "exceptional" AR (Ralph et al., 2019), seen in Figure 1. Our analysis of rainfall observations at Nelson indicate that the AR was responsible for extreme precipitation, as a 1 in 120-year (72 hour) rainfall event for Nelson as over 270 mm was recorded. In Tasman, Tākaka experienced one-third of their annual rainfall in just three days. As a result, the top of the South Island experienced numerous impacts; the Maitai river burst its banks, key parts of the state highway were inaccessible or destroyed, and numerous large slips were observed. Given the wide range of impacts, we attempted to quantify and rank this AR.

Method

An analysis was undertaken of ECMWF Reanalysis Generation 5 (ERA5) (Bell et al., 2021) fields of vertical integral of northward and eastward water vapour flux in the New Zealand region. Hourly meridional and zonal water flux was downloaded from 1959 – 2022 across the New Zealand region, extending from 33S to 48S and 164E to 180W. The maximum magnitude of the integrated water vapour (IVT) was calculated as the magnitude of these two vectors.

Results

The maximum IVT was found to be during the event, the highest in ERA5 data going back to 1959 for August, and the 2nd highest IVT value for winter (June-August). This preliminary analysis indicates that the 16-20 Aug 2022 AR could be one of the strongest cold-season ARs in recent history for NZ.

Further analysis indicates that this value may even rival warm-season ARs, as it appears to be in the upper end of all IVT values seen in the NZ region (figure 2).

We will use an automated AR detection algorithm over NZ to rank this AR and contextualise it in the history of NZ AR events.

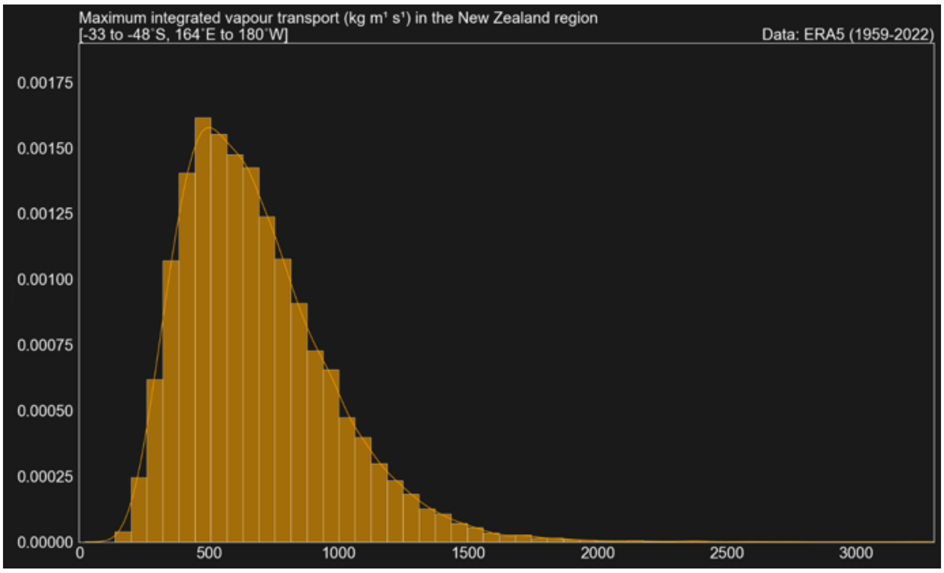

Figure 2: Distribution of IVT in in the New Zealand region from January 1959 - August 2022 in ERA5 data (Bell et al., 2021).

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CHEMISTRY-ASSISTED HYDROGRAPH SEPARATION: A NOVEL CONSTRAINT FOR GROUNDWATER MODELS

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Introduction

Groundwater inflows sustain surface water ways during periods of no rain. The rate of groundwater inflow changes as the gradients between instream water levels and groundwater levels vary with time. Knowledge of the magnitude and the flow paths contributing to these inflows, and how they vary over time can inform the setting of groundwater abstraction limits, where these limits are based on maintaining flow in streams during dry periods.

Aims

Woodward and Stenger 2018 and 2020 developed and demonstrated a Bayesian chemistry-assisted hydrograph separation method (BACH and BACH2), that identifies the contribution to stream flow from a combination of three separated flow paths – fast (event-response near-surface flow), medium (seasonal shallow local groundwater flow), and slow (persistent deeper regional groundwater flow). We have adopted this BACH method and applied it to NIWA monitored sites where there are simultaneous records of flow, phosphorus and nitrogen concentrations in New Zealand catchments.

Method

The total concentration of phosphorus (TP) and nitrogen (TN) and how this varies over time, allows a decomposition of the total flow into a fast flow (TP), medium flow (TN), and slow flow (low (TP and TN). For this study, we employed the Bayesian chemistry-assisted hydrograph separation (BACH) to provide estimates for each flow component a time-invariant concentration of the chemical tracers of all catchments in New Zealand. We then explore using these abstract fast, medium, slow flow components as history matching constraints for a numerical groundwater flow model deployed in a limit setting context. The worth of these constraints in terms of reducing the uncertainty of water allocation limits is explored.

Results

As expected the contribution of groundwater to surface water is around 100% of surface water flows during dry periods. However, the results also indicate that the contribution of groundwater to surface water flows (the slow and medium flow components identified in Figure 1 below) is significant for all flows. In contrast surface water runoff only becomes significant for higher surface water flows. These analyses convey the critical role that groundwater management has in maintaining surface water flows. These analyses can be used to reduce the uncertainty in groundwater models.

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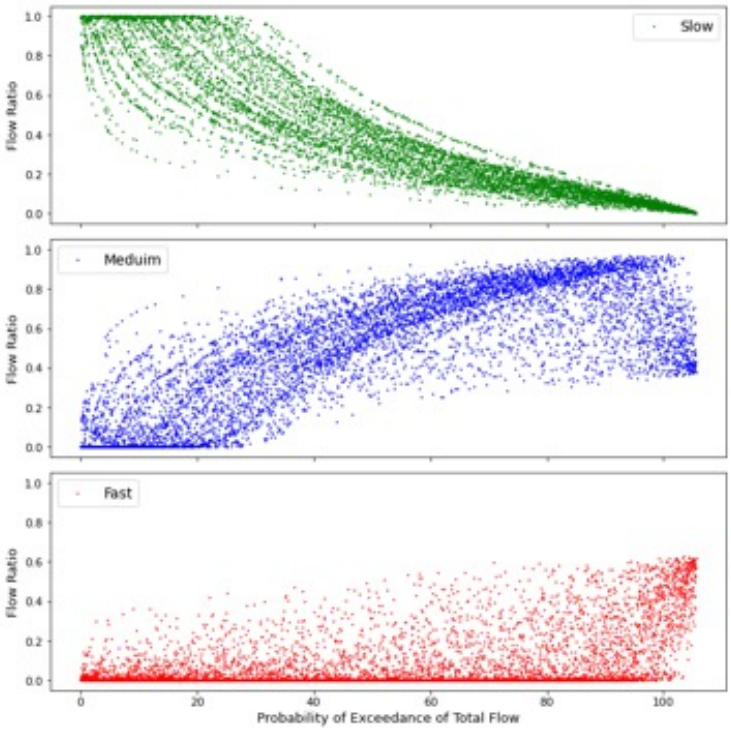

Figure 1: The ratio of slow, medium and fast flow components as a proportion of total flow across the range of measured flows at a selected site.

MODEL-BASED PROCESSING OF MEASURED AND HISTORICAL STREAM BEHAVIOUR; SEEKING CULTURALLY MEANINGFUL ENVIRONMENTAL RESTORATION

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We demonstrate a participatory process, working across cultures and knowledge systems, towards a shared goal of developing a groundwater modelling programme with the Bridge Pā community in Hawkes Bay, New Zealand. Its development is a shared journey where rigorous scientific principles and multiple sources of system information, including from indigenous knowledge (mātauranga Māori), are applied to issues of interest to the Bridge Pā community. Specific issues include diminishing flows in the Paritua and Karewarewa Stream system, declining groundwater levels and their relationship to the stream and cultural well-being. Figure 1 depicts the intermittent nature of stream flow at this location, with low flow and no flow periods becoming more frequent.

Figure 1: A fully-flowing Karewarewa stream at Bridge Pā pictured on left contrasts with the same stream pictured on the right. Flow in this stream at this location is intermittent in nature, but the frequency of low flow and no flow periods are becoming more frequent. Photo: Tom Kitchin, downloaded from RNZ https://www.rnz.co.nz/news/national/435391/extreme-drought-fears-in-hawke-s-bay-after-streams-dramatically-dry-up.

Aims

The aim of this study is to give a numerical voice to the concerns of the community. We endeavour to understand the major causes of reduced stream flows at Bridge Pā (e.g. water abstraction) and the uncertainties that remain. We then explore what it would take to restore the stream flow regime at Bridge Pā. Consideration is given to community preferences for restoration options that are natural, sustainable and culturally appropriate, rather than engineered solutions. We quantify the uncertainty around the success of restoration measures, as well as determine what further data could help reduce this uncertainty.

Method

This participatory modelling workflow is depicted in Figure 2 and involves:

gaining an understanding of community concerns surrounding groundwater and surface water, through discussions with local Iwi (Ngāti Kahungunu);

researching long-term changes in the groundwater and surface water with information from oral histories, archaeological and archival sources ("prior knowledge") as well as rainfall, water level data etc ("Data");

collating this information to form a conceptualisation of the groundwater-surface water system, use environmental tracer data to obtain information on the flow system to ground-truth the conceptual flow model, and building a numerical model ("simulator") on this basis;

history matching and hindcasting to conditions prior to widespread European settlement;

- uncertainty quantification, and exploring how the uncertainty of key predictions are reduced by the various sources of information
- exploring the feasibility of restoration options, while acknowledging the remaining uncertainties. The modelling process is ongoing (as shown in Figure 2), and forms a collaborative space with science and inquiry (into the system and how we interact with it) at the centre of water management.

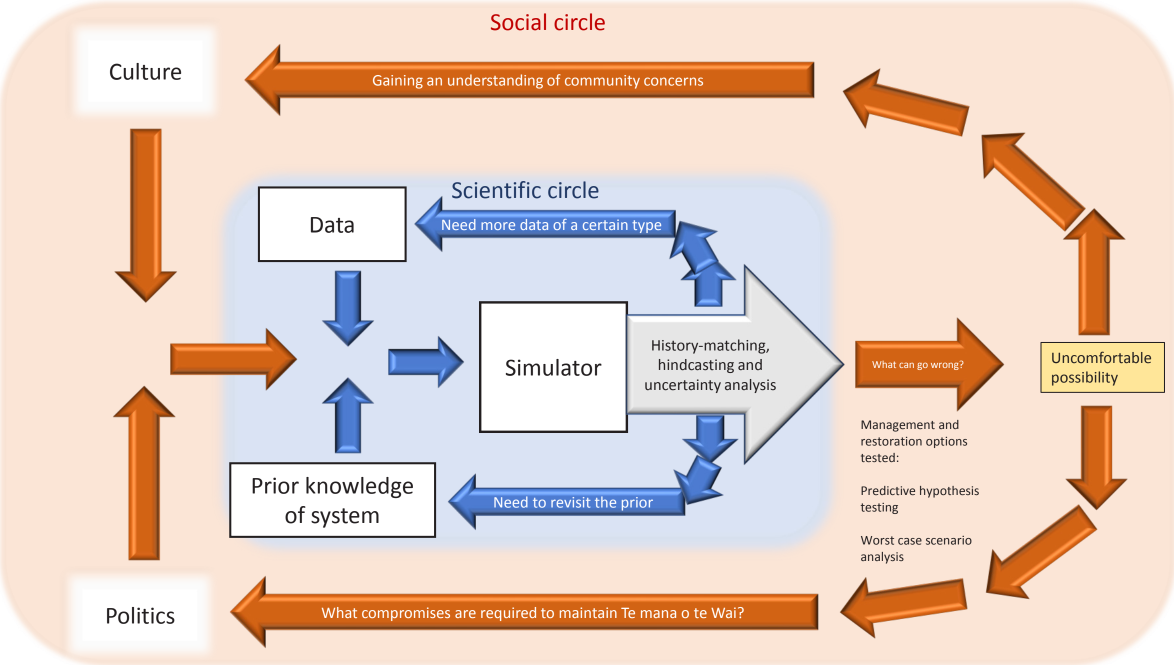

Figure 2: A participatory modelling workflow

Results

Simulation of the catchment biography has identified a range of impacts on stream flows from the natural and man-made changes in the catchment, both prior to and since European settlement. A diversion from the Ngaruroro River that sourced border-dyke irrigation had significant recent impacts on the water balance and stream flows. Increased groundwater pumping in the area since border-dyke irrigation has ceased has also had a profound impact. Further back in time, land clearing and drainage and the change in the course of the Ngaruroro River also had large impacts on stream flows. This history matching and hindcasting provides a basis for exploring restoration options which is the current focus of this work.

RECHARGE MODELS MAY NOT NEED TO BE COMPLEX FOR ROBUST GROUNDWATER MANAGEMENT PREDICTIONS

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Understanding the magnitude and timing of recharge fluxes that are due to rainfall percolation provides critical information for any groundwater management programme. Many models are available for the calculation of these recharge fluxes. Some represent significant details of these recharge processes and the spatial heterogeneity of the subsurface, requiring many parameters that cannot be measured nor verified and are computationally expensive. The computational load makes history matching and predictive uncertainty analysis difficult, sometimes precluding it altogether. Recharge models using simpler representations of the recharge processes and subsurface heterogeneity are often better able to assimilate information from local data but may be accompanied by 'simplification' induced errors. Regardless of how they are modelled, uncertainties of recharge predictions are usually high but must be properly characterised.

Aims
The study explored the implications of recharge model complexity and the additional uncertainty created by 'simplification' errors in a specific groundwater allocation decision context. The trade-offs of adopting a simpler rather than a complex recharge model are considered through questions such as, do the simplification induced errors exceed the uncertainties a simpler model is capable of quantifying and reducing through history matching or are these simplification errors insignificant in comparison to the total prediction uncertainty? Answers to these questions are considered separately for different predictions.

Method
This study explores simplification in recharge models focussing on groundwater management issues in south-west Western Australia, near the Perth metropolitan centre. We use a synthetic case study that is loosely based on the models that are used to manage Perth regional groundwater. In all cases the "model" represents a recharge simulator coupled with a groundwater flow model simulator (MODFLOW).

In total we explore 4 simpler models and compare this with a complex recharge simulator "WAVES" (Zhang and Dawes 1998) which is part of the Vertical Flux Model manager "VFM" (Silberstein et al 2009), which is parameterised on a cell-by-cell basis, referred to herein as VFM cell_by_cell.
Four simpler models have been selected for the model testing:

- A spatially lumped parameterisation of the WAVES model, referred to herein as VFM_lumped (Silberstein et al, 2009)
- A lookup table model, referred to herein as BASE (Dawes, 2008)
- The Farm process package of MODFLOW, refer as OWHM (Hanson et al. 2014)
- LUMPREM (Doherty 2021)

To explore whether there is any degradation of prediction uncertainty we use a paired complex and simple model analysis (Doherty and Christensen 2011) that allows us to compare the predictions made by the complex model with one made by the simple model. The pairs are constructed using outputs of calibrated (history matched) simple models against outputs of different realizations of the complex model outputs. We use the iterative ensemble smoother for history matching (White, 2018). Using these paired realizations, we compute predictions of groundwater levels and recharge fluxes.

The predictions are made under different climate, land use and pumping scenarios. The extent to which the analyses indicate predictive bias, or any simplification induced additional uncertainty (variance), is used to quantify the cost of model simplification for that prediction.

Results
History matching fits between the simple and complex models were generally good. See for example the 1:1 plots for the complex VFM "cell by cell" model and VFM_lumped model pairs, for a groundwater level at a monitoring well location and the median recharge at a lysimeter location within the model domain, as shown in Figures 1a and 1b.

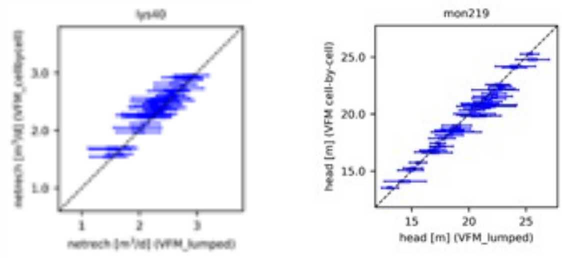

Figure 1: Paired VFM cell_by_cell vs VFM_lumped plots of a) head fit for the year 2019 at site mon219 (left) and median annual net recharge (right) at lys40.

Despite the good fits, the simple model performances were more variable for the predictions. See for example the 1:1 plots for the predictions made with the complex VFM "cell by cell" model and VFM_lumped model pairs, for an annual average groundwater level at one location (Figures 2a) and the median recharge within two different land use areas of the model domain (Figures 2b and 2c).

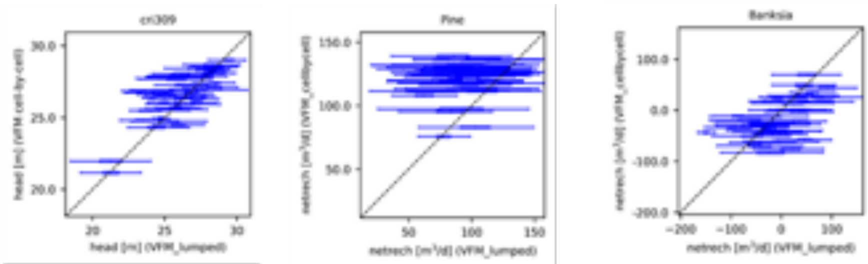

Figure 2 Paired VFM cell_by_cell vs VFM_lumped plots of a) average head predictions for the year 2019 at site cri309 (left);b) median net recharge in the Pine land use zone; c) median net recharge in the Banksia land use zone.

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NZRA: THE NEW ZEALAND REANALYSIS

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Aim

Global-scale atmospheric reanalysis datasets have been available for more than 20 years now, and continue to be produced at finer spatial and temporal resolutions. Regional reanalyses, however, provide a means to direct available computational resource to creating long-length datasets at even higher spatial and temporal resolutions more suited to the terrain complexity of the region of interest. These higher resolution regional reanalysis datasets are a valuable asset for understanding how local climate has changed over time-scales from which reliable trends can be obtained, and of particular importance when studying the frequency of extreme weather events.

The Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis for Australia (BARRA-R, Su et al. 2019) provides a 29-year (1990-2018) 12km horizontal resolution dataset over the Australasian region, including New Zealand (NZ). Observation data from across NZ was included in its data assimilation system. However, NZ's complex terrain is still highly unresolved at this spatial resolution and this can lead to biases, as described in Pirooz et al. (2021), that must be accounted for in any downstream application of the dataset.

The New Zealand Reanalysis (NZRA) project has been created to provide a reanalysis dataset better suited to NZ's complex terrain and the intricate atmospheric processes that drive NZ's local weather and climate. This paper describes the modelling set up of NZRA and early performance indications from a validation exercise over NZ's South Island.

Method

NZRA is a dynamical downscaling system whose initial and lateral boundary conditions are derived from BARRA-R. Like BARRA-R, NZRA uses the Unified Model, but is configured with the more recent RAL2-M convective-scale science package. This is built upon the RAL1-M science package (Bush et al. 2020) with modifications to the handling of lying snow and improvements to mixed phase cloud fractions in the cloud microphyiscs parameterisation scheme.

The NZRA model domain covers all of NZ's land mass and coastal waters with a horizontal resolution of 1.5km and 70 vertical levels from the surface to an altitude of 40km. At this scale, it is common for numerical weather models to not include a convection parameterisation scheme. NZRA follows this custom and aligns with NIWA's operational New Zealand Convective-Scale Model (NZCSM) which is also run at 1.5km horiztonal resolution and shares the same model domain and ancillary datasets.

The NZRA reanalysis is created by running the model four times a day starting at the 00, 06, 12 and 18 UTC analysis times out to nine hours ahead. The first three hours of each model run are considered as spin-up and removed. The remaining times from adjacent model runs are then concatenated to form a continuous timeseries of data for every grid point in the model domain. This set up largely follows the approach taken to create the BARRA-C dataset (Su et al. 2021) to generate kilometre-scale reanalyses over Australian cities.

To evaluate the skill of NZRA before beginning full production, a two month trial for the period June-July 2014 was conducted. NZRA was evaluated against an independent set of observation data collected at Hokitika during the 2014 DEEPWAVE field campaign (Fritts et al. 2016) and NIWA's Virtual Climate Station Network. Comparisons to BARRA-R, ERA-Interim (Dee et al. 2011), ERA5 (Herbach et al. 2020) and NIWA's NZCSM (as run in 2014) were also made.

Results

NZRA is found to yield considerably better predictions of wind speed and temperature at Hokitika over the trial period. NZRA closely matches the observed wind values up to the 99th percentile (Figure 1, left panel) while BARRA-R performs well up to the 95th percentile. The other datasets all exhibit large underestimates of wind speed beyond the 90th percentile.

For surface temperature (Figure 1, right panel), NZRA and BARRA-R show the best agreement with the observations for the whole temperature range and outperform the other datasets, particularly at the colder temperatures. NZCSM, ERA-Interim and ERA5 have large warm biases up to the 25th percentile and noticeable negative biases beyond the 50th percentile. NZCSM performs the worst of all the datasets for surface temperature, highlighting what an improvement the NZRA configuration is over the operational forecast model of the time.

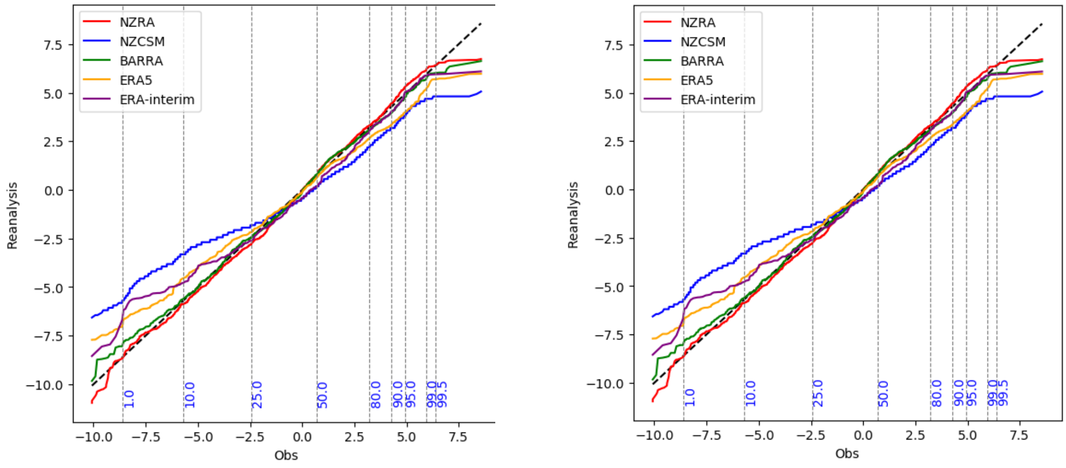

Figure 1: Comparisons of percentile values between observations at Hokitika and reanalyses for 10m wind speed (left panel) and 2m surface temperature (right panel). The vertical dash lines indicate the corresponding percentiles of the observations.

Spatial analysis of the biases in accumulated daily precipitation from NZRA, NZCSM and BARRA-R, with respect to the VCSN values, is presented in Figure 2. NZRA demonstrates a much reduced "spillover" in the lee of the Southern Alps compared to NZCSM and a smaller bias range compared to BARRA-R over the same region. NZRA also has a reduced wet bias overall along the west coast compared to BARRA-R, which has too much precipitation on the windward side of the Southern Alps. NZRA does retain a large wet bias over the Central Otago region for this trial period, but spatially, is an improvement over both BARRA-R and NZCSM.

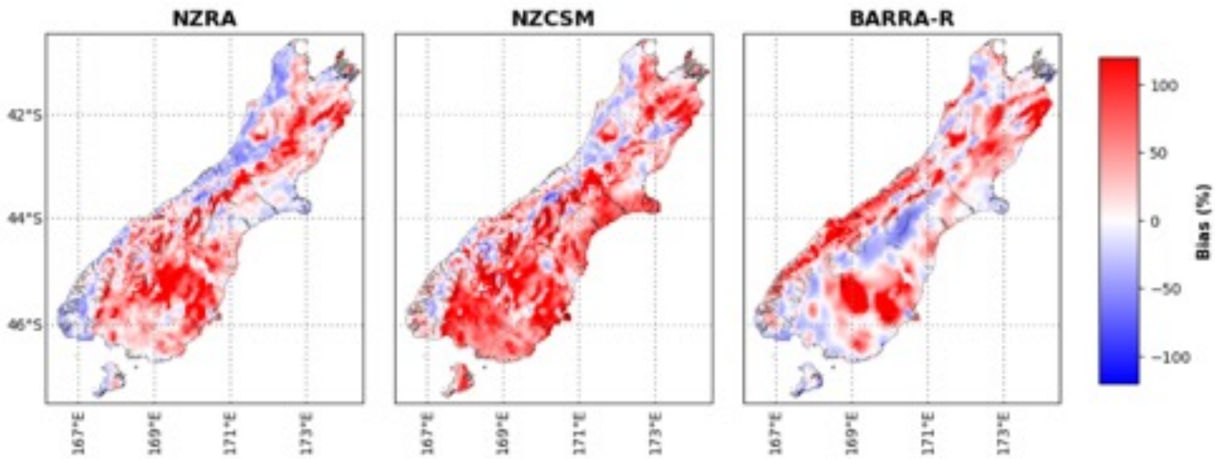

Figure 2: Mean bias percentages in daily accumulated precipitation over the South Island during June – July 2014 from NZRA (left), NZCSM (middle) and BARRA-R (right) against the VCSN.

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NUMERICAL MODELLING OF AEROSOL-CLOUD INTERACTIONS FOR THE GOSOUTH FIELD CAMPAIGN

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Aim

In late 2022, the "Model assisted vertical in-situ investigation of aerosols, and aerosol-cloud-turbulence interactions in the Southern Hemisphere marine boundary layer", aka "goSouth", field campaign (https://www.piccaaso.org/projects/gosouth/) will be undertaken from the southern tip of New Zealand's South Island. The primary aim of this field campaign is to better understand aerosol-cloud-turbulence-interactions through the boundary layer in a pristine Southern Ocean setting and compare findings against a similar campaign conducted in the Northern Hemisphere.

Collected over a three-week period, in-situ meansurements of aerosol concentrations, cloud and turbulence properties are made, supported by a bespoke Numerical Weather Prediction (NWP) workflow providing forecast guidance to assist field campaign operations. In the months following the campaign, a series of modelling studies will be undertaken to understand better the impact of aerosol physcial and chemical properties on aerosol-cloud interactions and the importance of marine cloud condensation nuclei (CCN) and ice nucleating particle (INP) species and concentrations in the Southern Hemisphere marine boundary layer on atmospheric processes important to forecasting with NWP models.

This paper describes the modelling work undertaken to support the goSouth field campaign and outlines the planned post-campaign modelling study.

Method

To provide forecast guidance for the duration of the field campaign, a one-way nested NWP workflow that forecasts the core weather variables and additional fields comparable to those observed by the campaign instruments, such as CCN and INP concentrations, is used. Figure 1 depicts the likely model domains, with an outermost domain covering the Australian deserts and the Southern Ocean upwind of New Zealand with a horizontal resolution of ~12 km (orange border). Multiple nests through ~4.5km (yellow border), ~1 km (green border) and finally ~300m horiztonal resolution (blue border) are implemented. The smallest domain is centred around the campaign measurement site and allows for a more explicit treatment of many of the atmospheric processes of interest to this work. This work will be done using a convection-permitting regional configuration of the the Met Office Unified Model (UM, Bush et al. (2020)), the NWP model that underpins all of NIWA's NWP forecasting and downstream hazard modelling research activities.

The second component of the modelling work in goSouth is to better understand how changes in aerosol concentrations in the boudnary layer affect cloud microphysics and radiative processes. To do this, aerosol concentrations modelled by the online-coupled aerosol and chemistry transport model, COSMO-MUSCAT ("Consortium Of Small Scale modelling + MUlti-SCale-Aerosol-Transport Model", Wolke et al. (2012)), operated by TROPOS, will be ingested into the highest resolution nestings of the COSMO (operated by TROPOS) and UM (operated by NIWA) models and their impact collaboratively investigated. For example, via a set of sensitivity studies, we plan to artificially increase the aerosol concentrations of specific species to closer mirror typical conditions observed in the more polluted northern hemisphere and investigate how the modelled clouds react to these.

Results

Early discussion of the real-time forecast model perofrmance over the course of the field cmapaign will be presented and the post-campaign numerical experiment plan will be further elaborated on.

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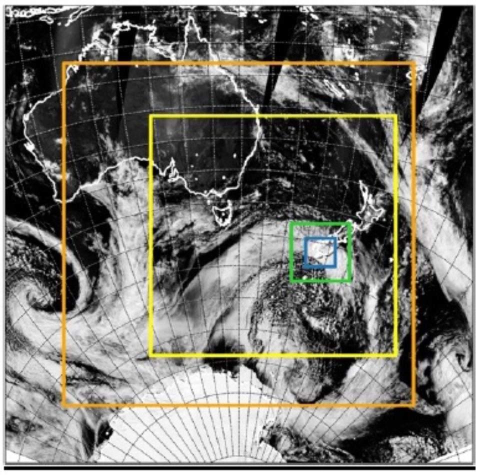

Figure 1: Indicative NWP model domains for the numerical modelling component of the goSouth field campaign. One-way nesting with horizontal resolutions of ~12km (orange border), ~4.5km (yellow border), ~1km (green border) and ~300m (blue border) will be used.

OFFSHORE FRESHENED GROUNDWATER IN NEW ZEALAND

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Aims
This study aims to: (1) screen for New Zealand coastal aquifers most likely to contain offshore freshened groundwater (OFG) and, (2) document evidence for OFG in New Zealand.

Methods
An OFG-likelihood rating scheme was developed as part of the study. An application of the rating scheme used survey responses from regional councils responsible for groundwater management, in combination with national and regional-scale technical documents.

Results
The rating scheme was found to be a simple and transparent first-pass approach for highlighting areas where OFG is more or less likely at the national scale. Results are presented in a map showing the likelihood of OFG around the New Zealand coastline. Regions with aquifers where OFG likelihood is high include Greater Wellington, Canterbury, Tasman, Hawkes Bay and Marlborough. Aquifers in these regions are associated with major fluvial depositional systems, including glacial outwash gravels. Despite high dependence on groundwater in these regions and extensive groundwater extraction near the coast, there are no major reported incidences of seawater intrusion, suggesting offshore groundwater may be augmenting onshore extraction.

For further details of this study, please refer to:
Morgan LK, Mountjoy JJ (2022) Likelihood of offshore freshened groundwater in New Zealand, Hydrogeology Journal, DOI: 10.1007/s10040-022-02525-1

QUANTIFYING LOSSES FROM BRAIDED RIVERS USING ACTIVE DISTRIBUTED TEMPERATURE SENSING

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Aims
Braided rivers in New Zealand are often volumetrically the most important source of groundwater recharge,

yet little is understood about the leakage process from braided rivers. As such, insights into how braided river systems recharge underlying braidplain aquifers, and how this can be measured, is of critical concern for river management practices. This study aims to spatially map and quantify groundwater leakage from a braided river with innovative field techniques that use heat as a tracer.

Methods
Two ~100 m long drillholes were constructed, using horizontal directional drilling, at a depth of ~5 m beneath and perpendicular to the river channel at a field site on the Waikirikiri-Selwyn River, Canterbury, New Zealand. The two drillholes were completed with a hybrid fibre optic cable, containing four multi-mode fibres and 2x18AWG copper conductors. Active distributed temperature sensing (A-DTS) measurements were collected along both cables using a Silixa XT-DTS™ distributed temperature sensor unit combined with a Silixa Heat Pulse System. Groundwater velocity and recharge were estimated along the length of both cables using temperature measurements and a mathematical model that simulates a moving instantaneous line source of heat.

Results
The horizontal installation of the fibre optic cable and the A-DTS method provided valuable insights into surface water-groundwater exchange between the Waikirikiri-Selwyn River and underlying shallow braidplain aquifer. We present results from two A-DTS surveys that show distinct temperature changes across the active river channel, which indicate spatial variability in river loss and preferential groundwater recharge pathways to the underlying shallow braidplain aquifer. Inversion showed groundwater velocities exceeding 10 m/d. Estimated river losses compared favourably with differential flow gauging conducted during the same time period.

COMPARISON OF ARCTIC AND ANTARCTIC STRATOSPHERIC CLIMATES IN CHEMISTRY VERSUS NO-CHEMISTRY CLIMATE MODELS

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Using nine chemistry-climate and eight associated no-chemistry models, we investigate the persistence and timing of cold episodes occurring in the Arctic and Antarctic stratosphere during the period 1980-2014. We find systematic differences in behaviour between members of these model pairs. In a first group of chemistry models whose dynamical configurations mirror their no-chemistry counterparts, we find an increased persistence of such cold polar vortices, such that these cold episodes often start earlier and last longer, relative to the times of occurrence of the lowest temperatures. Also the date of occurrence of the lowest temperatures, both in the Arctic and the Antarctic, is often delayed by 1-3 weeks in chemistry models, versus their no-chemistry counterparts. This behaviour exacerbates a widespread problem occurring in most or all models, a delayed occurrence, in the median, of the most anomalously cold day during such cold winters. In a second group of model pairs there are differences beyond just ozone chemistry. In particular, here the chemistry models feature more levels in the stratosphere, a raised model top, and differences in non-orographic gravity wave drag versus their no-chemistry counterparts. Such additional dynamical differences can completely mask the above influence of ozone chemistry. The results point towards a need to retune chemistry-climate models versus their no-chemistry counterparts. The results also indicate that while stratospheric ozone depletion, over both poles, provides potential seasonal predictability over both poles, a correct treatment of ozone would be essential for realizing this potential.

GROUNDWATER TRACERS FOR UNDERSTANDING WATER AND NITRATE FLOW THROUGH TE HOIERE / PELORUS CATCHMENT

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Aims
Marlborough District Council, Ngāti Kuia, the Department of Conservation, and the wider community are currently in the process of designing a groundwater restoration programme in the Te Hoiere / Pelorus catchment. This requires understanding of the water and nutrient flow through the catchment. The current environmental quality of Te Hoiere catchment is relatively good but is deteriorating, evident from increasing contaminant levels in some of the sub-catchments. Nitrate concentrations in Rai River at Rai Falls have increased by about 40% over the last 10 years of monitoring, and nitrate concentrations in a monitoring well near Rai Valley township have doubled in 2015.

The aim of this work is to re-visit age tracer baseline data from 2013 and interpret the data in order to understand how surface waters are connected to groundwater, what the nitrate transport pathways into the river are, why nitrate concentrations in streams and groundwater are different, and how important lag time through the groundwater storage component is. This work is part of our MBIE Endeavour programme Te Whakaheke o Te Wai.

Methods
The tritium (3H) method was used for dating stream and river water. For dating groundwater from wells, the complementary gas age-tracers chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF6) were used. For indication of areas with enhanced groundwater influx to rivers, radon-222 (222Rn) was measured in groundwater and river water. To distinguish between groundwater recharge from rivers or local lowland rain, the stable isotope composition (18O and 2H) of the waters was measured.

Results
Radon, water isotopes and gas tracers enable detailed understanding of loss of river/ stream water into the gravel underflow system, and discharge of such underflows and of locally recharged groundwater into the river – also providing understanding of the transport of contaminants with the water.

On Holocene gravel deposits, nitrate-loaded water from nearby intensive farming usually does not enter streams, as the streams are likely to lose water into the gravel instead of gaining water from the surrounding area. Therefore, water quality in streams can be good despite surrounding irrigated dairy farming. Instead of discharge via nearby streams, nitrate from animal farming on the gravel-deposit river terraces travels mainly through groundwater systems to the river. Where tributary streams and the river from more pristine catchments lose water into Holocene gravel deposits, nitrate in such groundwater from nearby intensive farming can be diluted.

Delayed arrival (lag) of nitrate in the Te Hoiere / Pelorus catchment is insignificant. Mean Transit Times of the water overall are less than four years, with the majority of nitrate flushed into the river very quickly via the winter rain pulses.

Shallow monitoring wells are likely to capture groundwater from seasonally changing sources: very young water from surrounding areas in winter, versus older groundwater from the deeper groundwater flow from further up in the catchment.

In the Rai Valley, it is likely that nitrate-loaded groundwater flows through anoxic zones, with potential to remove significant fractions of nitrate through denitrification before the groundwater discharges into the river. This may be the reason that nitrate levels in Rai River have not continued to increase over recent years.

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INDIGENOUS KNOWLEDGE TO UNDERPIN CLIMATE CHANGE ADAPTATION: WATER MANAGEMENT INSIGHTS FROM OVERSEAS

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Context

The New Zealand (NZ) government has recently made significant progress in building the nation's resilience to climate change, with the release of its first Emission reduction and National adaptation plans (Ministry for the Environment, 2022a and 2022b). The latter document recognises that climate change will affect everyone differently and outlines central/local governments, Māori/communities and private sector's roles in building a climate-resilient Aotearoa. Learnings from the implantation of adaptation actions by these different actors are still relatively scarce in NZ (Mourot et al., 2022).

Approach

Other nations have started implementing adaptation actions prior to NZ and have developed a larger body of literature on this topic. Based on these early actions, some authors (e.g., Imoro et al., 2021) highlight the limits of conventional adaptation and mitigation strategies. They promote integrating indigenous and local knowledge (definition in Figure 1) for improved resilience to climate change threats (e.g., Petzold et al., 2020).

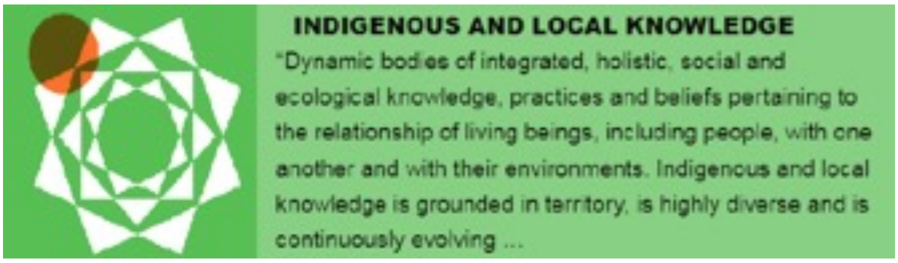

Figure 1: Definition of indigenous and local knowledge (UNESCO, 2018).

Recent global mapping of literature related to indigenous knowledge for climate change adaptation indicates that Africa and Asia have the largest number of references (each 39%) and Australasia limited references (5%; Figure 2; Petzold et al., 2020). This literature repartition probably reflects how indigenous knowledge is used for climate change adaptation worldwide, demonstrating a paucity in NZ at the time of this study. Since, the integration of Mātauranga Māori with western science has been developed for better freshwater management outcomes (Ministry for the Environment, 2020) and has recently been encouraged to support climate change mitigation and adaptation (Ministry for the Environment, 2022a).

Findings

This talk will present insights from other countries that have adjusted their land and water management practices by incorporating indigenous and local knowledge to help tackle climate change issues. The aim is to support the integration of Mātauranga Māori and local knowledge for more efficient adaptation actions among Aotearoa's climate change actors.

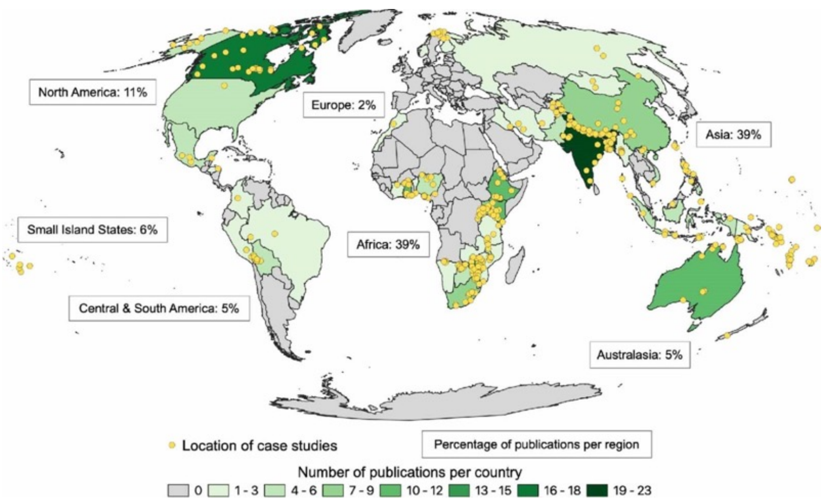

Figure 2: Global distribution of publications on indigenous knowledge for climate change adaptation (Petzold et al., 2020)

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A REAL-TIME FLOOD IMPACT PREDICTION TOOL: A JOURNEY IN THE ERA OF ARTIFICIAL INTELLIGENCE

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2022 tends to beat a new year record for insurance claims related to flooding in New Zealand. In July 2022, the Insurance Council of NZ published that damages were closing in on $200K by the end of June. Is 2022 going to be exceptional, or will it be the beginning of a new trend, which tends to rise a bit more each year? Flooding is an old topic, yet it is getting back more often on the news.

Can we predict when and where the next flood will happen? In the last decade, we have seen significant improvements in weather forecasts and flood prediction because of the progress made in the development and understanding of watershed models. However, physics-based models are complexes and use a lot of parameters. These hydrodynamic models require high computational time and resources and, therefore, cannot be performed in real-time.

As part of the TAIAO project, we have explored a data-driven approach to flood forecasting. The number of publications about using machine learning has kept rising in the last decade. This approach looks very attractive. However, few of these publications describe how machine learning models could be deployed in an operational environment.

Last year we began a flood impact prediction pilot initiative in the Coromandel region of Waikato, intending to provide accurate real-time flood impact information to the emergency response team in charge of the area. Building a machine learning model is becoming quite common, and tools are now available to make it easier and accessible.

In this presentation, we will relate our journey in the Era of AI to develop a flood impact prediction tool. We will describe how a machine learning model can be easily and quickly developed and how models can deliver wrong predictions. We will explain which data is relevant and how much data is needed. But most of all, we will share how we have constrained uncertainty and how we can communicate predictions to our communities and specify the degree of confidence in the information.

OTAGO USES NEW ENVIRONMENTAL DATA PORTAL TO MODERNISE DATA SHARING AND COMPLIANCE

Nicole, Nally[1] **Simon Wilson**[2]
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[2] Otago Regional Council

Aims:
The Otago Regional Council is required to monitor the state of the environment across Otago and is also required to monitor compliance with approximately 1,800 consents for the use of water, and a further 500 discharge consents.

ORC's state of the environment monitoring regime is well established but historically the public have had limited access to the information gathered. Previously public accessed static images on the ORC website that presented data over a fixed period. ORC plan to use our new Aquarius web portal to improve the way we share data with the public. The new portal includes maps which provide greater context for the data, pre-built interactive Dashboards and the ability for the public to access and download historical data. The new portal currently holds both water quantity and water quality data with more parameters to be added over time.

ORC is also using the new web portal to change the way we do compliance. ORC oversees consents that are held by a variety of customers ranging from individual households to large scale industry and territorial authorities. Many customers have multiple consents for similar activities and consents often need to be assessed together. Managing all these consents as efficiently as possible is vital to ensuring customers are achieving compliance and that Otago's water consumption and quality are well managed. ORC aims to use the new web portal to standardise the way we view information for these consents and to improve the speed of our monitoring program.

This presentation will demonstrate how environmental agencies and municipalities can similarly unlock the power of their environmental data to optimize regulatory compliance and the value they provide their communities.

Method:
ORC have recently implemented new Environmental Monitoring software which includes a public web interface. This web interface has been developed to share a range of water quantity and quality data to the public, alongside land and air quality data. The Environmental Data Portal includes flood and low flow warnings as well as contextual dashboards and the ability for the public to download raw data.

Behind secure logins, ORC is using the same system to improve the way we manage compliance. ORC has been able to achieve contextual insights through charts, mapping and dashboards, empowering ORC's compliance team to do their job efficiently and proactively.

Resource consent conditions often require interpretation and in the past ORC have found issues when different staff have interpreted consents differently. To solve this problem, we are in the process of building Dashboards (573 completed so far) for each consent. These Dashboards combine all the consent's environmental limits and their associated data in one place. This enables both a standard view of the consent and speeds up the compliance process. With some Consents having up to 20 different variables this is a major time saving for Compliance staff.

ORC have also used the Dashboard functionality to improve our management of low flows. Previously our low flow process involved checking each consent in a catchment individually, this could in some cases take well over an hour. This has been replaced by Dashboards which contain all water meters in a catchment. This combined with the increased provision of telemetered water meter data means that staff can tell immediately which consents are complying with their low flow conditions, enabling us to focus our compliance efforts.

Results:
ORC has significantly improved the way we share data with the public and is a long way down the road of improving the way we do compliance. As a public entity, ORC is driven to serve the community by providing valuable insights into the state of the environment.

Equipped with a powerful water data management system, we are becoming agile rather than reactive. Customers don't have to face roadblocks to access data, and our organisation can monitor consents in a more efficient manner.

By modernising the way ORC manages its data, we are improving the efficiency of the organisation and providing our residents with improved access to information for informed, proactive decision making.

We aim to demonstrate that Environmental Monitoring software makes ensuring compliance easier to better safeguard the environment and empower the community.

UNCERTAINTY IN PREDICTIONS OF FLOOD INUNDATION CAUSED BY MODEL GRID SAMPLING

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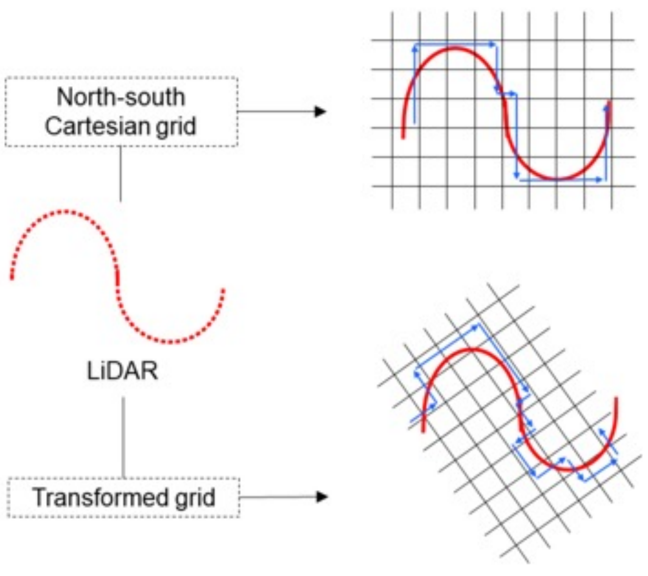
* This work is done for Mā te Haumaru ō te Wai

Aims

Computational flood models can simulate floods generated by overtopping rivers, intense localised rainstorms and coastal storm-tide and waves, and they provide useful information for decision-makers in mitigating losses and damages (Balica et al., 2013). Model results assist decision-makers in understanding the likelihood of inundation and the possible size of future floods given scenarios such as those related to climate change (Maskrey, Mount & Thorne, 2022). However, the accuracy of model predictions is affected by uncertainties with the source data used to create model inputs, and uncertainties introduced by the steps taken processing the data.



Accurate topographic data are critical for generating reliable flood predictions, since small variations in floodplain elevation can lead to large differences in predicted inundation. Usually, grid alignment is not considered in the processing, i.e., a north upwards convention is used. However, orientation in the grid sampling process may introduce variability in the resulting elevation model, leading to uncertainty that propagates through to flood model outputs by, for example, leading to differences in flow pathways on the floodplain. Figure 1 illustrates the differences between sampling points into a north-south Cartesian grid and sampling points onto a rotated grid. This leads to variations in the representation of key topographic features such as drainage networks or topographic barriers top flow, causing differences in the flow along or around these features. This paper aims to quantify the uncertainty in flood model outputs cause by orientation in model grid sampling process.

Figure 1. Applying different grid orientations in the procedure of developing LiDAR-derived DEM can lead to differences in flow pathways along linear features (blue arrows)

Methods

Figure 2 describes the methodology to capture the uncertainty. We used a Monte Carlo framework to generate multiple DEMs from LiDAR, each of which are equally-likely representations of floodplain topography. These DEMs were created by randomly adjusting the alignment (rotation) and point of origin (translation) of the model grid for selected spatial resolutions (2 m, 5 m, 10 m, 20 m). The hydraulic model LISFLOOD-FP was then employed to generate the flood extents and maximum water depths within the Monte Carlo framework. After being assessed, the variations in flood extent and depth were compared between different transformation types and different resolution versions.

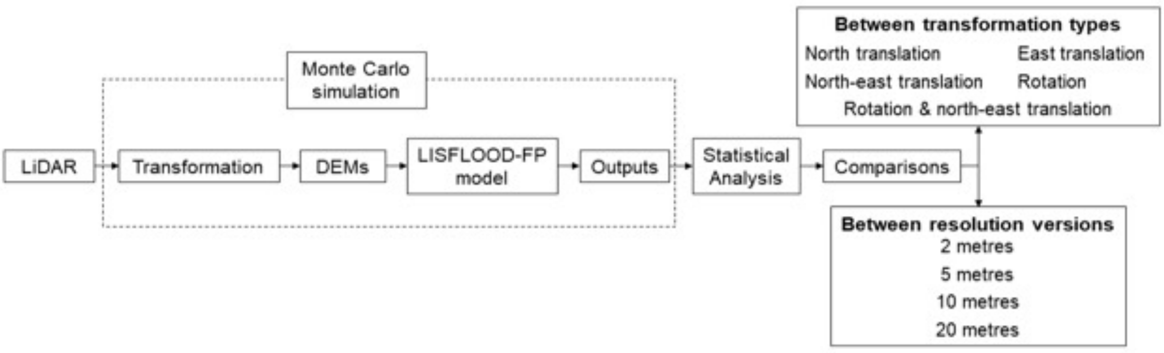
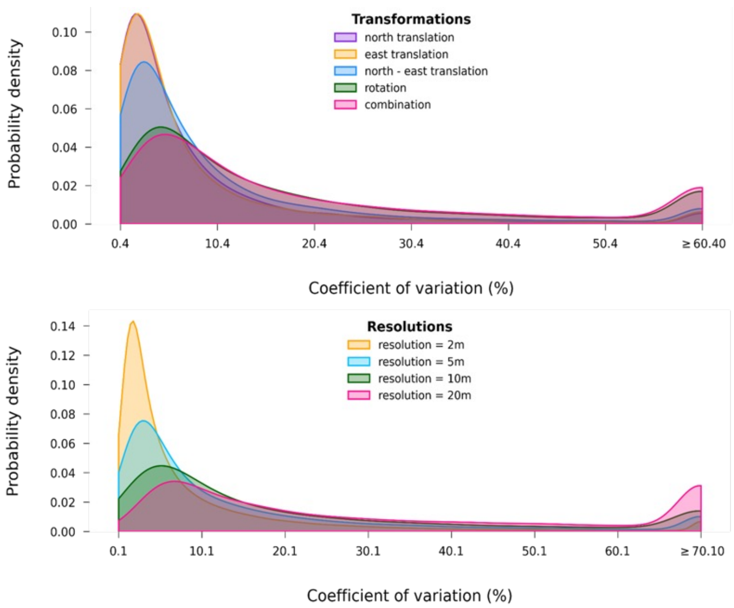


Figure 2. Methodology



Results

The findings showed high variations in water depth values, primarily concentrated along the riverbanks and at the edges of the flood extent. The density plot shown in Figure 3a shows that rotating the model grid orientation resulted in greater variation in water depth values than translating, indicated by the higher proportion of cell values with high variation in depth. The greatest variation in water depth values was found when both rotating and translating the model grid. In the density plot in Figure 3b, coarser spatial resolutions show greater uncertainty.

Figure 3. Probability density functions of coefficients of water depths of (a) all transformation types and (b) all resolution versions

The results highlight an issue with fixed grid models, which do not adapt their scale or orientation with topographic variability, meaning that key topographic features may not be sufficiently well represented for accurately simulating floodplain flow. Further work is needed to determine whether other modelling techniques – such as using a variable grid resolution or a sub-grid scale technique to incorporate unresolved topography – can overcome these limitations.

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CHARACTERISING EXTREME RAINFALL IN NEW ZEALAND AS A FUNCTION OF SPATIAL AND TEMPORAL SCALE USING RADAR OBSERVATIONS

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Aims

Understanding extreme rainfall as a function of duration and catchment scale is critically important for hydrological design and planning. However, the average recurrence interval of extreme rainfall is typically derived from rain gauge observations representing rainfall at a point location. In New Zealand, for example, NIWAs High Intensity Rainfall Design System (HIRDS) (NIWA, 2018) characterizes rainfall depths from 10 minutes to 72 hours for storm events which could occur at frequencies ranging from once per year to once per 250 years. Systems such as HIRDS are based on the analysis of long term rain gauge observations. Rainfall extremes tend to decrease with increasing spatial scale, e.g. an average rainfall rate of 20mm/hr is observed significantly more frequently over a few square kilometres than over an area of several hundred square kilometres. However, even moderate rainfall rates over large catchments can have catastrophic consequences.

The adjustment of rainfall depth at a point to an effective depth over catchments of various sizes is a fundamental consideration for design storm modelling. This adjustment is characterized by the Areal Reduction Factor (ARF), which typically represents the reduction in the average rainfall depth of annual maxima with increasing spatial scale. Both theoretical and empirical approaches have previously been developed (e.g. Pietersen et al., 2015; Svensson and Jones, 2010). Theoretical methods have large data requirements and assume that rainfall processes are stationary and isotropic. Empirical methods avoid such assumptions and broadly fall into two categories – storm-centred and geographically centred (fixed area). Fixed area methods estimate ARF values by averaging rainfall data over an area whereas storm-centred ARF values are the result averaging over a large number of storms (Olivera et al. 2008).

In New Zealand, Tomlinson (1978) examined seven storms with extreme rainfall totals, but was unable to calculate ARF values owing to very large variations in rainfall depth-area characteristics. Subsequently, Tomlinson (1980) recommended the use, with caution, of ARF values published by the Natural Environment Research Council (NERC, 1975) which were derived by the fixed-area method. These values are commonly employed in New Zealand without verification in the absence of alternatives. A fixed-area approach was also adopted in HIRDS which evaluated three standard methods for estimating ARF values.

These previous investigations into ARF values have relied on relatively dense networks of rain gauges. However, rain gauge networks seldom possess the necessary density (~1km2) up to the spatial scales (hundreds of km2) required to accurately observe the true spatial structure of extreme rainfall. Radar rainfall estimates are particularly well suited for investigations into ARFs due to their spatially continuous observations and high resolution (<1km2). Previous studies have proposed such approaches (e.g. Lombardo et al., 2006) though the validity of the findings are questionable due to the relatively short radar records considered. A major and ongoing challenge is the development of high-quality radar rainfall estimates over progressively longer time periods. Work over many years between Weather Radar New Zealand and Auckland Council has led to the development of a real-time high-quality radar rainfall product. This rainfall product combines raw data from a C-band radar of the national network operated by the MetService with observations from a dense network of rain gauges and vertically pointing radars in the Auckland region. Previous studies have validated the quality of these rainfall estimates (Reboredo et al. 2021) and a 12-year archive has been developed. This study revisits the estimation of ARF values in a New Zealand context utilizing direct observations of the spatial structure of rainfall for the Auckland region.

Methods

Raw radar reflectivity data has been recorded by a C-band weather radar located at Mt Tamahunga at an altitude of ~400m approximately 70km north of the Auckland CBD. Extensive quality control and post processing has been applied to the radar data to exclude regions affected by ground clutter (unwanted returns from the ground) and beam blocking. Additional corrections are applied for miscalibration, signal losses from attenuation due to rain and radome wetting, Doppler filter losses and changes in the vertical reflectivity profile. The development and validation of these corrections has been achieved via direct comparison of reflectivity measurements with those from a network of vertically profiling radar in the Auckland region. Following the conversion from radar reflectivity to surface rainfall, an advection adjustment is applied to compensate for the motion and development of rainfall between each scan of the radar (~7.5 minutes). Finally, Ordinary Kriging of Radar Errors is applied to merge the radar observations and those from a dense network of ~100 rain gauges in the Auckland region. Incorporating the accurate point measurements from rain gauge observations with the spatial structure detected by radar, the final rainfall product represents the best available depiction of surface rainfall with exceptional spatial and temporal resolution (500m x 500m, 1min).

This study utilizes these high-resolution radar rainfall observations to evaluate ARF values for durations ranging from 10mins to 72 hours and for spatial scales ranging from several km2 to over 500 km2. Following the approach used by HIRDS using rain gauge observations, several standard methods of estimating ARF values have assessed. These include the US Weather Bureau (1957) method, the UK Flood Studies report method (NERC, 1975) and Bell's method (Bell, 1976). Broadly speaking, these methods characterize extreme rainfall as a function of scale by the ratio of the averages, by the average ratio and by matching ranked observations, respectively.

Results

Empirical relationships for ARF values have been derived as functions of storm duration and catchment area. These relationships are compared with well-established results from previous studies derived internationally and in New Zealand using rain gauge observations. It is shown that the high resolution of the rainfall observations employed provide robust estimates of the ARF values over a broad range of spatial and temporal scales. An investigation of the relationship between ARF values and recurrence interval is also presented. Although the analysis is specific to the Auckland region, it is anticipated that the results may be used throughout New Zealand, though with caution in mountainous regions in particular. Future work will aim to apply similar analysis to other regions to assess the representativeness of the results presented.

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ASSESSING GROUNDWATER QUALITY IMPACTS FROM NEAR RIVER RECHARGE

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Aims and methods

As part of the Canterbury Water Management Strategy, Environment Canterbury have established a near-river recharge (NRR) scheme adjacent to the Waikirikiri/Selwyn River. This NRR scheme is one of a number of schemes that have been established within the Te Waihora/Lake Ellesmere catchment for the purpose of increasing water levels within the shallow groundwater system and enhancing flows in the streams and rivers that contribute flow to Te Waihora/Lake Ellesmere, particularly during dry periods.

The Waikirikiri/Selwyn River NRR scheme involves discharging clean, alpine water taken from the Rakaia River via the Central Plains Water (CPW) scheme infrastructure at a rate of up to 3.5 m^3/s into a purpose-built infiltration basin located on the true right bank of the Waikirikiri/Selwyn River near Hawkins Road.

Early in the development of scheme, two privately owned shallow domestic supply bores located downgradient of the Waikirikiri/Selwyn River NRR Scheme infiltration basin were identified. While most effects of the scheme operation were expected to be positive, there was the potential for some adverse changes to groundwater quality downgradient of the discharge to the basin, particularly from Escherichia coli (*E. coli*). Part of the objective of the commissioning trial was to work with downgradient bore owners to measure and assess changes in the quality of their water supply bores to help understand the risks to their supply from the future operation of the Waikirikiri/Selwyn River NRR scheme.

The NRR scheme commissioning trial ceased earlier than expected due to a large, forecast high rainfall/flood event that occurred between 29 and 31 May 2021. The effects of the flood event were also captured as part of the commissioning trial monitoring and enabled a comparison between the background groundwater quality conditions, the effect of the discharge to the infiltration basin as a result of the commissioning trial and the effect of a natural high flow event in the Waikirikiri/Selwyn River on groundwater quality.

Results

Water quality data was measured in two bores up to 30 m deep, prior to and during the commissioning trial. One bore was a dedicated monitoring bore located 90 m downgradient of the infiltration basin and the other bore was a privately owned drinking water supply bore located 960 m downgradient of the basin.

E. coli was detected in the closest downgradient monitoring bore (not used for drinking water supply) during the commissioning trial. Variations in *E. coli* concentrations measured in the closest downgradient monitoring bore coincided with variations in *E. coli* concentrations measured in the water discharged to the infiltration basin.

No detections of *E. coli* were recorded in the drinking water supply bore located further downgradient (960 m) of the basin during the commissioning trial.

An additional privately owned drinking water supply bore located 760 m downgradient of the infiltration basin was also identified, although this bore was unable to be accessed for water quality sampling during the commissioning trial. In the absence of *E. coli* data from this bore, *E. coli* transport to the bore was assessed using the approach outlined in Pang (2009).

E. coli log removal rates within the downgradient groundwater system were quantified using *E. coli* concentrations measured in the infiltration basin and the closest downgradient bore. The approach outlined in Pang (2009) for estimating removal rates requires *E. coli* concentrations representative of steady-state conditions within the downgradient groundwater system. Steady state conditions between the infiltration basin and the closest downgradient bore were determined using nitrate-N data that indicated when the water present in the monitoring bore was predominantly water discharged to ground at the infiltration basin.

Comparing the reduction in measured *E. coli* concentrations in the infiltration basin and the closest downgradient bore during steady state conditions, a log removal rate of 0.013 $\log_{10}$/m was calculated using the approach outlined in Pang (2009). This log removal rate is consistent with available literature which indicates a typical $\log_{10}$/m removal rate of 0.01 $\log_{10}$/m for fast flowing clean gravel and sand aquifers (i.e., pore velocities >11 m/day), on the Canterbury Plains (Pang, 2009).

Conclusions

Even using the slightly lower removal rate of 0.01 $\log_{10}$/m, the assessment indicated there would be sufficient removal of *E. coli* before a detection would be expected to occur in the two closest downgradient drinking water supply bores.

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MANAGING UNCERTAINTY AND RISKS WITH A NEAR RIVER RECHARGE PROJECT

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Aims

The Waikirikiri/Selwyn Near River Recharge project is a multi-million-dollar scheme to enhance cultural, environmental and recreational values in the region by discharging clean Rakaia River water into the groundwater system near the Waikirikiri/Selwyn River during dry periods.

The project is believed to be the largest scheme of its type in the world specifically focused on environmental, cultural and recreational objectives. It is a key aspect of the Canterbury Water Management Strategy and was recommended by the Selwyn Waihora Water Zone Committee and included in their Zone Implementation Programme Addendum (ZIPA) in 2013.

Caption 1 River Recharge Site

Methods

Utilising water from Selwyn District Council and Central Plains Water (CPW) consents, the project can discharge up to 3.5 cumecs of water from the Rakaia River into a large infiltration basin and the Waikirikiri/Selwyn riverbed. The recharge water percolates into the ground, recharging aquifers and supplementing downstream flows in the Bealey Stream Spring system, the Hororata River some 3-6 km away, without directly mixing water from the surface water systems.

Key steps undertaken in the scheme implementation include:

- Investment in environmental monitoring prior to and during commissioning to provide an improved understanding of the complex natural processes.
- Successful identification of natural recharge areas of the drainage basin.
- Development of the necessary scale of operation to readily identify effects of the scheme operation from other potential influences.
- Cost effective provision of a source water supply to locations required.
- Collaboration between Central and Local Government, local landowners and infrastructure providers.
- Integrating with habitat improvement opportunities.
- Robust assessment of effects on commissioning and on-going management of potential adverse effects and risks.

Results

The Near River Recharge project cost around $2.8 million dollars, funded by Environment Canterbury and the Ministry of Environment's Freshwater Improvement Fund with Central Plains Water providing in-kind support with connection to their Irrigation Scheme. The design of the recharge basin and distribution headworks were by CPW's lead designers Stantec. This was a significant investment and understanding potential risks and uncertainties is considered key to the successful outcomes achieved to date with this scheme.

A collaborative approach was achieved between Environment Canterbury and surrounding landowners, consent holders and infrastructure owners, who assisted to provide a cost-efficient result. The availability of the nearby land and water supply infrastructure significantly reduced the capital inputs required to trial the scheme. Financial assistance was also provided by Fonterra for an electric fish barrier to prevent predatory Trout entering the Bealey Stream system to devour Kōwaro (Canterbury Mudfish) within the area of flow enhancement. Lizard habitat has also been created at the recharge site, and Greendale School children are supporting efforts to restore native riparian vegetation at the recharge site and the waterways in the downstream spring field.

Despite a reasonable appreciation of the recharge processes, the difficulties in measuring recharge flows and durations meant considerable uncertainty of both the spatial and temporal surface and groundwater responses and location of the main recharge volume remained prior to operation of the scheme. An extensive monitoring programme from the commissioning programme provided real data under controlled conditions to provide confidence in the scheme operation and the assumptions undertaken with the design.

The scheme commissioning was undertaken from 11-28 May 2021 and successfully demonstrated recharge discharges of 1.9-3.0 m3/s, as well as increasing flows in the Hororata River at Mitchells Road (from 35 L/s to over 380 L/s). The Bealey Stream flows increased from zero to over 200 L/s at the head of the spring field and from 90 L/s to 450 L/s immediately prior to the Hororata River. Losses to groundwater occurred in the Hororata River downstream of the Bealey Stream and the Hororata River bed remained dry upstream of Bealey Stream throughout the commissioning period.

Observations and flow measurements indicated that the Bealey Spring field responded initially in the middle and downstream extent of the spring field, prior to the surface water responses at the head of the spring field closest to the recharge source. This highlighted spatial and temporal variations in the response to groundwater recharge from natural or artificial sources that were not previously known.

The recharge through the base of the of the infiltration basin was limited to approximately 300 L/s or 110 mm/hr once mounding effects equalised the recharge rate. This occurred just over a day after the initial discharge, and once the mounding equilibrium was reached. The wetted front then moved downstream in the Waikirikiri/Selwyn riverbed at an initial rate close to 1,000 m/day after the initial filling of the basin. After two days the rate of the wetted front slowed to less than 150 m/day before increasing to nearly 400m/day past the Bealey Bridge approximately 3.3km downstream of the recharge basin.

The following was identified during the extensive monitoring commissioning programme:

- Actual mounding effects on the discharge to ground
- Actual groundwater travel times
- Details of the temporal and spatial variability of the re-charge location
- Improved understanding of the low flow source of the Hororata River
- Benefits /Outcomes Achieved
- A means to supplement shallow groundwater aquifers in the area and to enhance a significant low flow source for the Hororata River.
- Potential to provide an enhanced and more reliable habitat for endanger native fish species within the Bealey Stream Spring.
- Potential to increase downstream habitat flows for a historically valued trout fishery in the Hororata River.
- Provision to mitigate low flows in the Bealey Stream and Hororata River from climate change effects and drought events.
- Improved understanding of contamination risks and natural influences on shallow drinking water supplies.

VERIFICATION OF SKY CONDITIONS IN PUBLIC FORECASTS ON THE SOUTH ISLAND'S WEST COAST

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There is long-term anecdotal evidence of the perception that cloud and precipitation are over-forecast on the West Coast of the South Island of Aotearoa New Zealand. In this study, forecasts written by operational forecasters at the Meteorological Service of New Zealand (MetService; Te Ratonga Tirorangi) in the months of January and July (2018 - 2021) were verified against imagery obtained from the Japan Meteorological Agency's (JMA) Himawari-8 satellite and local automatic weather station (AWS) data. Satellite imagery allowed for spatial verification of forecast cloudy conditions, while precipitation events were analysed using daily rainfall accumulations. The resulting data indicate a greater accuracy in recent years than the anecdotal data suggests, and allows for a potential alternative method for the verification of MetService forecasts.

XRAIN: EXTREME PRECIPITATION FOR DATA SCARCE AREAS

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Aims
There are many parts of the world where access to rain gauge data is limited: whether that be remote regions (e.g. deserts), developing countries that have not invested in rainfall monitoring equipment, or places where bureaucracy makes it hard to access data. When there is a need to model flooding in these areas—such as for the construction of infrastructure or for the development of works to safeguard communities from flooding—hydrologists often have limited precipitation information to draw from.

A new product has been developed that derives extreme precipitation statistics (used for flood modelling) from a 20-year satellite dataset of precipitation, covering the majority of the globe and providing data even in areas without rain gauges.

Method
The generalised extreme value (GEV) distribution was fitted to a total of 4.32 million cells at 25 durations; a total of 108 million curves. The Ailliot et al. 2011 CM1 method was used, combining the strength of L-moment and maximum-likelihood estimators for best performance at small sample sizes. L-moments and the shape parameter κ were regionalised to improve parameter estimation.

Results
The resulting estimates were compared with those from USA, UK, Australia and New Zealand to demonstrate spatial variability and the variability between different durations and frequencies. Patterns were replicated reasonably well, with the ratio between estimated depths and depth from the local dataset not varying dramatically. However it is recommended that predictions are calibrated against available local data wherever possible.

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WAIKATO RIVER DESIGN FLOODS: 20-YEARS ON

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Introduction
Flood estimates were last derived for the Waikato River Hydro-Electric Pwer Scheme (WHS) in the late 1990's. Long-duration, WHS region wide design floods were downscaled to derive sub-catchment flood hydrographs from 5-year ARI1 to the PMF2.

A reassessment of the individual (dam) sub-catchments design floods has been initiated because;

- over 20-years have passed since the last major review of the design floods;
- The uncertain origin and adopted methodology of the existing design flood hydrographs;
- Several recent floods with very high ARI based on the existing design estimates; and
- A desire to adopt contemporary analytical methods and a software platform which can also accommodate the potential impacts of land-use and climate change.

This paper reviews the methodology and processes adopted in reassessing the WHS sub-catchments floods, including; the assessment of measured triburary maxima, deriving design hydrographs both from observed flood hydrographs and from design rainfall-runoff catchment modelling.

Methods
The WHS consists of eight dams in series with a total catchment area of 4413km2. Individually, the sub-catchment areas range from 123km2 (Aratiatia) to 1482km2 (Ohakuri). Five of the eight dam sub-catchments have tributary flow records which commenced in the 1960's. Each of these flow records are characterised by the largest measured flood being considerably larger than the other floods on record.

A review of rating and gauging records, coupled with a site visit, determined that considerable uncertainty exists with these large events. The sites have experienced numerous rating changes, the highest gaugings (typically undertaken in the mid to late 1990's) are only up to half the maximum recorded flow. Some flow sites are influenced by backwater and some by over bank flow. Dispite this uncertainty it is difficult to retrosectively adjust maxima values. However, this uncertainty can be taken into consideration for frequency assessment and catchment rainfall-runoff calibration modelling.

An assessment of the annual flood maxima and frequency analysis were undertaken on the five long-term WHS flow sites. This assessment indicated that all sites have experienced a greater number of large flood events since the mid 1990's. For the westerly Waipapa and Mangakino catchments, the February 2004 and July 1998 floods were considerably larger than the other annual maxima. For the catchments influenced more by north-easterly storms (Tahunaatara, Waiotapu and Pokaiwhenua) only the April 2017 event ranks in the top 10 annual maxima across all three catchments.

The frequency analysis of the five WHS long-term flow records used several distributions and a statistical approach to determine the best fit distribution. This assessment indicated that either a Gumbel (EV1) or GEV was the preferred distribution for the tributary flow records.

The large flood hydrographs for each tributary location were "normalised" and a dimensionless average hydrograph derived. By scaling the normalised hydrograph to the design magnitudes derived from the frequency assessment, design hydrographs were determined. As several of the largest floods on record had high ARI's, this provided a reliable flood hydrograph design to use as a basis for verifing a calibrated catchment rainfall-runoff model (by using design rainfall with the same frequency (ARI) as the normalised design).

Typically sub-catchment rainfall records are limited, especially considering the size and topography of the WHS sub-catchments. Rainfall records associated with the flow sites commenced in the 1990's and this information was used to calibrate HEC-HMS rainfall-runoff models to observed floods. Typically, the measured rainfalls under-represented the calibration flood ARI. Site and regional rainfall was used to derive calibration rainfalls across the HEC-HMS model catchments. This typically increased rainfalls and the model rainfall loss used in calibration. As calibration events were selected from the large observed flood events (not from large rainfall events) this increased the bias towards "effecient floods" requiring less modelled loss. Both total hydrograph and quickflow hydrographs modelling was undertaken, the total hydrograph modelling was also used to determine the baseflow inflection point for baseflow seperation.Quickflow modelling was used for design modelling.

HIRDS3 design rainfalls to 250-year ARI were applied to the "calibrated" catchment model and "verified" to the normalised design hydrograph of the same ARI as the design rainfall. In all cases the modelled calibration parameters over-estimated the normalised design, and model losses needed to be increased.

Tomlinson & Thompson (1992) provided the methodology for determining PMP estimates. However, the 12-hour and 48-hour PMP estimates were derived using HIRDS duration ratios, and GIS4 and terrain data used to reduce the subjectivity in deriving the barrier height adjustment.

The PMP was "assigned" an AEP5 based on catchment area, a method recommended by ARR (2019). This method was dopted for consistency in deriving intermediate design rainfall estimates from HIRDS to the PMP. Extrapolating at-site or HIRDS design estimates to the PMP depth to determine intermediate depths (such as 10,000-year ARI) is beyond the credible limits of such extralopation. This also results in a wide range of PMP "AEPs" across the WHS without a physical explanation for such a wide variation.

Sub-catchment design flood hydrographs have been derived for some dam catchments and result compared. The process involves ongoing review, both with the client and peer reviewer, with further assessment to identify and clarify inconsistencies between the sub-catchment assessments.

Results

The flood magnitudes derived for the WHS sub-catchments for short duration events are higher than previously assessed; which downscaled long duration WHS design hydrographs. In the last 20-years some of the largest tributary floods on record have occurred. Some of these events are considerably larger than previously derived design of similar ARI.

Considerable uncertainty exists with the magnitude of the largest observed floods in the WHS. Assessing all the tributary flow records across the WHS improved the consistency of at-site frequency estimates. Normalised design hydrographs were determined from observed floods and were used to verify and adjust the calibration models used in design.

GIS was used to assess the spatial distribution of catchment calibration and design rainfall, and for providing a consistent method to derive the PMP barrier adjustment. The PMP was "assigned an AEP" based on the catchment area, and intermediate rainfall estimates from the HIRDS values derived.

References

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CONTAMINANT TRANSPORT AND RISKS TO GROUNDWATER QUALITY FROM AN ON-SITE WASTEWATER MANAGEMENT SYSTEM

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Approximately 25% of Aotearoa New Zealand's population are served by on-site wastewater management systems (OWMS), though this proportion is much greater rurally. Well-functioning OWMS can provide a high degree of domestic waste treatment (Robertson et al., 2019), yet in areas with high-densities of OWMS, their discharges can contribute to groundwater and surface water degradation (Rakhimbekova et al., 2021). OWMS discharges also contain microbial contaminants, which can pose risks to drinking-water quality of water pumped from shallow aquifers (Bremer and Harter, 2012; Murphy et al., 2020).

Canterbury's alluvial gravel aquifers are particularly susceptible to pollution from nitrate and microbial contaminants, given their typically oxic conditions (which limit denitrification), relatively limited capacity for attenuation, high permeability, and rapid flow-rates. Yet, the contribution of OWMS to groundwater pollution, and the suitability of setback distance guidelines to protect drinking-water wells are relatively untested in Canterbury.

Aims

This research aims to study and compare the chemical and microbiological risks to shallow groundwater from several OWMS configurations. Further, through the study, we will assess the response of contaminants to climate events, such as storms and droughts. We also aim to study the reliability of pollution indicators, such as emerging organic contaminants (EOCs) and DNA in a Canterbury setting.

Methods

We have installed an OWMS (Hynds Wastewater Pipesystems Oxyfix®) in Eyreton, north Canterbury (Figure 1). The OWMS will be adapted over five development stages (including primary, secondary and UV treatment stages), allowing comparisons between the treatment efficacy of several designs, and their impacts on groundwater quality. Through each stage, the OWMS, land application system (LAS) and groundwater will be monitored for microbial and chemical contaminants, whilst the impact of weather events (including storms and dry-periods) will be assessed.

Figure 1: A. Location of the study site in Eyreton, north Canterbury; B. Site layout.

Results

Preliminary field tracer experiments were undertaken using potassium bromide (KBr) and microbial tracers (E. coli and MS2 bacteriophage) (Weaver et al., 2013; Clemens et al., 2020). Each tracer was injected simultaneously via the land application system (LAS) and measured in a monitoring well 2 m down-gradient from the injection-point (Figure 2). Notably, there was a high removal rate for E. coli, owing to attenuation in a sand lens (~100 mm width) between the LAS and the monitoring well.

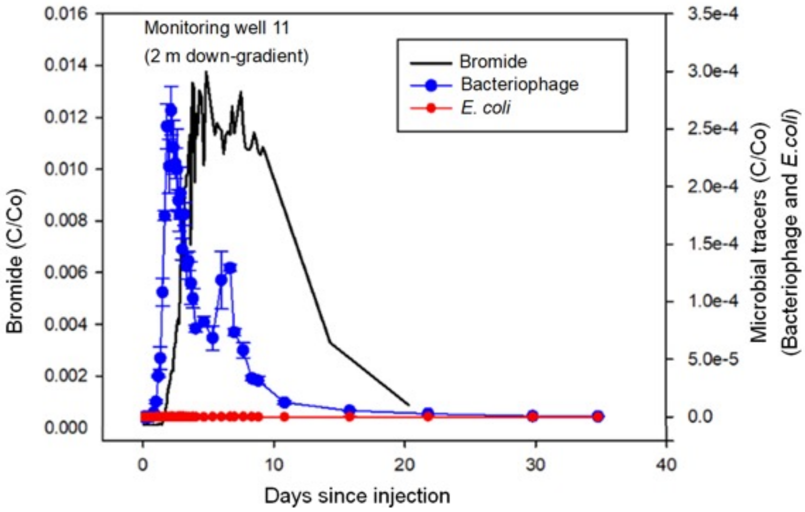

Figure 2: Bromide (potassium bromide (KBR)) and microbial tracers (MS2 bacteriophage and E. coli) relative to initial concentrations (C/Co) measured through time two metres down-gradient from the injection-point.

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AUTOMATED GENERATION OF HYDROLOGICALLY-CONDITIONED DIGITAL ELEVATION MODELS FOR NATIONAL-SCALE HYDRODYNAMIC MODELLING.

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Aims
We present GeoFabrics, an open-source Python framework and tool for simplifying and automating the process of hydrologically conditioning Digital Elevation Models (DEMs). Hydrological conditioning of DEMs is important as it improves the accuracy of flood modelling. We have focused on ensuring riverbed, drain and culvert elevations are captured in the conditioned DEM.

The framework is being developed as part of the Mā te haumaru ō te wai: Flood resilience Aotearoa. An overall aim of the programme is to provide a consistent methodology for modelling flood inundation, risk, and hazard maps from terrestrial flooding across Aotearoa. This aim for national consistency has guided the development of GeoFabrics. The framework is published on the Python Package Index (PyPI) and already used by several other researchers.

Methods
GeoFabrics has been developed as a multistage automatable framework, so that the same approach can be applied multiple times to different catchments with different types of available data. The framework is structured in four processing steps: DEM generation, riverbed estimation, drain and culvert bed estimation, and hydrological conditioning, as shown in Figure 1.

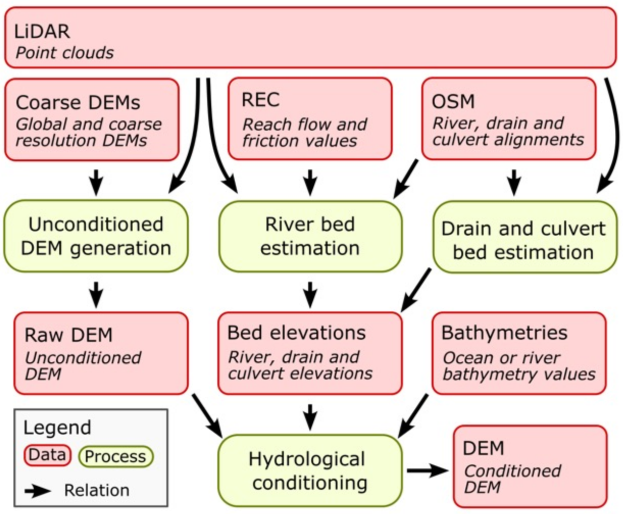

Figure 1: GeoFabrics, a multistage framework for producing hydrologically conditioned DEMs from a range of elevation data. Here REC stands for river environment classification (Shankar, 2019), and OSM stands for Open Street Maps.

The DEM generation stage converts classified LiDAR point clouds into gridded ground elevations by filtering for ground reflections and then averaging these results. In the absence of LiDAR point cloud data in some regions of the catchment, a coarse DEM may also be used.

In the riverbed estimation stage, river reach characteristics from the river environment classification (REC) (Shankar 2019) are combined with widths and slopes extracted from LiDAR along the river to estimate the river depths (Neal et al, 2021). These are converted to riverbed elevations. The width and slope estimates are derived from fine resolution DEMs generated directly from the LiDAR point clouds. A transition fan is also generated between the river mouth and the offshore ocean contours.

Drain and culvert bed estimation is achieved through a similar process. Drain and culvert networks are extracted from Open Street Maps (OSM) using community standardised tags. A fine resolution DEM is then generated from the LiDAR point cloud along the drain and culvert network. The DEM is sampled to give elevations along the drains and culverts, which are amended to remove obstructions in both.

Finally, in the hydrological conditioning stage the raw DEM is combined with the ocean bathymetry measurements, and the estimated river, drain and culvert bed elevations. This is achieved by producing a series of DEM layers for each region to be conditioned from the bathymetry or bed elevations and the surrounding unconditioned DEM values. These are then combined into a single hydrologically-conditioned DEM layer.

Results

This process has been applied across several catchments in Aotearoa with different characteristic (e.g. size, steepness, and level of flood control) including Waikanae, Wairewa and Buller catchments. The framework requires a geometry defining the catchment outline, as well as the name of the Land Information New Zealand (LINZ) LiDAR dataset hosted on OpenTopograpy, and the layer ID of the ocean bathymetry contours hosted on the LINZ data service. The required datasets are automatically downloaded and cached locally. The four processing stages are then run in turn to produce a hydraulically conditioned DEM of the catchment. These DEMs are then ready for use in flood modelling.

In Figure 2, the impact of each step of the GeoFabrics framework for improving the hydrological conditioning on the final DEM are show at the mouth of the Waikanae River. The red outlines highlight the improvements to the DEM introduced by each stage.

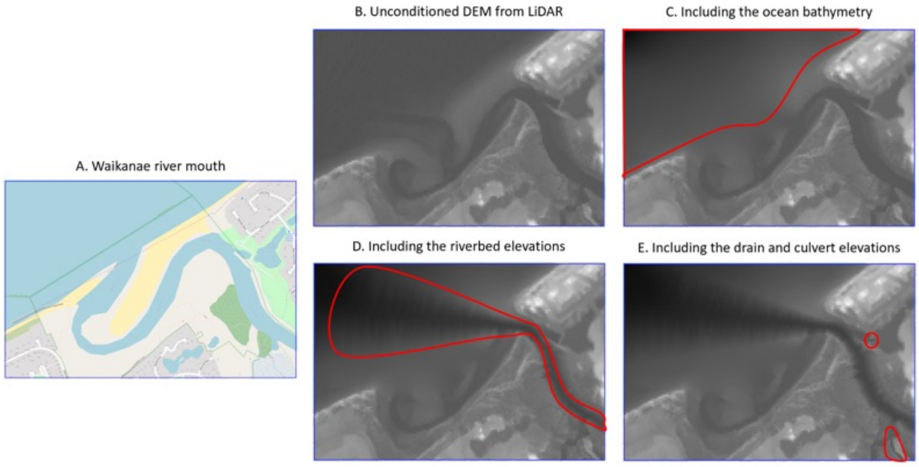

Figure 2: The impact of using GeoFabrics to hydrologically condition the mouth of the Waikanae River. A. the river mouth. B. The DEM generated from the LiDAR point cloud. C. The DEM after the inclusion of the ocean bathymetry measurements. D. The DEM after the inclusion of the riverbed elevations. E. The DEM after the inclusion of the culvert and drain elevations.

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DERIVING DRAINAGE FROM SOIL MOISTURE MULTI-DEPTH SENSORS

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Aims

Globally farmers are demanding technology that increases profitability. This includes an urgent need to develop knowledge to better manage water losses from irrigated land, because: i) Drainage is wasted irrigation and a lost economic opportunity to farmers, and ii) Drainage increases nutrient losses below the root zone and contamination of groundwater. We therefore develop an affordable technical solution that allows to increase irrigation efficiency and reduce nutrient leaching.

Method

This is performed by estimating drainage using a physically based hydrological model where the soil hydraulic parameters are derived from inverse modelling using continuous records of soil moisture, θ [L3 L-3], at different depths throughout the soil profile (Pollacco et al., 2022a). This requires deriving detailed soil hydraulic parameters of the soil profile that is highly challenging, particularly for heterogeneous soils. This alternative indirect methodology to calibrate the hydraulic parameters from θ time series at multiple depths uses the new physically based hydrological model HyPix (Pollacco et al., 2022b) .

HyPix solves the Richards equation with an increased stability since it includes a novel dynamic physical smoothing criterion for controlling the Newton–Raphson step, and a novel time-stepping management scheme based on soil water pressure without introducing further parameters. HyPix also includes rainfall interception, soil evaporation, root water uptake with a compensation algorithm, and ponding using a novel method for computing sorptivity (Lassabatere et al., 2021b, 2021a).

Pollacco et al., (2022a) developed a novel vertical multistep algorithm that enables to invert observed θ at multiple depths by fitting only five hydraulic parameters to every soil layer and optimising the hydraulic parameters in a particular pattern from top to bottom by successively splitting the profile. A novel algorithm is used to reduces the degree of sensitivity and freedom of the parameters (Fernandez-Galvez et al., 2021). The optimisation algorithm upscales the soil hydraulic parameters gradually, introducing heterogeneity, because optimising the hydraulic parameters of each layer individually produces poor results since it does not represent the overall soil water dynamics across the unsaturated zone. It has been shown that the minimum number of soil moisture sensors to accurately estimate drainage, evapotranspiration, and soil water content of the root zone computed from the HyPix model depends on the heterogeneity of the soil and the required accuracy for each output of the model. After the optimisation is performed the drainage is computed and different irrigation scenarios can be performed to assess drainage and nutrient in drainage water.

Results

We tested the multistep optimisation algorithm method using θ measurements at different depths at six heterogeneous experimental sites in New Zealand. The results show that the accuracy of the simulated water balance components increases with the number of soil moisture sensors. The methodology developed provides an estimate of the uncertainty of using a reduced number of soil moisture sensors. An example of the multistep calibration is shown in the Figure 1, which shows a good match with observed and simulated θ at multi-depth and drainage. We demonstrated the use of a profile soil moisture sensor along with novel solutions for the Richard's equation to derive soil hydraulic parameters. Such stable algorithms will lead to turnkey systems which can be used to enable on-farm hydraulic modelling in support of 'smart' water management.'

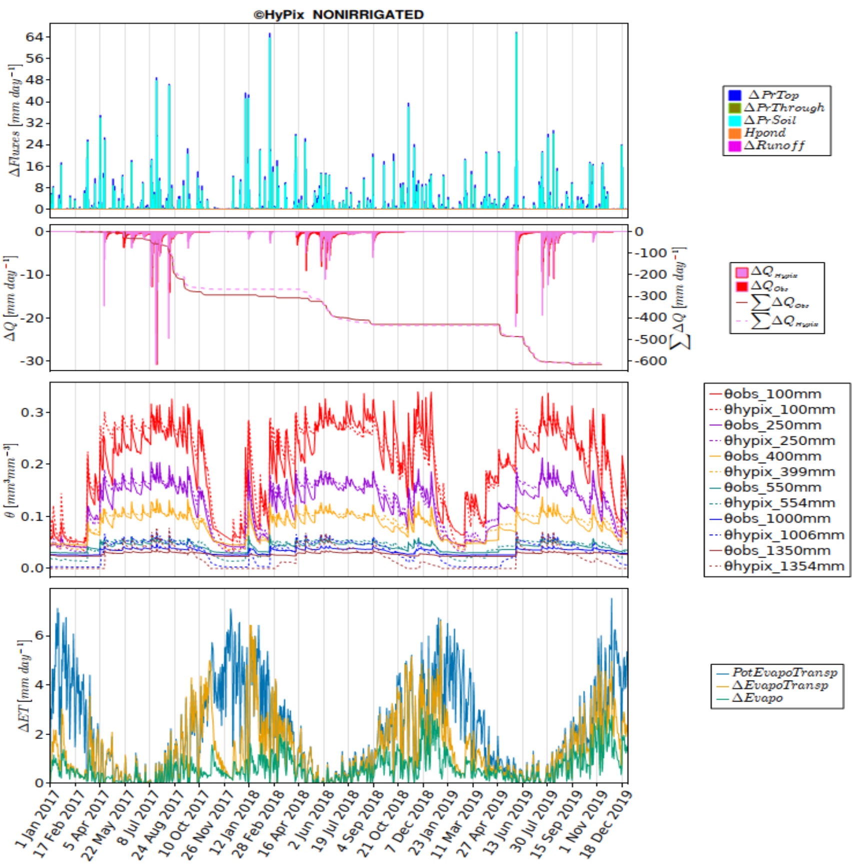

Figure 1: Lysimeter site of Lincoln University Ashley Dean Research (Graham et al., 2019): time series of precipitation at the top of the vegetation ΔPrTop, throughfall precipitation ΔPrThrough, precipitation infiltrating into the soil ΔPrSoil, ponding ΔHpond, runoff ΔRunoff, drainage at the bottom of the rootzone ΔQHypix, and observed drainage ΔQObs , potential evapotranspiration ΔPotEvapoTransp, actual evaporation plus transpiration ΔEvapoTransp, and evaporation ΔEvapo.

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S-MAP SOIL PARAMETERS FOR SWAT SOIL & WATER ASSESSMENT TOOL CATCHMENT MODEL

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Aims

The Soil & Water Assessment Tool (SWAT) (https://swat.tamu.edu/) is a small, watershed-to-river, basin-scale model used to simulate the quality and quantity of surface and ground water, and to predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used to assess soil erosion prevention and control, non-point source pollution control, and regional management in watersheds. SWAT has gained popularity internationally with over 8,381 citations worldwide in 2021, of which 83 citations involve New Zealand researchers (e.g. Parshotam 2018). SWAT v2009 (Neitsch et al. 2011) has gained popularity because it requires a reduced number of parameters to perform management scenarios.

SWAT requires an array of soil characteristics to characterise soil water dynamics in the landscape. Parshotam (2018) derived the SWAT hydro parameters by linking the high-level New Zealand Soil Classification (Hewitt, 2010) in the Fundamental Soil Layers to laboratory data stored in the National Soils Database (NSD). We present a methodology where SWAT is parameterised from S-map (https://smap.landcareresearch.co.nz Lilburne et al. 2012; McNeill et al. 2018) which is the most detailed soil map and digital database available for providing the necessary soil data in New Zealand. S-map now (2021) covers 37% of New Zealand, which constitutes most of the highly productive land.

S-map incudes soil-water release and soil hydrological data for all soils in the database. This includes soil-water retention, $\theta(\psi)$, at field capacity and wilting point, and the unsaturated hydraulic conductivity, $K(\theta)$, for up to six horizons to a maximum depth of 1 m. The $\theta(\psi)$ data points were derived from pedotransfer functions (McNeill et al. 2018). The $K(\theta)$ values are derived by Pollacco et al. (2017, 2013).

As part of this project we have:

- Derived a protocol to extract simplified SWAT hydraulic parameters from the more detailed S-map-Hydro,
- Identified inconsistencies between the soil requirements of SWAT and S-map,
- Made recommendations for modifications that could be made to SWAT (to create SWAT-NZ) to take advantage of S-map-Hydro.

The work can be extended to areas of New Zealand that do not yet have S-map coverage, by linking the older more inaccurate soil information (Fundamental Soil Layers) to representative S-map siblings. Once this has been done then the S-map engine can be employed to generate S-map-Hydro and thus the SWAT parameters.

Results

S-map has been developed to efficiently provide the soil input parameters needed to run a range of models. S-map can now export the soil parameters required by SWAT.

SWAT will take better advantage of S-map if it was modified to:

- Provide total porosity as an input parameter,
- Provide field capacity as an input parameter,
- Provide permanent wilting point as an input parameter,
- Increase the range of bulk density (in the SWAT code),
- Providing particle density as an input parameter,
- Providing hydraulic conductivity at – 1 kPa tension.

SWAT has been developed to run catchment hydrology with the least number of soil input parameters. Nevertheless, S-map-derived estimates are expected to provide better data of hydraulic parameters than estimates from simple pedotransfer functions derived in the USA.

Future research would help determine:

- Which saturated hydraulic conductivity model gives better results (a) derived from principles of soil physics, or (b) derived from soil morphology;
- We are currently testing the implementation of these methods for the Hauraki catchment in the Waikato region, for water quantity and quality.

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WEST COAST FLOODS IN 2021 AND 2022: HYDROMETROLOGY AND THE ROLE OF ATMOSPHERIC RIVERS

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Aim

Floods are among the most destructive natural hazards accounting for about one-third of all geophysical hazards globally (Adhikari et al. 2010; Smith and Ward 1998). The West Coast New Zealand's South Island has a long history of catastrophic floods mainly due to being in the path of north westerly airflows with frequent heavy precipitation. In 2021 and 2022 a series of floods hit the region causing severe impacts including slips, out of bank rivers, and evacuations. The most notable storms occurred in July 2021 and February 2022. Between 15-18 July 2021 a stand-out rain event brought over 690 mm of rain to parts of the West Coast in under 72 hours. Flows in the Buller River were the largest recorded in any New Zealand river in almost 100 years (since

November 1926). A record breaking of 7640 cubic metres per second was measured during the flood by NIWA's field team (the mean flow: 454 cubic metres per second). Only six months later, the majority of the West Coast observed their wettest February on record due to two back-to-back heavy rainfall events during the period from 2nd to 11th February 2022. The three rain events (Jul 2021, Feb 4-5th 2022 and Feb 11th 2022) resulted in flood return periods of 1 in 60 years, mean annual flood and 1 in 15 years for the Buller Catchment. A common factor between all these events was the arrival of atmospheric rivers (AR): the long, narrow corridors of warm moisture originated from tropics and delivering heavy rainfall to regions in the mid-latitudes.

The primary aim of this study is to conduct a forensic hydrometeorological analysis of these events and understand differences and similarities between them. The role of north westerly systems in the form of atmospheric rivers (ARs) and the local synoptic patterns associated with the events will be analysed in detail.

Data and Method

The data used in this study includes specific humidity (q, g kg-1), zonal and meridional wind fields (u and v, m s-1) retrieved from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-5 reanalysis data. To investigate the hydrometeorological characteristics associated with the floods, integrated vapour transport (IVT) was calculated during the days leading to the events. IVT is an indication of the total amount of water in the atmosphere and provides critical information about moisture transport from tropics to mid-latitudes. An AR detection method (Length ≥2000 km, Length/Width ≥2, and IVT ≥IVT85th; Guan and Waliser, 2015) was used to identify the relationship between moisture flux and ARs during the flooding events.

Results

Hydrometeorological analyses of atmospheric conditions during floods in July 2021 and February 2022 revealed that strong fields of IVT within a north-westerly airflow and concomitant low-pressure systems provided favourable conditions for heavy precipitation and flooding events on the South Islands West Coast The magnitude of maximum IVT during the rainstorms exceeds 1000 kg m1 s1 along the West Coast of the South Island. The duration of ARs at a given location combined with the intensity of the IVT values is the controlling factor in classifying ARs. According to the classification scale of Ralph et al. (2019), the AR associated with the July event was a Category 5 along the West Coast of the South Island (Figure 1). In February, two ARs both of which would rank Category 4 or 5 hit the West Coast back to back, inundating the rivers and residential areas. Considering the important role of ARs, further work is required to connect these large-scale atmospheric conditions and the catchment scale processes during flooding events. More detailed analysis of intensity and duration of ARs at specific locations will be conducted and the results will be compared with the total rainfall and river flows recorded at those locations. This information can be used to communicate more objectively what impacts an atmospheric river will have on flooding events in a region as well examining the appropriateness of the Ralph scales for NZ West coast.

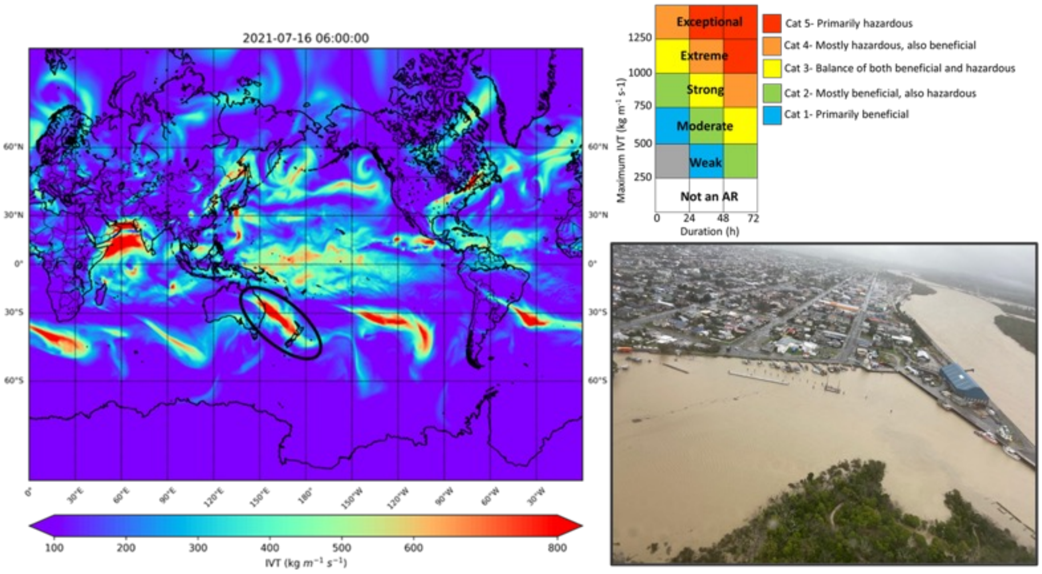

Figure 1. (left) IVT fileds during July 2021 floods showing a Cat 5 AR landing on the West Coast of New Zealand. (upper right) Ralph et al. (2019) AR impact category definitions, (lower right) inundation in Westport in July 2021.

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CROSS VALIDATION AND CHARACTERIZATION OF RAINFALL EXTREME EVENTS BETWEEN RAIN GAUGE DATAAND WRF MODEL IN NORTH CANTERBURY (NEW ZEALAND)

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Aims

The final 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 rainfall information is required since rainfall extreme events are the main inundation driver in the area. Weather Forecast Research numerical model (WRF) (Skamarock et al., 2008) can be a potential source of high grid spacing and temporal resolution rainfall data. This work aims to understand if WRF model generated rainfall data, specifically a rainfall dataset generated by University of Canterbury, represents well extreme rainfall statistics and can be used to characterize temporal and spatially rainfall extreme events. To this end, for this work, a cross validation between the WRF dataset and the rain gauge data in North Canterbury and a characterization of rainfall extreme events in the Banks Peninsula, are carried out. Eventually, a sample of flooding scenarios will be constructed for the Wairewa catchment based on the WRF dataset and other relevant variables for the flood modelling process. Selected scenarios from this sample will be modelled through a 2D hydrodynamic model (such as LISFLOOD-FP, first referenced in Bates & De Roo (2000)) 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 to rapidly estimate flood inundation in the catchment.

Methods

WRF rainfall dataset has been accessed and downloaded from 'The New Zealand Environmental Digital Library' (www.envlib.org). Rain gauge data, considered to provide reliable rainfall intensity estimations at a point, is considered the reference dataset, as with previous studies comparing rainfall observations and model predictions (Roy, et al., 2018). Data from 48 rain gauges, with less than 20 % of missing values and with at least hourly temporal resolution has been selected. The rain gauge network has certain limitations, such as its low density across most of the domain, which makes it very challenging to adequately characterize rainfall spatially. For overcoming the limitations of gauge networks, analyzing potential flood causing storms and enabling scenario assessments a high spatial and temporally resolution dataset is required. To this end a WRF generated rainfall database (from 2012 to 2022 with 1 km grid spacing at hourly scale), will be validated against rain gauge data to assess its ability to reproduce extreme rainfall events statistics in the study domain (North Canterbury). Focusing on extreme rainfall statistics, intensity duration frequency (IDF) curves for each rain gauge location and corresponding WRF dataset pixel are obtained, and the differences are estimated through error metrics, such as RMSE. As an additional part of the cross-validation process, in specific rain gauge locations with different topographic characteristics, Empirical Mode Decomposition (EMD) has been applied (Huang, et al., 1998). This technique can decompose a non-stationary and non-linear signal (in this case rainfall time series) in components (Intrinsic Mode Functions) in the time-frequency domain. This allows to explore the dominant frequencies present in the WRF database and the rain gauge data and compare them. After performing the cross-validation, we focus on the extreme rainfall events in the Banks Peninsula. To this end a population of extreme events is built based on the WRF dataset. Firstly, the hourly patterns are filtered using as threshold the 95th percentile (Dravitzki & McGregor, 2011), which is calculated for each pixel based on the rainy hours (rain over 1 mm/hr) (Nikumbh, et al., 2019). Afterwards, the events are built, based on a stablished rain threshold (0.1 mm/hr) that indicates the end and the start of the storm. The spatial variability of the population of extreme events is explored within different duration ranges (less than 5 hrs, 6-10 hrs, 11-15 hrs, 16-24 hrs, 24-48 hrs and more than 48 hrs), analyzing the total storm volume and the corresponding contribution of each pixel to it. Furthermore, to assess the relationship between storm duration and spatial variance and correlation, variograms are obtained and their corresponding range and sill values (variance and distance after which data are no longer correlated) are compared. The temporal variability is also investigated, looking into the different hyetograph shapes according across the study area. Finally, rainfall extreme events are linked to the synoptic conditions and large-scale climatic patterns (such as El Niño Southern Oscillation) to investigate their connection to them.

Results

Through the cross-validation it is found that extreme rainfall events statistics are reasonably well represented by the WRF model. For instance, in Figure 2, the intensity-frequency curves at a specific location for two different durations for both WRF model and rain gauge can be observed. Differences in the performance of the WRF dataset are found amongst the different locations storm durations. In this way, in the areas with complex topography, higher BIAS and RMSE values are observed. Longer durations also present higher error metric values. Figure 1: Intensity frequency curves for different durations for a specific location High variability across the spatial and temporal patterns can be found for extreme events in the Banks Peninsula. For instance, in shorter duration storms, more heterogonous rainfall patterns can be observed. These events are linked to variograms with higher sill values. Short storms are also associated with hyetographs that have one or two clear and distinct peaks. However, longer storms (especially above daily duration), present smoother and more homogeneous rainfall spatial patterns; accompanied by generally smaller sill values and hyetographs with multiple peaks of lower intensity.

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

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A REVIEW OF METHODS TO MAP AND ESTIMATE POPULATION SIZE FOR URBAN CATCHMENTS.

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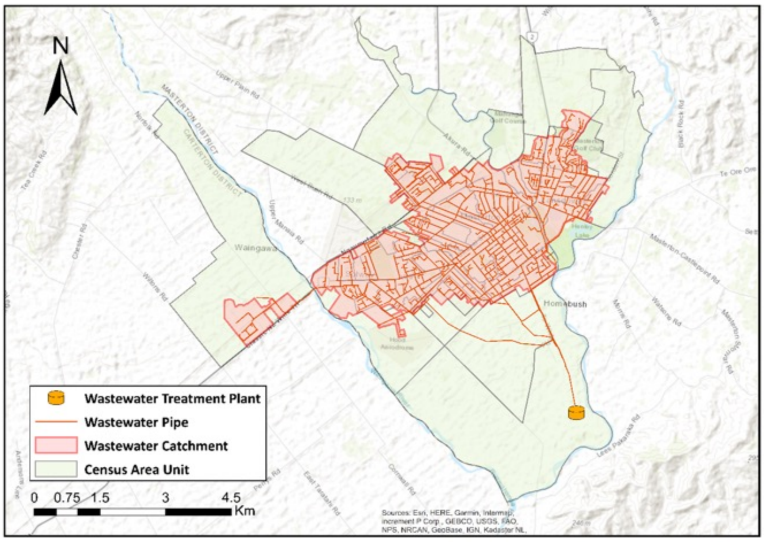
Aim
Accurate catchment population estimates are incredibly important for planning and management purposes. Population data are also fundamental to estimating community consumption of and/or exposure to chemicals (Price et al., 2021; Trowsdale et al., 2021). There are a range of methods to calculate population size, from the gold standard of census, to approximating household connections; none is perfect (Tscharke et al., 2019). All methods are reliant on accurate catchment mapping, which seems to have become a lost art, particularly in areas crosscut with urban water infrastructure. This paper reviews methods for urban catchment mapping and population estimation and draws recommendations for practitioners in New Zealand.

Method
The spatial coverage of wastewater pipe infrastructure was compiled for 46 wastewater treatment plants in New Zealand, covering 73% of the national population and encompassing a range of large and small communities. Wastewater catchment maps were created in geospatial software and were overlain with high-resolution census data (Figure 1). Different catchment mapping techniques to delineate catchment boundaries were compared. Four simple methods to calculate population from census were evaluated. The variability and uncertainty of these census populations were quantified and compared to WWTP-provided populations. Uncertainties relating to population change at daily and annual timescales were also assessed. Figure 1: Example wastewater treatment plant catchment and corresponding census area units.



Results

The results highlight the considerable variability in catchment mapping techniques and uncertainty population size calculations. These were particularly pronounced in smaller sites (< 200,000 population; Figure 2). Importantly, smaller sites have become the focus of wastewater-based epidemiology in the last couple of years with COVID-19 (Nicoll et al., 2022). There was striking variability in population estimates provided by WWTP operators. Rates of annual population change were highly variable across all sites. Such variability was not, however, associated with geographic differences, making generalisation across sites difficult. What is clear is that the magnitude of difference observed will significantly skew comparisons of consumption and exposure. The research stresses the importance of site-specific population dynamics. The key take home message is to 'know your catchment'.

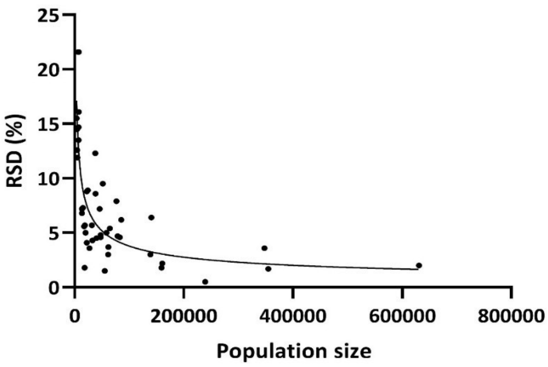


Figure 2: Variability in census population estimates across the four methods.

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SPATIOTEMPORAL TRENDS IN NEAR-NATURAL NEW ZEALAND RIVER FLOW

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Aims

Anthropogenic climate change is affecting rivers worldwide, threatening water availability and altering the risk of natural hazards. Rivers dominate the Aotearoa New Zealand landscape, providing communities with drinking water, irrigation for agriculture and food production, and most of the nation's renewable electricity. Rivers further provide habitat for many endemic species and are central to the Māori mauri (life force). Understanding observed changes in NZ streamflow can help us anticipate future changes and inform policies to protect these environmental, cultural, and economic resources.

Method

We present a benchmark data set of long, near-natural streamflow records across Aotearoa New Zealand and the first nation-wide analysis of observed spatiotemporal streamflow trends. Seasonal trends are assessed using the Mann-Kendall rank correlation test. In addition to assessing trends locally, we determine hydrologic regions through principal component and self-organizing maps cluster analyses to assess regional trends. While individual records rarely have significant trends, when aggregated within these regions, significant regional trends emerge.

Results

Over the last 50+ years, winter streamflow has significantly increased in the west South Island and has significantly decreased in the north North Island; summer streamflow has significantly decreased for most of the North Island; autumn streamflow has generally dried nation-wide; and spring streamflow has increased along the west coast and decreased along the east coast. Correlations between streamflow and dynamic and thermodynamic indices, as well as consistencies between the observed trends and known circulation and termperature changes, suggest possible climate change impacts on New Zealand hydrology.

AIERI CATCHMENT HYDROLOGICAL MODEL DEVELOPMENT TO SUPPORT NPS-FM LIMIT SETTING PROCESS

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Aims

In accordance with the National Policy Statement for Freshwater Management 2020 (NPS-FM), the Otago Regional Council (ORC) is preparing to draft and notify a new regional plan, the Land and Water Regional Plan (LWRP), by December 2023. The LWRP will give effect to the requirements of the NPS-FM and other relevant national and regional legislations. A key component of this plan will be to set limits on water quantity and quality to assist with meeting NPS-FM requirements. ORC has identified several Freshwater Management Units (FMU) and smaller management zones (Rohe) within FMUs where limits will be set individually. To assist with preparing the LWRP, a hydrological model was developed for the Taieri FMU. The Taieri FMU is climatically and hydrologically diverse; e.g., the median annual precipitation varies significantly within the FMU, ranging between over 1,500 mm in the headwaters at the Rock & Pillar Range to as low as 350 mm in the Maniototo Plains, where the majority of terrestrial water use occurs. River flows are managed by consumptive (agricultural, industrial and domestic) and non-consumptive (hydropower) uses. Growth in the primary sector during recent years has seen an upsurge of on-farm storage within the catchment. Surface flow within the catchment is influenced by several irrigation races that transfer water across the catchment. Several inter- and intra-catchment water transfers facilitate consumptive and non-consumptive water uses. These anthropogenic modifications complicate the already complex natural system that is influenced by uneven precipitation distribution. The inter- and intra-catchment water transfers are important components that need to be considered in overall water resources management and are a key contributor to the region's socioeconomic fabric and to municipal reticulation systems (e.g., Dunedin City water supply), industries (e.g., Oceania Gold), hydro-power generation and irrigation. ORC expects to use the hydrological model to assess the reliability of water supplies for existing takes for a range of land and water use, and climate change scenarios.

Our presentation will discuss the conceptual model for the Taieri catchment, criteria for model selection, input data preparation, hydrological model development, model calibration, flow naturalisation, model output and various scenarios to assist with managing water resources sustainably and make informed decisions for preparing the LWRP.

Method

The conceptual FMU model was derived by considering the purpose of the model (i.e., limit setting), hydrological complexity of the catchment, diversity of land cover and soil types, and other anthropogenic alterations such as water retention, transfer and discharge within catchment and between neighbouring catchments.

The model was selected based on 10 criteria that included availability of the model in a public domain (open-source); independent verification and peer-review of model processes and performance by the wider hydrology community; ability to simulate complex hydrological processes and practices such as water transfers between sub-catchments; extendibility of the model to include processes such as nutrient and sediment transport; and ease of altering land use/cover and simulate a range of water and land use scenarios and climate change conditions.

All available climate and hydrology data and information from ORC and other agencies (e.g., Manawa energy, NIWA, Manaaki Whenua – Landcare Research, AgResearch) were collated. These included precipitation (where snowfall is distinctly identified), surface flow, water use, water transfer, discharge, storage, stocking density and pasture productivity. Where data were found to be spare or incomplete, data infilling procedures were used.

Results

Based on the model selection criteria described above, the Soil and Water Assessment Tool (SWAT; Arnold et al. 1998) was selected as the hydrological model for the study. SWAT includes comprehensive surface and sub-surface hydrological processes such as surface runoff, percolation through soil layers, lateral subsurface flow, subsurface tile drainage, groundwater flow to streams from shallow aquifers, evapotranspiration, snowmelt, transmission losses from streams, water storage, and losses from ponds and reservoirs (Figure 1; Arnold et al. 1998). The model consists of a flexible structure with various modules, which can be turned on and off based on dominant hydrological processes in a catchment.

SWAT discretises a catchment into hydrological response units (HRUs). Each HRUs is a unique combination of land use/cover, soil type and elevation. For the Taieri catchment, a total of 1,428 Strahler order 1 subcatchments were identified, and each subcatchment comprised one or more HRUs. The model was run at a daily time-step, while the time scale of inputs varied from daily (e.g., rainfall) to seasonal (e.g., stocking density).

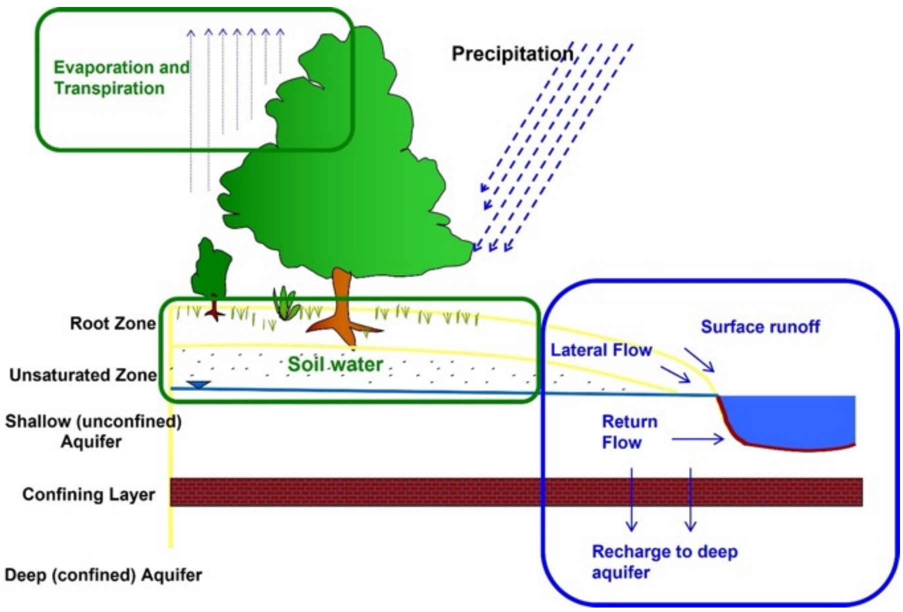

Figure 1: Hydrological processes represented in SWAT (Adapted from Arnold et al., 1998).

Acknowledgement
Authors are grateful to organisations that provided data and information for this project. Special thanks are extended to: Maniototo Irrigation Scheme, landowners within the catchment, Manawa Energy, Matt Hickey, Susie McKeague, Dunedin City Council, Sarah Mager of University of Otago, AgResearch, Manaaki Whenua – Landcare Research.

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COMBINING PHYSICS AND ARTIFICIAL INTELLIGENCE - A HYBRID MODEL FOR IMPROVED CLIMATE PROJECTIONS

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Introduction
Understanding how New Zealand's climate will continue to change throughout the 21st century critically depends on sophisticated Global Climate Models (GCMs). The typical spatial resolution (~100 km) of a GCM does not capture precipitation variability across New Zealand. Regional Climate Models (RCMs) are used to enhance the spatial resolution of such GCM simulations, simulate extreme events, and enhance the overall relevance for societal decision-making. However, the extreme computational expense of RCMs presents a major bottleneck for running the required simulations at very high spatial resolution. Statistical techniques are also widely used to enhance the resolution of GCMs and are computationally inexpensive, but they struggle to resolve extreme events.

Aims:
The aim of our research is to use artificial intelligence (AI) to enhance the resolution of CMIP6 GCM simulations (>100km) and of RCM-based downscaling simulations (~12km) to a 5km resolution. Where the AI-based algorithms can learn physical processes that are responsible for local-scale processes including extreme events.

Results:
To enhance the resolution of daily precipitation from CMIP6 GCM and RCM simulations to a 5km resolution, we have developed a Convolutional Neural Network (CNN) model that optimises the negative log-likelihood of a Bernoulli-gamma distribution. Our CNN can learn to resolve extreme events including highly localised extreme events. Additionally, our developed AI-based downscaling is approximately four orders of magnitude faster than dynamical downscaling. When tested independently against observations, we can explain on average 65% of the variance of wet days for New Zealand, an improvement of 30% in explained variance over existing statistical methods. Furthermore, we have been able to reduce the error in the 99th percentile of precipitation by over 30% relative to existing statistical methods.

When our model is applied to global and regional climate models, it can reduce biases in climatological rainfall by over 40%. Importantly, preliminary results suggest that our AI-based model can preserve the climate change signal from the host model, meaning the approach may be suitable for regional-scale climate change projections.

Our application of AI to downscaling GCMs has the potential to substantially improve decision-making for climate adaptation and support resilience for extreme events, through its both enhanced resolution and computational speed.

CHEMICAL CONTAMINATION IN LAKE OPUHA

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Aims

This paper describes the key results and conclusions of recent investigations into the presence of toxic waste in the bed of Lake Opuha, after members of the Ōpihi Catchment Enviroment Protection Society (OCEPS) notified Environment Canterbury (ECan) of very high concentrations of DDT, arsenic and various toxic metals in sediment samples collected from the lake bed in 2015. The potential for this contamination to be responsible for degraded river environments observed in parts of the Ōpihi River catchment, and the risk to human health and land health via the use of Lake Opuha water for drinking water and irrigation, is also examined.

Methods

Information from the literature and OCEPS on the state of rivers in Ōpihi River catchment, and analytical data for various fish, sediment and water samples collected by OCEPS and ECan between 2015 and 2022 determined by various accredited laboratories (Watercare, Eurofins, Hills, ALS), were used to assess the likelihood and location of possible toxic environmental contamination in the Ōpihi River catchment. Two ECan reports (Davie and Clarke 2015; Davie, Clarke and Beck 2015) examining pesticide contamination in the Ōpihi catchment were reviewed. Two site visits were made in April 2022 to see if any DDT nodule contamination found in the Opuha River in 2015 was still present, and to see the impacts of Opuha River water on insect life in the Ōpihi and Kakahu Rivers. Organic nodules found in sediment collected at the Skipton Bridge on 4 April 2022 were analysed by Watercare Laboratories.

Results

After the OCEPS findings in 2015, ECan conducted a further study but could not replicate the OCEPS results, only finding background degraded-DDT, and arsenic concentrations, typical of Canterbury soils in Lake Opuha bed sediments (Davie and Clarke 2015). However, the ECan sampling sites were at different GPS coordinates to those sampled by OCEPS. ECan found sediment contaminated with un-degraded DDT, and arsenic, at Skipton Bridge on the Opuha River, and concluded that this was contaminating the river and that it had been deliberately placed at the site (Davie, Clarke and Beck 2015). ECan accused four members of OCEPS of this action and notified the police. ECan removed the contaminated sediment from the river bed, and concluded there was no on-going problem (Davie, Clarke and Beck 2015). However, evaluation of the Davie, Clarke and Beck (2015) report has shown that there was no conclusive evidence supporting the deliberate placement of contaminated sediment at the Skipton Bridge. Also DDT contamination remained in the river after the removal of the contaminated sediment. This, and the presence of un-degraded DDT granules or nodules, from < 1 mm to > 4 mm across, in river bed sediment in the Opuha River, suggests that the river must have been severely contaminated with DDT from an external up-river source in 2015 (Rankin 2022).

Since 2015 OCEPS members have found elevated DDT concentrations in flesh and liver samples of trout and eels caught in Lake Opuha, and on-going very high DDT, arsenic and metal concentrations in 2020 and 2021 in lake bed sediments collected from sites sampled in 2015 (Rankin 2022a; Table 1). In September 2021 OCEPS collected seven water samples at different points throughout the Ōpihi River catchment and found significant DDT and arsenic concentrations in two water samples from the Opuha River, and one from Ribbonwood Stream that feeds into Lake Opuha (Table 2). In January 2022 ECan found no DDT or other organochlorine pesticides in five water and five sediment samples from the Opuha and Ōpihi Rivers (Sail and Black 2022), in contrast to the water samples collected by OCEPS in September 2021, and again concluded there was no contamination issue. Only nodules of highly toxic diisopropylnaphthalene (DIPN) were found in sediment collected at the Skipton Bridge in April 2022 (Rankin 2022). These could have resulted from inappropriate disposal of this agrichemical into the catchment, or from dispersal and biodegradation of DIPN sulphonates, used in formulating pesticide products and in metal plating products discarded in the catchment (Rankin 2022).

This data has led the author to conclude and document (Rankin 2022, 2022a) that there is likely an ongoing significant toxic contamination problem in the bed of Lake Opuha and with water from Lake Opuha. However, given the paucity of data available, a thorough and comprehensive research programme into the full nature and extent of toxic contamination at burial sites in Lake Opuha, and toxicant concentrations in water and sediment in the Opuha and Ōpihi Rivers over different seasons, is needed to confirm whether burial of toxic wastes in Lake Opuha is in part is responsible for the degraded river environments in the Ōpihi catchment, and any risks to human and land health through drinking and using Lake Opuha water.

Table 1: Organochlorine pesticide residues and arsenic and metal concentrations (mg/kg on dried samples; % by mass in parentheses) in Lake Opuha sediment samples collected on 26 May 2021

	Sample No. and GPS coordinates			
Analyte	1 S 43 deg 59’ 0.060” E 170 deg 52’	2 S 43 deg 59’ 0.905” E 170 deg 52’	3 S 43 deg 59’ 28.336” E 170 deg 52’	4 S 43 deg 59’ 26.337” E 170 deg 52’

	13.424"	14.812"	16.837"	13.414"
Total DDT	230 (0.023)	2300 (0.23)	2400 (0.24)	3000 (0.30)
Aldrin	<0.01	<0.01	<0.01	<0.01
Dieldrin	0.60	<0.01	<0.01	<0.01
Lindane	0.02	0.02	0.02	0.02
Arsenic	16.5 (0.002)	472 (0.05)	1210 (0.12)	1200 (0.12)
Cadmium	1260 (0.13)	2140 (0.21)	2750 (0.28)	5250 (0.53)
Chromium	369 (0.04)	560 (0.06)	811 (0.08)	1550 (0.16)
Lead	2200 (0.22)	3150(0.32)	4510 (0.45)	7610 (0.76)
Manganese	336 (0.03)	403 (0.04)	391 (0.04)	420 (0.04)
Mercury	<0.1	<0.01	<0.01	<0.01

Table 2: Contaminant concentrations (mg/L) in river water at various sites in the Ōpihi catchment

Analyte	Sample No. and location						
	1	2	3	4	5	6	7
	Opuha River at weir below dam	Opuha South Branch at Claytons Road bridge	Opuha North Branch at Claytons Road bridge	Ribbonwood Stream at Claytons Road bridge	Opihi River at Fairlie Main Rd bridge	Opuha River at Skipton bridge	Opihi River at Mill Road below Pleasant Point
Total DDT	2.15	0.00	0.00	4.20	0.00	1.13	0.00
Antimony	3.60	<0.02	<0.02	4.33	<0.02	2.06	<0.02
Arsenic	330	<0.02	<0.02	294	<0.02	186	<0.02
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	2310	<0.01
Copper	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Mercury	3.77	<0.01	<0.01	2480	<0.01	2.01	<0.01

If burial of toxic waste in the bed of Lake Opuha is confirmed, and it is causing environmental problems in the catchment, and if it can be removed, then there is a possibility of rectifying the problem. If no action is taken then the problem will persist. The issues that have led to such inappropriate burial, and difficulties that arise from it, are also briefly discussed.

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With respect to the abstract above, Environment Canterbury and Opuha Water Ltd (OWL), strongly disagree and refute the material and assertions as presented in this abstract. This subject was comprehensively investigated in 2015 with the full involvement of community stakeholders and external peer review. The investigation, in part, concluded that *"Overall the results from this investigation show us that Lake Opuha water is safe to drink, safe for agricultural use, and that the flesh of trout caught in the lake is safe to eat."* Environment Canterbury and OWL remain fully aligned with this conclusion. The full report published by Environment Canterbury in December 2015 is available here (https://api.ecan.govt.nz/TrimPublicAPI/documents/download/2427578).

LOSS OF CHRISTCHURCH’S HIGH QUALITY DRINKING WATER

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Aims

This paper aims to examine the little-known long-term loss of Christchurch’s high quality low-nitrate drinking water source, as a result of nitrate released to groundwater from the intensive farming that has been permitted in the Waimakariri catchment in Canterbury. The potential risk to human health and ecosystem health from this nitrate release is briefly examined, as are the reasons for this situation, and what is needed to rectify it.

Methods

Information from the literature, various Environment Canterbury (ECan) reports, and expert evidence presented to the Christchurch Regional Council Plan Change 7 (PC7) Hearing has been analysed. The magnitudes of increases in current nitrate concentrations in Christchurch aquifers from farming permitted in the Waimakariri catchment have been calculated from published data. Inconsistencies in data interpretation in some reports have been identified and examined. Nitrate-nitrogen load reductions and nitrogen release rates below the root zone required in an interzone transfer source area (ITSA), in order to retain Christchurch’s deep-aquifer groundwater nitrate concentrations at their current levels, and to meet other proposed standards, have been calculated.

Results

Nitrate concentrations are increasing in groundwater and surface water throughout Canterbury as a result of increased intensive farming, threatening human health and the quality of groundwater drinking water for Christchurch and Canterbury, and the health of freshwater ecosystems (Joy et al. 2022). The current New Zealand drinking water standard (DWS) for nitrate is a maximum acceptable value (MAV) of 11.3 mg NO_3^--N/L, and is set to protect infants from blue baby syndrome. A recent Danish population-wide drinking water study shows an increased colorectal cancer risk starting from levels as low as 0.87 mg NO_3^--N/L (Schullehner et al. 2018) and recommends discussions over lowering the DWS nitrate limit. Other studies suggest increased risks of poor birth outcomes and other cancer outcomes. The Christchurch City Council (CCC) aims to supply drinking water at typically 1.0 mg NO_3^--N/L, and has suggested a MAV of 1.0 mg NO_3^--N/L to protect citizens and Christchurch aquifers. The Australia and New Zealand guideline trigger level for ecosystem health is 0.44 mg NO_3^--N/L, below which ecosystems are considered healthy and above which they are considered damaged.

Most of Christchurch’s groundwater is increasingly sourced from the deep aquifers, as shallower aquifers are becoming increasingly contaminated with nitrate (Table 1).

Table 1: Current observed aquifer concentrations and modelled final steady state nitrate concentration (mg NO_3^--N/L) contributions (Etheridge, Hanson and Harris, 2018) and calculated changes in concentrations in the Christchurch aquifers for GMP and dryland farming scenarios in the interzone transfer source area of the Waimakariri Zone

Aquifer	Current concentrations			Farming type	Modelled concentrations			
	Median	95th percentile	Maximum		Median	Increase (times)*	95th percentile	Increase (times)
Shallow	2.5	7.6	27	GMP	3.7	1.5	7.9	1.04
				dryland	1.7	0.68	3.7	0.49
Mid	2.4	6.1	7.3	GMP	4.1	1.7	7.4	1.2
				dryland	1.3	0.54	2.4	0.39
Deep	0.3	1.6	2.6	GMP	4.7	16	7.3	4.6
				dryland	1.3	4.3	1.9	1.2

* Increases (or decreases where the value is less than 1) in modelled concentrations relative to current concentrations.

Nitrate leached from farming in the interzone transfer source area (ITSA; or catchment) in the Waimakariri Zone (WZ), where nutrients from farming are released into water supplying the Christchurch aquifers, will contribute significant contamination to all of Christchurch’s aquifers, as shown under a current proposed good management practice (GMP) scenario (Table 1). Nitrate concentrations increase in all aquifers, and especially in the deep aquifers, where the median and 95th percentile concentrations increase 16 and 4.6 fold, respectively. As a result Christchurch will lose its safe low-nitrate deep-well drinking water source. The increase in nitrate concentrations will take years to emerge (an estimated 10-50 years), as much of the nitrate load is yet to reach aquifers. This situation has arisen because Environment Canterbury (ECan) has permitted widespread intensification of farming (largely dairy farming) in the region with no controls on nutrient release.

A much less intensive dryland farming scenario in the WZ would have a lower impact on Christchurch's drinking water quality (see Table 1). The modelled concentrations would rise to lesser amounts in the deep aquifers, but fall in the shallow and mid-depth aquifers (Table 1). ECan proposes a median nitrate concentration limit of 3.8 mg NO_3^--N/L in the deep aquifers under PC7 by requiring a reduction of about 20 % in the nutrients released from farming in the ITSA. ECan claims in Kreleger and Etheridge (2019), and in a publicity video at the Christchurch office, that it is protecting Christchurch's groundwater, but this is clearly not true. PC7 will lead to a 12.7 fold increase in the median nitrate concentration and will not protect and retain the quality of the current low-nitrate water in Christchurch's deep aquifers.

Land use activities in the ITSA in the WZ and elsewhere would need to be restricted to protect the drinking water catchment/source and Christchurch's current deep groundwater quality. Calculated nitrate leaching reductions required in the ITSA to meet different standards are summarised in Table 2.

Table 2: Calculated reductions in nitrate loads (%) and N loads permitted (kg/ha/yr) for the ITSA to achieve different nitrate concentrations in the deep Christchurch aquifers

Farming type	Retain current median 0.3 mg NO_3^--N/L		Meet CCC MAV of 1.0 mg NO_3^--N/L	
	Reduction in nitrate load	Estimated nitrate N load permitted	Reduction in nitrate load	Estimated nitrate N load permitted
Current GMP	93.6	2.2	88.3	4.0
Proposed PC7	92.1	2.2	85.5	4.0

GMP farming and PC7 farming nutrient losses would need to be reduced by > 92 % to preserve Christchurch's groundwater quality and > 85 % to meet the proposed CCC 1.0 mg NO_3^--N/L DWS, which correspond to estimated N leaching limits of 2.2 and 4.0 kg/ha/yr, respectively. Similar very large reductions in nutrient release are also required to reduce the recently estimated mean nitrate concentration in groundwater impacted upon by dairy farming in Canterbury, of 21.3 mg NO_3^--N/L (Joy et al. 2022). This shows how unsustainable and impactful dairy farming is in the region.

What planning rules should be used to effect such changes? The results from this analysis suggest that, in order to protect Christchurch's drinking water supply, recharge areas need special land use classifications and constraints on nutrient release to control inappropriate development. Changed farming practices, such as herd shed dairy farming with no nutrient release to the environment, and farming in a truly sustainable fashion so there is no environmental degradation long-term, are needed to restore our degraded freshwater environments. Unless rules are reviewed and changed and made fit-for-purpose, and targets and timelines are set, nothing will change, and ecosystems will remain unhealthy and significant human health and new drinking water supply costs will not be avoided.

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INTEGRATING HIGH-RESOLUTION RAIN RADAR AND SPATIALLY DISTRIBUTED HYDROLOGICAL MODELLING FOR FLOOD FORECASTING IN NEW ZEALAND

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Aims

Accurate flood forecasts can help mitigate impact and improve preparedness, however, modelling rainfall-runoff processes during high-intensity events is challenging in New Zealand's complex topographic and fast responsive catchments (Cattöen et al. 2016). Hydrometeorological systems can suffer from biases from calibrating hydrological models with traditional rainfall estimates which are spatially or temporally too coarse, such as rain gauges or gridded products (e.g. the Virtual Climate Station Network [VCSN; Tait et al. 2006]). However, with high-resolution rainfall radar measurements now available, we explore their use with a distributed process-based hydrological model of comparable spatial resolution to answer questions about how high-resolution radar-based rainfall-runoff predictions compare with traditional rainfall products during flood events and about the implications and challenges for real-time nowcasting operations using this high-resolution hydrometeorological modelling approach.

Method

Radar Quantitative Precipitation Estimation (QPE) has been developed for the Auckland region (covering ~5000 km2) in New Zealand using a single-polarisation C-band radar. The quality of the QPE is first ensured by minimizing bias and errors through carefully designed data processing then a spatially dependent adjustment is made using gauge observations. Radar processing incorporates many corrections for errors including miscalibration, Doppler filter losses, radome and rain attenuation, vertical reflectivity profile and advection interpolation. The final stage of gauge adjustment is implemented using Ordinary Kriging of Radar Errors.

To evaluate the relative impact of radar-based rainfall-runoff modelling flood prediction performance, we also consider rainfall gauge stations and NIWA's observed gridded products which interpolate observed meteorological values onto a grid covering New Zealand at a 500m and at a 5km spatial resolution (VCSN).

We use TopNet, a semi-distributed hydrological model for simulating catchment water balances and river flow (McMillan et al. 2016). TopNet combines a water balance model within each sub-catchment (250-500m2 resolution) (Beven et al. 1995). The rainfall-runoff response of TopNet to high resolution rain radar data is compared to that of rain gauge measurements and/or VCSN for ten flood events in Auckland between 2010 and 2020. These events are some of the highest flow events recorded by natural flow sites such as Mangawheau Stream at Weir in the Papakura catchment (*Figure 1*) and during the study period. Furthermore, to assess rainfall-runoff uncertainties for flood modelling, we consider hydrological model uncertainties (e.g. model parameters) by running an ensemble of simulations and compare flood uncertainties between rainfall-runoff prediction approaches.

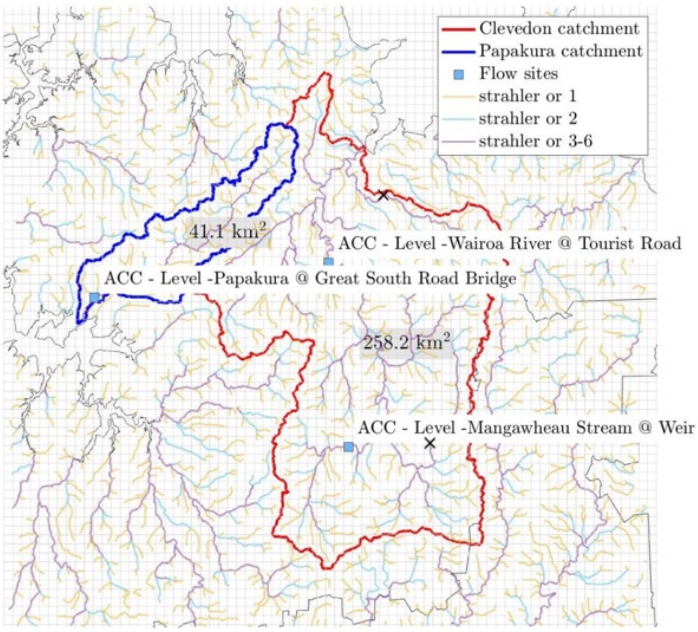

Figure 1: Study catchments in the Auckland region. The figure indicates flow sites, size of catchments and rivers network

Results
In this presentation we report on the general experiences running TopNet with high-resolution rain radar data. We focus on data preparation, model setup, and preliminary results for some catchments of interest in the country. We evaluate the performance of rain radar vs. rain gauge vs. VCSN-fed data inputs and against observations for the different flow sites in those catchments, and we discuss the utility of such data in real time operations and possible implications for developing nowcasting hydrometeorological systems based on distributed modelling.

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SATTELLITE OBSERVATIONS OF SNOW DEPTH TO SUPPORT HYDROLOGICAL MODELLING IN AOTEAROA NEW ZEALAND

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Aims
Historically, snow modelling in Aotearoa New Zealand has been limited by scarce observations of snow depth and distribution in alpine catchments. Within the surface water flow model of the New Zealand Water Model (NZWaM)/TopNet, snow is modelled in a semi-distributed fashion, with sub-catchment snow water equivalent (SWE) storage estimated for 100 m elevation bands. Sub-model scale (i.e., within elevation band) variability is parameterised with a two-parameter probability distribution controlled by the coefficient of variation (CV) of snow depth (Liston, 2004). Appropriate values for the CV parameter are, however, based on relatively limited in situ observations (e.g., Clark et al., 2011). Uncertainty remains around how well spatial variability in snow depth at the catchment scale is represented, particularly in terms of wind- and gravity-driven snow redistribution. Modern photogrammetry offers a step-change in mapping snow depth in a spatially continuous manner across relatively large areas (e.g., Redpath et al., 2018, Eberhard et al., 2021). Recently, substantial progress has been made in automating the workflow of satellite photogrammetric mapping (SPM) (Zareei et al., 2021), scaling up our ability to map snow depth at high spatial and flexible temporal resolutions (e.g., Eberhard et al., 2021). This research aims to leverage SPM to map snow depth through the central Southern Alps through the winter and spring of 2012, providing improved empirical characterisations of seasonal snow and supporting the development of a redistribution model, that taken together are anticipated to enhance the representation of snow variability within NZWaM/TopNet. This presentation will focus specifically on work carried out for the Jollie Catchment, targeting peak accumulation for the 2012 winter season.

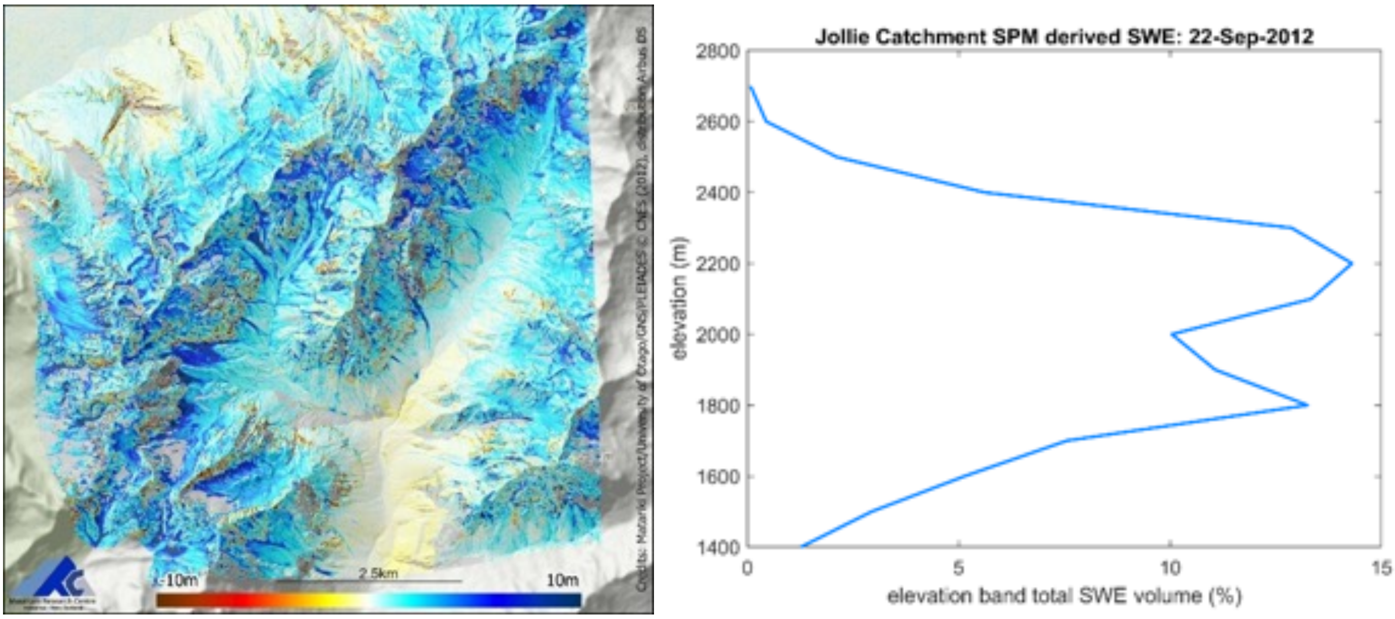
Methods
Calculating snow depth via SPM is essentially a three-step process involving the triangulation of photogrammetric models, generation of Digital Surface Models (DSMs) and orthoimages, and finally the computation of a DEM of Difference (DoD). Archived image triplets from Pléiades-1A were acquired for May 6 and September 22 2012. For each date, image triplets are tied to a reference triangulated photogrammetric image block spanning across the Main Divide and benefit from an existing network of sub-metre accurate Ground Control Points (GCP). The quality of the reference model is assessed by a leave-one out cross-validation (LOOCV) (Sirguey and Cullen, 2014). The 2012 photogrammetric models are triangulated using a variation of the methodology described in Zareei et al. (2021).

For each image date, DSMs were generated at 2 m resolution from each of the three available stereo-pairs. DSMs were accompanied by corresponding maps of ray intersection error, indicative of the stereo-matching quality. A final “blended” DSM was produced for each date using a weighted arithmetic mean, whereby the elevation from each constituent DSM was weighted by the corresponding ray intersection error (Eberhard et al., 2021). Uncertainty propagation provided a map of standard error for each of the blended DSMs. The blended DSMs are the primary intermediate product for snow depth derivation and are also used to produce an optimised pan-sharpened orthoimage for each date. A local image contrast derivative product was generated from the orthoimage to identify areas of poor stereo-matching and unreliable elevation estimates in addition to ray-intersection error.

The DoD was produced from the DSM pair (i.e.,) and quality assurance (QA) layers measuring the reliability of the DSM on either date. A map of DoD standard error was generated from constituent DSM ray intersection error, while a map of minimum local image contrast from both image constituents of the DoD. Following the filtering of spurious measurements using the QA layers, the remaining surface height change largely represents the accumulation of snow between May and September. Applying a snow density function allows the map of snow depth to be converted to a map of SWE.

Results

SPM reveals the distribution of snow depth and SWE across the Jollie Catchment at an unprecedented level of detail (Figure 1(a)). Clear detection of the snowline at approximately 1400 m highlights the performance of SPM in terms of signal-to-noise. Evidence snow of redistribution is widespread, with the role of avalanching particularly apparent in shifting substantial volumes of snow down-slope. Preliminary assessment of SWE storage in the upper Jollie Catchment (approximately 35 km2) indicates a total volume of approximately 14,000,000 m3, on September 22 2012. This volume equates to 31 hours of the mean annual inflow into Lake Pukaki. When based on SPM, estimates of total SWE storage become increasingly sensitive to the estimation of snow density, and highlight limitations around the measurement and characterisation of snow density in the Southern Alps. Hypsometric analysis (Figure 1(b)) reveals that maximal snow depths occur at mid-elevations within the Jollie Catchment, which translates to the bulk of SWE storage (75%) residing in the elevation range of 1700 – 2300 m (of a total range of 1300 – 2700 m), indicating that assumptions regarding elevation dependencies in seasonal snow modelling should be applied cautiously.



(a) *(b)*

Figure 1: (a) DEM of Difference (DoD), for May – September 2012, representing snow depth across the upper Jollie Catchment near peak accumulation and (b) distribution of snow water equivalent (SWE) volume across elevation bands within the catchment.

Going forward, the insights provided here will underpin work to refine the modelling of seasonal snow within NZWaM/TopNet, especially as the methodology is scaled up to the wider central Southern Alps region and extended in time through the winter and spring of 2012. These results, while focused on the challenging target of seasonal snow, also demonstrate the wider potential of SPM for improving understanding of a range of processes in steep and unstable catchments in Aotearoa New Zealand.

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WATER CYCLE CHANGES: THE IPCC AR6 VIEW

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The Working Group 1 component of the 6th Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) was published in August 2021. Chapter 8 of that report was focused on "Water Cycle Changes", an overview of how global warming and climate change is affecting water in the climate system (Douville et al 2021). The presentation will provide an overview of the content of the Chapter, including the theoretical basis for changes in the water cycle, observations and projections of change, and the potential for abrupt change. All aspects of the water cycle globally are affected by the warming climate, driven largely by a mix of the Clausius-Clapeyron relationship and changes in atmospheric circulation.

Figure 1 below illustrates many of the key points of large-scale change in water cycle behaviour globally.

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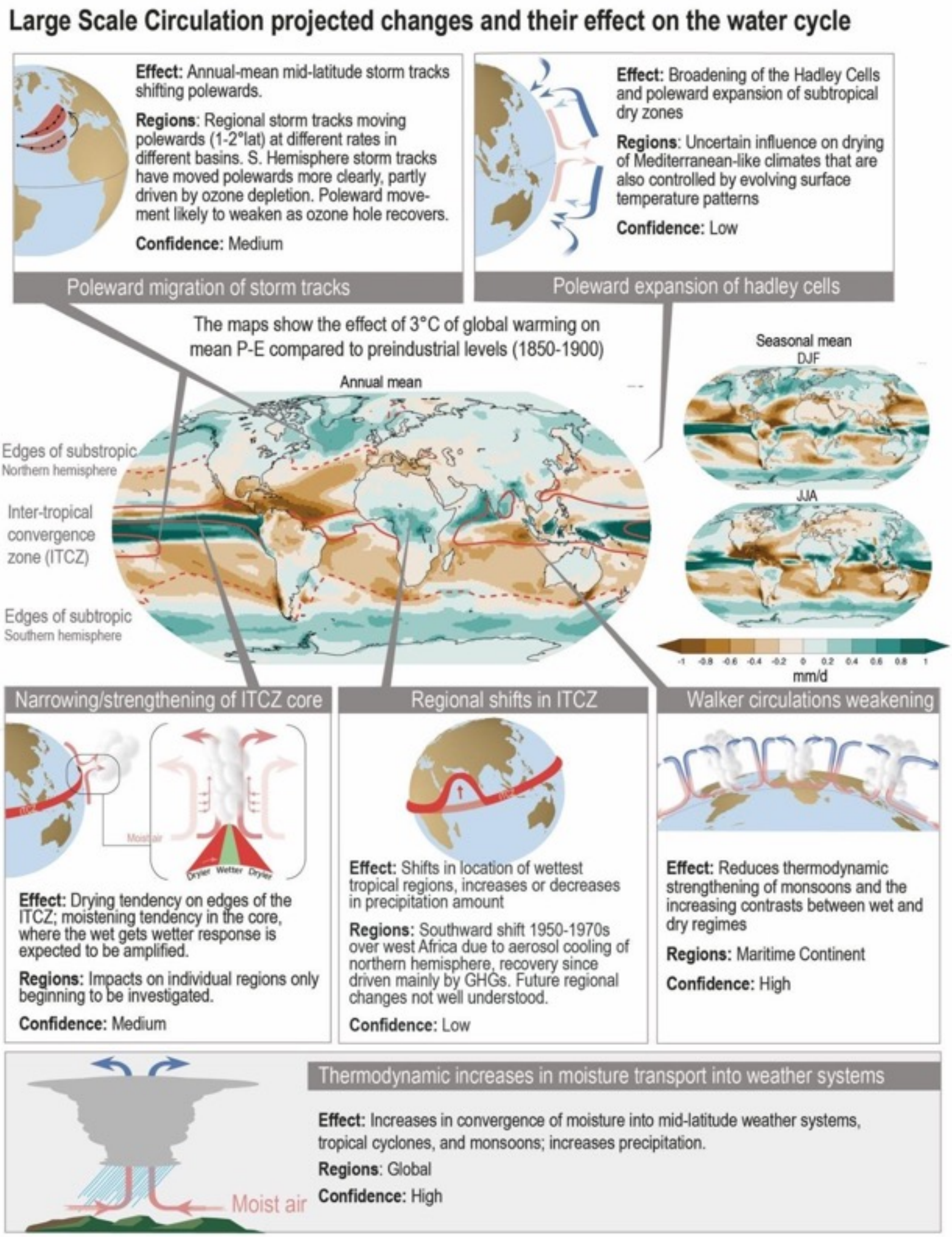

Figure 1: Schematic depicting large-scale circulation changes and impacts on the regional water cycle. The central figures show precipitation minus evaporation (P-E) changes at 3°C or global warming relative to a 1850-1900 base period (mean of 23 CMIP6 SSP5-8.5 simulations). Annual mean changes (large map) include contours depicting control climate P-E=0 lines with the solid contour enclosing the tropical rain belt region and dashed lines representing the edges of subtropical regions. Confidence levels assess understanding of how large-scale circulation change affect the regional water. From Figure 8.21, Douville et al (2021).

AN INVENTORY OF GLOBAL ROCKET LAUNCH EMISSIONS AND PROJECTED NEAR-FUTURE IMPACTS ON STRATOSPHERIC OZONE

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Abstract
Many governments and companies have expressed bold ambitions to grow their presence in space. However, rocket launches throw out a stream of air pollutants from their burnt fuel as they pass through the stratosphere, which is where the protective ozone layer resides. Currently, launch operators do not have to measure the impacts of their activities on the ozone layer. We gather together all the publicly available information we can find on rocket launches in 2019 from 17 active spaceports worldwide, and make some careful assumptions to convert each rocket's fuel to its burnt fuel products left in the atmosphere. To explore potential future impacts, we ran a climate model simulation in which each of the 17 spaceports has 120 rocket launches per year. Global average ozone decreases by 0.5%, with larger losses observed in polar regions. Today, the ozone layer is beginning to recover from the chlorofluorocarbons pumped into the atmosphere in the late 20th century. Our results suggest that sustained and frequent rocket launches in the 21st century will delay ozone recovery. Careful rocket fuel choices, along with ongoing assessment of stratospheric impacts, could counter this problem.

INFLUENCE OF OZONE FORCING ON 21ST CENTURY SOUTHERN HEMISPHERE SURFACE WESTERLIES IN CMIP6 MODELS

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Abstract
Global climate models must simulate Southern Hemisphere westerly winds accurately to simulate other key features of Southern Hemisphere midlatitude climate. During Southern Hemisphere summer, westerly winds are partly influenced by the Antarctic ozone hole. Global climate models simulate ozone in one of two ways: either they calculate ozone concentrations online via an interactive chemistry scheme, or they prescribe a precomputed ozone data set. The former approach is computationally expensive, yet the latter approach means that ozone cannot respond to internal changes in the model, potentially causing errors. In the sixth Coupled Model Intercomparison Project (CMIP6), most models prescribed ozone rather than calculating it online. We show that the ozone data set they prescribed is not consistent with other forcings used by the CMIP6 models, therefore models with and without interactive chemistry produce different 21st century Antarctic ozone projections, leading to differences in Southern Hemisphere westerly winds. This study adds another line of evidence as to why using interactive chemistry in a global climate model is important. It also acts as a cautionary tale for the next CMIP assessment, by showing that ozone forcing data sets must be produced in a way that is as consistent as possible with other CMIP forcings.

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EMERGENCE AND DE-EMERGENCE OF CFC-INDUCED OZONE DEPLETION IN THE SOUTHERN HEMISPHERE

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Aims

This research aims to establish how ozone concentrations are projected to evolve in different regions of the atmosphere in models that contributed to phase 1 of Chemistry Climate Model Initiative (CCMI1), using the signal-to-noise metric described by Frame et al. (2017). We also seek to establish whether it can be confirmed that the increasing ozone concentrations projected over the 21st century can be diagnosed as a full recovery based on the terms of the Montreal Protocol using these model data sets, given that greenhouse gas concentrations are increasing through the 21st century.

Method

This project analyses data produced by models contributing to phase 1 of the Chemistry Climate Model Initiative (CCMI) model group, in particular those contributing to the 'future reference' REF-C2 experiment, which follows the World Meteorological Organization's A1 scenario for halocarbons, and the RCP 6.0 scenario for greenhouse gas concentrations. The methodology used in this project closely follows that of Frame et al. (2017), with a few key differences. Frame et al. (2017) diagnose climate change emergence in the context of the signal-to-noise ratio (S/N) of surface temperature, while this project uses total column ozone instead of temperature to diagnose the emergence (and de-emergence) of Southern Hemisphere ozone depletion.

The CCMI models are all atmospheric models that use atmospheric chemistry in order to calculate chemical reactions within the model's architecture, which in the case of this project is used to analyse the impacts of the Montreal Protocol on ozone concentrations.

Results

It was found that the region and time with the highest signal-to-noise ratios in total column ozone was the Antarctic in October, consistent with previous knowledge on stratospheric ozone evolution. Given that greenhouse gas concentrations are changing through the 21st century, we also calculated signal-to-noise ratios in total column ozone for the CCMI1 SEN-C2-fGHG simulation, in which greenhouse gases are fixed at constant 1960 concentrations between 1960-2100. Given that greenhouse gases, for example CO2-induced stratospheric cooling, increase ozone concentrations, we find that ozone recovery from halocarbons (defined as a signal-to-noise ratio smaller than 1) occurs approximately 20 years later than currently estimated (Dhomse et al. 2018). Most significantly, October Antarctic ozone never recovers from halocarbons in the 21st century. This study shows that signal-to-noise is a useful metric in quantifying emergence and de-emergence relating to ozone depletion, and highlights the importance of all parties to the Montreal Protocol continuing to adhere to its requirements.

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MEASURING NITRATE CONCENTRATIONS IN WATER – THE PRO'S AND CON'S OF USING COMMERCIAL LABORATORIES OR DO-IT-YOURSELF

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Aims
Nitrate contamination is one of New Zealand's biggest threats to drinking-water quality, as well as groundwater and surface water Health and elevated nitrate concentrations are common in both freshwaters (StatsNZ 2019, 2022). In-field measurements, mail-in programmes and town-hall citizen science nitrate testing using hand-held instruments have become popular to provide insights into the size of nitrate contamination across New Zealand. Our study examines the practical reliability and limitations of different portable nitrate instruments that can be used in the field or on a kitchen table.

Methods
We test the precision and accuracy of three different types of portable nitrate testing instruments using a range of nitrate standards and compare with results of the same nitrate standards analysed at seven accredited testing laboratories. We prepared ten nitrate standards from 100 and 1000 mg/L nitrate standards ranging from 0.5 to 25 mg/L NO3-N. The standards were analysed using the hand-held instruments and submitted to commercial testing laboratories for an interlaboratory comparison to assess their precision, accuracy and cost.

Results
Our study showed that all accredited commercial testing laboratories performed within the expected accuracy criteria of between 0 to 5 % of the actual value. While hand-held instruments all suffer from limitations above the maximum acceptable value of 11.3 mg/L for nitrate, the performance of some systems can be improved through instrument recalibration or sample dilution. Three hand held insturments were investigated. A nitrate ion selective electrode (ISE) probe was found to be the most reliable hand-held instrument with a wider analytical range than the TriOS NICO UV Nitrate sensor and the Reflectoquant RQflex reflectometer.

The comparative performance of the hand-held instruments reviewed in this study provide confidence that citizen science testing, while not as robust as accredited commercial laboratory testing instruments, provides a strong measurement guide to within 10 % of the actual value of the nitrate content, although lower nitrate concentrations (±1 mg/L) have lower precisions, with up to 20 % error. These hand-held instruments act as an excellent screening tool, meeting the requirements for low-cost, rapid and reasonably accurate testing tool to use for in-field measurement and community activities although care should be taken that the calibration of handheld instruments is undertaken routinely.

Finally, a further study examining the effects of storage and holding time (X to Y days) on the nitrate concentrations in water samples showed no significant change for samples stored in the fridge or ambient temperature away from sunlight.

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SOURCE WATER RISK MANAGEMENT AREA MODELLING FOR GROUNDWATER: ISSUES AND UNCERTAINTIES

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[2] GNS

The first barrier for preventing waterborne illness is to protect the drinking water sources from contamination. To do so requires delineation of source water risk management areas (SWRMAs, previously referred to as SPZs), within which activities are controlled. The SWRMAs reflect the risk of source water contamination based on the time for contaminants to travel to the abstraction point, and also the time needed for some contaminants (e.g., bacteria) to attenuate or become inactive. The National Environmental Standards for Drinking Water (2007) (NES-DW) were intended to support source water protection by providing national direction on how to manage activities that could impact the quality of treated drinking water. In the recent review of the NES-DW there was found to be significant variation in the methods used to define those zones.

The technical guidelines for delineating SWRMAs recommend three levels of activity management to protect drinking water sources from contamination. The levels are:

- SWRMA 1: This is the immediate area around the source intake where contaminants have the potential to directly impact the intake structure. Strict control of land-use activities is required in this area. For a groundwater source this is the immediate well-head area.
- SWRMA 2: This is an intermediate area in which specific land-use activities or discharges which may contaminate the water source will be controlled. For groundwater sources, the travel velocity of any contamination which enters the contributing source waters is likely be relatively slow, meaning the purpose of the SWRMA is to provide contaminant attenuation. The SWRMA is sized such that, if a contaminant discharge occurred outside the SWRMA boundary, the water would travel through the groundwater system for a sufficient time that microbial contaminants would likely attenuate or become inactive by the time the contaminated water reached the drinking water abstraction point.
- SWRMA 3: This is the wider area, within which non-point sources from land use, cumulative effects of small-scale discharges, and large-scale discharges may need to be managed. This area is also intended to encapsulate more persistent contaminants which may not attenuate significantly as they travel through the groundwater system, such as nitrates, pesticides, and some emerging contaminants. For a groundwater source this is the total capture zone that could contribute water to the well.

A default methodology for delineating 'source water risk management areas' (SWRMAs, focussed on SWRMA2) has been proposed (Lough et al., 2018) to identify areas where activities have a higher likelihood of affecting source water. However, default zones may be too conservative in some cases, and not sufficiently conservative in others. There is a fine balance with conservatism. If the SWRMA is over-conservative, it could limit or restrict land use activities on highly productive land or lead to unnecessary barriers to the consenting and establishment of safe new community water sources. If not sufficiently conservative, then activities could be allowed within the SWRMA that could cause contamination of the source, or new sources could be allowed that are at risk. Simple approaches to defining SWRMAs must use a higher degree of conservatism than more robust methods. However, where risks are high, and/or there are large populations supplied by a well, then modelling-based methodologies have merit.

While SWRMA guidance (Moreau et al., 2014) has referred to numerical modelling, there has been a lack of specific guidance on what makes a good model for SWRMA purposes. In particular, the prediction context is important: this relates to the level of risk being addressed (i.e. the risk that people could get sick; the loss of land use capability; etc.). Existing groundwater models may not be suitable for SWRMA delineation, and a poorly-constructed/constrained model may be worse than a simple/default method. Uncertainty quantification (UQ) and sensitivity analyses are a central part of any risk-based modelling, and predictions made by a model need to be accompanied by assessments of their uncertainties. Rutter and Moore (2021) developed guidelines for risk-based minimum model design and uncertainty quantification, to provide an indication of modelling and UQ approaches to be used.

This paper outlines different approaches to SWRMA delineation and covers some of the issues and pitfalls that can occur.

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NITRATE TRENDS AND PULSES UNDER A CHANGING CLIMATE

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[2] Environment Canterbury

Canterbury had the wettest July on record this year, and severe weather has bombarded many other regions. Whilst a good thing from the point of view of recharging aquifers, the prolonged wet brought its own headaches, with many districts affected by waterlogged and flooded land, massive surface flooding, landslips, and other issues. Along with the rainfall, recharge has been very high. High winter recharge is often associated with elevated nitrate concentrations. High winter recharge in the later 1970s is thought to be responsible for the nitrate peak in the 1970s in some Canterbury regions. Figure 1 shows the average decadal nitrate-N concentrations for the Selwyn-Waihora zone in Canterbury, with wells grouped into different depth intervals (Rutter and Rutter, 2018). The peak in shallow wells in the 1970s has not been exceeded even in the 2010-2020 decade. The important point is that nitrate concentrations in groundwater (and groundwater-fed streams and rivers) are not a constant over time but the transport of nitrates, from the land surface to a stream or other receiving water body, is complex and not well understood.

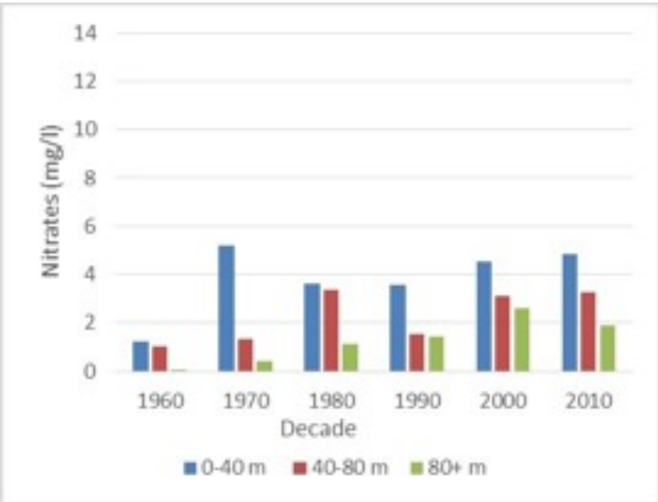

Figure 1: Average nitrate-N concentrations in wells from the Selwyn-Waihora groundwater allocation zone, grouped by ell depth and decade.

Previously we relied on sampling and measurements at a point in time. With good datasets, it is quite usual to see seasonal fluctuations in nitrate concentrations in groundwater, with autumn/winter recharge resulting in clear increases and decreases in the summer. Continuous monitoring is now becoming more common, and what we see is pulses of nitrate entering the groundwater system. Figure 2 shows water level and nitrate data from the 2021 winter: nitrates rise from a baseline level of less than 1 mg/l nitrate-N to well above the 11.3 mg/l drinking water limit, but then decline again following each recharge event.

While nitrate pulses are concerning for the freshwater environment, it's the long-term trend in the baseline level between recharge events that we need to watch closely.

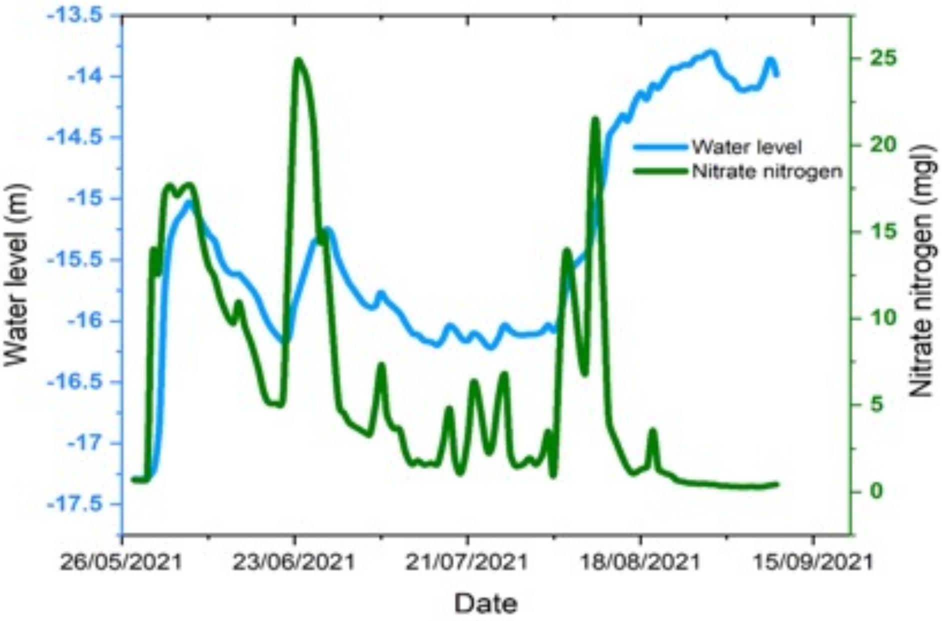

Figure 2: Water level and nitrate sensor data from 2021 for a site near Balmoral Forest

We are now collecting data from after the intense July 2022 rainfall and see similar pulses of nitrates emerging. While nitrate pulses are concerning for the freshwater environment, it's the long-term trend in the baseline level between recharge events that we need to watch closely.

Although their transport is somewhat different, bugs (microbes) can get transported with the rapidly recharging water and have very obvious and immediate health risks. Again, recent sampling post-July 2022 has shown increased exceedance of microbes in groundwater.

This paper will present data from recent sampling and monitoring to assess the impacts of extreme events and other drivers on nitrate concentrations. We will also outline some of the microbial sampling results. We will discuss the potential implications in terms of our understanding of nitrate sampling results and trends, and identify further research needs to add to our understanding of nutrient transport.

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COUPLED OCEAN-ATMOSPHERE SUMMER HEATWAVES IN THE NEW ZEALAND REGION: AN UPDATE

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Aims

This study examines the most recent intense atmospheric heatwave (AHW) and associated marine heatwave (MHW) for the NZ region covering the austral warm season (November – March) for 2021/22, and compares this with the warm seasons of 1934/35, 2017/18 and 2018/19. It diagnoses the atmospheric and oceanic drivers, impacts on marine and terrestrial ecosystems, including viticulture. Monthly to decadal atmospheric and oceanic mechanisms are investigated, along with an assessment of future likelihood of similar events.

Methods

Many of the methods used here were described in Salinger et al (2019a) and Salinger el al (2021). They are outlined briefly here, with new approaches described. The 22-station New Zealand air temperature (NZ22T) series (Salinger et al 1992) was used to calculate monthly mean air temperature anomalies for 1934-2022, relative to the 1981-2010 normal. These were combined with sea surface temperatures for the New Zealand region of 4 million square kilometres (NZSST) to form combined New Zealand temperatures for the entire New Zealand area (NZEEZT) described by Salinger et al (2020). Extreme statistics TX90p (percentage of days when the daily maximum temperature is above the 90th percentile), TN90p (percentage of days when the daily minimum temperature is above the 90th percentile), and number of summer days ≥25ºC averaged over New Zealand during 1940-2022 were calculated, as were daily sea surface temperature (SST) anomalies. Subsurface profiles were obtained from Global Ocean Data Assimilation System (GODAS, Behringer et al 1998) and Argo floats (Argo 2000). Monthly mean sea level pressures (MSLP) and 500-hPa geopotential heights were taken from the NCEP2 Reaanlysis (Kanamitsu et al 2002), plus several circulation indices (Trenberth (1976) Z1 and M1) and weather regimes over New Zealand (Kidson 2000) were used. The end of summer snowline (EOSS) time series (Chinn et al 2012) was used to estimate Southern Alps glacier mass balance from 1977 to 2021 for EOSSAlps (Salinger et al 2019b) and regression relationships for 2022. Estimates of water stored as seasonal snow in the South Island for 2021/22 were provided by the model "SnowSim", available through Meridian Energy Ltd.

Results

The coupled ocean-atmosphere heatwaves in the New Zealand (NZ) region during the four warm seasons (November – March) studied here were the most intense recorded in the NZ and Tasman Sea regions in 150 years of land-surface air temperature records, and ~40 years of satellite-derived SST records. For all four heatwaves, both land air and sea temperatures for NDJFM combined were 1.1° to 1.4°C above the 1981-2010 averages over the entire region (from 32° to 52ºS, 150°E to 180º) NZ22T anomalies were 1.4ºC, 1.7°C, 1.2ºC and 1.2 ºC respectively, by far the four warmest on record. Indices of temperature extremes (Fig.1) for NZ show that the percentages of annual warm days above the 90th percentile were 26%, 33%, 22%; and 19%. Counts of summer days ≥25ºC averaged 22, 32, 26 and 31days nationwide for the four warm seasons, all significant.

For the Tasman Sea and east of NZ (32º–52°S, 150º–180°E) the MHWs were characterised by SSTs 1.1°C, 1.4°C, 1.3°C and 1.2°C above average), the largest anomalies on record. All four showed a similar spatial pattern with highest anomalies to the west of the South Island of NZ. GODAS sub-surface ocean temperature patterns for recent three for 40-45ºS indicate shallow positive anomalies west of the South Island, with a narrow band down to 50m east of the South Island with positive SST anomalies also existed in the western Tasman Sea to the south Pacific. Argo floats in the eastern Tasman Sea confirmed surface warming peaking at 3ºC in 2017/18 and 1.5ºC in 2018/19, both with shallow anomalies to the upper 20m. The signal for 2021/22 was much weaker but more persistent.

The four seasons show a pattern of blocking (higher than normal pressures, Fig 2a,c,e,g) to the south and southeast of NZ, with negative pressure anomalies farther north. Kidson weather regimes showed a lack of zonal regime for the recent three warm seasons (NDJFMA) and more blocking throughout, especially for 2021/22, where troughing was also absent. The M1 and Z1 indices showed northeasterly airflow for 1934/35, 2017/18 and 2018/19. Airflow was easterly for 2021/22.

The 500-hPa geopotential height anomalies (Fig. 2b,d,f,h) were extremely consistent with very strong blocking to the southeast of NZ, with average positive height anomalies of 50 gpm or more in the most recent three. The 1934/35 season had positive height anomalies extending west of the North Island over the north Tasman Sea. The 2017/18 and 2021/22 anomalies were the most intense, reaching 70 gpm to the southeast of the South Island.

Volume loss in the Southern Alps for the small and medium glaciers was estimated to be 0.4 km3 volume in 1934/35, 2.1 km3 in 2017/18, 2.0 km3 in 2018/19 and 1.7 km3 for 2021/22.This totals 5.9 km3 for the three recent heatwave warm seasons, 22% of the total ice volume of the Southern Alps in the 1977 inventory. The three recent heatwave summers total losses from all glaciers amounted to 9.3 km3, 17% of the 1977 total. The 2018 – 2022 period represents the largest ice loss since 1949.

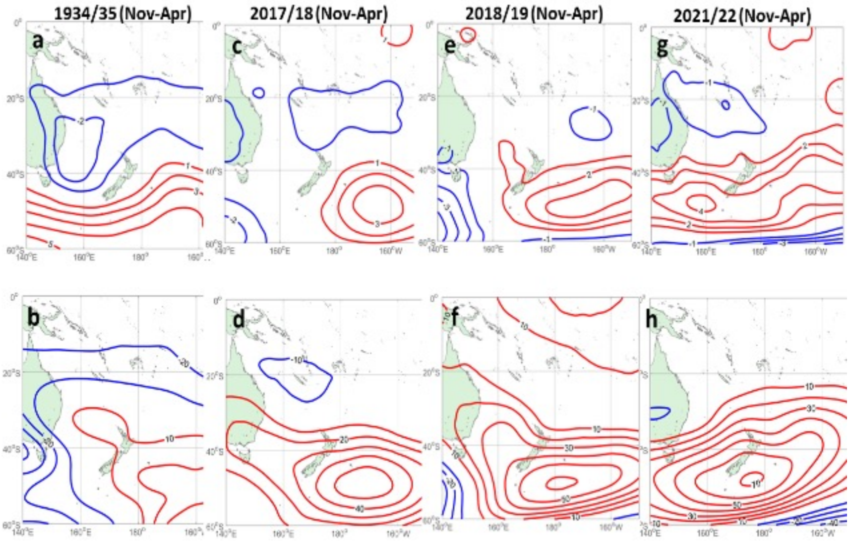

Figure 1. Extremes – TX90p, TN90p and days >25°C averaged over NZ 1934-2022.
Figure 2. Atmospheric circulation patterns.

NDJFMA mean sea level pressure anomaly: a. 1934/35, b. 1934/35 c. 2017/18, d. 2017/18 e. 2018/19 f. 2018/19, g. 2022 and h.2021/22. NDJFMA 500-hPa Geopotential Height anomaly:
In all four cases, SnowSim showed swift snowmelt commencing in mid-November with rapid melt.

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IDENTIFYING GAPS AND CHALLENGES IN BUILDING DISASTER RESILIENCE AMONG TWO FLOOD AFFECTED COMMUNITIES IN NEOLIBERAL SRI LANKA

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Aims
Communities at risk of recurrent flood disasters due to their geographical locality and poor-quality housing are easily exposed to vulnerabilities created by insecure work and poor infrastructure (Cannon 1994), where there is a disjunction between disaster affected local people, government and other disaster response donor agencies engaged in the process of disaster resilience in Sri Lanka. Kolonnawa in Colombo district and Thawalama in Galle District, Sri Lanka are high risk flood prone areas due to their proximity to the Kelani and Gin rivers. As a result of having experienced flash floods continuously, these riverside communities have become more flood resilient, developing their own internal capacities and experiences where Kolonnawa is more individual based and Thawalama is more community based in comparison. However, the 2016 flood in Kolonnawa and the 2017 flood in Thawalama alarmed the government and other stakeholders enough to investigate improvements to their long-term Disaster Risk Reduction (DRR) planning in the country. Thus, this paper aims to examine the gaps and challenges in the process of disaster resilience building as narrated by the two flood affected riverside communities.

Method
Surveys (n=204), in-depth interviews (n=60) and focus group discussions (n=6) with flood affected people, semi-structured interviews with community leaders (n=10) and local/national government, Inter-governmental organization, INGO and NGO officials (n=14) were conducted. In addition, Sri Lankan government DRR policies, structures, related reports produced by both the government and donors were systematically analysed.

Results
This paper outlines how the disaster resilience process was further extended in response to the recent large-scale flooding, and argues how certain practical concerns of the flood affected people have not been addressed during the process. Poor coordination of the relief distribution at different levels, non-transparency in monetary compensation distribution, no technical assistance to rebuild damaged built environment, unawareness of flood aid entitlements, delays in government officials' visit to measure the flood damage, non-consultation of flood affected communities in the process of policy making, absence of support to look after children, elderly and disable and absence of support to psychological well-being in the post flood disaster context were only a few gaps and limitations outlined in flood affected people's narratives. In line with Chandler (2014) and Chandler and Reid (2016), it can be suggested that the key elements to disaster resilience programmes including the coping capacities of citizens, the ability of citizens to respond, or adapt, to disaster crises have been neglected when addressing Sri Lankan riverside communities disaster resilinece building process by both the government and donors. Therefore, the paper highlights the significance of incorporating flood affected communities as a key stakeholder when developing DRR policy and decision-making programmes and considering their available community capacities including social, financial, human, built and cultural capital.

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NEW ZEALAND 3D HYDROGEOLOGICAL MAP: THE BIG PICTURE

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Aims

The "National Aquifer Characterisation by System" project is a GNS Science-led collaboration to develop the first 3D hydrogeological map of New Zealand. Hydrogeological maps are resource management tools that integrate geology, aquifer properties, and groundwater quality and quantity information (Gleeson et al. 2014). These maps will characterise our geologically-complex aquifer systems at a national scale, providing digital resources in a consistent template for evaluating aquifers according to the 2.5D Hydrogeological-Unit Map (HUM) framework of White et al. (2019). The project is funded by the New Zealand Ministry of Business, Innovation and Employment Strategic Science Investment Fund (contract C05X1702) through GNS's Groundwater Programme and is led by Stewart Cameron. Collaboration with regional councils, consultation with regional groundwater experts and integration of outputs from aligned projects (e.g., SkyTEM surveys, Aqua Intel Aotearoa, Groundwater Atlas) are key to ensure the produced hydrogeological maps will be fit-for-purpose.

This paper provides i) an overarching view of the project objectives, scope, methodology and potential applications for councils and other end-users; ii) the scene for three associated project papers (Building New Zealand's 3D aquifer map: facies mapped at the national scale for coastal systems; New Zealand 3D hydrogeological map: 3D facies in the Heretaunga Plains coastal groundwater system; New Zealand 3D hydrogeological map: the Wairau Plains coastal groundwater system).

Method

The project's approach involves three parallel workstreams at the national, sub-regional and local scales through the building of depositional facies models. The national-scale work involves refining the HUM units and associating them with attributes such as hydraulic properties and unit thickness. This workstream is crucial to maintain consistency across regions and has been sequenced using the 2D hydrogeological systems from Moreau et al. (2019). The sub-regional scale workstream involves the development of 3D facies models in representative areas. At the local-scale, the project aligns with system specific aquifer characterisation projects, such as SkyTEM surveys.

Surface and subsurface facies were developed for hydrogeological units outcropping within the 2D coastal systems at the national scale. In parallel, these systems were classified in categories, according to aquifer geomorphology, river type and network, main aquifer lithology type, topographic gradient, main aquifer size and tectonics. A representative aquifer for each category was selected to provide the basis from which attributes are inferred for other aquifers of the same category. A 3D facies model will be developed for these representative areas using key markers identified in lithological logs (e.g., shell, peat, organic material).

Preliminary Results

At the national scale, 2.5 D surface and subsurface facies (244 in total) mapping of coastal systems has been completed for the North and South Islands. These systems were classed into 13 categories and one representative area selected for each category (Figure 1).

At the sub-regional scale, we have started to build 3D facies models and develop an auto-facies generation system in four representative areas (Heretaunga Plains (Fluvial-Open Plain); Wairau Plain (Fluvial Fault Depression); Aupōuri Peninsula (Coastal Dunes); and Wellington Harbour (Fluvial-Open Plain).

Future work includes the assignment of hydraulic properties to these facies models and their application to other coastal systems under the same category.

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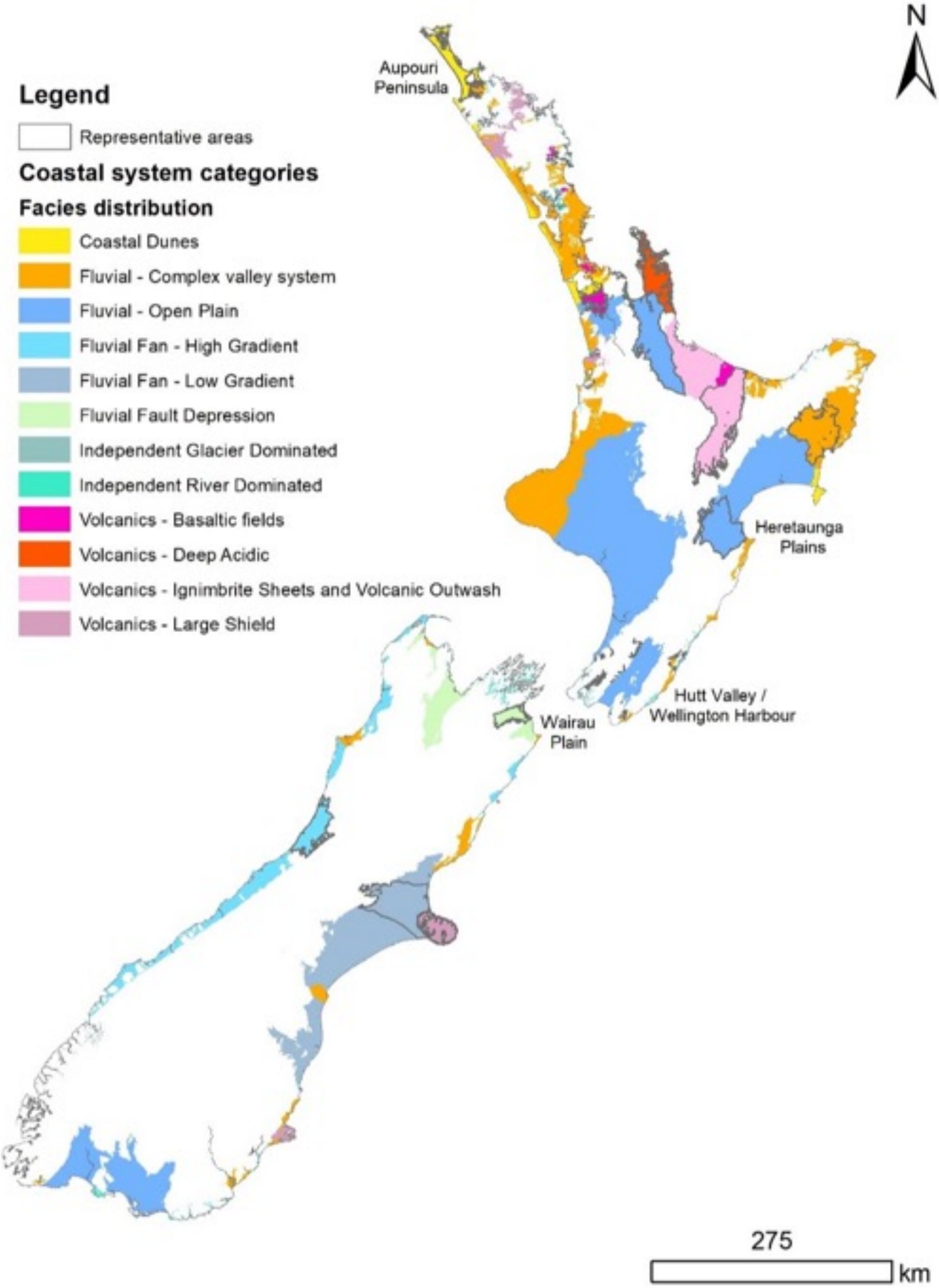

Figure 1: Coastal system categories and facies distribution. Figure highlights four representative areas where 3D facies models are being developed.

GROUNDWATER MODELLING TO SUPPORT MANAGEMENT OF SUSTAINABLE GROWTH OF THE CAMBRIDGE TOWNSHIP

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[1] Beca Limited
[2] Waipa District Council
[3] Beca Limited

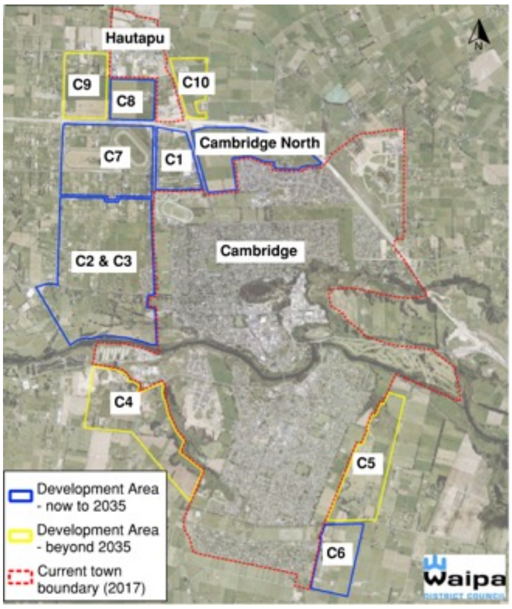
Aims

Cambridge has been identified as a high growth area with the population expected to almost double in the next 50 years (Waipa District Council, 2017). Approximately 450 ha of land will be needed to accommodate the residential, industrial, and commercial developments.

Waipa District Council (WDC) has been preparing for the increase in housing needs by developing Structure Plans (frameworks for managing residential development to meet infrastructure requirements in a coordinated and sustainable manner) for identified growth areas (Whakaahua 1).

bringing a significant increase in stormwater runoff for which the existing drainage networks were not designed to accommodate. The construction and operation of the stormwater treatment devices (e.g., soakage basin, wetlands, swales, etc.) could lead to changes in groundwater levels, e.g., the disposal of stormwater on land via soakage could cause local mounding and also impact the groundwater and surface water systems (i.e., changes in the baseflow regime).

In order to better inform the consenting process of any future developments and to identify and manage the potential groundwater effects from the urban intensification, WDC and Beca has developed a district scale groundwater model, covering the area from the Hautapu to the Cambridge C1-C3 growth cells.



Method

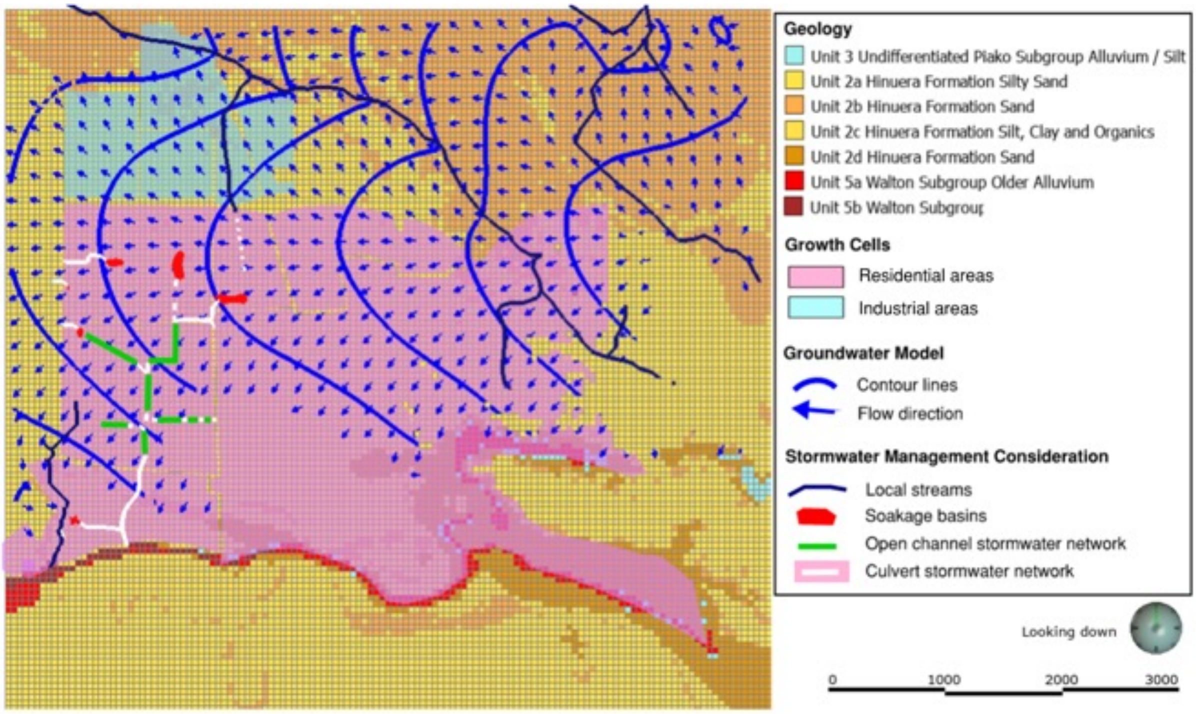
The development of the groundwater model included:

- Geotechnical investigations across the C1, C2, C3, C7, C8, C9 and C10 areas. Soakage and in-situ permeability testing were undertaken at 35 sites and groundwater levels were monitored at 14 piezometers to better understand the perched groundwater system found within the underlying Hinuera Formation (deposited by a laterally migrating paleo system of the Waikato River creating local variations in the shallow geology).
- Data collected from the investigation was used to better understand the complex groundwater system that is a result of the depositional history, e.g., perched groundwater levels due to low permeability iron pan (at least one in C2 extending to the southwest of the existing Cambridge Town Boundary).
- A three-dimensional (3D) geological model of the study area was developed using Leapfrog Works (Version 2.0) software. The model provides a representation of the subsurface geology based on the available borehole data and known geological profiles of the wider Waikato area. The model broadly identifies the lithological groups likely to be encountered; however with limited representation of the heterogeneity in the geological units on a local scale.

Based on the geological model and empirical aquifer parameters, the 3D finite-difference groundwater model was developed using MODFLOW2000, that is built in the modelling package Groundwater Vistas (version 7.17 build 15).

Results

The modelled groundwater contours and flow directions are shown in Whakaahua 2. To date, the model has been used to inform the potential groundwater effects from the construction of several infrastructure projects and has provided guidance around the following environmental concerns:



Whakaahua 2: Numerical groundwater model (50 m by 50 m grid size) used to support the sustainability of the stormwater asset management planning and consenting decisions

- **Effect of decreased perviousness on groundwater levels:** Pre-development, the perviousness across the growth cells is generally 90%, while post-development, the perviousness is expected to decrease to 30% across these sites. The model estimates that approximately 55% of the increase in runoff caused by the development could be allowed to infiltrate into the ground to maintain groundwater levels at or above the summer levels.
- **Effect of municipal soakage system on groundwater flow regime:** With six soakage basins expected within the growth cells, modelling indicates that the groundwater flow resulting from soakage would likely recharge the groundwater levels to near pre-development summer levels (counteracting the effect from the increase in imperviousness due to urban intensification). Mounding under the soakage basins is estimated to range between 2 m and 5 m. For one of the basins, the mounding will likely result in a water table less than 1 m below the ground surface (with possible standing water in the basin).
- **On-lot soakage potential:** The model was used to prepare a performance categorisation of potential shallow on-lot soakage device for the growth cells based on the known hydrogeological information.
- **Effects on local stream flow:** The model indicated increased imperviousness could cause a 20% to 25% reduction in groundwater baseflow to local streams. However, the modelling also suggested that the infiltration of stormwater into the basins will largely mitigate this potential loss in streamflow.
- **Groundwater inflow and drawdown assessment for constructing open channel network:** Modelling indicated the proposed open channel system will only experience minor inflow from the shallow perched aquifer and any drawdown is unlikely to result in consolidation settlement at nearby existing third-party assets.

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MULTIPLE CLASSIFICATION VIEW OF CLOUDS OVER SOUTHERN OCEAN CYCLONES

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Aims

Extra-tropical cyclones (referred to as cyclones from here on) play a major role in controlling weather over the Southern Ocean. The relationship between cyclones and clouds is complicated due to the wide range of dynamics that are present across a cyclone. Most cyclones are characterized by high clouds linked to the 'comma' structure in the centre and more complex relationships around the edges related to the cyclone's frontal structure (Field and Wood, 2007). As an example, figure 1 (sourced from Field and Wood, 2007) shows that cloud structure identified around strong Northern Hemisphere cyclones.

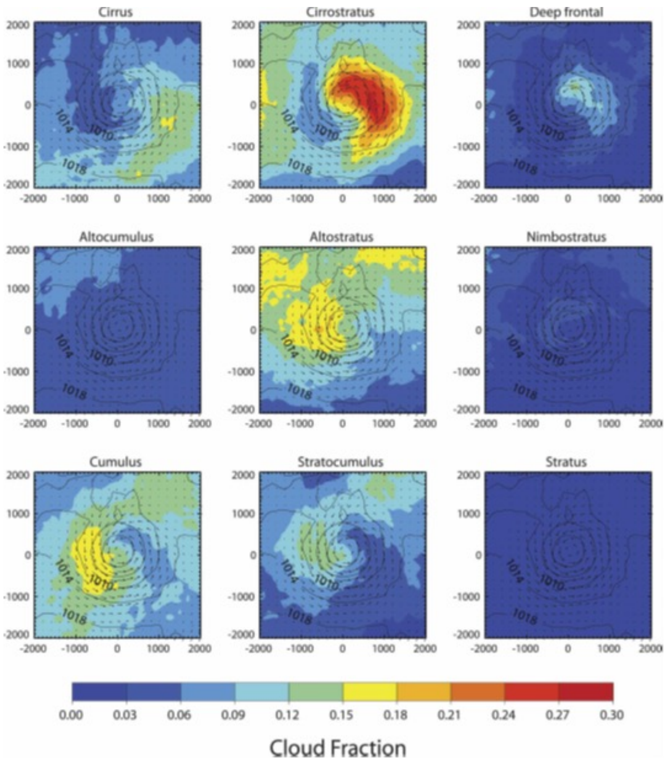

Figure 1: An existing cloud classification scheme applied to a select sample of cyclones over the North Atlantic region. The cloud classification scheme is based on data from the MODIS dataset and the cyclones are indentified with pressure fields from the NCEP-NCAR reanalysis. Figure from Field and Wood, 2007.

Our research aims to explore the consistency of these structures when different cloud classification approaches are used. Using multiple datasets will let us better understand if prior analysis has been biased by the usage of specific definitions for cloud types. Additionally, most prior research has studied cyclones in the Northern Hemisphere. Here, we work with a dataset of Southern Hemisphere cyclones, in which we hope to identify unique features that are not present in Northern Hemisphere cyclones. We are also interested in analysing how different cloud types are related to other atmospheric properties such as cloud phase and precipitation.

Method

We use three cloud classification datasets in this research, from the following papers:

- Schuddeboom et al. 2018 define cloud clusters by running a machine learning algorithm known as a self-organizing map on cloud top pressure cloud optical thickness joint histograms from the MODIS dataset. These are defined globally and have been used in a series of follow-up papers focused on model evaluation (Schuddebeboom et al. 2019 and Schuddeboom and McDonald 2021).
- Mcdonald and Parsons 2018 define cloud clusters with a similar methodology to Schuddeboom et al. 2018 but based on the ISCCP dataset rather than MODIS data.
- Kurihana et al. 2021 uses an unsupervised deep learning approach known as an autoencoder to define a set of cloud clusters from MODIS radiance data. These clusters are also defined globally but are impacted by gaps in the swath patterns of the satellite.

When then combine these three datasets with a set of cyclone locations to form cyclone composites for each cloud classification. The cyclone centres are defined using the cyclone tracking scheme from Crawford et al. 2021 and ERA5 sea level pressure data. We then employ various methods to compare the results from these composites.

Results

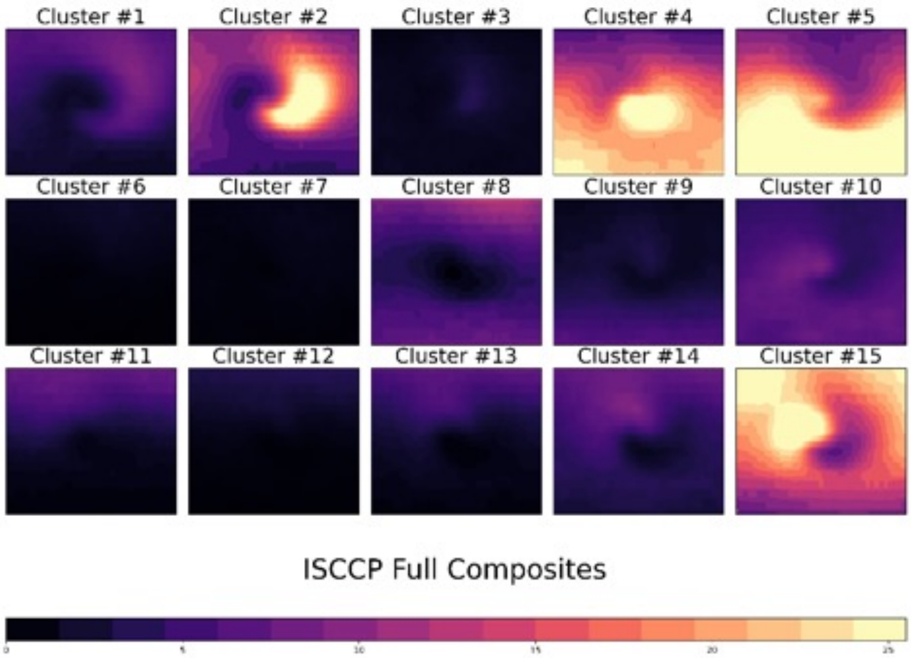

Figure 2: The cloud classification scheme of McDonald and Parsons 2018 applied to cyclones from the Southern Ocean region. Thier classification scheme is based on data from the ISCCP dataset. The cyclones are indentified with pressure fields from the ERA5 reanalysis

Each classification scheme shows elements of the expected cloud structure over cyclones, including a clear comma structure and low-lying frontal cloud around the cyclone edge. For example, the cloud clusters generated from the ISCCP dataset, shown in figure 2, shows many of the expected structures. This includes the comma cloud structure in cluster 2, which represents high-altitude optically thick cloud, and the frontal cloud structure shown in clusters 5 and 15 which represent low-lying optically thick cloud. We see similar results with the other two classification datasets. These results were then used as the basis for further analysis establishing the similarity between the different cloud classifications.

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THE CONVECTIVE OUTBREAK OF JUNE 2022 – WAS THE MARINE HEAT WAVE TO BLAME?

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Aims

In a year of 'unprecedented' weather, an early winter period of thunderstorm activity impacting western regions was notable. Locals and seasoned meteorologists alike were struck (if you will) by the duration and intensity of convective weather. By any measure, the event was extreme: the most intense winter-time thunderstorm episode to affect New Zealand in ten years, and the second most active period on record as determined by the Lightning Detection Network since its installation in 2000. Several tornadic events were also reported accompanying the memorable lightning displays, particularly in the lower west of the North Island from Taranaki to Kapiti.

At the time, meteorologists and climatologists naturally accused the enduring marine heat wave and residual effects of La Niña in supplying ample warmth and moisture into the wintery synoptic system to fuel the convective weather. This became the narrative. While this makes much sense, convective energy is a combination of the lower-level moisture supply and upper atmospheric temperature. Storm structure depends on the environmental forcing. Convective hazards such as lightning and tornadoes are functions of more complex interactions, such as the specific temperature, moisture distribution, wind and updraft conditions.

Method

As a matter of scientific curiosity, I undertook an analysis of atmospheric balloon data since the year 2000 to determine the climatological significance of the drivers of this event, including the likley role of regional sea surface temperatures. Upper atmospheric temperatures are a reliable indicator of the magnitude of the 'upper cold pool' of the synoptic weather system. Lower-level temperature and moisture could be taken as determining the influence of the upstream sea surface. Joint frequency distributions of these properties were derived to provide context. Numerous convective stability indicators were determined, along with attempts to assess the efficiency of the environment to produce charge separation and therefore lightning. Whether these assessments determined the period to have been as extreme as the observed weather would then serve as a simple test of their relative role in the event.

Results

The atmospheric dynamics during this period were strong and the marine heatwave likely played minimal role in the overall system development. Despite these dynamical drivers, the upper level temperatures over central NZ were not significanty cold. Likewise, observed lower-level moisture was also unremarkable through the convective period, further calling into question the role of the marine heatwave.

Convective parameters and joint frequency distributions of the combined upper and lower atmospheric conditions showed some signal, but were only weakly correlated with this and previous events. Better signals were found with more constrained conditions, such as instability combined with wind flow or convective buoyancy at typical levels of cloud charge seperation. Although 12-hourly balloon soundings may miss a great deal of the detail in transitory convective structures, frontal transitions were weak and the low-level moisture would not be expected to vary considerably over the period. This was corroborated with hourly model data and surface observations. Surface observations also showed the location of the soundings, at Paraparaumu, to be largely reprentative of the area of interest.

In summary, the dominant factors which seemed to be responsible for this event were the instability combined with flow direction, a buoyancy profile apparently favourable to charge seperation, and sustained synoptic dynamical forcing, with the marine heat wave playing a minimal demonstrable role.

CRITICAL ASSESSMENT OF THE BOWEL CANCER STUDIES ON THE EFFECTS OF DRINKING WATER NITRATE

Selvarajah, S.
[1] ENVIROKNOWLDEGE®

Aim
To critically assess key research papers on bowel cancer studies linking drinking water nitrate levels.

Method
Frequently referenced cohort and case-controlled studies linking bowel or colorectal cancer (CRC) with drinking water nitrate levels have been assessed critically and in detail.

Results
My critical review of the key epidemiological papers linking bowel cancer with drinking water nitrate (NO3) has found, many such studies have yielded unexpected and inexplicable results with increasing drinking water NO3 levels reducing cancer risks (Relative Risk (RR) values >1 but with reduction between exposures) and improving beneficial effects (with RR <1) between exposures (see Table 1 final column). Despite the frequent reduced risk observations of the increasing drinking water NO3, no workers have offered any scientific explanation of such anomalies. Plausible reasoning is the omission of the key and proven confounding factors causing bowel cancer.

Most studies were based on municipal water supplies which were of good quality generating numerous data from the exposure of relatively very low drinking water NO3 levels. Despite private/rural wells are known to have greater NO3 levels than municipal water supply water sources, exclusive epidemiological studies on private well water users have been rare and if conducted, key studies have failed to access NO3 data from private wells and water sources with >50 mg NO3/L.

Table 1. Summary of the studies on bowel cancer studies linking drinking water nitrate

Studies	Sample size	Country of study	Age	Sex	Diseases studied	Confounding factors	Drinking water type	Statistic used	Relationship
Case control studies									
De Roos et al. (2003)	Colon cancer cases 685 Rectum cancer cases 655 Control cases 2434	Iowa, US	40-85	F	Colon, rectum, brain, pancreas, bladder, kidney	Dietary nitrate/ nitrite, vitamins C, A & E, alcohol, smoking, physical activity, BMI, bowel inflammation, family history, chlorinated water, education, dietary quality and quantity	Residential	Odds ratio and logistic R model	[2]Reduced risk between >13.3 and ≤22.1 mg/L than >4.4 and ≤13.3 and increased risk ≥ 22.1 mg/L Beneficial effects from increasing dietary nitrate
Espejo-Herrera et al. (2016)	CRC cases Spain 1562 CRC cases Italy 307	Spain and Italy	≤57- >72	M/F	Colon, rectum and CRC	Education, smoking, physical activity, family history, oral contraceptive and anti-inflammatory drug use, BMI, energy, fibre, Vit C, Vit E, red and processed meat and water intakes	Ingested	Odds ratio	Increasing risk between ≤3.6 mg/L, >3.6- 7.1 mg/L and ≥ 7.1 mg/L Beneficial effect on rectal cancer at >3.6-7.1 mg/L Beneficial effect from Vit E and fibre intake
Chiu et al. (2010)	Colon cancer deaths 3707 Control deaths 3707	Taiwan		M/F	Colon	Magnesium in water	Residential	Odds ratio	Increasing risk between <1.7 mg/L, 1.7-2.5 mg/L and >2.7 mg/L
Yang et al. (2007)	Colon cancer death 2234 Control death 2234	Taiwan		M/F	Colon	Nil	Residential	Odds ratio	No effect between ≤0.9 mg/L, 1-2 mg/L and 2.1-12.7 mg/L
Fathmawati et al. (2017)	CRC patients 75 and controls 75	Indonesia		M/F	CRC	Protein intake, age, family history and smoking	Ingested (well)	Relative risks	>50 and <50 mg/L were compared and found increased risk with >50 mg/L
McElroy et al. (2008)	CRC cases of 475 and control 1447	Wisconsin US	20-74	F	CRC	Family history, smoking alcohol consumption, BMI, education	Residential (random well water nitrate)	Odds ratios	Increased risk at 2.2-8.4 and ≥44.2 but reduced risk at 8.8-26 and 26.5-43.8 mg/L
Cohort studies									
Weyer et al. (2001)	Sample size 21977 Colon cases 385 and Rectal cases 129 for year 1955-88	Iowa, US	55-69	F	Non-Hodgkin lymphoma, leukaemia, melanoma, and cancers of colon, rectum, breast, lung, pancreas & kidney	Confounding considered only to assess overall cancer risk not separately for CRC	Ingested based on 2 L/d (municipal and well)	Relative risks	Colon risk- Increased between 1.6-10.9 mg/L and decreased >10.9 mg/L Rectal risk- Beneficial effect >1.6 mg/L with greatest benefit >10.9 mg/L
Schullehner et al. (2018)	Total studied 2.83M but data on 1.74M	Denmark	>35	M/F	Colon, rectal and CRC	Education,& family history	Residential (municipal and well)	Hazard ratio	CRC risk- increasing risk in all quintiles except decreasing risk 2.33-3.87 mg/L Colon risk- beneficial effect at 2.33-3.87 mg/L but increasing risk ≥9.25 mg/L

1 Where needed, nitrate values were converted from NO3-N to NO3 by multiplying by 4.426
2 Reduced or increased risk ratio stays ≥1.00 whilst beneficial effect risk ratio was <1.00

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ARCGIS PRO RELAUNCH OF THE CATCHMENT LANDUSE FOR ENVIRONMENTAL SUSTAINABILITY (CLUES PRO) MODEL: HELP WANTED

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[1] NIWA Auckland
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Background
CLUES (Elliott et al., 2016) is a national, steady-state, catchment-scale modelling framework integrated into a GIS platform (ESRI ArcGIS) that estimates mean annual loads of total nitrogen (TN), total phosphorus (TP), E. coli and sediment in New Zealand freshwater rivers and streams. It was developed by NIWA (National Institute for Water and Atmospheric Research) with support from Landcare Research, AgResearch and Plant and Food Research, and Harris Consulting for the Ministry for Primary Industries (MPI). CLUES is primarily a screening model that allows users to rapidly create and run land use change and land management scenarios. CLUES has been used at the regional level to support catchment planning and policy implementation (e.g. Semadeni-Davies & Elliott, 2014; Semadeni-Davies et al., 2017) and nationally by central government to support policy development (Parliamentary Commissioner for the Environment, 2013; Semadeni-Davies et al., 2020). Since its first release in 2006, CLUES has been regularly updated and maintained and remains free to download for non-commercial users. As ArcMap is being phased out by ESRI, we have been transitioning CLUES to ArcGIS Pro, based on a user survey in 2019 that identified this as the preferred platform. A new public release, called CLUES Pro, is planned for 2024. In the interim we are releasing a limited beta version of CLUES Pro and need test users to help guide the final design of the model interface and for bug testing. Here we highlight some of the changes to CLUES and our plans for the next phase of CLUES development.

CLUES Pro beta
Integration of CLUES into the ArcGIS Pro environment is requiring us to completely rebuild the model from scratch – as such the beta version does not yet have full functionality. Changes that have been made include the following

- The model has been re-coded in Python to be compatible with ArcPro but the interface has been coded in C# to give us greater flexibility in the interface's design and function. Modules have been coded for TN, TP and E. coli with a new sediment module planned.

- CLUES Pro is now provided nationally, allowing simulations for catchments selections that extend into multiple regions.
- The underlying CLUES database has been streamlined and updated, including updating the digital river network to the latest version of the River Environment Classification (REC 2.5) network, and a new land use layer for the baseline year 2017 created with reference to LCDB51 and Agribase2.
- Development of catchment selection and tracing tools compatible with REC 2.5 that offers greater flexibility than those built into ArcGIS Pro. Like the original version of CLUES, the selection tools allow users to select multiple stream segments or catchments.

A screen shot of the CLUES Pro (beta version) display and interface showing estimated instream TN loads for streams draining into the Tairua Harbour in Waikato is shown in Figure 1.

Planned further development
Ahead of the full model release, we plan to undertake the following tasks:

- Re-calibrate the model by region to: a) improve regional fit; b) make use of updated water quality monitoring data sets; c) be compatible with updated land use; and d) offer an alternative to the Overseer component of CLUES.
- Re-integrate the CLUES Estuary model (Plew et al., 2015) into CLUES Pro. This tool estimates nitrogen and phosphorus concentrations for 370 estuaries around the country.
- Integrate and improve the currently stand-alone CLUES yield modification tool into CLUES Pro. This tool allows users to easily build land management / mitigation scenarios within REC subcatchments that are targeted to specific land use and location selection criteria such as slope and soil drainage class. This tool will be developed in conjunction with research into the effectiveness of edge of field mitigations being undertaken by NIWA.

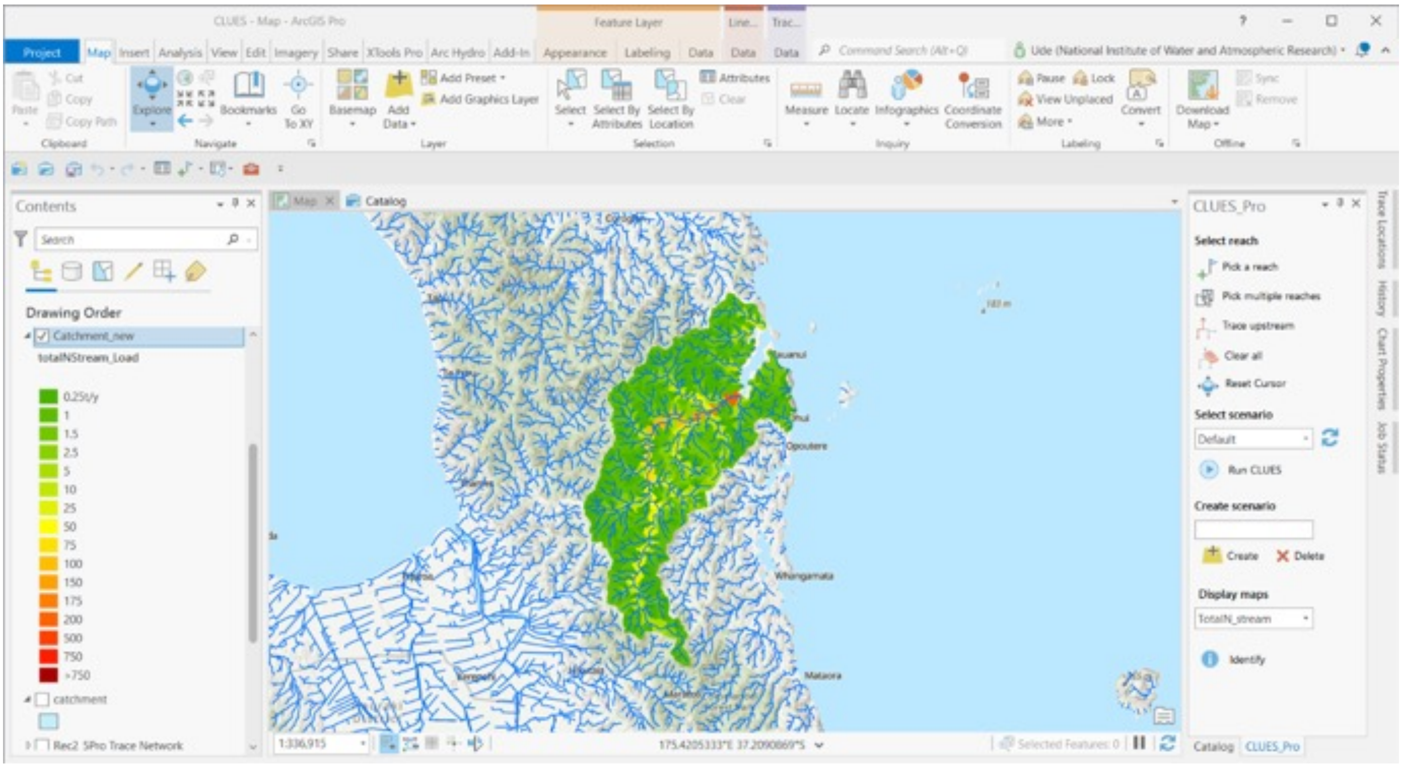

Figure 1 CLUES Pro (beta) interface and display showing default TN loads to the Tairua Harbour.

Integrate the New Zealand Sediment Yield Estimator (Hicks et al., 2019) as a replacement for the original CLUES sediment model to improve model fit and to be compatible with sediment yield estimates provided to the Ministry for the Environment.

Write a manual for CLUES Pro and document the model transition in a peer-review journal article.

Volunteer
If you would like to be a test user for CLUES Pro, please contact annette.davies@niwa.co.nz.

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SALTWATER INTRUSION FROM AN ESTUARINE RIVER IN CHRISTCHURCH

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Aims
- Document a case of saltwater intrusion (SI) from an estuarine river and examine the observed dynamics
- Determine the temporal variation of horizontal hydraulic gradients
- Employ signal processing techniques such as cross-correlation and Fourier analysis to analyse the relationship and lag time between the sea, estuarine river, and groundwater

Method
Two transects comprised of five shallow piezometers located perpendicular to the estuarine reach of the Ōtākaro/Avon River were used. Two of these piezometers were identified as among the most saline in a recent shallow groundwater survey by Setiawan et al. (2022). River parameters were monitored at one location between the two transects. Each monitoring location (groundwater and river) was equipped with a water level, temperature, and electrical conductivity sensor over a five-month period (1 January to 9 June 2021). This study focuses on summer dry periods to characterise groundwater response to tides in the absence of rainfall. The water level records were converted to freshwater head (Post et al., 2018) prior to flow interpretation. Cross-correlation was used to determine time lags between time series data of sea, river, and groundwater heads. Additionally, the Discrete Fourier Transform (DFT) was used to separate the influence of tidal signals in the collected time series data.

Results
Freshwater heads and specific conductance (SC) in the shallow aquifer at both transects fluctuate with that in the estuarine river. Hydraulic gradient reversals were observed with the ebb and flow of tides in both transects. During and around high tide, the direction of flow was from the river to the aquifer (SI), while the direction of flow during and around low tide was from the aquifer to the river (groundwater discharge). Additionally, the freshwater heads and hydraulic gradient on the true left side of the river were on average greater than that on the true right side. The maximum freshwater head occurred in all piezometers within 30 minutes after the maximum freshwater head in the river. The DFT of freshwater head and SC in both river and groundwater confirmed the prominence of the lunar semidiurnal tidal signal (M2), with the most saline bore showing the greatest M2 amplitudes in both freshwater head and SC analyses.

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A NEW EVENT-BASED RAINFALL-RUNOFF EQUATION

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The hydrological response of a catchment to a rainfall event is commonly known as the rainfall-runoff process (Critchley et al., 1991).Event-based rainfall-runoff models are widely implemented in practice (Beven, 2012; Ponce & Hawkins, 1996; Soulis et al., 2009). One of the main concerns of the existing rainfall-runoff event-based methods is that the characteristics of rainfalls are neglected in model development (Mishra S.K., Singh V.P., 2018). A novel event-based rainfall-runoff equation is suggested to incorporate rainfall characteristics into account. Seven relatively small catchments ranging from 0.3 Km2 to 16.3 Km2 around the North Island of New Zealand are selected for this study. The catchments' outlet locations are shown in Figure 1, and the catchment information, including size, predominant land use type, and soil drainage class, are listed in Table 1. Figure 2 shows the observed and estimated direct runoff using the new equation and SCS-CN method versus total rainfall for each event for Opanuku, Ngakoroa, West hoe, and Mangemangeroa catchments are illustrated.

Nash–Sutcliffe model efficiency coefficient of the new equation and SCS-CN method shows that the new equation has a better performance in all seven catchments. Considering the new equation is simple, efficient, and only based on one empirical parameter, the new equation has the potential to become a robust alternative to the conventional curve number method in hydrologic engineering projects.

Figure 1. Location of the outlet of investigated catchments in upper North Island of New Zealand

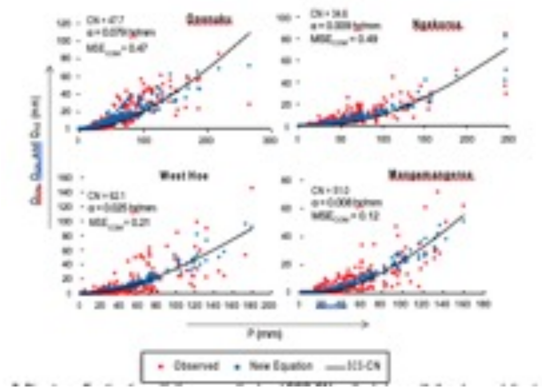

Figure 7: Direct runoff estimation with the new method and SCS-CN method along with the observed direct runoff in Opanuku, Pukekohe, West Hoe Heights, and East Tamaki Heights rivers

Table 1: Detailed information about the case studies, including size, land use type, and soil drainage class

Catchment Name	Catchment Area (km²)	*Predominant Land Use	**Predominant Soil Drainage	Number of Events	Study Period
Opanuku	16.2	FL (86%)	A (76%)	654	2007-2017
Ngakoroa	4.7	GL (63%)	A (97%)	548	2009-2019
West Hoe	0.3	FL (98%)	A (100%)	593	2008-2017
Mangemangeroa	4.4	GL (51%), FL (45 %)	C (100%)	605	2008-2017
Orewa	9.6	GL (77%)	C (89%)	647	2008-2018
Maungaparerua	11.7	GL (91%)	B (47%), C(28%)	661	2008-2018
Ngunguru	12.5	GL (46%), FL (53%)	C (94%)	625	2009-2018
Raumanga	16.3	GL (43%), FL (29%)	B (46%), C (29%)	602	2008-2017

*GL-grassland, FL-forest land. ** A- well-drained; B- moderately well-drained; C- imperfectly drained

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IMPROVING GRIDDED RAINFALL SPATIAL INTERPOLATION FOR EXTREME EVENTS

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Aim
Interpolated rainfall grids from station observations are used for flood modelling from extreme rainfall events. ANUSPLINE (Hutchinson & Xu, 2013) is a widely-used spline-based interpolation routine used for interpolating climate observations onto a grid. In New Zealand, ANUSPLINE is used to generate products like the Virtual Climate Station Network (VCSN) that spatially interpolates rainfall (Tait et al., 2006). VCSN uses 3-dimensional spline interpolation based on station latitude, longitude and 1951-1980 Mean Annual Rainfall Surface (MARS). MARS may differ from extreme events spatially/geographically leading to biases when used in interpolation in the VCSN. High-resolution Numerical Weather Prediction model (NWP) may have more realistic spatial patterns for these extreme events. So as part of the Endeavour project “Ma te haumaru ō te wai: Increasing flood resilience across Aotearoa”, we aim to test the interpolation of rainfall during extreme events using Numerical Weather Prediction rainfall fields as the third dimension in Buller and Canterbury regions and compare the results against MARS-based outputs. We aim to compare these grids based on the interpolated rainfall depth and spatial distribution. In addition, we will validate the rainfall fields using a hydrological model.

Method
Using the historical dataset, we chose to use major storm events in the Buller and Canterbury catchments as test cases – the July 2021 and May 2021 events respectively. We chose these catchment events to highlight the challenges in using the MARS-based method to interpolate rainfall for these types of events. These include low station density in high elevation areas for Buller and the Canterbury storm event following a non-climatological wind direction. First we used an augmented input combining station data from the climate database and regional council datasets. ANUSPLINE was then used for interpolation to generate daily rainfall grids at 500m resolution. We then tested the use of two of NIWA’s weather forecasting models - either NZCSM (New Zealand Convective Scale Model) or NZENS (New Zealand Ensemble model) as the covariate for the rainfall interpolation. We compare the interpolated rainfall at all the stations with respect to the observed depth at the same location. We use Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) to quantify the differences between the observed and interpolated rainfall at these stations. We also validate the interpolated rainfall at the catchment scale using the TOPNET (McMillan et al., 2016) hydrological model to compare the results with observed hydrographs for the events.

Results
Figure 1 shows scatter plots of observed depth vs interpolated depth using MARS (current VCSN method) vs using NZCSM for Buller catchment. We observe both NZCSM and MARS based methods perform broadly well in terms of interpolated rainfall depth at the stations where the rainfall is significantly greater than zero. Figure

2 shows the spatial pattern of accumulated rainfall at Buller using MARS and NZCSM. This highlights some unphysical characteristics in the MARS based interpolation compared with the NZCSM interpolation which looks more realistic. There is some evidence that NZCSM has lower bias. These early results indicate that the NZCSM-based interpolation performs well in interpolating extreme rainfall spatially. Next step would include generalising the results with more catchments and events.

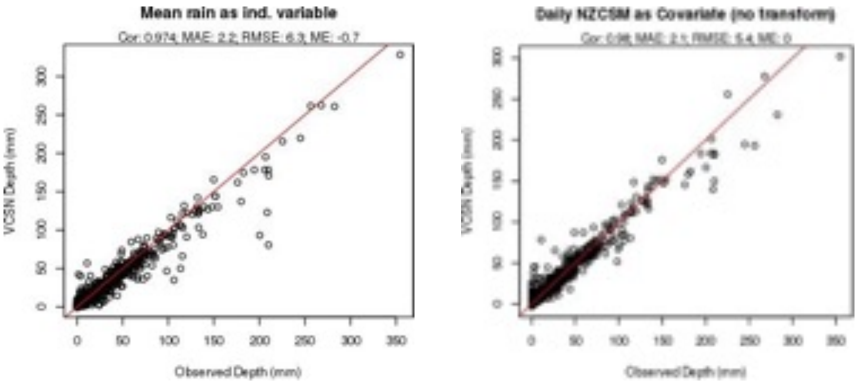

Figure 1: Scatter plots of observed depth vs interpolated depth using MARS vs NZCSM methods for Buller

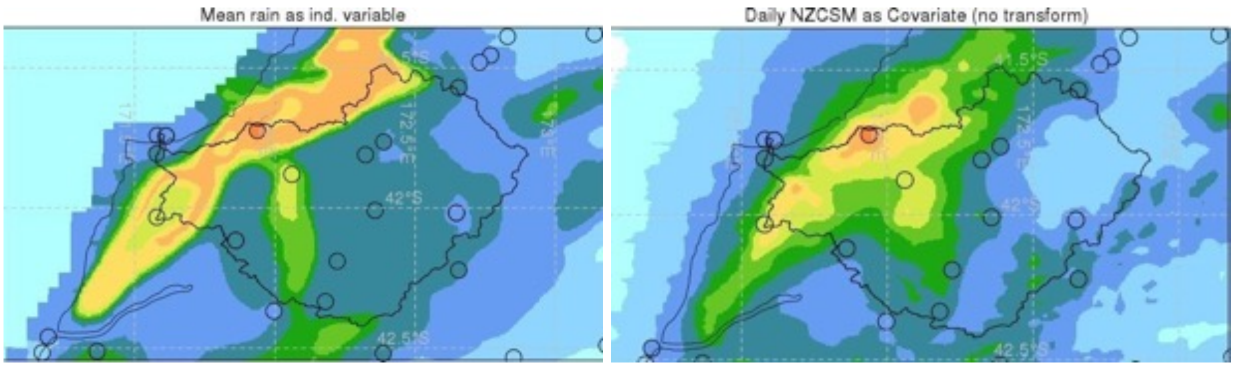

Figure 2: Aggregated rainfall distribution for the storm event at Buller using MARS (left) vs NZCSM (right) methods.

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MAKING USE OF ROUTINE STREAM MONITORING DATA TO UNRAVEL HYDROLOGICAL PATHWAYS THROUGH CATCHMENTS

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Aims

Based on a diverse group of 48 catchments in Taranaki, Waikato and Hawke's Bay, we investigated which routinely monitored water constituents are most suitable as environmental tracers to unravel the hydrological pathways sustaining stream flow (aka 'discharge'). The Bayesian chemistry-assisted hydrograph separation (BACH) model (Woodward and Stenger, 2018), which uses two environmental tracers for 3-component chemistry-assisted hydrograph separation (into near-surface, shallow groundwater, and deep groundwater pathways) was employed for this purpose.

Methods

This research is based on two underlying hypotheses. Firstly, we hypothesise 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, we hypothesise that these pathway contributions differ in their typical concentrations of environmental tracers, which in first approximation can be considered time-invariant.

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 km2 (median 136 km2) 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%).

To evaluate whether a concentration gradient across the three pathways can be expected for a given water constituent, concentration-discharge relationships (CDRs) were established by fitting power functions to the data (see Singh and Stenger (2018) for detail). The slope and the coefficient of determination (R2) were used to evaluate the shape and strength of these CDRs.

Based on the number of available data points over the 15-year period and their CDRs, a group of water constituents potentially suitable as environmental tracers in BACH were identified. For reasons discussed in detail by Woodward and Stenger (2018), the tracer combination Total Nitrogen (TN) and Total Phosphorus (TP) was used in the original BACH research focusing on 8 Waikato catchments. Having now datasets from a much wider range of catchments available has enabled us to consider alternative tracer combinations. The potential information content of a tracer combination is elevated if 'crossed proxies' can be used, i.e. two tracers that carry complementary information. This could either be the case for a tracer with a positive CDR (i.e. increasing concentration with increasing flow) combined with a tracer with negative CDR (i.e. decreasing concentration with increasing flow). Alternatively, it could be one tracer particularly informative for the separation of NS and deeper pathways (e.g. TP) combined with another that largely separates SGW from DGW (e.g. TN).

Results

Only a limited number of water constituents (N and P species, electrical conductivity, pH, dissolved oxygen) were in the majority of catchments measured in sufficient frequency to allow for their potential use for BACH calibration. Environmental tracers typically used in research projects (e.g. silica, chloride, major cations) were in most catchments only sporadically measured. TN, Electrical Conductivity (EC), Inorganic Nitrogen, Nitrate+Nitrite Nitrogen (n = 31 - 40), and TP (n = 18) had the highest number of acceptably strong CDRs ($R2 \geq 0.30$) across all catchments. EC featured negative CDRs, while all N and P species had positive CDRs. Accordingly, combining EC with an N or P species creates a desirable 'crossed proxy', i.e. a tracer combination with complementary information. Given that the highest number of catchments (n=40) featured strong TN CDRs, TN+EC emerged as the most promising alternative to the previously used TN+TP combination.

Using the goodness-of-fit between measured and modelled tracer concentration time series as criterion, the TN+EC combination was considered to produce well-supported results in 36 of the 47 catchments to which BACH was ultimately applied (one catchment removed due to flow regulation for power generation). Catchments with low confidence levels for the TN+EC results comprised 8 out of 10 Hawke's Bay catchments and three Waikato catchments (Fig. 1). In contrast, TN+TP appeared well-supported in only 26 catchments (predominantly in Waikato, Coromandel Peninsula excepted).

A few more geographical patterns were apparent in the results. Most noteworthy, neither of the two tracer combinations worked particularly well in 8 of the 10 Hawke's Bay catchments. Furthermore, TN+EC proved superior to TN+TP in 6 of the 8 Taranaki catchments (equal to in the remaining 2) and the 6 Waikato catchments located on the Coromandel Peninsula. This is likely to reflect the predominantly low nutrient concentrations in these areas due to high percentages of forest/bush cover combined with high rainfall.

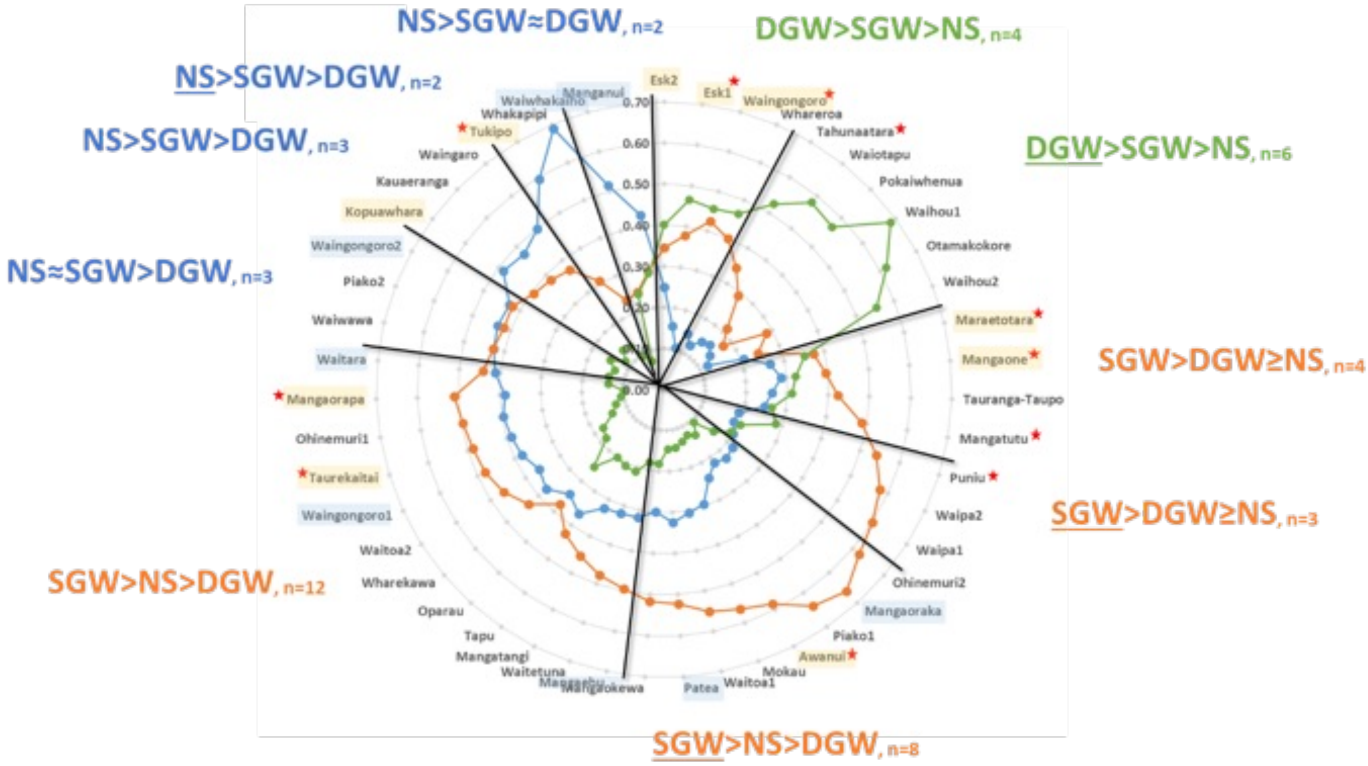

Figure 1: Catchment clusters based on the long-term average contributions (2006 – 2020) by near-surface (NS), shallow groundwater (SGW), and deep groundwater (DGW) pathways to stream flow. Estimated using the TN+EC tracer combination in BACH. An underlined pathway indicates that it contributes >50% of the flow. Red asterisks indicate catchments with low confidence level for pathway estimates. Taranaki catchments with blue shading, Hawke's Bay catchments with gold shading, Waikato catchments without shading.

The radar chart (Fig.1) illustrates that at least two pathways contributed ≥20% of the flow in all but one catchment (Waihou1) and all three pathways contributed ≥ 20% in 12 catchments, challenging the notion of a single dominant pathway.

DGW was the greatest flow contributor in 10 catchments, predominantly ones with large recharge areas on the central North Island's volcanic plateau. SGW occupied that role in 27 catchments spread across all three regions, particularly in lowland areas. NS flows were estimated to be the greatest stream flow contributor in a range of steep catchments with high rainfall (e.g. Coromandel Peninsula, Mt Taranaki). However, some of the high NS flow contributions estimated for the remaining catchments appear implausible (particularly Whakapipi) and are being investigated further.

From a freshwater policy point of view it is noteworthy that long hydrological lag times are only to be expected where DGW contributes a high fraction of total stream flow. Based on our analysis, such conditions are largely restricted to catchments with recharge areas in young volcanic geology on the central North Island's volcanic plateau (e.g. Upper Waikato catchments, Waihou headwaters).

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GROUNDWATER NITRIFICATION – NATURAL PRODUCTION OF NITRATE BELOW THE WATER TABLE AT TE WAIKOROPUPŪ SPRINGS

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Aims
The objective of this work is to understand the sources of nitrate to Te Waikoropupū Springs (TWS).

Methods
Previous work has shed light on the recharge sources of water to TWS (Stewart and Thomas, 2008). A nitrate mass balance calculation based on the recharge model shows what the nitrate concentrations in the recharge waters are when they reach TWS (Stewart and Thomas, 2021). Comparing these with the nitrate concentrations when the waters first enter the groundwater system show that the waters gain nitrate by nitrification during their passage through the unsaturated zone and groundwater system to TWS (Fig. 1).

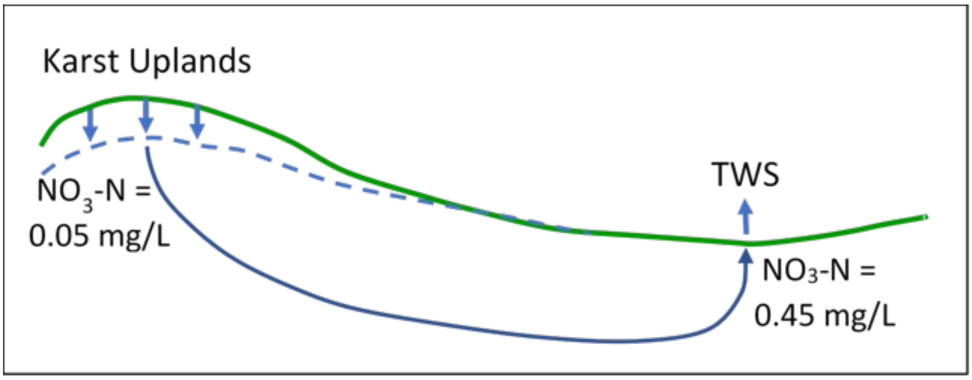

Figure 1: Nitrate-N concentrations of Karst Uplands recharge increase along the flowpath.

Nitrification (bacterial conversion of ammonium to nitrate) is widespread in soils, unsaturated zones and groundwater systems when they contain dissolved oxygen. Investigation of the nitrification process at the springs has been carried out by: Examining the total nitrogen (TN) concentrations of the waters, Preliminary studies of the stable isotopes (15N and 18O) in nitrate in the groundwater system, and Reading the scientific literature on karst (particularly related to pristine oxic karst like the Arthur Marble that hosts TWS).

Results

- **Total nitrogen concentrations** include dissolved species (e.g. DIN [dissolved inorganic nitrogen such as nitrate, nitrite and ammonium], and DON [dissolved organic nitrogen]), and particulate species (fragments of twigs/leaves etc.). Values of TN (except particulates) are given by McGroddy et al. (2008) for first order streams from pristine forests in NZ. TN is expected to be approximately conservative in the groundwater system, whereas nitrate is not conservative.

  The increase in nitrate-N along the flowpath from the Karst Uplands to TWS implies input of about 5 kg/ha/yr of organic-N from the recharge area of 170 km2, which is within the range found by McGroddy et al. (2008). The efficient oxidation process including nitrification ensures that none of this organic matter reaches TWS enabling the remarkable clarity of the water.

- Stable isotopes in nitrate: Fig. 2 shows nitrate isotope measurements in Takaka Valley groundwaters. Green points show mainly natural nitrate from nitrification (TWS Main Spring, Spittal Spring and Riwaka Resurgence), these karst springs have low δ15N and δ18O values characteristic of nitrification. Red points show nitrate from dairy farming, these are groundwater samples from wells in the dairy farming area of the valley floor. Much of this nitrate is produced by nitrification of urine and urea fertiliser (UUF) in the soil and unsaturated zone, and plots in the UUF zone in Fig. 2. The Fish Creek Spring point is shown as purple as it may have nitrate dominantly from farming according to the nitrate balance calculation.

  Fig. 2 also shows the denitrification line from Stewart and Aitchison-Earl (2020) for Tinwald, although no denitrification is observed in the Takaka area. Instead, the samples lie in the nitrification area at low values of the δ values. Spittal Spring and Riwaka Resurgence are other springs from Arthur Marble.

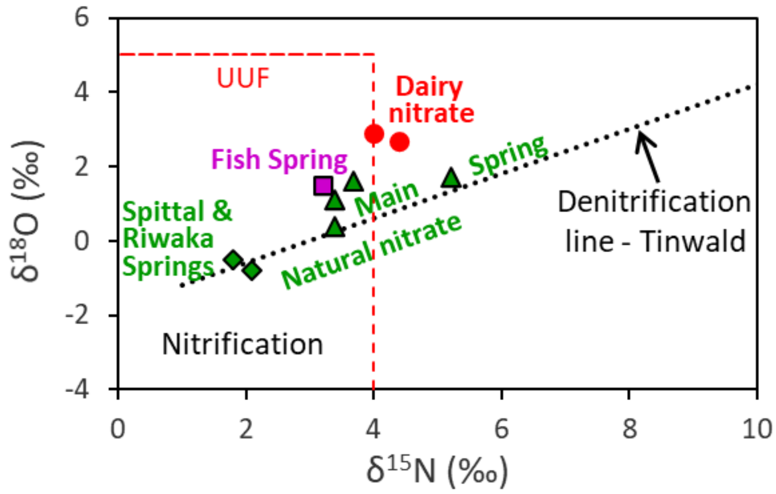

Figure 2: Nitrate isotopes in groundwater samples from the Takaka Valley. Green shows mainly natural nitrate from nitrification (TWS Main Spring, Spittal Spring and Riwaka Resurgence), while red shows nitrate from dairy farming. Fish Creek Spring may have nitrate mainly from farming (purple).

- **Scientific literature:** Several recent papers have reported nitrification as a previously unrecognised source of nitrate in oxic karst systems. The first was Musgrove et al. (2016), who showed that groundwater nitrate concentrations in the Edwards Aquifer were elevated relative to the surface water recharge. They concluded that nitrification within the aquifer is the source of some of the nitrate in the groundwater.

  Likewise, this new understanding indicates that nitrification in the unsaturated and saturated zones of the Karst Uplands and other aquifers in the Takaka Valley contributes substantial amounts of nitrate to TWS.

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FIRST RESULTS FROM GROUND-BASED AND BALLOON-BORNE AEROSOL AND TURBULENCE MEASUREMENTS DURING THE GOSOUTH CAMPAIGN

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Aims

Southern-Ocean (SO) clouds are routinely misrepresented in the present generation of climate models that informed the 6th Assessment Report of IPCC. The modeled SO clouds allow too much sunlight to penetrate to the ocean surface, causing a warm sea-surface temperature bias and associated consequences such as underestimated sea ice extent, locations of the ocean circulation belts, and a southward displacement of the storm track (Flato et al., 2013). Also, for the latest generation of climate models, such misrepresentations of cloud properties reduce the ability of climate models to correctly reproduce important climate properties such as climate sensitivity (Zelinka et al., 2020).

A major part of this problem is our still incomplete knowledge concerning the microphysical properties (e.g., droplet size distribution and phase state (liquid or frozen), Choi et al., 2010; Kanitz et al., 2011; Vergara-Temprado et al., 2018; Villanueva et al., 2020) of (SO) clouds, including the combined influences of aerosol particles, boundary layer dynamics, atmospheric and cloud turbulence, and thermodynamics on these properties.

To tackle this problem, the goSouth campaign focuses on the vertical distribution of aerosol chemical composition and physical properties, turbulence, and meteorological variables in the marine boundary layer, featuring a combination of ground-based and balloon-borne measurements of aerosol, thermodynamic and turbulence properties.

Methods

Ground-based and balloon-borne measurements of aerosol physicochemical properties and concentrations, as well as meteorological parameters, including turbulence, will be carried out.

Measured properties are:

- Aerosol particle total number concentration
- Aerosol particle number size distribution
- Cloud Condensation Nuclei number concentration
- Ice nucleating particle concentration
- Particle chemical composition
- Spectral resolved aerosol particle light scattering and hemispheric backscattering
- Vertical profiles of selected turbulence and aerosol particle properties

Results

This talk will give a preliminary overview of the first results gained during the ground-based and balloonborne aerosol and turbulence-related activities. The long-term goal is to develop or improve models for ocean-aerosol-cloud interactions in the SO, which are currently a source of error in climate projections.

Acknowledgments

goSouth is funded by BMBF (German Federal Ministry for Education and Research, Project 01LK2003A), TROPOS, the Deep South Challenge and NIWA through SSIF.

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AN OVERVIEW OF THE GOSOUTH MEASUREMENT CAMPAIGN

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Aims
goSouth is an international collaboration between the Leibniz Institute for Tropospheric Research (TROPOS), the Institute for Meteorology and Climatology (IMUK) at the Leibniz University of Hannover, the University of Auckland, the University of Canterbury and NIWA. Rejoicing in the full title of "Model assisted vertical in-situ investigation of aerosols, and aerosol-cloud-turbulence interactions in the Southern Hemisphere marine boundary layer (goSouth)" it has two main purposes:

- Characterisation of climate relevant aerosol processes in the turbulent boundary layer over the Southern Ocean
- Proof of concept for collaboration between Germany and NZ with a view to a larger ship and air-borne programme to follow

A measurement campaign is planned for November at a site overlooking Te Waewae Bay near Pahia (46.31°S, 167.71°W, 10 m a.s.l.), about 50 km west of Invercargill. Five researchers from TROPOS and one researcher from IMUK will join the NZ contingent for three weeks of aerosol and turbulence measurements from ground level to 1 km.

The campaign will focus on the vertical distribution of aerosol physicochemical properties, turbulence and meteorological variables in the marine boundary layer. A combination of ground-based and balloonborne measurements of aerosol, thermodynamic and turbulence properties will be carried out. The goSouth measurement campaign will be jointly realized with a remote-sensing campaign of the LOSTECCA project (Hofer et al., 2022).

A subsequent data workshop will be held along with a special session at the meteorological society conference in Dunedin on 6th December.

Methods
Measurements will be made of aerosol physicochemical properties and concentrations. The instrumental suite consists of:
- Filter samples for aerosol chemical analysis
- Aethalometer
- Condensation Particle Counters
- Cloud Condensation Nuclei Counter
- Mobility Particle Sizers
- Hemispherical Sky Imager
-

Furthermore, there will be a complete suite of meteorological measurements. Aerosol particle and meteorological – including turbulence – measurements will also be made from tethered balloons up to a height of 1000 m.

The partner project LOSTECCA will in addition contribute continuous observations of the vertical distribution of aerosol, clouds and atmospheric dynamics from multi-wavelength Raman polarization lidar and Doppler lidar, as well as integrated measurements of atmospheric water vapour, liquid water, and aerosol optical thickness from microwave radiometer and Sun-photometer.

Results

The Metsoc special session will be held one week after measurements have finished. This talk will give an overview of the measurement campaign as an introduction to the other talks in the session which will discuss data collection and initial findings from the campaign.

The results will be used to develop or improve models of Southern Ocean ocean/aerosol/cloud interactions which are currently a source of error in climate projections.

Acknowledgements

Go South is funded by BMBF (German Federal Ministry for Education and Research, project 01LK2003A), TROPOS, the Deep South Challenge and NIWA through SSIF.

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IMPROVING AUCKLAND'S RAINFALL OBSERVATION SYSTEM

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Aims

Tāmaki Makaurau (Auckland) experiences significant spatial and temporal variability in rainfall. While Auckland is well served by a network of some 84 rain gauges, these observations only sparsely sample the 4900km2 surface area of the region, resulting in gaps in understanding of rainfall. Numerous projects which are extremely sensitive to the accuracy of rainfall inputs have been initiated in recent years to deliver improvements for Auckland residents, including bathing water quality warnings and overflow upgrades (Safeswim, Neal et al. 2018), surface water quality modeling for planning guidance (FWMT, Grant et al. 2018, Stephens et al. 2022), floodplain mapping and forecasting (Islam and Tay 2022) and wastewater network modeling (NP2M, Donald and Haarhoff 2022), all of which require rainfall data beyond that available from the rain gauge network.

Rain radar can deliver spatially complete Quantitative Precipitation Estimates (QPE) over the Auckland region, however inadequate quality control and data processing from the MetService radar's built-in software previously resulted in data which was unusable for Three Waters applications (e.g. Milsom et al. 2007). A systematic and rigorous approach to treating rainfall data has now been established to combine the MetService radar and regional gauge network observations and provide the required rainfall information for current and future Three Waters work streams.

Method

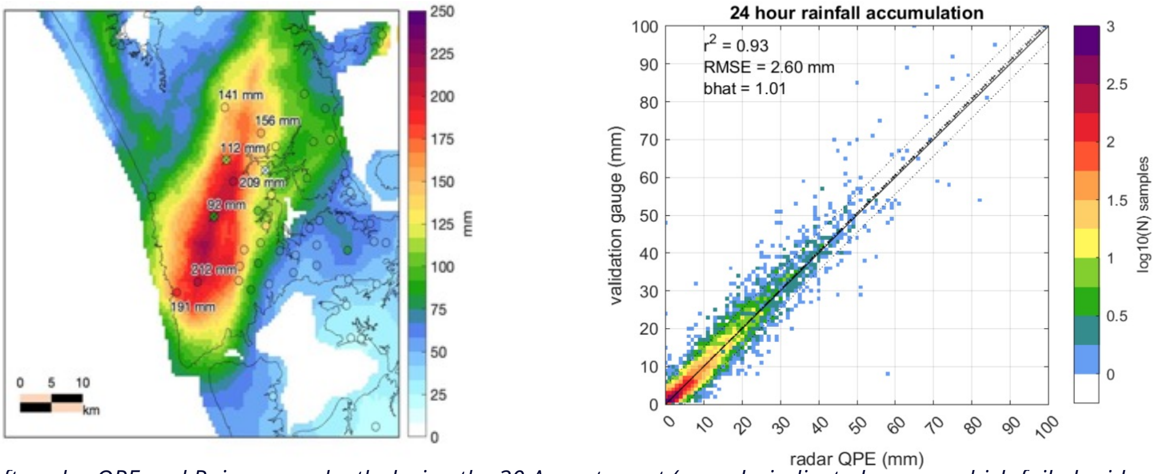
24 and 9 GHz profilers and tipping bucket rain gauges at Anawhata (left) and a 24GHz profiler operated adjacent to a rain gauge enclosure equipped with both tipping bucket and weighing rain gauges in Orewa (middle/right).

Radar QPE are impacted by a variety of measurement uncertainties related to the underlying physical characteristics of the system including returns from non-meteorological targets, artifacts introduced by doppler signal processing, calibration uncertainty, attenuation of the radar's electromagnetic signal, geometric considerations, sampling intermittency and an unknown raindrop-size distribution. Tipping-bucket rain gauge data is not well suited to investigating and correcting these uncertainties due to a fundamental mismatch between the sample time and volume of rain gauge and radar systems.

To address the limitations of the existing rainfall observation network, we have developed advanced rainfall observatories around the Auckland Region, the sites are equipped with 24GHz MRR-PRO (Metek GmbH) Vertically Profiling Radar (VPR) alongside 9 GHz VPR of our own design. Dual frequency VPRs enable simultaneous, instantaneous measurement of radar reflectivity, rainfall rate and updrafts. The VPR observatories allow independent estimation of the individual sources of uncertainty in the MetService radar system and development of improved Quality Control (QC) and data processing methods. Further confidence in radar performance is gained from advanced in-situ rainfall observations provided by a laser disdrometer and weighing rain gauges.

Following application of the improved radar data QC, the resulting radar QPE is largely free of systematic errors. Residual biases (e.g. due to unknown raindrop size distributions) are then mitigated with an Ordinary Kriging or Radar Errors (OKRE) approach. Our implementation of OKRE incorporates an error covariance model which is sensitive to the different error characteristics of the radar and tipping bucket gauge data, further enhancing the reliability of the radar QPE by favoring data with the lowest uncertainty.

Results
The improved radar QPE has been compared with rain gauge observations in a leave-one-out cross validation, skill statistics exceed conventional gauge interpolation at all time and space scales, with the biggest benefits realized in sparsely gauged areas. The utility of the radar QPE is also characterized in event case studies, including the recent Kumeu flooding event during which two gauges in the highest rainfall area were flooded mid-event, further highlighting how the radar QPE system contributes to a reliable understanding of rainfall patterns in the Auckland region.



Left: radar QPE and Rain gauge depth during the 30 August event (x marks indicated gauges which failed mid-event). Right: Leave-one-out cross-validation results for the radar QPE system utilizing all Healthy Waters tipping bucket gauges for the period March 2021-March 2022.

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IMPROVING WIND GUST ESTIMATION FROM NWP MODELS: METHODOLOGIES AND DEPENDENCY ON MODEL RESOLUTION

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[2] MetService, New Zealand

Aims
Improve wind gust forecasting from NWP model output.

Methods
Wind gust forecasting provides essential information for informed decision-making in a range of industries, such as maritime operations, aviation, and construction. By design operational numerical models calculate the mean wind speed, consequently, as wind gusts are not calculated by the model, wind gusts are obtained using a wind-gust estimator (WGE). Wind gusts are primarily driven by atmospheric turbulence generated by surface friction, wind shear, and buoyancy fluctuations (convection) in the boundary layer. Most of these processes are parameterised in operational NWP models. Yet, as operational model resolutions increase, some features, such as small-scale mesoscale structures and/or large-scale boundary layer turbulence, become better resolved. The increase in resolution poses some challenges for currently employed WGEs. WGEs often depend on the modelled mean windspeeds, which increases in spatial variability and magnitude as more features are resolved. Furthermore, with flow structures currently parameterised in WGEs becoming partially resolved, it is unclear if current WGEs are suitable for convection resolving resolutions.

Results
In this study, we run a range of numerical simulations with resolutions ranging from 6km-300m for several coastal locations in New Zealand, such as the Christchurch region and Napier Bay region. We evaluate the performance of (1) statistically based, and (2) physically based WGEs for a range of model resolutions against wind gust observations to identify the most suitable WGE for different model resolutions.

A GROUNDWATER ISOSCAPE FOR NEW ZEALAND

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[2] Greater Wellington Regional Council

Aims
Isoscapes are spatial models of variation in the isotopic composition of various substances in the environment. We have created an isoscape for New Zealand groundwater, utilising measured stable isotope data to develop a predictive model for hydrogen and oxygen isotopic spatial patterns in groundwater. Groundwater acts as an integrator of the isotopic signal of long-term precipitation inputs, and can provide benefits for studies involving catchment hydrology, groundwater hydrology, groundwater/surface water interaction, and other studies that may require knowledge of the average isotopic composition of water such as agricultural authentication and biosecurity.

Methods
Stable isotope data (δ18O and δ2H) has been collated for more than 2000 New Zealand groundwater samples over hundreds of sites. This data has been mapped and modelled to create a national-scale groundwater isoscape. Modelling techniques such as general linear models (GLM) kriging and random forest have been explored using correlations with variables commonly associated with variations in stable isotope values, such as elevation, latitude, distance from the coast, air temperature and precipitation.

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AN UPDATE ON RESEARCH PROJECTS OF THE WEATHER AND WILDFIRE THEME:RESILIENCE TO NATURE'S CHALLENGE 2
TE HUARERE ME TE AHI PŪKĀKĀ: KIA MANAWAROA – NGĀ ĀKINA O TE AO TŪROA.

Richard Turner[1], Sally Potter[2], Andrea Wolter[2], Nick Locke[3], Liam Wotherspoon[4], Richard Flay[4], Sylvia Tapuke[5], and Lisa Langer[5]
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[2] GNS Science
[3] WSP, Lower Hutt
[4] University of Auckland
[5] SCION

Aims

Kia Manawaroa – Ngā Ākina O Te Ao Tūroa (The Resilience to Nature's Challenge 2 Science Challenge) is now 3 years through it's 5 year-funding cycle. High impact weather and attendant risks have significant direct and indirect adverse effects for New Zealand; as the recent Nelson Floods and rain-induced landslides in August 2022, being one of several recent examples. Te Huarere Me Te Ahia Pūkākā, The Weather and Wildfire, theme aims to enhance preparedness to extreme weather and support better decision making by creating: novel tools, multi-hazard interoperable datasets, comprehensive case studies and models of high impact weather events as well as generating new insight into; risk perception and behaviour of communities, the communication of warnings, and the adverse effect on communities, infrastructure, and economic activity. This presentation aims to provide status updates and key results obtained thus far from each project in the theme.

Methods.

In order to achieve the it's aims, the Challenge has ten research themes connected under two broad frameworks of "Multi-hazard risk " and "Resilience in Practice Model" (See Figure 1) and each theme able to structure its own research. The Weather and Wildfire Theme structure consists of ten research projects (4 co-funded with the Built theme) each related in some way to one of three high impact weather event scenarios; a major ex-tropical cyclone with heavy rain and strong winds impacting Auckland; a major winter snow storm affecting critical infrastructure in the South Island; and the growing spectre of wildfire menacing communites at the rural-urban interface.

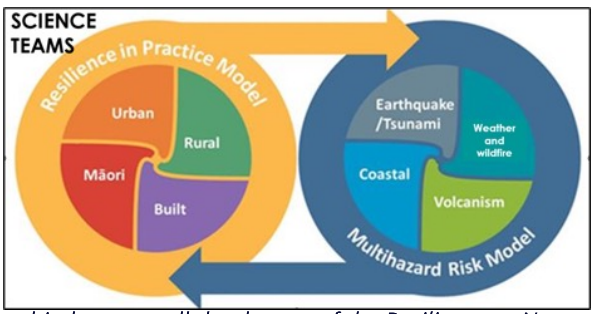

Figure 1 Schematic showing the relationship between all the themes of the Resilience to Nature's Challenges.

Results
High-resolution modelling of each of the three high-impact weather events have been completed with over datasets for 35 ex-TC cases run (see Figure 2 for sample output from some of the ex-TC Cook cases), 6 winter-storm cases, and 5 wildfire cases produced.   Coastal inundation, rain-induced landslide, flood, ice-accretion, wind, and fire-spread modellers have taken these inputs and are currently using them to create additonal hazard layers for use in the impact models such as RiskScape and/or use in other RNC2 projects that plan to use the outputs, e.g., the "Māori Cultural Impact" project. The advantage with the datasets created is that they are all fully consistent and allow hazard simulation at neighbourhood detail. These datasets are freely available to any researcher or stakeholder interested in using them.

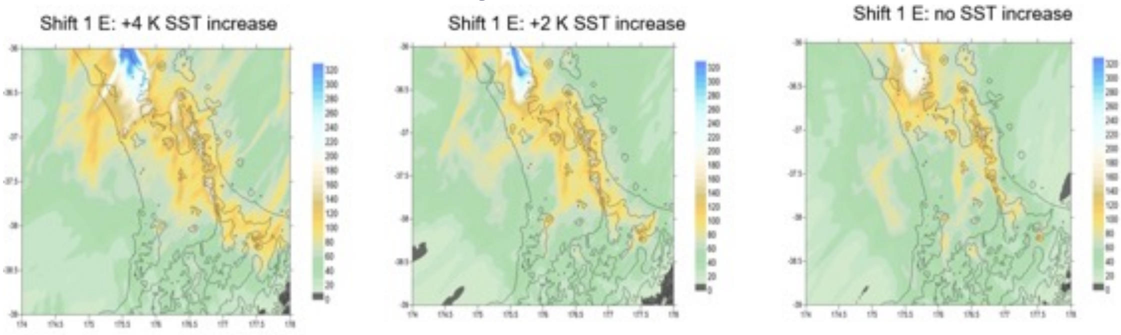

Figure 2 Plots showing total event rainfall from ex-TC Cook (April 2017) with New Zealand shifted east 1 degree with enhanced SST's of +4 K (left), +2 K (middle), and +0K (right) (after Boutle et al 2021).

From the social science projects on communication of weather warnings, key findings have been that impact-based warnings can be effective at influencing risk perception and lead to a better understanding of impacts, but are more effective when used by emergency and/or official agencies than prompting responses in individuals. The social wildfire research team has completed a survey of risk perceptions of Mt Iron, Wanaka residents to wildfire.

Apart from the physical model and survey datasets, the theme's outputs to date also include 10 Journal articles (either fully or significantly funded) and 1 book chapter.

Each project had significant stakeholder input and priority setting in the planning stage but ongoing engagement has lagged while the research has been carried out. This is mainly due to Covid causing cancellation of planned workshops and huis, but also due to regional lockdowns limiting travel for field work meaning some projects have been seriously delayed by over a year. Researchers have been catching up with online meetings in 2022 and over the final eighteen months (2023 and to June 2024) the aim is to increase engagement as research results become available in order to ensure uptake and impact.

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THE INFLUENCE OF REACTIVE HALOGEN SPECIES IN DMS OXIDATION OVER THE SOUTHERN OCEAN

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Aerosols, the micro-scale solid and liquid particles suspended in the atmosphere, influence the Earth' radiation budget both directly and indirectly. While the direct effect is through the absorption or scattering of radiation, the indirect effect arises from its pivotal role in the formation of clouds by serving as cloud condensation nuclei (CCN) or ice-nucleating particles (IPCC, 2021). The 5th Assessment Report of the Intergovernmental Panel for Climate Change (IPCC) identified that then state-of-the-art climate models were biased in simulating the clouds over the SO resulting in erroneous representation of fields such as sea surface temperature and sea ice extent (IPCC, 2013), hence making climate projection for mid-latitudes, including NZ, challenging.

Aims

The Earth System Modelling and Prediction programme, part of the Deep South National Science Challenge, addresses this gap and aims to better understand cloud-aerosol interactions using the NZESM, an Earth system modelling capability in NZ developed within the programme.

Marine aerosols such as sea salt have been regarded as suitable CCN because of their hygroscopic properties (Cotterell et al., 2017). Dimethyl sulfide (DMS) is another major marine aerosol of biogenic origin (Revell et al., 2019). Both sea spray aerosol and sulfate aerosol formed by oxidation of DMS can serve as efficient CCN (Breider et al., 2015). It has previously been shown that halogens play an important role in DMS oxidation, particularly over the Southern Ocean (Chen et al., 2018).

Methods

This study will incorporate sources of halogens such as bromine and chlorine into the NZESM based on the recognised approaches within the community as adopted in chemistry-climate models such as TOMCAT (Breider et al., 2010; Breider et al., 2015), Community Earth System Model (CESM) (Lamarque et al., 2011) etc.

Results

We will show how sea spray sources of bromine and chlorine affect DMS chemistry, CCN and cloud droplet number concentrations, and aerosol optical depth over the Southern Ocean.

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FLUID FLOW ALONG TECTONIC FAULTS IN LITHIFIED ROCKS

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Aims

Hydraulic conductivity and permeability along faults have major implications for groundwater protection and management in bedrock aquifers. Faults can behave as conduits and barriers to fluid flow. Flow along faults should be accounted for when modelling pollution transport in the aquifer, designing water source protection, tunnelling and any deep sub surface infrastructure. Previous studies have found permeability values vary along fault zones depending on the rock type (Balsamo, 2010; Farrell, 2013; Rawling, 2001) and fault-zone architecture (Evans, 1997; Micarelli, 2006), however, all these studies were limited to two-dimensional observations. We currently have very little knowledge of the flow patterns over fault surfaces and of the parameters that control the three-dimensional spatial distribution of permeability.

Method

This study uses three-dimensional patterns of secondary calcite mineral deposits in fault zones, as a proxy for past flow paths, and provides a new dataset that has not been analysed before. Fault-zones characterised by calcite-filled fracture voids could indicate high permeability zones, while fracture surfaces with mostly unfilled voids may indicate low permeability zones.

We use a high-resolution CT scanner (Mars bioimaging Ltd.) to scan a hand sized (10x8x3 cm) siliciclastic rock sample containing a calcite-infilled fault system (Figure1). The high-density contrast between the sedimentary host rock, the calcite filling and the voids allows us to map fault zones in three-dimensions and to infer fracture permeability.

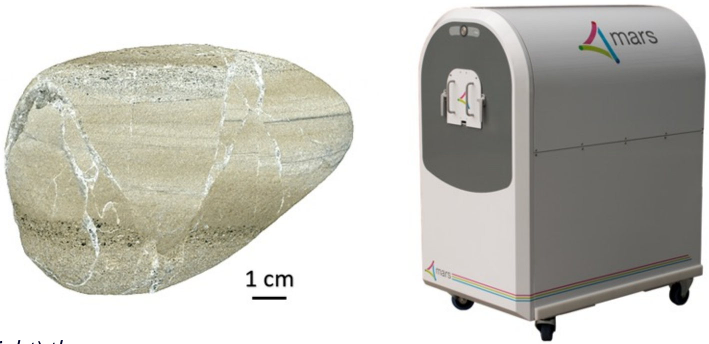

Figure 1: left) The rock sample, right) the mars scanner.

Results

The CT-scanner model shows mineralisation patterns of variable thickness along 17 faults (Figure 2). To determine what factors primarily control fault mineralisation (and the inferred fault permeability) we compare the thicknesses of the mineralised fault zones to fault displacement, length and orientation, to changes in strata type and to the proximity with other faults. Preliminary results suggest that fault mineralisation often occurs at fault steps and intersections. The results may have application to Torlesse Supergroup rocks, which likely form New Zealand's largest bedrock aquifer system.

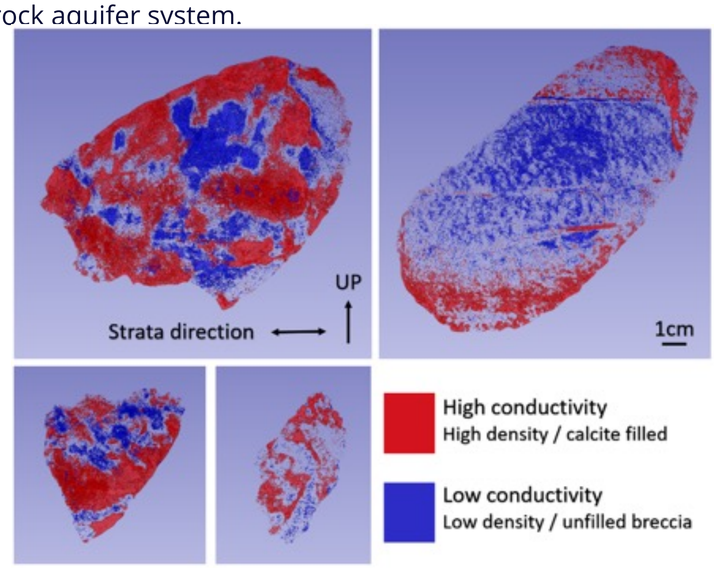

Figure 2: Density analysis on 4 of the 17 fault planes, showing areas high density (<2.3 kg/m3, indicating calcite deposits in voids) in red and areas of low density (> 1.3 kg/m3, indicating breccia / area without calcite deposits). View is at normal to fault plane.

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USING SURFACE NUCLEAR MAGNETIC RESONANCE TO CHARACTERIZE RIVER SYSTEMS IN NEW ZEALAND

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Aims
Characterizing confining layers in the subsurface is crucial to fully understand the dynamics of subsurface water. Resistivity measurements are commonly used to identify such layers, yet limitations arise in high resistivity geologies due to lack of sensitivity of these methods in very resistive layers. Here, surface Nuclear Magnetic Resonance (SNMR) can be used to retrieve lithological boundaries by using its direct sensitivity to water in the subsurface, where boundaries are identified due to changes in water content. We present a case study of three rivers in New Zealand: Ngaruroro, Wairau, and Selwyn, where a dense grid of SNMR measurements have been acquired. Our aim is to identify confining units and improve understanding of these complex river systems by using SNMR derived information.

Method
The nuclear spin of hydrogen nuclei is the origin of the SNMR signal. When hydrogen nuclei, are placed in a magnetic field, the magnetic moment preferentially aligns along the direction of the magnetic field (Hertrich, 2008). Historically, a pulse and collect style measurement, called a free induction decay (FID), has been the dominant acquisition technique for SNMR. The FID involves transmitting an excitation pulse in a transmitter loop at the surface. This pulse excites hydrogen nuclei at depth, i.e., perturbs them out of equilibrium. The nuclei then precess about the magnetic field while slowly decaying back to equilibrium. This decaying magnetization is measured at the surface. A suite of different amplitude current pulses is used to alter depth sensitivity.

Processed data are inverted to estimate depth profiles of water contents and relaxation parameters (T2* and T2), which are linked to pore sizes (Behroozmand et al., 2015). Water in larger pores, as in sand/gravel, will have longer relaxation times, whereas clays will have very rapid decays which cannot be measured by the SNMR instrument. Therefore, a low water content can be a sign of clays, or a sign that the sands/gravels are not saturated. Recently, a new measurement scheme was proposed by Grombacher et al. (2021), which enhances stacking rates and enables high density mapping.

Results
Three rivers were investigated in this study, the Ngaruroro, the Wairau, and the Selwyn. SNMR data was collected using the Apsu instrument developed at Aarhus University (Liu et al., 2019). A total of 77 soundings were acquired using a small coil (20m x 20m) for enhanced shallow resolution. At each site, the water contents and relaxation parameters are estimated as in Figure 1. For brevity, we focus on the Wairau results are discussed in this abstract.

To identify layer boundaries of the river systems, a methodology is implemented to estimate boundaries from the smooth inversion results, as steady state SNMR modelling schemes are currently limited to these many-layer discretizations. The rapid decrease in the water contents, example shown in Figure 1, is interpreted to be the interface between an upper low saturated unit and the underlying confining unit (which appears as low water contents due to an inability to measure clay-bound water). Therefore, the boundary of a confining unit is determined by the minimum of the derivative of the water contents. Similarly, the depth of the peak water content has been extracted to identify which part of the subsurface is most saturated. If the aquifer is saturated, the water contents can be directly translated to a porosity, yielding a porosity of 16% from Figure 1. Furthermore, the relaxation parameters show a similar trend with large pore sizes in the upper layers and a decrease towards very rapid decays.

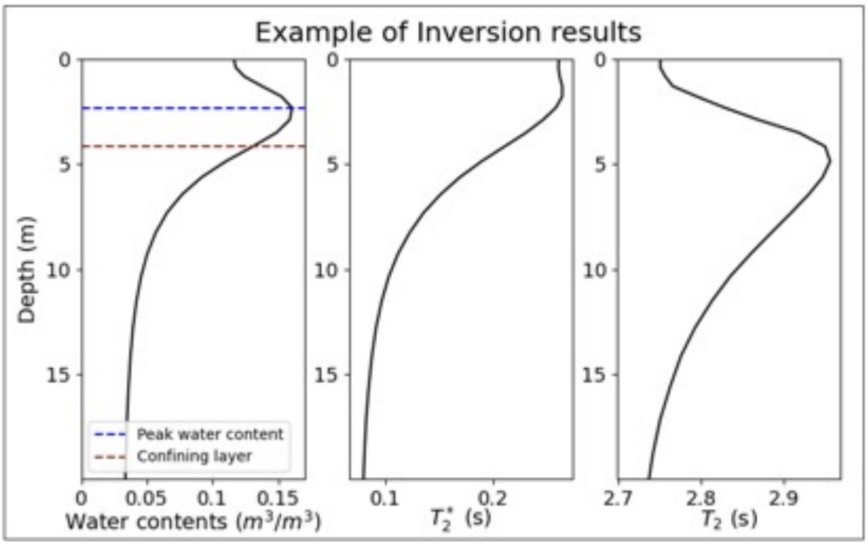

Figure 1: Inversion results and example of defining the depth to the confining layer and to the peak water content.

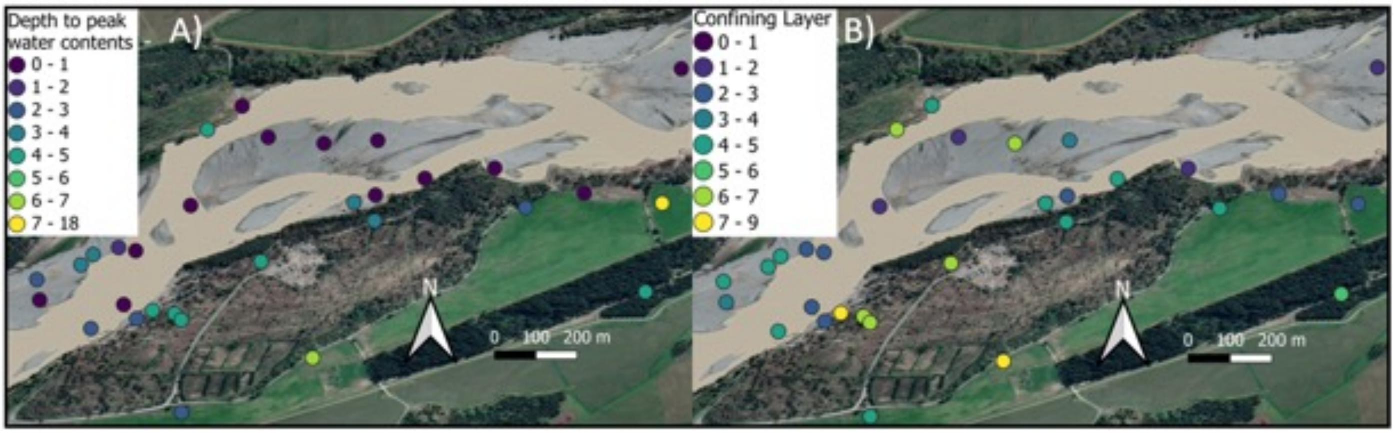

Figure 2A illustrates the Wairau River results. Shallow depth to peak water content, mostly in the depths of 0-5 meters, are observed across the investigated area. In the riverbed, the peak saturation occurs in the first 2 meters, where the coarse material of the rivers is deposited, composed primarily of cobbles to gravels. When crossing on to the river bank the depth to peak water content increases, likely due to topography changes. These shallow depth of peak water contents indicate a decrease in porosity at depths. In figure 2B, the confining layer depth is shown revealing a shallow confining layer in the riverbed. The confining layer depth varies in the riverbed and is especially shallow in the middle bar, where the depth to peak water content is almost at the surface. This relates to a very shallow local groundwater system, possibly not interacting with deeper aquifers. This shallow aquifer is identified throughout the river highlighting the possibility of mapping very shallow structures in river systems with SNMR.

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EXAMINATION OF THE CLASSIFICATION OF PRECIPITATION EVENTS IN THE EXTREME WEATHER EVENT DATABASE FOR AOTEAROA NEW ZEALAND

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Extreme weather events, particularly those associated with precipitation, cause significant damage to property, and have other negative socioeconomic impacts in many parts of the world, including Aotearoa New Zealand. With the growing importance of understanding extremes, New Zealand scientists have compiled an Extreme Weather Event (EWE) database that records a range of extreme weather events occurring between March 1996 and December 2021 over New Zealand. The EWE database incorporates a subjective classification of extreme events based on the predominant meteorological phenomenon associated with each (e.g.; R, C, S, W, T for rainfall, convection, snow, wind, and temperature) and some measure of the intensity of the extreme event. The present study aims to examine this subjective classification using reanalysis datasets (ERA-5, MERRA-2 and possibly others such as BARRA-R). Preliminary analysis of the fraction of convective (CP) and large-scale precipitation (LSP) to the total precipitation (TP) from the reanalysis show that there is a clear distinction between the rainfall (R) and convection (C) classes. Our analysis confirms that there is a clear dominance of LSP over CP for "R" events while the dominance of CP is less clear with a moderate fraction of LSP present in a number of "C" events. We also compute spatially averaged percentile scores relative to the long-term precipitation climatology for a range of regions. For every event, the analysis would not only quantify the accumulated precipitation within each region but would also help us to examine whether the events included in the database include information about risk and vulnerability.

MAKING THE UNSEEN SEEN: HIDDEN TAONGA IN OUR GROUNDWATER

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[2] Second Organisation Affiliation
[3] Third Organisation Affiliation

Aims
Identify across taxa diversity present in our groundwater. Does the abundance and diversity change according to physico-chemical variation? Is there an indication of seasonality within our groundwater?

Introduction
The importance of groundwater as both a resource and a taonga is increasing globally. The current climate crisis is beginning to include groundwater in its discussion on the issue of water quantity and quality. Up until recently, groundwater has, however, only been seen as a resource and measures put in place were to protect the end use (e.g. drinking water, stock water, irrigation) rather than the groundwater itself. The National Policy Statement for Freshwater Management, NPSFM (2020) has moved to address this by including as its central (number one) priority a requirement to uphold Te Mana o te Wai and protect the water itself (including the biology within it). That said, there is still a huge knowledge gap in the biology present in groundwater and its role in keeping our water safe.

Our research aims to bridge this gap and bring the taonga that is groundwater, and its biology to light. In this presentation we will describe the broad diversity present in our groundwater from micro- to macro-fauna and the role they play in the groundwater ecosystem. We will compare across taxa diversity present in different aquifers and identify correlations between physico-chemical parameters. Finally, we will begin to build a picture of the season shifts in this diversity and what that may mean in future climate scenarios.

Method

To capture as many taxa as possible we used a combination of environmental (e)DNA, specimen collection and microbial culuture techniques. Methods were followed according to the “Updated sampling considerations and protocols for assessing groundwater ecosystems” (Weaver et al 2021).

Once in the laboratory, samples were processed using; taxonomic identification for specimen identity to as low a taxonomic grouping as possible; extraction of DNA and sequencing using Illumina MiSeq for eDNA, and culturing bacteria with specific plate media. Water chemistry was analysed according to specific protocols by Hill Laboratories. Field parameters were measured using calibrated YSI multiprobes.

Results

We have identified a broad range of diversity across micro- to macro-fauna present in groundwater. Within the microorganisms present (bacteria and archaea) there is a high diversity present but a low abundance (Figure 1), in particular related to depth; the lower we go the lower the abundance present. This could also be seen within the macrofaunal specimens collected, but in addition to the depth (where we do note a decrease in the macrofauna, less so the meiofauna present (<50 uM), the lithology present played an important role in diversity present. Changes were observed within specific taxa present depending on physico-chemical parameters, in particular dissolved oxygen, pH, and temperature. It must be noted, however, these correlations were not present at all regions investigated. In terms of seasonality, we have extended our previous studies on microbial diversity related to seasonal shifts to include macrofauna and fungi presence. There was not a significant change in microbial or macrofauna present according to seasons but there was for fungal presence. That said, there were changes observed in the diversity and relative abundance present at different sampling occassions, just not significant changes. There was a difference in the diversity and abundance presence depending on the depth of the well, less change occuring as depth increased. Changes appear to be due to recharge events, changes in the water chemistry present, indicating the close connection between shallow systems and land use and surface water.

The complex changes occurring in the patterns across taxa over time highlight the importance of undertaking temporal studies over time across a wide range of environments. This will enable a more complete understanding of groundwater taonga and its role in groundwater ecosystems. Investigating responses to changes in water chemistry and physical parameters will allow us to understand and predict changes in the groundwater ecosystems in response to land use change and climate stress.

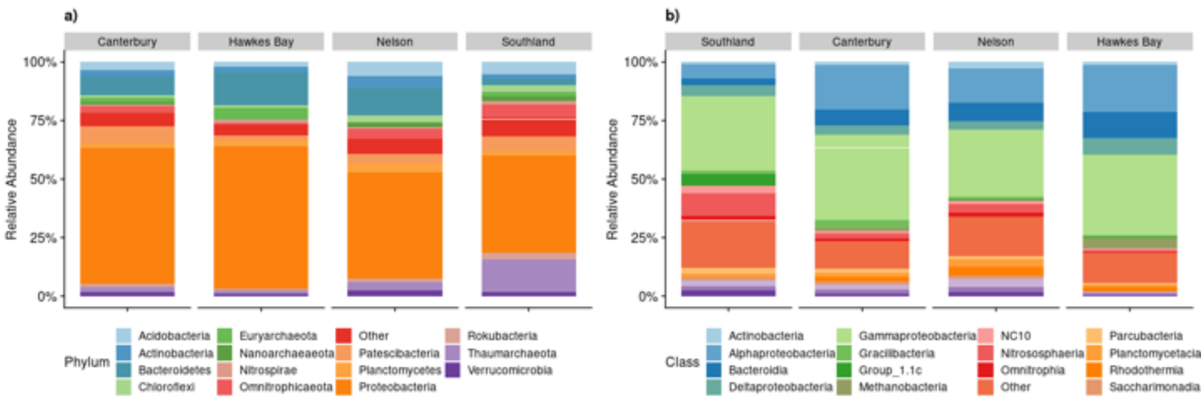

Figure 1 Example of the relative abundance of bacteria and archaea in different regions studied. a) represents Phyla present and b) represents Class present.

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WAIMEA PLAINS GROUNDWATER QUALITY INVESTIGATION 2021

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Aims
Elevated nitrate-N concentrations have been measured in parts of the Waimea Plains since the early 1970's, although isotopic data suggests the initial nitrate-N contamination dates back to the 1940s (Stewart et al, 2011). An intensive piggery operation is thought to be a major contributor to historic nitrate-N contamination, alongside diffuse nitrate-N inputs from horticultural and agricultural activities. The piggery closed in the late 1980's and Tasman District Council has undertaken several comprehensive synoptic investigations in the Waimea Plains to monitor nitrate-N through all four aquifer systems since. The most recent synoptic investigation was undertaken in 2021.

Method
Between October to December 2021, 137 bores/wells were sampled across the four main aquifer systems: Appleby Gravel Unconfined Aquifer (AGUA), Hope Minor Confined and Unconfined Aquifer (HU), Upper Confined Aquifer (UCA), Lower Confined Aquifer (LCA). 12 river and spring-fed streams were also sampled to measure the quality of the recharge and receiving waters.

Results
The highest nitrate-N concentrations in 2021 were found at the intersection of Bartlett Road/Ranzau Road West (31 g/m3) and along Blackbyre Road (30 g/m3-N), see Figure 1. All bores/wells sampled between these two locations exceeded the maximum acceptable value (MAV) in the Drinking Water Standards for New Zealand 2005 (Revised 2018) for nitrate-N (11.3 g/m3). The area between Bartlett Road and State Highway 60 is where the AGUA and the UCA merges together and becomes hydraulically indistinguishable. Blackbyre Road is outside of the UCA reach, however water from Bartlett Road is likely to travel towards Blackbyre Road as the flow of groundwater progresses towards the coast. As these areas are unconfined, additional inputs of nitrate-N from overlying land use activities between Bartlett Road and Blackbyre Road adds to the background nitrate-N discharging from the UCA, resulting in the elevated nitrate-N concentrations reaching well above 20 g/m3.

Groundwater north of Brightwater on both sides of the Waimea River has nitrate-N approaching or above 50% of the MAV (5.6 g/m3) in areas of overlying horticultural and agricultural activities. This suggests that a combined input from present-day activities is contributing to nitrate-N entering in the groundwater in all four aquifers. Outside of these areas, nitrate-N in the rest of the Waimea Plains groundwater was well below 50% of the MAV.

Aside from nitrate-N, the 2021 survey found the majority of the water chemistry in the Waimea Plains groundwater were well below the DWSNZ for both the health significant and aesthetic factors. River water quality (main source of recharge for the AGUA) is also of good quality, with nitrate-N concentrations averaging under 1.5 g/m3. Spring-fed streams varied in quality, and had higher nitrate-N compared with the rivers, the highest averaging 6.3 g/m3.

All pesticide residues detected by ESR in 2018 were well below the MAV in the DWSNZ (Close et al, 2019). EOCs were detected at one bore in the Waimea Plains; the effects of those EOCs are largely unknown but it is likely to be of low toxicity to humans. No glyphosate was detected in any of the selected Tasman region bores.

The 2021 water quality investigation did identify various risks to the security of the aquifers which could have health risks to public health. These include inappropriate sitting of bores/wells and bore/well heads not fully sealed which were resulting in localised contamination of Escherichia coli (E.coli). In most instances these were not intentional but more a lack of knowledge.

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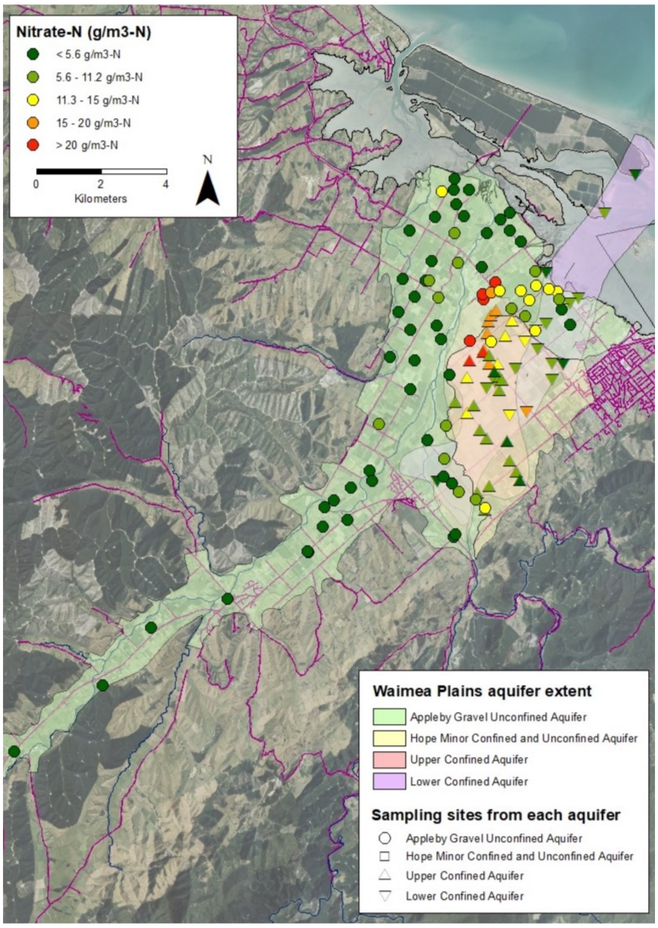

Figure 1: Distribution of nitrate-N across the Waimea Plains from 2021 investigation.

NEW ZEALAND 3D HYDROGEOLOGICAL MAP: 3D FACIES IN THE HERETAUNGA PLAINS COASTAL GROUNDWATER SYSTEM

<u>P. A White</u>[1], N. E. Santamaria[1], Udawatta[1], T Sahoo[1], M. Crundwell[1], D., Strogen[1], and S. Harper[2]
[1] GNS Science, New Zealand.
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Aims

The “National Aquifer Characterisation by System” project is a GNS Science-led collaboration to develop the first 3D hydrogeological map of New Zealand. Hydrogeological maps are resource management tools that integrate geology, aquifer properties, and groundwater quality and quantity information (Gleeson et al. 2014). These maps will characterise our geologically-complex aquifer systems at a national scale, providing digital resources in a consistent template for evaluating aquifers according to the 2.5D Hydrogeological-Unit Map (HUM) framework of White et al. (2019). The project is funded by the New Zealand Ministry of Business, Innovation and Employment Strategic Science Investment Fund (contract C05X1702) through GNS’s Groundwater Programme and is led by Stewart Cameron.

The Heretaunga Plains is a coastal groundwater system that is the water source for agriculture, industry and the population centres of Napier, Hastings and Havelock North; as such it is one of the most highly-valued (economically) groundwater system in New Zealand (White et al., 2004). Hawkes Bay Regional Council and GNS Science record 4029 wells, with 29,763 individual geological descriptions by drillers, in the Heretaunga Plains. This database provides the opportunity to understand the depositional facies of Quaternary sediments in the Heretaunga Plains which is relevant to numerous facets of the groundwater system, e.g., locations, and properties, of aquifers, aquicludes, springs and spring-fed streams.

This paper develops a facies model for the Heretaunga Plains coastal groundwater system to a depth of approximately 60 m below sea level. Modelled facies include: coastal plain (alluvial gravel), coastal plain (other sediments), estuary and beach. The paper will discuss findings relevant to the groundwater system and describe how the model assists in the understanding of Late Pleistocene-Holocene evolution of the system (i.e., geology and groundwater).

Method

Firstly, a Digital Terrain Model (DTM) was developed from LiDAR data (Figure 1A). This model became the top surface of the facies model. Identification of 3D facies was made using 'automated' assessment of geological descriptions by drillers with boolean equations (White et al., 2021). For example, 'beach' facies are identified where descriptions include any of: 'cobble', 'shingle', 'gravel', 'sand', 'shell', and 'beach'; but does not include any of: coastal plain (alluvial gravel), coastal plain (other sediments), 'wood', and 'organic'. Then, facies were converted to pseudologs and modelled in 3D (White and Reeves, 1999).

Results

Fluvial gravels are the dominant sediments in the Heretaunga Plains (Figure 1A). Estuarine facies are common south of Napier, and south of Hastings (Figure 1B); beach facies are similarly distributed (Figure 1B and 1C, respectively). West of Hastings, fluvial gravels are modelled at the ground surface (Figure 1D). Towards the coast, the facies deposition sequence can have three coastal plain (alluvial gravel) units interspersed with beach and estuary deposits. A zone of relatively low permeability in shallow sediments east of Hastings is identified by coastal plain (other sediments) that are up to approximately 50 m thick at the coast. South of Napier, the presence of relatively low-permeability shallow sediments, i.e., estuarine and coastal plain (other sediments), is probably associated with artesian conditions in the area's deeper gravel aquifers.

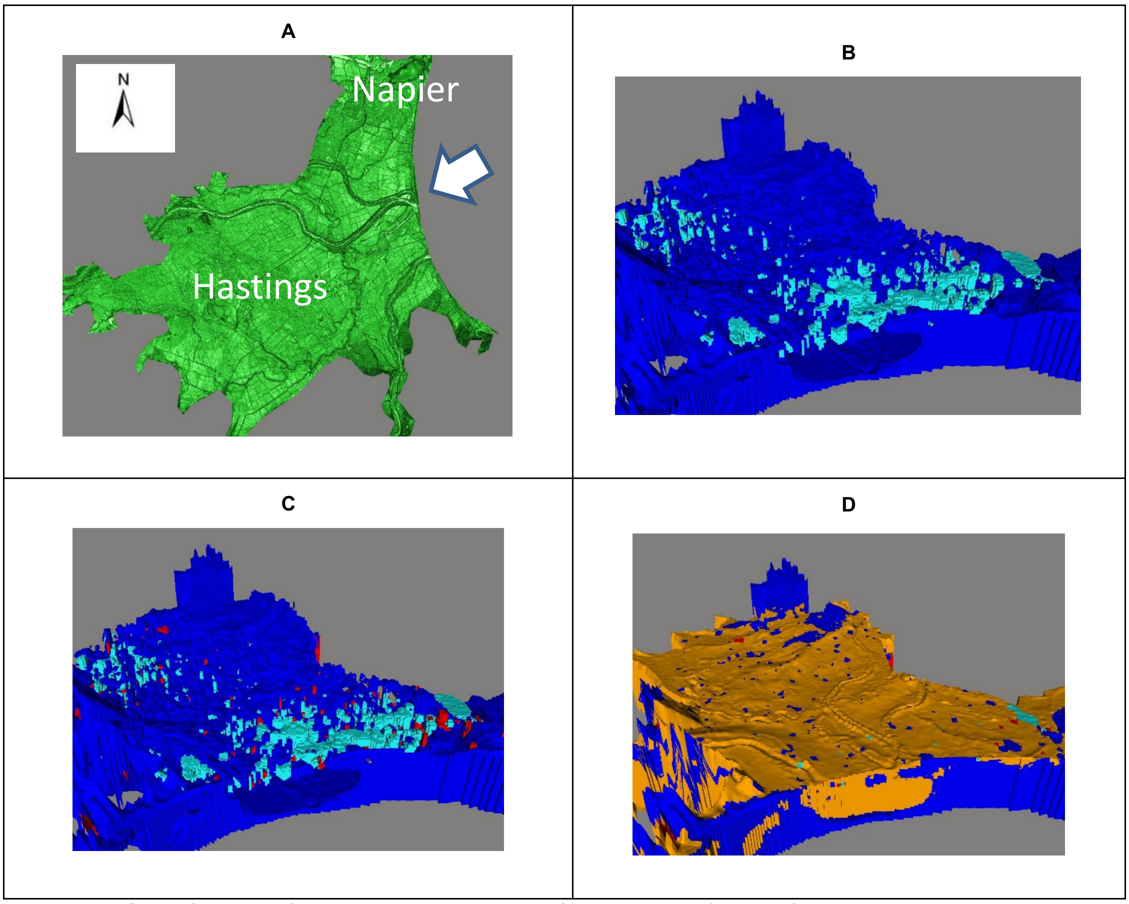

Figure 1: Some features of the Heretaunga Plains 3D facies model: A) DTM of Heretaunga Plains and arrow showing the viewing angle of other images with facies: coastal plain (alluvial gravel) - royal blue; estuary - teal; beach - red; and coastal plain (other sediments) - ochre.

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BUILDING NEW ZEALAND'S 3D AQUIFER MAP: FACIES MAPPED AT THE NATIONAL SCALE FOR COASTAL SYSTEMS

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[1] GNS Science, New Zealand

Aims

The "National Aquifer Characterisation by System" project is a GNS Science-led collaboration to develop the first 3D hydrogeological map of New Zealand. Hydrogeological maps are resource management tools that integrate geology, aquifer properties, and groundwater quality and quantity information (Gleeson et al. 2014). These maps will characterise our geologically-complex aquifer systems at a national scale, providing digital resources in a consistent template for evaluating aquifers according to the 2.5D Hydrogeological-Unit Map (HUM) framework of White et al. (2019). The project is funded by the New Zealand Ministry of Business, Innovation and Employment Strategic Science Investment Fund (contract C05X1702) through GNS's Groundwater Programme and is led by Stewart Cameron.

To develop this map, geological and depositional facies are incorporated into nationally-consistent hydrogeological-units (White et al. 2019). Facies are used as a key to move between local and national scale, which is reflected in the datasets through refinement of units, themselves qualified through attributes. Potential attributes may include hydraulic properties, unit thickness and or groundwater chemistry data. The mapping approach includes consultation with regional experts and water managers to ensure the produced maps are fit-for purpose. The work 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 of the coastal systems, which will be released as a public dataset.

Method

Published hydrogeological units (HUM) were 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 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 extent based on existing geological information and expert knowledge. Where geological units comprised multiple depositional environments over a large time period, secondary facies were included.

Rationale for HUM modifications and references, as well as developed facies mapping rules were recorded as part of the mapping process within a national mapping guideline document which will be made available upon completion of the project.

Results to date*

Modifications to the HUM units included: remapping of the North Island Oligocene and Miocene units to better represent the tectonic setting; remapping of the Quaternary deposits to incorporate local conditions in the Wanganui-Taranaki Basin (three new units created, in an approach consistent with mapping of similar units in the South Island); revision of units associated with the Taupo Volcanic Zone to reflect its evolution, the ancestral Waikato River channel and associated graben features, as well as minor corrections.

In total, 20 surface facies and 18 subsurface facies were developed (7 facies overlapped between surface and subsurface) and associated with each corresponding hydrogeological unit. For instance, the “Clastic Fluvial/ Coastal Plain” facies was mapped through 22 units (Figure 1). Example of applications of the new facies classification at the national scale will 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.

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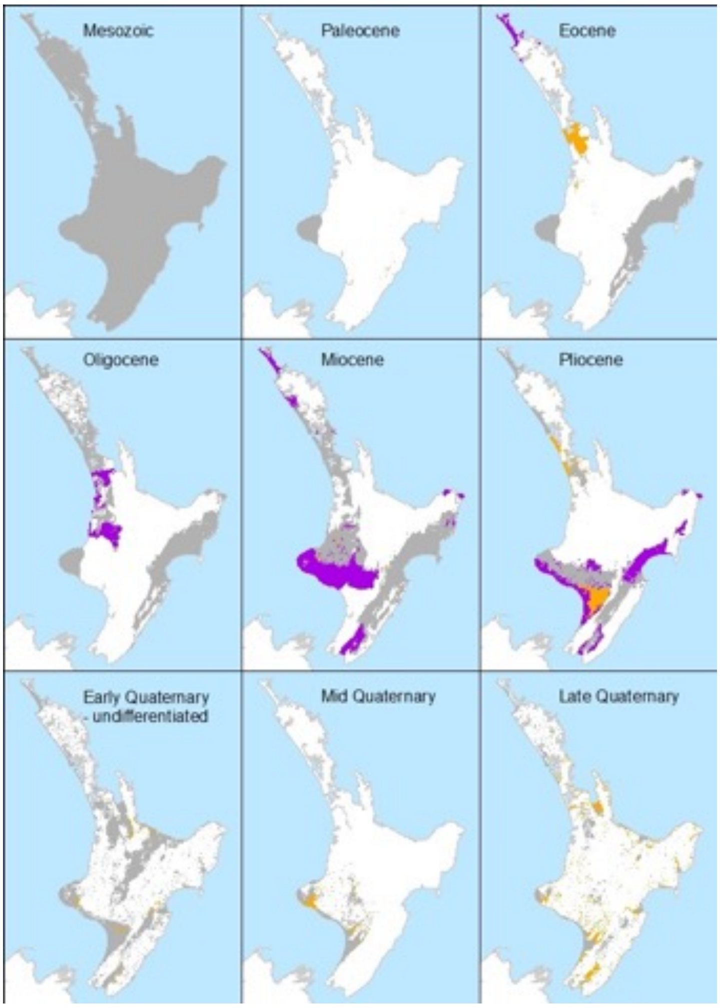

Figure 1: Spatial distribution of the “Clastic – Fluvial/Coastal Plain” (orange) and the “Clastic – Shallow Marine” (purple) facies within HUM units (coloured areas), grouped by geological era as of August 2022. On each panel, the grey areas show the extent of the HUM units, a combination of other mapped facies and unmapped facies. Note that some era comprises multiple HUM units.

MODELLING THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON AUCKLAND'S WATER RESOURCES

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Aims

Watercare Services Ltd (Watercare) is responsible for supplying high quality drinking water to more than 1.7 million people with more than 400 million litres supplied every day. Following Auckland's 2019/2020 drought, the security of the city's water supply both today and into the future has been brought into sharp focus.

Tonkin & Taylor Ltd was engaged by Watercare to investigate the impacts of climate change on Auckland's metropolitan water supply. This included the creation of hydrological datasets for a range of climate change scenarios. The overall project aim was to enable their source allocation model to simulate future climate scenarios and thus to assess the yield of Auckland's metropolitan water supply system under a range of possible future climates. The outcomes of this work will be used to inform Watercare's long term strategic planning to ensure security of supply to Auckland under a changing and uncertain climate.

Method

Over the past twenty years Watercare has used an Integrated Source Management Model (ISMM) to assist operational and planning decisions. For example, it is used to help identify when new water sources may be needed. One of the functions of the model is to determine the current system yield. Climate change is expected to impact the pattern and reliability of precipitation as well as to increase potential evapotranspiration (PET). ISMM has recently been updated to consider multiple potential climate futures and assess how the system yield might be expected to change in the future.

In alignment with Watercare's 2019 Climate Change Strategy, the analysis presented here considered two time horizons (2040 and 2090) and two Representative Concentration Pathways (RCP 4.5 and 8.5). Six Global Climate Models (GCMs) (selected for dynamical downscaling based on past performance and model diversity) have been used to simulate each combination of time horizon and RCP, resulting in a total of 24 modelled future scenarios.

To model the impacts of projected changes in rainfall, a version of the "delta method" has been employed. This involves calculating the changes (or "deltas") in the downscaled GCM projections (compared to their respective baselines), imparting them onto the historical baseline (observed past), and then using the perturbed series as inputs. This approach seeks to preserve the natural variability of the long-term (168-year) historical rainfall record and allows for the direct estimation of impacts (i.e. avoiding assessing changes in relative terms). In this application, the "deltas" have been calculated based on fitted gamma distributions and their two-parameter descriptions (i.e. the shape, α, and rate, β). This particular method (of matching series based on assumed distribution functions) is sometimes referred to as "Distribution Mapping". It allows for the adjustment of both the mean and variance of a series and, furthermore, preserves the extremes (Themeßl et al. 2012).

After the deltas were applied, a stochastic weather generator was used to extend the rainfall datasets for each scenario. Corresponding PET datasets were then calculated as annually repeating functions based on the downscaled GCM predictions.

The impacts on Auckland's water supply have then been modelled and quantified by estimating the yield of the system under the historical baseline climate and then each future climate scenario. Yield, as it is discussed here, represents the annual average daily demand that can reliably be provided by a water supply system, while meeting the required security of supply standard. Preliminary conjunctive-use yields have been estimated using the ISMM model to consider the performance of the integrated system. This has been done for two supply system configurations, one approximating the current system configuration (hereby referred to as the '2021/2022' system) and the other representing a future configuration accounting for anticipated resource consent changes and infrastructure upgrades.

Yields are presented here in mega litres per day (ML/d) and defined in relation to Watercare's current drought security standard, that being:

"The metropolitan water supply will be operated to a 1-in-100-year event with a 15% residual storage at the end of the drought event." (Watercare 2021)

Results

Preliminary yield modelling suggests that, at or around Watercare's drought level of service, the conjunctive system yield by 2040 is likely to reduce for both RCPs and all GCM scenarios considered:

- For the 2021/2022 system configuration, modelling indicates this change could range from -1 ML/d to −57 ML/d (or -0.2% to −11%), with a mean decrease of 32 ML/d.
- For the future system configuration, the change could range from +3 ML/d to −60 ML/d (or <1% to −10%), with a mean decrease of 30 ML/d.

By 2090, the conjunctive system yield is likely to reduce for both RCPs and all but one of the GCM scenarios considered:

- For the 2021/2022 system configuration, modelling indicates this change could range from +9 ML/d to −69 ML/d (or +2% to -13%), with a mean decrease of 38 ML/d.
- For the future system configuration, the change could range from +6 ML/d to −68 ML/d (or +1% to -11%), with a mean decrease of 38 ML/d.

Figure 1 presents a summary of the changes outlined above but drilling into both time horizons and emissions scenarios. Note that ±5% has been added to the conjunctive-use yield results to represent the uncertainty associated with data and model inaccuracy. This aligns with Watercare's adopted methodology for assessing headroom.

To put these results into context, an average reduction in yield of 32 ML/d by 2040 (and 38 ML/d by 2090) would be analogous to losing much of Cosseys reservoir in the Hunua Ranges – this being the third largest reservoir in the system with a current baseline yield estimate of 44 ML/d. Furthermore, the maximum reduction in yield could of 69 ML/d by 2090 would be equivalent to losing four of the five reservoirs in the Waitakere Ranges – these being the Waitakere, Upper Nihotupu, Upper Huia, and Lower Huia reservoirs which have a combined baseline yield of 68 ML/d.

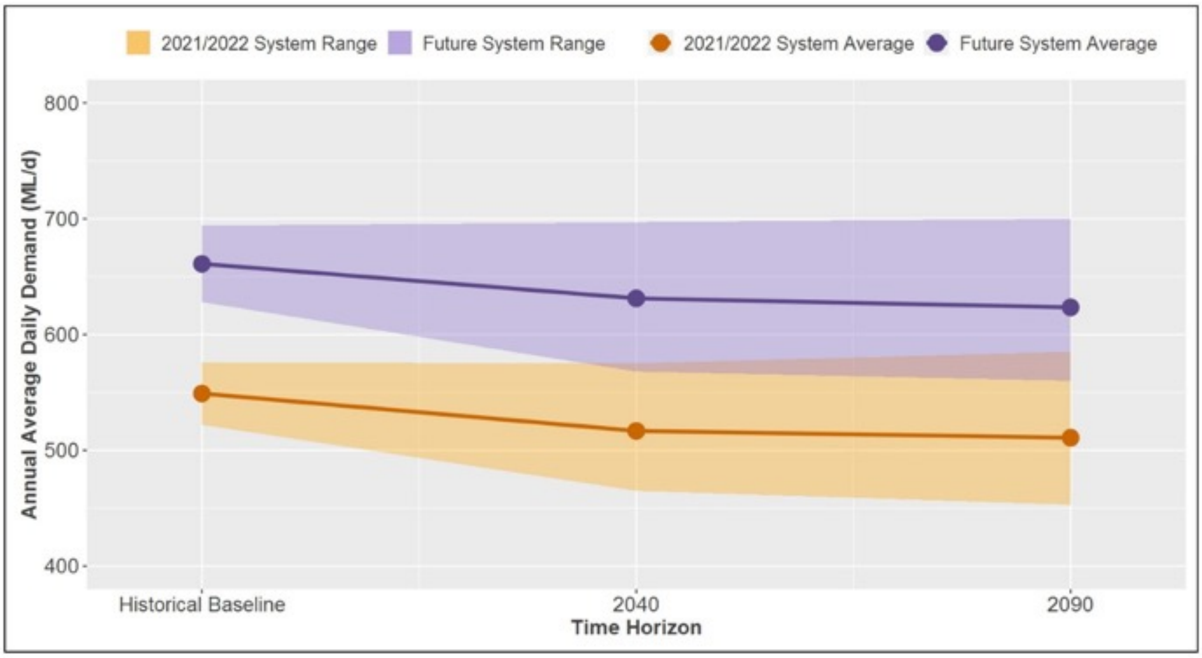

Figure 1: Conjunctive-use yield estimates under all climate scenarios for two system configurations at Watercare's drought level of service

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USING PRINCIPAL COMPONENT ANALYSIS AND HIERARCHICHAL CLUSTER ANALYSIS TO EXPLORE GROUNDWATER QUALITY DATA SETS

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Aims
Environment Canterbury undertakes groundwater quality investigations, often to gain an increased understanding of areas where we lack data. We often measure more than 30 water quality variables at multiple bores and it can be difficult to describe the relationship between these variables for such a large dataset. A technique to help understand large water quality data sets is to simplify the data using dimensionality reduction (Daughney and Reeves, 2005; Smith, 2002). It is benefical to do this because visualising and making sense of a 30 dimension graph is not practical. To help understand large data sets of groundwater chemistry in areas that we have investigated, we have used Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA).

Method
We sampled 47 wells in winter and 40 wells in summer in the West Melton area west of Christchurch. We selected 13 water quality variables for PCA and HCA analysis that can be used to comprehensively describe the groundwater source, age and aquifer condition.

PCA reduces the dimensionality by selecting the variables in the dataset that have the most information (in this case the most variance) and creates new variables called principle components (Guggenmos et al., 2011). The first principle component explains the largest covariance between water quality variables, which gives an indication of water quality type occurence. The second component explains a lesser amount of covariance between variables and so forth.

HCA allows groundwater types to be grouped together based on a number of selected variables such as physical, chemical and biological controls on groundwater quality (Donath et al., 2015; Raiber et al., 2012). The results of HCA are often easier to interpret than other methods that are limited by the number of variables that can be clearly presented. The relationship between water quality at each bore is identifiable on a dendrogram based on similarity.

Results
In West Melton, HCA described three groundwater types (Figure 1). The first, which made up the majority of the samples, has low ion concentrations and represents water from the Waimakariri River. The second cluster of samples is from shallower wells that are more distant from the Waimakariri River and have higher concentrations of chloride and nitrate nitrogen from rainfall recharge and soil percolation. The third cluster's water chemistry has been altered by more intensive land uses and generally had the highest concentrations of metals and nitrate nitrogen.

PCA identified two principal components that describe the majority of the variation between groundwater samples (Figure 2). Principal component one seems to be describing the age of the water, with ions we expect to see from river recharge, rainfall recharge and shallow groundwater lumped together. The water quality parameters that have a negative loading on principal component one (iron, manganese, dissolved reactive phosphorus and silica) represent older groundwater. Iron and manganese are from anoxic groundwater that indicates slow groundwater movement and dissolved reactive phosphorus and silica have higher concentrations in deeper groundwater (water-rock interaction).

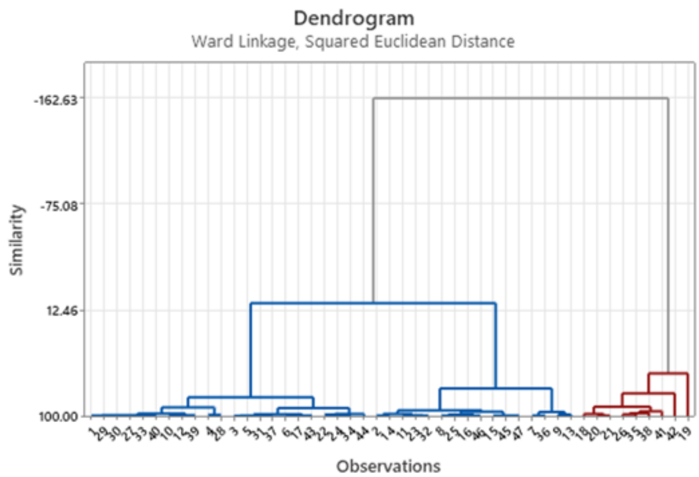

Figure 1: Dendrogram created using HCA of West Melton wells based on their water quality similarity. Observations each represent a different well and associated water quality variables.

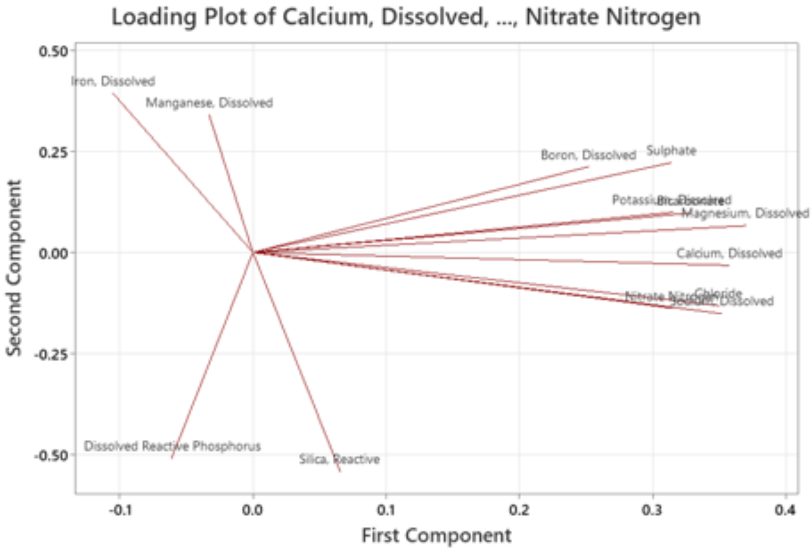

Figure 2: Loading plot created using PCA of water quality varibles in West Melton and the principal components that describe water chemistry types.

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VIABILITY OF CONSENTS UNDER CLIMATE SCENARIOS USING HYDRODESK

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Aims

HydroDesk is a web-based interface developed by NIWA-GNS Science and Manaaki Whenua Landcare Research, that makes research carried out in the New Zealand Water Model (NZWaM 2018) project available. HydroDesk enables users to run both uncalibrated and calibrated hydrological models across New Zealand. To demonstrate the usefulness of HydroDesk, this paper explores consent viability under different climate scenarios.

Method

In this paper, HydroDesk is used to model groundwater recharge and long-term water table depth in the Edendale catchment using river environment classification (REC2) (Shankar 2019) under various climate scenarios. Groundwater recharge is generated using an uncalibrated surface water model TopNet (Clark et al, 2008) set up to assess state of water resources in New Zealand (Griffiths et al., 2021). Water table depth is generated from groundwater recharge using the steady state Equilibrium Water Table model (Westerhoff 2018). The viability of some chosen consented water extractions that depend on a certain minimum groundwater recharge, or a maximum water table depth, in the Edendale catchment are examined under these various climate conditions.

Results
Scenario analysis is provided for nzsegment ID 15306430 near Mataura township (Figure 1).

Figure 1 reach ID 15306430 near Mataura

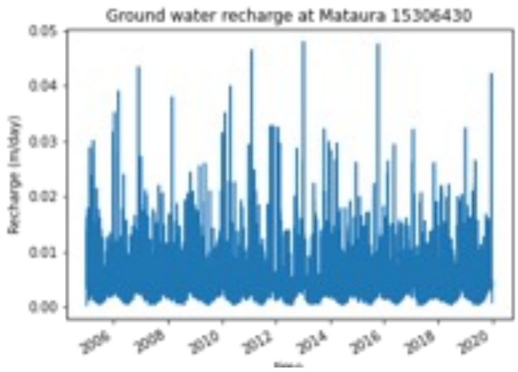

Figure 2: Watershed scale ground water total daily recharge timeseries near modelled by Topnet for watershed 15306430

Analysis of the ground water recharge time series for watershed 15306430 over the 15-year period 2005 to 2020 as calculated by TopNet is shown in Figure 2.

Dry and wet years are determined based on annual climate analysis, with 2017 found to be the driest year, and 2006 the wettest. The total daily recharge can be seen in Figure 3.

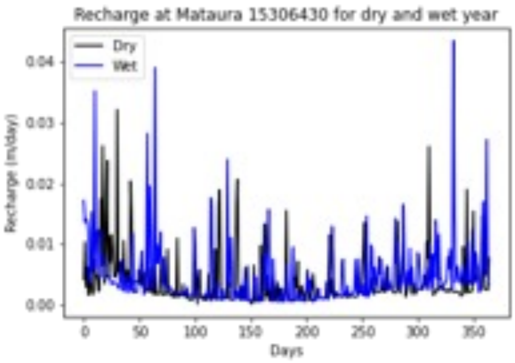

Figure 3: Watershed scale ground water total daily recharge for watershed 15306430 for the wettest and driest years

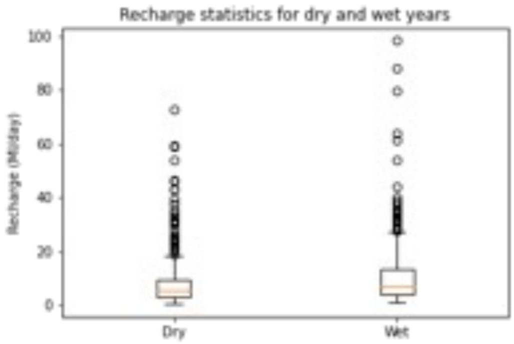

Figure 4: Ground water total recharge statistics for the two extreme years

Statistics (minimum, lower quartile, median, upper quartile, and maximum) can be calculated for ground water recharge for the two years in question, as seen in Figure 4.

Reliability of groundwater resource viability in the dry year as compared to the wet year for consented activity can assessed based on these statistics.

The steady-state water table depth will be calculated for the two extreme years using the Equilibrium Water Table model (Westerhoff 2018) driven with Topnet recharge output, and a viability study of the chosen consented activity undertaken.

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STRUCTURAL CONTROLS ON GROUNDWATER RECHARGE FROM BRAIDED RIVERS

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Aims

To understand the structural controls on leakage from braided rivers and develop a conceptual model of how they function in the susbsurface. The work is part of a larger research programme to understand how river management may be affecting the river-aquifer water balance.

Method

We have established instrumentation and carried out field campaigns in the main losing reaches of three rivers, the Selwyn, Wairau, and Ngaruroro. Surface water-groundwater interaction studies require a multi-method approach. The methods applied to our study rivers are geomorphological (lidar, bathymetry), geological (coring, logging, grainsize analysis), geophysical (resistivity, NMR), thermal (fibre optic sensing, temperature time series), isotopic (radon), and hydrological (loss gaugings, flow and pressure time series). In addition, some hypothesis testing has been carried out using Hydrus 2D.

Results

Subsurface saturation in all three of our study rivers is associated with gravels of the contemporary braidplain. Due to recent reworking, these gravels have fewer fines and are less compacted compared to the adjacent gravels. This enables an aquifer to form within these gravels, with shallow groundwater flow subparallel to the dominant river flow direction. This alluvial aquifer, which we are calling the 'braidplain aquifer' provides a storage reservoir for hyporheic exchange.

Exchange between the regional aquifer and river is mediated by the braidplain aquifer (there is no direct exchange of water between the river and regional aquifer). The implication of this is that water exchange (e.g. as formulated by Brunner et al. 2009) occurs at two scales, at the river-braidplain aquifer interface, and at the braidplain aquifer-regional aquifer interface. In a case where the braidplain aquifer is perched above the regional aquifer, flow losses are regulated by vertical hydraulic conductivity in the underlying sediments, and the rate of loss to the regional aquifer is fairly steady throughout the year (Di Ciacca et al. 2022). In a case where the braidplain aquifer is hydraulically connected to the regional aquifer, our results suggest that the exchange is controlled by horizontal conductivity of the sediments on the margins of the braidplain, vertical conductivity of the underlying sediments, and the hydraulic gradient. As such, flow losses can be highly variable throughout the year and appear to form a power-law relationship with flow (Woehling et al. 2018).

The specific controls on vertical flow beneath the braidplain aquifer are different in each of the case studies. In the Selwyn River, the base of the braidplain aquifer is marked by a transition from postglacial to glacial outwash gravels. In the Wairau, there is a similar transition, although the gravels at the base of the braidplain aquifer are thought to be postglacial fans extending south from the Richmond Range. In both cases the basal gravels have a matrix with a significantly higher silt and clay content than the braidplain aquifer. In the Ngaruroro River, the structural control appears to be gravel stratification rather than a clear change in lithology. In the vicinity of Glenside, exchange between the braidplain and regional aquifers appears to be limited by the presence of a paleosol, which is thought to have formed prior to the 1867 flood, with the river having since changed its course.

Current work is focussed on obtaining vertical hydraulic flow estimates for sediments beneath the braidplain aquifer using temperature data and radon sampling.

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AN IMPROVED GROUNDWATER REDOX MODEL FOR NEW ZEALAND

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Aims

National predictions of groundwater redox status were presented by Wilson et al. (2020). One of the drawbacks of that model was its use of ground surface as a reference point for the predictions rather than the water table. Our aim in this work is to create a national water table to use as a reference level so that redox status predictions can be made at a specified depth below the water table. In doing so we also aim to improve the accuracy of the predictions, particularly at the regional scale.

Method

Redox assignment of regional council sample data was undertaken in a manner similar to that of McMahon and Chapelle (2008). The same initial geospatial parameter datasets were used as for those of Close et al. (2018) and Wilson et al. (2020) with some minor changes. Soil data were updated to the current s-map database, and we removed the binning previously used on continuous variables, opting for raw values instead. Also, two new parameters were added; 'artificial drainage (Manderson, 2018)', and natural soil bypass (Pearson & Rissman, 2021).

A workflow was established in R, consisting of the following steps:

- Identify and remove correlated parameters from a PCA-derived corelation matrix
- Generate positional eigenvalues from Easting and Northing using PCA
- Predict static water levels using a random forest regressor and use the results to estimate water sample depth. Eliminate parameters which do not significantly contribute to model performance.
- Balancing the observations data using Smote-NC (to remove data bias towards oxic conditions)
- Train a conditional inference random forest model to predict groundwater redox status using five-fold cross validation. Eliminate parameters which do not significantly contribute to model performance.

The trained groundwater redox model could then be applied nationally using an optimal parameter set which is computationally manageable. One of the key innovations is the use of eigenvalues derived from coordinates to represent spatial relationships in the data. This involves a simple dimensionality reduction of the spatial coordinates using PCA, to generate one variable to represent a sample's position in 2D space.

Results

The only parameter removed from the initial list was artificial drainage, which was found to be highly correlated to soil drainage. Static water levels were predicted with an r2 of 0.52 using five parameters: positional eigenvalues, elevation, soil drainage, PET, and rainfall.

The trained groundwater redox model performance was excellent, with an out of bag error of accuracy=0.78, kappa=0.67. The confusion matrix gave accuracy=0.875, kappa=0.81 when applied to the whole dataset. This is a great improvement of the previous model (accuracy=0.81, kappa=0.71), mainly due to the inclusion of positional eigenvalues. The influential parameters were found to be positional eigenvalues, soil drainage, river Fre3, sample depth, subrock geology, soil class, and elevation.

While the model performs well at a national level, the water level and redox models are trained to reach a global optimum solution, which does not provide for accurate predictions in some regions. This is currently being addressed by the application of a clustering algorithm to separate the country into groups with similar substrate characteristics so that regions with less observation data can be predicted more accurately.

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MODEL-BASED HYPOTHESES TESTING FOR STRUCTURAL CONTROLS OF BRAIDED RIVER WATER EXCHANGE: THE WAIRAU RIVER

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[2] Lincoln Agritech Ltd, New Zealand

Aims
New Zealand has many braided rivers, which play an important part in the country's hydrological cycle. These rivers typically interact with the aquifer systems below, exchanging water along their paths. Unfortunately, there are still many open questions about the exact nature of these interactions. We test different hypotheses about hydrogeological structural controls (see Brunner et al. 2009, for example) of braided river – groundwater exchange to evaluate their plausibility under the scrutiny of measurement data from an extensive study site on the Wairau Plains. This aims at identifying the most likely hypothesis on structural control of braided river exchange that is commensurable with both our conceptual understanding and with field data.

Method
The study area representing a short reach of the Wairau River and underlying Wairau Plain aquifer near Blenheim on the South Island of New Zealand is reproduced in a complex, three-dimensional surface water – groundwater model using HydroGeoSphere (HGS). This area has previously been studied on a different scale (Wöhling et al. 2018). The results from this study are also used to inform the HGS model. The 3D HGS model is utilized to simulate under different real-world forcings while incorporating groundwater state measurements and various locations. These simulations are conducted with implementations of the different hypotheses of hydrogeological structures and possible exchange pathways to assess their plausibility. Furthermore, the sensitivity of these hypothesis tests to the choice and resolution of the numerical grid of the model is evaluated.

Results
The HydroGeoSphere model can simulate the overall flow patterns and groundwater head field of the study area satisfactorily. Of several tested hypotheses of hydrogeological controls, the "braidplain aquifer" seems to be the one most in agreement with field data. This hypothesis describes recent fluvial sediments directly underneath the river channel which form a distinct near-surface reservoir above the deeper regional aquifer. It interacts with both the regional groundwater as well as the river above. Further analysis revealed that the simulation results are sensitive to the numerical grid resolution which should be chosen carefully for the specific modelling problem.

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TOWARDS AN EXTENDED WAIRAU PLAINS GROUNDWATER MODEL

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Aims

To extend the existing Wairau River recharge model to the domain of the entire Wairau Plain in order to estimate the water balance components and fluxes in the entire associated groundwater system. The model will support decision making for groundwater management under changing climate conditions and changes in hydro-morphological characteristics.

Method

The existing MODFLOW model for the Wairau Aquifer and the river-groundwater interactions with the Wairau River (Wöhling et al., 2018) has been extended to the East and South to cover the domain of the entire Wairau Plains. This involved the development of a conceptual hydrogeological model based on the work by Brown (1981), Raiber et al. (2012) and Wilson (2016). A large variety of observations, ranging from groundwater heads to spring/river flows and river-groundwater exchange rates, were built into the model to allow an assessment of model performance.

The complex surface flow network of the Wairau Plains and strong contrasts of hydraulic conductivity (up to 4 orders of magnitude) between older hydrogeological units and more recent, interwoven fluvial sediments have been a major challenge in the model setup and for numerical stability. The definition of an appropriate initial groundwater head field proved to be critical too. This was particularly challenging in the Southern Hills formations, where groundwater residence times are larger and observations are sparce.

Another big unknown – already in the previously developed model - was the spatio-temporal distribution of groundwater abstraction. 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. Irrigation demand and groundwater recharge were implemented as boundary conditions in the extended MODFLOW model.

An iterative procedure with step-wise increasing complexity of parameterization was adopted to derive a plausible model structure, that is commensurable with the various observation types and that is also numerically stable.

Results

After extensive iterations for an appropriate model setup, structure, as well as initial and boundary conditions, the extended, transient MODFLOW model was pre-calibrated using the PEST software. The model performs well with respect to the plausibility of the flow field and the overall water balance. The groundwater heads, river-groundwater exchange flows and spring flows in the region of the previous MODFLOW model domain can be reproduced well by the extended MODFLOW model. Larger discrepancies were observed in the Southern Hill domain which can likely be resolved by better initial conditions and further structural improvements. The groundwater flow in these units constitutes, however, only a minor contribution to the overall water balance of the more conductive central Plains aquifers.

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MODELLING LOW FLOWS WITH MACHINE LEARNING TECHNOLOGY TO SUPPORT WATER MANAGEMENT IN THE WAIRAU VALLEY

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Aims
Hydro dams are used for hydropower generation and their operation influences downstream river flow and environmental conditions. The Branch River Hydroelectric Power Scheme (Branch HEPS) in the Wairau Valley is a 'run of river' scheme with minor buffering storage. To efficiently manage the river flows in the catchment, Marlborough District Council (MDC) wishes to better understand:

- How does the flow in the Wairau River respond to the operation of Branch HEPS?
- What is the potential impact of its operation on low flows?

Answering these questions using traditional hydrologic modelling is very challenging due to limitations of available data and information.

Method
To overcome of limitations of available data and information, we implemented a machine learning algorithm (Long-short-term memory - LSTM) and a linear regression model to assess the impact of the hydro dam on the low flow. The low flow here is defined as river flow at "Wairau at Barnetts Bank" lower than 60 m3/s from October to April next year (Note: This is different from MDC's typical definition, which is lower than 30 m3/s from December to May next year, and the increase to 60 m3/s is simply to allow enough data to construct the machine learning model).

Model inputs include flow time series from the Upper Wairau River and its tributaries, hydro dam intake and discharge, weather data, and water take data, while the model output is the low flow at a downstream assessment site "Wairau at Barnetts Bank".

The relationship between flow at site "Wairau at Barnetts Bank" yt can be modelled as: yt = f(Xt-1, Xt-2,..., Xt-M) where X is the input vectors mentioned above. When performing the modelling, a logarithm transformation was applied to the flows.

Both LSTM model and the linear regression model were run at a 3-hour time step. Models were trained and tested for separate periods, and predictions were assessed using the published procedure for quantifying predictive performance suggested by Moriasi et al (2015).

When assessing the impact of hydro dam on the low flow, a scenario was developed by removing the Branch HEPS which would return all hydro dam inputs to the Branch river and stop hydro dam discharge to the Wairau river, and then the flow at "Wairau at Barnetts Bank" would be simulated with the developed model.

Results
The machine learning algorithm (LSTM) model achieved better performance when simulating low flow at "Wairau at Barnetts Bank" than a linear regression model (Figure 1). LSTM model performance was classified as "Very good" using performance evaluation criteria (after Moriasi et al. (2015)) and therefore suitable for simulating low flow.

Compared to current operations, removing the hydro dam (Branch HEPS) will generally result in a decrease in low flow, but the change in low flow varies (i.e., increase the flow in some periods while decrease in other periods), and the change will vary according to flow (Figure 2). Although our results suggest that the hydro dam generally has a positive impact on low flow (i.e., generally increasing the low flow), optimal hydro dam operation should account for multiple uses - hydropower generation, irrigation demands, and instream ecological and community values. The LSTM model that we have developed could be further refined and used to improve analysis of complex flow variations. More results and analysis can be referred to Yang and Rajanayaka (2022).

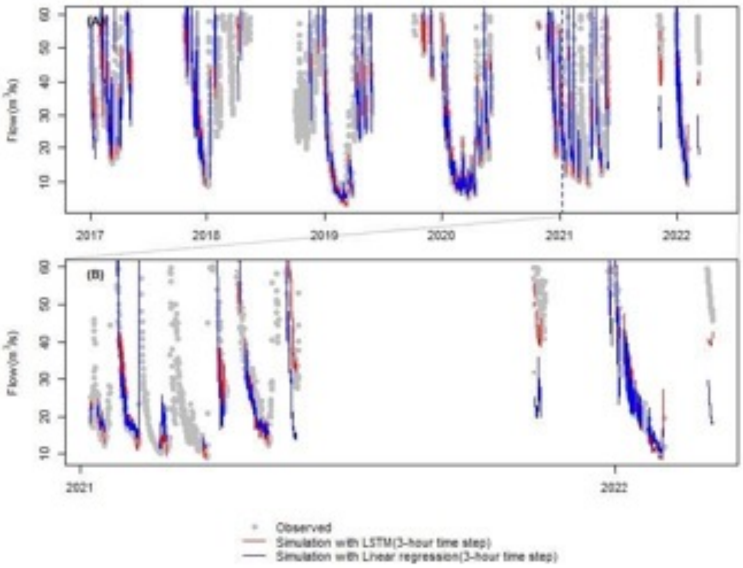

Figure 1: Comparison of model simulations for the low flows at 3-hour time step with observed flow at "Wairau at Barnetts Bank" for LSTM and linear regression model. (A) Model simulation for both training and validation periods; (B) Zoomed model simulation from 2021 to 2022. Gaps in the simulations are due to the unavailable data in the model inputs.

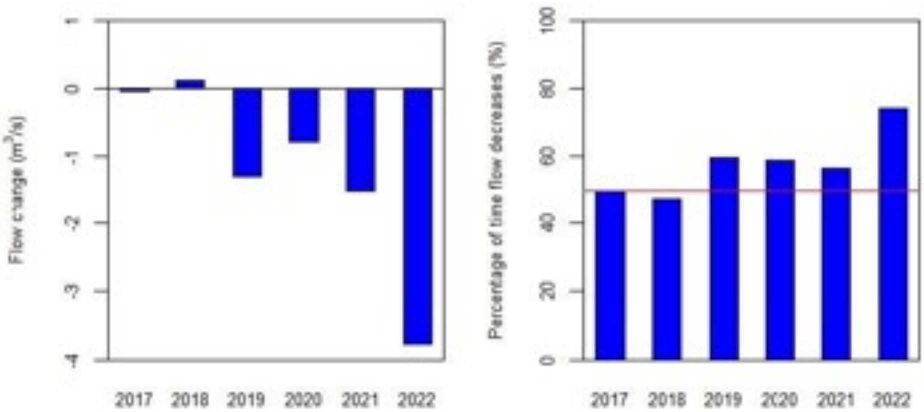

Figure 2: Flow change (low flows) summarised for each year for the scenario with no hydro dam, as a comparison to that with hydro dam. The red line in the right plot is the 50% line, indicating the threshold between low flow increase or decrease.

METAMODELLING NATURALISED GROUNDWATER LEVELS ACROSS GREATER WELLINGTON REGION

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Aims

Like many parts in the world, groundwater is an important resource for the Greater Wellington region and is a major source of water supply for municipalities, rural communities, industries and farms. Greater Wellington Regional Council (GWRC), which is responsible for managing water resources in the region, requires an understanding of naturalised groundwater levels for sustainable groundwater management and to fulfil national regulatory requirements such as state of the environment reporting and limit setting for resource use. However, as the groundwater systems have been altered by humans through water extractions, the available measured groundwater level data do not represent natural groundwater levels. Whilst GWRC has previously used physical-based modelling approaches (i.e., FEFLOW by Gyopari and McAlister 2010a, b & c, and MODFLOW by Gyopari 2014) for estimating naturalised groundwater levels, in recent years data and information hungry processes such as plan changes have encouraged GWRC to consider innovative alternatives to support faster decision-making. Our aim is to develop and test an innovative method for this purpose.

Method

Here we have developed a stepwise linear regression model that emulates the functionality of previously applied physical-based models across the region without re-calibration of physical-based models. The model inputs include local weather data (i.e., precipitation and temperature, representing the local weather system influencing local groundwater recharge), and nearby river flow (representing the upstream weather system).

Mathematically, the groundwater level at a location (L) can be simulated as a function of river flow and local weather conditions: $L_t = f(Q_t, \dots, Q_{t-i}; P_t, \dots, P_{t-j}; T_t, \dots, T_{t-k}; PET_t, \dots, PET_{t-l}; \dots)$ (1)
where t is time, and i, j, k and l are the time lags between the change in water level and the change in other variables (Q - river flow, P - precipitation, T - temperature and PET - potential evapotranspiration).

Then the stepwise linear regression model for Equation (1) can be written as:

$$L_t = \sum_{i=1}^{N_0} a_{0,i}X_{i,t} + \dots + \sum_{i=1}^{N_k} a_{k,i}X_{i,t-k} \qquad (2)$$

Where $X_{i,t}$ and $X_{i,t-k}$ are the weather or flow variable at time step t and at time step t-k (i.e., with a lag time of k time steps), respectively, and $a_{k,i}$ and b are corresponding regression coefficients. In this study the time step length is one week.

The model was trained against the available historical naturalised groundwater level time series at 47 sites that were previously developed using GWRC's physical-based models for the period of 1992 to 2007 in Wairarapa Valley and Kapiti Coast and 1992 to 2019 in Hutt Valley. Model predictions were assessed using the published procedure for quantifying predictive performance suggested by Moriasi et al (2015).

Results

Results (e.g. Figure 1) indicated that the metamodels show good simulation results in all three primary aquifers with model performances for 36 out of 47 wells classified as from "Satisfactory" to "Very Good", while the wells with poorer metamodel performance are mostly located in the middle valley or close to the sea. Thus, the complexity associated with interaction of the aquifer, sea and weather needs special attention during the future updates. The results indicate that the metamodels can adequately mimic the naturalised groundwater level dynamics as simulated by the three physical-based models.

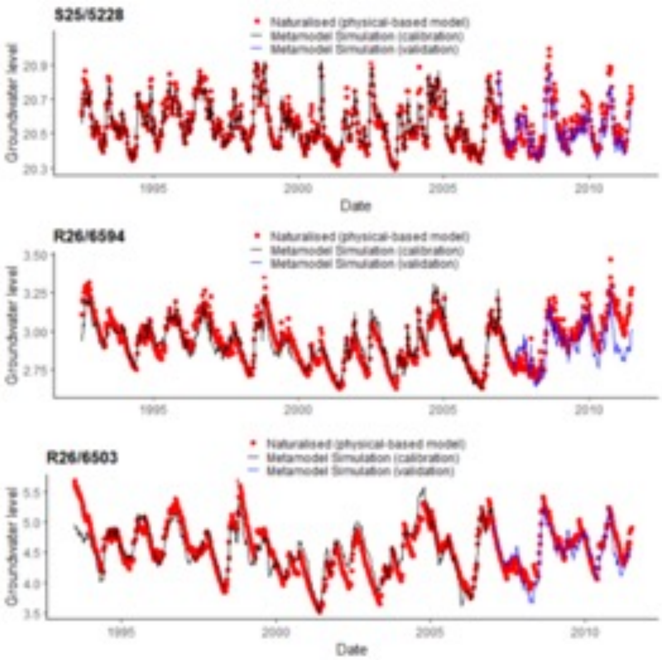

Figure 2 Comparison of naturalised groundwater levels estimated from physical-based models versus metamodels at three selected sites in Kapiti Coast

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THE EFFECTS OF SNOW ON SURFACE METEOROLOGICAL VARIABLES: SENSITIVITY TESTS

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Aims

Snow on the ground is characterized by high albedo, low thermal conductivity and low roughness. Temporal and spatial variations in snow cover and amount play an important role in the surface energy balance (Arons and Colbeck 1995; Gustafsson et al. 2001), affecting surface air temperature, winds, and precipitation. The low thermal conductivity of snow, especially, acts like an insulator for the soil preventing large air temperature changes. Heavy snow frequently occurs over New Zealand mountains due to its humid maritime climate (Owens et al., 2004). For the Southern Alps in particular, the seasonal snow accumulation in the early spring can be 3 – 4 m at some locations, with large seasonal variations (Yang et al. 2020).

This study aims to understand the effects of snow cover (snow amount and area) over the Southern Alps on the surface meteorological variables: air temperature, winds, and precipitation. The results will serve as guidance on how to prescribe the initial conditions of snow cover for regional weather and climate models over New Zealand.

Method

The numerical weather prediction model used in this study is the regional configuration of the Met Office Unified Model (UM), which uses the first Regional Atmosphere and Land (RAL) science configuration for mid-latitude regions from the Met Office (Bush et al., 2020). It was set up to cover the same geographic domain and use the same vertical layers (70 vertical level and a 40 km top) and horizontal resolution (1.5 km) as NIWA's operational NZCSM (Yang et al. 2017). The JULES snow scheme (Best et al., 2011) was used in this study.

The snow case chosen for this study occurred on 24 November 2021. In the afternoon on that day, a surface high extended over the Tasman Sea and New Zealand. Under the high pressure, the near surface winds over the Southern Alps were dominated by the local diurnal circulations. Six experiments were conducted and are described in Table 1. For CTRL there was no snow cover over the Southern Alps. For SNOW800, SNOW1200, and SNOW1600 the snow lines were set to 800, 1200, 1600 m above MSL, respectively, and the snow amount was set as a linear relationship with height. For SNOW1200S, the snow amount was set to 1/10 of that of SNOW1200. This is to make sure some of the snow accumulation for SNOW1200S completely melted over the course of the afternoon. In addition, SNOW1200M was setup using a three-layer snow model (40, 120, 340 mm, the snow layer setting in RAL) to understand the impact of the multi-layer snow model.

Table 1. Description of experiments. h is the mountain height above the mean sea-level.

Experiments	Snow model	Snow amount (kg)
CTRL	one-layer	no snow over the Southern Alps
SNOW^{800}	one-layer	(h-^{800})*^{3}/^{5} + ^{1}. For h > ^{800}. m
SNOW^{1200}	one-layer	(h-^{800})*^{3}/^{5} + ^{1}. for h > ^{1200}. m
SNOW^{1600}	one-layer	(h-^{800})*^{3}/^{5} + ^{1}. for h > ^{1600}. m
SNOW^{1200}S	one-layer	(h-^{800})*^{3}/^{50} + ^{1} for h > ^{1200}. m
SNOW^{1200}M	three-layer (^{40}, ^{120}, ^{340} mm)	the same as SNOW^{1200}

Results

For CTRL with no snow cover over the Southern Alps, land surface heating, especially in the afternoon, induced upslope airflows and local convection over the mountains, leading to widespread rainfall (Fig. 1). For experiments with snow cover over the Southern Alps, the snow significantly reduced the land surface heating resulting in much less cloud and precipitation in the mountainous areas than CTRL. Over some of the snowlines on the slopes, convection and cloud were found due to strong thermal contrast between land with snow and land with no snow.

Large differences in surface air temperature, winds, and precipitation between CTRL and the experiments with different snow cover conditions were found throughout the diurnal cycle, with the largest differences in the afternoon. At some locations (Fig. 2), these differences were up to 15 °C, 10 m/s, and 20 mm for surface air temperature, surface wind speed, hourly precipitation, respectively.

These results indicated that the initial snow conditions of a model simulation, in terms of amount and coverage, need to be well described in New Zealand weather and climate models to accurately simulate surface meteorological variables over the Southern Alps.

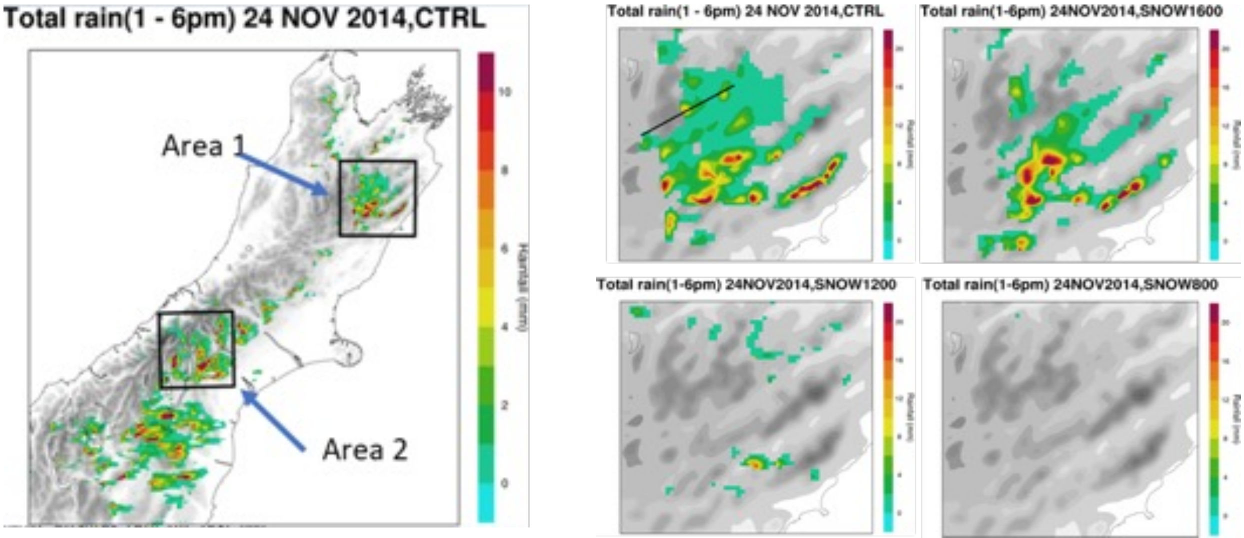

Figure 1. Simulated 6-h (1 – 6 pm) rainfall amount. The right panel is for area 1 in the left panel.

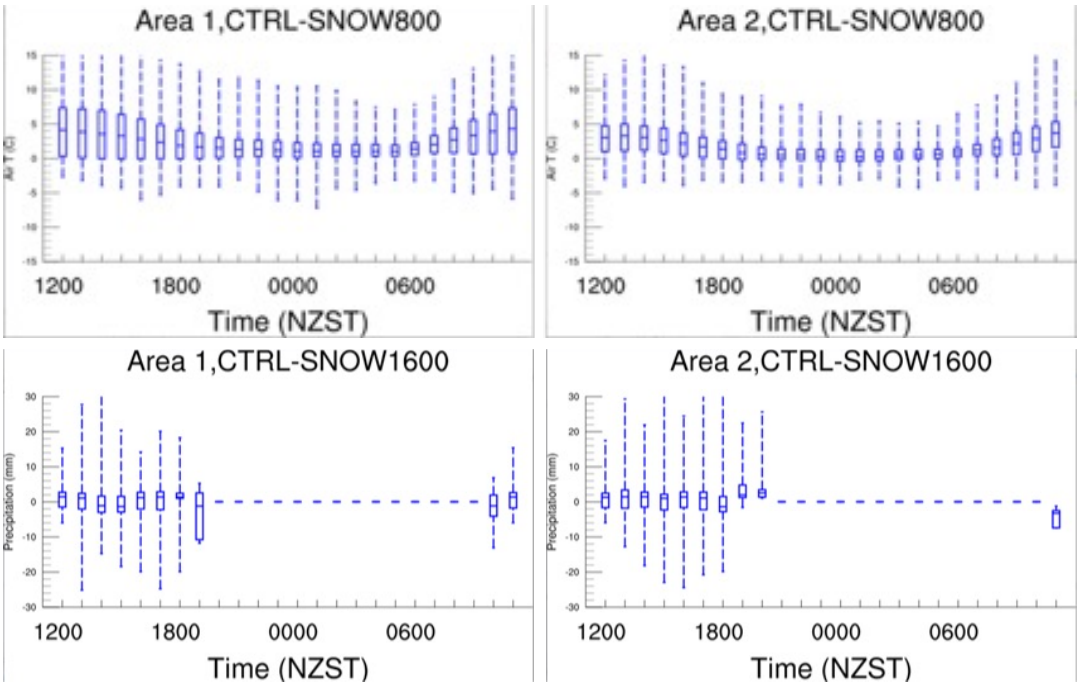

Figure 2. The diurnal cycle of difference in air temperature (upper panel) and hourly precipitation (lower panel) between CTRL and SNOW800 or SNOW1600 for Area 1 (left panel) and Area 2 (right panel) shown in Fig.1.

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GROUNDWATER – SURFACE WATER INTERACTION AT THE KAURU RIVER, NORTH OTAGO

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Aim
The Kauru River in North Otago has high in-stream values and supports the habitat of the critically endangered lowland longjaw galaaxis (Galaxias cobitinis). Studies carried out by both the Department of Conservation and the Otago Regional Council (DOC, 2004; ORC, 2003) show the galaxias inhabit high porosity, loosely packed gravels, and coarse gravels to cobbles. During periods of low flow, the fish are able to burrow down into the substrate, to occupy the hyporheic zone until flows are replenished. ORC have in recent years, identified that the drying reaches of the Kauru River appear to be receding further upstream, potentially stressing the galaxias habitat. Therefore, this study aims to understand the complex interaction between Kauru River flows and the underlying Kauru-Kakanui braidplain aquifer and investigate why the flows in the middle reaches of the Kauru River have been declining in recent years.

Methods
To help understand how stream flows affect groundwater levels two transects of piezometers were installed in March 2022 (Figure 1). This array was designed to understand the hydraulic gradient between river stage and groundwater levels, and how these change through time. Sonic drilling methods allowed for detailed geological logging and observation of the nature of the sediments that comprise the aquifer.

All the piezometers have had downhole pressure transducers installed, and ORC already monitors river flows and stage height within 20m of the newly drilled piezometers.

Differential gauging of Kauru River flow was carried out in winter of 2021, to determine flow losses/gains without interference from irrigation.

Lastly a desktop study was carried out to determine the length of the drying reaches, which can then be compared to river flows using aerial photographs.

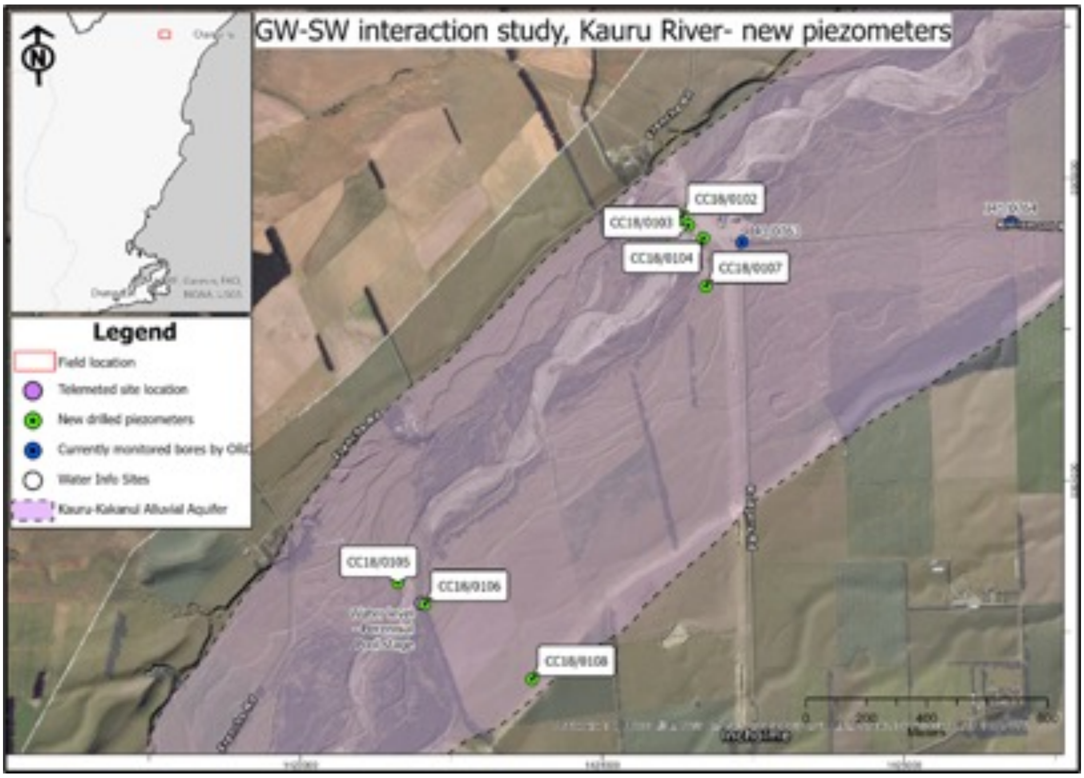

Figure 1 Locality map showing newly drilled piezometers

Results
Monitoring in this area will continue over several seasonal cycles to obtain a meaningful dataset; however, some preliminary results are listed below:

- Initial analysis of groundwater levels relative to flow show strong communication between the bores in the riverbed and close to the active channel, however the bore at the outer edge of the aquifer does not appear to respond to the comparatively low river flows measured to date. Since this data was analysed there have been a series of flood events in this catchment, which may be reflected in the distal bore (CC18/0108). However, this bore is potentially reflecting the regional water table rather than direct influence from the Kauru River.

1. The bore in the middle of the active river channel (CC18/0103) shows the largest amplitude compared to all the other bores.
2. Bores within 20m of the active river channel show a strong and relatively rapid response to river flows.
3. Results of differential flow gauging shows the section of the Kauru where the piezometers are drilled is a losing reach.
4. Observations of aerial photographs show flows beginning to disconnect during low flows, however instead of the wetted front moving up and down the valley, the river instead turns into a series of disconnected pools. This suggests that groundwater storage remains in the gravels even during very low flows instead of discharging into the river.
5. Furthermore, observations of drill core show that the permissive gravels that host groundwater flow are thin (on the order of 2-4m deep). These observations suggest that the storage volume of the gravels must be relatively small and therefore the river keeps this storage relatively replenished, even during low inflows upstream. The ramifications of this are the fish habitat is extremely vulnerable to either water abstractions during low flows or low river inflow into the catchment during drought conditions.

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WHERE'S THE BEST WATER? ALTERNATIVE WATER SUPPLY INVESTIGATIONS IN RURAL NEW ZEALAND: A CASE STUDY OF CARTERTON, NEW ZEALAND

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[1] WSP New Zealand

Aim

Ensuring there are sufficient and reliable potable water sources for both current and future demand is a growing issue that is being faced throughout New Zealand. This issue is especially prevalent in small towns that are experiencing accelerated population growth. Therefore, an increasing number of studies are being undertaken throughout New Zealand to investigate potential alternative water sources.

This paper presents a clear, robust and easy-to-use methodology to assess existing and potential new water sources, using a case study for Carterton, which is a small town situated in the Wairarapa. The approach taken in this case study can therefore be applied to other towns and districts in New Zealand, helping to identify suitable water sources efficiently and effectively.

Method
The methodology developed can be described in three key stages: data collection and quantification, multicriteria and suitability analysis, and presention of feasible options for investigation.

The first stage to investigate water supply options involved analysing the surface water and groundwater resources within the area, their connectivity, and their current allocation status. Any factors that could affect the suitability of an area to establish a new water supply and the relevant infrastructure were also identified. These factors included land use, discharges, location of current infrastructure, and hazards such as active faults and liquefaction potential. GIS processing was carried out to apply classifications to each of these factors, such as exclusion zones, buffers, and proximity weightings.

Using the information gathered from the first stage, suitability maps were then created by inputting the data and associated weightings in order to identify the most favourable areas, for both alternative surface water and groundwater options. In tandem with this process, a multi criteria analysis (MCA) process was employed to assess a range of different alternative, and current, water supply options. The software GoldSET was used to compare a range of indicators divided into four categories: environmental impact, social, economic and technical that were assigned weightings, which were determined between the client and technical teams. These were then applied to each of the short listed water source options, resulting in each of the options being ranked in terms of their overall suitabilty, and thus comparable.

Lastly, the results from the MCA were then combined with the suitability maps to present feasible options to the client. This enabled a clear direction of where further investigation into the most feasible alternative (or current) water sources could occur.

Results
Initial results from the MCA suggested that the most favourable options for the Carterton water supply were to upgrade the current supply infrastructure, establish a new groundwater supply, establish a new surface water source, or connect to a neigbouring towns water supply system (Figure 1). Further investigation into the feasibility (both technical and regulatory) of the options is currently being undertaken in order to recommend the most suitable option to implement in Carterton.

The suitability maps were used to target the areas that were identified as most suitable for establishing each of the groundwater and surface water options outlined above. It was determined that the most suitable location for a new groundwater source was to the south east of Carterton township (Figure 2), whereas for surface water it was in the Tararua ranges, where the current supply is located.

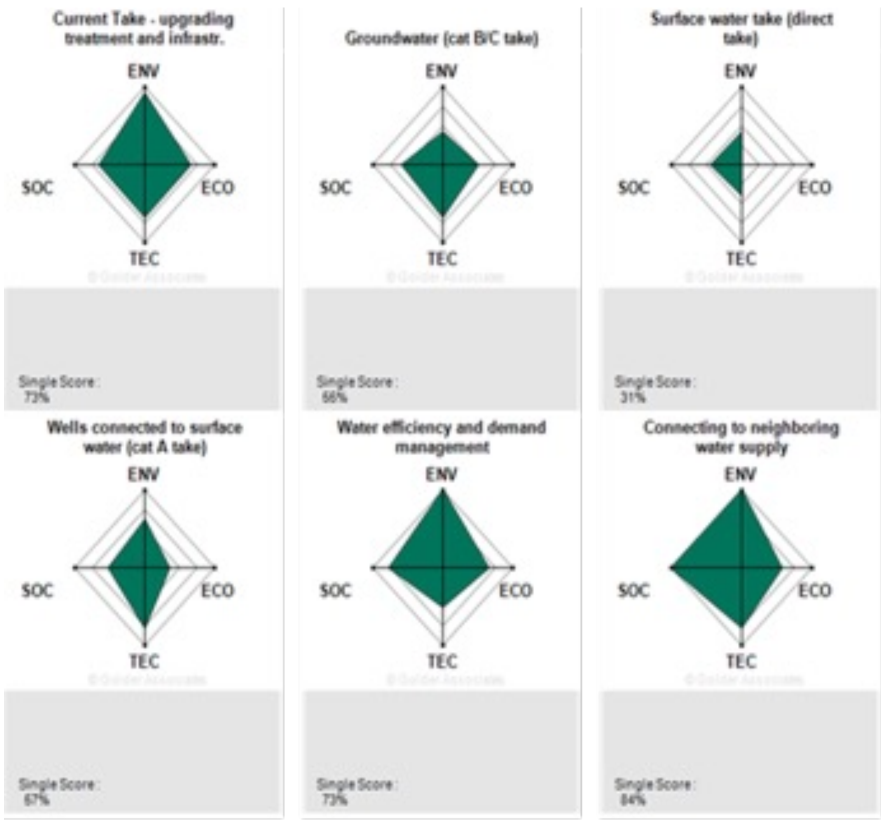

Figure 1: Preliminary MCA results for a range of alternative water source options for Carterton, New Zealand.

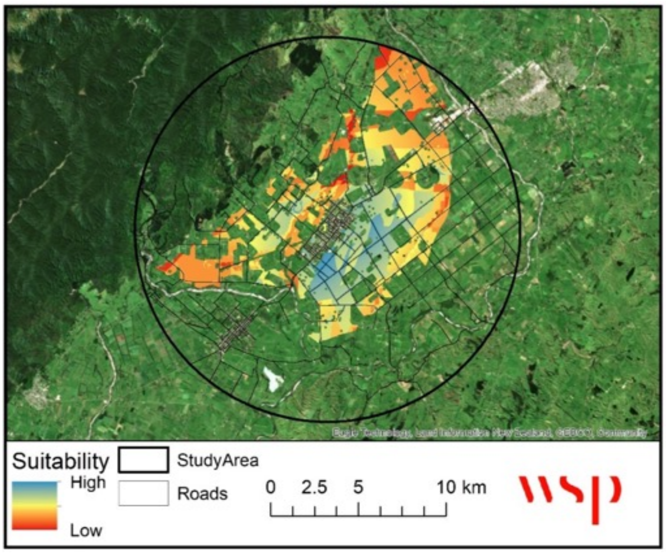

Figure 2: Suitability map indicating the most favourable areas to locate an alternative groundwater supply in Carterton, New Zealand.

ROUNDWATER CAPTURE AND PROTECTION ZONES – CAPTURING THE WATER SERVICES ACT REQUIREMENTS

Hisham Zarour[1], **Lauren Cooper**[1], **Mark Scaife**[1], **Henrietta Jackson**[1]
[1] Stantec

Introduction

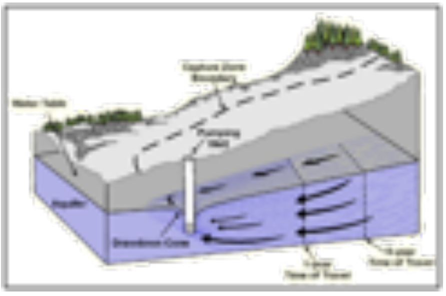

Figure 1: Idealised shape of the CZ for a well in a homogeneous isotropic unconfined aquifer; as adapted in Moreau et al. (2014) from the Ministry of Environment, British Columbia (2004).

The Water Services Act 2021 (WSA) establishes requirements that all persons and organisations that supply drinking water in Aotearoa New Zealand are to meet. The WSA states that its main purpose 'is to ensure that drinking water suppliers provide safe drinking water to consumers'. This includes providing a source water risk management framework that, together with existing regulations and policies, 'enables risks to source water to be properly identified, managed and monitored'.

Under the WSA, source water risk management plans are required to be prepared and implemented by a drinking water supplier as part of their drinking water safety plan. These plans must be submitted for review by Taumata Arowai, the water services regulator.

Identification of the source is a prerequisite to being able to perceive potential contamination risks. A groundwater take is sourced from a distinct mass of the aquifer known as capture zone (CZ), which is specific to the water supply spring or bore termed the 'abstraction point' in the WSA. A CZ extends from where the water enters the aquifer to where it is abstracted (Figure 1).

The aim of this paper is to highlight important practical hydrogeological considerations for effective CZ delineation within the framework of groundwater source water risk management planning.

Protection Zones
The commonly parabolically shaped zone of groundwater contribution, the CZ, can be divided into chunks demarked by time of travel (TOT) isochrones. Conveniently, TOT intervals are selected to correspond to the perceived threats to the water supply, e.g. one-year for virus and microbial die-off or longer lengths of time for persistent and mobile chemicals. The planar projections of selected isochrones are used to define groundwater abstraction point protection zones (PZs). Land use activities including water resource development in PZs are restricted by regulatory authorities to secure the water supplies against point and nonpoint source pollution. Commonly, a first-level protection zone (PZ1) is defined at the immediate vicinity of the abstraction point (e.g. 3–30 m buffer) to protect the water supply at the wellhead. A second-tier protection zone (PZ2) is defined by the one-year's TOT isochrone. Finally, a third-tier zone (PZ3) is defined as the full CZ (upper catchment) or by specific TOT isochrone, e.g. ten years' TOT.

Guidelines
In the 1980s, regulatory and standard-setting agencies worldwide commenced on the development of guidelines for the delineation of groundwater PZs, then commonly referred to as wellhead protection areas. In 1995, the Australian and New Zealand Environment and Conservation Council (ANZECC) suggested a zonation system to protect 'raw water for drinking water supply', recommending strict restrictions within 50 m radius around bores and within wellfields (Zone I), with no waste dumping and sentinel monitoring within 10 years residence time (Zone II). For greater residence time (Zone III), ANZECC recommended no restrictions beyond those imposed by a regional protection plan and monitoring system to provide warning of deterioration in water quality. ANZECC highlighted the value of the source. For example, some deep groundwater may have limited environmental or economic value, not requiring restrictions of the use of overlying land. They also considered the difference in the source aquifer vulnerability due to depth and confinement conditions, defining two arbitrary source aquifer vulnerability classes, high and low, corresponding to the two end members of a spectrum of aquifer types. High vulnerability aquifers are shallow (usually unconfined), highly permeable aquifers with little attenuation character. Low vulnerability aquifers are deep, usually confined systems or have properties that slow and attenuate contaminant transport.

There have been few attempts to develop guidelines for PZ delineation in New Zealand including PDP & ESR (2005), Toews & Gusyev (2013), Moreau et al. (2014), Lough et al. (2018), and Rutter & Moore (2021). Some regions like Canterbury introduced region-specific guidance (Ethridge et al., 2018). Some councils have instituted default or provisional PZs as part of their plans.

Like the rest of the world, New Zealand PZ delineation guidelines rely on common scientific basis and risk perceptions. They are useful, but they unfittingly leave important matters to the discretion of the individual practitioner, namely, ambiguities relating to how to deal with the aquifer confinement conditions and the bore screen depth. These two aspects are emphasised in nearly all the guidelines. However, the guidelines make no precise recommendations on how to deal with them.

The shapes of the CZ and PZs depend on the abstraction rate, the aquifer thickness, hydraulic conductivity, porosity, confinement, hydraulic gradients, recharge, and boundary conditions, including interconnections with surface water. These quantities are inherently uncertain. In addition, there are uncertainties relating to unavoidable simplification including decision on the dimensionality of the analysis. Importantly, the shape of the CZ is determined by the proportional magnitude of the above quantities. For example, aquifer confinement will have small influence on the shape of the CZ and PZs for a large abstraction compared to a small one. In this paper, we use numerical groundwater modelling examples to provide insights into CZ and PZ delineation considerations.

It is important to provide clear guidance on how to incorporate hydrogeological conditions like aquifer confinement and bore depth in CZ and PZ delineation guidelines. Quantitative and qualitative methods are required to be specified. There are many adaptations and practical examples of the DRASTIC system developed by Aller et al. (1985) for standardised evaluating groundwater pollution potential based on hydrogeological settings. There are also numerous examples of aquifer classification systems, e.g. the New Zealand Groundwater Atlas (White et al., 2019). An efficient CZ and PZs delineation system for Aotearoa must integrate such approaches in the prescribed methods.

The combined lack of precise delineation method guidance and conceptual and parametric uncertainties makes the estimated CZ and PZs inevitably uncertain. The estimation uncertainty increases with the length of the predictions time and, subsequently, distance from the abstraction point. As a result, the drawn PZs for deep bores and/or bores in confined aquifers could be unrealistic, unwarrantably restricting land and water resources uses.

Results

With the introduction of the WSA 2021, PZ for numerous groundwater drinking sources will require delineation throughout Aotearoa. Review of existing PZ delineation guidelines reveal that they do not adequately address important hydrogeological conditions like the aquifer confinement conditions and bore screened depth. This may result in overly relaxed or restrictive land use policies. Taumata Arowai must provide complete, practical PZ guidelines to ensure consistency on the national level.

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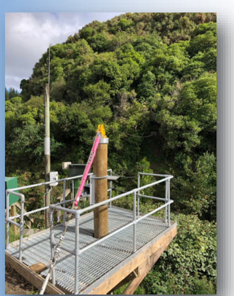

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