HIGH RESOLUTION NITRATE MONITORING - JOINING THE DOTS

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Aims

This study aims to better understand the nutrient pathways operating in the groundwater and surface waters of the lower Waimakariri-Eyre plain, particularly the high nitrate loads observed in Silverstream, a tributary of the Kaiapoi River. This work is part of the MBIE-funded Transfer Pathways Project (TPP) and is collaboration between ESR and Lincoln Agritech Ltd.

Method

Generally environmental agencies, such as Regional Councils are restricted to taking discrete samples from a site at a specific time interval. Typically, this is done annually or quarterly to determine spatial patterns or long-term and seasonal trends in water quality. Discrete sampling however may over or under estimate the concentrations involved and provide little information on what is happening to concentrations between sampling events or spatially down the reach of a river. It often overlooks inputs from extreme storm events, which are important because this is usually when the most leaching and run-off occurs. Regrettably routine water quality monitoring is generally inadequate to provide sufficient detailed data to fully determine the nutrient pathways and loads operating in a catchment (Kronvang and Bruhn, 1996).

High frequency sampling technologies can provide the fine resolution needed for catchment modelling and their use is valuable to inform the magnitude and timing of nutrient load delivery (Cameron et al, 2014).

Recent advances in portable optical UV photometers developed by TriOS, originally for the process engineering industry, have allowed continuous high resolution environmental monitoring of nitrate, nitrite and dissolved organic carbon. ESR has recently invested in this TriOS technology and Opus sensors have been deployed in the field.

Results

In this talk I will present the technical challenges and practical application of deploying these sensors to collect high resolution data in two situations;

1. Real-time nitrate stream survey – An Opus optical nitrate sensor, YSI Proplus sensor and GPS tracking were mounted on a kayak and high resolution data was collected in real-time down Silverstream. This gave a better understanding of changes in water quality throughout the catchment and highlighted low nitrate inputs from springs fed by the Waimakariri River, and high nitrate inputs from tributaries fed by tile drains (Figure 1).

2. Continuous nitrate monitoring of groundwater and surface water – an installation was established at Tram Rd, Silverstream. Automated sampling and analysis of samples from a multi-level well array and adjacent surface water was carried out using an Opus photometer, conductivity and temperature sensors and water level loggers. This provided a long-term high resolution data set from which to characterise and give a better understanding of the groundwater-surface water interaction in the Silverstream catchment (Figure 2).

3. A companion conference presentation by Lee Burbery will present the detailed results of the TPP study in Silverstream.

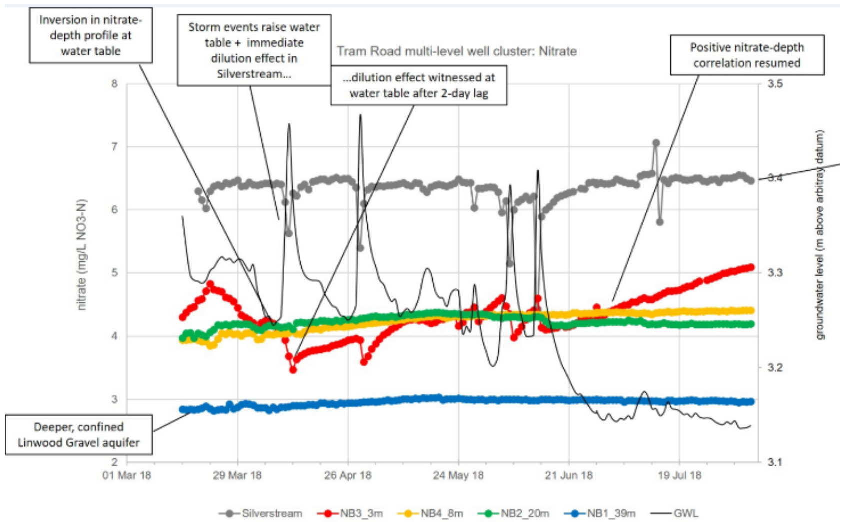

Figure 1: Phil Abraham enjoying a day out the office during ESR's real-time survey of Silverstream, Kaiapoi. Nitrate-nitrogen concentrations ranged from < 4.5 mg/L (blue dots) to > 6 mg/L (red dots). Decreased concentrations at points 1,4 and 5, and increases at points 2 and 3 correspond to inputs from alpine river sourced springs and tile fed-drains, respectively.

Figure 2: Tram Rd multi-level well installation with Opus sensor, manifold and flow cell. High-resolution time series water level and nitrate data collected from different depth wells and the surface waters of Silverstream

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DETERMINING SOURCES OF NITRATE USING NITROGEN ISOTOPES IN THE TINWALD, ASHBURTON AREA

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Near Tinwald, Ashburton there is an area approximately 3km wide and 11 km long where Nitrate concentrations in groundwater are high, commonly greater than drinking water Maximum Acceptable Valve (MAV). This area of high nitrate is often referred to as the 'Tinwald plume'. Previous investigations (Abraham and Hanson (2004), Hanson and Abraham (2010) identified several factors that may contribute to the high nitrate concentrations including leaching from cropping land upgradient of Tinwald, nitrate leaching associated with spray irrigation, and the influence of aquifer geology on potential denitrification, but could not identify which factor was the most important. Land use has traditionally been a mixture of sheep and beef and cropping, with increasing dairying over time. There are potential point sources of nitrate such as from septic tanks, historic landfills and the Tinwald Saleyards.

Aims

Ashburton District Council (ADC) and the Managed Aquifer Recharge Governance Group (MARGG) are interested in methods to remediate the Tinwald plume. Knowledge of the source or sources of high nitrates and how they may change over time is needed to target remediation. We chose to use nitrate ($\delta^{15}N$ and $\delta^{18}O$) and water molecules ($\delta^{18}O$ and ^{2}H) isotope tracer techniques to identify potential recharge and nitrate sources.

Method

We sampled 33 wells for major ions, isotopes $\delta^{15}N$ and nitrate-$\delta^{18}O$ water-$\delta^{18}O$ and ^{2}H in February and March 2018. Well depths ranged from < 30 to 75 m. Isotopes were analysed at the GNS laboratory. We compared isotope values to expected ranges for nitrate sources from fertilisers and manure/septic waste, together with other geochemistry to identity potential sources.

Results

Nitrate concentrations range from < 1 to 26 mg/L as nitrate nitrogen, with the highest concentrations occurring in areas of dominant cropping land use, and the lowest in wells closer to the Ashburton River which provides a source of dilution (Figure 1). Animal or septic tank waste is clearly identified in four samples with $\delta^{15}N$ in excess of 15 ‰ (Figure 2). Two of these samples were located downgradient of the old Tinwald Saleyards where effluent and stormwater discharges may be a source of nitrate in groundwater. In these samples dissolved oxygen was also low, suggesting nitrate is potentially removed by denitrification – actual nitrate concentrations for these samples were all < ½ MAV.

Several samples had $\delta^{15}N$ below 3 ‰, typical for inorganic fertiliser (Kendall, 1998), which may suggest a cropping source. These samples were downgradient of cropping areas, mainly inland of State Highway 1.

Other samples fell in the intermediate range between 3 and 10 $\delta^{15}N$ ‰. We suspect that some sample intermediate results in the cropping-dominant areas are the result of isotopic enrichment potentially during denitrification. This is because they fall along one slope on the $\delta^{15}N$/ $\delta^{18}O$ graph suggesting a similar source, and because the very high nitrate nitrogen concentrations (> 20 mg/L at some sites) are unlikely to be sourced from soil nitrate alone. Some samples appear to indicate some mixing of different sources.

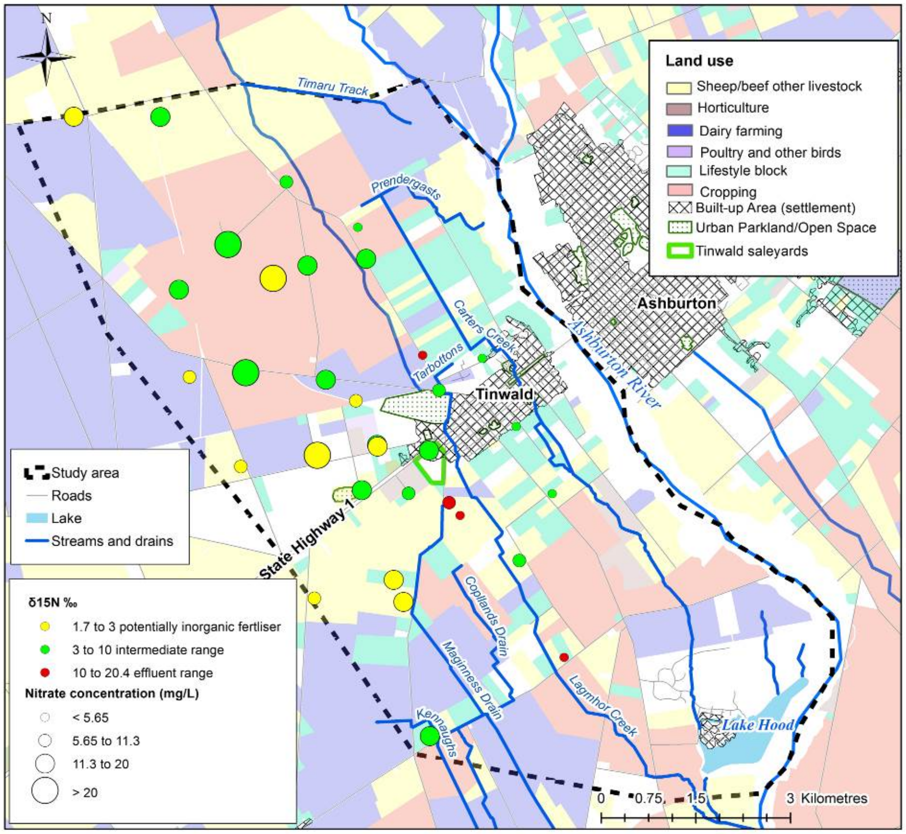

Figure 1: Map of δ15N ‰ and nitrate concentrations for samples in the Tinwald Investigation

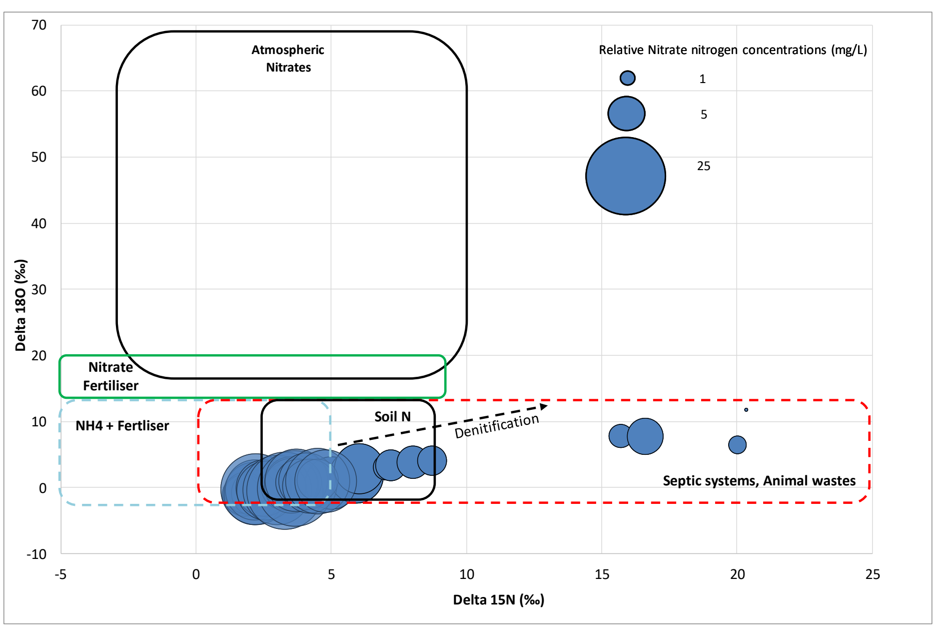

Figure 2: $\delta^{15}N$, nitrate-$\delta^{18}O$ and nitrate concentrations for samples in the Tinwald Investigation

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SPATIAL AND TEMPORAL DIFFERENCE BETWEEN RAIN RADAR AND RAIN GAUGES, IMPLICATIONS FOR CANTERBURY

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Background

Radar-derived rainfall measurements are used operationally in many countries of the world because their high spatial and temporal resolution overcomes many of the limitations of point-based rain gauge data. The Canterbury Plains is an area where rain gauge measurements are extensively used for irrigation and flood management. The excellent rain radar coverage (Figure 1) of much of the area indicates that these services could benefit from also using radar-derived measurements. One barrier to the uptake of these data is convincing evidence of the advantages of the radar-derived rainfall measurements in comparison to gauge-based measurements.

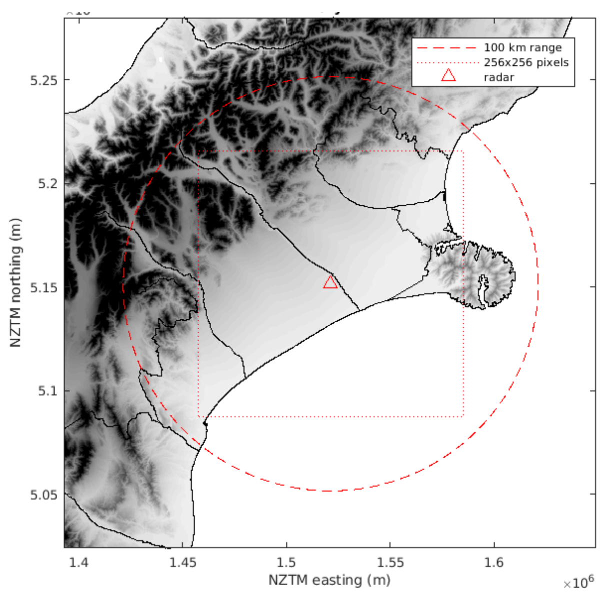

Figure 1: Rain radar location in Canterbury with respect to the Canterbury Plains. Shading is elevation.

Aims

To compare radar rainfall measurement to rain gauge measurements and discuss implications for Rainfall data users in the Canterbury Plains

Method

Four notable precipitation events that occurred in Canterbury during the 2011 to 2014 period were identified from an online media search and the NIWA Historic Weather Events Catalogue (https://hwe.niwa.co.nz/). Hourly rainfall data were obtained from the NIWA Climate Database. Hourly gauge interpolated rainfall maps were prepared from these data for the duration of each event.

For the same events, radar measurements of rainfall were aggregated to hourly values based on existing radar analysis methodology (Sutherland-Stacey et al 2017).

Validation statistics of the interpolated rain gauge data, and the radar rainfall measurements were prepared using rain gauge sites not used in the generation of the radar rainfall accumulation estimates.

Results

The high spatial detail is a distinguishing feature of the radar rainfall measurements. This is reflected in the statistics for occurrence of rainfall for the validation sites that are between rain gauges where one gauge has rain and the other does not. The interpolation system is necessarily limited in identifying where the rain/no rain boundary exists, whereas the rain radar's high resolution enables a much more precise identification of the rainfall limit. In a similar manner, the interpolation scheme is unable to estimate rainfall between two gauge sites that is greater than the rainfall that is observed at either site, whereas the radar rainfall estimates has no such limitation. This is an important feature where localised precipitation events (e.g. associated with convective storms) may not be centred over a rain gauge, and so their associated rainfall amounts may be underestimated by gauge interpolation.

These differences are important considerations when accurate rainfall magnitude and distribution are required for flood and irrigation management. The results indicate that radar-derived rainfall observations have the potential to provide improved rainfall observation services in the Canterbury region.

USING TRADITIONAL STATISTICAL TOOLS IN THE BIG DATA ERA: MANAGING GROUNDWATER LEVEL VARIATIONS IN WETLANDS

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Aims

Kāpiti Coast has several wetlands with significant ecological and cultural value in which even small changes in surface and groundwater level outside normal seasonal levels may have a deleterious effect on wetland health. The construction of major infrastructure projects like the Mackays to Peka Peka (M2PP) Expressway or abstraction of water for water supply in close proximity to sensitive wetlands involve potentially significant alterations to the near surface groundwater system. Resource consent conditions for the construction and operation of these projects require groundwater monitoring and management to avoid, remedy or mitigate changes in groundwater levels in wetlands caused by the construction and operation of the project. For the M2PP project a rigorous groundwater monitoring programme was established prior to construction commencing, with some 110 piezometers to record natural variations in groundwater levels. These were used to set alert and action levels for the majority of the piezometers (lowest recorded level minus the predicted drawdown reduced by 25% or 200mm). However, there was a limited number of measurements available for the understanding of what constitutes "normal" wetland levels.

Method

The Kāpiti Coast wetlands were formed in different ways and the water level in some of them will naturally vary more than in others. For this reason, a statistical approach was developed for calculating the drawdown and high water trigger levels for the 22 telemetered piezometers located in and around five sensitive wetlands.

Using data from telemetered piezometers monitored by the Regional Council for many years and are screened in the same shallow aquifers outside the project area, the "expected" water level was calculated for each project piezometer based on a multiple linear regression analysis for each reading. A 0.2m variation of the expected value increased by the standard error of the 80% confidence prediction interval outside the expected water level, triggers an alert for the monitoring bore (Figure 1).

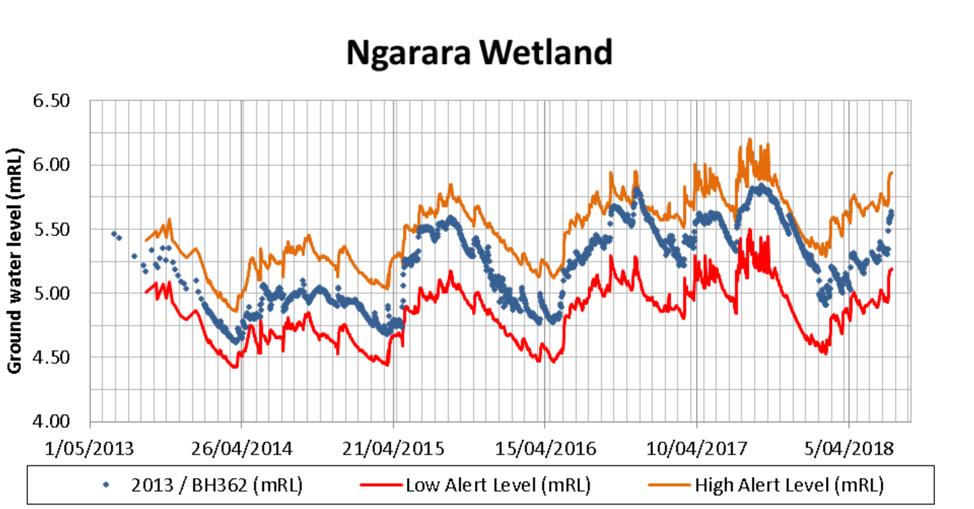

Figure 1: Groundwater levels plotted against statistically calculated trigger levels

This statistical approach was also employed to check exceedances in piezometers that were in active construction zones (earthworks within 200m) but where the works were not anticipated to influence the groundwater levels.

Results

In general, the shallow groundwater systems of the Kāpiti Coast interact rapidly and directly with climatic factors such as rain fall and evaporation as well as variation in the water levels of adjacent water bodies. The monitoring data demonstrate that the statistically calculated triggers take into consideration district-wide changes in groundwater levels and more clearly distinguish natural effects such as weather patterns (a low trigger level alert during dry summer months) from those resulting from construction activities (pumping during excavation) than triggers set as a standard difference (as illustrated in Figure 2).

a

b

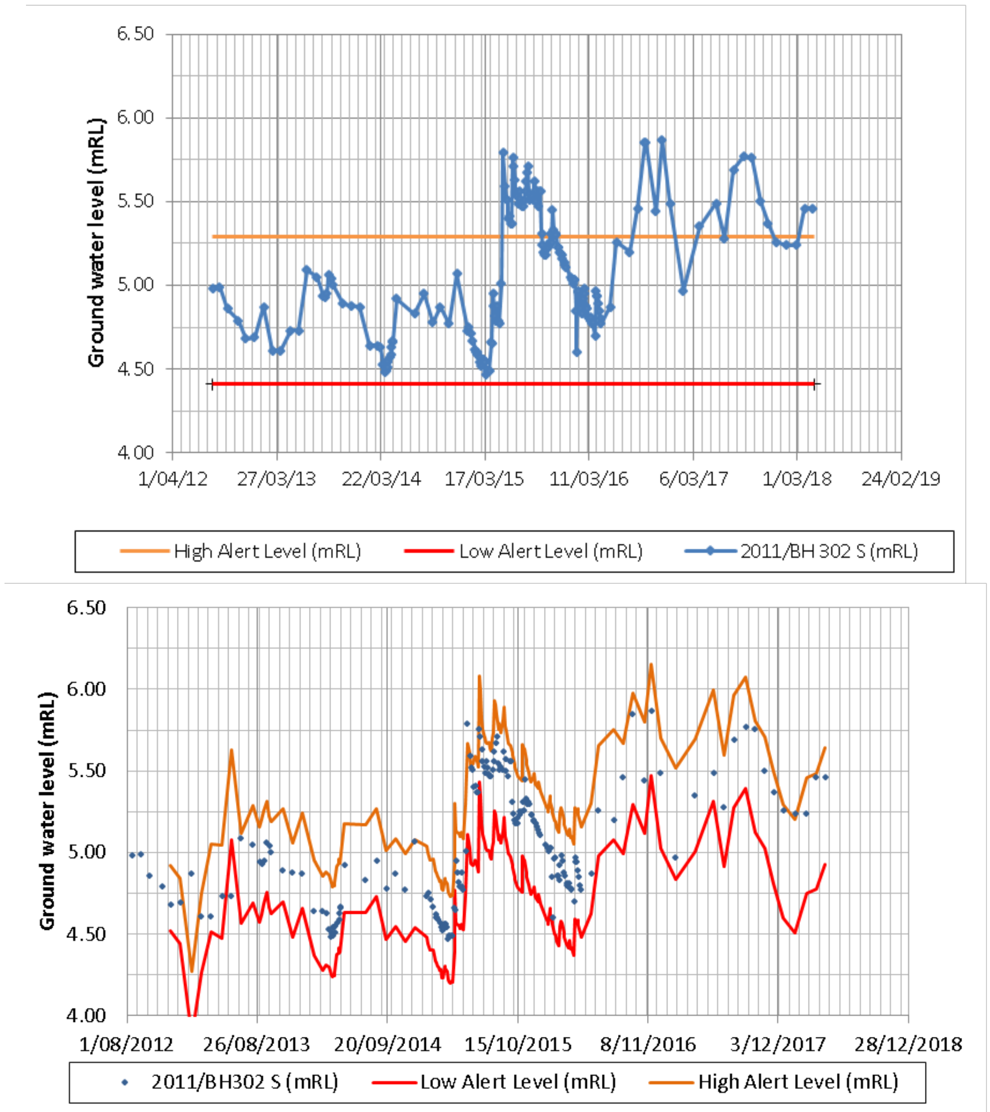

Figure 2: Observed Water Levels in piezometer 2011/BH302 S plotted against a) constant and b) statistical trigger levels calculated based on regional data

This approach allowed for minimum disruption to the construction works from unwarranted alert or alarm readings, and no adverse environmental effects.

THE EFFECT OF PILOT POINTS LOCATION ON CALIBRATION RESULTS

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Aims

Traditionally, models were calibrated using a zonation approach, in which a model domain is discretized into a finite number of zones representing the variability of any calibrated parameter, and thus reducing the number of variables. The problem with the zonation approach is that the boundaries between zonation can cause an abrupt change in parameter values, which is unrealistic (Anderson et al 2015) and the structural error can be large (Moore and Doherty, 2005).

De Marsily et al (1978) introduced pilot points as a means to reduce the computational burden of the zonation approach. In the pilot points approach, the hydraulic parameter domain is represented by a finite number of points distributed over the domain. The inverse problem solves for this parameter at these points and the results are interpolated (i.e., using kriging) over the entire domain. While no rules exist for the placement of pilot points, it is recommended to place them in a uniform pattern and avoiding large gaps between them, and to use the characteristic length of hydraulic properties as a guide for separation distance (Anderson et al 2015).

While most of the previous studies focus on the number of pilot points and how to select their locations, this study explores the uncertainty resulting from the spatial distribution of a constant number of pilot points in a model domain.

Methods

A model case study was used, with a finite difference grid of 222 rows and 148 cells, covering an area of 8214 km^2. For the spatial distribution of pilot points, another grid was created with 17 rows and 11 columns covering the model domain. It should be noted this grid was created for the sake of placement of pilot points and is different than the finer finite-difference grid described before. In each realization, the locations of pilot points were randomly selected in such a way that one point occurs in each grid. One pilot point was placed randomly within each cell of the latter grid so the total number of pilot points was 187. The area of study is located in the northern karst aquifer of Qatar. The geology of the aquifer comprises three layers of limestone and dolomite from Pliocene and Eocene age, namely the Dam and Dammam Formation, Rus Formation and Um Al-Radhuma Formation. The model was run and calibrated using twenty different configurations of pilot points, keeping the same threshold of sum of squared weighted residual for both head and flow below 500.

Results

The calibrated model before uncertainty analysis showed the hydraulic conductivity varies between 0.001 and 80.0 m/day. Figure 1 shows the mean value (left) and the standard deviation contour maps (right) of the calibrated hydraulic conductivity resulting from the 20 iterations. The mean hydraulic conductivities values vary between 0.001 and 80 m/day, whereas the standard deviation values vary between 0.0 and 92.0 m/day. Whiles the majority of model domain has low standard deviation (below 1) values of high standard deviation can be seen in the north-east and south of model domain. The mean values for the hydraulic conductivity map mean (Fig. 1 –left) is 9.58 m/day and the mean value of the standard deviation map (Fig. 1 right) is 10.23 m/day.

The maps show areas with high mean values have high variance. In general, the three areas with high variance are those in the east, west and south of the model area. This reveals these areas need more attention in calibration process

The results highlight the effect of pilot point location on model results and may help focus on areas of high uncertainty to collect more field data.

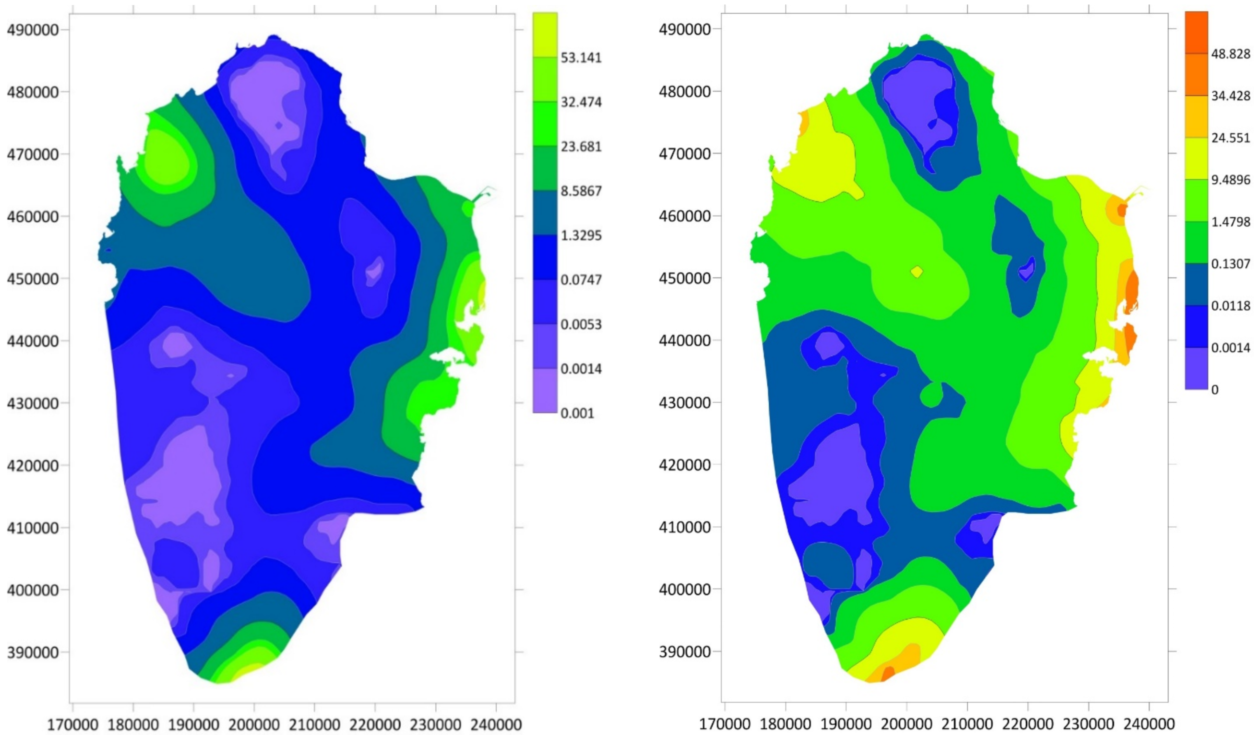

Figure 1: Mean value (left) and standard deviation (right) of calibrated hydraulic conductivity (m/day)

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Acknowledgment

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IMPACTS OF ON-SITE SEWAGE MANAGEMENT IN GLENORCHY - PIECING TOGETHER THE PUZZLE

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[1]*e3Scientific Ltd*

Aims

Glenorchy is a popular eco-tourism destination located on the Rees/Dart River delta at the head of Lake Wakatipu. Bordered by Lake Wakatipu to the west, old river terraces at the foot of the Richardson Mountains to the east, Glenorchy Lagoon and Rees River to the north and to the south the Buckler Burn River; the site hydrology is complex and poorly understood. Due to rapid growth in the area, Queenstown Lakes District Council commissioned e3Scientific Ltd to assess the impacts of on-site sewage management on the Glenorchy environment.

Method

Multidisciplinary investigations were tailored to improve the conceptualisation of Glenorchy's complex site hydrology. Four (4) additional piezometers were installed across the township to complete a monitoring network of eight (8) bores and seven (7) surface water sites. The monitoring locations were surveyed and water level data collected to clarify the groundwater flow dynamics and understand the sources and receptors of contamination from the township. Three rounds of water quality sampling were completed with measurement of field parameters and sample analysis for major ions, iron, manganese, nutrients and dissolved organic carbon. An ecological assessment of the lake margins and lagoon was completed in conjunction with the summer sampling. In response to the discovery of high iron concentrations in groundwaters and extensive iron deposition on the Glenorchy foreshore (**Error! Reference source not found.**), the ecological assessment was adapted to ensure that areas with and without significant iron deposition were surveyed.

Results

Contrary to previous groundwater and landfill investigations (Lindqvist, 1997) (QLDC, 2013), water level monitoring and surveys have provided evidence that groundwater flows from the north (recharging from Lagoon outflow/Rees River), east (rainfall recharge off the Richardson Mountains) and south (losses from Buckler Burn) beneath the township towards the receiving environment of Lake Wakatipu (**Error! Reference source not found.**).

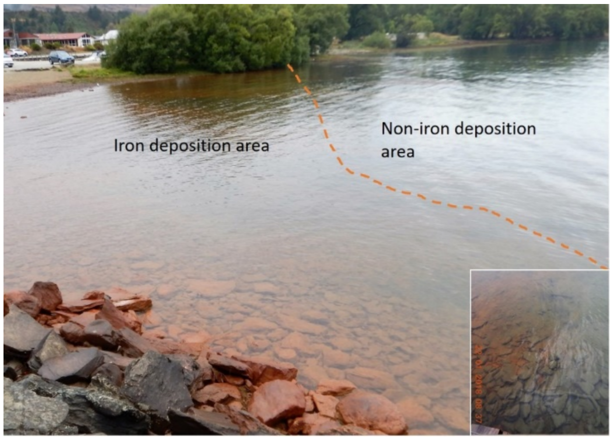

Figure 2: Lake Wakatipu north from Glenorchy jetty.
Insert: edge of the iron deposition from jetty.

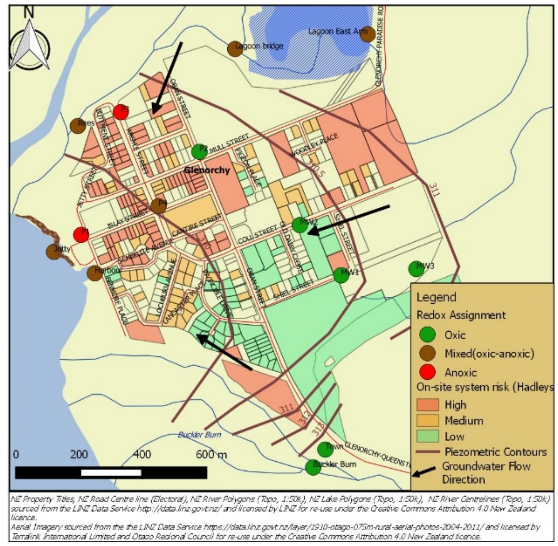

Figure 3: Redox state of sampled waters, piezometric contours and septic tank risk.

Oxygen-rich recharge waters from rainfall and surface water are depleted of oxygen as they flow beneath the township. Septic tanks provide additional inputs of organics and reduced forms of nitrogen, which promote further reduction of iron oxides and sulphates on the flowpath between the Rees River and Glenorchy Jetty (

Figure *4*), where the groundwater is shallowest and there is the greatest concentration of high risk septic tanks present in the township. This highly reduced, iron-rich groundwater discharges into Lake Wakatipu near the Glenorchy Jetty, resulting in significant deposition of iron oxides (**Error! Reference source not found.**). Groundwater flowing from the east and south towards Glenorchy Harbour is less reducing, therefore some nitrates and sulphates remain in the groundwater and there is less iron (no noticeable iron deposition) (**Error! Reference source not found.**). This may be due to less high-risk septic tanks present over the southern half of the town and consequently less organics leaching to groundwater.

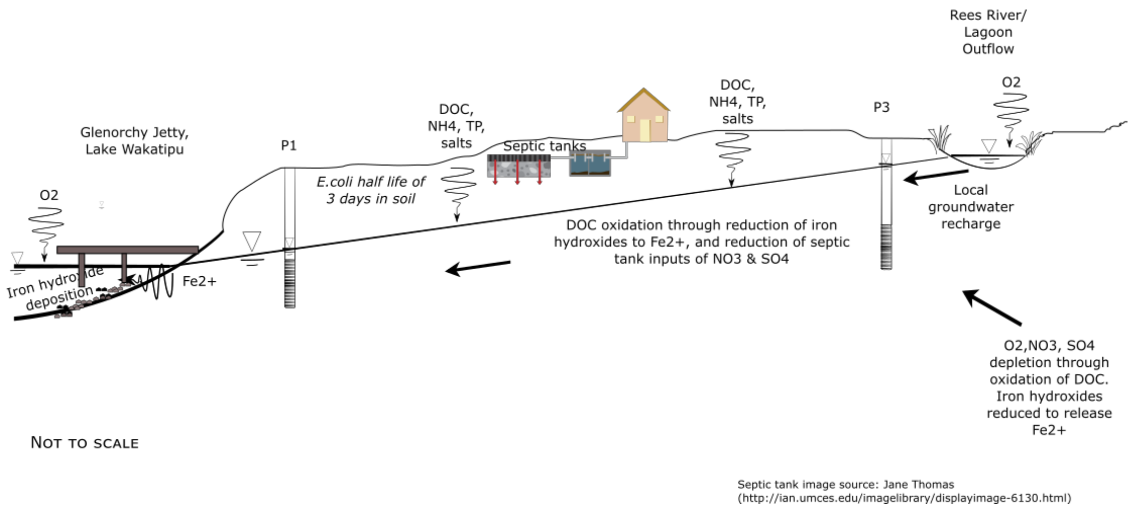

Figure 4: Conceptual Model from Rees River to Lake Wakatipu

Based on the measured nitrogen concentrations in groundwater and surface water, and groundwater gradients across the township, nitrogen flux was estimated to range from 1243 - 1264 kg N/year from groundwater into Lake Wakatipu. This equates to 29-42 kg/ha/yr TN across the southern end of the Glenorchy lakefront. Septic tank impacts on key sites in Lake Wakatipu are summarised in

Table **1**:

Table 1: Summary of Septic Tank Impacts in Glenorchy

Site	Hydrology	Water Quality	Ecology
Glenorchy Harbour	Receives groundwater discharge. Sheltered harbour results in poorly mixed waters.	Exceeds ORC (2016) Schedule 15 good water quality targets for Lake Wakatipu for TN, NH_4-N and *E.coli*. Mn and Fe concentrations elevated.	Evidence of seasonal surface water quality degradation within the harbour that, based on the limited historical data available, may be declining annually.
Glenorchy Jetty	Receives groundwater discharge. Well mixed due to Rees River flows & wind waves exposure.	Septic tank inputs have induced or exacerbated a highly reducing groundwater environment which discharges into Lake Wakatipu between Glenorchy Harbour and the Rees River outlet, resulting in significant iron deposition.	Macroinvertebrates diversity and abundance is decreased in the area of iron deposition, and there are indications that the longevity of benthic dwelling fish may be limited in this area. Macrophyte communities located entirely within the iron deposition area suffered morphological iron toxicity symptoms

The results of this assessment highlighted the importance of a multidisciplinary approach incorporating hydrology, chemistry and ecology to assessing the impacts of on-site sewage management in Glenorchy. Each dataset – elevations of monitoring points, continuous water level monitoring, major ions, redox sensitive species and ecological data – contributed to the conceptual model development. Previous data collection programs incorrectly interpreted the site hydrology. Likewise monitoring for only nutrients and

E.Coli would have lead to incorrect conclusions regarding the extent of on-site sewage management impacts.

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LABORATORY STUDIES OF MIXING AN OPEN FRAMEWORK GRAVEL CHANNEL AND A PERMEABLE REACTIVE BARRIER

Laura Banasiak[1], Murray Close[1], Kurt McBeth[1], Richard Sutton[1], Elisa Lahely[2], Roger Nokes[3]
[1]ESR (Institute of Environmental Science and Research), [2]National School for Water and Environmental Engineering, [3]University of Canterbury

An effective groundwater mitigation method for oxic alluvial aquifers, namely a denitrifying permeable reactive barrier (PRB), is being developed. This method is focused on alluvial gravel sites as they are important to NZ's primary productivity, given their plentiful supply of groundwater for irrigation purposes. These aquifers are, however, vulnerable to nitrate contamination due to their lack of natural nitrate attenuation and most nitrate entering the aquifers from excess fertiliser or animal waste passes through into receiving environments such as rivers and lakes. In a denitrifying PRB, nitrate contaminated groundwater is intercepted by carbon-rich woodchip media which stimulates the conversion of nitrate to inert di-nitrogen gas (N_2) by bacteria. Gravel aggregate provides structural support to the PRB. A key aspect is how the PRB will interact with the permeable channels or open framework gravels (OFG) within the alluvial gravel aquifer and what modifications to PRB design are feasible and effective to promote denitrification reactions. Successful PRB design requires an understanding of the hydraulic and chemical properties of the aquifer and the PRB fill medium. Can we promote dispersive mixing within the PRB with the selected fill medium of gravel and woodchip in order to induce and enhance denitrification?

Aims

The over-arching research question is "Can we sustainably reduce nitrate fluxes in fast-flowing alluvial aquifers, whereby natural nitrate attenuation is insignificant, by inducing conditions conducive to denitrification?" The specific aim of this study is to examine the influence of PRB media with different ratios of hydraulic conductivity (*K*) between the PRB and the OFG in NZ's alluvial gravel aquifers (i.e. *K* equal to and lower/greater than that of the OFG) to determine how that will influence the degree of mixing.

Method

K values were determined for the media to be used in flow visualisation experiments: (1) A 50:50 mixture of gravel (4-40 mm)/woodchip (ungraded) using a 0.3 m diameter, 1.5 m long column; (2) Various mixtures of sand (~1.2 mm)/pea gravel (2-8 mm) using a 0.1 m diameter, 0.5 m long column. All column experiments were carried out with upwards flow conditions. To ensure complete mixing of the gravel/woodchip and sand/pea gravel, the media was prepared in 10 L and 1 L batches, respectively, which were used to fill the columns. It is not yet decided whether the gravel/woodchip media in the field PRB will be tamped or not. Therefore, experiments were conducted to determine the difference in *K* for tamped and untamped gravel/woodchip media. Tests were also undertaken on the SAP spheres (10 mm) using a 0.2 m diameter and 4.6 m long stainless steel flume whereby water flowed in a horizontal direction. In order to determine the drainable porosities of the media (primary porosity), at the end of each test, the column or flume was left to drain under gravity overnight. Measured *K* values were determined from Darcy's Law and linearity between flow (*Q*) and hydraulic head differential (Δh) was inspected for each observation as a check for turbulent flow effects.

The flow visualisation experiments were carried out at the Fluid Mechanics Laboratory, University of Canterbury, NZ in a transparent Perspex tank 2.4 m long, 0.15 m deep and 1.2 m wide. The middle section of the tank represents the PRB (Figure 1). The end sections represent the OFG channel. Modifications were made to the tank to reduce the size of the mesh between the inlet, outlet and middle porous zones and add mesh panels to the middle of the inlet/outlet zones to enable the addition of SAP spheres to these zones and to the porous zone to prevent the movement of the above-mentioned gravel/woodchip and sand/pea gravel media into the SAP spheres. A linear array of white light-emitting diodes (LEDs) were placed below the tank. Optical flow measurement using the light attenuation (LA) technique was undertaken by introducing a dye (red organic food dye Carmoisine powder) into the flow in the tank and, based on the intensity of light transmitted, the concentration of dye was determined. Digital images of the tank during the experiments were captured with a JAI GO-5101C-PGE monochrome camera (2454×2056 pixel resolution, 50 mm fixed focal-length high transmission lens) orientated vertically 2.5 m above the tank. Processing and analysis of the images was undertaken using the computer software Streams version 2.06 (Nokes, 2017).

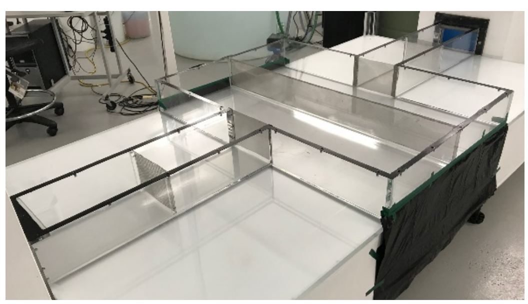

Figure 1 Photo and schematic of tank used to simulate groundwater flow through the denitrification PRB

Results

The average *K* of the SAP spheres was determined to be 2,364±330 m/d (Table 1) with a minimum and maximum of 1,835 and 3,410 m/d, respectively. This is significantly less than the *K* of OFG channels in NZ's alluvial gravel aquifers (16,000 m/d) (Dann et al. (2008)). There was a significant difference between *K*, and subsequently the primary porosity, of the untamped and tamped gravel/woodchip media with the average *K* of the tamped media (15,862±1,296 m/d) being 44% less than that of the untamped media

(35,740±5,748 m/d). The untamped media would be significantly more efficient in promoting mixing within the PRB compared to the tamped media. The relationship between sand/pea gravel content and *K* was used to determine the appropriate media mix to be used in the flow visualisation experiments.

Table 1: Physical and hydraulic properties of SAP spheres, gravel/woodchip and sand/pea gravel media examined

Media	Gravel content f_g (% v/v)	Woodchip content f_w (% v/v)	Sand content f_s (% v/v)	Bulk density ρ_b (10^3 kg/m^3)	Primary porosity θ[1] (%)	Hydraulic conductivity *K* (m/d)
SAP spheres	0	0	0	0.51	12.9	2,364±330
Gravel/woodchip						
Tamped	50	50	0	1.48	39.6	15,862±1296
Untamped	50	50	0	1.24	46.2	35,740±5748
Sand/pea gravel	54	0	46	1.77	30.8	321±42
	70	0	30	1.76	28.9	620±92
	80	0	20	1.62	43.6	1238±85
	90	0	10	1.59	36.0	5,847±1356
	100	0	0	1.59	43.2	18,863±4321

Flow visualisation experiments were undertaken using media with *K* values equal to (2364 m/d (84% gravel, 16% sand)) and 20% lower/greater than that of the SAP spheres (1468 m/d (87% gravel, 13% sand), 4092 m/d (81% gravel/19% sand)). Increased dispersive mixing was seen in the experiment with *K* greater than the SAP spheres compared to the experiment with *K* lower than the SAP spheres. Therefore, a lower denitrification rate would be expected to occur in a PRB media with a *K* lower than that of the OFG channels within an alluvial gravel aquifer compared to PRB media with a *K* greater than that of the OFG channels. Further experiments are planned to investigate the influence of a distribution baffle for flow enhancement in the PRB.

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LAKE TAUPO STORAGE: IS IT NEEDED?

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Introduction

Release or non-release of water from our main hydro lakes is related to the current electricity market and specific lake management requirements. Attention is drawn here to the possibility of formulating a modified operating model for Lake Taupo, with emphasis on aiming toward a consistent target lake level lower than the present upper limit. The argument is that Lake Taupo has a relatively high shoreline population that is vulnerable to environmental impacts of both high and low water levels. In particular, high Taupo water levels may lead to both lake shore erosion and increased risk of Waikato River floods in the event of major inflows into an already-full lake. The alternative operating mode would largely eliminate the Lake Taupo seasonal hydro storage role, which in fact is somewhat redundant in any case given the seasonal river inflow regime.

Current operation

Present water level management of Lake Taupo by Mercury is reflected in Figure 1. Any given year may differ but lake levels generally are increased in the second half of the year, followed by subsequent enhanced summer releases that increase Waikato River low flows. The present consented hydro storage operation allows lake levels to be between 355.85 and 357.25 metres above sea level.

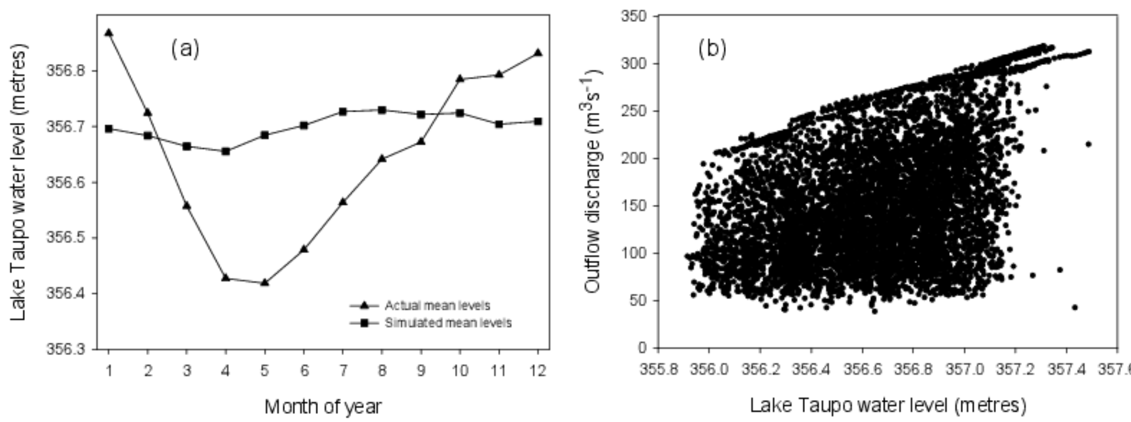

Figure 1: Taupo water level management 1998-2016: (a) mean monthly levels, (b) daily water releases plotted against lake level (data provided by Mercury). The simulated mean levels in (a) are generated from an alternative operating mode incorporating a target lake level of 356.7 metres (see text).

The maximum possible rate of water release from the Taupo Gates is an approximately linear function of lake level. However, there is little correlation between water level and rate of water release because small water releases are often coupled with above-average lake levels, largely reflecting periods of accumulating water storage (Fig.1b).

Alternative lake management mode

Toward avoidance of Taupo high and low levels, the proposed strategy is to release water at a relatively high rate whenever the lake exceeds a target level, and at a lower rate for lower levels. This release regime would need to be subject to avoiding downstream Waikato River flooding, creating hydro spill, or causing later Waikato River low summer minimum flows.

As a purely illustrative exercise in simulating Lake Taupo in a target level mode, lake daily inflows over 1998-2016 were "managed" using a crude model which releases water for a target lake level of 356.7 metres. At higher levels, the outflow was set at the maximum possible rate for the level concerned. For lower levels, the simulated water release was fixed at 75 m^3s^{-1}.

The simulated and actual lake levels make a strong contrast for both monthly means (Figure 1a) and daily levels (Figure 2). The simulated daily water release values rarely exceed 272 m^3s^{-1}. Also, the few high-level events in the simulations only last for brief periods of time. Low lake levels were avoided because of the low minimum release rate. In principle, therefore, controlled water releases can stabilise Taupo levels, largely independent of lake inflows. In fact, the simulated lake levels were held between 356.6 and 356.8 metres for 92% of the time. A practical model would need checking against Waikato River impacts. It could be desirable, for example, to allow lake levels to go above the target in order to hold some lake water back to reduce a Waikato River flood peak. The present model avoids the 1998 high lake level peaks but would need to be checked in detail to confirm that this also reduced the Waikato flood peaks in that year. One obvious improvement would be include some degree of inflow anticipation for coming days. The model also does not anticipate seasonal inflow variation which might enable upward adjustment of the low 75 m^3s^{-1} minimum flows, which would have some downstream impact on the Waikato River. Similarly, ability to forecast coming extended periods of low inflows might enable increased minimum outflows, perhaps to 100

m^3s^{-1}. The presentation will include results from a more sophisticated model utilising linear programming optimization.

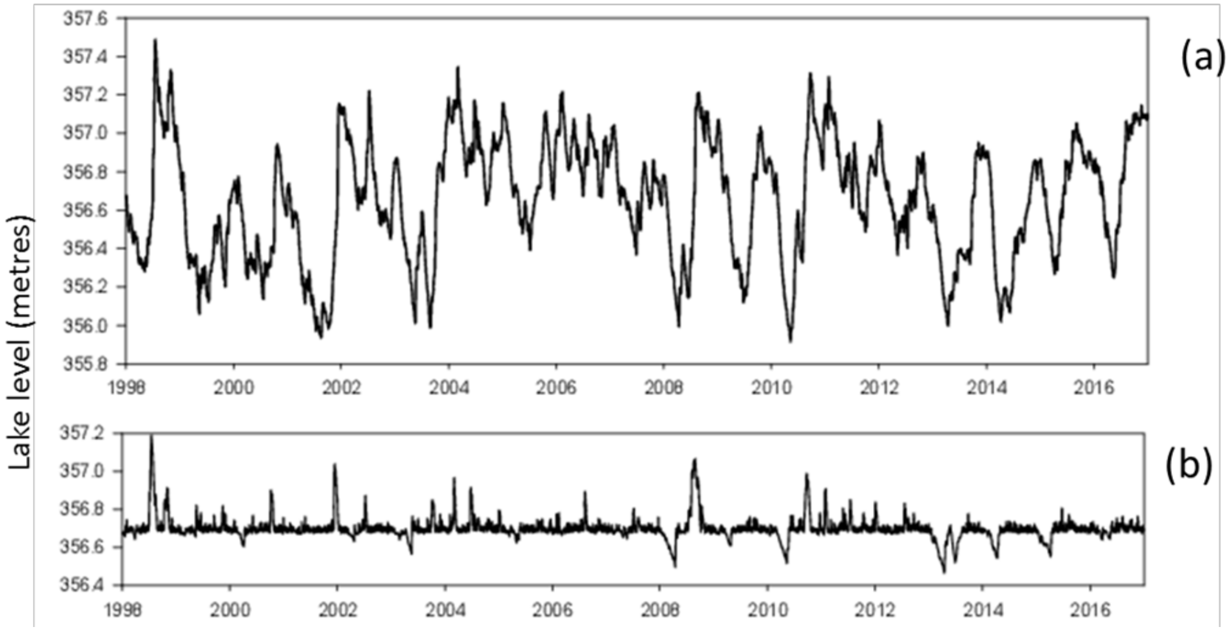

Figure 2: (a) Recorded Taupo water levels 1998-2017, (b) as simulated for a target level of 356.7 metres.

Discussion and Conclusion

There are environmental and flood control benefits to be gained from moving Lake Taupo toward a targeted operating level which is away from the upper limit. However, New Zealand has limited hydro storage so it might appear undesirable to reduce national seasonal storage capacity. The important point here is that the highest inflows to Lake Taupo (including Tongariro diversions) tend to be in winter, so seasonal storage for winter electricity supply does not apply to the same extent. There would seem no particular need to accumulate winter storage water in Taupo while the North Island is getting some of its power from other sources. Put another way, converting the Waikato hydro power stations to run of the river may seem drastic, but the river already “runs” well in terms of approximating the seasonal power demand. At the national level, giving generation priority to Taupo water is simply a reordering of hydro lake releases. For example, Tekapo storage might be used subsequent to Taupo.

A useful overall approach to Lake Taupo managment could be by way of a cost-benefit analysis with respect to both the lake and the Waikato River. This would take into account the frequency and impact of high- and low lake inflow extremes, and also the commercial gain of generating more Waikato River power in winter against the loss of needing to sometimes generate when prices are low.

EXPORT OF NITROGEN AND PHOSPHORUS FROM SUBSURFACE DRAINED DAIRY PASTURES ON THE HAURAKI PLAINS

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Introduction

In artificially drained land, the subsurface drains are well recognised as being potentially the most significant transfer pathway for agricultural contaminants into surface waters. Drainage flows bypassing the soil matrix potentially allow very fast and un-attenuated nitrogen (N) and phosphorus (P) transfers from the root zone directly into surface waters. However, the actual importance of subsurface drains under varying hydrological and hydrogeochemical conditions around New Zealand remains poorly understood and rarely quantified.

The lack of attenuation in this “short circuiting” pathway is attributed partly to the high soil water content causing the majority of the drainage to move in the larger sized soil pores. This results in reduced contact with the soil matrix, poor filtration and bypassing of P-adsorptive capacity of the soil. Additionally, as the drainage is normally installed within the soil profile, the draining water is captured and discharged, before it has opportunity to move through the deeper subsurface zones where N removal (denitrification) may occur.

While the lateral export of contaminants via artificial drainage is poorly quantified, equally poorly understood is the extent of vertical recharge into the shallow groundwater system underlying artificially drained land and the fate of contaminants exported on this pathway. Subject to the physical characteristics of the shallow subsurface materials (e.g. location of poorly permeable layers) and the site’s hydrological landscape position (e.g. reflected in average and temporal variation of the depth to groundwater), vastly differing ratios between shallow lateral and deeper vertical fluxes can be expected. The fate of vertically recharged nutrients depends strongly on the biogeochemical characteristics of the groundwater system, and in the case of N, this is largely determined by the redox status of the groundwater.

Aim

To determine the lateral and vertical water fluxes and N and P discharge dynamics at two artificially drained dairy farms on the Hauraki Plains (Waikato) over the winters of 2016 and 2017. Additionally, ascertain the influence of biogeochemical conditions on the fate of nutrients vertically recharged into the groundwater underlying the artificial drainage system.

Method

Artificial drainage flows from grazed pasture on two dairy farms, Tatuanui and Waharoa on the Hauraki Plains, were routed through surface water monitoring weirs, enabling the drainage flows to be continuously monitored. Flow based proportional samplers were then used to sample the drainage water. The collected samples were analysed for concentrations of various forms of N and P. Sub-soil coring at both sites was completed to understand the physical controls on the drainage hydrology. Subsequent to these investigations, shallow groundwater monitoring wells were installed enabling the locations of the water tables to be continuously monitored. Depth profiling of the shallow groundwater at discrete depths was undertaken, using a dual packer system. Groundwater samples were analysed for N and P concentrations, as well as indicators of redox status. Samples were also analysed for tritium to allow water ages to be estimated.

Results

The rainfall measured at the Tatuanui site over the 2016 drainage season was 434 mm (Fig 1a). The 2017 drainage season was extremely wet, with drainage starting in April, i.e. two months earlier than in 2016 and running one month longer (to Nov 2017). During this 2017 period, 949 mm of rain fell.

Based on the subsurface investigations it was determined that the Tatuanui site is effectively behaving like a sealed bucket, due to a 2 m thick blueish-grey clay layer at a depth of 10.5 m, vertically sealing the site. Above this layer slowly decomposing peat materials occur up to 1.0 m depth, with a silty mineral soil above. The peat material has an extremely low hydraulic conductivity, which prevents any significant lateral flow. The drainage is installed at the base of the mineral soil at 0.7 m depth. As the groundwater rises into the drained zone the installed drainage system removes the excess water, resulting in the drainage being very similar to the rainfall (Fig 2a).

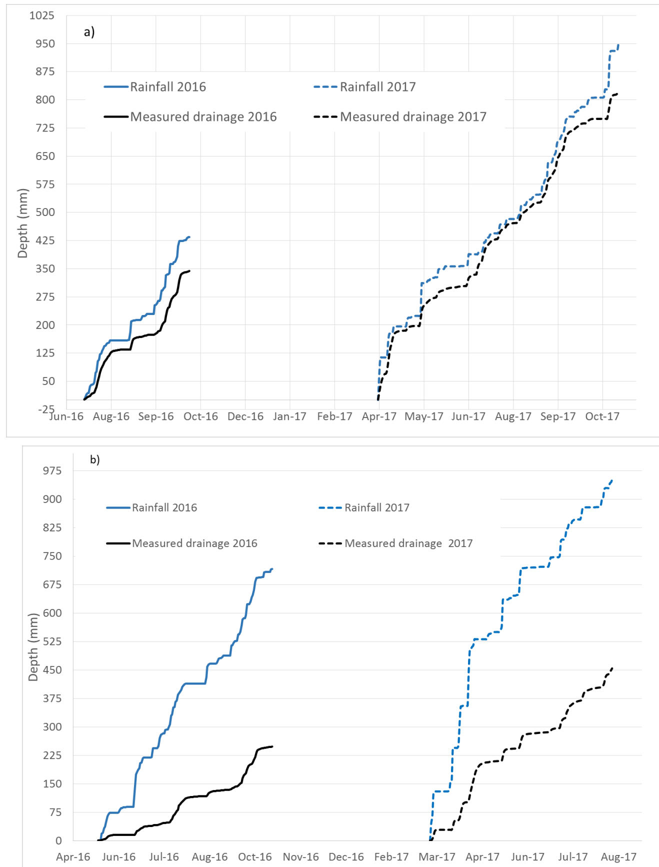

Figure 1: Rainfall (blue) and drainage discharge (black) at the (a) Tatuanui, (b) Waharoa, over the two years of monitoring

In 2016, the drainage season at Waharoa was two months longer than at Tatuanui with 716 mm of rainfall being recorded (Fig 2b). The earlier initiation of drainage was due to the slowly permeable layers present within the soil profile. These restricting layers created short-duration perching conditions, causing drainage. In 2017, drainage started already in March. However, due to extremely wet winter conditions the Waharoa measurement flume was flooded out in August 2017. Over the six-month measurement period possible in 2017, 952 mm of rainfall was recorded. For the 2016 drainage season, the measured drainage corresponded to approx. 35% of the rainfall, and in the part-season of 2017 the recorded drainage was 48% of rainfall. This result demonstrates that the shallow groundwater pathway at Waharoa had a much more significant role in the hydraulic discharge than at Tatuanui. Higher subsurface hydraulic conductivities measured at Waharoa are consistent with this result.

Contaminant exported in artificial drainage

The forms and masses of N and P measured in the artificial drainage exported from the two sites over the two seasons, are presented in Table 1. With drainage volumes more than doubling in the second year, a similar response was seen in the mass of N leached. However, the P leaching disproportionally increased by approximately a four-fold increase.

Table 1: Masses and forms of N and P exported via artificial drainage from the two sites in 2016 and 17

Site	Nitrogen (kg N/ha)								Phosphorus (g P/ha)			
	Total N		NO_3^-		NH_4^+		Org N		Total P		DRP	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Tatuanui	9.2	22.1	7.0	16.7	1.2	3.0	1.1	2.5	14.3	90.5	3.8	16.9
Waharoa	10.2	15.0$^+$	8.7	10.8$^+$	0.1	0.3$^+$	1.4	3.8$^+$	47.6	284$^+$	13	54.0$^+$

$^+$ Drainage season in Waharoa was incomplete as the site was flooded in mid Aug-2017

Role of shallow groundwater in N export

Interestingly, the average nitrate concentrations measured through the shallow groundwater at both sites are all less than 0.2 mg N/L. Concomitantly, the shallow groundwater redox conditions indicated that denitrification was likely to be a very significant removal process at both sites. Based on these results, and other data that will be discussed, it is concluded that artificial drainage is the only significant N export pathway from both sites.

MODELLING THE FLOW-ON EFFECTS OF CLIMATE CHANGE: MAROKOPA, NZ

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Aims

Ecosystem service models are increasingly used to inform holistic land management decisions. Over the last decade they have improved in their ability to represent complexity, multiple time and spatial scales, physical mechanisms and provide meaningful outputs. However, the question of how such models represent climate change impacts, particularly at local scales, needs further investigation. The climate change challenges facing the Marokopa region (Fig. 1), lends itself to the modelling of flood risk, for future hazard reduction, due to the threat of increased flooding in the area. The flooding hazard is exacerbated by not only the projected increase of precipitation due to climate change, but the steeply dipping sandy-limestone topography, shallow-rooted pastoral land and large tidal influence on the lower catchment. In this paper we use the spatially explicit Land Utilisation and Capability Indicator (LUCI) model to explore the impact that different land management decisions and climate change scenarios have on the spatial expression of flooding and flood mitigation. As LUCI is a spatially explicit and highly resolved ecosystem service model that can track water and other mass through the landscape, trade-offs in different ecosystem services can be explored and modelled for decision making. This study presents the impact of climate change on flooding, seen through a comparison of modelled outputs from LUCI for different climate scenarios.

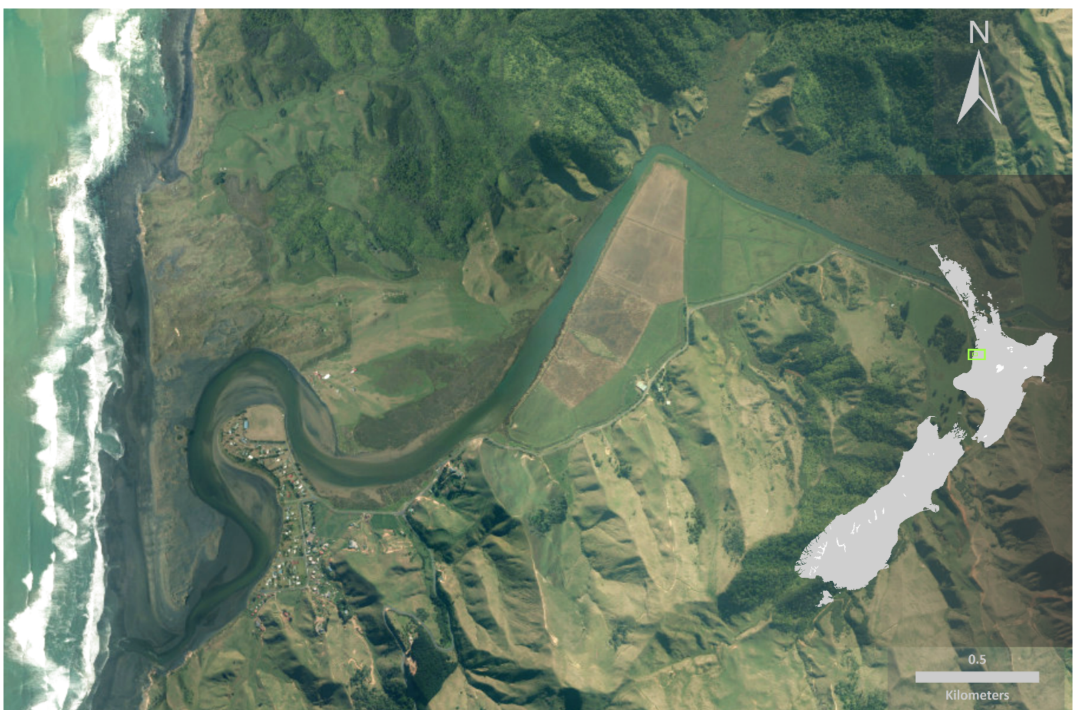

Figure 1: Marokopa catchment: Marokopa township and surrounding catchment (Land Information New Zealand, 2014).

Method

The LUCI framework focuses on outputting useful information needed for decision making by highlighting which features of the landscape have potential for flood mitigation and projected maps of inundation (Jackson et al., 2013). Several relevant maps are generated when processing, including erosion, precipitation and water inundation maps, as these factors greatly impact the flooding hazard in the Marokopa catchment. The flooding algorithms use input Digital Elevation Model (DEM), stream network, land cover and soil data, historic flood extent and precipitation-flow relationships as the foundations to model the direction and flow of water. Two methods are used, with the first analysing how different land characteristics impact flood risk. The second method models how water will be dispersed across the landscape with different flood volumes through the extrapolation of past flood event extent-flow relationships. These past flood extents are generated through the utilisation of local knowledge of flooding at Marokopa.

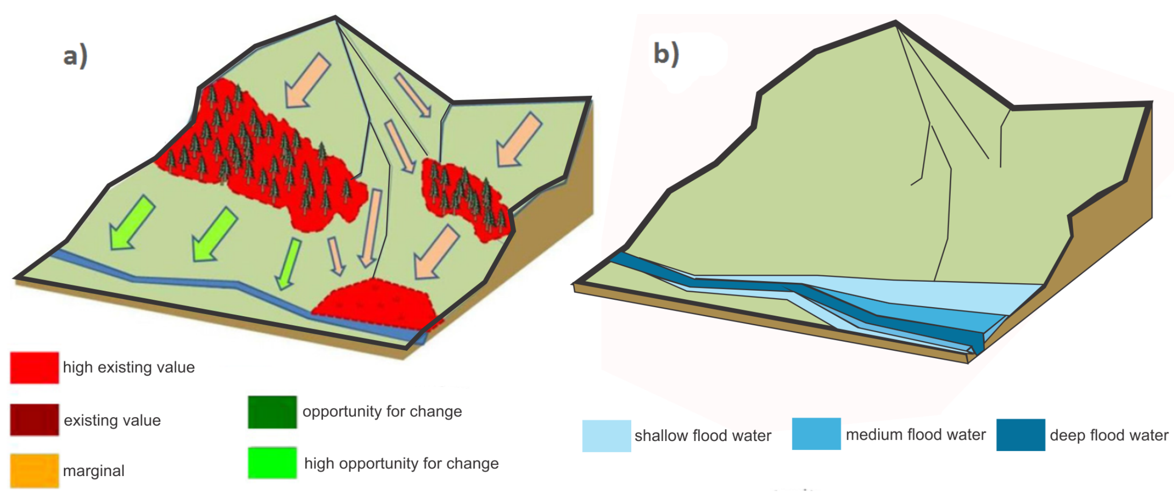

Figure 2: LUCI outputs: Adapted from Jackson et al. (2013), showing a) classification of LUCI outputs. Red indicates areas that already have mitigation features in the landscape, such as wetlands or deeply rooted vegetation and green highlights opportunities for more mitigation against flood risk. Figure b) shows the outputs for the flood modelling, whether different colours indicate flood depths for different climate scenarios.

Results

LUCI flood outputs can be divided into 1) flood risk and 2) inundation extent, where the first looks at the translation from different land use, soil and elevation patterns to flood risk. The second identifies breach points along a rivers outline, which have input overtopping-volumes. Modelling various scenarios allows different flow volumes to pass through the catchment and give visual results of the flood inundation hazard. From flood risk analysis, 5m x 5m resolution maps of precipitation, land-use, erosion, sediment delivery and water quality for the set climate conditions are generated. Outputs spatially define where the catchment is already mitigated against flooding and erosion (red), where more mitigation is needed (green), or areas in-between (yellow) (Fig. 2). While customizable, the ‘traffic-light’ colour scheme used allows users to easily recognize which landscape features need further flood management, and which do not. Different tiers within flood risk modelling allow for comparison between design and recorded events as well as climate change scenarios. Inundation model outputs provide high resolution maps of flood extent that outline where different areas on the floodplain may be breached by different flow volumes and events. Through extrapolating precipitation values from present records to those under different climate change scenarios, and understanding the catchment relationship between precipitation and flow, flood extents under climate change scenarios can be modelled.

Conclusion

In this study, outputs generated by the LUCI model includes flood risk and inundation maps for the Marokopa catchment under different climate scenarios. By parameterising features that impact the hydrology of the Marokopa catchment, such as the topography, soil, land use and historic flood data, the LUCI model can analyse which features mitigate or promote flood risk. This study provides a look at climate change modelling that is environmentally process-based. This allows for management decisions to fully consider and analyse the impact changes in the environment and climate have on catchment ecosystem services. We hope that with frameworks such as LUCI, the further development of ecosystem service models and maps will better guide land management and climate change decisions into the future.

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INVASTIGATING THE GROUNDWATER RESOURCE BENEATH WELLINGTON HARBOUR: A NEW CONCEPTUAL GEOLOGICAL ANALYSIS FOR HYDROGEOLOGICAL MODELLING

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Aims

Presently the Wellington City water supply is derived from the Hutt River and the Waiwhetu Aquifer and piped from Upper and Lower Hutt, respectively. The water supply pipe crosses the active Wellington Fault multiple times so should the fault rupture the city would be exposed to prolonged loss of water supply during a period of post-earthquake stress. To increase the resilience of the water supply during such a natural disaster, Greater Wellington Regional Council (GWRC) and Wellington Water Ltd (WWL) are investigating ways to avoid the inherent fault rupture hazard.

The aims of the project were to investigate the possibility of locating a reliable and high-quality water supply from the Waiwhetu Aquifer beneath the Te Whanganui a Tara/Wellington Harbour. If successful, the associated infrastructure needed to access this subsurface water supply would be established on the Wellington City side of the Wellington Fault, making this source more secure than the present pipeline.

Methods

In the lead up to this project, existing data from previous research was assessed, providing evidence that Waiwhetu Aquifer is present beneath the Wellington Harbour floor. This conclusion was inferred from existing seismic reflection profiles, from the existence of a productive well at Matiu/Somes Island within Wellington Harbour, and from water leakage indicators from beneath the harbour floor. To supplement existing sparse data, new seismic reflection profiles were acquired, and two carefully sited exploratory bores were drilled and tested.

The new marine geophysical datasets were collected during NIWA voyages KAH1505 in August 2015 and KAH1602 in February 2016. Data were collected using a mini-GI air-gun source and were integrated with shallow 'boomer' data collected by Applied Acoustics Ltd (voyage IKA1012) in 2010, and by NIWA for an It's Our Fault project (voyage IKA1303).

Two boreholes were drilled beneath Wellington Harbour using a barge-mounted, Fraste sonic drilling rig to extract near-continuous core material. Each hole was logged geophysically (neutron and natural density) and were probed to refusal using downhole cone penetration test equipment. Both boreholes were located on seismic reflection lines so that results from the different datasets could be calibrated. The two boreholes logs are consistent in recording sequences of alternating non-marine and marine units, underlying the uppermost marine silt and mud. Logs were interpreted based on the known glacial and interglacial sequence present within the basin. The results of this interpretation are summarised below.

Results

Having collated independent geological and geophysical data new marine seismic reflection and drillhole information, the opportunity existed to calibrate the more spatially extensive seismic profiles with borehole logs to yield planar surfaces representing known geological horizons. Prominent reflectors were traced throughout the network of seismic reflection lines, using intersections to correlate horizons. Three horizons were common to most lines, the “sea floor”, “base Holocene”, characterised by an abrupt change from acoustically semi-transparent marine muds to high-moderate amplitude, discontinuous reflections at the top of the Waiwhetu gravels, and “base Waiwhetu”, comprising a strong reflector inferred to represent a contrast in water content near the bottom of the upper Waiwhetu unit. Although primary reflectors are present beneath the “base Waiwhetu”, they are difficult to trace across the harbour basin.

Wellington Harbour boreholes		E3A		E8	
	sea floor	-23.37		-22.62	
Stratigraphy		depth bsf	RL	bsf	RL
Petone Marine Beds (Holocene)	thickness	22.9		18.3	
upper Waiwhetu gravel (Q2)	top	22.9	-46.27	18.3	-40.92
	base	27.75	-51.12	29.3	-51.92
	thickness	4.85		11	
intra-Waiwhetu fine-grained aquitard (Q3)	thickness	17.25		3.5	
lower Waiwhetu gravel (Q4)	top	45	-68.37	32.8	-55.42
	base	48	-71.37	43.7	-66.32
	thickness	3		10.9	
Total Waiwhetu	thickness	25.1		25.4	
Wilford (Q5)	top	48	-71.37	43.7	-66.32
	base	74.5	-97.87	61	-83.62
	thickness	26.5		17.3	
Moera (Q6+)	top	74.5	-97.87	61	-83.62
	end of hole	80.06	-103.43	71.15	-93.77
	thickness drilled	5.56		10.15	

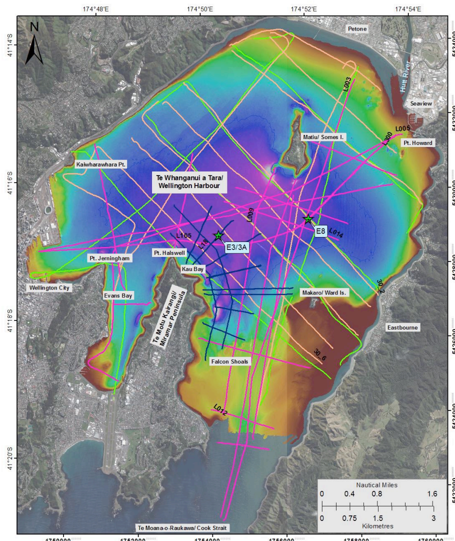

Figure 1: (Left) Summarised stratigraphy of two borehole logs, E3A and E8, from Wellington Harbour. (Right) Location of new NIWA seismic reflection profiles used in compiling this work, showing also the location of the two boreholes.

We assumed that horizons bounding these contrasting seismic units would be clearly visible in lithological changes in the borehole logs. The “base Holocene” seismic reflector corresponds to the abrupt change between the Holocene Petone Marine Beds and the upper Waiwhetu Gravels. By fixing these tie points, it became clear that the “base Waiwhetu” horizon identified in the seismic lines represented the top of the intra-Waiwhetu aquitard.

Having picked these two prominent horizons throughout the seismic profile network and correlated them with the borehole logs, we used Leapfrog Geo software to generate correlative surfaces across the basin. The two surfaces are interpreted to represent the base of the Petone Marine Beds aquitard and the base of the Upper Waiwhetu Aquifer, respectively.

Modelling clearly shows that the thickness of Holocene Petone Marine Beds varies across the harbour basin, is thickest offshore from Ngauranga Gorge and northeast Te Motu Kairangi/ Miramar Peninsula and thin beneath Makaro/Ward Island shelf and off Ngāmatau/Point Howard. The base of the muds dips gently to the northwest (c.0.1°), generally thickens towards the northwest of the harbour, and thins rapidly southwards from Point Gordon to the Harbour Heads.

The Waiwhetu Gravels are largely restricted to the eastern side of Matiu/Somes Island though small streams may have traversed swamps close to the western side of the island. The area south of E8 was low-lying and river flow was only locally capable of supporting a gravel bedload. Most of the southwestern harbour area was occupied by a swamp and/or a lake during most of the Last Glaciation. In general, the base of the unit dips to the northwest at c. 0.2°, but also rises southwards towards the Harbour Heads, perhaps due to tectonic activity.

We conclude that deposition in the harbour basin has been controlled by tectonics, at least during the last 130 kyr, and almost certainly for considerably longer. Wairarapa Fault uplift in the east and Wellington Fault subsidence in the west result in progressive tilting of the basin. We conclude also that uplift rates near the Harbour Heads (presumably in part related to Wairarapa Fault displacements) may match subsidence (largely related to the Wellington Fault displacements). These sea level and tectonic changes are primary drivers for deposition and are consequently of underpinning importance in providing a sound basis for the hydrogeological modelling of the yields and volumes of artesian water within the Waiwhetu Gravels (see also companion abstract by Gyopari et al.).

The authors wish to thank Wellington Water Limited and Stantec Limited for permission to present the findings of the harbour bores investigation project. Wellington Water

THE DATA, OR THE GEOLOGY? A MULTI-MODEL ANALYSIS OF SOLUTE TRANSPORT IN SYNTHETIC BRAIDED-RIVER DEPOSITS

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The spatial configuration of hydrofacies in the subsurface is a dominant influence on groundwater flow and solute transport. However, uncertainty in the distribution of these features in aquifer systems remains an open question in hydrogeological research. We are interested in the differences in solute transport behaviour that are induced by different methods for simulating subsurface heterogeneity. Ultimately, we want to explore how stochastic hydrogeological approaches informed by geological depositional concepts can be used to improve the characterisation of steady-state contaminant plumes in groundwater.

We generated a “synthetic virtual reality” based on extensive characterisation of braided-river deposits in the Upper Rhine valley, Germany, using an object-based, geology-mimicking method (Bennett et al., 2018). We then generated ensembles of parameter fields that mimic the synthetic virtual reality using the following methods: the same object-based simulation package; the multiple-point geostatistical DeeSse (Mariethoz et al., 2010); and the sequential Gaussian co-simulation algorithm GCOSIM3D (Gómez-Hernández & Journel, 1993). The latter two simulation methods were conditioned to borehole information sampled from the synthetic virtual reality, as well as training images generated using the object-based simulation package. Numerical flow-and-transport simulations (including particle tracking) were then conducted and the results analysed.

The results demonstrate that both quantitative data (such as borehole data) and qualitative information (such as geological conceptual models) are important for constraining predictions of solute plume location and extent. Multiple-point geostatistical methods offer a way forward for the integration of these types of information in a stochastic hydrogeological framework. Training images can introduce more geological realism into parameter field generation by constraining geostatistical simulations, both two- and multiple-point methods.

Themes: Groundwater and surface water processes

Modelling, prediction and data assimilation

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ASSESSING SUBSURFACE DRAINAGE OF THE KAIMAUMAU PEATLANDS

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Introduction

The project area within the Kaimaumau Peatlands is a land parcel of approximately 950 hectares (ha), within the Kaimaumau Peninsula (adj. Rangaunu Harbour), in the Far North District, New Zealand.

The proposed peat processing operation, with associated temporary dewatering, is to cover discrete working areas within the Kaimaumau Peatlands. Prior to abandonment of previous extraction endeavours in the early 1980's, several kilometres (km) of open drainage network had been formed, for pre-excavation dewatering of peat resources.

Processing of peat materials represents potential for change in hydraulic properties (arising from mechanical separation & industrial processing), which need be accounted for in long-term design for mitigation of adverse effects.

Three (3) potentially impacted area of ecological & cultural value surround the site:

- Waihuahua Swamp Scientific Reserve (upstream);
- Lake Waikaramu (lateral);
- Waiparera Stream / Rangaunu Harbour (downstream).

Aims

The aims of the work were primarily in relation to identification of constraints on dewatering (with respect to protection of potentially impact environments), and provision of recommendations to mitigate adverse effects. Specific items to be addressed included assessment of:

- Patterns in potential drainage flow;
- Recharge patterns/mechanisms for the peat layers and underlying sand layers;
- Feasibility & preliminary design of drainage structures for peat dewatering;
- Potential water quality issues arising from drainage discharge from peat;
- Changes in hydraulic conductivity arising from processing of materials.

Method

The project has been undertaken taken in two phases, being:

1. Desktop Assessment:
    a. Site reconnaissance;

    b. Literature Review;

    c. Catchment delineation & runoff assessment;

    d. Preliminary groundwater modelling (desktop assumptions);

2. Detailed Assessment:

    a. Establishment of baseline monitoring;

    b. Groundwater site investigation & in situ testing;

    c. Laboratory testing (hydraulic conductivity & PASS screening);

    d. Refinement of groundwater model;

    e. Development of dewatering framework for site.

Results

Groundwater model results indicate dewatering is unlikely to have appreciable effect on the Waihuahua Swamp or Lake Waikaramu, primarily due to stratigraphic and topographic features. Potential for offsite effects is however identified in one area, arising from a significant break in topography. Management of physical adverse effects is practicably achievable by way of drainage design, or construction of shallow low permeability cut-of walls.

Quantitative assessment of pre- (i.e. in situ) and post-processed (i.e. re-deposited) peat indicates negligible changes in hydraulic conductivity, remaining in the order of 10^{-7} to 10^{-8} m/s.

Potential for increase in downstream TSS is inherently identified due to proposed mechanical excavation, and will require management through drainage design. Potential for acid sulphate generation has been largely ruled out by way of pH_{Field}/pH_{FOX} ("Field/Fox") reactivity testing.

Baseline measures indicate that existing drainage is largely ineffective, due to the state at abandonment and lack of maintenance (30+ years).

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INTRODUCTION TO THE EIGENMODEL METHOD FOR DETERMINING THE DYNAMICS OF GROUNDWATER LEVEL AND DISCHARGE

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Aims

The eigenmodel is a simplified groundwater model specifically for the purpose of determining the dynamic behaviour of groundwater level and discharge to surface waters in response to recharge and groundwater abstraction. Since the development of the New Zealand application in 2002, spreadsheet-based versions of the eigenmodel have been applied to a number of water resource investigations by consultant and regional council staff. The purpose of this presentation is to introduce the concepts and capabilities of the eigenmodel, as a precursor to presentations about particular applications by other authors.

Method

The name "eigenmodel" is derived from the mathematical theory of eigenvalues and eigenfunctions, as used to describe the dynamic response of a linear system to external stress. Sahuquillo (1983) shows that the partial differential equations for groundwater flow in a linear aquifer (time-invariant properties and boundary conditions) can be expressed in terms of eigenvalues and eigenfunctions. The result is that dynamic behaviour of groundwater can be described (Fig.1) as a set of linear storages each of which receives an allocation of recharge, and discharges at a fixed proportional rate (the eigenvalues). The contents of these storages completely describe the state of the groundwater system at any time. Prediction of groundwater head, groundwater discharge, and groundwater storage, is obtained by applying response coefficients to the states of the linear storages.

There can be significant computational advantages in the eigenvalue description, especially because in many situations only a few of the linear storages (eigenvalues) are required for satisfactory model performance, and because the model is continuous in time. Pulido-Velazquez et al. (2007) demonstrate how the coefficients shown in Fig. 1 can be calculated from a calibrated spatially-distributed aquifer model, as well as the predictive effect of varying the number of linear storages.

The original version of the eigenmodel (Bidwell, 2003) employs no more than three linear storages (including vadose-zone storage). The allocation and response coefficients for groundwater level are combined so that, with the three discharge coefficients, calibration of the model becomes feasible. Implementation of this version in spreadsheet format relies on the z-transform mathematics of time-series analysis. One advantage is that it enables easy implementation of real-time forecasting of groundwater levels (Bidwell, 2005).

Stream-aquifer interaction and groundwater discharge response to pumped abstraction are more dynamic phenomena, in the sense that more of the linear storages are required for satisfactory model performance. Direct calibration of the larger set of coefficients is then not feasible, and an underlying groundwater model is required. Pulido-Velazquez et al. (2005) provide the analytical solutions for the coefficients in Fig.1 for pumped abstraction from a rectangular homogeneous aquifer. The values of these coefficients are directly related to the properties of the homogeneous aquifer, which can then be used as the model parameters. These results are incorporated into the revised version of the eigenmodel (Bidwell and Burbery, 2011) in a format that allows for spatially-variable recharge/abstraction zones.

Results

The eigenmodel method is directed primarily towards the dynamic response of whole aquifers or catchments to the history of recharge and abstraction. It can be efficiently calibrated from observations of groundwater level, and then applied to prediction of the groundwater discharge component of streamflow.

The underlying homogeneous, rectangular-aquifer, groundwater model would appear to be a restriction on application to various aquifer descriptions. However, the relative magnitudes of the eigenvalues, and related coefficients, are typical for many aquifer geometries, boundary conditions and hydraulic properties.

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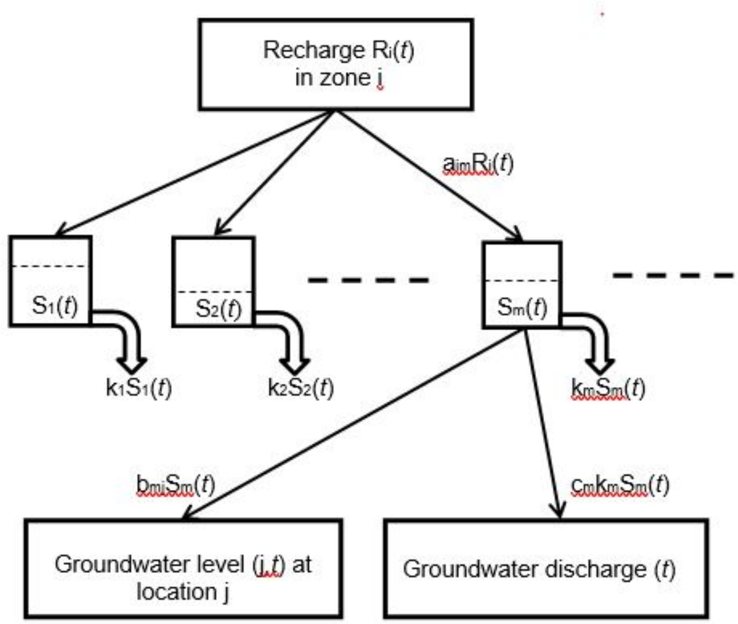

Figure 1: The eigenvalue structure of the dynamic behaviour of a numerical groundwater model. The coefficients k_m are the eigenvalues. Variables $S_m(t)$ are the water storage states. Coefficients a_{im}, b_{mj}, c_m, k_m are calculated from the calibrated numerical groundwater model.

THE SNOWPACK ENERGY BALANCE AND DRIVERS OF SNOWMELT IN THE AUSTRALIAN ALPS

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Snowmelt from the seasonal snowpack in the Australian Alps is a significant source of water for irrigated agriculture, electricity generation and environmental flows in the Murray-Darling Basin. Previous studies have reported negative decadal to multidecadal trends in maximum snow depth, snow season duration and snow-covered area. Here, we investigate the energy balance of this marginal maritime snowpack for the first time.

Aims

The principal aims of this study are: 1) to characterise the individual components of the snowpack energy balance and their variability, and 2) to build on these results to determine the relative significance of the drivers of snowmelt.

Method

An energy balance station was installed at an elevation of 1828 m ASL in the upper Pipers Creek catchment, Kosciuszko National Park, New South Wales. Turbulent fluxes were evaluated using the eddy covariance method and the four radiative fluxes were measured using a CNR4 radiometer. Ground heat flux was measured at the site and the rainfall heat flux was estimated using a nearby precipitation gauge, fenced to minimise the effect of wind-induced undercatch. Data were collected between 12 June and 24 October 2016 and a rigorous gap filling procedure was used to create a dataset suitable for the evaluation of energy balance components over the season. The snowpack energy balance was based on those periods with more than 1 cm of snow on the ground.

Results

The components of the snowpack energy balance exhibited strong within-day, between-day and seasonal variability. When examining the drivers of snowmelt, we found incoming longwave radiation to be the most significant term, accounting for more than 80% of the total energy source over the season due to the warm atmosphere and high moisture content. Net shortwave radiation was the second largest energy source; its overall contribution was smaller than elsewhere due to the relatively short Australian snow season. During a significant rain-on-snow event in July 2016, the rainfall heat flux played a relatively minor role, with most of the energy for melt supplied by longwave radiation and the enhanced turbulent fluxes.

Bormann et al. (2014) suggested that the relatively poor performance of temperature index snowmelt models in the Australian environment may be due to a violation of the assumption that the proportions of the energy inputs remain relatively constant. The observed variability in the energy balance lends support to this hypothesis although the dominance of incoming longwave radiation in this setting, and its strong link to air temperature (Ohmura, 2001), indicates that other factors may also be important. We suggest that a key feature of the snowpack is its sensitivity to individual meteorological events, which results from its marginality.

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SAMPLING GROUNDWATER MACRO-FAUNA – WHAT DOES IT TELL US?

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Background

Groundwater ecosystems remain one of the most understudied systems in New Zealand. This is partly because of the nature of sampling methodologies and difficulties in site access. However, there is now slow but growing acceptance of there being "life under the ground", and information is rapidly being generated in this emerging area of research.

Here, we present a site-specific study from ESR's well array at Burnham, Canterbury. We sampled several wells of similar construction drilled in the same aquifer using identical sampling methodology. We examine the ecosystem distribution (macro-fauna and water chemistry) and ask the following questions:

1. What does a single groundwater sample tell us in terms of biodiversity (macro-fauna) and is it representative of the aquifer system?

- What could determine the macro-fauna distribution?
- Does sampling technique affect the biodiversity recovered?

We are still crunching those numbers so you will have to wait and see!

Aims

To compare the diversity of macro-fauna in several wells from the same aquifer.

Method

Groundwater samples from a number of different wells from within the same aquifer were collected using a pump or hand netting method. Samples were all collected on the same day across different seasons. Sub-samples were stored for water chemistry and compared to the level of biodiversity.

Results

Preliminary studies suggest there is a relationship between water chemistry and biodiversity.

YOU DON'T HAVE TO VISIT A RIVER TO KNOW ITS HYDRAULICS

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[1]*Niwa,* [2]*Irstea*

Aims

Quantifying temporal and spatial variations of river hydraulic characteristics across stream networks is vital for catchment management. Hydraulic conditions are important because they influence physical habitats and biodiversity, water temperature, nutrient fluxes, sediment transport and associated ecosystem services. At-a-reach hydraulic geometry relationships describe changes in reach-averaged width, depth, and velocity with flow within a reach. Downstream hydraulic geometry relationships describe changes in reach-averaged width, depth, and velocity along or between rivers at a given reference flow (e.g., median flow). This study aims to develop models of at-a-reach and downstream hydraulic geometry for ungauged sites.

Method

We collated hydraulic survey data from many sites across New Zealand and France. These surveys were originally conducted for the purposes of physical habitat modelling. Each survey included observations of depth, depth-averaged velocity and areal substrate cover composition across many representative cross-sections at one flow. Further paired stage-discharge observations over several flows at each site were available for each site. Estimates of stage at zero flow were also available for some sites. Reach-averaged wetted width, depth and velocity were then simulated for each site for flows ranging between zero and the median by applying standard hydraulic modelling methods for fitting stage-discharge relationships.

We located each site on the digital national river network. This enabled extraction of catchment and site characteristics from various national-scale GIS datasets. Catchment-scale information such as catchment area, site elevation, river environment classification classes (Snelder and Biggs 2002), estimated substrate conditions (Haddadchi et al., 2018), and hydrological regime (Snelder and Booker, 2012) were obtained for each site. Estimates of the median flow were calculated for each site using the method of Booker and Woods (2014).

We devised a formulation of the at-a-reach hydraulic geometry equations for depth and width that incorporated depth and width at the median flow, thus negating the need for a separate downstream hydraulic geometry formulation. For each of depth and velocity, this formulation was fitted to each simulated hydraulic dataset. This process resulted in four parameters required to describe the hydraulic geometry at each site. We related each of these four parameters as a function of catchment and site characteristics from various GIS datasets. The random forest machine learning technique was applied to predict each of the four parameters, and therefore the hydraulic geometry at any ungauged site. Velocity was calculated as a function of the depth and velocity. We tested our prediction using an out-of-bag cross-validation procedure to ensure independent tests. These tests therefore represent performance as if each site were an ungauged site. Amongst other performance measures, we used Nash-Sutcliffe efficiency (NSE) as a measure of predictive power.

Results

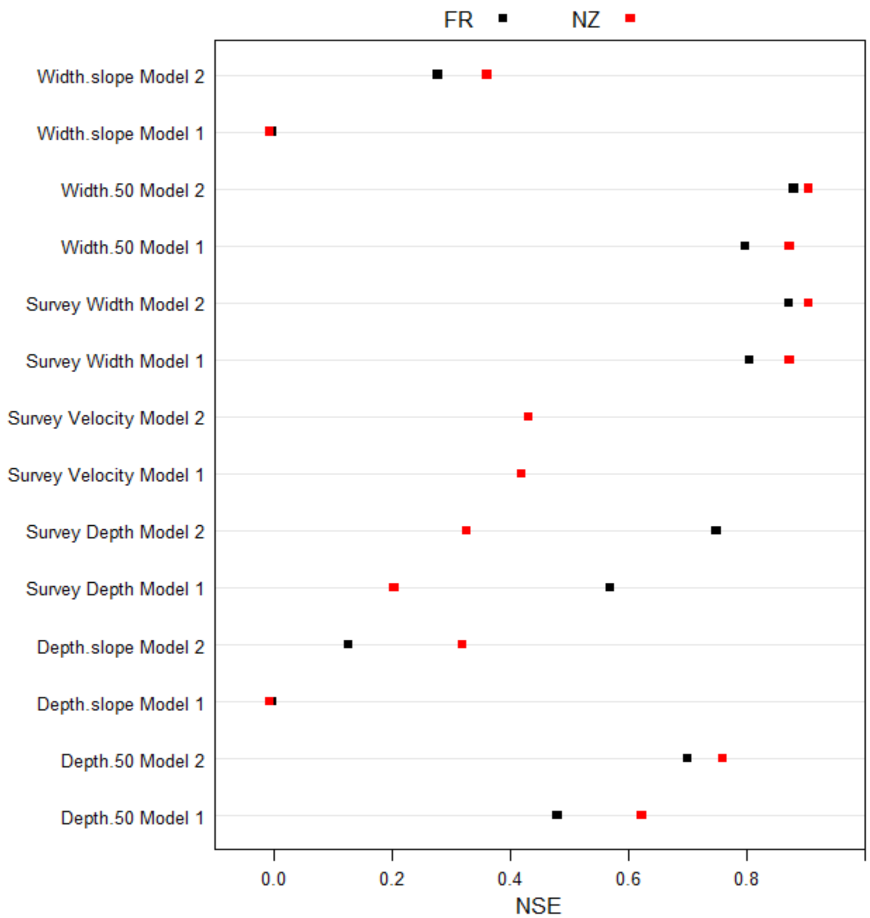

Figure 1: Out-of-bag cross-validated Nash-Sutcliffe efficiency (NSE) for predicted reach averaged depth, velocity and width. “Survey” indicates the observed field data. “50” indicates conditions at the median flow. “slope” indicates a hydraulic geometry parameter. Model 1 and Model 2 indicate different formulations used predict hydraulic geometry from catchment and site characteristics. NSE values of one indicate perfect performance, whereas values of zero indicate predictions are not an improvement beyond predicting the mean for all cases

Our preliminary results indicate width was well predicted regardless of country or method (Figure 1). Positive NSE values for depth and width also indicate ability to predict patterns across ungauged sites. Surveyed depth was better predicted for French rivers than New Zealand rivers. This may be caused by an inability to predict surveyed hydraulics in braided rivers within the New Zealand dataset.

The hydraulic geometry models developed in this study present considerable potential for improving catchment management tools. This is because variations in reach-averaged width, depth and velocity are useful inputs when predicting a variety of conditions relevant to stream communities. For example, predicted hydraulic geometry patterns can inform on physical habitat conditions, transport of contaminants, nutrient fluxes, deposition of fine sediment, water temperature and water temperature.

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INTEGRATED WATER MANAGEMENT IN THE HEKEAO/HINDS PLAINS UTILISING THE TOOLS OF MANAGED AQUIFER RECHARGE

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[1]*WGA NZ*

Aims

The aim of the Hekeao/Hinds Managed Aquifer Recharge Trial in Year 2 was to explore the application of MAR techniques across the Hekeao/Hinds Plains to achieve integrated water management.

Method

After the successful completion of Year 1 operations a steering committee, the Hinds/Hekeao MAR Governance Group (MAR GG), was formed. This governance group guides the development of the trial.

Primary activities in Year 2 of the trial were:

- Ongoing operations at the Lagmhor Trial site, including the design of site upgrades to improve recharge performance and quantifying the extent of the clean water plume resulting from the recharge.
- Identification and testing of additional MAR sites and techniques across the Hinds/Hekeao Plains.
- Sourcing of water, land and resources to support on-going trial operations.
- Consenting and construction of a river recharge project (Hekeao/Hinds River Project),
- Development of a business case to support the development of a catchment wide GRS.

Results

During Year 2, approximately 1,854,000 m^3 was recharged through the Lagmhor Trial site (10 June 2017 to 31 May 2018). This volume compares to 2,442,000 m^3 recharged during Year 1. Operations were disrupted more by rainfall and irrigation requirements during Year 2 than during Year 1. Flow rates to the site varied during Year 2, peaking at about 95 L/s. Of this total flow, approximately 22 L/s was infiltrated to groundwater through the base of the delivery race.

Total infiltration rates at the Lagmhor Trial site varied significantly during Year 2. Forebay infiltration has decreased substantially due to clogging by accumulated sediment. An assessment of water level responses following site shutdowns suggests that infiltration rates in the main basin may be influenced by depth of water in the basin, antecedent rainfall and depth to underlying groundwater.

The clean water plume generated by the Lagmhor Trial continued to propagate toward the south east, advancing at a rate of approximately 11 m/day. The plume is considered to have migrated a total distance of seven kilometres from the trial site and appears to be spreading out at the southern end. Water quality in the receiving groundwater beneath the trial site continues to be good. E. coli was not detected in the clean water plume during Year 2. Nitrate concentrations in the clean water plume remained low, even with the increased leaching of nitrates from the topsoil during the very wet periods of Year 2. Water quality responses in shallow groundwater and springs within the upper catchment of Flemington Drain may start to appear during Year 3 of the trial.

Geophysical information was used to support the design of a site upgrade at the Lagmhor Trial site to direct source water past interpreted restricting layers and increase the overall site recharge efficiency. The upgrade to the site will progress in August 2018 and the effectiveness of the upgrade will be assessed in Year 3.

To date (August 2018) six new MAR sites have been tested with a total of 352,388 m^3 of groundwater recharged. The combined Year 2 recharge volume for the Hinds/Hekeao Plains is approximately 2,206,000 m^3, including the Lagmhor Trial. The results show that the new MAR test sites can typically receive long-term flow rates between 15 L/s and 30 L/s. High groundwater levels due to rainfall events in the recharge period restricted flow rates at some sites during the initial test periods.

Through community consultation, the Hekeao/Hinds River Project has developed a range of beneficial outcomes for stakeholders whilst working toward achieving the targets for environmental restoration, reversing declining trends in groundwater levels, and improving groundwater quality in the catchment (Figure 1). A resource consent application was lodged in June 2018 and the consent process is still underway. The project will continue with construction and monitoring in Year 3.

Figure 1: Multiple Objectives for the Hekeao/Hinds River Project.

THE ELUSIVENESS OF ADAPTIVE GOVERNANCE: SOME PRELIMINARY INSIGHTS FROM THE PHILIPPINES

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Aims

The last decade has seen a growing interest, both theoretically and empirically, in adaptive governance. As a form of environmental governance, adaptive governance is considered to be key to dealing with uncertainties and expected, experienced and abrupt changes in the societal and/or natural environs. As a theory, adaptive governance has been mostly applied to water related issues and acknowledges the equal importance of and interdependence between social (human) and ecological (biophysical) systems. Despite the appeal of adaptive governance, a number of previous studies have shown the difficulty in establishing and operationalizing it. Why this is the case is what this paper seeks to investigate. This paper examines water management in Metro Manila, Philippines in relation to the Angat Dam and Reservoir and gives preliminary insights on why the Philippine water management system, despite having key features of adaptive governance, is far from being adaptive, as evidenced by problems related to water supply, conflicts resulting from competing water allocations, and water-related extreme weather events such as flooding and drought.

Method

This paper employs qualitative methods of document analysis and interviews. It examines both primary and secondary data. Primary data come from data gathered from interviews with key respondents. Meanwhile, sources of secondary data include materials gathered during the author's fieldwork. Available scientific/scholarly literature such as journal articles, books and reports as well as grey literature related to the topic has also been consulted. Secondary data also come from legal and government policy documents, reports, publicly available information on the official websites of the different government agencies/departments and current news articles.

Results

Initial findings from the Philippines show that collaboration and having a polycentric governance system do not necessarily lead to adaptive governance. The sheer number of agencies involved in water resources management has made coordination difficult and transaction costs high. It has also resulted in fragmentation in terms of activities and programs (e.g., data collection). This paper finds that despite the multi-level, collaborative and polycentric nature of Philippine water management system, predict and control approach to water resources management still dominates. Such an approach is inherently inflexible not only when it comes to stakeholders' participation but also in terms of approaches to problems. For instance, there is a propensity to include and rely only on scientific knowledge (i.e., six month-rainfall forecast and information regarding historical inflows from the Philippine Atmospheric, Geophysical and Astronomical Services Administration); integration of indigenous knowledge, which adaptive governance deems important, is lacking. Moreover, there is an obvious incompatibility between the principles of adaptive governance (e.g., flexibility) and the current institutional contexts that restrain policymakers and practitioners. For instance, when it comes to decision-making and policymaking on water resources allocation, the Water Code of the Philippines stipulates that, during critical periods (e.g., droughts), domestic/municipal has prior rights over other water users. Such stipulation is a major constraint for policymakers because it only prioritizes domestic/municipal water supply rather than ensuring water supply for all sectors in light of climate change impacts, which are predicted to worsen in the coming years. This has resulted in conflicts between water users/sectors, particularly between domestic/municipal and irrigation/agriculture. Thus, amendments to the Water Code to address these issues have been proposed. But whether or not the proposed amendments will be integrated and result in better decision-making and policymaking is yet to be seen. Moreover, although no other stakeholders besides national governmental actors/agencies are involved in decision-making processes, outside intervention by politicians from the provincial governments of Bulacan and Pampanga has made it possible for water to be allocated to certain users (i.e., farmers) even during critical periods. These interventions highlight the key weakness of adaptive governance – its inability to provide a broad or a more complete understanding of how power relations underpin governance structures. This paper argues that there is scope for improving the theory of adaptive governance by explicitly tackling issues of politics and power relations, which will shed light on the challenges involved in operationalizing and establishing adaptive governance. Whether adaptive governance can be applied to and is relevant to developing countries such as the Philippines will depend on an understanding of how institutional context and unequal power relations reinforce existing governance structures.

THE OBSERVED AND SIMULATED TROPICAL SEA BREEZE OVER THE GREAT BARRIER REEF

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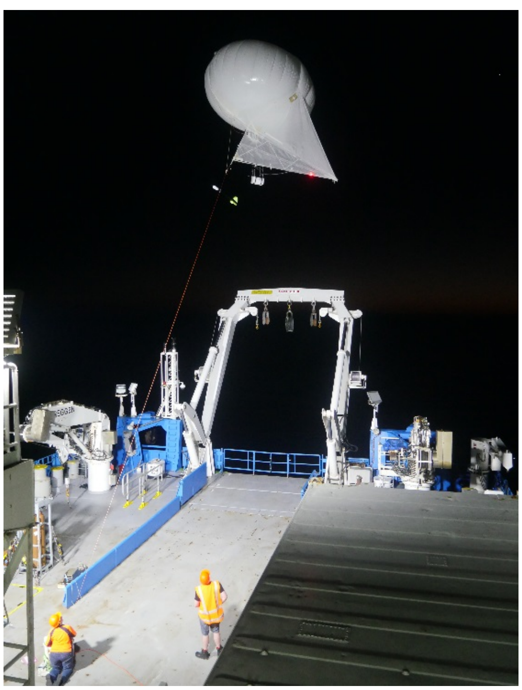
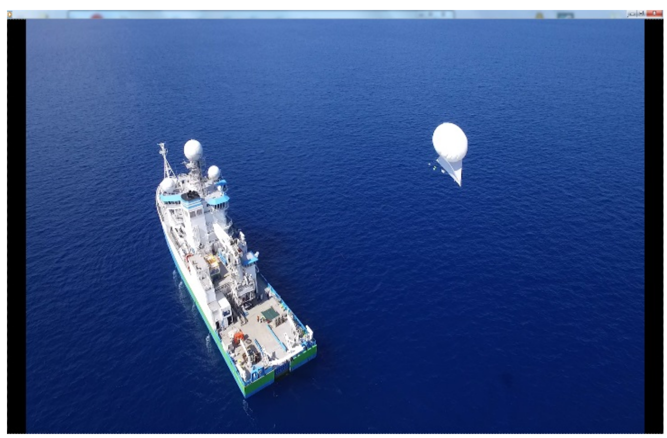
[1]Niwa, [2]School of Earth Sciences, The University of Melbourne, [3]Australian Antarctic Division, [4]Bureau of Meteorology

The tropical sea breeze and associated aerosol and cloud signatures were observed several hundred kilometres offshore over the Great Barrier Reef, Australia, using instruments mounted on a tethered helikite and a Raman UV polarisation lidar and simulated with the Weather Research and Forecasting model. Three periods of nearly 24 hours of continuous observations were analysed. Of these cases, one showed a density current extending over 150 km offshore, one showed rays of sea breeze disturbances propagating upwards and outwards from the coast as gravity waves, with little signature near the surface, and one was dominated by the large-scale flow. Observations from a ship located 150 km offshore and simulations from the first case indicated land breeze onset at around 0400 Local Solar Time, with a reversal in wind direction and an increase in the particle linear depolarisation ratio with values consistent with a shift from marine to continental air in the lower boundary layer. A line of low-level clouds was observed along the highest extent of the land breeze, providing direct evidence of coupling between the tropical sea breeze and offshore convection.





AUTOMATIC DISCHARGE MEASUREMENT OF LOWLAND WEEDY STREAMS

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[1]NIWA, [2]Hawke's Bay Regional Council

Aims

Lowland streams are of fundamental importance to the NZ agricultural economy, providing a significant proportion of irrigation and stock-water. However, it is difficult to accurately measure how much water is present and available, and determine whether consented amounts are taken, or not taken. Stream dynamics directly control the sourcing, sinking and attenuation of contaminants, such as nitrate, from runoff. These lowland streams supply a high proportion of the water that drives our economy and supports intrinsic environmental values.

Conventional stream-flow monitoring requires precise measurement of channel cross-sectional area and velocity in the downstream axis. To derive discharge, you need to account for depth, cross-section and boundary layer thickness. Conventional methods require the use of a surrogate (stage), monitored continuously, and related to discharge by empirical calibration (a rating curve).

The presence of aquatic vegetation makes this relationship insensitive and unstable, resulting in 'difficult-to-impossible' measurement conditions.

Currently, there is no technology that can easily, accurately, directly and continuously measure discharge in lowland weedy streams. We aim to develop a monitoring tool that transforms the Rising Bubble Method (RBM) into standard measuring equipment. Previous work by others, using the RBM, has not been able to produce bubbles with the precise characteristics needed, nor to instantaneously identify their surfacing locations with sufficient accuracy.

We have developed a bubble injector module that injects bubbles with the precise diameter needed to achieve constant rise velocity. A bubble is injected simultaneously from each of the injectors (e.g., 20) spanning the streambed. The bubbles intrinsically integrate the downstream displacement, resolving infinitesimally-small changes, including negative ones, as they rise to the surface. The horizontal distances, from the line of bubble injectors to where the bubbles first break the water surface, are directly proportional to discharge.

We aim to directly and accurately determine this 'just-surfaced' location, in near-real time, from a video taken of the water surface.

Method

An overview of the method we are using to measure discharge is shown in Figure 1.

To identify the 'just-surfaced' location, we are developing an Artificially Intelligent Deep Convolutional Neural Network (CNN) and training it to recognise a 'just-surfaced' bubble, against a background of 'visual irrelevance'.

One advantage of a CNN is that there is no need to manually extract the unique features that define a 'just-surfaced' bubble – the CNN extracts them for us, directly from bubble images, at pixel level. The trained model will be compiled and run as a standalone software application, on site, where it will automatically scan a few seconds of video, frame by frame, 'looking' for 'just-surfaced' bubbles.

Results

This method can shift the paradigm and enable us to measure flows ‘where we need to’ (leading to impactful information) not just ‘where we can’. We have transformed the measurement domain from the ‘end cross-section’ to the water surface. Results so far, indicate that this method is realisable and will enable a new standardised approach that measures discharge automatically; one that is independent of channel topography and moderate turbulence. It will reduce the cost-per-measurement, enable measurement where measurements were previously not practical, and hence increase the impact of stream flow information and ‘downstream’ benefits to national water management.

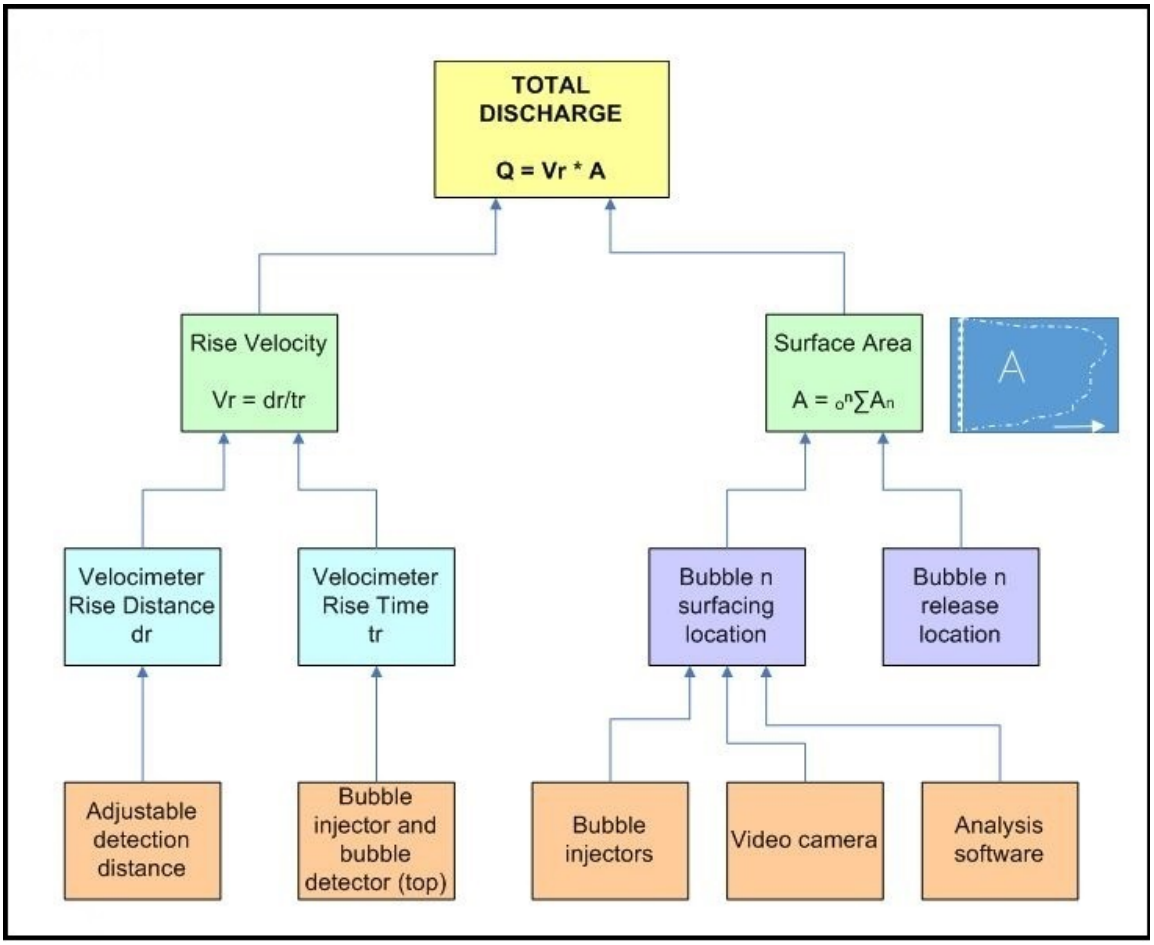

Figure 1: Overview Schematic

We are grateful to Envirolink for funding this phase of the project.

INVESTIGATING THE FATE AND TRANSPORT OF GROUNDWATER NITRATE IN THE SILVERSTREAM CATCHMENT, NORTH CANTERBURY

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Background & Aims

The coastal confined aquifer system under Kaiapoi is a northern extension of the Christchurch City aquifer system and comprises a geological sequence of interbedded proglacial gravel and interglacial alluvium. Groundwater from the North Canterbury Plains discharges at the margin of this coastal confined aquifer system, supplying spring-fed streams and drains, the largest of which is Silverstream. Nitrate is a contaminant of concern in Silverstream with in-stream concentrations regularly exceeding the NZ bottom line of 6.9 mg/L NO_3-N. Groundwater nitrate concentrations and redox conditions vary across the Silverstream catchment and this conceivably influences in-stream nitrate concentrations.

As part of the MBIE-funded Transfer Pathways Programme (TPP) we are trying to elucidate groundwater flowpaths and transport pathways for nitrate entering Silverstream, as well as examine the potential for natural attenuation of nitrate in the groundwater system. To permit such a study and with financial support from Environment Canterbury, we have conducted exploratory drilling investigations and established clusters of multi-level wells at three locations within the Silverstream catchment. The drilling investigation has provided a unique opportunity to profile the geological, hydraulic, chemical and biological properties of strata belonging to the Christchurch Formation, Sringston Formation, Riccarton Gravels, Bromley Formation and Linwood Gravels that make up the coastal confined aquifer system. As a means for characterising the dynamics of nitrate transport, automated groundwater monitoring stations have been installed at two of the well cluster sites and provide daily measures of groundwater nitrate at different depth levels in the aquifer system.

Method

Drilling investigation was conducted at three strategic locations in the Silverstream catchment, targeting areas where Close et al. (2016) have previously mapped different states of redox potential. The locations represent: i) the springheads at the top of the catchment; ii) the inland margin of the coastal confined aquifer system about mid-point in the catchment, and iii) within the coastal confined aquifer zone, towards the bottom of the catchment. Boreholes were drilled using sonic methods that limited our depth of exploration to 40 m, but allowed for undisturbed sediment cores to be collected. The geological profile was logged in detail and samples taken for biogeochemical analyses: elemental and mineralogical compositions of the sediments were examined by XRF and XRD, respectively; denitrifying enzyme bioassays were performed on freshly sampled sediments, and environmental-DNA in the sediments was analysed.

Between 4 and 5 multi-level monitoring wells were installed at each site; targeting discrete hydrostratigraphic units. Through slug tests and point dilution tests, hydraulic conductivity-depth and velocity-depth profiles have been determined. These data have been correlated with water chemistry-depth and age-depth profiles. Since March 2018 we have been compiling a daily groundwater nitrate, electrical conductivity and hydrostatic pressure time-series dataset for the wells screening gravel aquifer units. Concurrent nitrate recordings are made in Silverstream also. The monitoring system is built around operation of an optical UV nitrate sensor – the technical details of which are covered in a companion presentation by Abraham and Burbery.

Results

The sonic drilling method provided good sample recovery and enabled high resolution geological logging. Fine-grained silt and clay belonging to the Bromley Formation aquitard were logged at 30 m depth at all the sites. Only at the drill site near Kaiapoi was beach sand and silt belonging to the Christchurch Formation observed, acting as a confining layer to groundwater in the Riccarton Gravels. Discoloration displayed in the sediment profile near Kaiapoi indicated an obvious vertical redox gradient, although this was not picked up in the XRD results that recorded quartz (60-70%), sodium feldspar (30-40%) and trace amounts of kaolinite and/or illite as the only measurable mineralogy. No measurable nitrate was found at the Kaiapoi site (see Figure 1).

Below the vadose zone, very little denitrifying enzyme activity was detected anywhere. Interestingly, minor denitrifying enzyme activity was detected at approximately 21 m depth in the Riccarton Gravel aquifer near Kaiapoi. This depth coincided with where we noted (from observed geology) a slight transition in redox state. We hypothesise this marks a transmissive zone within the Riccarton Gravels where transport of young nitrate-impacted water is likely to be focussed. Slug test results and groundwater age determined from the monitoring well that screens 4 m below this level however do not support this hypothesis. Preliminary results from e-DNA analyses made at the phyla level reveal differences in microbial community structure with depth.

Groundwater ages determined from ^{3}H data and velocities determined from point-dilution tests confirm slow groundwater movement through the strata of the coastal confined aquifer zone, relative to groundwater movement inland and at the headwaters of Silverstream. Interestingly, whereas nitrate impacts penetrate down into the confined Linwood Gravel aquifer (40 m) at the mid-catchment site, no such impacts were detected for the same system at the springheads where deep groundwater is anoxic (Figure 1).

Whilst only a short groundwater nitrate time-series dataset has so far been collected, it displays some interesting patterns. For example, in April 2018 an apparent inversion effect occurred in the nitrate-depth profile that reverted back to a positive nitrate-depth relationship in July 2018. At this stage we suspect this may be an indication of limitations on nitrate leaching from the soil zone during what proved to be a very wet winter. In the future, continuous groundwater nitrate results will be reconciled with nitrate concentrations observed in Silverstream and the drivers of the system will be characterised.

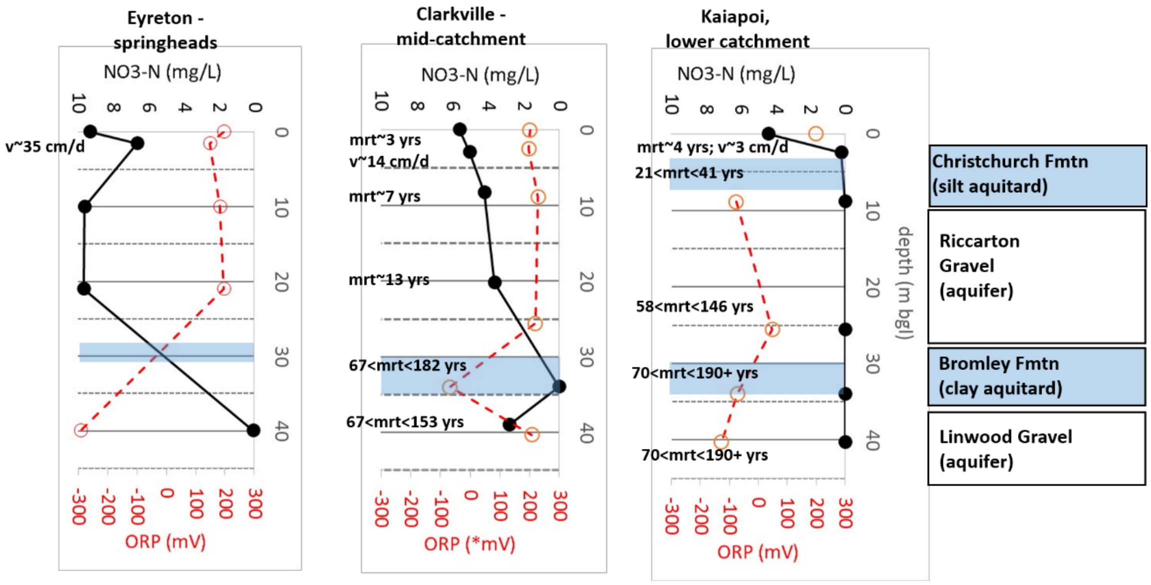

Figure 1: Example groundwater nitrate-depth profiles measured at the three multi-level well cluster sites in the Silverstream catchment. Eyreton marks conditions at the springheads; Clarkville is about mid-way down the catchment and Kaiapoi is on the coastal confined aquifer zone near Kaiapoi. Mean residence times (mrt) as determined from tritium data and velocities (v) measured from point dilution tests are marked. Note: data points at 0 m depth are in-stream values, measured in Silverstream.

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WORKING TOWARDS ESTABLISHING A NZ GROUNDWATER SUPERFUN SITE?!?

Lee Burbery[1], Phil Abraham[1], Richard Mellis[2], Louise Weaver[1], Michelle Peterson[3], Michael Finnemore[2], Murray Close[1]

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Background & Aims

Gravel aquifers typify NZ hydrogeology and are particularly vulnerable to nitrate contamination from land-use impacts because they are often overlain by thin, free-draining soils prone to nitrogen leaching, and the aquifers themselves generally have limited capacity to naturally attenuate nitrate.

The aim of the SSIF-funded 'Enhanced Mitigation of Nitrate in Groundwater' programme led by ESR in collaboration with Lincoln Agritech Ltd, Aqualinc Research Ltd, Southern Geophysical, and University of Canterbury, is to research and develop practical ways for remediating groundwater nitrate impacts in such systems. A particular objective of the programme is to pilot a woodchip denitrification wall (also known as a denitrifying permeable reactive barrier (PRB)) in a shallow alluvial gravel aquifer setting. While denitrifying PRBs have been demonstrated effectively in sandy aquifers (e.g. Schipper et al., 2000; Schmidt and Clark, 2012), no such examples exist in gravel aquifer settings. Alluvial gravel aquifers pose a particularly challenging environment to target with a PRB, because they are highly transmissive groundwater systems that are inherently heterogeneous and subject to preferential flow phenomenon. Through our project we intend to examine the practicalities of designing, building and operating a woodchip PRB; monitor its performance, and assess the impacts it has on the surrounding natural environment, including evaluation of any pollution-swapping phenomena and disruption of the natural groundwater ecology.

In 2017, we took on lease of Silverstream Reserve in the Waimakariri District, North Canterbury, for the prime objective of operating a scientific research site at which to pilot a denitrifying PRB. Silverstream Reserve is set upon outwash gravels of the Waimakariri-Eyre River fan complex. The first stage of our practical field project was to characterise the background hydrogeological conditions at the site; to establish the baseline condition and to evaluate design parameters so we might tailor the design of the experimental PRB to suit the site conditions. We like, or at least Lee likes, to imagine the Silverstream Reserve site as a New Zealand version of the Cape Cod aquifer superfund site operated by the United States Geological Survey. At least, in so much that it is a site where the hydrogeological and biogeochemical conditions, and function, of a small portion of alluvial outwash related to the Canterbury Plains will be examined at a very high resolution. Regrettably we lack the superfunds the USGS benefitted from for their scientific research, hence the 'superfun' reference.

The purpose of this presentation is to share the findings from our first stage of practical field study at Silverstream Reserve. This includes a description of the geological and hydrogeological conditions so far characterised at the 3.5 ha experimental field site and the methods we undertook to achieve this. Socio-political aspects of the project will be touched upon and the tailored design of the PRB will be presented.

Investigative Methods and Results

Investigative methods so far deployed at the study site include:

1. ground penetrating radar to examine the aquifer structure
- sonic rotary drilling from which the geology has been logged and aquifer sediments sampled
- particle size distribution analysis of sediments from key facies
- denitrifying enzyme assays made on aquifer sediments
- e-DNA analysis of aquifer sediments
- installation of monitoring wells– including multilevel sampler units and downhole electrode arrays
- piezometric surveys
- water chemistry analyses
- assessment of macrofauna

As at the time of submitting this abstract, 26 investigative boreholes had been drilled at the study site. From this we have discovered that the sand and sandy gravel strata that constitutes the shallow aquifer is underlain at approximately 5 m depth by an extensive bed of silt. This layer is evident in the GPR images. We interpret this to be the Bromley Formation aquitard. Sandy gravel belonging to the Riccarton Gravel aquifer underlie this. Our intention is to toe the PRB into the top of the silt and target treatment of nitrate in the surficial aquifer. Embedding the PRB in the silt strata conceivably will mitigate against any risk of flow submerging beneath the reactive barrier.

Whilst shy of the 10,000 multi-level sampling ports in the alluvial shallow aquifer at Cape Cod, Silverstream Reserve has so far been instrumented with 47 multi-level sampling points from which we have surveyed groundwater nitrate across the site. Nitrate concentrations vary across the site. Indeed, we have identified some localised parts of the Reserve where relict organic matter in alluvial sand beds appears to be fuelling denitrification and naturally attenuating the groundwater nitrate. The PRB is to be sited in a zone we have confirmed as being aerobic, devoid of any active denitrification and where nitrate-laden groundwater is transmitted. Groundwater nitrate concentrations in this target zone are 6 mg/L NO_3-N, which is consistent with concentrations measured in the nearby spring-fed Silverstream surface waterway.

Downhole CCTV images have confirmed the existence of stygofauna in the shallow aquifer. Studying what impact the woodchip PRB has on microbial community structure, including macroinvertebrates forms an objective of the research project.

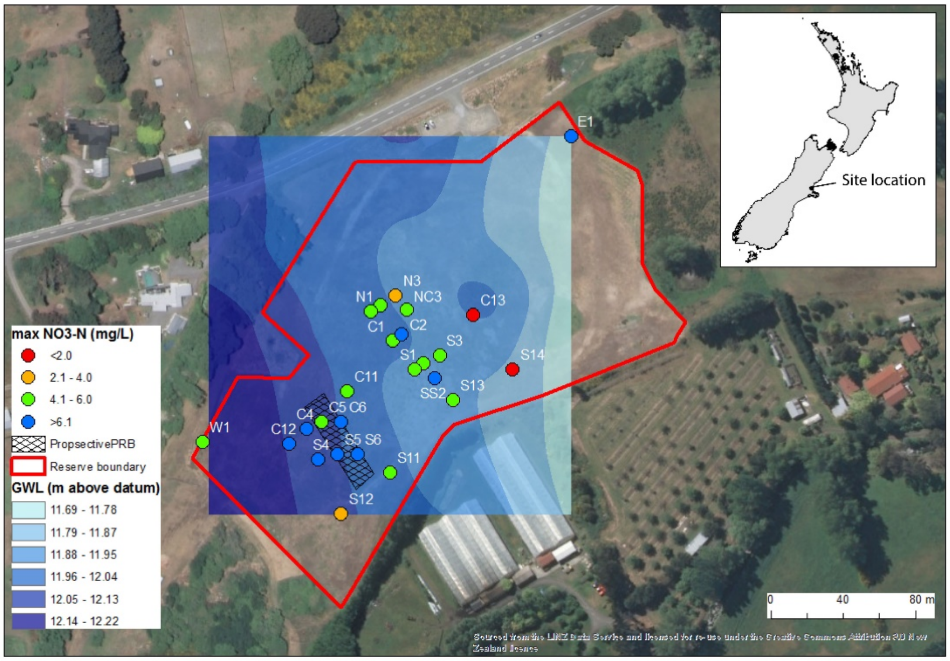

Figure 1: Site plan of Silverstream Reserve showing monitoring well locations, maximum groundwater nitrate concentrations and contoured piezometric surface. Planned location of the denitrifying PRB is shown as hatched area.

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GDA-MC^2 – ESTIMATING UNCERTAINTY BOUNDS IN THE GROUNDWATER DATA ANALYSIS TOOL

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Background

Sloan (2000) and Pulido-Velazquez et al. (2005) provide a particularly efficient analytical solution to the linearized Dupuit-Boussinesq groundwater flow equation that is presented in terms of a mathematical eigenproblem, which they demonstrated is applicable to modelling the dynamic behaviour of the groundwater system in idealised watersheds with spatially distributed and time varying recharge stresses. Pulido-Velazquez et al. (2005) named the general solution the Embedded Multi-Reservoir model (EM model) on account that, conceptually, the groundwater system is simulated as a series of independent linear storage reservoirs, the drainage coefficients of which correspond to the eigenvalues of the eigenproblem. In the eigenvalue approach, hydraulic heads and groundwater discharge are evaluated from a simple explicit state equation, expressed as a function of initial conditions and external stresses in the time period.

Bidwell et al. (2008) coupled the EM model described by Pulido-Velazquez (2005) with a soil moisture budget and vadose zone model, and cast the solution in terms of a set of difference equations to produce a hydrometric model that was applied to examine the areal extent of the Pukemanga Stream catchment, New Zealand (NZ). The process models described by Bidwell et al. (2008) have since been formatted into an Excel spreadsheet that is available to the public and referred to as the Groundwater Data Analysis Tool (GDA-Tool) (Bidwell and Burbery, 2010). The GDA-Tool was developed to assist groundwater practitioners with analysis of groundwater level monitoring data, from which knowledge might be inferred about the hydraulic characteristics of the monitored aquifer.

Aims

In this work we take the process models of the GDA-Tool and apply them to characterise the hydrodynamics of the Riversdale aquifer, Southland, NZ. The same problem has been examined previously (Burbery and Bidwell 2010; Bidwell and Burbery 2011), although shorter observational datasets were available at that time for interrogation. A key distinction between those modelling exercises and the work we present here, is that in this case we apply formal Bayesian inference methods to calibrate the systems model. In doing so we demonstrate how predicted modelled outcomes can be presented with uncertainty bounds. The acronymous title of this paper stems from our combining the GDA-Tool with Markov Chain Monte Carlo (MC^2) methods.

Method

Site Description

The Riversdale aquifer is located within the mid-Mataura basin and ranks as one of Southland regions most developed and productive aquifers. It is a shallow unconfined Quaternary alluvial sand and gravel aquifer, about 10 – 30 m thick. Its base is defined by Tertiary lignite measures. The groundwater system shares a strong hydraulic connection with the Mataura River, such that Environment Southland (ES) classify it as a riparian aquifer system. In 1999 ES installed a groundwater level monitoring observation well (F44/0181) near the centre of the aquifer from which the water table depth is recorded continuously.

Hydrometric Model and Calibration

We employed the mathematical process models incorporated in the GDA-Tool. Figure 1 shows our conceptualisation of the Riverdale groundwater system and how we perceive recharge processes to be distributed. We assumed rainfall recharge and flow losses from the Mataura River are hydraulic drivers of the system, and that the aquifer is stressed by pumped abstraction for irrigation. The following time-series data were used in the modelling process that ran on a daily time-step: rain and PET from NIWA's virtual climate stations; averaged Mataura River flows and groundwater usage for irrigation. Matura River flow data were transformed to a recharge signal using a parabolic flow-loss equation.

Groundwater level data from well F44/0181 served as the observational dataset to which the model was fit. Calibration was performed on a shortened data record (2000-2005), such that groundwater levels simulated beyond that time effectively represented predictions. At least nine parameters were involved in the optimisation problem that was performed in a stochastic framework, using the DREAM software (Vrugt et al., 2009). DREAM employs advanced MC^2 methods to estimate the posterior parameter distributions which allow to derive confidence intervals around the model predictions.

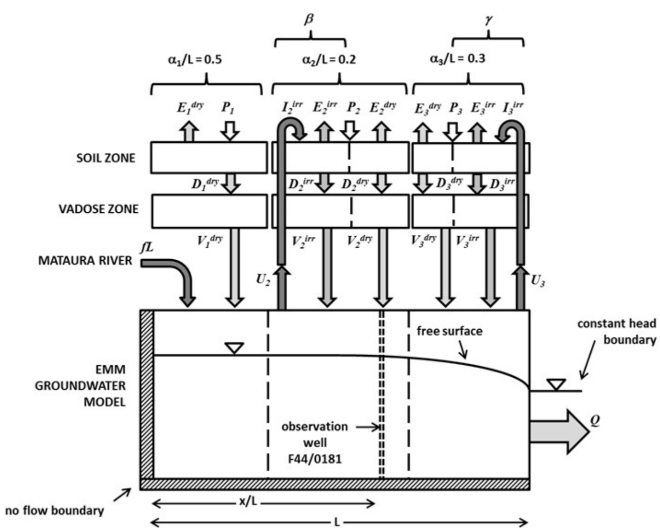

Figure 1: Conceptualisation of the Riversdale groundwater system. Recharge is distributed across three discrete zones (α_1:α_3), some portion (β,γ) of which in zones 2 and 3 is presumed to be affected by pumped abstraction and return irrigation. Arrows denote general fluxes evaluated in the mathematical model.

Results

We found the hydrometric model to be fairly insensitive to both the evaporation reduction factor and drainage threshold parameters that are implicit to the soil water balance model component. The proportions of irrigated land area also proved to be relatively insensitive model parameters in this case. The model proved a very good simulator of groundwater levels in the Riversdale aquifer (Nash-Sutcliffe index >0.8), as the hydrograph in Figure 2 demonstrates.

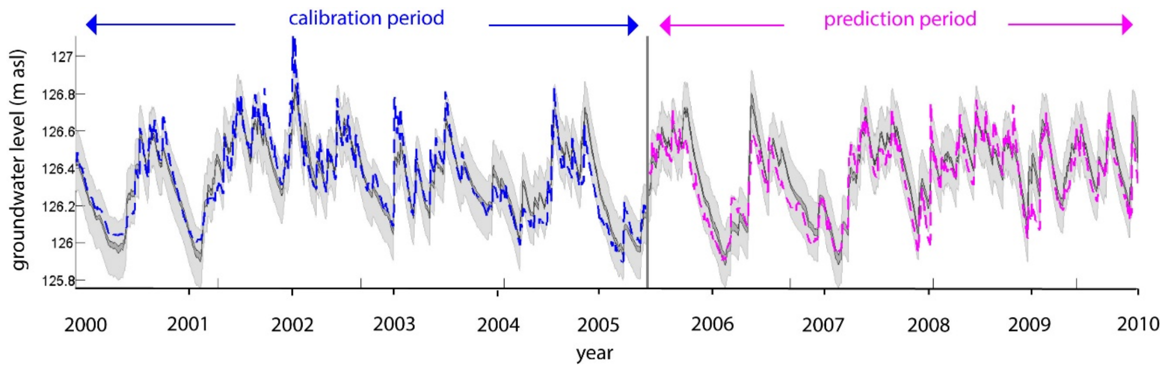

Figure 2: Example model fit to observed groundwater levels at well F44/0181. Dashed line marks observed data; solid black line is the best-fit simulated record; grey shading plots 95% confidence bands.

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MONITORING AND MODELLING RIVER LANDSCAPES WITH UNMANNED AIRBORNE VEHICLES (UAV'S)

Filippo Bandini[1], Michael Butts[2], Beat Lüthi[3], Peter Bauer-Gottwein[1]
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Aims

Traditionally, monitoring of rivers and streams has relied on in-situ measuring stations and surveys. However, the costs of performing these surveys, as well as the costs of installing and maintaining in-situ hydrometric sensor networks, place limits on the amount of spatially distributed hydrometric data that can be measured and contribute to the declining number of ground-based measurement stations. Alternative solutions include aerial surveys and satellite monitoring, and more recently low-cost sensor networks, crowd-sourcing, unmanned airborne vehicles (drones) and unmanned surface vessels. The rapid advances, in recent years, in Unmanned Airborne Vehicle (UAV) technology, both with regards to platform performance and sensors, have created several opportunities in water resources management. These include monitoring to manage land and water, to plan investments in new hydraulic infrastructure, to design and adapt environmental policies and legislation and to ensure legal compliance. UAVs offer unprecedented levels of spatial and temporal resolution and can be equipped with sensors that are similar to the space-borne sensors. UAV's are also advantageous in remote or inaccessible locations. Recently, under the SmartUAV project, a prototype hybrid drone was developed that combines helicopter and airplane capabilities for monitoring difficult-to-access locations (Bandini et al., 2018b). While conventional UAV's are widely used for photography, to date only few studies have investigated the quantitative application of UAV technology in water resources monitoring and modelling. An understanding of the advantages and limitations is needed, not only in comparison with conventional technology but also in terms of operating regulations. In this paper we present recent experience in the application of UAV's for hydraulic monitoring and modelling under two research projects: the recently completed "SmartUAV" project (2013-17) and the recently initiated "RIVERSCAPES—Monitoring riverscapes with unmanned airborne vehicles" (2017-20) project.

Method

We present a summary of the state-of-the-art and an overview of the advantages and disadvantages of ground-based, satellite and airborne monitoring methods. The SmartUAV project demonstrated the possibility to measure water level from a UAV platform, using a ranging system and a GNSS (Global Navigation Satellite System) receiver. Subsequently, the potential for UAV-borne water level monitoring is demonstrated at specific locations of Mølleå River, Denmark, and a synthetic study was performed to analyse the value of these new data for hydrological model calibration and prediction (Bandini et al., 2017b). These results provide the starting point for the RIVERSCAPES project, whose overall goal is to develop new unmanned airborne vehicle (UAV)-borne solutions for hydrometric and ecological monitoring of rivers and streams.

Results

The coarse spatial and temporal resolutions of satellite data result in several limitations when assessing the water level of surface water bodies and determining complex water dynamics using remote sensing techniques. Unmanned Aerial Vehicles (UAVs) can bridge the gap between spaceborne and ground-based observations and provide high spatial resolution and dense temporal coverage data, in quick turn-around time, using flexible payload design. One of the main technical barriers is the payload weight constraint of small UAVs (around 1.5 kg), capable of accurately measuring the range to water surface. Three different ranging sensors, a radar, a sonar and an in-house developed camera-based laser distance sensor (CLDS), were evaluated in terms of accuracy and precision. It was found that the GNSS system delivered a relative vertical accuracy better than 3–5 cm, water level can be retrieved with an overall accuracy better than 5–7 cm. However, more interesting is the capability of this approach to measure water level profiles along river reaches. Based on an integrated model of the groundwater–surface water (GW–SW) interaction in Mølleå River Denmark, we found that calibration against distributed surface water levels showed a significant improvement in estimating spatial patterns and time series of GW–SW interaction. Currently, within the RIVERSCAPES project, a range of UAV-based hydraulic measurement methods are being explored and evaluated. These include measurement of water level and surface velocities for estimating discharge (Lüthi et al., 2014; Philippe et al., 2017), measurements of bathymetry and cross-sections using tethered buoys (Bandini et al., 2018a) and well as photogrammetric methods for topography and flood extent (Tamminga et al., 2015).

Figure 1: The small UAV platform being used in the RIVERSCAPES project

Acknowledgements

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MONITORING; FOR WHAT PURPOSE?

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Environment Canterbury's groundwater monitoring networks are designed to collect data from a range of environments across the region to assess changes over time and inform scientific investigations, regional plans and consent processes. In Canterbury there are a plethora of documents that set rules, guidelines, and expectations regarding the state of the water resource (Figure 1). These include expectations for monitoring and reporting, so we must consider them when we review our monitoring networks.

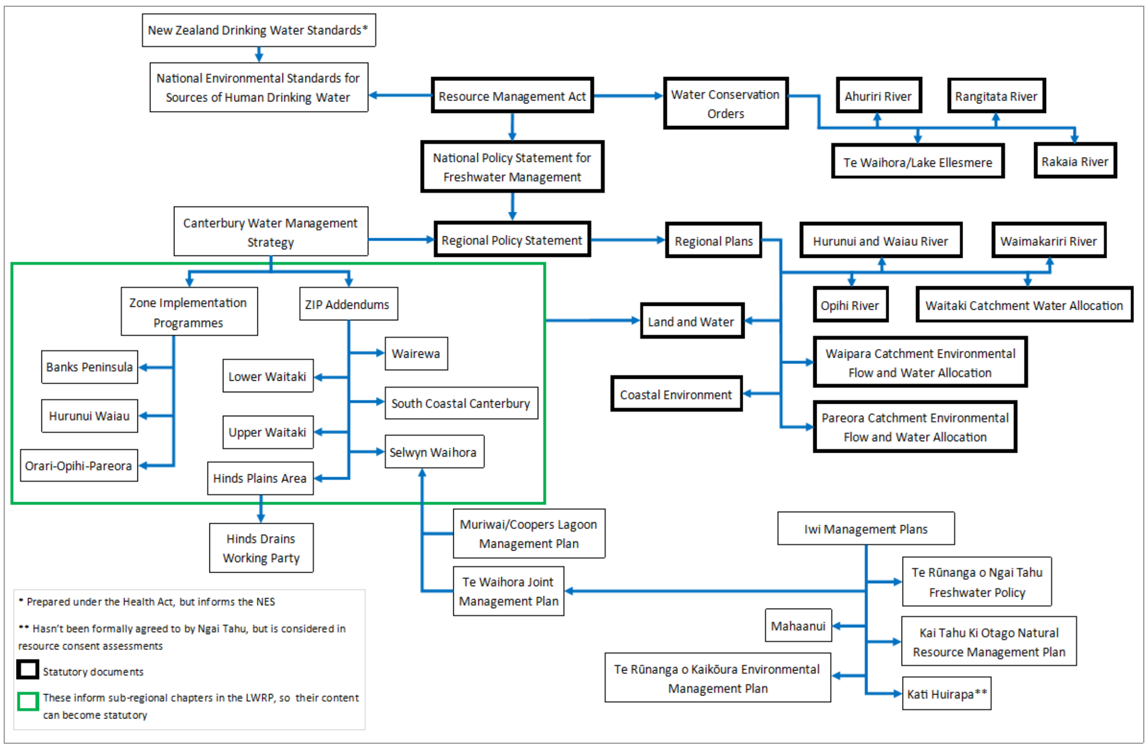

Figure 1: Water management documents in Canterbury (as at 1/01/18). Iwi Management Plans, though listed separately, sit alongside all other listed documents

Aim

To identify how well Environment Canterbury is delivering on its statutory and non-statutory responsibilities as relating to groundwater monitoring (level and quantity) through assessment of the networks against relevant planning and policy documents.

Method

Through review of the documents listed in Figure 1, key themes as relevant to groundwater (either inherently or via interpretation) were identified. For each theme, criteria were developed to enable assessment of the adequacy of the monitoring networks. Criteria included requirements to assess across a range of scales and parameters.

Amongst the water management documentation are Iwi Management Plans. Early on it was identified that to be successful in assessing for key iwi themes, iwi input was necessary. Engagement via internal and external structures enabled successful translation of scientific objectives to values-based conversations with iwi and back again into qualitative criteria.

Assessment of Environment Canterbury groundwater monitoring networks against criteria is ongoing. This presentation will discuss preliminary results as relevant to the Selwyn-Te Waihora Zone.

DECISION-MAKING USING RAINFALL FORECASTS FROM MULTIPLE MODELS

Trevor Carey-Smith[1]
[1]*National Institute of Water and Atmospheric Research*

Aims

As part of the Irrigation Insight Endeavour Programme, we are examining the application of high resolution weather forecasting for day-to-day operational management of irrigation in dairy farms. Making decisions based on multiple rainfall forecasts from a range of numerical weather prediction (NWP) systems can be time-consuming and complicated. Also, forecasts derived from combining a group of models often out-perform the best single model in the group (Woodcock and Engle 2005). This abstract describes a post-processing method that can be applied to different types of NWP systems at different spatial and temporal scales and which produces a unified forecast containing both probabilistic and continuous predictions.

Method

The NWP systems used as input to the post-processing system can have different spatial and temporal scales, different forecast lengths and can be deterministic or ensemble based. Lagged members of each system, that is forecasts from older initialisation points, can also be used.

Before combining forecasts from different models, it is critical that they are unbiased. In this case, gauge observations and past forecasts were used to derive bias correction surfaces using a variant of the quantile matching approach. This technique can generate incorrect results due to sampling issues, particularly in dry regions or for high rainfall amounts. This was addressed in two steps. First, at each observing location, corrections were estimated for a range of quantile “bins” and then a loess smoother, with tied endpoints, was applied to these results, thus removing variability due to sampling. Second, a spline surface was fitted to the quantile corrections to ensure regional consistency and minimise spurious results that were obtained at some locations. Results from this bias correction technique are shown applied to NIWA’s 1.5 km convective scale model (NZCSM) in Figure 1.

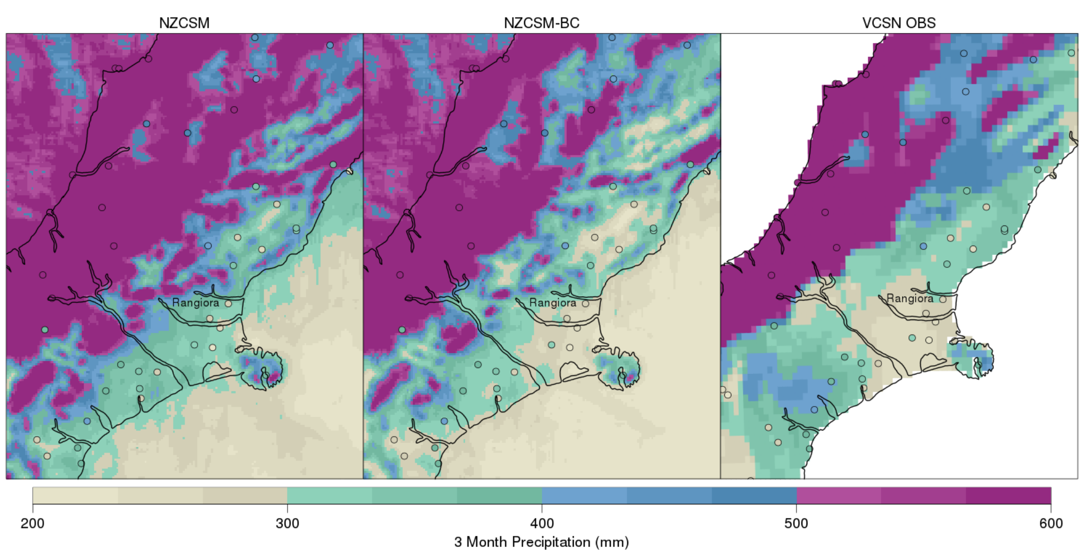

Figure 1: Feb to Mar 2018, three-month rainfall totals before (left) and after (centre) bias correction. Results from the Virtual Climate Station Network (VCSN) are shown for comparison (right). Gauge observations are depicted by filled circles which use the same colour scale. Note that the scale has been clipped at 600 mm.

After bias correction, forecasts from different models are combined using a weighted ensemble approach. For each upstream model, a forecast ensemble is created, made up of that model's ensemble members (if any), available lagged forecasts and forecasts from neighbouring grid boxes (particularly for models with high spatial resolution). The final ensemble is then created by selecting different numbers of members from each upstream model weighted by that model's forecast skill. The forecast metric used for weighting can be anything ranging from expert judgement to a score such as the ranked probability skill score. In selecting the final ensemble, care must be taken to ensure that the temporal evolution of a given member is physically sensible. This can be done by ordering the members of each upstream model based on the rainfall accumulated over the same contiguous period, analogous to the Schaake shuffle (Clark et al. 2004).

Results

A key outcome of the post-processing system is a unified forecast which contains, for each lead time, the most likely rainfall amount, a measure of the confidence in this value (for instance the smallest and largest potential amount) and the probability of exceeding a set of given thresholds. This information can be provided at a range of temporal scales; for instance, 3-hourly or daily. A product at the daily timescale has been specifically designed in conjunction with the Irrigation Insight programme for use by farm managers making irrigation decisions in Canterbury and is shown in Figure 2. A key benefit of this approach is that precise, high resolution rainfall forecasts available at short lead times are combined with lower resolution, medium range forecasts in a consistent manner and can therefore be presented as a unified forecast.

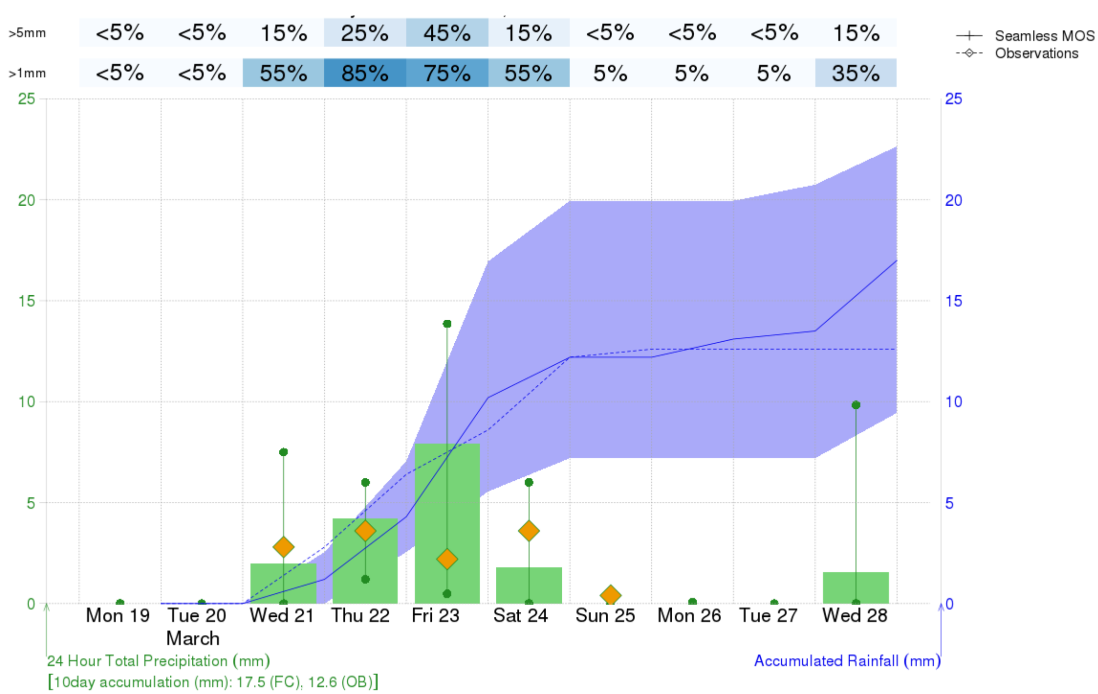

Figure 2: An example site-specific daily rainfall product for Rangiora. Forecast rainfall is shown by the green bars with the range of likely amounts shown by the vertical lines with dots. Observed daily rainfall is shown by the orange diamonds. The forecast cumulative rain is shown by the solid blue line with shading, and the dashed line showing the observations. Estimates of the probability of exceeding 1 mm/day and 5 mm/day are shown at the top of the image.

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NZ WATER MODEL – RIVER FLOW FORECASTING

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Aims

In New Zealand, flooding is the most frequent natural disaster while water is its main source of renewable energy (NZ, 2015). A national river flow forecasting system has potential benefits not only for disaster risk reduction through early awareness of potential floods, but also for hydropower operation, recreation, irrigation planning and regulatory/monitoring activities. The New Zealand Water Model flow forecasting system is a first attempt at overcoming the challenges of producing and communicating qualitative 48h river flow forecasts at the national scale for all catchments (both gauged and ungauged), and is designed to provide information where no local forecasting system exists. We present the key hydro-meteorological components and computational framework of this operational system, alongside the national flow forecast videos developed to communicate river forecast information.

Method

The New Zealand Water Model is NIWA's framework for national river modelling; it encompasses model data (geofabric), hydrological models (quantity or quality), and applications (e.g. river flow forecasting, climate change scenarios). To develop river flow forecasts, we coupled its hydrology model, NZWaM-Hydro, to NIWA's high-resolution (1.5km) convection-permitting numerical weather prediction model for New Zealand, NZCSM. Both models run on NIWA's high performance computing facilities within a computational framework based on CYLC suites containing a collection of tasks and scheduling instructions to pass input and output model data automatically between models and tools (Oliver, 2015). The operational system generates ensemble flow forecasts every 6 hours, producing hourly hydrographs at more than 60,000 river reaches (Strahler order 3 and above) for up to 48 hours lead time. In a parallel system, an operational gridded product of observed climate data (Virtual Climate Station Network (Tait et al., 2006)) is coupled to the hydrological model to create initial conditions for the flow forecasts.

NZWaM-Hydro is a distributed hydrological model based on TOPMODEL concepts of runoff generation controlled by sub-surface water storage. It combines a water balance model within each sub-catchment, with a kinematic wave routing algorithm (Beven et al., 1995, Goring, 1994). NZWaM-Hydro can provide natural flow information nationally, and replicates the strong environmental diversity of New Zealand catchments (McMillan et al., 2016). Model parameters are based on nationally available information on catchment topography, physical and hydrological properties derived from the River Environment Classification (REC), soil, land use and geology databases. Model parameters are therefore independent of biases in input rainfall data and are estimated using the same method in both gauged and ungauged catchments.

The national NZWaM-Hydro is uncalibrated to observed historic flows to use a consistent approach for gauged and ungauged catchments. To provide unbiased forecasts, we developed categorical flow forecast thresholds (e.g. below normal, extremely high), relative to modelled flow duration curves at every river reach. The modelled flow duration curves were produced from 40 years of hydrological model simulations driven by the observed gridded product VCSN (Tait, et al., 2006). For consistency and to reduce biases from the VCSN driven model climatology, each NZCSM forecast is bias corrected at different rain rates using a quantile matching procedure based on VCSN (Cattoën et al., 2016).

To visualize and communicate flow forecast information, we produced a new video approach generated with the Presentation Cartography software. We created two forecast views: the basin overview, and river network view (Figure 1). The basin overview displays all the river reaches of Strahler order 3 and above. The river network layer shows three levels of river thickness to differentiate between river sizes of Strahler order 3, 4 and 5 to 7. Forecast flow videos are automatically rendered daily within the computational framework presented above.

Results

While the forecasting system is still producing a forecast archive for thorough statistical scoring evaluations at the time of writing, hindcast storm events and non-events were produced to evaluate the two flow forecasting video approaches and conduct preliminary evaluations of the system. The ability to efficiently visualize the flow forecasts at national scale during the ongoing development of the computational framework, categorical thresholds and creation of video layers was critical. Storm event case studies highlighted the importance of generating accurate NZWaM-Hydro initial conditions from the VCSN data, and the required length of warm-up period for the forecasting system based on a VCSN driven flow climatology.

The river level categories displayed in the video (well below normal, below normal, normal, above normal, well above normal and extremely high) represent the modelled flow duration curve exceedance thresholds at every reach (90%, 66%-90%, 33%-66%, 33%-10%,10%-1%, top1%). Future evaluation of the model will refine these thresholds and number of categories conveyed.

Based on case studies and stakeholder feedback, the basin overview seems more suited for a national overview and for users interested in catchment area information as opposed to specific rivers. However, the river network approach better conveys potential impact with river sizes becoming significant in a relativistic context. For example, using the basin overview, a region could appear dominated by extremely high flows (top 1%of FDC) when the river network layer would clarify that only the smaller rivers are in this top category and the main rivers in the category below. Refined basin overview layers will be tested in the future.

The NZ water forecasting system is a first attempt at producing and communicating national flow forecasts driven by a convective scale weather model. To further develop and assess the system, extensive testing and statistical scores will be undertaken at available gauged stations. In parallel, engaging with potential users and stakeholders to acquire critical feedback and refine the system’s usefulness and future development directions will be fundamental to the project.

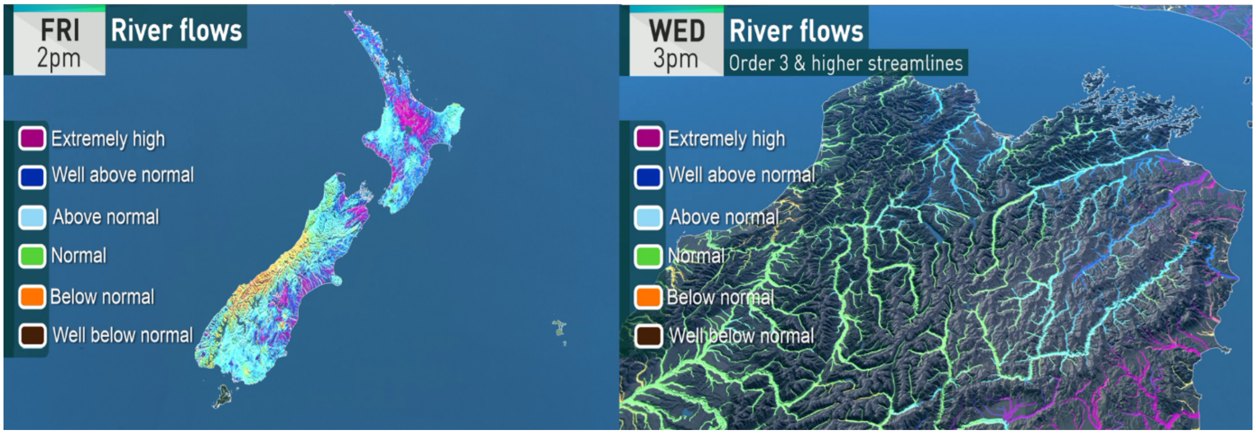

Figure 1: Flow forecasting video snapshots using a basin overview layer (left) and river network layer (right).

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THE INFLUENCE OF UNSATURATED ZONE DRAINAGE STATUS ON SHALLOW GROUNDWATER REDOX CONDITIONS IN REPOROA BASIN

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Aim

To investigate whether a soil characteristic with national GIS data coverage, like the soil drainage class, could help identify areas of reduced groundwater redox status and subsurface denitrification in order to better predict the effect land use has on the local freshwater ecosystem.

Method

Eight shallow (≤ 6 m deep) wells were installed along a 5 km transect in the Reporoa Basin, with soil drainage status ranging from well drained to very poorly drained (Fig. 1). At each well, groundwater was sampled at multiple depths using a mini bladder pump and packer system. Field measurements (DO, pH, EC, temperature, ORP) were taken and samples were analysed for various N, P, and C species as well as the stable isotopes of nitrate (NO_3^-), dissolved gases (dinitrogen, argon, nitrous oxide and methane), and at selected depths, tritium. The predominant reduction process occurring at each sampling depth was determined using thresholds modified from McMahon and Chapelle (2008) and Stenger et al. (2018).

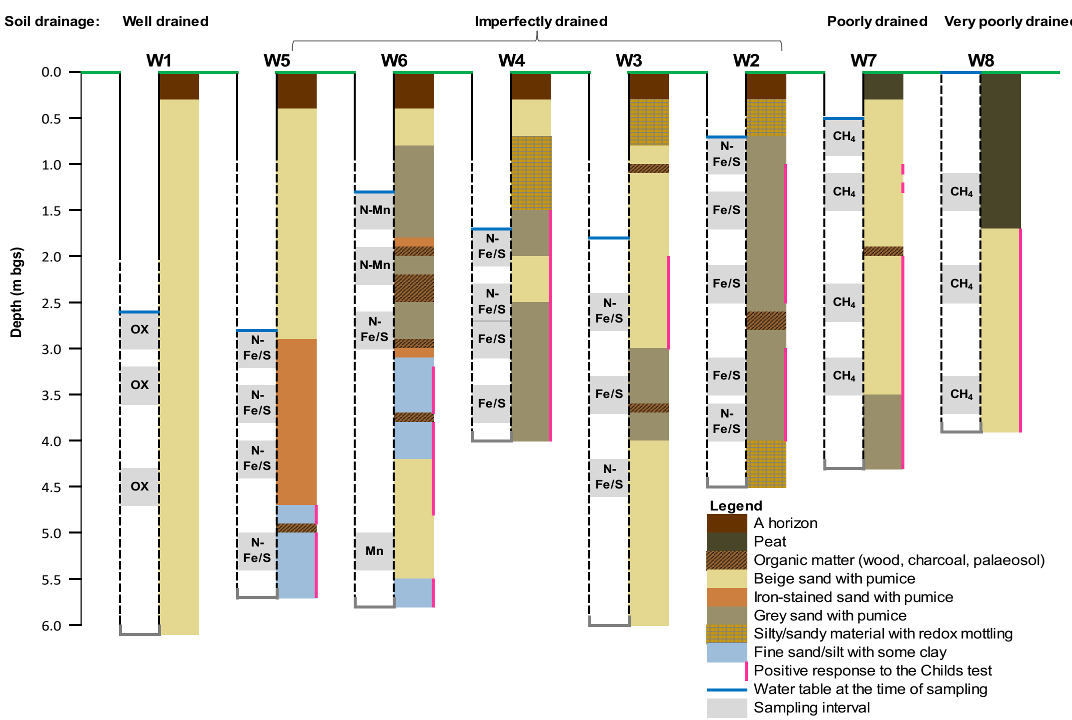

Figure 1: Subsurface profiles documented across the transect, ordered by unsaturated zone drainage status. Modified thresholds (from McMahon and Chapelle (2008) and Stenger et al. (2018)) were used to classify the dominant redox process occurring at each sampling depth: OX = oxic, Mn = manganese reduction, Fe/S = iron and sulphate reduction, CH_4 = methane generation, N-Mn = a mix of nitrate and manganese reduction, N-Fe/S = a mix of nitrate and iron and sulphate reduction.

Results

The well drained site W1 had oxidised groundwater redox conditions throughout the profile (Fig. 1), with relatively high concentrations of nitrate + nitrite nitrogen (NNN), of up to 9.6 mg L^{-1} (Fig. 2), reflecting the nutrient losses of dairying from a freely draining Pumice soil overlying Taupo Ignimbrite deposits.

Apart from W1, all sites had dissolved oxygen (DO) concentrations < 2 mg L^{-1}, even directly at the water table, indicating that reduction processes were already occurring in the imperfectly to very poorly drained unsaturated zone. This was reflected in the NNN concentrations measured, which except for W5 and W6, were all < 2 mg N L^{-1} throughout the profiles sampled (Fig. 2). The somewhat elevated NNN measured at W5 and W6, combined with other geochemical parameters such as dissolved gases and isotopic signatures suggested that denitrification was actively occurring there in the saturated zone. This is in contrast to the also imperfectly drained sites W3 and W4, where geochemistry indicated that the dominant reduction process had progressed past the denitrification stage.

The groundwater sampled at the poorly and very poorly drained sites (W7 and W8) was strongly reduced, with methane generation as the dominant reduction process (Fig. 1). However, the concentrations of dissolved gases, isotopic signatures (where available), and estimated mean residence times (50 to >110 y) demonstrate that the very low concentrations of NNN at these sites were due to the high age of the groundwater rather than being a result of denitrification in the saturated zone.

Figure 2: Concentration profiles of nitrate + nitrite nitrogen (NNN) measured in the groundwater samples from the Reporoa Basin

Conclusions

In contrast to the situation previously described for a well field in the Lake Taupo catchment (Stenger et al., 2018), the data from our well transect in the Reporoa Basin suggest that a high degree of oxygen and nitrate reduction processes is already occurring at Reporoa in the vadose zone. The soil zone drainage class is therefore a useful indicator of the groundwater redox status, but it is crucial to recognise that the drainage class mapped in S-map may not be representing actual conditions at a particular monitoring site.

Acknowledgement

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NATURAL BACKGROUND NUTRIENT YIELDS IN THE RUAMAHANGA RIVER CATCHMENT - A COMPARISON OF OVERSEER AND INSTREAM WATER QUALITY DERIVED NUTRIENT GENERATION YIELDS FOR NATIVE FOREST CATCHMENTS

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Aims

Regional Councils across New Zealand are setting freshwater objectives (FWOs) for in-stream nutrients. In-stream nutrients can come from anthropogenic sources, such as agriculture, and from natural sources. The anthropogenic nutrient yield can be reduced through management techniques however cannot be reduced below the background catchment 'natural yield', that is the nutrient yield that would occur were the entire catchment native forest or other native landuse. To assist Greater Wellington Regional Council in setting FWOs for the Ruamahanga catchment, the potential background 'natural load' for the Ruamahanga River catchment was reviewed.

The objective of this assessment was to identify whether the OVERSEER loads are suitable to be used as background 'natural loads', representing an unmodified system prior to human development. An assessment of instream nitrate-nitrogen (Nitrate-N) and total phosphorus (TP) yields (kg/ha/yr) for native forest catchments, using water quality monitoring data, was undertaken to compare against OVERSEER modelling input data.

Method

There are six GWRC water quality monitoring sites in the Ruamahanga catchment which have catchments with predominantly (93-99.7%) native forest land use. The sites were primarily based in the Western Hills (Tararua and Remutaka Ranges), with one site also present in the Eastern Hills (Haurangi Ranges). Two methods were considered to determine the yields from the catchment upstream of the various monitoring sites. Both methods utilised flow data from either concurrent flow and water quality stations, or in the absence of flow data, nearby catchments. Mean annual in-stream loads were calculated for each WQ monitoring site using the two different methods to analyse the last 5 years of monthly nutrient concentrations:

- Method 1 – 'coarse' calculation, utilising mean concentrations and calculated mean annual flows to calculate the mean annual attenuated load; and

- Method 2 – a more accurate approach, involved the assignment of water quality samples to ten 'flow bins', which are represented by each 10th percentile from a flow duration curve. The average flow and concentration within each bin were then used to compute an average flow-weighted load, and then translated into an average flow weighted attenuated load (Roygard, McArthur and Clark, 2011).

A generic attenuation factor (representing processes such as in-stream removal and denitrification) of 0.5 was applied to both methods to translate 'attenuated' loads (kg/yr) to un-attenuated loads and yields generated off the land. This allows direct comparison to the OVERSEER yields assigned in modelling for Nitrate-N and TP.

Results

The resulting generated yields for the Ruamahanga catchment native catchment sites are shown on Table 1.

Table 1: Comparison of generated yields (kg/ha/yr) for Method 1 and 2 at native forest catchment water quality monitoring sites versus input values from Ruamāhanga OVERSEER modelling

Watershed location	Method	Nitrate-N yields (kg/ha/yr)	Total Phosphorus yields (kg/ha/yr)
Western Hills (Tararuas and Remutakas)	OVERSEER leaching map	1.9	0.2
	Instream method 1	2.3	0.7
	Instream method 2	1.9	0.9
Eastern Hills (Haurangis)	OVERSEER leaching map	1.0	0.2
	Instream method 1	0.4	0.2
	Instream method 2	0.6	0.4

The study has found that generally OVERSEER performed well when calculating generated annual yields of Nitrate-N. OVERSEER may be overestimating loads in the eastern hills, however the effects of this on modelling would be minor given the intensive dairy pasture in the catchment. Further studies into the Nitrate-N for native landuse in the low valley catchment could be beneficial to accurately define the background natural load.

This study has found that TP yields are being significantly underestimated in OVERSEER, by a factor of 2–5 times in the native forest catchments. This is particularly evident in the Western Hills, where the high rainfall and steep slopes are likely to be carrying entrained phosphorus within sediment associated with erosion processes.

For water quality monitoring sites further downstream of the native forest catchments, where the water quality catchment land use includes a larger percentage of agriculture, the derived difference in TP reduces to approximately two times greater than the OVERSEER data. This is likely due to a combination of reduced TP erosion loads on the flatter land, greater river flow buffering concentrations, and increased accuracy of the OVERSEER phosphorus models developed for farmland.

OVERSEER has limitations in its phosphorus sub-models as described in Grey et al. (2016) and Freeman et al. (2016), especially for non-agricultural sites. The OVERSEER model takes into account sediment losses from some types of erosion, such as sheet and some gully erosion, however a key limitation is that it does not model P loss to water from river/stream bank erosion or mass flow events (i.e. landslides). Based upon the significant underestimation of TP by the OVERSEER model, the study has shown that OVERSEER does not account for all TP generation yield in the native forest catchments located in the hill areas for the Ruamahanga catchment.

Future models and studies into catchment background 'natural loads' should include a review of native landuse nutrient generation rates, utilising instream water quality data, prior to model development. The inputs to any nutrient model should take into account the soils, rainfall and topography for TP generation yield, and ensure that all sources of erosion are taken into account when deriving the sediment-derived phosphorus load especially in areas of high erosion and rainfall.

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DRY WEATHER DISCHARGES FROM A MONITORED STORMWATER CATCHMENT

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Introduction

Stormwater is known to be a major source of contaminants to aquatic environments within urban areas. Research and monitoring over the past two decades has provided a good understanding of the types of contaminants and the concentrations of these from different land uses and land covers, such as roading, roofing and residential areas (Mills & Williamson, 2008; Kennedy & Sutherland, 2008; Auckland Regional Council, 2010). This monitoring is the basis of many models in use in New Zealand. However, there is somewhat limited information on some land use types, including stormwater from industrial catchments. The available information suggests the stormwater from these catchments can have very high contaminant concentrations and loads. Compounding this, dry weather discharges have been identified as a contributing issue to environmental degradation (Beck & Birch, 2014). Often dry weather discharges are associated with a combination of illicit discharges and failing infrastructure. Illicit discharge of contaminants to stormwater networks can occur at any time, and water quality measurements targeted to storm events may not capture such activities (Beck & Birch, 2012). Information into frequency and quality of dry weather discharges is unknown and goes unmonitored.

Aims

The Whau Catchment Contaminant Survey (Stage 1) was commissioned by Auckland Council and undertaken by NIWA and Pattle Delamore Partners Ltd between July 2017 and June 2018. The main aim of the project was to understand pollutant concentrations during storm events from two mixed industrial catchments (92,454 m^2 and 89,398 m^2) in the Whau Catchment, Auckland. As part of the data gathering process, in-situ multi-parameter sondes were deployed to continuously measure a suite of water quality indicators.

This paper presents some findings from the Whau Catchment Contaminant Survey, namely around "dry weather events" when unusual values of water quality indicators were observed. This in turn indicates the value that is placed on these particular stormwater networks by stakeholders and the community in the catchment.

Method

Rectangular sharp crested weirs were constructed at the outfall of two piped stormwater catchments servicing predominantly mixed industrial land use. Water level was recorded using a stilling well and float-and-counterweight system and flow was calculated using a theoretical rating (ISO, 2017). An in-situ EXO 2 multiparameter sonde measuring dissolved oxygen, pH, turbidity, temperature, oxidation-reduction potential and conductivity was deployed alongside the water level recorder.

Water level (and hence flow) and the water quality parameters were measured and recorded at two minute intervals continuously over the 11 month project period. Automated sampling and deployment of passive sampling equipment (DGT, GAC and Nalgene stormwater first flush bottles) was targeted to storm events. Regular checks of site equipment were undertaken and QA/QC of data was completed to NEMS. Visual reconnaissance of public spaces within each catchment was undertaken during checks of site equipment.

Results and Discussion

During data processing and analysis it was observed that measured levels of the water quality suite often ‘spiked’ when there was no recorded rainfall. This suggests that water quality was influenced by other factors within the catchment. This was observed to happen for some water quality indicators at a regular frequency, and for other indicators at a less frequent interval. At one site, regular spikes of turbidity (>200 NTU) were often observed during the early afternoon on weekdays and visual observation within the catchment confirmed this coincided with washdowns of a topsoil and aggregates supply yard. Less frequently, periods were observed where high values for conductivity coincided with elevated turbidity and low pH, however no visual connection was made with catchment factors for this.

Overall, these dry-weather events were responsible for the highest concentrations on record for conductivity (75,904 µS/cm) and both the highest (10.06) and lowest (2.34) pH values at both sites. At one site the highest turbidity value on record (3,508 NTU) was associated with a dry weather event.

Conclusion

Although the primary aim of this monitoring programme was to sample storm events, the continuous monitoring revealed numerous dry weather events, characterised by either high turbidity, high conductivity or low pH. It is unlikely that these contaminant values represent a natural source within each catchment. Rather, it is proposed that the stormwater network is being deliberately used to dispose of contaminants, despite widespread regional education efforts and local signage.

As the continuous monitoring equipment only measured water quality indicators and not specific contaminants (such as sediment, metals or hydrocarbons) it was not possible to quantify the mass of contaminants discharged during these events and further study is necessary. However, identifying dry weather discharge events may be most useful for identifying areas where community attitudinal change may be possible. Given Auckland’s location adjacent to low energy estuarine and harbour zones where deposition of contaminants into marine sediments readily occurs (plus the lack of flushing flows) (Williamson & Morrisey, 2000), these dry weather event results identify catchments where further education, implementation of best-practice stormwater management and local business engagement could provide tangible improvements in water quality.

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USE OF SONICATION TO BETTER SAMPLE ATTACHED MICROBES FROM GROUNDWATER SYSTEMS

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Background & Aims

Microorganisms are responsible for the majority of the primary production in aquifers and the vast majority of the microorganisms live as biofilms on the aquifer sediment surface (Ugolini et al. 2014). This presents significant challenges for sampling groundwater microbes as only the suspended microbes will be sampled through normal pumping. Methods to obtain attached microbes include coring, which is expensive, destructive and can be technically difficult for many aquifer materials, and growth of microbial biofilms on artificial or natural sediment samples placed down a well for a period of months, which is very time consuming. The use of a down-hole low frequency sonicator has been suggested as a method of detaching microbes from the biofilm and allowing rapid sampling of this community.

The aims of this project were to develop a low frequency sonicator that would work at a wide range of well depths and evaluate its performance for a range of well depths, casing types and diameters.

Methods

Ugolini et al. (2014) demonstrated the potential of using sonication to detach microbes from aquifer biofilms. Concrete vibrators operating at a frequency of 200 Hz were successful showing an increase in extracted microbes of up to 13 times. The depth in the study was limited to about 1 m below the groundwater table. Previously we have extended the use of the concrete vibrator to a depth of 8.5 m bgl by adding an extension length (Huynh et al. 2015). The concrete vibrator generates the vibrations at the surface and transits them to the probe via oscillating metal rods. However, the concrete vibrators are limited to a depth of around 10 m, even with using an extension. We have developed two electric sonicators that are small enough to go down 50 mm and 100 mm wells, respectively. These sonicators produce the vibrations down the well at the required depth using an electric motor with an offset cam. This design overcomes the depth limitation of the previously used concrete vibrators. They are powered by 12 or 24V batteries.

Wells were sampled from the Hawkes Bay, Nelson, Southland and Canterbury regions. A pre-sonication sample was collected and then the wells were sonicated for 3 minutes with the electric sonicator while being pumped. A post-sonication sample was collected at the end of the sonication period. The samples were analysed for heterotrophic plate count (HPC) and turbidity. Sampling were also sent away for Next Generation Sequencing to provide information on microbial community composition but those results are not reported in this presentation.

Results

A total of 52 samples were collected from 48 wells (4 samples were collected from the same wells approximately 3 months later). HPC counts increased an average 30-fold and turbidity values increased on average 100-fold. There was a wide range in the increases in HPC and turbidity. The influence of well diameter, depth below the water table, well screen material and water chemistry will be discussed.

This study is funded by the Biological Heritage National Science Challenge “Indicators of groundwater biodiversity and ecosystem health” project, by the ESR SSIF-funded “Groundwater Health Index” project, and by the ESR SSIF-funded “Enhanced Mitigations of Nitrate” project.

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INVESTIGATION OF METHODS TO PREDICT GROUNDWATER REDOX STATUS WITH VARIABLE AMOUNTS OF AVAILABLE WELL DATA

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Background & Aims

The redox status of a groundwater system is a key factor determining whether any denitrification will take place as nitrate is being transported through the groundwater system. As the amount of denitrification can vary between zero and 100% it is necessary to have good estimates of denitrification when considering loading of nitrogen to receiving waters or trying to spatially optimise land use, land management, or environmental policies. This study is part of a Sources & Flows, Our Land & Water National Science Challenge project, and is working towards having national coverage of regional scale groundwater redox state maps to assist with resource management and policy development.

A method has been developed to predict groundwater redox status relevant to denitrification at a regional scale using a data driven approach (Close et al. 2016). This was developed in the data rich regions of Canterbury and Waikato. It was extended to the Southland region (Wilson et al. 2018). There are significant areas of New Zealand where there are much less available groundwater quality data for deriving a regional scale map using this approach. In addition, investigations had indicated the presence of bias within the models due to a skewed distribution of observations (most wells were oxic) and a lack of observations relative to the total range of possible attribute combinations.

The aims of this work were to develop robust regional scale models of groundwater redox state that accounted for bias in the observational data, and could be used in areas with a limited number of water quality data from wells.

Methods

There are two types of data required for the model derivation: suitable groundwater quality data from wells at a range of depths, in particular parameters such as NO_3, Fe, Mn, SO_4 and O_2, and complete GIS layers for relevant environmental parameters from domains such as geology, soil, topography and hydrology.

These methods were applied in 3 regions; namely Waikato, Wellington and Tasman. Groundwater quality data were obtained from the regional and district councils. A range of hydrological and physical attributes such as mean low flow, depth to groundwater table, rainfall and PET, were included in addition to the geological, soil, topography and land cover parameters that were used in the previous studies. Principal components analysis was applied to create a correlation matrix so that we could reduce the dataset from an initial total of 22 attributes to more manageable 14 attributes for linear discriminant and random forest modelling.

In previous studies separate redox maps had been derived for different groundwater depths. In this current study, a combined shallow to deep model was derived for each region to maximise the amount of available data for deriving the models and to focus on the impact of data quantity. Cohen's Kappa statistic was used to identify the model predictive power as it takes the agreement due to chance into account. The impact of decreasing amounts of observational data from groundwater wells was assessed by reducing the amount of data from 100% to 20% in 20% increments.

Results

There were 588, 463, and 689 wells with suitable water quality data available for the Waikato, Wellington and Tasman regions, respectively (see Table 1). Maps of redox status together with associated depths were prepared for the program.

Table 1: Sample redox status statistics for the three study regions

	Tasman		**Wellington**		**Waikato**	
	Sampled	**%**	**Sampled**	**%**	**Sampled**	**%**
Oxic	598	86.8	376	81.2	375	63.8
Mixed	39	5.7	38	8.2	105	17.9
Reduced	52	7.5	49	10.6	108	18.4
Total	**689**		**463**		**588**	

Two sources of model bias were detected in the models when a null-case test was applied to the data (the relationship between observations and attributes was randomised). Bias is apparent in the model performance statistics, which can show a high predictive accuracy, but a very low kappa value (Table 2). The first source of bias is caused by a preferential selection of attributes during the random forest bootstrapping process. This bias was corrected for by using the "cForest" model in R. However, removal of this bias decreased the model kappa values, which indicates the presence of a second form of bias. This second form of bias comes from sample selection, and arises from the sample populations being unequal. In this case the dataset is overwhelmingly oxic, and the model accuracies reflect the proportion of oxic samples in each dataset (compare Table 1 and 2).

Table 2: Model performance metrics for the different models used

	Tasman		**Wellington**		**Waikato**	
	Accuracy	Kappa	Accuracy	Kappa	Accuracy	Kappa
cForest null-case	0.835	0	0.800	0	0.648	0
cForest (unbiased)	0.839	0.14	0.808	0.13	0.655	0.10
LDA	0.874	0.28	0.841	0.34	0.668	0.22
Hybrid ML model	1	1	0.922	0.98	0.757	0.87

A new hybrid machine learning method was developed to overcome the problem of sample selection bias. The details of the new model development and the data synthesis procedure will be given in a companion presentation by Mike Friedel. The results of the impact of decreasing amounts of observational data from groundwater wells will be presented.

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CALIBRATION OF A SCANNING X-BAND RAIN RADAR WITH A VERTICALLY POINTING DOPPLER KU-BAND RAIN RADAR

Andrew Coffin[1,2], Luke Sutherland-Stacey[2], John Nicol[2], Geoff Austin[1,2]
[1]University of Auckland, [2]Weather Radar New Zealand Ltd

Aims

Accurate calibration of scanning radar systems is essential for making unbiased estimates of rainfall, as well as properly estimating path integrated attenuation (Nicol and Austin, 2003).

The radar measurement (returned power, P_r) depends on both the scattering reflectivity (Z) of the rainfall and attenuation due to rain between the target and radar (both of which vary) and fixed parameters such as the dish gain, operating wavelength and pulse length and attenuation and signal loss factors in the receiver. For simplicity, the radar equation is often re-written to combine all the fixed parameters in one unknown radar constant (C), and neglecting path integrated attenuation:

$$P_r = \frac{CZ}{r^4}$$

where r is the range to the target. While some of the parameters contributing to C are fixed, such as the dish gain and operating wavelength, other parameters such as the end-to-end performance of the radar receiver or transmitted power are difficult to measure directly or may change as the equipment ages, making any "factory" calibration of the radar system unreliable.

One approach for field calibration of X-band radar for measurement of rainfall is to simply find a C which ensures optimal long-term agreement between nearby rain gauge measurements (R) and the radar rainfall estimation, by applying the Marshal-Palmer raindrop size distribution ($Z = 200R^{1.6}$). However, the assumption of a fixed drop-size distribution will almost certainly in turn lead to biases in estimation of C and in turn errors in estimation of Z and the path integrated attenuation. Similarly, distrometers may also be used.

An alternative approach is to calibrate the X-band radar directly against another, better calibrated, radar system. In this work we develop a procedure for calibration of scanning radar against a co-located vertically pointing doppler radar, which can be easily calibrated in a laboratory setting, does not degrade in performance over a timescale of years as pulsed radar systems do, and as it estimates R directly from the doppler reflectivity spectra, may be directly validated against a local tipping bucket rain gauge.

Method

Two University of Auckland manufactured X-band radars (for a description see Sutherland-Stacey et. al. 2011), a vertically pointing radar (MRR-2, Metek GmbH) and an array of four tipping bucket rain gauges were run over the summer of 2017/2018 at the University of Auckland Atmospheric Physics field site at Ardmore in South Auckland. Both X-band radar were run in vertically pointing mode to allow direct comparison of with the MRR-2. The MRR-2, having been previously calibrated elsewhere, was first validated as being unbiased compared to the local tipping bucket gauge network. C for each X-band radar was then found by minimising the difference between the MRR-2 reflectivity measurement in a range bin thought to be high enough to be free of ground clutter and low enough to be relatively unaffected by attenuation at moderate rainfall rates.

Results and Significance

Both X-band radars were found to have very different radar constants. This is unsurprising given the physical differences between the dish and feed horns attached to each radar and age of the transceivers and magnetrons. After calibration with their respective constants and application of climatological a Z-R relationship determined from the MRR data, the X-band radar rainfall estimates agreed much better with the co-located rain gauge measurements. The new radar constant was also applied to re-calibrate previously logged PPI (Plan Position Indicator) data to generate calibrated spatial rainfall estimates. This data also compares more favourably with nearby Auckland Council rain gauge records.

This work is significant for radar users in New Zealand because the methodology could equally well be used to directly calibrate reflectivity measurements made by the C-band radars which comprise the national rain radar network. The methodology could be applied by co-locating a vertically pointing radar at each C-band radar and including a vertically pointing measurement in the current radar scan procedure in order to allow long-term performance monitoring of the C-band radar.

References

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POTENTIAL HYDROPOWER GENERATION UNDER DUTURE CLIMATE CHANGE

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Aims

Hydropower supplies approximately half of New Zealand's electricity. Driven by inflows to major lakes and rivers, this supply is entirely dependent on the amount and timing of precipitation and snow- or ice-melt. As the climate changes this century, these inflows are also projected to change, with implications for hydropower supplies. This is particularly important for the wider energy sector as hydropower is among the more climate-neutral energy sources, and as the country's vehicle fleet transitions from fossil fuels to electricity.

Method

River flows across New Zealand were simulated for the period 1972-2099 using down-scaled and bias-corrected climate simulations from six Global Climate Models (GCMs) and four Representative Concentration Pathways (RCPs). Multiple GCMs help to contain climate model error (epistemic uncertainty), while multiple RCPs encapsulate different plausible global emissions futures ranging from rapid decarbonisation of the global economy to business as usual. Monthly inflows to six major hydropower schemes (North Island: Waikato, Matahina, Waikaremoana; and South Island: Waitaki, Clutha, and Manapouri), collectively accounting for over 80% of the country's generating capacity, were converted to potential hydropower generation. Differences and trends in the resulting time-series were analysed using the Kolmogorov-Smirnov and Mann-Kendall ranking tests, with a significance threshold of 5%. Results were considered robust if at least four of the six GCMs produced the same pattern.

Results

Changes in future potential hydropower generation under climate change varied across the six hydropower schemes, six GCMs, and four RCPs. The three North Island schemes tended to show declines in potential generating capacity, although only three of the six GCMs at most showed statistically significant declines. More of these schemes exhibited significant declines for the more extreme emissions scenarios. Conversely, the three South Island schemes tended to show increases in potential generating capacity, with more GCMs producing statistically significant differences, and hence more robust results. Again, more significant trends were present under the more extreme emissions scenarios. Combined nationally, the six schemes studied here are projected to generate more (potential) hydropower under future than under present-day climates.

PLAN CHANGE 2 – WHAT IT MEANS FOR NUTRIENT MANAGEMENT AND FARMING

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Introduction

Horizons' regional plan, the One Plan, employs a system of nutrient management where nitrogen (N) leaching maximums from farms are determined by Land Use Capability (LUC) class with a sinking lid on leaching over a 20-year period. Values in Table 14.2 of the One Plan were derived from version 5 of OVERSEER®, which were appropriate in 2007 when the scheme was developed, but the Table has since become out of date as OVERSEER® was updated. Therefore, managing nitrogen leaching within the Region has become adversely affected between the disconnect of Table 14.2 and up-to-date versions of OVERSEER® being used to estimate farm leaching. Proposed Plan Change 2 updates the leaching numbers to those calculated using the latest version. This presentation explores the implication of those changes for the river and the farmer.

Methods

To determine the updated values in Table 14.2 for each LUC class, the equivalent input data used in OVERSEER® v5.2.6 was then entered into OVERSEER® v.6.2.3. The inevitable increase in N leaching maximums led to a reassessment of the N transmission coefficient (i.e. attenuation) to best match N loads measured in the river. Subsequently, an assessment was made of how many farms the new N leaching maximums would be able to get consent under the restricted discretionary rule compared to the original Table 14.2 values.

Results

The N leaching maximums obtained with OVERSEER® v6.2.3 were 32.5 – 66.0% higher than the original Table 14.2:

LUC* I	LUC* II	LUC* III	LUC* IV	LUC* V	LUC* VI	LUC* VII	LUC* VIII
51 ~~30~~	45 ~~27~~	40 ~~24~~	29 ~~18~~	25 ~~16~~	24 ~~15~~	11 ~~8~~	3 ~~2~~
46 ~~27~~	40 ~~25~~	35 ~~21~~	25 ~~16~~	22 ~~13~~	19 ~~10~~	8 ~~6~~	3 ~~2~~
44 ~~26~~	37 ~~22~~	32 ~~19~~	23 ~~14~~	20 ~~13~~	17 ~~10~~	8 ~~6~~	3 ~~2~~
43 ~~25~~	35 ~~21~~	30 ~~18~~	21 ~~13~~	19 ~~12~~	16 ~~10~~	8 ~~6~~	3 ~~2~~

The increased N leaching maximums do not imply that more nitrogen is being leached to rivers and waterways. The N load measured in the river is fixed (or at least not determined by OVERSEER® leaching estimates), therefore the transmission coefficient must change accordingly. To fit the measured river N loadings, the transmission coefficient had to be reduced (i.e. attenuation increased) from the previous estimate of 0.5 for each LUC class. The updated OVERSEER® values come closer to previous estimates of N attenuation in the catchment that have been previously calculated (Elwan, 2015). Furthermore, without an increase in the river N loading as a result of this change, the new N leaching maximums will allow farmers to gain consent within the restricted discretionary rule while still achieving as much N leaching reduction as originally planned. The river will also see the same reduction in N as intended. These changes demonstrate how much more accurately Horizons' nutrient management tools and regulation will reflect natural systems.

Reference

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THE WORLD CATALOGUE OF FLOODS – ARE THESE FLOODS OUTLIERS?

Rob Connell[1]
[1]*Self*

Ten rivers discharges in water catalogue of largest observed floods were compared with other floods in their annual maxima flood series to see if these floods were outliers. Analysis showed that 3 of the floods were outliers, 2 could be outliers and 5 floods were 100 year floods or less.

Introduction

The world catalogue of the maximum observed floods, Herschey (2003), Rodier and Roche (1984) contains the largest floods recorded for catchments between 12 km^2 to the world's largest river the Amazon at 4,640,000 km^2.

Aims

This analysis plotted the other or all annual flood peaks on each river to investigate whether the maximum observed flood was an outlier or not, i.e. it statistically fits into the river's flood series.

Method

For ten rivers in the world catalogue of maximum floods, an analysis was undertaken of all the flood discharges given in the catalogue (normally several floods) together with an internet search to find the annual flood series and any changes to the discharges from updated information.

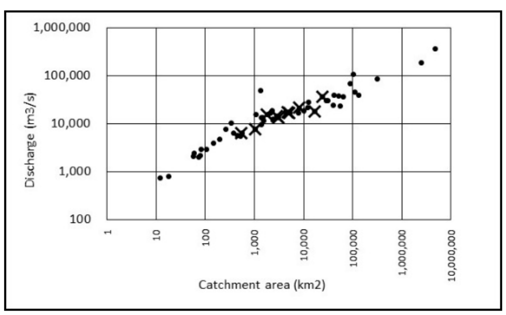


Figure 1: Rivers analysed, "**X**", from 500 to 20,000 km^2 and the whole catalogue data "•".

The criteria to decide whether the maximum observed flood was an outlier were the Grubb test and/or else graphical analysis, if the flood series only contained one or several other large floods, that came within 80 % of the maximum observed flood.

Results

The analysis found that the maximum flood; on three of the rivers were outliers; on two rivers were possibly outliers and on five rivers were about 100 year floods. Gumbel plots of the flood series are below. The plotting positions are subjective, Connell and Mohessen (2016).

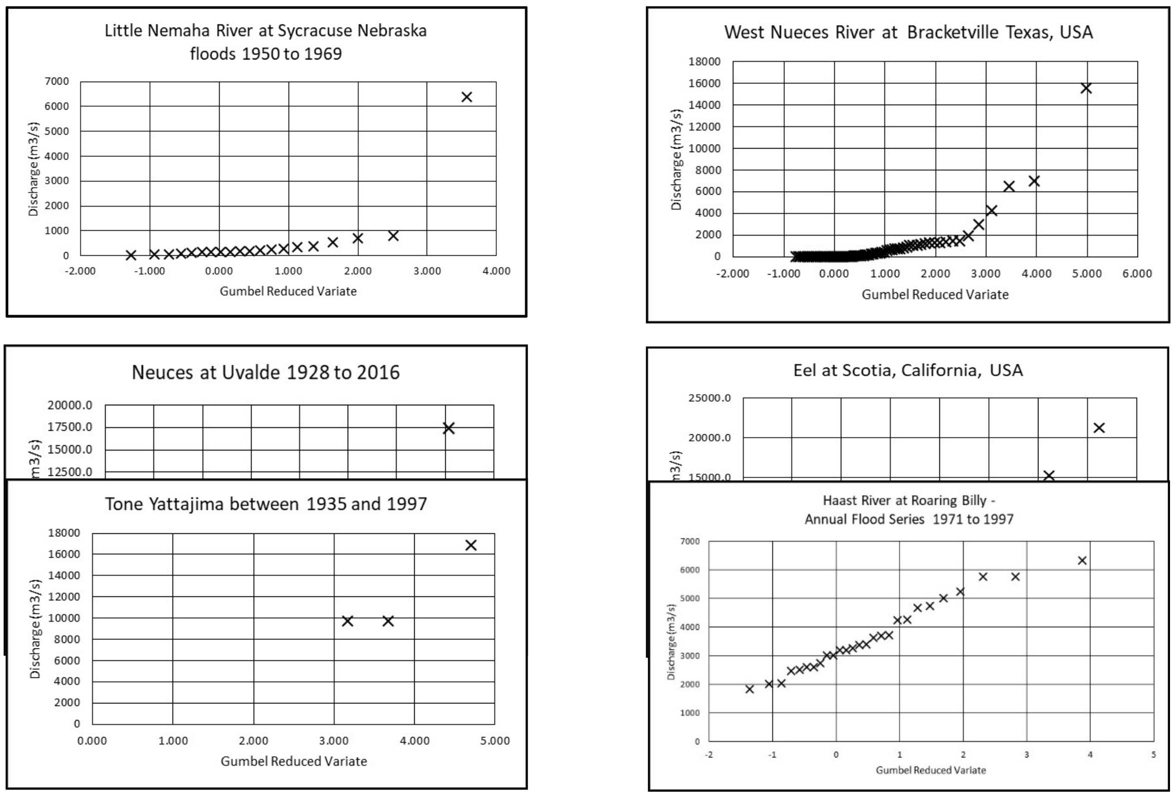
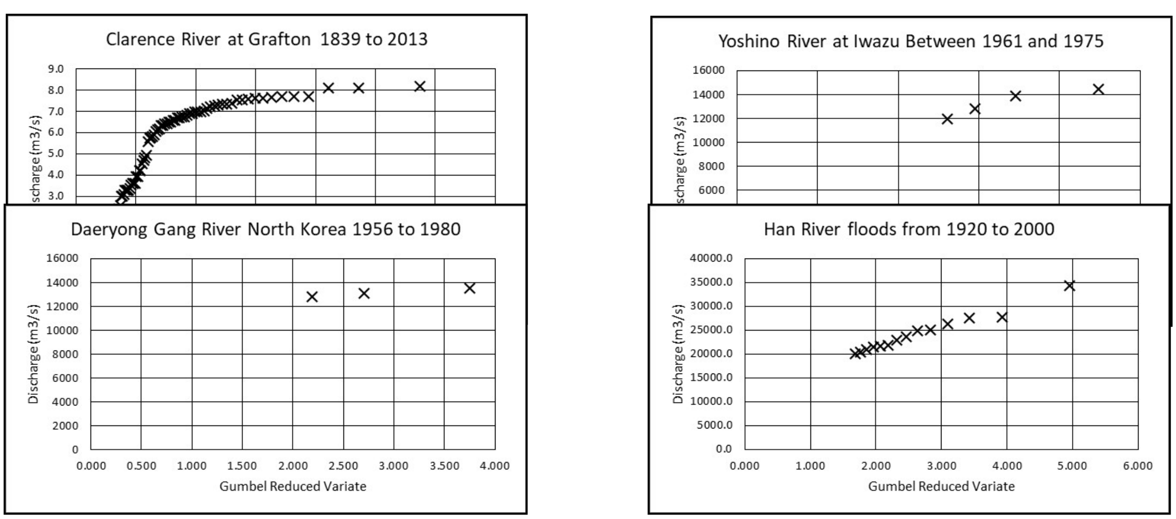


Figure 1: Gumbel plots of all the rivers analysed.

Table 1: list of rivers and their estimated outlier category

Probable outliers	Catchment Area (km^2)	Observed flood m^3/s
Little Nemaha, Syracuse	565	6,371



W. Nueces, Bracketville	1,797	15,600
Nueces at Uvalde	4,820	17,400
Possibly outliers		
Eel at Scotia (outlier by Grubb)	8,062	21,300
Tone Yattajima	5,150	16,900
100 year flood or less		
Haast River, New Zealand	1,020	7,690
Clarence River, Australia	16,690	18,300
Yoshino River, Japan	2,810	14,470
Daeryong Gang, North Korea	3,020	13,500
Han River, South Korea	26,000	34,400

References

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BETWEEN TWO OCEANS: AUCKLAND'S URBAN AEROSOL

Guy Coulson[1], Gustavo Olivares[1], Sally Gray[1], Oliver Wilson[1]
[1]*NIWA*

Aims

Auckland, the largest city in New Zealand, is unique in being the largest city in the World to be almost completely surrounded by ocean and hence have no up or downwind sources of pollution. The city lies on a narrow isthmus between the Pacific Ocean and the Tasman Sea. Because of the lack of outside sources, average urban background concentrations of between 1000 and 4000 particles/cm^3 are common away from major sources with very steep concentration gradients approaching sources such as roads (Pattinson et al., 2014). Consequently, Auckland's typical urban aerosol tends to be similar to other cities in character but with lower concentrations (Coulson et al 2015).

The Aerosol Tropospheric Chemistry in Urban Auckland (ATChU) experiment aimed to track the changes in aerosols and aerosol precursors as they move from open-ocean (clean background) across the city (polluted) and out into ocean again. Auckland has two prevailing wind directions WSW from the Tasman and ENE from the Pacific, so a transect along this line will almost always be in the prevailing wind direction.

Method

The experiment measured various aerosol parameters including composition, Black Carbon, particle number and size distributions along with gaseous pollutants simultaneously at three points across Urban Auckland, one on the upwind coastal urban edge, one in central Auckland and one on the downwind coastal urban edge for a period of approximately one month during March and April 2015.

Results

Results from the west coast site have a similar character to the central Auckland site but with lower concentrations and a noticeable marine influence, whilst the east coast site has a more marine character with some urban influence. This presentation will examine results from the ATChU campaign with an emphasis on looking for the urban influence in a marine setting.

References

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Acknowledgements

Thanks to Melita Keywood and Paul Selleck at CSIRO for measurements of chemical composition. This work was funded by NIWA under the Strategic Science Investment Fund - Impacts of Atmospheric Pollution Programme.

WATER AND THE HYDROLOGICAL CYCLE – THE SOURCE OF LIFE, BUT A MAJOR DRIVER OF FUTURE HAZARDS

Simon Cox[1]
[1]*GNS Science*

Our naturally evolving climate has been radically influenced by human activity. As we shift deeper into the Anthropocene, climate change is about to have some very profound effects on the hydrological cycle that will determine where, and how, populations can exist. Climate change has already started affecting the availability of freshwater resources, but there are equally significant changes occurring to our hazardscape. Increased frequencies of events such as drought, wildfire, surface water flooding and coastal surge are perhaps the most well-known, but there are less-obvious yet equally important changes to groundwater, and the associated natural hazards such as groundwater flooding and land inundation.

Challenges of downscaling

The global picture that climate is changing and sea-level is rising now seems reasonably well-established, albeit bound by a wide range of uncertainties. We have a probabilistic understanding of global sea-level rise and national climate scenarios that are constantly improving. The exact nature of local effects, however, are far less clear. There are significant challenges and problems associated with **downscaling** from regional to local models. Downscaling involves a shift from general probabilistic scenarios to a deterministic understanding of where and how often the effects will be felt. It requires holistic understanding of natural systems and the processes that can perturb their present state. Local (cf. global) processes and impacts of climate change and sea-level rise are for the most-part still poorly quantified/understood, with significant **temporal** (frequency) and (perhaps more importantly) **spatial** uncertainty in the hazards faced across our communities. Understanding the spatial reach of hazards, and how various hazards interplay, is becoming an expectation for planning and mitigation. It will be increasingly important in the near-future, but requires significant science investment and lead-in time from research to practice.

Constraining spatial uncertainties - example

Mapping of the shallow groundwater table in Christchurch exemplifies applied science to constrain spatial and temporal uncertainties that has resulted in a major evolution of our understanding of local groundwater. Following the 2010-2011 earthquakes, a network of shallow monitoring wells was installed for geotechnical purposes. Initial models generated with 806 wells had subtle differences depending on whether only sites with longer-term (>9 months) records were used, or a larger dataset that included <9 month records with proxy values inferred for annual variability (van Ballegooy et al., 2013). A statistically more-robust version (van Ballegooy et al., 2014) used median values from ~967 monitoring wells over a longer-period accompanied by statistical surfaces (e.g. 15th & 85th percentiles) to account for the range of seasonal fluctuations. Depth to water models were determined by subtracting water table elevations from LiDAR surveys of land elevation.

The large number of wells and new LiDAR data enabled groundwater mapping in Christchurch with unprecedented spatial resolution. Only a small subset (44) of wells, however, had records continuous through the earthquake-cycle with extended long-term (>20 year) decadal records. Data from these wells raised questions as to the influence of earthquakes on the water table, highlighted the occurrence of inter-annual variation, and raised issues around long-term climatic trends. In addition, since water table surfaces at each site were incremented observations over a period ~3 years, the maps were not instantaneous measures of the potentiometric surface at any one time, so could not be assumed to be valid indicators of the gradient and direction of groundwater flow. Although the scale of water table monitoring in post-earthquake Christchurch far exceeded anywhere else in New Zealand at the time, and is likely to be amongst the most-extensive of any cities in the world, the water table mapping provided for earthquake recovery was accompanied with strong caveats around temporal uncertainty.

Constraining temporal uncertainties and observing processes

Investment into shallow groundwater monitoring in Christchurch was rationalised by the Earthquake Commission (EQC) in late 2016, when manual dipping (then at 967 sites) was replaced with automated transducers at ~250 sites. Although spatial resolution was decreased, the new network measuring both temperature and pressure at 10 min intervals provides a step change in temporal resolution. Data spanning 24/09/2016-4/09/2017 has been processed by John Haines into a series of movies with 5516 instantaneous surfaces, 1.5 hours apart. Interpolation was achieved using radial basis functions in triangular grids between sites. The movies characterise relative elevation, rate of vertical change and horizontal gradient of the water table, as well as absolute temperature and rate of temperature change. Statistical damping of data over different time-steps highlight fluctuations caused by tidal, rainfall and seasonal forcing. Recharge from rainfall and rivers, cyclones Debbie (5/04/2017) and Cook (14/04/2017), spring tides, as well as areas of anomalous heat-flow, clearly influenced groundwater during 2016-17. The movies provide a unique and unparalleled visualization of Christchurch's shallow groundwater system.

Hazard modelling application

Christchurch and South Dunedin are examples of vulnerable cities constructed on coastal land underlain by shallow groundwater, where hazards such as liquefaction and flooding vary with seasonal and inter-annual variability in groundwater, and potentially over even shorter time-scales. A new monitoring network presently being installed in Dunedin, following the precedent set in Christchurch, should also provide high-temporal resolution of short-term groundwater responses to rainfall, tides and surface water infiltration. Future needs that can be informed by such data include real-time integration of groundwater data into flood modelling, ground-source heat resources, contaminated sites and time-varying liquefaction prediction. Understanding the groundwater variability and patterns of flow beneath these cities is expected to be critical to infrastructure investment decisions including sewers, storm water, underground services, roading or land development as climate-change and sea-level rise take effect.

Sea-level change is expected to lead to groundwater rise and inundation within both cities, but vulnerability is not a simple function of land elevation. Instead, hazards are strongly dependent on local permeability and hydrogeology. Surface flooding and groundwater inundation work at different temporal (1-10 vs 50-100 year) and spatial (one suburb vs the next) scales. It is perhaps the increased frequency of rain-driven flood events that will be the more-important hazard that first drives a social response. To make zonation decisions around investment for mitigation or managed retreat, both cities need greater clarity about hydrological processes in the subsurface. There is also a need to understand whether rates of landscape change (eg land subsidence/uplift, beach erosion/progradation) is meeting, or exceeding, rates of sea-level change and hazard evolution, and what influence current engineering is having on hazard magnitude and frequency. While steps are now in place to begin addressing these knowledge gaps, there are still deep social issues to explore with regard to how communities should respond and adapt. As technical work continues to refine and downscale hazard information from probabilistic to deterministic models, we need to communicate and embrace the uncertainty associated with downscaling. The process of 'planning for planning' can also be encouraged, rather than waiting for all the answers while climate change takes a greater effect.

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2. van Ballegooy, S., Cox, S.C., Thurlow, C., Rutter, H.K., Reynolds, T., Harrington, G., Fraser, J., Smith, T. (2014) Median water table elevation in Christchurch and surrounding area after the 4 September 2010 Darfield Earthquake. Version 2. *GNS Science report* 2014/18. 79 p + 8 appendices.

Acknowledgements

This presentation will draw on data provided by EQC, NIWA, Christchurch and Dunedin City Councils, Environment Canterbury and Otago Regional Council, amongst others. I would also like to acknowledge work of my collaborators, in particular: John Haines, Emeritus Scientist at GNS Science; Helen Rutter and the Aqualinc team; Sjoerd van Ballegooy and colleagues at Tonkin & Taylor.

EARTHQUAKE-INDUCED AQUIFER LEAKAGE EXACERBATED MANIFESTATION OF LIQUEFACTION IN CHRISTCHURCH, NEW ZEALAND

Simon Cox[1], Sjoerd van Ballegooy[2], Helen Rutter[3], David Hart[4], Caroline Holden[4], Anton Gulley[5], Virginie Lacrosse[2], Michael Manga[6]

[1]GNS Science, [2]Tonkin & Taylor Ltd, [3]Aqualinc Research, [4]GNS Science, [5]University of Auckland, [6]University of California Berkeley

Abstract

Vast quantities of sediment and dirty water repeatedly rose to the surface and inundated Christchurch during the 2010-2011 Canterbury earthquake sequence in New Zealand. Our study suggests the ability of aquitards to confine groundwater was compromised during earthquakes, by subsurface processes such as liquefaction or fracturing, causing aquifer leakage. Upwards flow in areas with positive (above ground artesian) pressure led to subsurface erosion and promoted ejection of liquefied sediment. Aquifer leakage can locally exacerbate liquefaction-induced ground damage and inundate built environments.

Aims

The Canterbury earthquake sequence of 2010-2011 devastated New Zealand's second largest city of Christchurch. Damage has exceeded ~US$15 billion, costing >12% of the country's GDP, and the earthquake sequence has become one of the world's largest and most complicated natural disaster insurance events. As well as intense accelerations and shaking damage, the earthquakes induced liquefaction at a scale rarely seen on our planet, causing widespread differential settlement, foundation damage, lateral spreading, and ejected sediment. As people's homes and properties were repeatedly invaded by sediment and dirty water, and thousands of families were displaced, the term 'liquefaction' became a New Zealand household name. Our work sought to understand whether the extensive ejection of groundwater and sediment might have any correlation with the geological setting of a city constructed on an aquifer system with confined groundwater pressure.

Method

This study examined the two major events of the Canterbury earthquake sequence that both induced widespread liquefaction-related land damage: the Mw7.1 Darfield (4 September 2010, 04:35 NZST) earthquake, and Mw6.3 Christchurch (22 February 2011, 12:51 NZST) aftershock. Collating hydrological, geological, shaking and geotechnical data, we defined the aquifer pressure regime and water table during the earthquakes, then looked at relationships between hydrological parameters, mapped occurrence of ejected sediment and geotechnical parameters used to evaluate site liquefaction vulnerability.

Analysis was carried out in two parts at different scales. Firstly, spatial correlations were assessed across a wider study area straddling the transition from inland semiconfined to coastal confined aquifers, and a wide variety of hydrogeologic conditions and groundwater pressure. Spatial probability distributions show clear relationships between the occurrence of ejected sediment and deep aquifer pressure. However, there is always potential for spatial correlations to be coincidental rather than due some direct causal-relationship. To address any concern and further inform mechanistic explanations, the second part of our examination focused on a more-restricted urban area where liquefaction vulnerability indices from geotechnical testing provide a proxy that account for local variations in shaking, soil strength and water table depth. Geotechnical testing sites within the smaller urban area were grouped according to their expected liquefaction vulnerability, irrespective of their spatial location, then assessed against aquifer pressure.

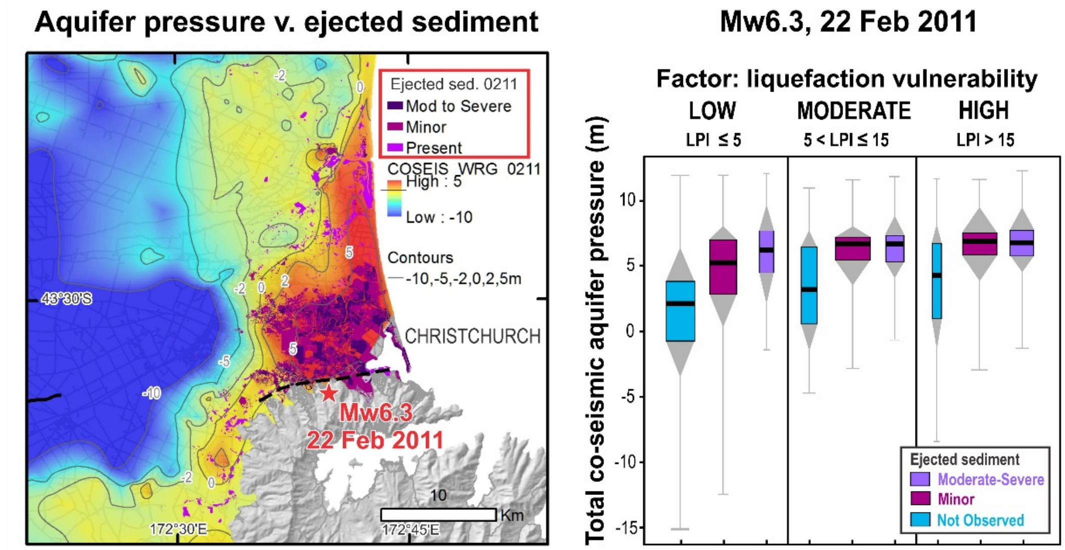

Figure 1: (Left) Map of the occurrence of ejected sediment as observed at the surface after 22 Feb 2011 Mw6.3 earthquake, classified by severity in the Christchurch urban area, overlain on coloured grid and contours of total co-seismic groundwater pressure. WRG refers to water pressure relative to ground, with thin grey-black contours showing where this is at -10, -5, -2, 0, 2 and 5 m. (Right) Ordinal multinomial response of dynamic and total co-seismic pressures at geotechnical testing sites within the Christchurch urban area during the Mw6.3 (right) earthquake. Aquifer pressure parameters are plotted against ejected sediment classes of 'not observed', 'minor' and 'moderate-severe', factored against liquefaction vulnerability categories defined by the Liquefaction Potential Index (LPI) values.

Results

Results from our wider study defined the range of aquifer pressures present before each earthquake and the pressure changes induced by shaking. There are strong spatial correlations between the occurrence of ejected sediment with co-seismic groundwater pressure in deep aquifers during the earthquake (Figure 1 – left). Geotechnical testing sites were then grouped according to liquefaction vulnerability indices (to control variance relating to shaking strength, water table depth and soil profile strength) in the more-restricted urban area. Regardless of whether sites had low, medium or high expected vulnerability during the Mw6.3 shaking, places with minor or moderate-severe ejection were associated with higher aquifer pressure than places where there was no manifestation of ejected sediment (Figure 1 – right). Together with observations of earthquake-induced pressure changes and observed transfer of groundwater from deep aquifers to shallower levels in previous studies, our interpretation is that leakage from aquifers with artesian (above ground) pressure provided an additional driving mechanism for surface manifestation of water and sediment. We argue leakage from aquifers promoted suffusion and piping along flow-pathways and liquefied horizons, which contributed to and locally exacerbated the near-surface ground damage that devastated Christchurch.

The suggested mechanism has implications for evaluating potential for earthquake-induced liquefaction and ground damage wherever groundwater is confined. Where most engineering addresses shallow soil conditions, our study highlights that hazard assessments must consider the wider hydrogeologic environment. We suggest Christchurch sediment ejection is in part related to aquifer leakage, where it has only been attributed to shallow liquefaction in other studies. We provide simple mechanistic explanations of observed data, that help account for disparity between 'observed' and 'predicted' liquefaction in engineering studies and enable predictive tools for investigating variability in the severity and consequence of liquefaction-induced ground damage. Built over aquifers with substantial artesian groundwater pressure, the severity of the observed liquefaction damage in Christchurch was perhaps an extreme example. Although such hazards may not be presently widespread elsewhere in the world, due to drawdown and depletion of urban aquifers, they may become more common as urbanized coastal-plain groundwater is affected by sea level rise. As an extreme example, the devastation of Christchurch enables different mechanisms to be elucidated and understood, so mitigation measures can be applied and others can avoid similar experiences elsewhere.

SOUTH ISLAND WEST COAST RAINFALL – A POLARIMETRIC RADAR VIEW

John Crouch[1]
[1]*MetService*

The west coast of the South Island is the wettest part of New Zealand with an annual rainfall of 2,000-3,000mm about the coast, and greater than 8,000 to 10,000mm about the ranges. Heavy rainfall events are common, and often exceed 100mm in a 24-hour period, with significant spill-over into the headwaters of the main Canterbury and Otago lakes and rivers.

In the 1990s, the New Zealand Southern Alps Experiment (SALPEX, Wratt et al., 1996) was a large multi-faceted study into the influence of the mountains on the distribution of rain and snow fall across the Southern Alps. Observational data was obtained through a combination of local weather stations, rain-gauges, balloon flights, satellite data and research aircraft measurements, but radar observations were limited to an operational MetService C-band single polarisation radar on the Canterbury Plains and two small mobile X-band radars on the West Coast (Purdy et al., 2005).

In November 2011, MetService installed a new dual-polarisation C-band weather radar near Hokitika. This radar has given a new insight into the weather systems along the West Coast and about the Southern Alps. In addition to the normal reflectivity and Doppler velocity fields, the radar provides extra fields by simultaneously scanning precipitation targets in two-dimensions compared to older weather radar which only scan in one direction. These additional radar fields provide new information about the shape and diversity of precipitation targets, allowing forecasters to better identify radar echoes and observe many of the microphysical and mesoscale processes associated with rainfall, snowfall and thunderstorms.

This keynote presentation will describe some of the processes involved in producing heavy rain on the South Island West Coast and Southern Alps, and show how the new radar imagery from Hokitika is revealing these processes to forecasters.

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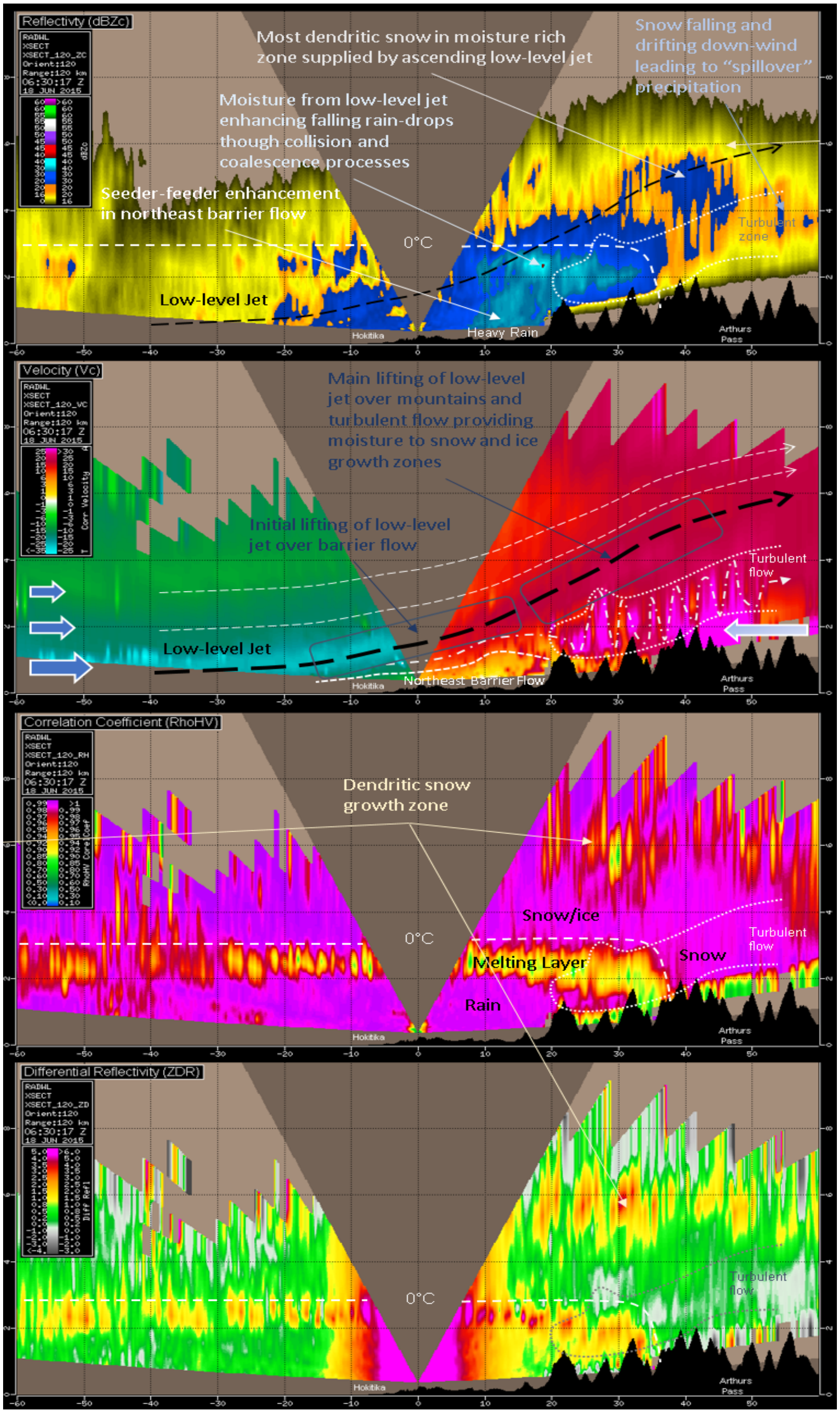

Image 1: Vertical cross-section from the MetService dual-polarisation weather radar at Hokitika (6:30pm, 18 June 2015) showing some of the mesoscale and microphysical processes associated with a heavy rainfall event on the South Island West Coast.

PROTECTION OF DRINKING WATER SOURCES UNDER MULTI-BARRIER RISK BASED APPROACHES FOLLOWING THE HAVELOCK NORTH OUTBREAK

Tony Cussins[1], Brett Chapman

[1]Tonkin + Taylor Ltd

In August 2016, the Havelock North public water supply suffered a major Campylobacter contamination event, resulting in significant illness in the Havelock North community. Recommendations within the December 2017 Government Inquiry Stage 2 report reinforced the critical importance of assessing water supply security and risk mitigation measures under a multi-barrier, risk based approach, including the potential for mandatory treatment of the water supply.

This paper will present the approaches used to establish groundwater source protection zones (SPZs) for the Hastings District Council public water supply, and to evaluate and characterise the risk posed to the supply from contaminant sources within the SPZs.

The HDC approach comprises standard methods to delineate SPZs, followed by a detailed assessment of the available information in the context of Catchment Sanitary Investigation under the Drinking Water Standards for New Zealand, to identify existing land uses and activities that may pose a risk to drinking water safety. A semi-quantitative risk matrix was subsequently developed within the existing GIS system to provide a risk based heat map to locate and visualise high risk elements within the catchment requiring mitigation or management, including treatment as necessary. The GIS based risk assessment tool also provides a basis for statutory controls to manage activities within catchments, related to the level of risk posed to the drinking water supplies, and to prioritise infrastructure works to mitigate risk.

The paper will present current methodologies for assessing the risk posed to public water supplies from contamination within the SPZ, including microbiological pathogens, organic and inorganic contaminants, and emerging contaminants, for example Per- and Polyfluoroalkyl Substances (PFAS) and endocrine disruptors. It will also compare and contrast the various methodologies developed within New Zealand to delineate source areas will be discussed, and evaluated against international best practice.

Keywords

Source protection zones; Water supply security, Risk based, multi-barrier approach to drinking water safety, Water safety plans, Public water supply, Drinking Water Standards NZ; Water supply infrastructure management, Government Inquiry into Havelock North Drinking-Water.

Presenter Profile

Tony Cussins is Technical Director, Hydrogeology for the Tonkin & Taylor Group. He has specialist expertise in contaminant hydrogeology, contaminated land management and human health & environmental risk assessment. Tony's principal experience is in the hydrogeological assessment (including human health and environmental effects) of major infrastructure projects (including water supply projects), and the remediation of contaminated sites and hazardous waste facilities. Tony is regularly called upon to provide expert evidence in consent hearings, the District Court, Environment Court, High Court and a Government Inquiry, on hydrogeology and contaminated land issues. He is an accredited RMA hearings commissioner

CONTROLLED METEOROLOGICAL BALLONS OVER ROSS SEA POLYNYAS

Ethan Dale[1], Marwan Katurji[1], Adrian Mcdonald[1], Paul Voss[2], Wolfgang Rack[1], Daisuke Seto[1]
[1]University Of Canterbury, [2]Smith College, Picker Engineering Program

Polynya within the Ross Sea provide a large source of heat and moisture flux from the ocean to the atmosphere. We compare observations made during our field campaign with forecast data from the Antarctic Mesoscale Prediction System (AMPS). Using these data we explore the near surface influence of open water within the Ross Sea and Terra Nova Bay polynyas on these on air parcels passing over the Ross Sea.

CMET Balloons are controlled helium balloons that are designed to make flights of several days duration at altitudes less than 4km. Throughout their flight CMET balloons measure air temperature, pressure, relative humidity and GPS location. From the GPS location the velocity of the balloon can be derived and therefore the local wind can be inferred. Data is transmitted back by a on-board Iridium satellite phone that is also used to receive commands allowing the balloon to be remotely controlled during flight.

During November 2017 4 CMET balloons were released from Mario Zucchelli Station, Antarctica (74.695 S, 164.114 E). The second and fourth of these flights returned useful data, these were launched on 2017-11-10 at 1300 UTC and 2017-11-22 at 1230 UTC respectively. The first of these flew for 18 hours providing data throughout this time and the final balloon provided over 70 hours of data as it flew north out of the Ross Sea.

Trajectories were calculated within the AMPS data field using a fourth order Runge Kutta method. Trajectories were propagated both forwards and backwards in time over a grid covering the Ross Sea. These simulated trajectories allow both the Eulerian and Lagrangian derivatives of temperature and specific humidity to be calculated. These are then used to compare to balloon measurements to understand the variations in our observations.

The success of the field campaign is encouraging and suggests the possibility of future, more intensive campaigns. The ability the make repeated soundings with a single balloon and the long duration of each balloon make CMET balloons a useful tool that allow measurements to be made that are not possible with a traditional radiosonde.

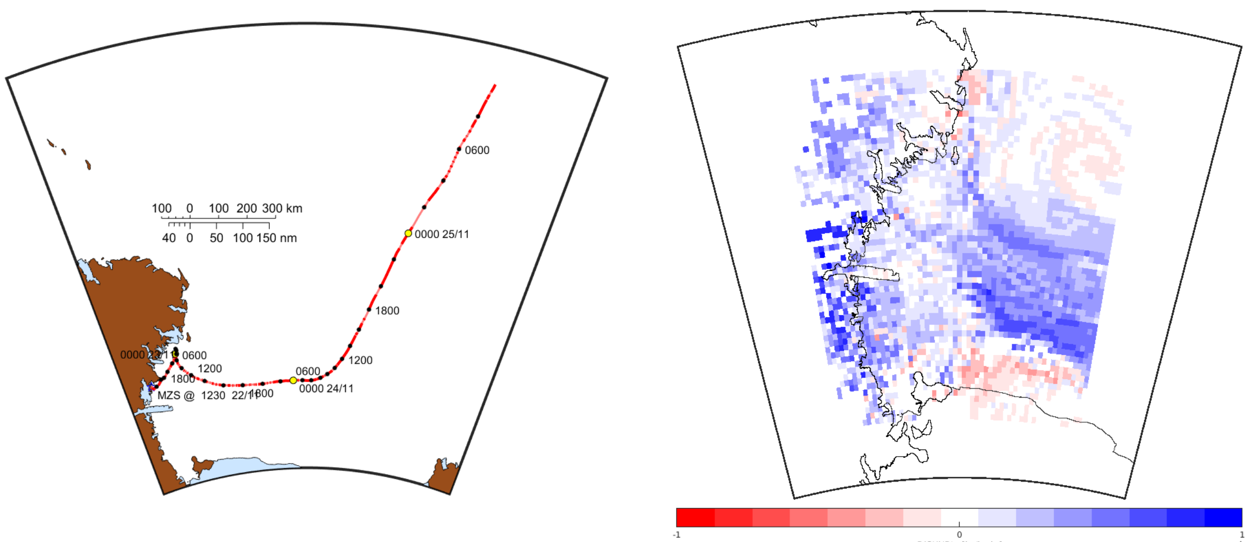

Figure 1: (Left) Flight path for the fourth CMET flight, launched on 22nd Nov 2017. (Right) Lagrangian derivative of specific humidity at 250m altitude on the 23rd Nov 2017

INCREASING COMMUNITY RESILIENCE BY ESTABLISHING EMERGENCY WATER BORES IN FRACTURED GREYWACKE

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[1]Cardno NZ Ltd, [2]Southern Geophysical Ltd

The Wellington City reticulated water supply is piped from the Hutt Valley and Wainuiomata and is likely to be disrupted for a significant period of time following a major earthquake event. The supply pipe crosses the Wellington Fault and runs through areas that are susceptible to liquefaction and shaking. Failure of the supply pipe network may leave areas around the Wellington region without bulk water for up to 100 days.
To increase community resilience, our solution was to find localised drinking water resources in high-risk areas. A comprehensive desktop study identified water wells installed in fractured greywacke as a stable source of drinking water. Geophysical methods were used as a reconnaissance tool at eighteen sites in the Wellington region. Using the geological context from the geophysical profiles, a total of fifteen bores were completed. The success rate was 60%, with nine bores producing sufficient water for establishment of an emergency water resource. It is emphasised that the success rate would have been significantly lower without a prior desktop study and reconnaissance geophysical surveys. The establishment of the emergency drinking water supplies has reduced the impact of a severe earthquake on local communities.

Aims

The city of Wellington is at risk of a severe earthquake event (Stirling et al.,1998, Begg, 2000). The overall aim of the project was to reduce the effects of the earthquake and increase community resilience by forward planning emergency water resources by the provision of 20L per person per day.

Method

A comprehensive review of existing water resources and historical bores was conducted, considering reticulated water supplies, surface water and water wells. Outside of the Hutt Valley, little is known of groundwater resources in the Wellington area. Many of Wellington's surface water resources have been either culverted or are susceptible to contamination in the aftermath of a major earthquake. Deeper groundwater options were explored as a more stable, long-term source of water.

Incomplete records from historic bores drilled in sediment from the 1930s around Wellington's CBD and more recent exploratory bores in Miramar indicate sedimentary aquifers are unsuitable as a stable water resource. Some success was found in bores drilled into fractured greywacke during the 1930s with withdrawal rates of 1 to 2 L/s recorded in one third of bores. Although the withdrawal rate is not large, sustainable rates of ≥1 L/s were identified as sufficient for an emergency supply.

A shortlist of potential sites was compiled within areas at high risk of having water supply disrupted after a large earthquake. Each extraction site would be equipped with a containerised treatment station and large storage bladders (Community Stations).
Very little geological information was available at the sites. Reconnaissance geophysical surveys were used to provide information on the character of the substrate. The main methodology used was shallow seismic reflection, with some sites surveyed with electrical resistivity methods. The reflection surveys were undertaken with a saw-tooth setup using a 72 channel system and 30 Hz geophones, with sledgehammers as a seismic source. The resistivity used a standard Wenner Alpha electrode configuration with a 128 channel system. The geophysics characterised the depth to unweathered greywacke at each site, as well as apparent dip directions, zones of more disturbed and fractured rock that could be targeted for drilling, and the seismic velocities of the substrate. A number of the shortlisted sites were rejected due to unpromising geophysical results or practical concerns with establishing a long-term Community Station.

Given time restraints, two drilling companies were engaged, both using the same drilling methodology. The top 1.5 m was excavated using jet vacuum and the remaining length drilled using air hammer (152 mm diameter hole). Successful bores were installed with blank casing with a diameter of 127.5 mm (ID) and stainless steel 316 Screen with a diameter of 127.5 m. Generally, screen lengths were between 18 and 21 m to maximise groundwater inflow from fractures. Wells were finished to above ground and are currently being completed with headworks. After well installation step tests followed by 72 hour constant rate pump tests were undertaken.

Results

Electrical resistivity was only tested at two sites. The resistivity method was found to have insufficient depth penetration for the aims of the project. While greater depth imaging could have been achieved, the boundaries of the sites were not able to accommodate the required length of array. The shallow seismic reflection surveys achieved good depth penetration and showed a strong reflection on unweathered greywacke. Reflections between the Quaternary alluvial and colluvial deposits and weathered bedrock were generally not observed, and the P-wave velocities indicated a gradation increase in velocity across this boundary. The apparent dip directions of bedrock and zones of reduced reflection energy (interpreted to indicate higher fracture density) were identified at eighteen sites.

The geophysical profiles added context to the planning process for the drilling program. Groundwater was typically found in the less weathered greywacke, and deriving the approximate target depths from the seismic profiles gave us the ability to plan ahead for the drilling program. We were able to more accurately estimate both drilling times and casing and screen lengths ensuring these could be ordered in advance.

A total of fifteen boreholes were drilled, with nine producing sufficient water supply. The step tests and 72 hour pumping tests indicated sustainable rates between 1 L/s and 3 L/s, sufficient to supply nine Community Stations. Typically, successful bores were located within less weathered fractured greywacke. Where bands of argillite were present water inflow was significantly lower. Water quality was within New Zealand Drinking Water Standards with the exception of treatable manganese and iron concentrations exceeding the aesthetic guidelines for three groundwater samples. Although within human health limits for drinking water all groundwater will be treated prior to distribution to the public.

The success rate for the drilling program was 60%. A thorough desktop study identified promising sites throughout the Wellington region. The geophysical surveys advanced the project significantly. Knowing the geological setting of the sites before drilling reduced the risk of drilling into deep alluvial deposits unsuitable for water extraction or drilling into unweathered and unfractured bedrock. The dip directions of the bedrock surface and the alignment and character of the reflections with the bedrock informed the hydrological model at each site. In addition, the seismic surveys increased the efficiency of the drilling program, as the drillers knew the depth of bedrock prior to drilling.

Wellington remains at risk of a severe earthquake event. While this risk can never be eliminated, it can be mitigated through careful forward planning for reduction of the earthquake impacts and improvement of the response and recovery phases. By establishing emergency water resources in communities throughout the region, we have enhanced the resilience of Wellington's drinking water supply to a major earthquake event.

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EFFECTS OF CLIMATE CHANGE AND WATER RESORCE LIMITS ON WAIRAPA VALLEY WATER RESOURCES

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Aims

Investigations for a storage-based bulk water supply scheme in the Wairarapa Valley, providing water for irrigation, environmental flows, town supplies and water races, have been ongoing for a number of years. In parallel, the Ruamāhanga Whaitua Committee has been investigating water resource limits that aim to meet water quality and quantity objectives.

Our work aimed to assess the potential impact of:

- The proposed water resource limits,
- Climate change out to the year 2100, and
- The combined effects of proposed water resource limits and climate change on water resources on the Wairarapa valley floor, within the proposed Black Creek scheme command area.

Method

We modelled the balance of water availability, water demand, and storage volumes on a daily time-step using an Excel spreadsheet model. The model implemented minimum flow rules in each sub-catchment to calculate water availability from mean daily river flows. The minimum flows were adjustable parameters in the model to allow the current and proposed scenarios, and a transition regime, to be investigated.

Daily irrigation demands were calculated using Aqualinc's soil-moisture balance and irrigation simulation model, IrriCalc. The IrriCalc outputs were processed to create time-series of irrigation demand for existing and new irrigated areas, incorporating the mix of soils and land-uses. These time-series were inputs to the spreadsheet model.

For the historic period (1978 – 2014) we used measured river flows to calculate water availability, and rainfall and PET data from NIWA's virtual climate station network (VCSN) to calculate irrigation demands. Results from the measured datasets were used to investigate the effects of the proposed water resource limits, and to provide a baseline for the climate change assessment.

For the future climate (2015 – 2100) we used flow and climate data based on RCP8.5 scenario outputs from the GFDL-CM3 model (i.e. a single RCM / RCP combination). NIWA provided modelled daily river flows from TopNet, based on this climate scenario, for the river reaches corresponding to the flow control points for the minimum flows. Future irrigation demands were calculated in IrriCalc using the daily climate model outputs.

As there are differences between the measured and modelled climate data for the historic period, comparisons between historic and future flows and demands are all based on modelled data. To do this we combined the RCPpast and RCP8.5 model outputs to give a record from 1978 – 2014.

To enable comparisons between the baseline supply reliability results and the climate change scenario, we adjusted the minimum flows for each sub-catchment in the model so that the water availability for the modelled historic period (RCPpast) was comparable to the measured historic period. Relative changes between the modelled historic and future periods were applied to the baseline values to give estimates of future reliability.

Results

Introducing the proposed water resource limits would result in a reduction in water availability for surface water users in the Upper Ruamāhanga, Kopuaranga, and Waipoua catchments, with the average number of days per year on full restriction increasing. As a result of this, supply reliability (without storage) would decrease. Existing hydraulically-connected groundwater users would experience a greater reduction in supply reliability, as they will eventually become subject to the same rules as surface water users.

River flows within the proposed scheme area are expected to reduce over time as the climate changes: mean flows, median flows and 7-day MALFs (i.e. low flows) are expected to be lower in the 2040s than in the historic period. Further reductions will occur by the 2090s. This will result in less water being available for abstraction.

The volume of water required over an irrigation season is expected to increase over time. Average seasonal irrigation demand volumes are expected to increase by approximately 15% in the 2040s, and approximately 30% in the 2090s, relative to the historic period. Levels of seasonal irrigation demand that are currently considered very high will become the “new normal”: the average seasonal demand for the 2090s is 6% - 9% higher than the 90th percentile seasonal demand for the historic period. This is illustrated in the figure below:

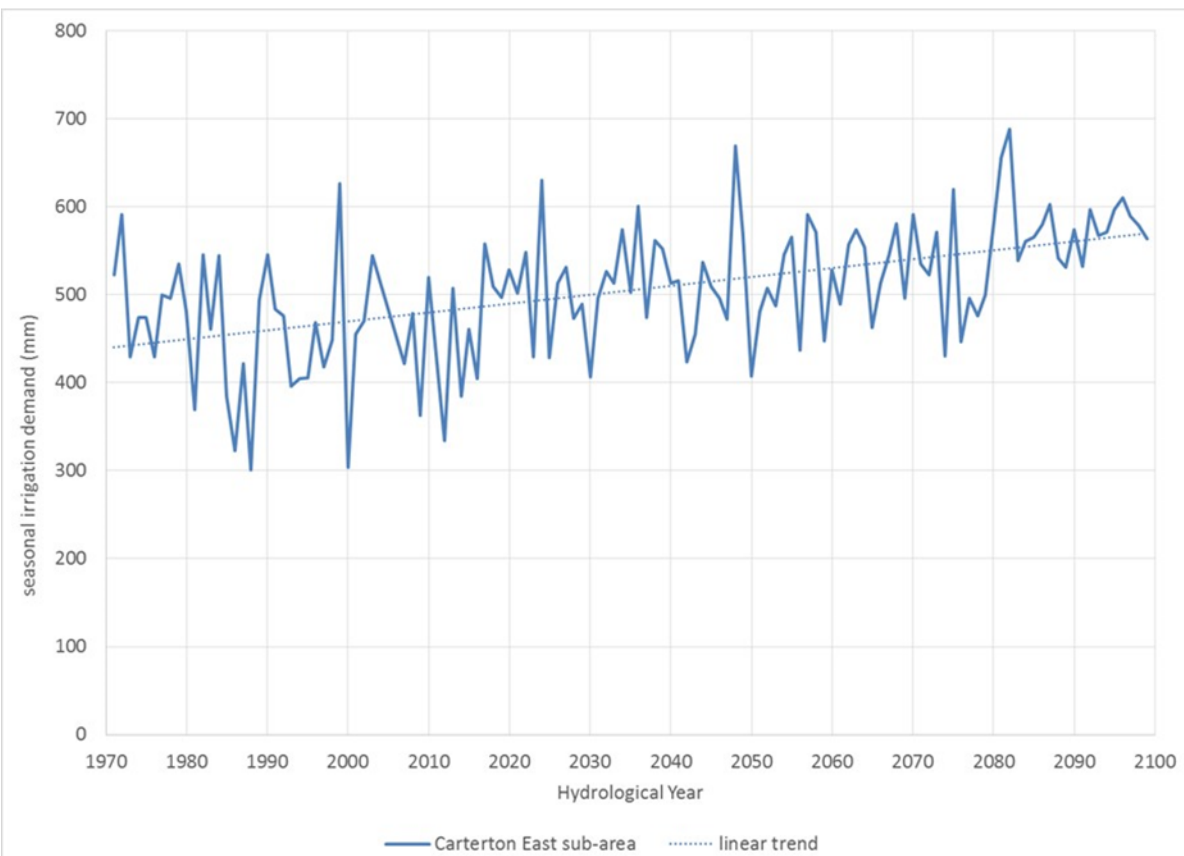


Figure 1: Seasonal irrigation demand 1970 – 2100

With the proposed scheme in place, over the whole irrigation season the combined effects of the proposed water resource limits and climate change would result in supply reliability that is slightly worse than under climate change alone, for both existing and proposed users. Climate change is the dominant effect compared with the effect of the Whaitua Committee's proposals.

In all scenarios that we have modelled, the greatest impact to supply reliability will be in the January – March period. However, the most substantial water demand volume changes will occur during September to November.

In order to maintain supply reliability in the future with the same volume of storage, it may be necessary to either reduce the new irrigated area in the proposed scheme, or introduce other mitigations such as land-use change or a managed restriction regime in years when stored water volumes are low.

REMOTE SENSING OF THE MC-MURDO DRY VALLEY MICRO-CLIMATES AND THEIR HYDROLOGICAL IMPACTS

Rajasweta Datta[1], Marwan Katurji[1], Peyman Zawar-Reza[1]
[1] *Dept of Geography, University of Canterbury*

Aim

McMurdo Dry Valley, the largest Antarctic oasis spanning around 4800km [5], is a hyper-arid desert with annual precipitation less than 50 mm yr^{-1} [7]. The climate across MDV is highly variable and influenced by McMurdo sound with relatively warm maritime climate and East Antarctic ice sheets with dry and cold climate [8]. Also the Foehn events generated as a result of the strong synoptic pressure gradient in the Transantarctic mountain region due to cyclonic activities over the Ross sea region [7] drastically increase the air temperature in MDV above 0°C over austral summer period and triggers high glacial melts [6,7]. The meteorological variability in MDV is highly contrasting such that the temperature difference of up to 15°C during the summer and 30°C during winter between two location in a valley at same elevation [3] and climatic condition of one location cannot represent the climatic condition of the adjacent site [3,1].The Ephemeral streams are formed by glacial melt over austral summer, for a period of 6 to 12 weeks (Cozzetto, McKnight, Nylen, & Fountain, 2006). These streams are affected by change in climate variables with some years showing higher flow rates than yearly average during the flood season. (Doran et al., 2008).The ephemeral streams support photosynthetic cyanobacterial mats and associated heterotrophs [10,11], which are the only life form that dominates the region. They flourish during the austral summers and their number are highly susceptible to the climatic conditions and associated hydrology over MDV [9]. There is limited study on the large-scale spatial changes in the climate across MDV and are mostly based on data from AWS.

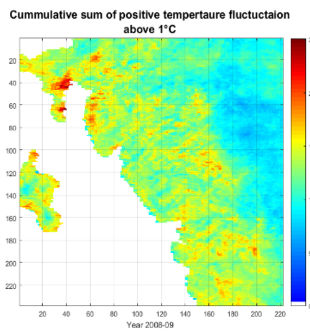
Aim of the research is to 1) Study MDV climate variability in 2008-09 (flood season) austral summer over a larger spatial scale using Satellite Remotes Sensing (SRS) data from MODIS in conjunction with Automatic Weather Station AWS and Antarctic Mesoscale Prediction System (AMPS) meteorological data; 2) Identify the microclimates in MDV and study the contributing factor leading to their drastic climatic contrast from their adjacent region.

Method

The accuracy and response of MODIS Land Surface Temperature (LST) product from AQUA (MYD11A1) and TERA (MOD11A1) was evaluated over MDV using meteorological data. Warming trend maps are generated based on the cumulative sum of warming events experienced by each pixel due to a daily mean temperature difference of greater than 1 °C between two consecutive days LST. The warming trend maps are used to identify the region with maximum positive fluctuation in temperature. The influence of climatic conditions (solar radiation, Foehn events), and terrestrial conditions (Land cover, elevation, terrain shadow) on positive fluctuations was investigated. The microclimates in MDV were identified from perturbation in temperature derived from individual LST images. The response of the microclimates to climatic changes was studied over the summer period to understand the response of individual location in MDV to warming caused by solar radiation and Foehn.

Results

Each location in MDV has a distinct response to warming events. The warming of each location is dependent on the climate, land cover, Foehn events and solar radiation. The SRS derived evaluation showed that the smaller valleys in MDV have higher positive temperature fluctuations as well as higher temperatures as compared to larger valleys like Taylor. The use of SRS was found to be helpful in studying the inter-valley temperature variation in Taylor Valley which is caused by land cover, elevation and solar radiation received by the location. Foehn events along with higher solar radiation are responsible for higher temperatures in MDV. The transition between warmings caused by solar radiation during a clear sky day to warmings caused by atmospheric advection during Foehn events can be identified using the SRS data. SRS identify the regions that are mostly affected by the warming due to Foehn events. It also determine that regions that are susceptible to regular warming due to solar radiation and the effects of terrain shade during the diurnal cycle. SRS provides an understanding of the meteorological variability over MDV over a larger spatial scale and the response of the MDV to this change.



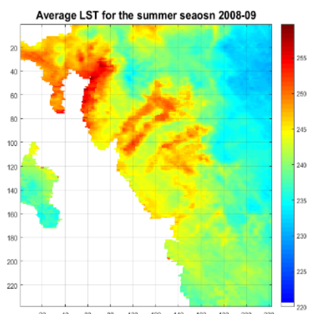
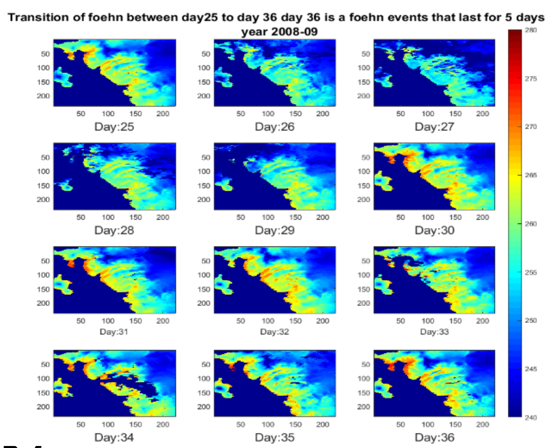


Figure1: (a) The cumulative sum of the warming events experienced by each pixel with a daily mean temperature difference greater than 1°C. (b) Average LST for the summer season 2008-09 (1 Nov 2008 to 28 Feb 2009. (c) LST changes over MDV during a Foehn event from 25th November to 7th Dec 2008. (d) The climatic condition during the period of Foehn for Fryxell station.

(a) (b)



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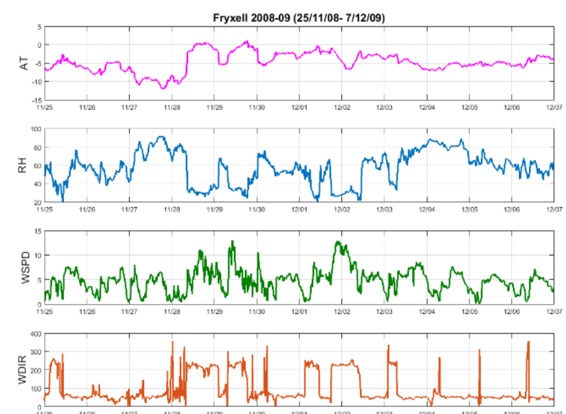

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UNDERSTANDING GROUNDWATER DYNAMICS FROM TRITIUM AND 18O IN COASTAL WAIRAU PLAIN AQUIFER; NZ PART 1

Peter Davidson[1], Uwe Morgenstern
[1]*Marlborough District Council*

Aims

Review groundwater isotope tracer and associated hydrochemistry results collected in Marlborough district between 1970 and 2018 to improve understanding of the hydrogeology of the Wairau Plain aquifers for groundwater allocation and land use management purposes. The purging of bomb tritium from the Wairau River catchment and linked aquifer systems has eliminated the previous ambiguity of water dating, and provided new opportunities to reinterpret the data.

Part 1 of the presentation sets the scene hydrologically. Part 2 describes the reinterpretation of the larger information set; its implications for aquifer reservoir volume, how quickly land use leachate is turned over, vertical aquifer stratification and recharge mechanism processes.

Method

Describe the rainfall/runoff distribution, mineralogy, topography and water flow transit time of the Wairau River catchment which flows from the main divide near Lake Rotoiti to the Pacific Ocean near Blenheim. Describe the structure and hydraulic properties of the aquifer systems underlying the Wairau Plain and their associated springs.

Discuss Wairau Aquifer issues. These include a small but long-term declining trend in well levels thought to be related to a combination of: increasing consented abstraction from the Wairau River, falling Wairau River channel bed levels isolating permeable recharge pathways, a succession of drier than normal seasons (late 2014-2016) and long-term climate variability. The possibility of river management affecting the rate of Wairau River leakage rates to groundwater is being investigated.

DEVELOPMENT OF A SURFACE WATER ISOTOPE LAYER FOR NEW ZEALAND

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[1]*Niwa*

Aims

The stable isotope values of oxygen and hydrogen in river and stream water store information on catchment water sources and evaporative fluxes. Hence, a national map of surface water isotope values is a potentially powerful tool in the development of a national hydrological model. We present methods and available data for a GIS-based model of long-term annual average surface water isotope ratios in New Zealand.

Method

We will use gridded precipitation isotope maps produced from published relationships between precipitation isotopes and NIWA Virtual Climate Station Network data (VCSN). VCSN precipitation and evapotranspiration data are also used to incorporate monthly variation in precipitation evapotranspiration (P-E) differences into calculations of isotope values of catchment surface water flows. Flows, and isotope values associated with those flows are summed across a flow direction grid which is derived from a DEM.

For validation, we will use river water samples from the NIWA National Water Quality Monitoring Network as well as regional water isotope sampling carried out under the National Hydrological Program in collaboration with Regional Council partners.

Results

We will present progress to date on modelled surface water stable isotope values (delta values) for deuterium and oxygen-18. We will also present validation results to date from samples from NIWA's National River Water Quality Monitoring Network.

ESTIMATION OF THE FIVE-YEAR IMPACT OF THE HINDS MAR TRIAL ON GROUNDWATER LEVELS AND QAULITY

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[1]Waterways Centre, University of Canterbury, [2]Institute of Environmental Science and Research

Aims

The Hinds Plains managed aquifer recharge trial (MAR) is now two years into its five-year programme. This research aims to use groundwater modelling to estimate the effects of the MAR pilot on groundwater levels and water quality at the trial's completion in 2021. Specifically, the research focuses on the:

- assessment of how far downgradient the 0.1 m of mounding will propagate
- assessment of groundwater head change at a set location
- area of groundwater head changes greater than 0.1 m
- change in volume at a change in groundwater head > 0.1 m.

Method

Two approaches were used to consider the impact of the trial after five years of operation, namely analytical modelling and numerical modelling.

Analytical methods were used to:

1. analyse the mounding response in the groundwater observation wells as a constant discharge test to estimate aquifer parameters, such as transmissivity (*T* $[m^2/d]$), storativity (*S [-]*), specific yield (*Sy*) and leakage coefficient (*K'B'* $[L^2/T]$). The estimated parameters are then used to consider the long-term mounding using the well function utilised in their determination.

2. estimate the steady-state mounding response, using conventional mounding models such as the Hantush equation (Carleton, 2010).

Numerical modelling was used concurrently with the development of the analytical modelling and was setup using the USGS tool MODFLOW-NWT (Harbaugh, 2005; Niswonger et al., 2011). The specific package used for its ability to replicate unsaturated conditions and accommodate drying cells. Groundwater Vistas was adopted as the modelling interface. Several steps were involved in the numerical modelling:

1. estimation of groundwater recharge. This was undertaken using two approaches: a soil moisture balance method and, from the water table fluctuation method. In the second approach changes in groundwater head following recharge events were used together with an estimate of S_y to determine recharge. The resulting recharge estimate was compared to the soil moisture balance model. Ultimately the soil moisture balance approach was adopted as the preferred method as the assumptions in the estimate were easier to quantify.

2. transformation of the conceptual model into a MODFLOW numerical structure with grid refinement around the MAR Pilot area. Groundwater level and river flow observations held by Environment Canterbury were used as model calibration targets.

3. calibration of the steady-state MODFLOW model using the Pilot Point PEST (Doherty, 2003) method via the BeoPEST tool

4. use of the model to make a deterministic assessment of the mounding response out to the end of the trial

Ongoing work focuses on uncertainty analysis of the flow model results using the Null-space Monte-Carlo method. With the final analysis using the mean, median and 95th parameter percentiles to build a transport model in MT3DMS to investigate the water quality implications of the MAR trial.

Results

Though the research is ongoing, several components have reached their natural conclusion and can be reported. Analytical modelling has been completed and has highlighted the complexity of what would otherwise seem a simple problem. Significant uncertainty in results was encountered as a consequence of data gaps. Specifically, several major confounding factors render a deterministic analytical approach suspect. These confounding factors include the presence of a leaky stock water race running past the site with no recorded flow, several nearby farm irrigation ponds and a leaky water delivery race to the MAR site. All these features are resulting in time varying groundwater mounding immediately adjacent to the trial site.

Initially, two approaches to numerical modelling were investigated; firstly the model was calibrated only using observation data collected before the trial, and secondly including trial observations in the calibration. While the second approach successfully reproduces the observed results of the first two years of the trial, the first approach does not. These results demonstrate the need for site-specific testing before the further development of additional basins and highlights the utility of models to estimate observed effects when site specific information is available, as would be required when applying for resource consents.

At the time of writing uncertainty analysis has yet to be undertaken, however, preliminary results will be presented on the day.

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Keywords

modelling, uncertainty analysis, confounding variables., managed aquifer recharge (MAR), MODFLOW, transport modelling.

STREAM BANK EROSION AS A RESULT OF SOCIO ECONOMIC GOALS AND WHY WE SHOULD THINK MORE BROADLY

Tim Ellis[1], J Hodgetts[2]
[1]Environment Southland, [2]SciArt

Aims

To contribute to New Zealand's knowledge for decision making processes in combating problem stream bank erosion.

Method

We reviewed available knowledge on stream bank erosion processes, modelling capability and the history of human influences on the geography, hydrology and stream hydraulics in Southland. We then examined the question of how to better inform decision making processes for mitigating problem sediment from stream bank erosion.

Results

We presented the case that the primary, overall drivers of excess stream bank erosion include socio-economic factors that are typically omitted or inadequately considered from decision-making processes.

We found that the catchment hydrology of Southland has been hugely modified by agricultural activities and hydroelectric generation and has been comprehensively drained. The hydraulic characteristics of Southland's streams have been modified to increase drainage of the landscape and the artificial drainage network, streams and rivers are routinely modified to maintain hydraulic efficiency. Southland's hydrology and stream morphologies are therefore far from equilibrium. Further, we found that catchment hydrology and stream hydraulics, in general, are sub systems of an overall *complex* system, rather than a *mechanistic* system, and one which has socio economic drivers.

Stream bank erosion models can make important contributions to resource management decision processes, however we argue that their utility can be limited without an understanding of catchment history and broad scale drivers of stream bank erosion.

Stream bank erosion models typically treat catchments and streams as mechanistic systems and such models, when calibrated, can provide useful 'snapshots' of some catchment and stream processes. However, because they are often limited in scope and may not include all stream erosion processes, such as scouring, they may not suit local conditions. Further, because such models do not treat catchments and streams as complex systems, we suggest they cannot describe responses to interventions designed to reduce stream bank erosion in the long-term.

We go further to argue that popular methods for on-site stream bank erosion mitigation, such as riparian planting, address *symptoms* rather than the *causes*. Therefore, these mitigation methods may ultimately fail, or make matters worse, unless the main drivers are simultaneously understood and addressed.

We conclude that an holistic approach involving some cooperative blend of whole systems thinking and a considered use of predictive modelling tools is needed to address management decision-making around problem sediment.

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COLLABORATIVE DEVELOPMENT OF A STOCHASTIC GROUNDWATER MODEL OF THE WAIMAKARIRI – CHRISTCHURCH AQUIFER SYSTEM

Zeb Etheridge[1], Matt Hanson[1]
[1]*Environment Canterbury*

Aims

The pressure on Canterbury's water resource has increased significantly over the last two decades. This lead to a highly adversarial approach to resource allocation and disagreement over the science which underpins decision-making. Numerical groundwater models are a widely used and valuable predictive tool for decision-making but are prone to expert disagreement and, in some instances, pedantic fault-finding. Our study aimed to develop a numerical groundwater model with minimal risk of expert disagreement during the plan notification process, by working in collaboration with external experts to develop a stochastic numerical groundwater model of the Waimakariri zone and provide the best available science information to decision-makers.

Method

Doherty and Moore (2017) note that a groundwater model's support for the decision-making process rests on its ability to provide a receptacle, or container, for information about the system that is undergoing management. This information falls into two broad categories, namely expert knowledge and the historical behaviour of the system. Expert knowledge is expressed through the construction details of the model, its boundary conditions and its parameterisation (i.e. how real world hydraulic properties are represented in the model). Conceptually, all of these (especially its parameterisation) must be stochastic, as that is the nature of expert knowledge for environmental systems. The first stage of the modelling project therefore required extraction of knowledge from a panel of experts in a stochastic form. We used the Sheffield Elicitation Framework (SHELF, see Oakley and O'Hagan, 2016) for expert judgment elicitation to guide this process.

The practical steps undertaken during the elicitation process (see O'Hagan, 2012) were as follows:

1. Select and engage expert panel. The selection process objectives were to recruit a pool of experts which together provided good knowledge of the local hydrological system, groundwater modelling expertise and were trusted by key local stakeholders.
2. Orientation and training. Options for the elicitation were discussed, such as whether uncertainty should be considered in terms of absolute values or percentage deviation from best estimates. The concept of personal probability was introduced: the outcome of the elicitation should be the experts' own assessment of uncertainty based on their expert knowledge. The experts were given a training exercise to undertake, to cement the concept of personal probability and to familiarise them with the elicitation method.
3. Problem definition and elaboration.
4. Compile evidence dossier, circulate amongst panel and incorporate additional expert knowledge: a literature review of previous modelling, uncertainty and sensitivity analysis studies, aquifer property information and climate modelling was undertaken; results were summarised in an evidence dossier. Experts were invited to contribute additional information and knowledge to the evidence dossier.

5. A one-day elicitation workshop was convened to discuss the information contained within the evidence dossier, finalise the elaboration, discuss quantity dependencies and undertake the uncertainty elicitation.

The information obtained from the elicitation process was incorporated into a steady state groundwater model, details of which are provided in Hemmings et.al (2018). The optimised model and calibration-constrained uncertainty analysis were presented to the expert panel. The panel were then asked a series of questions to elicit their views on the reliability of the model for decision-making purposes.

Results

The expert judgement elicitation process provided an effective means for transferring expert knowledge into a numerical groundwater model. The calibration-constrained uncertainty analysis provided a first order assessment of model predictive uncertainty. Model predictions were subsequently provided for a 90% confidence interval range of nitrate concentrations in key receptors. However, this quantification of uncertainty was based on expert judgement estimates, which were themselves uncertain, and a model with an unknown degree of structural error/noise. The model reliability expert judgement elicitation provided a means by which the second order uncertainty could be assessed; i.e. the level of confidence that could be placed in the modelled 90% confidence interval results. This information was highly valued by key stakeholders and decision-makers.

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WE'VE BEEN REALLY CLEVER AND BUILT A STOCHASTIC MODEL. NOW, HOW DO WE MAKE RESOURCE MANAGEMENT DECISIONS WITH THE RESULTS?

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[1]*Environment Canterbury*

Aims

The aim of this work is to show how quantified uncertainty was used by a Zone Committee to make nutrient management recommendations which weighed the risk of excessive economic impacts against the likelihood of meeting water quality targets.

Method

A stochastic groundwater flow and transport model was developed for the Waimakariri zone, as discussed in Etheridge and Hanson (2018). The purpose of the model was to evaluate likely future nitrate concentrations in drinking water wells, springs and streams in the Waimakariri zone and in the Christchurch aquifer system. The uncertainty quantification (see Hemmings et al., 2018) yielded a wide range of possible future nitrate concentrations. If the true future nitrate concentration ultimately proved to be at the lower end of the results range, small reductions in nitrate leaching would be required by farmers in order to meet water quality targets in some instances. Conversely, if the correct nitrate concentration ultimately proved to be at the upper end of the modelled range, major nitrate leaching reductions would be required in some areas. Faced with uncertain results, decision-makers often pick the median value, considering this to be the "best estimate", or use the 95th percentile projection to minimise the risk of an adverse outcome. Given the variability and potential magnitude of economic impacts on farming associated with which value was selected from the modelled range, a more considered approach was required.

The Zone Committee was presented with economic impact graphs which plotted change in farm profitability against percentage reductions in nitrate leaching rates. Information was also provided to show the percentage reduction in nitrate leaching rates that would be required to meet water quality targets for the range of projected future nitrate concentrations in each receptor.

Results

Providing quantified uncertainty around model projections, guidance on what the probability distributions meant and economic impact information that could be used in conjunction with the modelled range yielded several benefits:

1) The Zone Committee were able to weigh the risk of excessive economic impacts against the likelihood of meeting water quality targets and then select a model projection from the range which reflected the desire to balance the risk of these competing adverse outcomes.
2) The uncertainty burden was shared, which facilitated a more collaborative working environment
3) The science team did not need to try to defend a single deterministic model, whilst being unable to explain what the implications were of the model inevitably being, to some degree, wrong. This created more trust between scientists and stakeholders

4) Some challenges remained, however. Vested interests still sought to dispute the model credibility by viewing the median model projections as a deterministic prediction and arguing that these values were unlikely to eventuate based on past trends in nitrate concentrations.

References

Etheridge Z. and Hanson M. 2018 Collaborative Development of A Stochastic Groundwater Model of the Waimakariri – Christchurch Aquifer System. Proceedings of NZ Hydrological Society 2018 (this issue)

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UNDERSTANDING NITRATE TRANSPORT PATHWAYS IN THE WAIMAKARIRI – CHRISTCHURCH AREA: INSIGHTS FROM WELL DATA

Zeb Etheridge[1], Matt Hanson[1], Henry Dillon[2]
[1]Environment Canterbury, [2]Golder Associates

Aims

An initial phase of nitrate transport modelling in the Waimakariri management zone suggested that nitrate seepages from some agricultural land could potentially be transported southwards beneath the Waimakariri River and towards the Christchurch aquifer system, which supplies water to the city. Analysis of the model inputs and results showed that lateral and vertical hydraulic gradients, vertical zonation of model aquifer transmissivity and bulk scale x/y anisotropy were key drivers of this projected outcome. The aim of this paper is to present the methods used to analyse groundwater levels and aquifer properties in more detail, and the implications of the analysis results for nitrate transport.

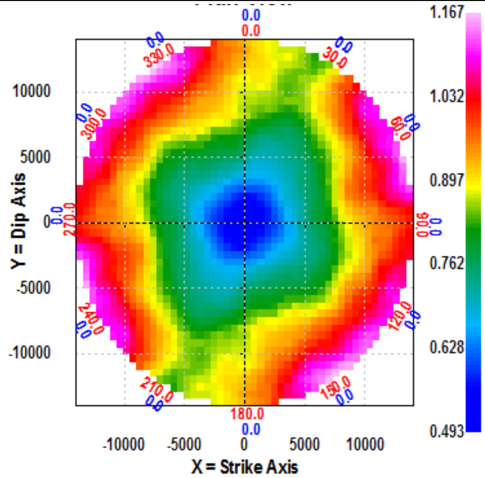
Method

Preliminary analysis of groundwater level data from the Waimakariri management zone showed significant downward vertical gradients in the inland plains area and upward gradients in the coastal zone. The presence of elevated nitrate concentrations in the deep part of the inland plains aquifer suggested relatively close connectivity with the shallow part of the system, which receives nitrate-enriched recharge from the land surface. Groundwater flow in the deeper aquifer may therefore be an important transfer pathway between nitrate sources and receptors. Nine new monitoring wells were installed at three depths (nominally 50, 100 and 150 m) and a piezometric survey was undertaken to facilitate better understanding of nitrate transfer pathways.

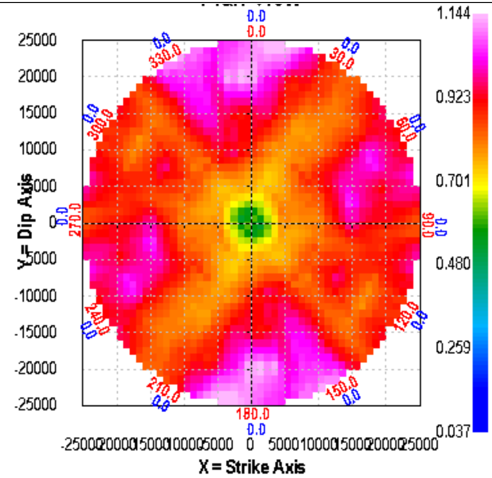
Specific capacity and pumping test transmissivity data were analysed to investigate the nitrate transport potential of the aquifer at different depth intervals and the broad scale anisotropy of the aquifer system.

Results

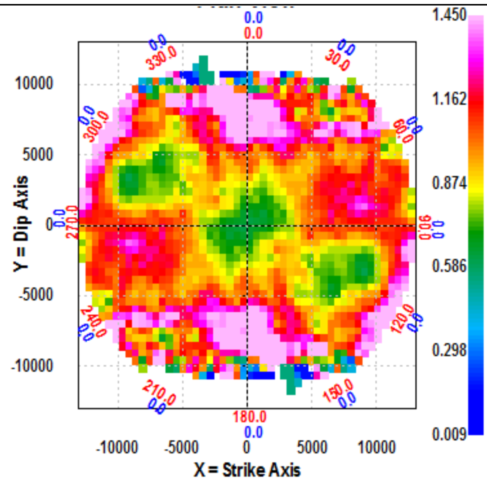
Analysing the specific capacity, transmissivity and lateral hydraulic gradient data showed that whilst the majority of lateral nitrate transport is likely to occur in the upper part of the aquifer system (e.g. <50 m depth), lateral gradients and transmissivities in the deeper aquifer (e.g. >90 m) are sufficiently high to facilitate lateral transport of nitrate towards key receptors (e.g. water supply wells). Analysis of lateral variance in specific capacity using semi-variograms (Figure 1) suggested significant bulk scale anisotropy in some areas of the plains. This anisotropy is expected to influence groundwater flow directions, and hence the standard assumption that groundwater flow is perpendicular to interpolated groundwater contours may not be valid. The analysis also showed some areas of consistently higher specific capacity (e.g. in the near coastal zone) and lower specific capacity, where aquifer sediments may be dominated by overbank deposits. The results of this analysis were used as inputs to an extended numerical groundwater model of the Waimakariri, Christchurch and Selwyn aquifer system, and by a panel of experts tasked with assessing the potential for nitrate contamination in aquifers north of the Waimakariri River to be transported beneath the river and into the Christchurch – West Melton and Selwyn – Te Waihora management zones.



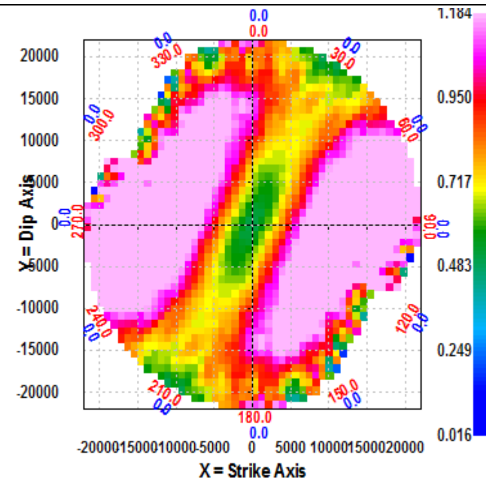
a. Specific capacity – extended model domain (1 km lag). No clear orientation



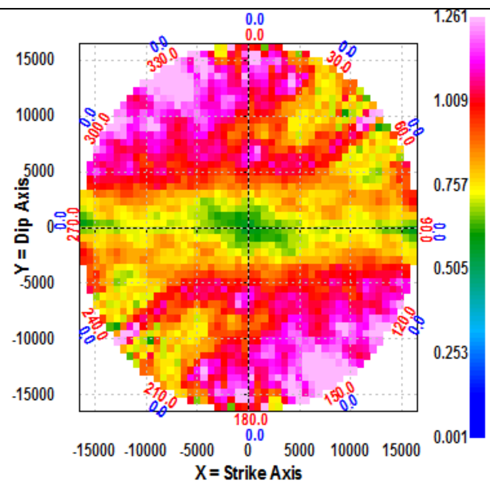
b. Transmissivity – extended model domain (5 km lag). Major axis azimuth 149°



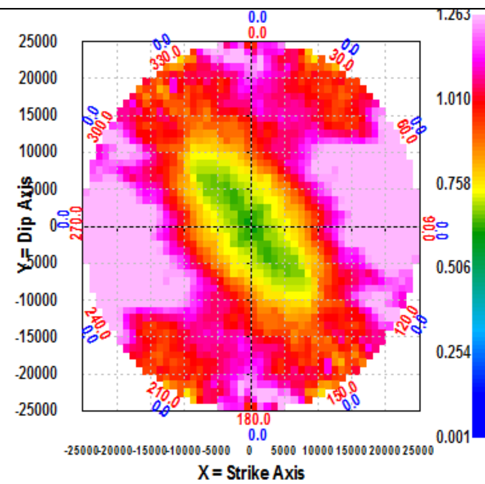
c. Ashley area – 500 m lag. No clear orientation



d. Halswell – Te Waihora – 1 km lag. Major axis azimuth 20°



g. Oxford – Eyre – Belfast – 500 m lag. Major axis azimuth 110°



h. Selwyn – 1 km lag. Major axis azimuth 127°

Figure 1: Variogram maps

SOURCE ZONE DELINEATION FOR NITRATE MANAGEMENT IN THE WAIMAKARIRI AND CHRISTCHURCH AQUIFER SYSTEM

Matt Hanson[1], Zeb Etheridge[1]
[1]Environment Canterbury

Aims

The Canterbury Water Management Strategy provides a framework for management of diffuse nitrate discharges to groundwater and a pathway for achieving the water quality outcomes in drinking water supply wells and spring-fed streams sought by local communities and stakeholders. Management of nitrate concentrations in these receptors requires information on their source/recharge zones so that appropriate land management controls can be developed, if required. Our study used a stochastic steady-state groundwater model with particle tracking to evaluate the recharge areas for spring-fed streams and community water supply wells in the Waimakariri zone and for the Christchurch city water supply aquifer.

Method

A stochastic groundwater flow and transport model of the Waimakariri zone was developed, as discussed in Etheridge and Hanson (2018) and Hemmings et al. (2018). Forward and reverse particle tracking simulations were run on the suite of 165 model realisations retained after a rejecting sampling process (using e.g. End Member Mixing Analysis, as detailed in Scott et al., 2018). For the forward particle tracking particles were applied uniformly to every 200 x 200 m cell within the model domain; particles were released from well, stream and drain boundary conditions cells for the reverse particle tracking simulations. Results were aggregated to show the number of particles which originated from each cell and scaled to create a raster layer. The latter showed the number of model realisations for which some or all of the water in every cell flowed to each receptor of interest. The combined results for private and community water supply wells were also scaled based on the population served by each well to create a "heat map".

Results

The particle tracking results provided the following information:

- The land areas which are likely to recharge the Christchurch aquifer system (Figure 1)
- The likely recharge zone for every significant spring-fed stream and river in the Waimakariri zone
- The likely recharge zone for all community water supply wells in the Waimakariri zone
- The "heat map" of recharge to drinking water supply wells, showing the number of people likely to receive their drinking water recharge from each cell within the model domain (Figure 2)

This information is currently being used for decision-making, development of planning controls and implementation of on-the-ground actions within the Waimakariri zone.

References

Etheridge Z. and Hanson M. 2018 Collaborative Development of A Stochastic Groundwater Model of the Waimakariri – Christchurch Aquifer System. Proceedings of NZ Hydrological Society 2018 (this issue)

Hemmings B., Knowling M., Moore C., Hanson M. and Etheridge Z. 2018 Calibration-Constrained Monte Carlo Uncertainty Analysis of Groundwater Flow and Contaminant Transport Models for the Waimakariri-Ashley Region of the Canterbury Plains. Proceedings of NZ Hydrological Society 2018 (this issue)

Scott L., Etheridge Z. and Hanson M. 2018. End-Member Mixing Analysis of Recharge Sources in the Christchurch Aquifer System. Proceedings of NZ Hydrological Society 2018 (this issue)

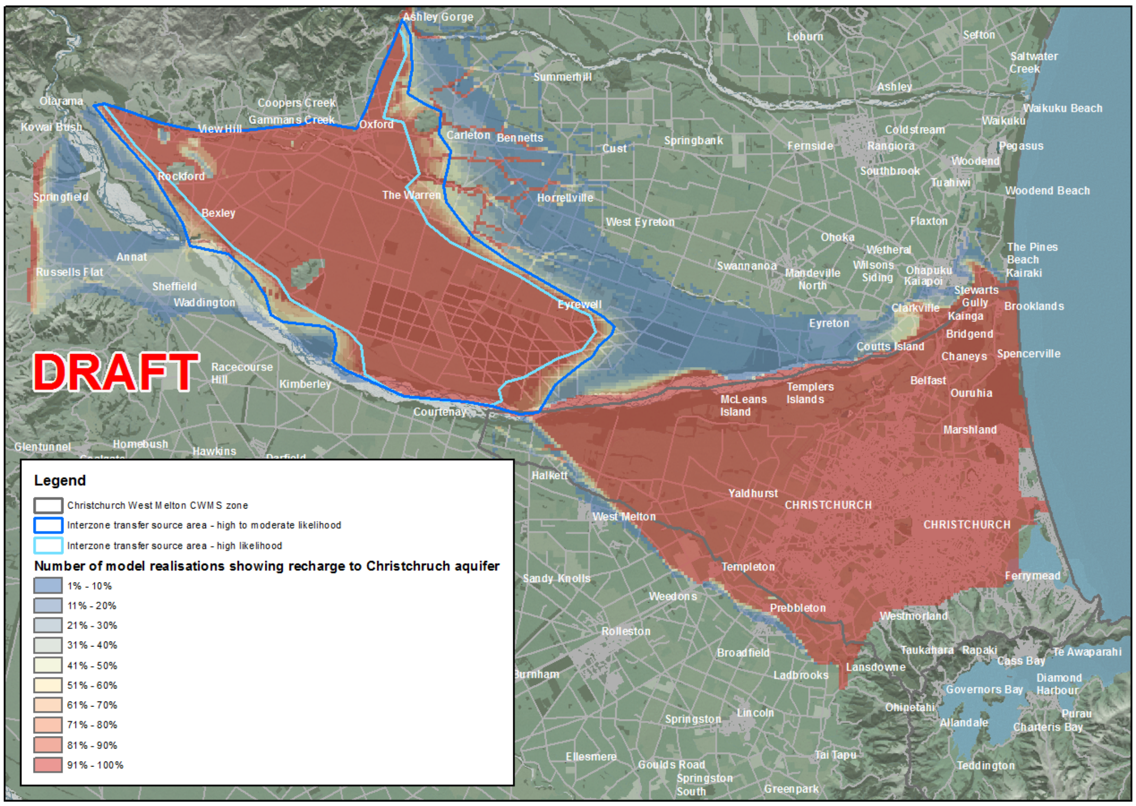


Figure 1: Christchurch aquifer groundwater recharge zone

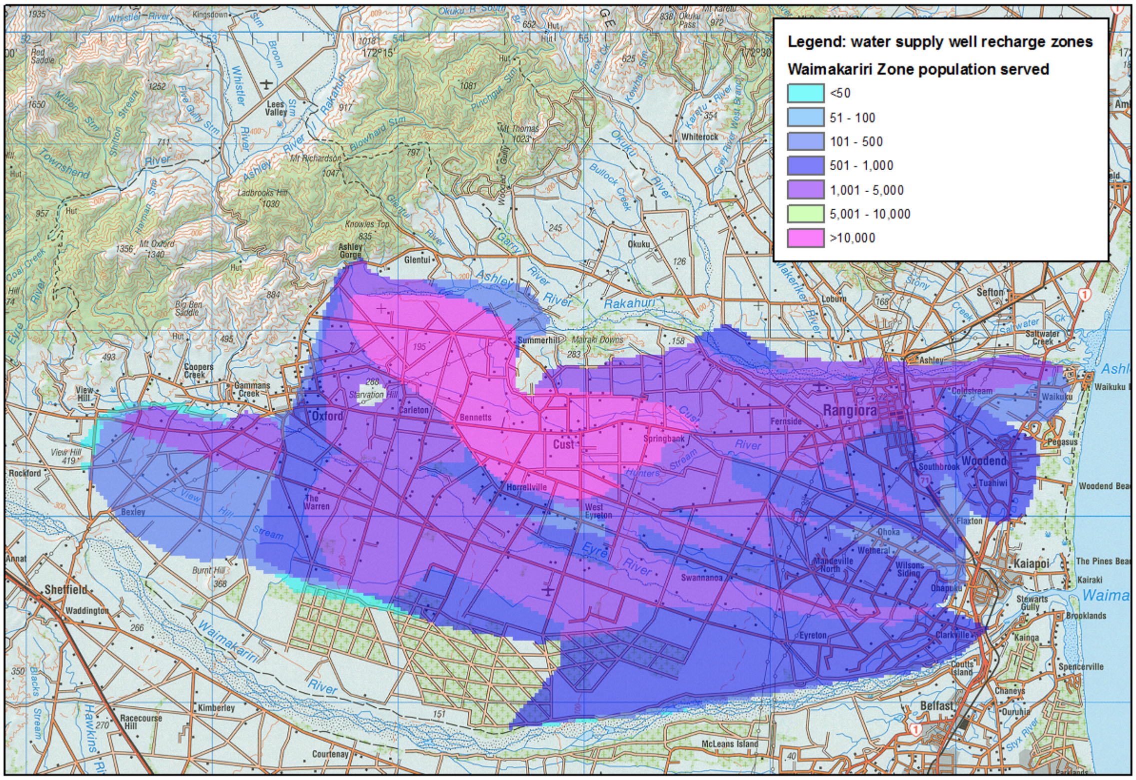


Figure 2: Waimakariri water supply well recharge zone “heat map”

EIGEN-MODELLING TO INFORM FLOW AND WATER QUALITY LIMITS FOR THE WAIKOROPUPU SPRINGS, GOLDEN BAY

Andrew Fenemor[1], Julian Weir[2], Joseph Thomas[3]
[1]Manaaki Whenua Landcare Research, [2]Aqualinc Research, [3]Tasman District Council

Aims

British statistician George Box famously said “all models are wrong, but some are useful.” He also observed “The scientist cannot obtain a ‘correct’ [model] by excessive elaboration” (Box 1976).

This presentation describes the utility of eigen-modelling and associated nitrogen mass balance modelling to understand the effects of land use on flow rates and nitrate-nitrogen concentrations at Te Waikoropupū Springs. These karst springs near Takaka are the largest in New Zealand with a combined mean flow of 13,300 l/sec. They are regarded by manawhenua iwi as wai tapu.

Various hypothetical scenarios for irrigation development in the Takaka catchment, and of the current catchment state but without the Cobb Dam, have been simulated (Weir and Fenemor 2015). This work informed a water management plan change for the Takaka catchment being developed by Tasman District Council’s Takaka Freshwater and Land Advisory Group (FLAG). It was also presented as expert evidence (Fenemor 2018) to assist the special tribunal hearing the application for a Water Conservation Order for the Te Waikoropupū Springs. The validity of critiques of the modelling raised in these processes will also be discussed in this presentation.

Method

Water balances were calculated for the three interconnected aquifers of the Takaka catchment: the Arthur Marble Aquifer (AMA) [Fig 1], the Takaka Limestone Aquifer (TLA), and the Takaka Unconfined Gravels Aquifer (TUGA) incorporating their individual surface water and rainfall recharge interactions. The dynamic response of these systems (both groundwater levels and river flows) was calibrated for the period 1980-2014 using eigen-modelling. For modelling nitrogen loads to the springs, modelled flows were converted into nitrogen loads by assigning average annual nitrogen loss rates from OVERSEER or from literature to classes of land use or land cover across the contributing catchments. By changing the inputs (particularly the proportion of different land cover types) for various scenarios, the models were used to predict changes in AMA groundwater levels, spring flows and nitrate concentrations at Te Waikoropupū Springs.

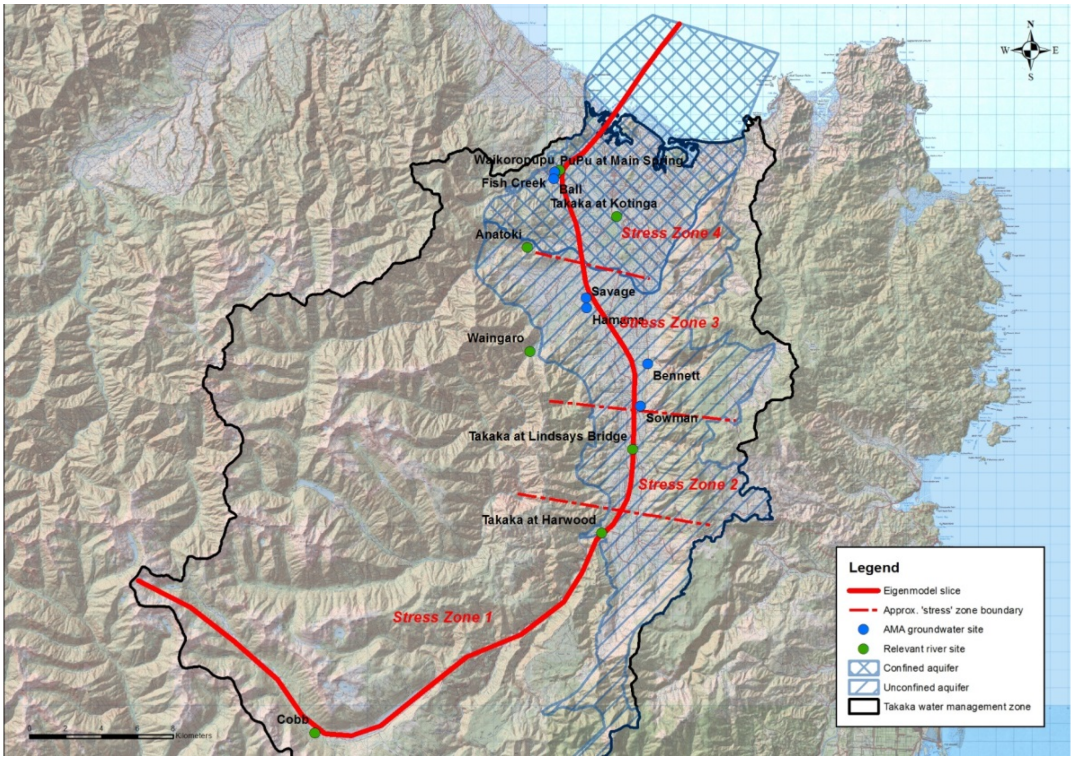


Figure 5: Eigen-model conceptual slices (stress zones) used for modelling the Arthur Marble Aquifer (AMA)

Results

The flow modelling shows that flow releases from the Cobb Dam increase the springs' 'no development' MALF7 of 6,610 l/sec by 18% while current consumptive water takes decrease it by 4%. The nitrate modelling suggests that farming in the valley floor of the Takaka Valley contributes 97% of the current (2016-18 average) nitrate-nitrogen concentration at Te Waikoropupū of 0.41 g/m^3. However, all modelled scenarios for increased irrigation development of dairy land in the Takaka Valley [Fig 2] would likely keep Te Waikoropupū Springs average nitrate-nitrogen below the upper range median limit of 0.55 g/m^3 proposed by aquatic ecologists.

This has prompted debate about the degree of reliance that can be placed on modelling, and how precautionary the tribunal and Takaka FLAG should be when setting flow and water quality limits in a nationally outstanding water body such as Te Waikoropupū Springs.

This modelling framework can also be used to examine the effects of changes in land management practices, for example, by incorporating dairy management practices such as wintering cows off properties in the recharge zone, or changing stocking rates.

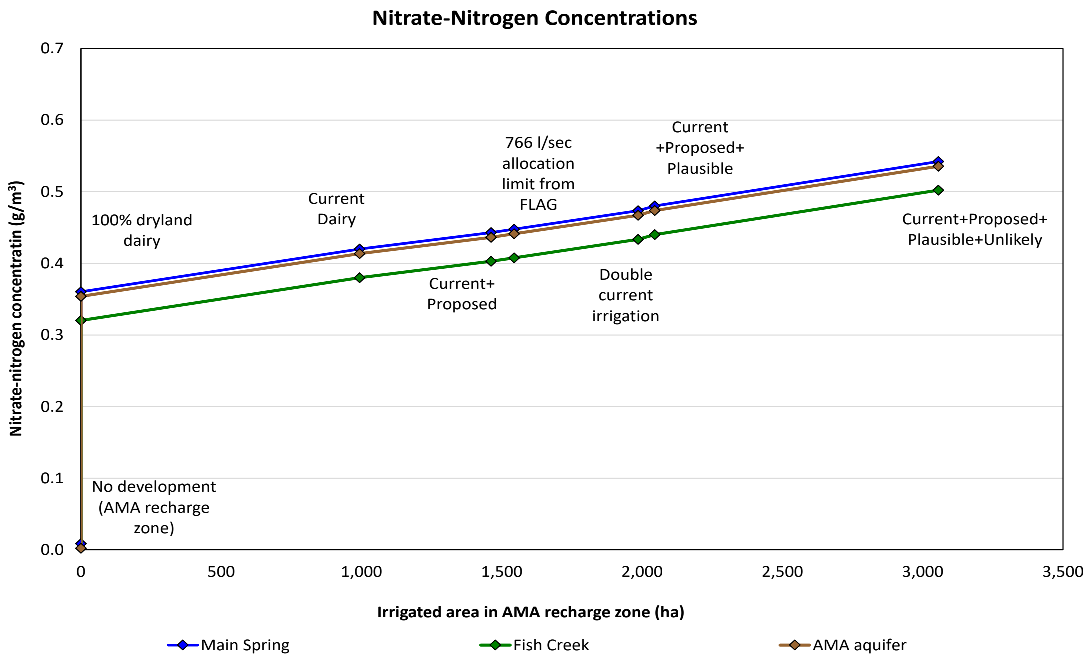


Figure 6: Modelled nitrate-nitrogen concentrations in Te Waikoropupū Springs for various scenarios

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DOES A QUICKFLOW COMPONENT IMPROVE THE REPRESENTATION OF NITRATE TRANSFERS IN THE REPOROA BASIN?

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Introduction

Regional Councils are currently at various stages of implementing the National Policy Statement for Freshwater Management (NPS-FM), which includes setting limits for surface water quality. As most surface water systems are fed by groundwater, including interflow, the common crunch point in the implementation process is **"what is the contaminant load to come?"** The extent and timing of the "load to come" is a function of; i) the history of nutrient losses from the root zone ii) the hydraulic flow paths and the associated travel times from the root zone to the receiving surface water bodies, and iii) the transformation of the contaminants that occur along these pathways.

Methods

In earlier MBIE funded work a steady state (SS) numerical groundwater flow and transport model (MODFLOW with MT3DMS) of the Reporoa Basin was developed (Close *et al*., 2016). The focus of the Close *et al*. (2016) presentation was on how to include subsurface denitrification in a SS groundwater model. The SS model developed was based on current land uses and nutrient losses, to predict the "final" long-term SS nutrient concentrations in the groundwater and loads in the surface waters. Importantly, it estimated these loads by including the assimilative capacity of the groundwater.

Subsequent research carried out in the Transfer Pathways Programme (TPP) has focussed on improving the description of the relevant transfer pathways in the Reporoa Basin model (Rajanayaka *et al*., 2017) and work covered by this presentation. This is achieved by accounting for the near-surface flows, such as surface runoff, interflow and artificial drainage, which are largely responsible for the quick flow component in stream hydrographs.

This presentation focuses on accounting for flow and concentration data for the near-surface pathways to determine the effect of including or excluding these pathways on the nitrogen concentrations and flows at various strategic points in the Reporoa stream network. This analysis will be applied over two average periods of simulation, where land uses and associated nitrate losses and recharge are different in the Basin.

An updated SS groundwater model including improved pathway implementation has been developed to provide an understanding of the nitrate fluxes and transformation processes in the Reporoa groundwater system and the resulting nutrient loads that are discharged into the receiving surface waters. The model has four layers, with the top layer corresponding to the Taupo Ignimbrite and the lower layers corresponding to the Oruanui Ignimbrite. The top Taupo Ignimbrite layer is divided into two numerical layers to improve the accuracy of flow and transport dynamics. The cells are 200m by 200m and the model covers an area of 658 km^2.

Two periods have been chosen to assess the effect of including or excluding the near-surface flows. These periods were from 1995 to 2000 and from 2006 to 2011. To calibrate the quickflow estimation method, the measured flow over 12 years in the main stream (Waiotapu) was separated into base flow (from groundwater) and the quick flow component assumed to be generated by the near-surface flows using the methods of Nathan and McMahon (1990) and Ladson *et al*. (2013). The duration and depth parameters used for this separation analysis have been subsequently applied over the model domain, to estimate the volume of quickflow in all stream reaches.

Results

The hypothesis that quickflow has a significant effect on the mass of nitrate in the stream network is to be tested by comparison of the model outputs with and without a quick flow component. In the non-quickflow scenarios, all rainfall excess from the land surface is routed into the groundwater system as recharge and subject to denitrification, as appropriate. In the simulations, where quickflow is included the estimated amount of quickflow is directly routed into the closest stream, without transport, or assimilation, through the groundwater system.

The comparison between the mass of nitrogen and flows at strategic nodes in the stream network between the non-quickflow and quickflow model outputs will be presented for the two simulation periods. The differences and their implications of the representation of quickflow in the stream network for the four scenarios modelled (+/- quickflow for 95-00 & 06-11) will be discussed.

Acknowledgement

This work was carried out under the MBIE “Transfer Pathways Programme” and co-funded by Waikato Regional Council and DairyNZ Ltd.

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FROM STOCHASTIC AIRBORNE EM INVERSION TO GEOLOGIC MODEL: APPLICATION OF A TWO-STEP MACHINE LEARNING WORKFLOW

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[1]Lincoln Agritech Ltd, [2]Semeion Institute, [3]US Geological Survey, [4]Federal Institute of Education, Science and Technology of Brasilia

Aims

In developing a geologic (or any subsurface-resource) model, geoscientists have various types of physical and geophysical data available from airborne, surface, and borehole surveys. It is challenging for geoscientists to account for all the details associated with these disparate, sparse and spatially-limited data when setting up the geologic model. Our aim is to develop and test a machine-learning workflow that simultaneously integrates stochastic airborne electromagnetic (EM) measurement and borehole lithologic information into a statistically valid geologic model.

Method

The proposed workflow involves two machine-learning applications. *First*, machine-learning is used to perform data fusion (integrate deterministically inverted layer resistivities, EM measurements, and distance of resistivity soundings to sample boreholes), data mining (quantify autocorrelations among resistivity-distance relations for each borehole) and feature selection (identifying maximum distance from sample boreholes from which to select EM measurements for Bayesian Markov chain Monte Carlo inversion). *Second*, machine-learning is used to perform data fusion (integrate quantile models fitted to stochastic layer resistivities determined using Bayesian MCMC inversion, and initial lithology estimates as equal proportions to drillers indication of presence or absence of lithology), and the simultaneous estimation of borehole lithologies based minimization of an objective function comprising the topographical error and quantization error vectors (Dickson and Giblin, 2007). The publicly available airborne EM survey data used herein were collected on behalf of the gold exploration company Glass Earth New Zealand Limited and the Otago Regional Council (Fugro, 2007). These EM data were inverted using a trans-dimensional Bayesian Markov Chain Monte Carlo approach (Minsely, 2011) which provides an estimate of the model a-posteriori distribution, consisting of a large number (100,000) of 1D models with different numbers of layers and constant resistivity within each layer.

Results

Preliminary results using the proposed machine-learning workflow are presented for the shallow (<150 m) groundwater system in central Otago Region, NZ. Cross-validation of the estimation results reveals that the workflow provides accurate and unbiased estimates of the drillers observations (presence or absence). Moreover, averaging the simultaneous quantile estimates provides fractional lithologies of gravel, sand, silt, clay, and bedrock that are statistically conservative (sum to 1) for all depths and at all boreholes (Fig. 1). Collective analysis of the modelled borehole lithologies reveal a highly heterogeneous subsurface reservoir with readily identifiable (permeable and confining) units associated with the shallow groundwater system. Other results (not shown here) indicate that it is possible to extend the quantile estimation procedure to include water levels, hydraulic properties, and water chemistry. These results lend themselves to extending the workflow to include a third machine learning algorithm for automated classifying of spatial groundwater features (aquitard and aquifer) and the determination of hydrostratigraphic units.

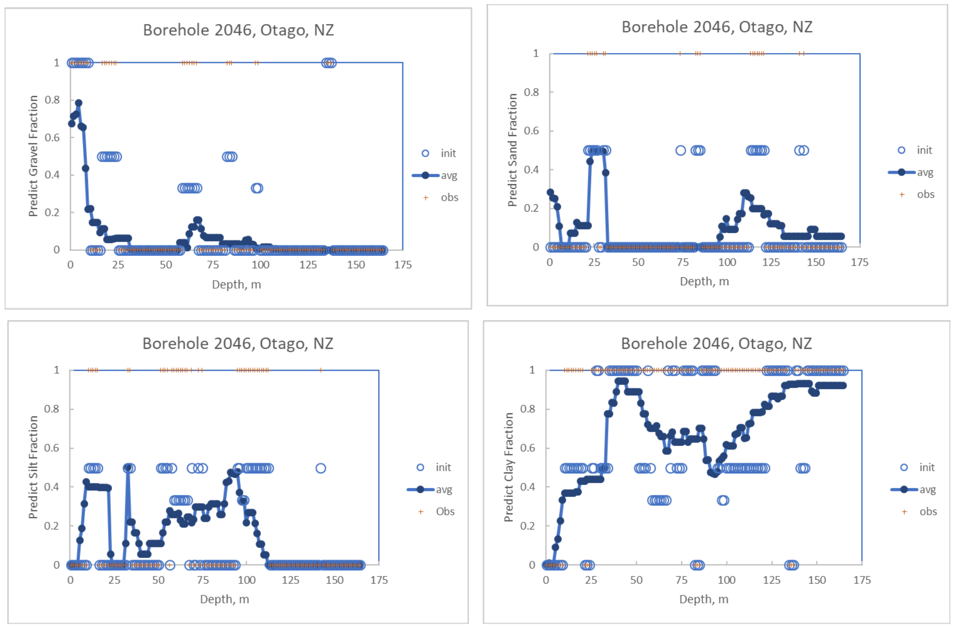
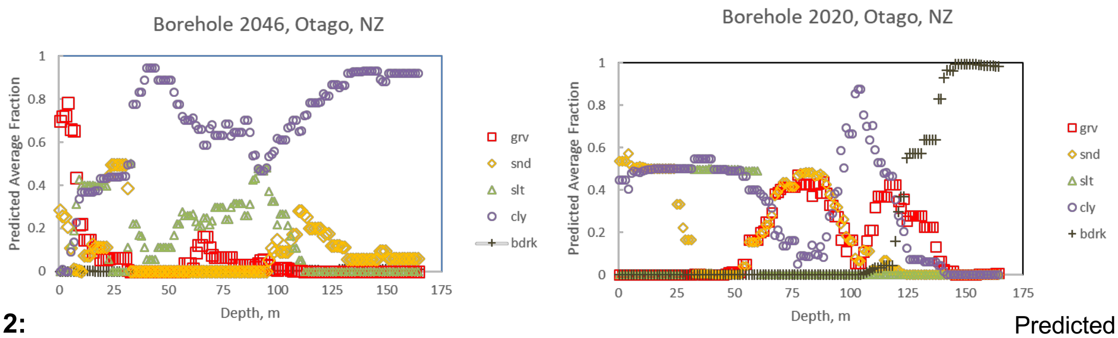


Figure 1: Averages of quantile estimates of borehole fractional lithologies: (a) gravel, (b) sand, (c) silt, and (d) clay. There were no bedrock estimates for this borehole. Init = …, avg = fractional lithology based on average of quantile estimates (0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95), obs = drillers log: presence (1) or absence (0) of lithology.



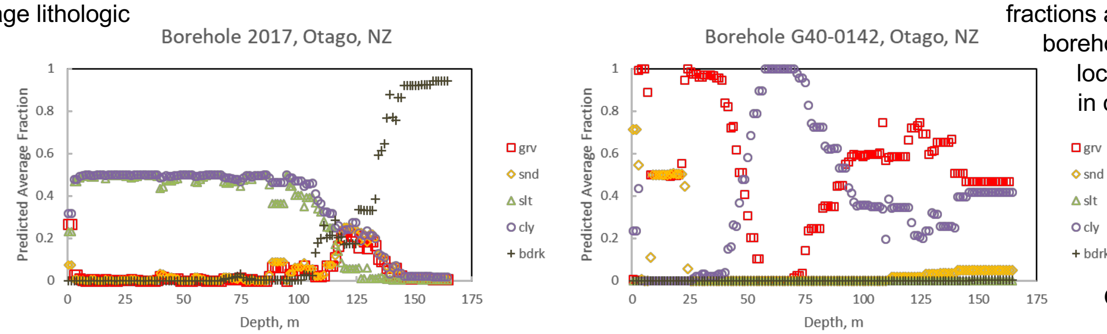


Figure 2: Predicted average lithologic fractions at 4 borehole locations in central Otago, NZ.
Note: grv = gravel, snd = sand, slt = silt, cly = clay, bdrk = bedrock.

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ON THE SENSITIVITY OF URBAN CATCHMENT RESPONSE TO THE DIFFERENT PRECIPITATION SOURCES

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[1]CSIRO Data61, [2]CSIRO Oceans and Atmosphere

With the rising urban population leading to an ever increasing burden on the urban infrastructure, a greater number of people are at risk from the natural hazards including flash floods. The risks posed by the flash floods gets further exacerbated by the deficiencies in urban planning and uncontrolled city expansion. To ascertain the risks posed by the weather extremes, for instance excessive precipitation resulting in flooding, it is important not only to study the meteorological conditions leading to such extremes but also the interaction between the extreme precipitation and the urban infrastructure.

In urban areas, the rainfall response is predominantly due to the run-off from impervious surfaces of small to medium sized catchments. The size and spatial variability of the surface porosity of these urban catchments can result in a relatively wide range of response times. The response of these urban catchments are usually quantified using either a distributed hydrological model or a hydrodynamic model. In modelling the run-off generation in urban areas, rainfall is by far the most significant contributor. This is in contrast to the natural catchments, where, the relatively higher spatial homogeneity of surface topography and the presence of lower porosity surface poses less stringent spatial and temporal resolution requirements.

In addition, it is also worth noting that there exists a clear distinction between the process scale and observed scale of such events, where the former refers to the appropriate scale of the phenomenon, whereas the latter refers to the scale at which the said process is observed. The latter scale is largely governed by the measurement techniques and the methods employed. Previous studies like Schilling (1991) pointed out that there exists a discrepancy between the available and required density of the rainfall gauge networks. For example, Schilling (1991) stated that a rain gauge network with spatial resolution of 1 per km 2 with a temporal resolution of 1 minute is required to model the rainfall response of an urban catchment. It is desirable that both the process and observed scale match, but it most cases, it is not possible, thus requiring techniques to either upscale or downscale to obtain a match between the two. In light of the foregoing discussion, it behoves us to investigate the implications of such spatial and temporal heterogeneity originating from the various modelling and measurement techniques.

Aims

The aim of this study is to investigate the response of an urban catchment to the different sources of precipitation. More specifically, in this study, the differences between the run-off generated using the input from rain gauge, rainfall radar and modelled precipitation from a numerical weather prediction (NWP) model will be examined. Additionally, this study will also elaborate on the effects of spatial and temporal resolution of a NWP model on the modelled run-off.

Method

In a previous study by Prakash et al. (2015), a hydrodynamic model for the city of Port Phillip in the state of Victoria (Australia) was developed using Swift, which is a two dimensional shallow water solver developed at CSIRO. For the present study, we use Swift for modelling the rainfall run-off generated during 2010 Victorian Floods in City of Port Phillip. The modelled precipitation was obtained using the Conformal Cubic Atmosphere Model (McGregor, 2005; McGregor and Dix, 2008), which is a numerical weather prediction model developed at CSIRO. Additionally, it is well accepted that the precipitation obtained from the numerical weather prediction models can have large biases due to the limitations of the parametrization schemes used in the NWP models. Within this study, we also compare the differences in the modelled run-off generated from modelled precipitation before and after bias correction. Lastly, as stated in the previous section, to illustrate the sensitivity of the modelled run-off, this study uses three different sources of precipitation as an input to the hydrodynamics model.

Results

The results obtained from this study will provide information on the spatial and temporal resolution required for an urban area like the city of Port Phillip. As stated in Berne et al. (2004), contrary to natural catchments, the difference in the characteristics of an urban area e.g. the emissions, the type of vegetation, the density of the urban infrastructure and the weather regimes that are present in that area necessitates the development of models for respective urban catchments. In spite of such constraints, the methodology investigated within this study and the conclusions deduced would still be applicable to other urban areas within Australia and worldwide.

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EVALUATING NEW ZEALAND'S AGRICULTURAL METHANE EMISSIONS

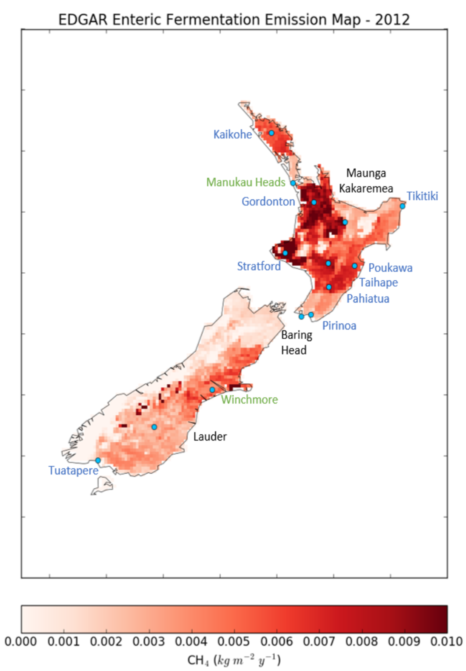
Dr Alexander Geddes[1], Sara Mikaloff-Fletcher[1], Gordon Brailsford[1], Hinrich Schaefer[1]
[1]*Niwa*

Aims

The aim of this work is to assess the capability of our current, planned and potential network of methane observations to detect reductions in enteric methane emissions from agriculture. In addition to this, we evaluate what additional observations would best support top-down estimates of methane emissions.

Method

We have simulated synthetic methane mixing ratios (the proportion of methane to all other gases in an air volume) for a trial year that uses the observed meteorology and a gridded emission map from 2012 at a total of fourteen sites (Figure 1). To compute the synthetic measurements, we firstly need an enteric methane emission map, which we have obtained from the Emission Database for Global Atmospheric Research (EDGAR, Janssens-Maenhout et al., 2017, Figure 1). Additionally, we calculate site footprints using the Numerical Atmospheric dispersion Modelling Environment (NAME, Jones et al., 2007), these footprints are effectively the geographic sensitivity of a measurement (Figure 2). By combining the footprint and the emission map, we produce the enteric methane response at each site throughout the year. This can then be combined with background methane measurements to produce synthetic measurements. To assess our ability to detect methane reductions we compare the response to our instrumental sensitivity, we then reduce the EDGAR emissions uniformly across New Zealand by 10%, 20%, 30 % and 40% and recompute the response. By looking at the relative change in the response between the reference case with no reductions and the cases with various reduction levels, we can assess to what extent we can confidently detect reductions in methane on a regional and national level. This analysis also allows us to assess our current ability and to help inform us on what future and potential sites could add to our understanding and the capability of the network.



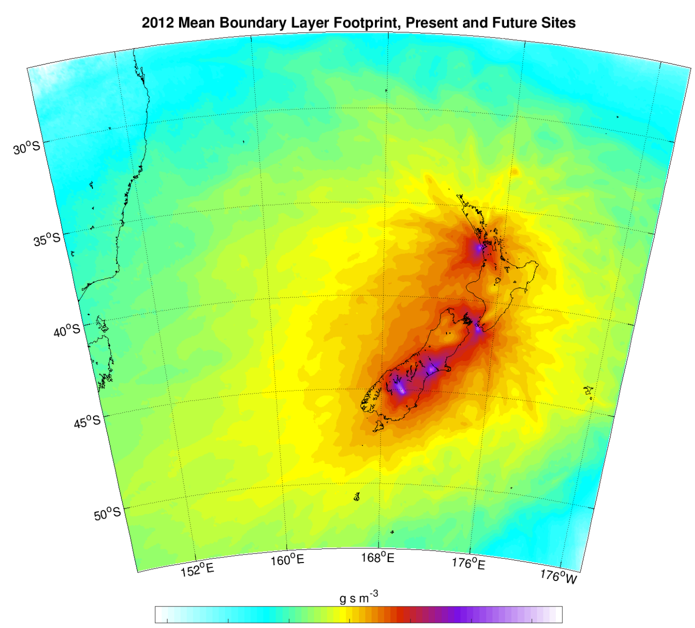


Figure 1: Left; Agricultural methane emissions from the EDGAR database (kg m^{-2} y^{-1}) overlaid with existing (black), planned (green), and potential (blue) atmospheric greenhouse gas observing sites. Right; The combined footprints of NIWA's two existing and two planned national methane observing stations, based on NAME model simulations. Red and purple colours represent the regions that are best observed by our current network. Yellow and pale orange areas are not as well sampled by the network.

Results

NIWA's current and planned methane observing network could robustly detect a uniformly distributed nation-wide methane emissions reduction of 20% or more, but is unlikely to be able to robustly detect smaller emissions reductions. New observing sites that are being established in the Canterbury plains and to the west of Auckland would play a key role in this effort, as they are able to detect emissions from key agricultural regions. Comparisons with observations suggest that the model and gridded emission maps are able to represent key features of atmospheric transport, which is a prerequisite if we are to use the atmospheric data to infer emissions. Thus, we conclude that this approach is a promising way forward to independently estimate and verify agricultural methane emissions reductions at regional to national scale. We also demonstrate that we can further enhance the monitoring potential of the network by the addition of new analysers in regions of intensive agricultural emissions

Our current observing network does not adequately capture methane emissions for much of the North Island, with poor coverage of some key agricultural regions including the Waikato, Taranaki, and Manawatu. Therefore, if the methane emissions reduction varied by region, additional measurements would be needed. Adding methane measurements to our existing station at Maunga Kakaramea, a carbon dioxide observing station near Rotorua, would provide methane observational coverage over a broad cross section of the central North Island. Estimates would be further enhanced by additional observing stations in the central Waikato (Figure 2), Taranaki, and/or Manawatu-Whanganui. This study provides a roadmap for future expansions to our observing network, if this approach is to be used either to infer emissions reductions at national scale or over a target region where a mitigation technology is initially deployed.

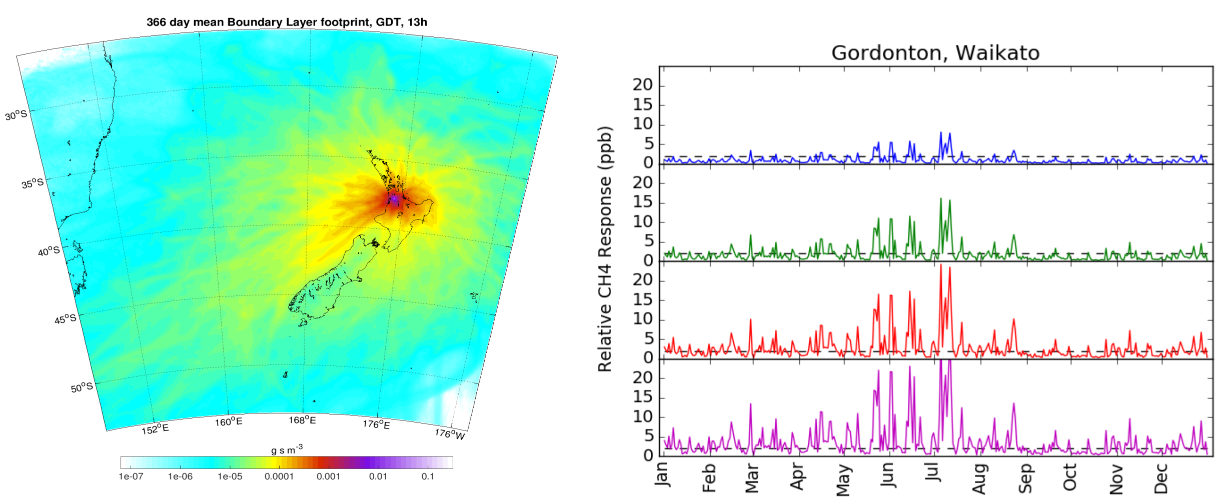


Figure 2: Station footprint (left) and relative change associated with methane emissions reductions (right) for an example potential site, Gordonton. The change in methane mixing ratios is shown for national agricultural emissions reductions of 10% (blue),20% (green),30% (red), and 40% (magenta). Dashed line indicates the uncertainty associated with our methane measurements.

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UTILITY ASSESSMENT OF REDUCES ORDER MODELS (ROMS) AS SURROGATES FOR THE WAIRAU PLAIN GROUNDWATER MODEL

Moritz Gosses[1], Thomas Wöhling[1,2]
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Background

The Upper Wairau Plain Aquifer in the Marlborough District of New Zealand is a system mostly driven by interaction with the Wairau River. Managed by the Marlborough District Council (MDC), the aquifer is the main source of drinking water and used for irrigation in the region. Declining groundwater levels and spring flows in the past decades heighten the interest in system understanding for sustainable management of the aquifer.

For this reason, a complex numerical model has been set up for the Wairau Plain aquifer to compute several different quantities of management interest such as groundwater levels, spring and river exchange flows, storage, and groundwater residence times (Wöhling et al. 2018). The numerical burden associated with the complex model for operative management can potentially be mitigated by the use of simplified models, provided they reproduce the outputs of the original model with sufficient accuracy.

Aims

The goal of the study is to present different reduced order models (ROMs) of the Wairau Plain system and to analyse their performance and applicability for different modelling tasks such as surrogate modelling, predictive uncertainty assessment or data worth analysis. Here, we specifically investigate the model simplification error. The complex model serves as a benchmark in the analysis. We address the following questions in our study:

1) Which ROMs can be utilised for which applications and for which model prediction types?

2) How efficient and accurate are the different ROMs for the applications and are there trade-off costs involved?

Method

We present three different ROMs based on the complex numerical Wairau Plain aquifer model:

a) a spatially and parametrically simplified MODFLOW model,

b) a set of artificial neural networks (ANNs) and

c) a linearised sub-space model based on proper orthogonal decomposition (POD).

We utilise a paired model approach developed by Doherty & Christensen (2011) and Watson et al. (2013) to analyse the simplification error associated with the ROMs for different model predictions. We then evaluate the ROMs for their applicability to the different modelling tasks based on both their fundamental applicability and their performance in representing the complex model.

Results

All three ROMs are generally able to reproduce features from the calibration dataset, i.e. groundwater levels, spring flows and river-groundwater exchange fluxes. The simplified MODFLOW model and the POD model describe the entire model area (and all quantities of interest within) spatially distributed, while the ANN technique requires an individual model for each data type and location of interest.

The different ROM types perform very different with respect to bias and magnitude of model simplification error. Each ROM type also displays variation for different model predictions. The paired model analysis shows a deterioration of quality for the simplified MODFLOW model for predictions different in type and location to the calibration data set. This is because the simplified MODFLOW model has lost some important small-scale detail of the complex model. The ANNs provide superior accuracy due to their specialization to only specific data locations. This specialization, however, limits their real-world applicability to predictions of data types and locations that are contained in the measurement data set. The POD model is superior in its applicability to the simplified MODFLOW model as it retains the significant features of the complex model. All three ROMs exhibit strengths and weaknesses for different applications and different prediction types. A thorough analysis of these limitations allows the informed choice of appropriate ROM for different modelling (and management) tasks.

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THE USE OF SIMPLE TOOLS FOR MANAGING RISKS TO WELLFIELDS

Katy Grant[1], Geoff Williams[2]
[1]Pattle Delamore Partners Limited, [2]Wellington Water Limited

Aims

Following the recommendations of the Havelock North Enquiry, many water suppliers are reviewing their procedures regarding drinking water safety; looking at treatment options, catchment risk and bore protection. In Wellington this process was already underway due to changes to the water quality at the main Waterloo Wellfield following the Kaikoura Earthquake. Upgrades to the treatment plant at this wellfield were planned, but to ensure there was sufficient supply it was necessary to bring the backup wellfield at Gear Island back online whilst the upgrades occurred.

Based on recent experience, Wellington Water were concerned about potential water quality issues at this wellfield post-earthquake and the risk of drawing poor quality shallow groundwater down from the Taita Alluvium, through the confining layer, into the main Waiwhetu Aquifer. At their request, PDP developed a simple Microsoft Excel™ based tool which used existing monitoring data to allow Wellington Water to quantify and manage the risks on a daily basis. The tool focused on identifying the potential risk of a groundwater pressure head reversal between the shallow Taita Alluvium and the main Waiwhetu Aquifer.

Method

The tool was set up in Excel with a simple Dashboard allowing the operator to select which bores were in use; before groundwater level data, tidal data and wellfield pumping rates for the previous day were imported. This information was then used to estimate a "resting" water level for the Waiwhetu Aquifer, when tidal variation and the various pumping effects were removed. This value was used as the static water level and then projected drawdown was estimated for each bore at the Gear Island Wellfield based on several possible pumping scenarios. The water levels in each bore were compared with the maximum water level within the Taita Alluvium to answer the following questions each day:

- Is there a significant risk of reversal of the upwards hydraulic gradient between the aquifers due to pumping?
- Which bores at the Gear Island Wellfield can be used today with minimal risk?
- What is the maximum allowable pumping rate for the Waterloo Wellfield?

A contingency factor of 1 m was included based on tidal variations and lags, the location of the monitoring points relative to the wellfield and a factor of safety to address the effects of other groundwater takes from the aquifer.

The results were displayed on the Dashboard for easy use and also recorded everyday within a sheet tracking the outputs so longer term effects could be noted.

Results

The management tool was used over a six month period to monitor the risks and worked very effectively after some initial calibration. The main adjustment was the inclusion of varying pump rate for Bore 3, as the drawdown around this bore was significantly higher than the other bores and it was necessary to run this bore at a reduced rate on several occasions.

Groundwater within the Taita Alluvium is rapidly recharged from the Hutt River following large rainfall events. When such events occur, the risk of hydraulic gradient reversal was significantly increased. This risk was also increased by the higher demand and lowering water pressures within the Waiwhetu Aquifer as a result of an unusually dry spring and early summer period.

The management tool allowed Wellington Water to assess the potential risks at the wellfield and to consider these in comparison to their demand issues and the risks associated with other streams of supply (e.g. incomplete upgrade of water treatment facility associated with the Waterloo Wellfield and low flow conditions in the Hutt River).

Wellington Water decided to run the wellfield at the maximum rate in late November and early December, despite the tool indicating that the upwards head gradient between the aquifers was minimal and the chance of hydraulic gradient reversal high. This was done because the risks were considered to be less than the alternative supply options available at this time. On 1 December 2017 Enterococci was detected at a concentration of 54 CFU/100mL in the Gear Island raw water collector main following a period of high abstraction from the wellfield, indicating that a contaminant pathway may exist between the shallow and deep aquifers in the vicinity of the bores.

Due to the high demand experienced, it was necessary to continue abstracting from this wellfield until the upgrades at the Waterloo treatment plant were completed three weeks later. The water was chlorinated to treat for bacteriological pathogens prior to supply to the public.

Figure 1: Effects of total abstraction and varying water levels on upwards head gradient

Conclusions

Simple management tools, based on a good conceptual model of the aquifer system, can provide a very useful interim measure to manage drinking water safety risks whilst more permanent solutions are put in place. Such tools are quick to develop and can be instigated using existing data sources and systems. This means they are of particular use following seismic events, where concerns around bore and aquifer integrity frequently arise in the immediate aftermath.

Given the recent recommendations of the Havelock North enquiry, many suppliers will be reassessing their water supply safety and water treatment options. In some cases simple tools, similar to the example presented here, could be used to help manage potential risks while the most appropriate long-term measures are evaluated and implemented.

A PILOT STUDY OF AEROSOL CONCENTRATIONS AT TWO LOCATIONS NEAR COOK

Sally Gray[1]

[1]*Niwa*

A pilot study was undertaken in May and June 2018 at Baring Head and Outlook Hill on the Wellington south coast to determine the variation in aerosol concentrations at two different elevations and the suitability of the paired sites for a major aerosol-cloud interaction study in late 2019.

We present a preliminary investigation into the data collected during a short period when aerosol equipment was operational at the two sites. The condensation particle counters were installed at the NIWA Clean Air Station at Baring Head (elevation 80m AMSL) and the Metservice Radar site on Outlook Hill (elevation 587m AMSL) and recorded data every 5 minutes. During some periods the two data sets show the same trends but there are periods when they deviate. We will discuss some possible reasons for these deviations focusing on the synoptic meteorology.

Special thanks to Metservice for allowing us to use your site.

UTILITY OF SATELLITE DATA FOR HYDROLOGICAL MODELLING

James Griffiths[1], Shailesh Singh, Kelsey Montgomery
[1]*Niwa*

Aims

There is an increasing range of satellite remote sensing data available across the globe that can be used to estimates different hydrological fluxes (see Mohanty et al., 2017; Zenmansky, 2015; McCabe et al., 2017). There is a high demand for remote sensing data related to land-surface processes for use in precision farming, slope stability, flood and drought planning, and climate impact assessments. In this research, the extent to which catchment-scale hydrological modelling can be improved by using satellite derived evapotranspiration estimates will be assessed. This research consists of:

1. Review of available satellite data that can be used in estimation of potential evapotranspiration (radiation, albedo, LAI, NDVI, soil moisture, and land-surface temperature).

2. Comparison of satellite-based estimates of evapotranspiration in three regions across NZ (Southland; Horizons; and Gisborne), with terrestrial based measurements (NIWA's Station data and VCSN network data).

3. Assessment of catchment-scale hydrological-model performance (surface-water flow) using satellite-derived potential evapotranspiration.

Method

Estimates of potential evapotranspiration are based on the Priestley-Taylor or Penman-Monteith (depending of the available data). The TopNet model is then used to calculate catchment runoff and stream flow. Assessment of hydrological model performance with satellite data is then made for catchments in Southland, Horizons and Gisborne regions to represent a range of hydrological conditions.

Results

The results that will be presented will be drawn from the Southland region and will describe monthly differences in potential evapotranspiration estimated from satellite (for example Figure 1) and terrestrial based data. The extent to which satellite-based estimates of evapotranspiration can be calibrated to improve hydrological model performance was also assessed.

Figure 1: Normalised Difference Vegetation Index (NDVI) used to calculate evapotranspiration for Southland region in January 2018 (left) and June 2018 (right). [https://worldview.earthdata.nasa.gov]

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INVESTIGATING THE GROUNDWATER RESOURCE BENEATH WELLINGTON HARBOUR: EXPLORATION ACTIVITIES AND HYDROGEOLOGICAL ANALYSIS

Mark Gyopari[1], Katy Grant[2], John Begg[3], Scott Nodder[4]
[1]Earth in Mind Limited, [2]Pattle Delamore Partners Ltd, [3]GNS Science, [4]NIWA

The Waiwhetu Aquifer provides a major component of the public water supply system for Wellington with groundwater abstraction taking place from a borefield located in Lower Hutt. Wellington Water Limited (WWL) recognise that the reticulation system linking this borefield with Wellington City could be compromised following a major seismic event. To improve the resilience of the city's water supply, the extension of the Waiwhetu Aquifer beneath Te Whanganui a Tara/Wellington Harbour was identified as a potential emergency or supplementary water source located closer to the city. The WWL investigation programme to assess the supply potential of the sub-harbour aquifer system included marine seismic reflection surveying, geological modelling, the drilling and testing of two exploration bores (termed E3 and E8), and groundwater modelling.

Selection of drill sites was guided by several criteria including saline intrusion risk associated with areas of known or perceived ocean connectivity, anticipated aquifer conditions derived from geological modelling, and seismic risk related to the location of known active and inactive faults in the harbour. The key hydrogeological aims of the drilling program were to confirm the following:

- The existence of viable aquifer formations and conditions beneath the harbour floor;
- The water quality and scope potential treatment requirements;
- A provisional aquifer yield; and
- The potential saline intrusion risks.

The investigation successfully identified the presence of a sub-sea freshwater resource within coarse Waiwhetu gravels under artesian pressure of 3-4m above mean sea level which are hydraulically connected to the onshore aquifer. Test pumping and onshore wellfield shut down testing provided a provisional assessment of aquifer transmissivity.

Fresh potable water was identified within the Upper Waiwhetu Aquifer in both bores, although treatment for ammonia, iron, manganese and arsenic would be required for public supply. Slightly elevated chloride is indicative of small amounts of seawater mixing (0.3-0.5%). Unpotable water with a chloride concentration of 850 mg/L was encountered in the basal Lower Waiwhetu gravels at one bore site (E8), indicating a much higher seawater mixing component of about 4.5%. This may be associated with a diffuse saltwater interface, dilute seawater trapped in base of the aquifer formation or salt diffusion from the underlying marine aquitard.

When compared to the water chemistry at the Petone shoreline and at a bore located off Somes Island, the different chemistry encountered in the exploration bores suggests a highly variable throughflow dynamic across the sub-harbour aquifer with very little throughflow occurring south of Somes Island (discharge having occurred through submarine springs up-gradient). Age dating shows the groundwater encountered in both exploration bores is in excess of 100 years - compared to less than 20 years at the foreshore and at Somes Island

A variable-density groundwater flow and solute transport (SEAWAT) model was developed to simulate a series of abstraction scenarios from the most favourable target site south-east of Matiu/Somes Island (borehole site E8). A conservative, sensitivity-based approach was adopted based upon plausible system conceptualisations and through testing alternate model calibrations. The results of the modelling indicated the following:

- The water quality in the Upper Waiwhetu Aquifer may be from an ocean source due to the sensitivity of the low-gradient system to dispersion-diffusion processes;
- The higher salinity concentrations in the Lower Waiwhetu Aquifer at E8 can be explained by aquifer heterogeneity and preferential dispersion/diffusion from a diffuse saline interface predicted to occur in the southern harbour entrance area;
- The saline interface location was shown to be sensitive to both onshore and offshore abstraction rates; and
- The salinity distribution exists in a state of fragile equilibrium which would be disrupted when abstraction stresses are imposed on it.

A significant salinisation risk was identified to be seawater backflow into the Upper Waiwhetu Aquifer via submarine spring vents and through weak aquitard materials on the eastern (Eastbourne) margin of the harbour. This risk could be managed through restricting aquifer drawdown at critical sites and therefore is a principal constraint on the sub-harbour groundwater abstraction rate. Modelling provided a provisional yield from the Upper Waiwhetu Aquifer of between 10 and 20 MLD under low aquifer recharge conditions.

The SEAWAT model was also used to investigate whether the brackish water observed in the Lower Waiwhetu Aquifer could cross-contaminate the Upper Waiwhetu Aquifer and enter abstraction bores. Since there is a very small separating aquitard between the upper and lower Waiwhetu aquifers (only about 3.5m at E8) and recognising that the immediate lateral continuity and integrity of the aquitard is tenuous, a significant risk of aquifer cross-contamination is possible. This was confirmed by the modelling which indicated that saline water could migrate into the Upper Waiwhetu Aquifer under all of the pumping scenarios, although there is a high level of model uncertainty regarding concentration predictions. It is possible that a pumping induced mixing effect may not be easily reversed or may take considerable time given the almost stagnant offshore aquifer throughflow dynamics.

The modelling was unable to provide certainty that sub-harbour abstraction from the preferred location would not negatively impact on the water quality of the Upper Waiwhetu Aquifer. Further uncertainty analysis may provide more clarity, but the only way to provide certainty regarding the cross-aquifer salinisation, other risks and aquifer yield is to undertake further exploration work which would need to include extended duration and high yield pump testing accompanied by appropriate monitoring.

The authors wish to thank Wellington Water Limited for permission to present the findings of the harbour bores investigation project.

DESIGN HYETOGRAPHS IN FLOOD MODELLING - REAL OR FANTASY

John Hansford[1]
[1]*Tonkin + Taylor*

Aims

It is still a requirement of many local authorities in New Zealand to use Chicago-type 24 hour (or sometimes longer) nested hyetographs as input in flood modelling. An argument for adopting this approach is the nested hyetograph incorporates both short and long duration storms in one hyetograph making it possible to estimate flood discharge and extents throughout a catchment using single model run, an important consideration when run times are measured in hours and often in days. Proponents of the method agree that simulation results will be conservative (overestimate flood peaks) and increasingly so as the catchment gets larger. This paper addresses the potential overestimation of peak discharge using 24 hour or longer duration Chicago-type nested hyetographs and presents alternatives that generate more realistic hydrographs.

Method

The Chicago nested storm approach was developed by Kiefer and Chu in the 1950s and is still currently prescribed for generating 10 minute time step 24 hour hyetographs for input to flood modelling by many authorities in New Zealand. The hyetographs are generated using the rainfall depths for the desired recurrence interval nested symmetrically about the 10 minute peak. The likelihood of getting short duration rainfall with the same recurrence interval as the 24 hour rainfall within the 24 hour storm is addressed using the results from analysis of the Christchurch Botanical Gardens 56 year-long rainfall record.

The impact on simulated peak discharge from small catchments using a 24 hour nested hyetograph instead of possibly more appropriate shorter duration hyetographs is investigated with a plot (Figure 2) showing the differences in the hydrographs generated for a 10 km^2 catchment.

Alternative design hyetographs that may be more realistic include:

- The design rainfall temporal distributions included in NIWA's HIRDS 4, published earlier this year
- Nested hyetographs with the peak rainfall intensity limited to between 3 and 5 times the storms average intensity
- Australian Rainfall and Runoff (ARR) that presents regional temporal distributions giving 10 ensembles for each storm duration

Results

The likelihood of the short duration maximum being within the 24 hour event is shown in Figure 1.

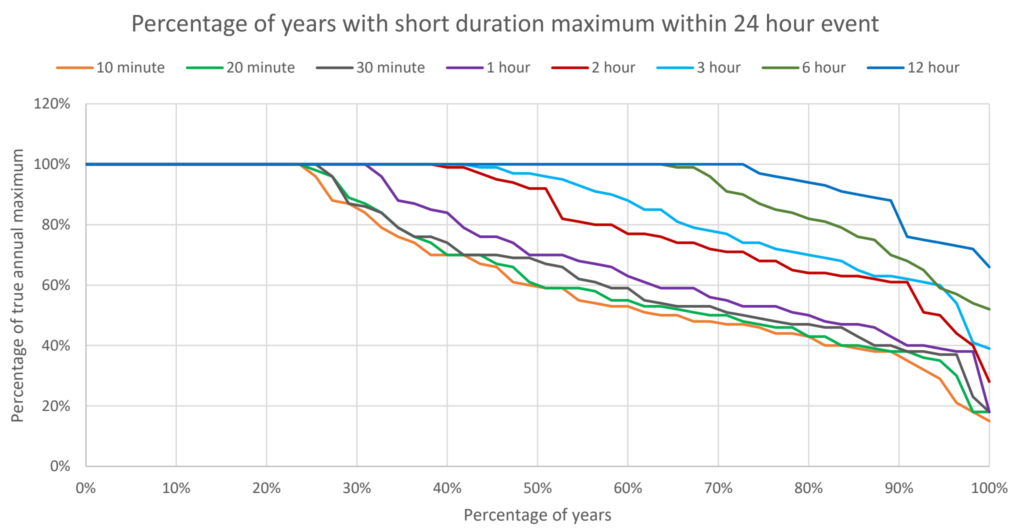

Figure 1: Percentage of years with short duration maximum within 24 hour maximum

The results show that for the Botanical Gardens record, the maximum 10 minute and 20 minute rainfall for the year occurred within the 24 hour maximum in only 25% of the years. The "strike rate" improves with increasing duration and reaches 73% for the 12 hour component duration.

Figure 2 shows the 100 year ARI hydrographs for three storm durations generated using nested hyetographs with the peak rainfall intensity limited to between 3 and 5 times the average intensity of the storm together with the 24 hour hydrograph generated using the same rainfall in a Chicago-type nested hyetograph without limiting the peak rainfall intensity. The figure shows that the critical storm duration is between 12 and 24 hours. The simulated peak discharge of 59 m^3/s using the 24 hour unlimited peak intensity nested rainfall is potentially overestimated by 68%, which would translate to a difference in ARI of an order of magnitude or greater.

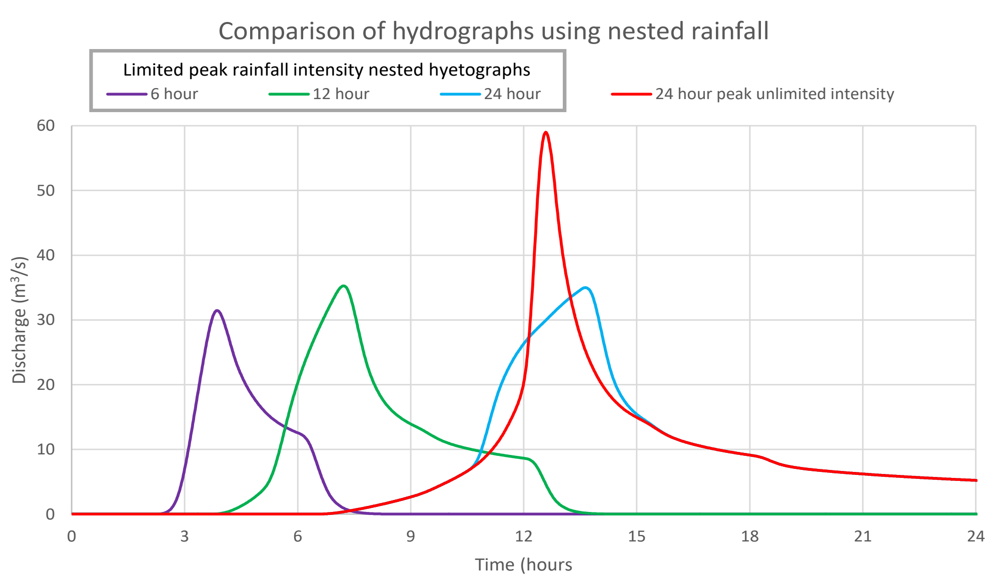

Figure 2: Comparison of hydrographs using nested rainfall

Figure 3 shows 100 year ARI hydrographs generated using the HIRDS V4 temporal rainfall distribution for 1, 6, 12 and 24 hour storms together with the 24 hour hydrograph generated using a nested Chicago-type hyetograph. The HIRDS V4 hydrographs show that the critical storm duration for the catchment is 6 hours and the peak discharge is less than half of the peak discharge generated using the 24 hour Chicago-type hyetograph.

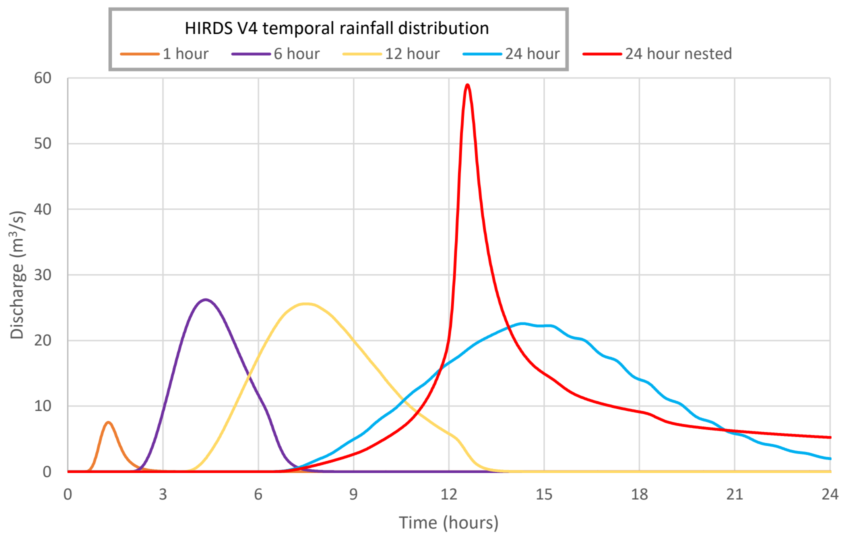

Figure 3: Comparison of hydrographs generated using HIRDS V4 temporal distributions and the Chicago nested 24 hour hyetograph

ESTIMATING ACTUAL EVAPOTRANSPIRATION FROM A RAINGARDEN USING THE BOWEN RATIO ENERGY BALANCE METHOD

Tingting Hao[1], Asaad Shamseldin[1], Keith Adams[1], Bruce Melville[1]
[1]*University Of Auckland*

Much research has been done on the performance of raingardens, both at the laboratory scale and the field scale (Roy-Poirier, Champagne & Filion, 2010). But there is little research to specifically quantify actual Evapotranspiration (ET) from a raingarden (Hess, 2017). Reports of raingarden ET research have widely varying, even contradictory, results (e.g., Dietz & Clausen, 2005; Selbig & Balster, 2010). In addition, it seems that in design guides for raingardens in New Zealand, and in other parts of the world, there is no specific content aimed at estimating ET.

Aims

The main aim is to:

- Calculate daily actual ET using the Bowen ratio energy balance method (BREB) method

Contributory objectives are to:

- Develop criteria for excluding Bowen ratio data and carry out data exclusion frequency analysis
- Analyze energy fluxes (net radiation, latent heat flux, sensible heat flux and soil heat flux) on a low radiation day and a high radiation day
- Derive Bowen ratio values on a low radiation day and a high radiation day
- Investigate the effect of meteorological variables on actual ET estimated from the BREB method

Method

The BREB method was chosen as the energy balance method for actual ET estimation in the Hooton Reserve Raingarden (North Shore, Auckland, New Zealand), after comparison with the EC method, mainly because of the fetch requirement.

The BREB method is based on the law of conservation of energy, and sensible heat flux and latent heat flux are the two key variables. Previous BREB research shows that this method is applicable in a small area such as that of the Hooton Reserve Raingarden, but data from some wind directions were excluded.

Many instruments were installed onsite, such as for the measurement of net all-wavelength radiation, soil heat flux, water vapour and temperature gradients, wind direction and wind speed.

Data quality control is critical when using the BREB method; adopted criteria for excluding unsuitable data are Bowen ratio between -1.3 and -0.7, and wind direction from 315 to 360 and from 0 to 135 degrees (because of the alignment of the raingarden).

Results

1) Data exclusion frequency

For the combined Bowen ratio and wind direction criteria, the average exclusion proportions (04/08/2016-31/08/2016) were fairly large for most of the time, mostly because of wind direction (Figure 1).

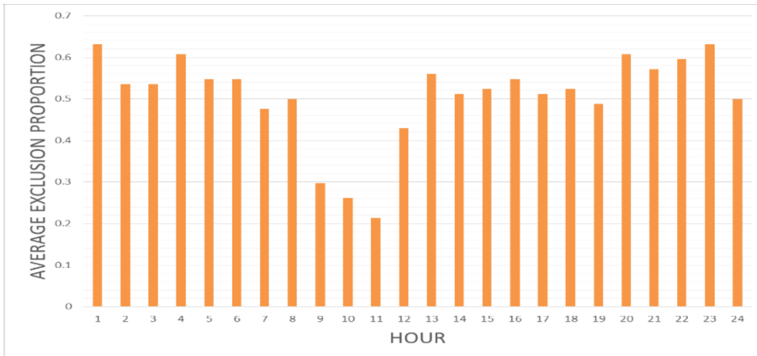

Figure 1: Average daily pattern of data exclusion for the combined Bowen ratio and wind direction criteria for August 2016 (04/08/2016-31/08/2016)

2) Typical daily energy fluxes

A low radiation day (14th August 2016) and a high radiation day (1st February 2017) were selected for the analysis of typical daily energy fluxes and typical daily Bowen ratio values. On both days, the average energy fluxes from large to small are latent heat flux, sensible heat flux and soil heat flux. On the high radiation day, all the fluxes (except the soil heat flux) were about twice those on the low radiation day.

3) Typical daily Bowen ratio values

The Bowen ratio was highly variable at the hourly scale; the average Bowen ratio value on the high radiation day was almost twice that on the low radiation day, indicating a higher proportion of the available energy was being used for sensible heat flux on the high radiation day (a warm day in the dry season). (Figure 2).

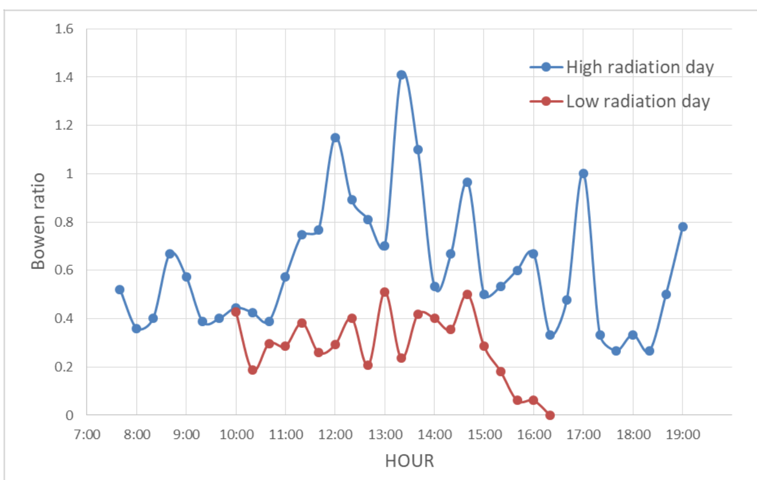

Figure 2: Plot of Bowen ratio using the BREB method on two typical days

4) Spearman coefficient of correlation between actual ET and meteorological variables

To investigate the effect of meteorological variables on actual ET estimated from the BREB method, the Spearman's rank-order correlation (a non-parametric method) was used. Table 1 shows correlations for the combined results for wet months (April to September) and dry months (October to March). As expected, for both wet season and dry season, radiation is the most significant meteorological variable for actual ET, and relative humidity is the second most significant meteorological variable. Comparing the wet season correlations for relative humidity, radiation and wind speed with the dry season, it can be seen that the correlations for the dry season are greater than those for the wet season.

Table 1: Spearman coefficient of correlation between actual ET and meteorological variables

Season	Months	Relative Humidity	Radiation	Temperature	Wind Speed
Wet	April to September	-0.344**	0.585**	0.147	0.137
Dry	October to March	-0.701**	0.903**	-0.075	0.358**

Notes: ** Indicates significant at the 0.01 level (2- tailed)

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CALIBRATION-CONSTRAINED UNCERTAINTY ANALYSIS OF GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODELS FOR THE WAIMAKARIRI-ASHLEY REGION

Brioch Hemmings[1], Matthew Knowling[1], Catherine Moore[1], Matt Hanson[2], Zeb Etheridge[2]

[1]GNS Science, [2]Environment Canterbury

Aims

A groundwater flow model for the Waimakariri-Ashley region of the Canterbury Plains has been developed for use with MODFLOW-NWT (Niswonger et al. 2011). Over 3,800 model parameters have been calibrated to historical data and expert judgement estimates including, groundwater levels, surface water-groundwater exchanges, in-stream river flows, and offshore discharge, using PEST (Doherty 2016). The calibration process can be thought to produce a single realisation of parameters that provide satisfactory representation of the historical observations, while deviating to a minimum extent from expert knowledge - derived from field observations (e.g. specific capacity data), geological studies, and literature, and implemented in the calibration as Tikhonov regularisation constraints. However, as with all ill-posed inverse problems the calibrated parameter values are non-unique; they represent one of many potential parameter combinations that provide both an acceptable fit to historical observations and to expert parameter knowledge. Use of a single deterministic model, such as this, for making predictions about the behaviour of a natural system can result in significant and unknown prediction bias and/or error (e.g., Moore and Doherty 2006). Uncertainty analysis, although demanding additional computational requirements, is essential to provide decision makers with a quantification of model prediction uncertainty and therefore the power to make decisions informed by some knowledge and understanding of risk.

Predictions of interest for the Waimakariri region model include identifying potential sources of nitrate contamination in surface water and groundwater in the Waimakariri zone, and estimates of nitrate concentrations in key receptors when nitrate concentrations reach steady state. This work aims to provide decision support for water- and land-use management in the extended Waimakariri region through the application of calibration-constrained non-linear uncertainty analysis.

Method

This calibration-constrained uncertainty analysis involves propagation of a linear Bayesian approximation to the posterior probability distribution and is referred to as "linear-assisted Monte Carlo" (LAMC, Doherty (2015)). This method is used to calculate a posterior parameter covariance that incorporates, the prior parameter covariance matrix, defined by expert knowledge; the calibrated model sensitivity matrix (Jacobian), generated through assessment of changes in model outputs resulting from incremental changes in model parameters; and an error covariance matrix which accounts for estimates of observation error as well as structural errors inherent in the numerical representation of a natural system. The resulting posterior parameter covariance matrix provides the basis for multivariate Gaussian sampling of parameter space; the product of which is an ensemble of parameter realisations centred around the calibrated parameter values which define the posterior parameter uncertainty. A total of 4,000 realisations were generated. We used rejection sampling (or "filtering") of parameter realisations that fail to provide "acceptable" model-to-measurement misfit ("acceptable fit" is informed by the calibration process). Further rejection sampling for the Waimakariri model ensemble was undertaken based on the ability of each realisation to represent particular observations (e.g. steep downward head gradients, identified as critical observations), and also recently collected data (lateral and vertical head gradients from an updated piezometric survey). A final stage of realisation rejection sampling has been undertaken by combining the flow model realisations with steady-state, MT3D-USGS (Bedekar et al. 2016) transport simulations, with realisations filtered based on a comparison of simulation outputs to end-member mixing analysis (estimates of water provenance); see Scott et al (2018).

The realisations remaining after rejection sampling, are used to generate an ensemble of steady-state, conservative (no reaction or decay) contaminant transport simulations. This transport model ensemble represents the contribution of flow model parameter uncertainty to contaminant transport prediction uncertainty. The transport simulations focus on transport pathways from contaminant sources north of the Waimakariri River.

Results

The LAMC analysis revealed that the calibration process results in a limited reduction in uncertainty, relative to the prior parameter uncertainty, for the majority parameters. This suggests that the simulation of the available data is relatively insensitive to the value of many parameters; these parameters, therefore, are not well-informed by model calibration data and the calibration process. Despite this, a number of parameters (boundary flows and select stream-bed and aquifer hydraulic conductivities) do show some reduction in uncertainty. The ensemble of 4,000 parameter realisations, representing the stochastic sampling of the calibration-constrained posterior parameter covariance matrix, was reduced by approximately half through rejection sampling, based on model-to-observation fits for specific observation groups and for a series of new observations. Contaminant transport simulations using the remaining ensemble provide an indication of potential groundwater nitrate concentrations in key receptors associated with nitrate loading in the portion of the model domain north of the Waimakariri River (Figure 1.).

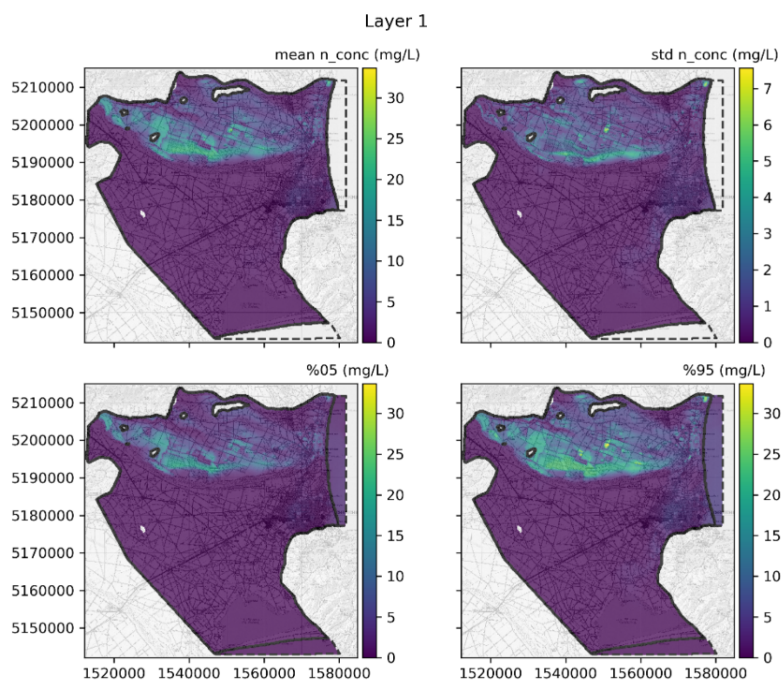

Figure 1: Maps of layer 1 cell-by-cell concentration statistics across all transport simulation with median estimate of nitrate load north of the Waimakariri River. N.B. These maps are not representative of any single realisation but instead represent the concentration statistics for each model cell across all realisations; also, concentrations reflect only the contribution to concentration from sources north of the Waimakariri River. The reference grids display Easting and Northing in NZTM.

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REGIONAL FLOOD ESTIMATION TOOL FOR NEW ZEALAND

Roddy Henderson[1], Dr Daniel Collins[1], Martin Doyle[2], Jeff Watson[3]
[1]Niwa, [2]Tasman Disrict Council, [3]Horizons Regional Council

We have derived a new model of flood magnitude for New Zealand catchments and a re-assessment of the uncertainty inherent in the existing method that this work is intended to replace. This work was prepared for the regional sector and forms the final stage of the revision to the 1989 regional flood estimation procedure funded by a MBIE Envirolink Tools grant.

Flood estimation and its companion discipline, extreme rainfall intensity estimation, are critical aspects of the design of a large amount of the built infrastructure of New Zealand. The previous method for flood estimation, dating from 1989, needed updating because more extreme events have been observed in the interim, and because of the probable effects of climate change, which will increase into the future. The previous method was derived using subjective expert opinion to build the empirical model, and in this work, we specified a more objective procedure, to allow more frequent and convenient updating in the future.

The new dataset has twice as many sites and three times the annual maxima than the previous study. Nearly 58% of sites are operated by regional councils, 38% by NIWA, and the remaining 4% by other organisations. Preliminary analysis suggested no spatially coherent temporal trends in the annual series of flood maxima. The new dataset is systematically organised with inclusion of both monthly and annual maxima for each series, annotation of the years potentially affected by gaps and expert assessment of the true impact of gaps, and inclusion of early historic annual maxima.

Workshops held in late 2015 for regional council stakeholders and for a wider audience provided useful feedback about aspects of the new model. Changes made following these are incorporated in the current model, including the division of the dataset by island.

Over the past two years we have explored ways to better estimate mean annual flood (MAF). This has involved co-learning approaches between researchers and regional council practitioners. As a result, we have chosen regression models that seek to optimise information gain without incorporating too many variables, thus remained conceptually tractable and transparent. We have investigated alternative regional approaches and developed objective contouring methods to account for any spatial organisation of residuals. We have also adopted an unbiased error estimator, being the ratio of logs of data-based estimates of MAF and modelled MAF.

Ordinary least squares (OLS) regressions in log space have been performed on each Island individually, using a three-variable equation (area, annual precipitation and hydrogeology) in the North Island, and a two-variable equation (area and annual precipitation) in the South Island. The residuals of these equations have been contoured and a leave-one-out cross validation performed. The result of this process is an all-New Zealand record-length-weighted factorial error of 1.82 for MAF, or a relative error of ±61%. To compare with the previous method, the worst 5% of sites are removed and the factorial error reduces to 1.62. As a relative error this is ±49%, which is as good as or better than the assessed error of the previous method for 95% of all New Zealand, at ±49% to ±70%. We propose ±50% as the standard error of estimate for mean annual flood.

The regional growth curve model of the previous study was found to be still applicable, and we propose ±20% as the standard error of estimate for q100 (Q100/MAF).

The MAF model is combined with the regional growth curve model to provide return period estimates from 5 to 1000 years, with standard error estimates, across all stream reaches. The results are displayed on a web-based map application, with the option to download flood statistics for selected rivers and streams. At-site annual flood series and calculated flood statistics are also displayed and may be downloaded.

The method provides a good balance of technical depth, repeatability, physical realism, and transparency, all aided by the joint application of statistical modelling and co-learning among researchers and stakeholders.

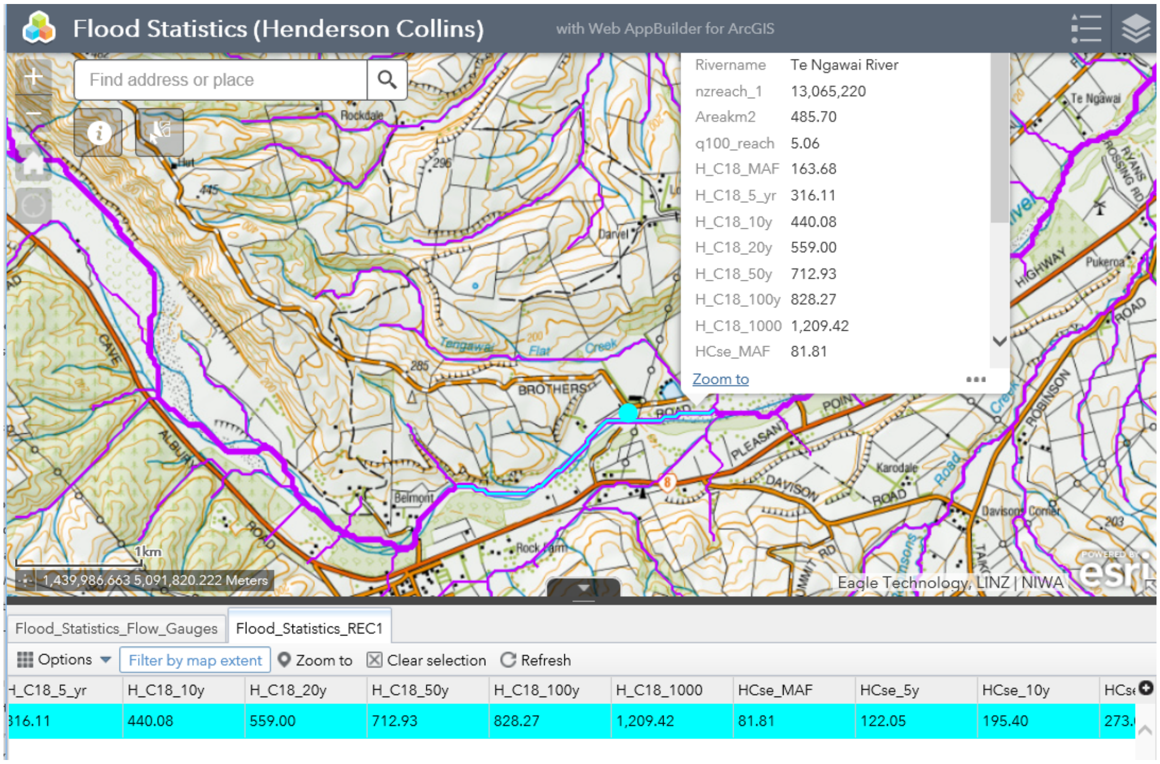

Figure 1: Screen shot from the map server at:

http://niwa.maps.arcgis.com/apps/webappviewer/index.html?id=933e8f24fe9140f99dfb57173087f27d

showing the flow site at Te Ngawai, and the regional method answers for the reach through the flow recorder

BENCHMARKING IN THE NZ WATER MODEL; WHAT IS IT AND WHY DO IT?

Roddy Henderson[1], Dr Christian Zammit[1], Dr Ir Shailesh Singh[1], Dr Rogier Westerhoff[2], Dr Linda Lilburne[3]

[1]Niwa, [2]GNS Science, [3]Manaaki Whenua Landcare Research

Aims

The benchmarking sub-task of the New Zealand Water Model-Hydrology project (NZWaM-Hydro) aims to provide a set of tools for the objective comparison of NZ Water Model output under differing input assumptions. Tests are conducted between model runs, but also against real world data of the phenomena under consideration.

Examples of varying inputs include: the different digital river networks of New Zealand (DN1 and DN2 based on contour-derived DEMs, and the developing DN3 based on Lidar data); use of soils information from the Fundamental Soil Layer of the NZLRI or on the recently published SMap; hydro-geology information based on the NZLRI or on the recently published QMAP; different evapotranspiration representations; inclusion or exclusion of lakes; precipitation inputs based on operational VCSN and an enhanced VCSN incorporating Regional Council (RC) gauges; and inclusion or exclusion of a groundwater module in the NZWaM.

We aim to provide a standard procedure for rainfall-runoff model testing that can be applied to other models as well, should these be implemented over parts of or all New Zealand.

Method

The metrics described in McMillan et al. (2016) have been coded in R and configured to routinely process the NZWAM outputs.

A significant challenge is the development of suitable datasets from the real world against which to test model output. Since the NZWaM uses natural input to produce natural outputs everywhere, spatially extensive datasets of natural conditions for the parameters of interest are needed. For example, the national dataset of some 600 to 1,000 river flow records can reduce to less than 100 if we require that the total potential abstractions from points upstream of the flow recorder be less than 10% of the mean flow, to allow the assumption of natural low flow behaviour. For other parameters such as rainfall and soil moisture, the challenge is to derive a suitable spatially extensive map based on data that are essentially point information.

NZWAM was run for the Aparima and Mataura FMU in Southland over the period 1993-2014, with combinations of three nationally available datasets: the original national hydrological model dataset (McMillan et al, 2016) and updated geospatial information collected as part of the NZWaM-Hydro.

- River network version: Digital River Network version 1 (DN1) and version 3 (DN3)
- Climate inputs: Operational VCSN (OpVCSN) and VCSN augmented by manual and automatic precipitation data from regional councils (VCSN2)
- Soils: Fundamental Soil Layer (FSL) or FSL merged with S-Map (SMap) with soil process parametrisation using the same pedotransfer function

Results

Figure 1 shows comparative flow duration curves in winter (top) and summer (bottom) from Mataura at Parawa, January 1993 to December 2014. Scenarios are recorded flow (blue), modelled flow with DN1 and operational VCSN and FSL soils (orange) and modelled flow with DN3, augmented VCSN and some SMAP soils information (green).

In winter the augmented run is closer to recorded over a wide range of flows and especially at low winter flows. In summer the significant under-prediction has been reduced by an order of magnitude under the augmented scenarios.

Performance metrics will be presented to further illustrate the effects of scenarios.

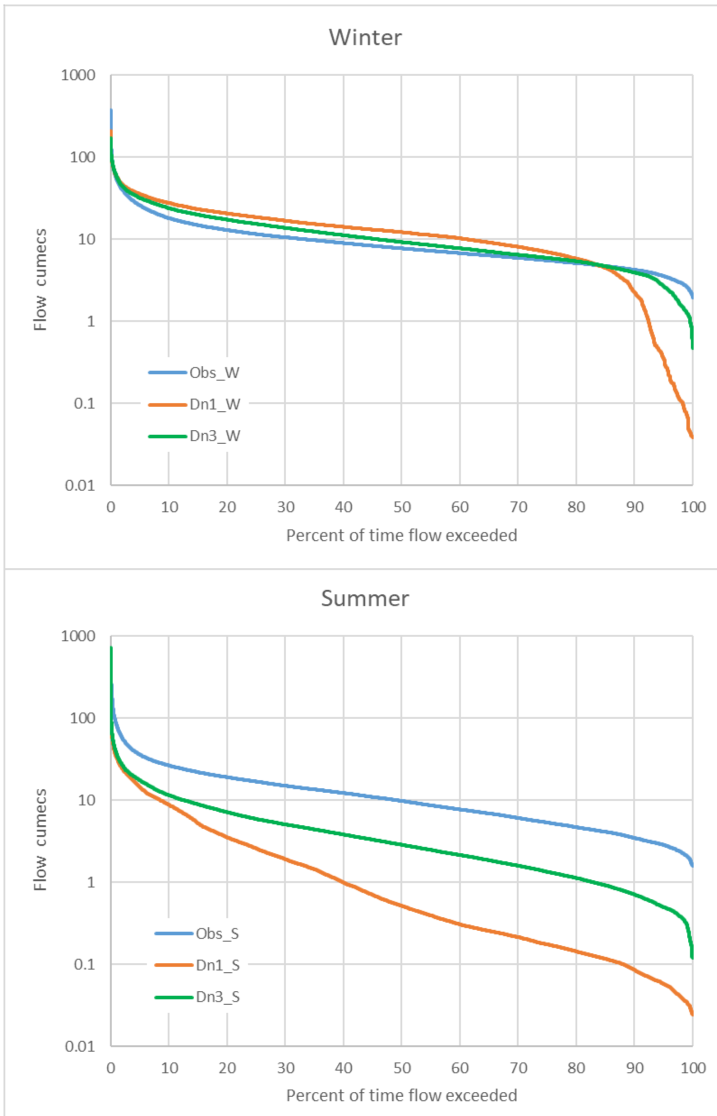

Figure 1: Mataura at Parawa flow duration curves from recorded flow and two different model runs.

References

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A NEW INSTRUMENT FOR MEASURING IN-SITU SUSPENDEN SEDIMENT CONCENTRATION AND SIZE GRADING IN RIVERS

Murray Hicks[1], Arman Haddadchi[1]
[1]*NIWA*

Aims

This presentation introduces a new, commercially-available instrument (LISST-SL2) that measures the concentration, size-grading, and flux of river suspended sediment (SS) in-situ. After appropriate calibration from manually-collected samples, it offers the prospect of gathering results on the cross-section-totalled suspended load and its size grading “on-the-fly” in the field, without the need for expensive laboratory analysis of manually collected samples. This should help overcome the present paucity of information on suspended load size grading around New Zealand, which is urgently needed to help manage the environmental effects of sediment in freshwater environments.

In particular, knowledge of SS size grading is important for understanding relationships between SS load and sediment-related environmental variables such as water clarity, turbidity, and fine sediment deposition, all of which depend on both SS size grading and concentration. Moreover, while turbidity is typically used as a proxy for SS concentration for monitoring SS load (and is inversely related to particle size), it is only observed at one point in a stream cross-section – so all-of-section SS measurements are required to develop a relationship between the point and cross-section average SS concentration, and this relationship is influenced by the spatial variation in SS particle size.

To date, it has been necessary to take water samples to the laboratory for particle size analysis. This is not only expensive, but the sediment size grading in water samples can alter between the river and the laboratory due to the growth or break-up of particle flocs.

The instrument

The LISST-SL2 (short for Laser In-Situ Scattering and Tranmissometry, Stream Lined, version 2), developed by Sequoia Instruments, is essentially a laser-diffraction particle-size analyser mounted in a weighted, streamlined “bomb” that is deployed into the river from a cable (e.g. from a bridge, boat, manned cableway or slackline cableway). It has on-board pressure-based depth and velocity sensors, with the velocity data being used by the instrument to draw-in water for analysis at the ambient stream velocity (enabling “isokinetic” sampling, which is essential to avoid bias when sampling for particle size). It uses laser beam scattering principles to measure the volumetric concentration and particle size of the sample. It is thus able to collect all the data required to determine the flow-weighted flux of river suspended load separated into 36 size fractions (2.5 to 500 microns) – without pulling any sample from the river. The instrument is connected using a standard USGS B-56 stream-gauging reel and cable to a topside control box and then on to a laptop, which processes the raw data from the immersed instrument, displays real time results, and logs the data. Calibration samples are required to relate the apparent volumetric concentration and particle size distribution to their mass values, since this is influenced by particle density and other properties (shape, colour) which are lumped into an “effective density” adjustment factor (Agrawal and Hanes, 2015; Czuba et al., 2015).

Early results

To date, we have deployed the LISST-SL2 on the Oreti River, Southland, at relatively low SS concentrations using a jetboat (Figure 1). The instrument was traversed between the water surface and the bed, sampling at intervals of depth, with this repeated at five verticals located at the centroids of sub-sections each conveying 20% of the total discharge (as determined by a prior discharge gauging using an ADCP). Manual depth-integrated samples were collected from the same verticals using a D-49 isokinetic sampler, with the samples analysed in the laboratory for SS mass concentration (filtering).

Figure 1: LISST-SL2 deployed from a jetboat on the Oreti River at 29 m^3/s.

Example results from two verticals (Figure 2) show depth trends consistent with theoretical expectations, with concentration increasing with depth (both verticals) and mean size (in coarse silt range) increasing slightly with depth, at least at the near-bank (Q_{90}) vertical. The concentration was towards the low end of the instrument's sensitivity, but the effective density indicated by the ratio of sampled mud mass concentration to LISST-measured volumetric concentration was 1.13, which is similar to values reported in the literature (e.g. Czuba et al. 2015).

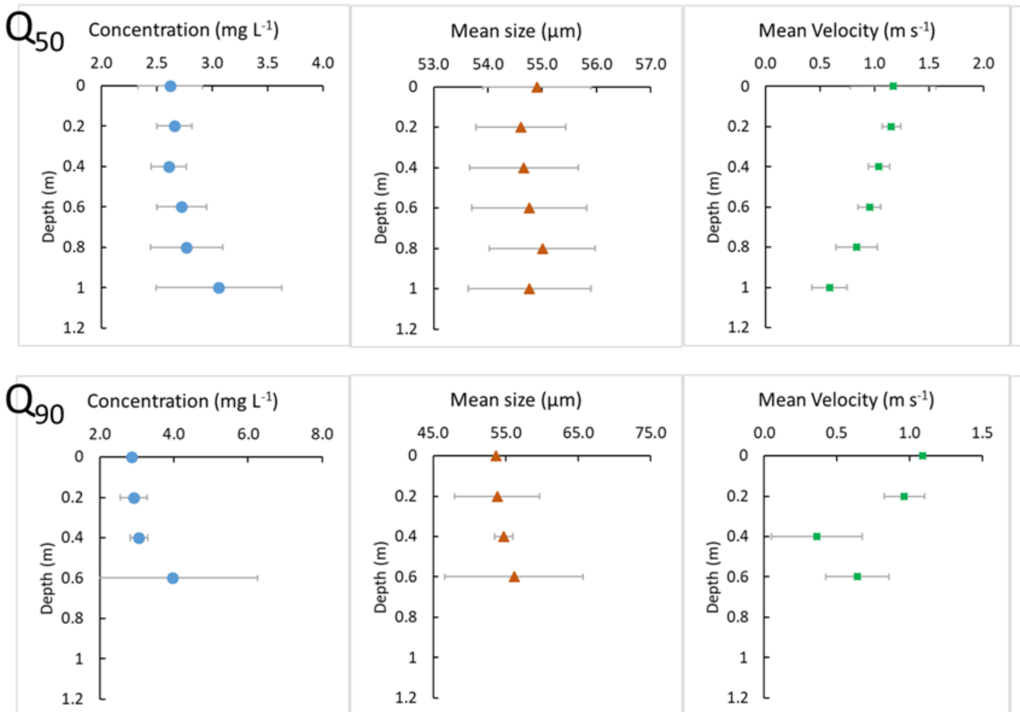

Figure 2: Depth profiles of SS concentration (unadjusted for effective density), mean particle size, and velocity measured by the LISST-SL2 at two verticals on the Oreti River at 29 m^3/s.

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A NEW APPROACH TO SUBSTRATE MAPPING: SUPPORTING HIGH RESOLUTION HABITAT SUITABILITY ASSESSMENTS FOR ENVIRONMENTAL FLOWS

Jo Hoyle[1], Arman Haddadchi[1], Jochen Bind[1]
[1]*NIWA*

Environmental flows are often designed based on predictions of the physical habitat that will provided by a given flow for key species (typically fish and aquatic invertebrates). A common approach used is the Instream Flow Incremental Methodology (IFIM), which involves using habitat suitability indices to calculate weighted usable area for key species based on depth, velocity and substrate composition (by areal proportion). With advances in modelling capability, velocity and depth for a given flow are now commonly predicted using high resolution 2-dimensional hydraulic models, creating a need for substrate composition to be mapped at an equivalent resolution. Mapping substrate across large study reaches (e.g. 1-2 m grid resolution over 1-2 km long reaches) presents a significant challenge and pushes the boundaries of what has been previously attempted. Developing a semi-automated substrate classification workflow is necessary to provide a cost-effective approach.

Aims

To develop a workflow which enables underwater and sub-aerial mapping of substrate over large reaches from imagery for ready integration with 2d hydraulic models.

Method

The workflow developed involves six key steps as outlined in Figure 1.

1. Substrate image collection - using aerial photographs collected by UAV or underwater video.
2. Preparation of images for automated substrate classification – extracting image tiles over a regular grid, or extracting video frames, and discarding blurry/noisy images or those where substrate is obscured by vegetation, bubbles, algae etc.
3. Automatically classifying the proportion of substrate in each image that is sand, fine gravel, gravel, small cobble, coarse cobble, and boulder (Wentworth 1922) using batch-processing of the Morlett Wavelet approach developed by Buscombe (2013).
4. Non-automated classification (for locations where automated classification could not be run) - using either manual (visual) classification or synthetic classification based on facies mapping and the allocation of surrogate classifications.
5. Combining and checking substrate classification approaches for consistency (Figure 2).
6. Interpolating substrate grids for integration with hydraulic model grids.

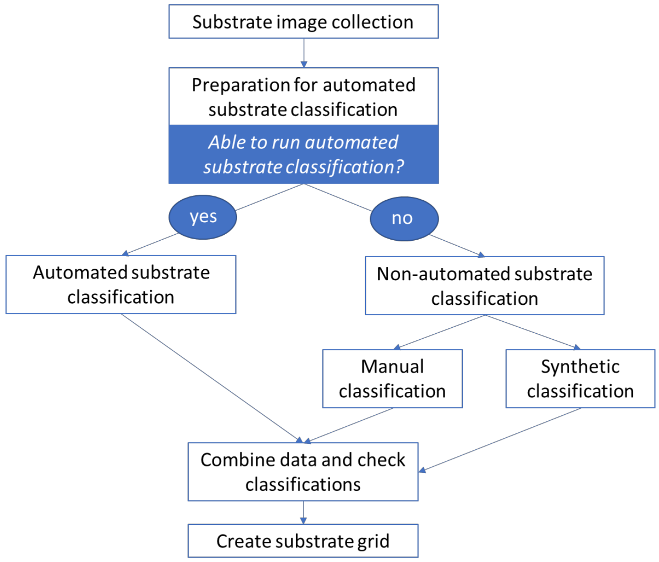

Figure 1: Workflow developed to map substrate over large river reaches

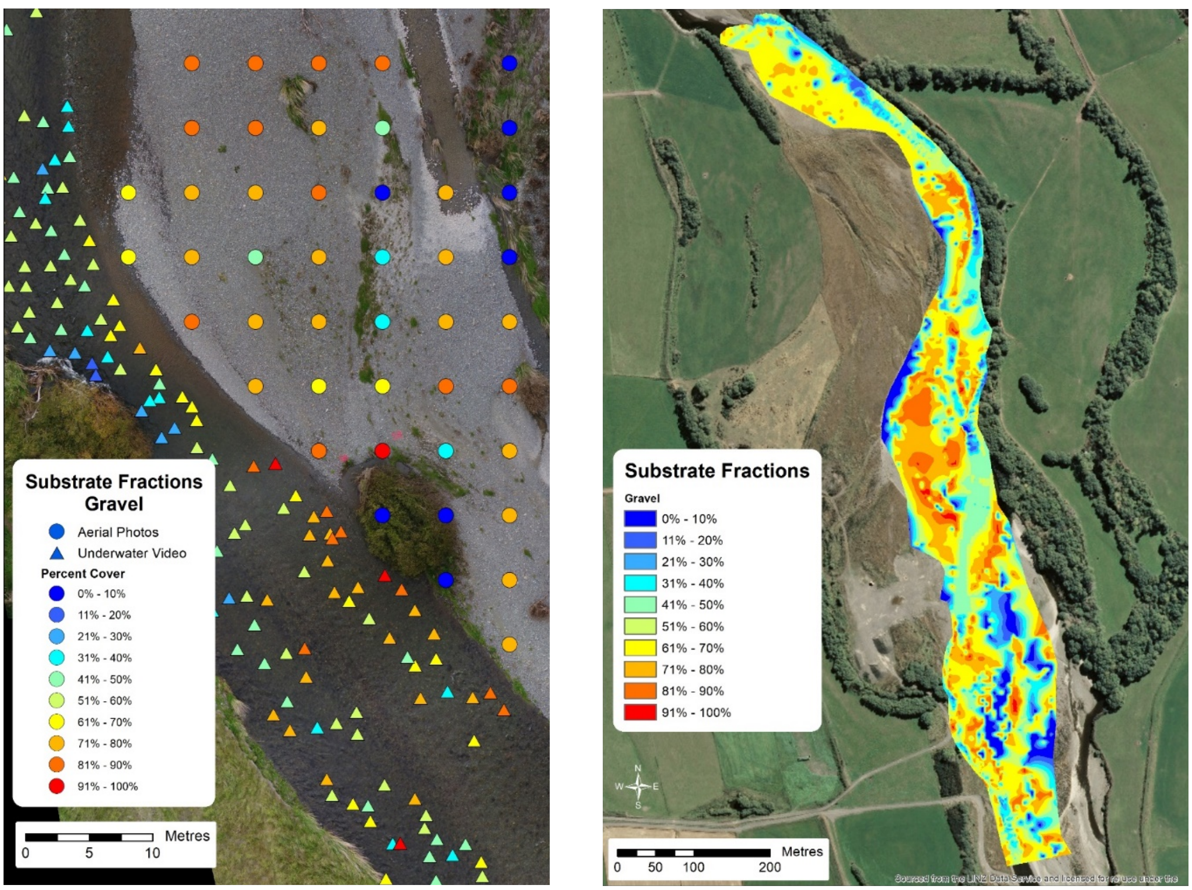

Figure 2: Example of substrate classification in a reach of the Aparima River, Southland. Left image shows proportion of gravel in the substrate at locations where aerial/underwater imagery was classified (both automatic and manual classification). The right image shows the resulting substrate map (again for proportion in the gravel class).

Results

There are several limitations with the Morlett Wavelet approach:

1. The smallest grains that can be resolved using this approach are those covered in the imagery by at least a few pixels – this makes it challenging to classify sand (<2 mm) on UAV imagery at efficient altitudes and speeds.
2. Shallow depths in underwater imagery typically under-predict coarse substrate as clasts may extend beyond the image frame.
3. The approach requires good quality imagery, i.e. appropriate ISO setting and minimal blur.
4. Substrate cannot be automatically classified where there is vegetative or algal cover.
5. Underwater imagery requires a concurrent measurement of depth to scale the image.

Despite these limitations, we consider that the automated classification performed very well and the overall workflow provided excellent results. This approach has substantial advantages over the commonly used approach of visually estimating grainsize proportions on site: it is more objective, more consistently reliable, and it can be applied over large areas.

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THE OCCURRENCE AND ORIGIN OF SALINITY IN NON-COASTAL GROUNDWATER IN THE WAIKATO REGION

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[1]Waikato Regional Council, [2]Wintec

Aims

The aims of this project are to describe the occurrence, and determine the origin of non-coastal saline groundwater in the Waikato region. High salinity limits the use of the water for supply and agricultural use. Understanding the origin and distribution of non-coastal salinity will assist with development and management of groundwater resources in the Waikato.

Method

The occurrence of non-coastal groundwater salinity was investigated by examining driller's records and regional council groundwater quality information. Selected wells were sampled for water quality analyses and temperatures were profiled where possible. Water quality analyses include halogens such as chloride, fluoride, iodide and bromide. Ratios of these ions are useful to differentiate between geothermal and seawater origins of salinity (Hem, 1992). Other ionic ratio approaches for differentiating sources and influences on salinity such as those developed by Alcala and Emilio (2008) and Sanchez-Martos et al., (2002), may also be applied. Potential sources of salinity include seawater, connate water, geothermal and anthropogenic influences. The hydrogeologic settings of saline occurrence were also investigated, to explore the potential to predict further occurrence.

Results

Numerous occurrences of non-coastal saline groundwater have been observed in the Waikato region. Where possible, wells with relatively high total dissolved solids (TDS) were selected for further investigation. Several groundwater samples are moderately saline and exceed the TDS drinking water aesthetic guideline of 1,000 g m^{-3} (Ministry of Health, 2008).

Selected ion ratios (predominantly halogens) were used to assist in differentiating between influences on salinity such as seawater and geothermal. Bromide to iodide ratios, in particular, infer a greater geothermal influence on salinity, although other ratios are not definitive.

The anomalously elevated salinity observed appears natural but nevertheless has constrained localised groundwater resource development for dairy factory, industrial and prison water supply use. Further work may show some relationship with geology or tectonics, which could assist prediction of inland saline groundwater occurrence.

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A STUDY ON THE DEVELOPMENT OF LOSS FUNCTION FOR THE TRANSPORTATION FACILITIES IN SOUTH KOREA

Shinbum Hwang
[1]KWRA

In order to protect the lives and property of the people from disasters, it is necessary to prepare countermeasures by estimating and analyzing the extent of the damage according to increase in frequency of disasters and the tendency to become large in size. In this study, the researcher has developed a loss function of transportation facilities utilizing the data for damage on the transportation facilities and flooding trail of the National Disaster Management System in order to estimate the extent of damage on transportation facilities, which are social infrastructure used for movement of the recovery equipment and the evacuation of people in the event of a disaster. It is expected that the loss function for transportation facilities will be used as a basic data for measures to reduce disasters and of assistance to support the decision making.

Aims

Abnormal climate due to global warming is increasing the frequency and intensity of natural disasters such as flood, typhoon and heavy rainfall. In order to be prepared for such natural disaster, it is necessary to predict the exact magnitude of the damage that may occur. In order to predict the economic loss to the disaster, damage and loss function models have been developed in HAZUS-MH and HEC-FIA in the United States and the MCM in UK, but most of them are for civilian facilities and present limited loss estimation method for the public facilities. In Korea, the Simple method, Improved method and Multidimensional Flood Damage Analysis (MD-FDA) have been applied to estimate the amount of flood damage. However, the amount of damage to public facilities such as traffic facilities is based on the proportionality coefficient of general property damage. In this paper, the researchers have developed a loss function for estimating the damages on traffic facilities based on actual damage data generated by heavy rain and typhoon.

Method

In order to estimate the traffic facility damage caused by flooding in the protected low land due to river flooding, the researchers set Korean standard basin as a spatial standard which is used as the basic range of hydrograph analysis. A total of 1,953 flooding trails and 603 traffic facilities damage data from 2009 to 2016 were analyzed. The flooding area and the road area (hereinafter, "flooding road area"). As a result of Pearson correlation analysis, it was identified that there is a significant correlation between flood area and flooding road area and damages of traffic facilities. In order to extract the appropriate data for these variables, the normal distribution and the experience distribution were reviewed based on the damage amount, the flood area and the damage amount per flooding road area, and data filtering was performed using the experience distribution with 90% confidence interval.

For filtered data, secondary filtering was performed to remove abnormal value of data by using standard residual method according to linear relationship between dependent variables and independent variables. After developing various loss functions of linear and nonlinear types for the selected data, the researchers developed a nonlinear traffic facility loss function as shown in the below formula (1), taking into account the estimated parameter values and the coefficient of determination (R^2).

$$D.C_{Tr} = 6357.280 \times IA^{0.197} + 0.064 \times RA_{IA}^{1.311} \quad < R^2\ 0.778 > \quad (1)$$

Where, $D.C_{Tr}$ is the damage amount of transportation facilities (unit: 1,000 Won), IA is flooding area (m^2) and RA_{IA} is flooding road area (m^2).

The transportation facility loss function in this study was developed through the same process as the one in Figure 1. In order to investigate the error that occurs when applying this loss function to past damage data, the researchers divided the data into two groups. One is the entire data group (before removing abnormal value) and another is the confidence data group (after removing abnormal value). The results are shown in Table 1, which shows that the error of the confidence data group with the abnormal values removed has much smaller error and continuous function improvement work is required to enhance the accuracy of the loss function.

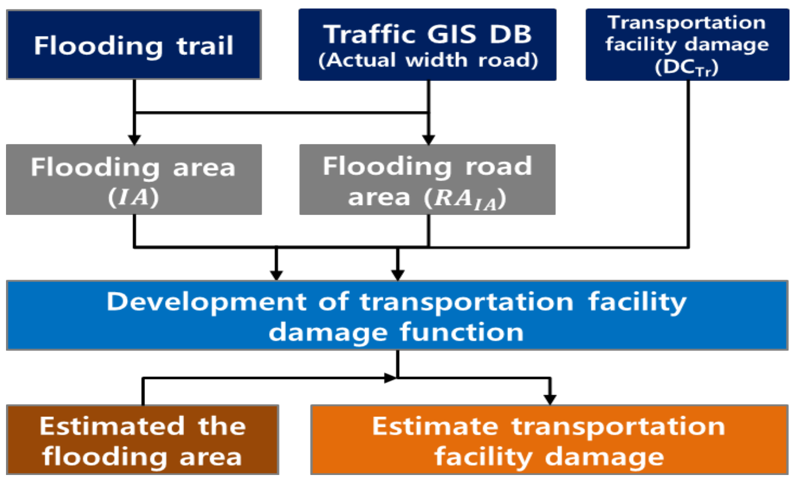

Figure 1: Process of Loss Function Development

Table 1: Result of application of transportation facility damage function (Unit : 1,000 Won)

Classification	Entire data group (before removing abnormal value)				Confidence data group (after removing abnormal value)			
	Damage amount	RISE	NRMSE	NSE	Damage amount	RMSE	NRMSE	NSE
All	21,542,545	479,036	16.60	0.11	12,455,452	176,234	6.11	0.78
2009	3,290,677	737,025	35.73	- 0.25	1,206,634	228,648	36.54	- 0.08
2010	210,074	147,199	224.14	- 34.01	210,074	147,199	224.14	- 34.01
2011	7,975,600	593,648	23.89	0.21	2,079,063	183,796	21.02	0.16
2012	2,209,580	379,169	105.19	- 12.37	1,247,443	91,088	25.27	0.09
2013	1,924,411	132,090	28.93	0.25	1,915,142	127,984	28.03	0.31
2014	4,821,777	344,613	11.94	0.87	4,821,777	344,613	11.94	0.87
2016	1,110,426	773,616	260.99	- 65.80	975,319	39,566	13.35	0.85

Results

In this study, the researchers developed a transportation facility loss function that can estimate flood damages on transportation facilities using actual damage data and flood trail of Korean national disaster management system. In order to increase the explanatory power of the loss function and the suitability of the utilization data, the 90% confidence interval of the experience distribution was applied and the abnormal data were removed through the standardized residual method. A nonlinear transportation facility loss function has been developed through application of various functional equations and it is required to develop a reliable loss function through continuous data accumulation and research.

This research was supported by a grant [MOIS-DP-2015-05] through the Disaster and Safety Management Institute funded by Ministry of the Interior and Safety of Korean government.

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MOIS, NDMS DB.

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FEMA, Getting started with Hazus-MH 2.1.

ACHIEVING FLOOD PROTECTION AND MULTIPLE VALUES IN THE ŌPĀWAHO/HEATHCOTE RIVER URBAN CATCHMENT

Peter Christensen,[1] Dennis Jamieson,[2]

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[2] *Canterbury Water Management Strategy*

Aims

The Ōpāwaho / Heathcote River catchment has a history of flooding and poor water quality. The impact of flooding was increased due to land settlement and channel damage as a result of the Canterbury Earthquake Sequence (CES) from 2010 onwards. The response to the effects of the CES was primarily to restore flooding to pre-earthquake levels, but also provided an opportunity to improve water quality and provide for some of the community aspirations for the Ōpāwaho / Heathcote River corridor. This demonstrates good practice in considering multiple values within floodplain management.

Method

The Ōpāwaho / Heathcote River catchment covers approximately 103 km² in the south of the city.

Flooding is not new along the river, but became a particular problem when the lower river terraces were settled in the early 20th century. The Christchurch Drainage Board (CDB) regularly dredged the lower reaches of the river, raised some houses, and developed a scheme to reduce further flooding, particularly through upstream storage. However, this scheme, conceptualised in the late 1980s, was not implemented apart from some isolated works.

Subsequent to the CDB plan, in addition to ongoing river maintenance, flooding was primarily managed by Christchurch City Council (CCC) through stormwater management plans (SMPs), the South-West Area Plan (SWAP) and other planning controls to reduce property damage, such as the District Plan. These plans manage flood impacts by setting minimum floor levels, restricting development in flood prone areas, and requiring mitigation of increased runoff from new subdivisions.

The CES increased both the frequency and severity of flooding along the Ōpāwaho / Heathcote River. Several episodes of severe rainfall in the catchment have demonstrated this increased vulnerability to flooding along the river corridor. The increased flooding vulnerability as a result of the earthquakes resulted in CCC initiating a number of investigations into the impacts of the earthquakes, from condition assessments of assets through to the development of a new catchment model to assess post-earthquake flooding.

In July 2017, once the majority of the investigations were completed, the third significant period of flooding since the CES occurred. A number of houses flooded above floor, while a much higher number were flooded underfloor. A response to frequent flooding was adopted by CCC in November 2017 which included:

- Purchase of the worst affected dwellings through the Flood Intervention Policy
- Dredging of the lower Ōpāwaho / Heathcote River
- Bank stabilisation through the mid-reaches
- Four significant storage schemes in the upper reaches, with a combined storage over and above existing or proposed storage of 800,000m³
- Feasibility study into low stopbanks in the mid-reach

These works are currently in progress. Combined with works in the Bells Creek sub-catchment and the programme for existing basins and wetlands to manage subdivision growth, the total programme represents an investment in excess of $100 million by CCC into flood mitigation in the Ōpāwaho / Heathcote River catchment. This will result in the largest reduction in flood levels and improvement in stormwater quality in the catchment since intensive urbanisation began affecting the catchment.

Results

The key outcome of the project is to reduce flood risk. Modelling indicates that above floor flooding in the design 2% average recurrence interval event (current climate) following the CES affects 222 houses in the main Ōpāwaho / Heathcote River catchment. The proposed works will reduce this below the pre-earthquake level of 175 to approximately 114. Work by CCC is ongoing to optimise this further.

However, the investment throughout the catchment to reduce flood risk also provides an opportunity to achieve other outcomes as well. CCC has a multi-value approach to stormwater management, considering not only drainage (e.g. flood mitigation) but also ecology, culture, landscape, heritage, and recreation as well.

To achieve these multiple values engagement has been undertaken with iwi, other Local Government organisations, and community groups. For example, the Ōpāwaho Heathcote River Network (OHRN) is a collaborative network which advocates for the regeneration of the whole of Ōpāwaho Heathcote River with a vision of "an ecologically healthy river that people take pride in, enjoy, and care for." OHRN members have had input into the replanting following the bank works and have provided valuable feedback on proposed mitigation measures such as eel hotels.

At a local government level, Canterbury councils have also been working together in partnership under the auspices of the Canterbury Mayoral Forum with Ngāi Tahu since 2009 to deliver improved outcomes for water across Canterbury. This approach, the Canterbury Water Management Strategy (CWMS), has first order priorities that include the environment and customary use and primary principles of sustainable management, a regional approach and tangata whenua. The collaborative governance approach for the CWMS is based on moving from a 'top down' model to 'local people planning locally' and operates though Zone Committees (in this case the Christchurch West Melton Zone Committee) and a Regional Committee. Presentations to the Zone Committee have provided opportunity for feedback, as have public meetings and formal consultation.

Some of the 'non-drainage' results achieved by CCC adopting a multi value approach and obtaining input from a wide range of groups includes:

- Wetland treatment of stormwater on two of Christchurch's most polluted streams (the tributaries Curletts and Haytons Streams)
- Sediment capture on the two most significant sediment sources for the Ōpāwaho / Heathcote River (Cashmere-Worsley and Hoon Hay valleys)
- Removal of contaminated sediments through dredging
- Planting of several kilometres of banks with primarily native vegetation
- Restoration of significant areas of wetland habitat drained for farming
- An urban forest (Te Oranga Waikura) co-located with a stormwater basin
- Filtration of a large (160 hectare) commercial/residential catchment with the largest proprietary treatment device in New Zealand
- Recreation areas, such as an area of tracks and open space of approximately 100 hectares
- Isolation of important bird habitat areas from predation
- Incorporating cultural and heritage information in signs
- Enhancement and extension of inanga spawning habitat
- Adoption of areas by local school groups to maintain and extend planting

Working across organisations and inviting a more collaborative approach has allowed CCC to implement a flood mitigation project while achieve multiple aims. As an example of the aspirations of the community, the vision of the OHRN is *"an ecologically healthy river that people take pride in, enjoy, and care for"*. The project has sought to leverage the essential flood mitigation infrastructure to provide a sound foundation to allow the community to work towards fulfilling these aspirations for the river. Having both local and regional organisations provide input into the project has helped to ensure multiple values are achieved in the catchment, while not losing sight of the central aim to reduce flood risk.

FORECASTING RECHARGE RATES FOR MAR INFILTRATION BASINS

Cameron Jasper,1 Ryan Nicol,1 David Wright,1
[1] *Pattle Delamore Partners Limited*

Aims

Managed aquifer recharge projects that utilise infiltration basins can include a range of objectives including the improvement of surface water and groundwater quantity, quality, and flow for the benefit of communities and ecosystems. Although these projects can offer a robust, cost effective approach for meeting these objectives, they can suffer from poor hydraulic loading rates due to limited available information for estimating discharge rates. Gathering sufficient information regarding aquifer heterogeneity at infiltration basins can be difficult and recharge rates are often estimated using localised information provided from boreholes, test pitting, pumping tests, and/or infiltration testing. A combination of physical infiltration testing and geophysical methods can be used in conjunction to delineate higher or lower permeability soils across larger areas than standard physical methods alone. An example of this is a study undertaken at the Aurora Water Aquifer Recharge and Recovery Site, Colorado U.S.A which used a combination of geophysical and physical methods to map infiltration pathways, characterise subsurface sediments, and measure vertical discharge rates in and around an infiltration basin with an area of approximately 3 ha (Jasper and Revil, 2014). It is expected that the combination of techniques discussed in this paper will be applicable to New Zealand conditions and provide beneficial information for the siting and design of infiltration basins.

Method

Several geophysical methods were used at the Aurora Water Site by this study. These methods included Electrical Resistivity Tomography (ERT), Electromagnetics (EM), and underwater Self-Potential (SP). High-resolution Distributed Temperature Sensing (DTS) and laboratory testing of soil samples were used to provide physical verification of the soil permeability and verify the results obtained from the geophysical surveys. It is advantageous to combine geophysical methods with other methods and results because often times these approaches are sensitive to multiple parameters and additional information can be used as boundary conditions and for interpreting results. This study used DTS in lieu of standard physical methods to measure discharge and verify the geophysical survey results.

ERT provides spatial information of resistive material properties and is sensitive to saturation, salinity, and sediment textures at depth with strong vertical resolution by injecting current and measuring electrical potential. ERT surveys were conducted within and around the infiltration basin when it was dry and also during wet conditions with recovery well pumping and basin drainage. Modern electrical resistivity units, such as the ABEM Terrameter used in this study, can measure resistance to 40 m depth and over 400 m laterally in a short period of time**.** Electrical resistivity tomography typically images well-drained sediments (sands and gravels) as more electrically resistive zones, whereas finer grained sediments with more silts and clays, which hold more water by capillarity, are imaged as more electrically conductive zones.

EM methods provide spatial information of measured apparent electrical conductivity of a medium at depth by taking quadrature measurements of the secondary electromagnetic fields generated in the subsurface after the transmission of electromagnetic radiation above the ground surface. Ground conductivity meters, such as the Geonics EM-31 used in this study, can measure apparent conductivity of subsurface materials, which is influenced by aquifer characteristics including saturation, solute content, minerology and texture.
SP mapping has been conducted for decades for qualitatively locating primary fluid flow pathways through embankments and earthen dams. Negative underwater SP anomalies are theoretically dominated by increased permeability and streaming current contributions associated with infiltration, coarser sediment textures, and higher porewater velocities with lower near-surface excess charge densities in diffuse layers around negatively charged surfaces. The underwater SP method was used to map passive measurements of spontaneous current at the ground surface within the infiltration basin during drainage.

High resolution temperature sensing DTS was used to physically measure discharge rates at the site and verify the data collected from the geophysical methods described above. DTS utilises temperature as a naturally occurring groundwater water tracer and is used to estimate specific discharge by measuring water temperature at various depths below ground. This is typically achieved by coiling fibre-optic cable to provide much higher spatial resolution to temperature measurements and estimating groundwater advection in saturated media from ambient diurnal temperature patterns within streambeds. This study constructed an array of 2 m long, vertical in-situ, DTS probes with 20 mm vertical resolution to estimate vertical specific discharge during a flooding and recharge event at points in the south and the north of the infiltration basin.

Results

DTS indicated higher vertical discharge rates up to 400 m/day in the north of the infiltration basin and lower vertical discharge rates of approximately 40 mm/day in the south of the basin. The results from geophysical surveys are provided in the figures below.

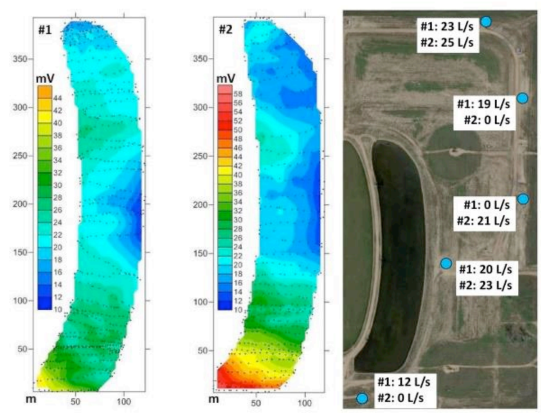

Figure 1: Underwater SP survey results

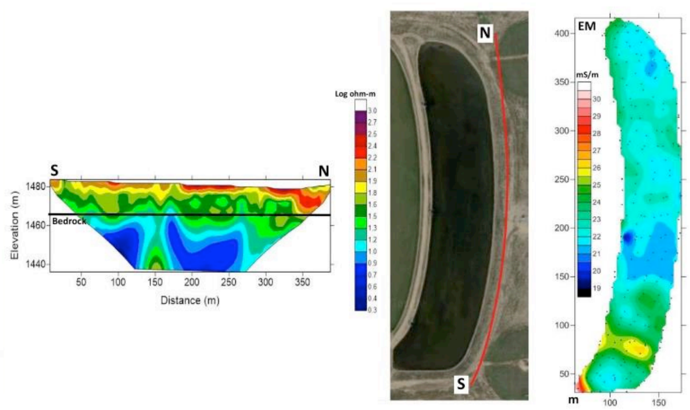

Figure 2: ERT and EM survey results

The more negative SP (blue) areas represent coarser sediments and the more positive SP (red) areas in the south of the basin correspond to finer sediments (Figure 2). The more resistive (red) portions in the ERT tomogram indicate drier, coarser, sediments undergoing drainage during a dewatering phase with no basin flooding (Figure 3). The EM survey observed higher electrical conductivities (red and yellow) in the south of the basin, which is attributed to finer sediments and more residual water content. All three geophysical survey methods provided consistent results between each method and generally indicated coarser, higher permeability sediments in the east and north of the basin and finer, lower permeability sediments at the southern area of the basin. The geophysical surveys provide a good correlation with the physical DTS measurements which also showed higher permeability in the coarser sediments in the north of the basin and lower permeability in the finer sediments in the southern area of the basin.

Overall, the results from this study showed promising results between the physical infiltration measurements and the geophysical surveys. Enhanced recharge in the east of the basin is inferred from geophysical results because of the correlations between physical and geophysical methods observed in the north and the south of the basin. It is expected that standard methods for direct discharge measurements could be applied instead of DTS. Therefore, a combination of both physical testing and geophysical testing can be used to better forecast hydraulic loading rates across larger areas and potentially guide the design and siting of infiltration basins.

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MODELLING LAGOON RESPONSE TO ASSESS FUTURE MANAGEMENT REGIMES AND CLIMATE SCENARIOS

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[1]*Environment Southland*

Southland's Waituna Lagoon is located 40 km south east of Invercargill, and is regarded as one of New Zealand's best examples of a natural coastal lagoon. The surrounding wetland and its flora and fauna is of international significance and is valued for its recreational, cultural and scientific values. The catchments that contribute to the lagoon are intensively farmed and there are concerns that the health of the lagoon and its tributaries are under stress.

In a 'healthy' state, the lagoon should be dominated by aquatic macrophytes such as *Ruppia*. When the lagoon is open to the sea for extended periods, salt water can compromise the growing conditions. Conversely, when the lagoon is closed, drainage to surrounding farmland is compromised.

Current management of the lagoon allows the affected landowners to mechanically open the lagoon when it reaches 2.0 MSL during winter months and 2.2 MSL from Spring through to autumn.

Maintaining lagoon health whilst satisfying the landowners drainage requirements is a complex situation, and future climate scenarios add to the complexity. Stakeholders have queried the effects of various management criteria.

Aims

Environment Southland aimed to develop an effective water balance model that incorporates user defined scenarios based on the proposed management and forecast climate change. The model outputs for each scenario can be used to assess frequency and length of land inundation. This information can be considered for future management of the lagoon.

Method

A water balance was developed for the Waituna Lagoon using continuous flow and rainfall data from the nearby Waihopai catchment and continuous lagoon level and climate data from the east end of the lagoon. Lagoon storage was established using LiDAR. Seepage through the beach barrier was estimated when inputs and outputs were equal during prolonged periods of stable lagoon levels. A stage/discharge relationship of lagoon level versus barrier seepage was established and the resulting model was validated by comparing modelled daily values against average lagoon level for the period 2012 to 2016.

To model the natural variability of lagoon closures, historic records of lagoon openings and closures since 1972 were tabulated, and the probability of the lagoon closing within a given month was estimated.

A Monte Carlo method was used by running the model 30 times using the 39 years of Waihopai flow data with random closing events and openings for desired criteria. The simulation was repeated for six different spring – autumn management criteria and for projected rainfalls for Southland for 2031-2050 (Ministry for the Environment 2016, p. 77) derived from representative concentration pathways (RCPs) (van Vuuren et al, 2011).

Results

Modelled lagoon levels for the four climate pathways using baseline management showed that the annual average number of days above 2.0 MSL increased from 2.7 under current climate to 4 for RCP 4.5 (Figure 1). The maximum number of days above 2.0 MSL increased from 23.1 to 53.5 for RCP 2.6. These results indicate that land use will be affected with changes in climate.

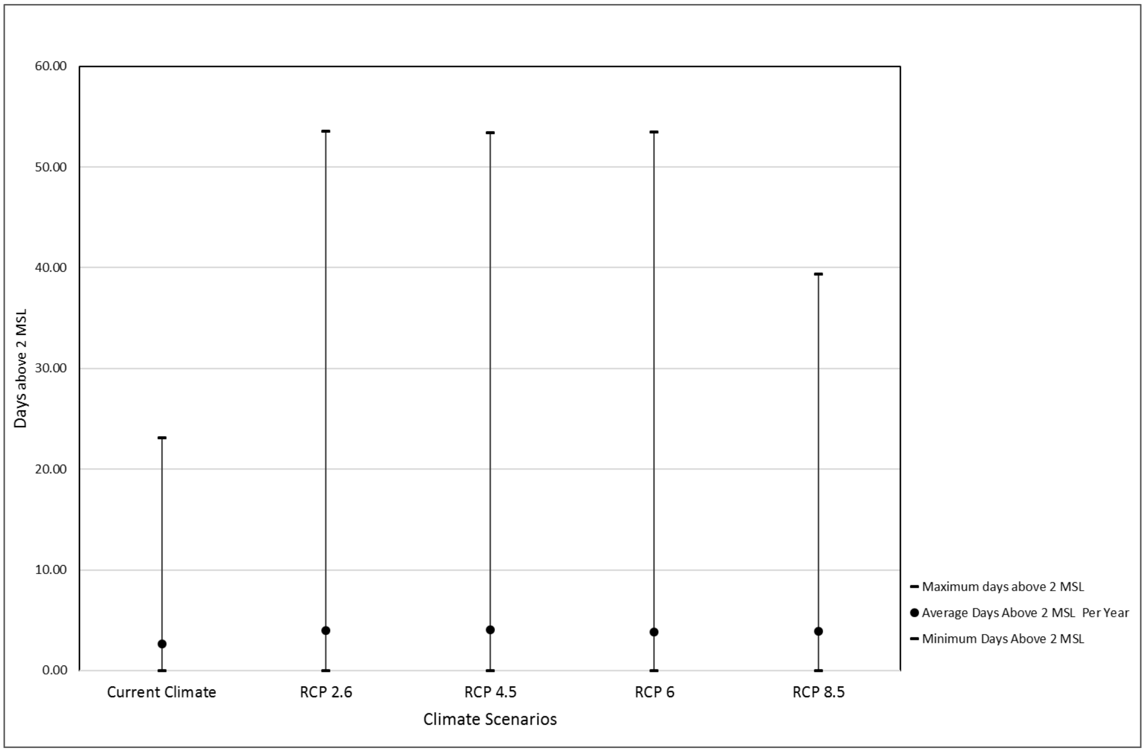

Figure 1: Number of days the Waituna Lagoon water level is > 2.0 MSL based on baseline management for various climate change scenarios

Spring - autumn openings currently average 0.16 openings per year but could increase to 0.36 for RCP 4.5, whilst winter openings remain generally unaffected, with minor increases from 1.23 openings per year to 1.45 for RCP 4.5.

Changing the spring - autumn opening level from 2.2 MSL to 2.4 MSL increased the annual average time the lagoon was above 2 MSL by only two days. The spread of individual events however increased, with the maximum modelled time above 2 MSL increasing from 23.1 days to 48.8 days.

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HIWEATHER NEW ZEALAND: OPPORTUNITIES TO CONNECT TO A CO-OPERATIVE INTERNATIONAL RESEARCH PROGRAMME

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The World Meteorological Organization has launched a 10-year programme, High Impact Weather (HIWeather) to address the weaknesses in society's capability to reduce the impacts of weather-related hazards. The purpose of the HIWeather research programme is to promote cooperative international research to achieve a dramatic increase in resilience to high impact weather. In the past decade advances in meteorology have radically improved the precision and accuracy of forecasts of hazardous weather. Together with advances in coupling to land surface, atmospheric chemistry and ocean models, it is now possible to predict weather-related hazards that could previously only be inferred in a qualitative sense. Advances in ensemble prediction have also made it possible to produce meaningful quantitative probabilities.

Taking the next step of utilising vulnerability information to generate a quantitative risk assessment is now feasible, but very demanding and currently in its infancy. In some context there is evidence that these advances have resulted in increased trust in weather forecasts and warnings. Yet, in others, evidence of a lack of response to warnings, especially in disasters with many fatalities, has led to a questioning of the benefits of this research and recognition of the need to communicate information more effectively.

Radical changes in the communication landscape in the past decade, especially the rise of social media, have created opportunities and threats that challenge traditional approaches to warning communication. The growth of population, especially in urban areas, together with the occurrence of weather outside historical norms, partly as a result of climate change, poses an increasing threat to communities around the world; this demands that the best science is applied to improving the capability of warning systems, particularly in the developing world. The HIWeather Programme provides both an opportunity for New Zealand researchers and practitioners to connect to global research but also contribute our New Zealand-based activities to international activities.

RESOLVING CONTROLS ON SNOW DISTRIBUTION IN THE PISA RANGE, NEW ZEALAND

Lucy Just[1]
[1]*Otago University*

Aims

Reliable simulation of catchment snowmelt and runoff requires effective representation of snow water equivalent (SWE), which exhibits high temporal and spatial variability (Clark et al., 2011). Spatial variability of SWE at the catchment scale is often described to be shaped by the variability in near-surface meteorological fields (e.g. elevation gradients in temperature). However, recent research in New Zealand reveals other control factors, such as topographic and snow redistribution, can play a governing role for SWE distribution at this scale (Redpath et al., 2018). The aim of this study is to leverage a semi-distributed hydrological model, with a blowing snow component, to resolve the second order controls on snow distribution and investigate the timing and magnitude of snowmelt runoff in seasonal snow catchment in the Pisa Range.

Method

The study catchment is a small, unnamed tributary, of the Leopold Burn stream with an area of 0.41km^2, located in the Pisa Range, Otago. The catchment extends from the confluence with the Leopold Burn at around 1440m a.s.l. rising to a maximum elevation of around 1580m. A winter field campaign was carried out during 2017 to produce a meteorological forcing dataset from the catchment's automatic weather station (AWS). A rain gauge installed at the AWS, from October 2017 to April 2018, yielded a summer precipitation dataset for reconstructing winter precipitation. Pisa range precipitation totals from the 13th October – 20th April were compared with the surrounding gauges of Wanaka, Queenstown and Cromwell at a 12hr temporal resolution. Water level and streamflow measurements undertaken at the gauging station, situated at the catchment outlet, were used to produce a hydrograph for model validation.

The Cold Regions Hydrological Modelling platform (CRHM) was selected to develop a hydrological model to simulate the dominant hydrological processes in the Leopold Burn tributary catchment. CRHM is an object-orientated modular platform where the user constructs a purpose-built model from a selection of physical process modules (Fang et al., 2013). Spatial application of CRHM is over hydrological response units (HRU), which may be linked in process-specific sequences, such as a blowing snow component to incorporate redistribution processes.

Preliminary results

Results from the precipitation reconstruction using an Ordinary Least Squares Multiple Linear Regression (MLR) model, indicates Wanaka and Cromwell totals are better predictors of precipitation for the study catchment than Queenstown totals. Model RMSE (2.56mm) and R^2 (0.82) are the same when three predictors (Queenstown, Wanaka, Cromwell) or two predictors are used (Wanaka and Cromwell). However, Queenstown's negative coefficient and large P-value indicate it is not a significant predictor in the model and can be excluded from the reconstruction (Table 1). Reconstructed winter precipitation is then accepted by CRHM at 12 hour totals.

Table 1: Multiple Linear Regression model output

	coef	std err	t	P>|t|	[0.025	0.975]
Cromwell	1.0766	0.102	10.578	0.000	0.876	1.277
Wanaka	0.4396	0.079	5.544	0.000	0.284	0.595
Queenstown	-0.0650	0.061	-1.059	0.290	-0.186	0.056

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TIME SEQUENTIAL THERMOGRAPHY FOR SPATIAL TURBULENCE MEASUREMENTS

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Aims

The Atmospheric Boundary-Layer (ABL) is the turbulent medium through which the surface exchanges scalars and energy with the free atmosphere. These communication pathways are controlled by quasi-steady patterns in the velocity field (or coherent turbulent structures, CTS) with a range of integral length scales that define their coherency (Traumer et al. 2015). CTS tend to be studied statistically from point measurements of *in-situ* turbulence with sonic anemometers setup on towers. The problem with this approach is that it attempts to relate point measurements to a wider spectrum of non-observed upwind spatial footprints of turbulent motion (Taylor 1938). Our climate and mesoscale weather models include parametrizations of land-atmospheric energy flux processes, so it is essential to address these principles through a critical reassessment of the measurement techniques especially if we are developing models capable of sub-kilometre scale resolved dynamics. We aim to test and progress the application of high speed infrared cameras to analyse spatial near-surface turbulent processes (Katurji and Zawar-Reza 2016). Our first objective is to study the effect of surface roughness on measured brightness temperature and then demonstrate the capability of our methods to be applied for micrometeorology, and thereby providing methods that could help in developing new theoretical formulations for atmospheric boundary-layer turbulence.

Method

We will demonstrate field and laboratory based methods of in-situ turbulence measurements using hot wire anemometers, and eddy covariance systems. Research grade infrared camera measurements capable of 200 frames per second and a temperature sensitivity of 25mK are also applied over several landscapes including artificial hockey turf (Fig. 1a), Dry Valley of Antarctica (Fig. 1b), and vineyards. During the initial stages of the analysis traditional measurements of kinematic heat flux and turbulence energy spectrum were compare with the infrared camera derived brightness temperature perturbations. Several wind tunnel experiments were conducted to study the impact of surface roughness on the brightness temperature spatial and temporal heating patterns.

Results

Our preliminary field and laboratory results indicate that there is a relationship between the brightness temperature and near surface wind turbulence (Fig. 2). Some of the highlights are bulleted below:

1. For low surface roughness the brightness temperature turbulent perturbations are explained by rapid adjustments of the impinging flow field over a very shallow surface layer.

- The spatial patterns of brightness temperature appear to correlate with the very near surface wind velocity structure.

- The turbulent energy spectrum resolved by the infrared camera measurements are dependent on the sampling rate of the camera and results reveal heating and cooling periodicity similar to that measured by eddy covariance system.
- 3D measurements of above-surface flow structures, like wind tunnel- and field-based Particle Image Velocimetry (PIV), are required to understand how coherent flow structure dynamics impact the spatial heterogeneity of brightness temperature.

Current work will focus on developing a sensible heat flux model that incorporates implicit and spatial proxies derived from infrared turbulence. This program is supported by the Royal Society of New Zealand.

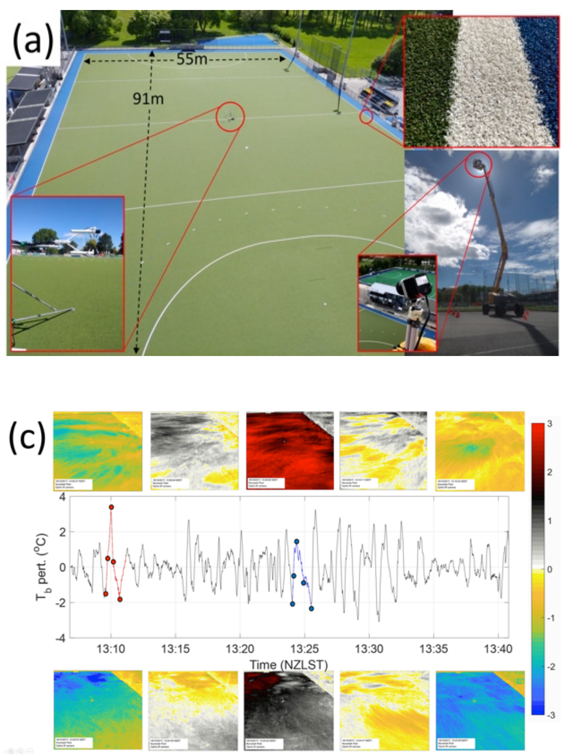

Figure 1: (a), (b) Application of infrared turbulence imaging for a hockey field (Christchurch) and the Dry Valley (Antarctica). (c) Surface brightness temperature temporal and spatial perturbations. (d) Wavelet decomposition of brightness temperature perturbations for different cloud cover cases.

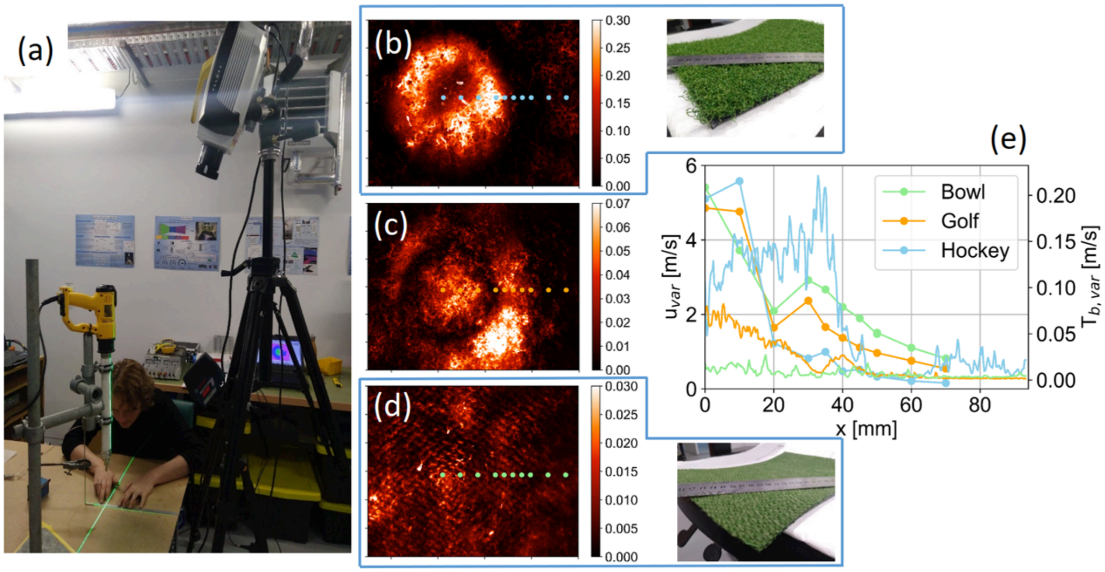

Figure 2: (a) Laboratory infrared and hot wire anemometer measurements of jet turbulence. (b), (c), (d) Brightness temperature variance resulting from jet impingement on different turf roughness types. (e) Brightness temperature variance (solid lines) and *in-situ* velocity variance along the traverse indicated by the coloured points on (b), (c), and (d).

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DETERMINATION OF OPTIMAL IRRIGATION RANGE FOR ROTATIONAL GRAZING PASTURE IN CANTERBURY, NEW ZEALAND

Dr Birendra KC[1], Dr Magdy Mohssen[2], Dr Henry Chau[3], Andrew Curtis[4], Professor Emeritus Richard Cuence[5], Dr John Bright[1], Dr MS Srinivasan[6]

[1]Aqualinc Research Ltd, [2]Otago Regional Council, [3]Lincoln University, [4]Irrigation New Zealand, [5]Oregon State University, [6]National Institute of Water and Atmospheric Research Limited

Expanding dairy farming around the world including the Canterbury region of New Zealand is causing increasing demand for irrigation, placing more pressure on already stressed water resources (Baskaran et al., 2009; Mekonnen & Hoekstra, 2012). The challenge for New Zealand dairy farming is to maintain an appropriate equilibrium between pasture production and environment protection, achievable through the proper management/utilization of agricultural water, for which application and expansion of carefully identified and evaluated irrigation scheduling can play a key role (Cameron et al., 2012; KC, 2016) .

The focus of this research was, therefore, to contribute to the development of irrigation scheduling to determine the irrigation range within the soil water holding capacity taking into consideration precipitation (P), evapotranspiration (ET), plant available water (PAW) and crop coefficient (K_c). This was achieved through estimating K_c of pasture at different grazing rotations by field measurements and analysing irrigation and deep percolation under a range of PAW-based irrigation triggers by applications of mathematical modelling of irrigation scheduling. A farmers' survey was carried out with 32 dairy farmers in Canterbury, New Zealand to collect information on current irrigation practices, particularly in relation to PAW and grazing rotation.

The experiments were conducted at Lincoln University Dairy Farm (LUDF), New Zealand during the period August 2014 to March 2016. A network of 20 non-weighing lysimeters and an Aquaflex installed on LUDF were utilized for the study. Pasture height, precipitation, irrigation application, deep percolation and change in soil moisture in the lysimeters were measured throughout the study period. Time Domain Reflectometry (TDR) probes with 200, 500 and 900 mm lengths were installed vertically adjacent to the Aquaflex and lysimeters for improving soil moisture determination in the lysimeters without disturbing natural water flux inside the lysimeters. To account for climatic variability, available 16 years of climatic data were collected from Broadfield weather station lying 3km north east from LUDF. Irrigation and deep percolation have been estimated using two soil-plant-atmosphere mathematical models (IrriCalc and CropWat 8) under a range of irrigation management strategies, including those identified in the farmers' survey, and commonly applied crop coefficient values in addition to those estimated in this research.

Based on reference and actual evapotranspiration, K_c of pasture was estimated for different grazing rotations. Analysing the relationship between K_c and crop canopy represented by pasture's height (h in cm) showed that a linear fit simulates well this process (KC, 2016). Aquaflex soil moisture (SM) readings resulted in a value of 0.43 for the coefficient of determination (R^2) for the K_c – h relationship, which increased to 0.66 when Aquaflex SM measurements were adjusted for each lysimeter using corresponding TDR readings (KC et al., 2017). This signifies the importance of accurate soil moisture determination to improve irrigation planning. The estimated values of K_c just after and before grazing were 0.6 and 1.0 for corresponding pasture heights of 10 cm and 30 cm (KC et al., 2017). Average K_c for one grazing rotation was estimated at 0.7. This implies conventional irrigation planning with a constant pasture crop coefficient of 1.0 would provide "on average" 30% more water compared to the actual water demand of pasture under grazing condition. This significant amount of water saving can contribute to conserve water and reduce leaching of nutrients.

During the shoulder seasons (September – October and March – May) current irrigation strategy leaves sufficient space for potential rain. However, during the peak irrigation season (November - February), the majority of farmers apply irrigation to fill soil up to 100% of the Field Capacity (FC), which is prone to cause deep percolation if rainfall follows an irrigation event (KC, 2016). Analysis of the irrigation and deep percolation predicted for 14 irrigation seasons indicated that a minimum soil moisture (SM) level to start irrigation at 55 and 60% of PAW, respectively on the shoulder and peak irrigation seasons, and stopping irrigation correspondingly at 80 and 90% of PAW were optimal for this case study (KC et al., 2016). This would allow for rainfall harvesting and thus, reduce net irrigation requirement and deep percolation losses.

The proposed irrigation scheduling contributes to agricultural water management, eventually supporting the sustainable development of dairy farming industries in New Zealand and around the world. In addition, it would also decrease water pollution by reducing nutrient leaching from pastoral farms to water resources.

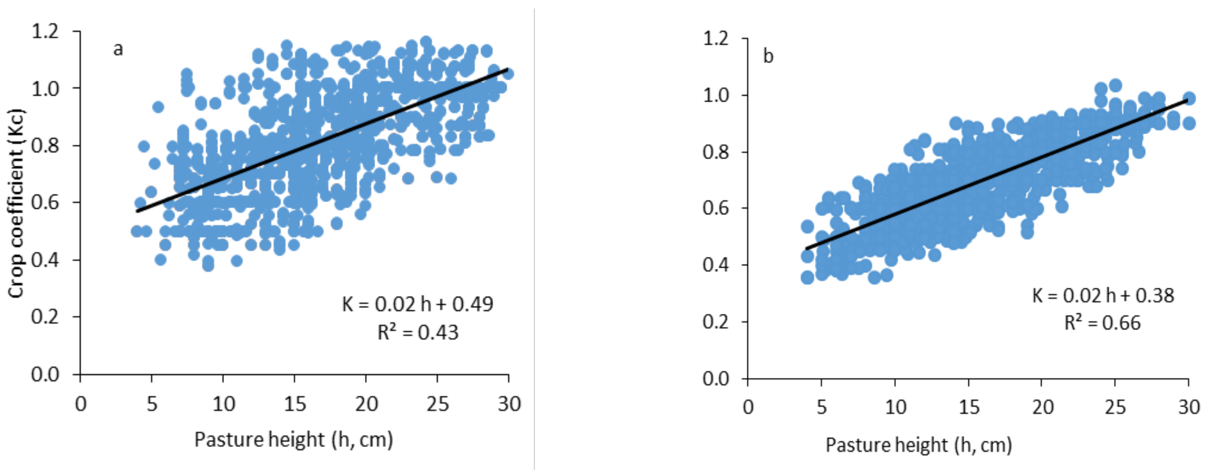

Figure 1: Linear relationship between crop coefficient and pasture height: (a) based on Aquaflex soil moisture without adjustment (b) based on TDR adjusted Aquaflex soil moisture

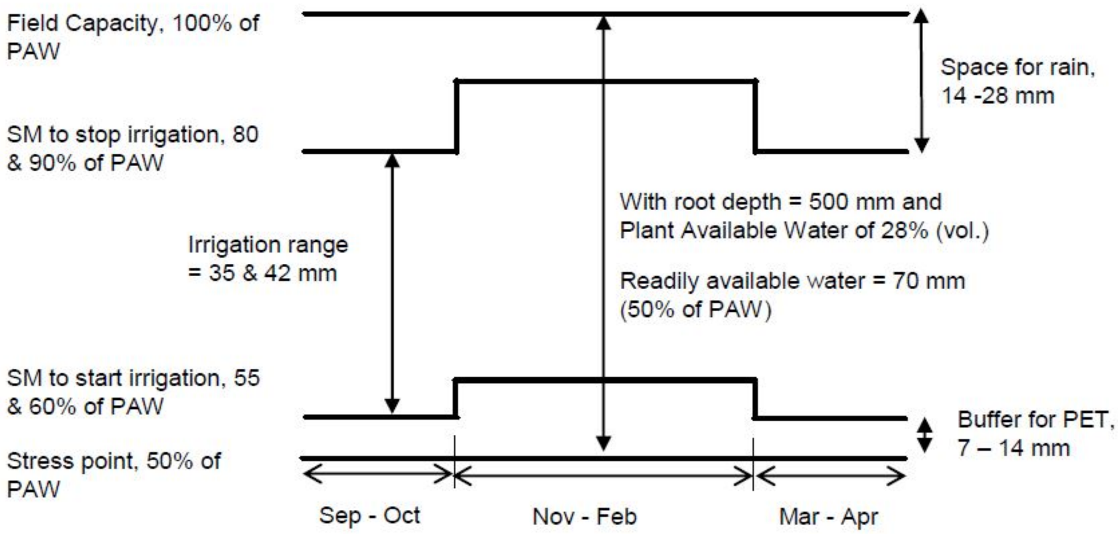

Figure 2: Optimal irrigation range to start and stop irrigation for rotational grazing pasture

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GROUNDWATER AVAILABILTY OF THE FRANKLIN DEEP WAITEMATA AQUIFER USING FEFLOW MODELLING AND FLOW-NET ANALYSIS

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The Franklin Waitemata resource is located within a deep (>100m) confined aquifer that extends under the Manukau lowlands covering an area of about 250km². Aquifer transmissivity is low to moderate with a range of 5m²/d to 109m²/d and average of 32m²/d from 34 pumping tests. The moderate transmissivity conditions are due to the influence of fracturing associated with block faulting. Average aquifer storativity is 7.0×10^{-4}.

Regional groundwater flow is to the north and northwest from the Bombay Hills to the Manukau Harbour. Superimposed on the regional flowpath are a number of groundwater "mounds" within the piezometric surface in the Waiau Pa, Te Hihi, Karaka and Papakura areas.

Aquifer recharge occurs primarily by vertical infiltration through the overlying geology where the Waitematas are close to the ground surface associated with upfaulted horst blocks that extend between Waiau Pa and Papakura and in the vicinity of Bombay. South of the horst blocks, vertical recharge is limited due to the presence of the more transmissive Kaawa aquifer that forms a preferential flowpath.

Aquifer discharge primarily occurs to the Manukau Harbour. The deep confined aquifer has no direct connection to fresh surface water.

Groundwater availability has been assessed with:

i. Subdivision of the aquifer into seven management areas reflecting individual flow systems.

ii. Assessment of aquifer recharge from flow-net calculations supported by FEFLOW groundwater modelling in three management areas.

For the four management areas extending over the groundwater mounds, aquifer recharge is 2% to 6% average annual rainfall. The remaining management areas have low recharge at 0.3% to 0.5% average rainfall.

Total groundwater availability is assessed at 4,262,000m³/yr based on 65% of annual average recharge. The availability based on 65% recharge is considered appropriate for the deep confined aquifer with no connection to surface water.

THE NEAR FUTURE OF GROUNDWATER LEVEL FORECASTING

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[1]Aqualinc Research Ltd., [2]Environment Canterbury

Aims

Map out a pathway to provision of a simple automated groundwater level forecasting tool.

Background

Knowledge of the likely variation in groundwater levels over an upcoming season is desirable for water resource managers to plan more efficiently for the future. There appears to be no technological barrier to providing such forecasts regularly and automatically. One option is to provide a simple forecast product rapidly. This has the advantage of low cost of development combined with rapid feedback to and from users.

Simple Groundwater Forecast Approach

Groundwater level eigenmodels (Bidwell and Burbery, 2011) are a logical approach for rapid implementation of a forecasting system (e.g. Bidwell 2005). The output from an eigenmodel provides an intuitive match to groundwater levels that are measured at many sites by most regional councils. The input to an eigenmodel may be simply generated using a soil-moisture balance model (e.g. Aqualinc's IrriCalc model), driven by weather, land use, irrigation and soil properties. In the simplest case, land use and irrigation may be assumed to follow a regular seasonal cycle, while soil properties may be assumed to be constant. Therefore, only weather variability is required to generate forecasted land surface recharge and groundwater levels.

The ability to provide seasonal weather forecasts is a subject of much research globally. Seasonal forecast accuracy in New Zealand is either low (i.e. little better than the climatology), or unreported. This greatly limits the value of its application to groundwater level forecasting. An alternative approach is to drive the forecast model with an ensemble of past weather observed for the forecast season. This assumes that the future weather is likely to fall within the range of historical weather. An ensemble approach has the added advantage of enabling the provision of likelihood statistics for the forecast. This is helpful in ensuring users apply the correct level of confidence to the forecasts. Using past weather greatly simplifies the overall forecast system as the data are already available. Given this, the forecasting method then simplifies down to five steps:

1. Obtain current weather variables (rainfall and potential evapotranspiration);
1. Update the modelled soil moisture state;
2. Update the modelled groundwater state;
3. Apply historic weather to the forecast period to generate land surface recharge and groundwater level forecasts and
4. Present the range of forecast groundwater levels.

This system can be implemented on a standard personal computer with the resulting forecast uploaded to a web site or client information system. Once implemented, feedback from users will identify the value and limitations of having a formalised groundwater forecast product. This feedback will enable direction for further development.

Potential Groundwater Forecast Enhancements

Some obvious paths for development beyond the simple approach include:

- Optimisation of how the forecast information is provided and presented
- Provision of land surface recharge information (e.g. soil moisture; drainage to groundwater).
- Limitation of future forecasts to use only specific years (e.g. known worst case years).
- Limitation of future forecasts to use a limited range of years (e.g. only dry years).
- Assimilation of soil moisture measurements into the land surface recharge modelling.
- Assimilation of satellite-derived estimates of crop types and growth stages into the land surface recharge modelling.
- Assimilation of irrigation water usage measurements into the land surface recharge modelling.
- Assimilation of recent groundwater level measurements into the groundwater eigenmodel.
- Use alternative/additional land surface recharge models (e.g. SPASMO, Ausfarm).
- Use alternative groundwater models (e.g. MODFLOW).

Summary

Simple automatic groundwater level forecasts for New Zealand are technologically possible using currently available tools. Such forecasts are to be trialled in the near future. Feedback from users following the initial implementations will provide a guide as to the optimum level of complexity, and the best method of presenting the information. With care in the forecast development path, groundwater level forecasts could be a standard service of regional councils within a few years.

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WHERE DOES OUR WATER COME FROM – AND HOW DOES IT GET HERE?

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Aims

River water possesses high cultural and economic value. River water comes ultimately from precipitation; over 90% of New Zealand's precipitation comes directly from ocean evaporation (Dirmeyer et al. 2009). However, exactly where this water evaporates from, and the atmospheric pathways by which this water is delivered to New Zealand, are not fully understood. The aim of this work it to investigate the extent to which there are distinct areas within the oceans where evaporation occurs, and the atmospheric pathways that are responsible for delivery of this water to New Zealand.

Method

There are two components to the methods. Firstly, geochemical analysis of river water following exemplar substantial rain events in a series of representative pristine high country and alpine catchments in the South Island. Stable isotopes of water are strongly sensitive to the latitude, elevation, and temperature of the source airmass during condensation and so these analyses will provide a 'fingerprint' that can be tracked from precipitation into the river source. Secondly, the large-scale weather conditions at the time of these exemplar rain events will be characterised. Specifically, trajectory analysis will be used to identify the exact pathway through atmosphere of airmasses associated with precipitation, and calculation of vertically integrated water vapour flux will allow the moisture content of these airmasses to be quantified.

Results

Preliminary analyses reveal distinct isotopic signatures within discharge events (Figure 1), suggesting different precipitation source areas. This finding is reinforced by trajectory analysis results, which indicate a marked shift in airmass origin coincident with the change in isotopic signature (Figure 2). In this case, the change appears to be the result of initial rain from a northerly source, followed the passage of a cold front and subsequent rain originating from a more south/southwesterly location.

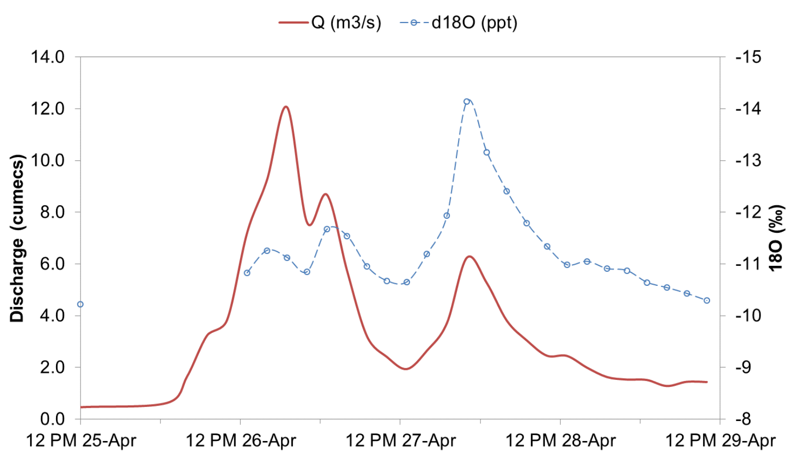

Figure 1: Exemplar discharge and ^{18}O time series for a high flow event in a headwater tributary of the Lake Pukaki catchment (Birch Hill Stream).

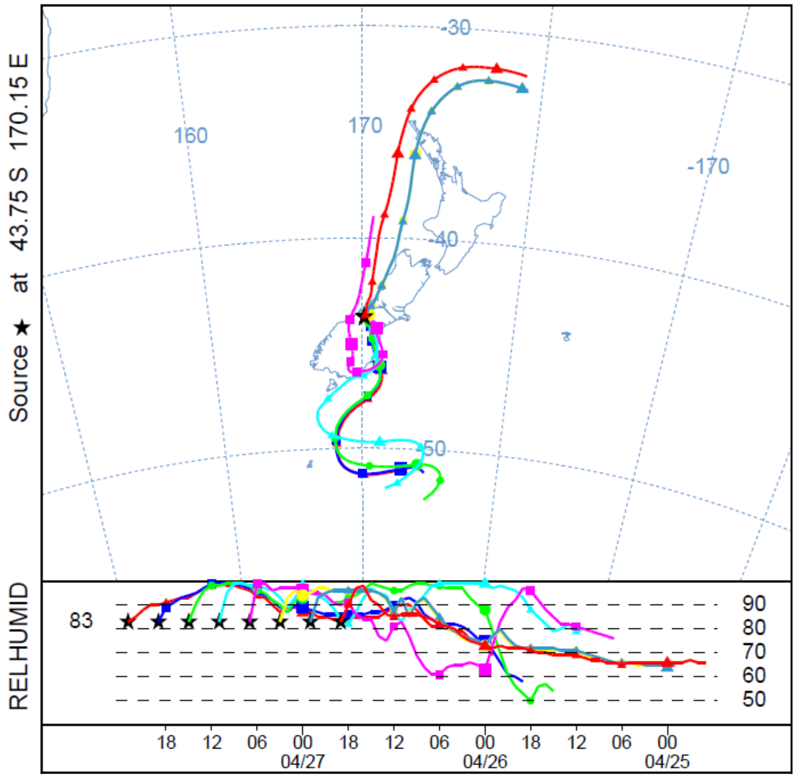

Figure 2: Back trajectory analysis and relative humidity for air parcels associated with the Birch Hill Stream high flow event on 27th April 2015.

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A MODELLING TOOL FOR REAL-TIME NITRATE-LOADING OPTIMIZATION UNDER UNCERTAINTY AND DECISION SUPPORT: THE STOCHASTIC IMPULSE-RESPONSE EMULATOR

Matthew Knowling[1], Jeremy White[1], John Kim[2], Catherine Moore[1]

[1]Gns Science, [2]Market Economics

Aims

There is a critical need for environmental management optimization to be risk-based and probabilistic. So-called "optimization under uncertainty" (OUU) problems address this need. OUU using environmental simulators such as groundwater models is a notoriously computationally burdensome task. This challenge is increasingly being addressed through "model emulation" strategies, which involve deployment of fast models that emulate the relationship between complex physics-based model outputs with respect to their inputs (Asher et al., 2015).

The well-documented linear relation between nitrate-loading and surface water quality (e.g., McLay et al. 2001) presents an opportunity to employ such a strategy, in particular, through the use of a "response matrix" in-place of complex nutrient transport models. The aim of this study is to exploit this linear relation by means of developing a tool, named the Stochastic Impulse Response Emulator (SIRE), to facilitate rapid (i.e., near-real time) nitrate loading OUU subject to water-quality (and direct land-use) constraints.

Method

Central to SIRE is the response matrix **A**. This matrix represents the relationship between simulated surface-water and groundwater nitrate concentrations at given locations ($conc_i$) and spatially distributed nitrate loading rates ($load_j$). This relationship is derived from a complex MT3D-USGS (Bedekar et al., 2016) model. In this way, **A** emulates the action of the full numerical transport model (which seldom run fast enough to employ in OUU contexts) by simply multiplying a desired loading-rate vector by **A**.

First-order, second-moment (FOSM) (e.g., Tarantola, 2005) techniques are used here to propagate uncertainty from model parameters to simulated surface-water and groundwater concentrations. These simulated concentrations are used as constraints in the OUU problem. The uncertainty variance of simulated concentrations σ^2_s is expressed as:

Where $\boldsymbol{\Sigma_\theta}$ is the parameter covariance matrix (here we employ the prior covariance matrix), and **y** is a vector of derivatives relating changes in parameters to changes in the simulated constraints (i.e., rows of **J**; see below), and where $param_j$ is an (uncertain) model parameter.

Following estimation of the uncertainty surrounding given surface-water or groundwater outputs of interest, the technique of chance-constraints (e.g., Wagner and Gorelick, 1987) is employed to yield deterministic, risk-based values for these simulated concentrations. This is achieved by moving along the implied Gaussian distribution in accordance with a user-specified risk value (ranging from 0.0 to 1.0). A single optimal nitrate-loading distribution can therefore be obtained, with uncertainty implicitly expressed therein.

The OUU problem is solved via a (chance-constrained) sequential linear programming (CCLP) using PESTPP-OPT (White et al., 2018)

The utility of SIRE for land-use OUU is demonstrated for a large-scale complex synthetic model. The interface is written in the Python scripting language, utilising heavily the pyEMU package (White et al., 2016), and is presented within a Jupyter Notebook (Jupyter, 2016)).

Results

The results of this study are in the form of an easy-to-use tool for near-real time land-use OUU. The tool's utility in optimizing nitrate loading for the synthetic model considered will be demonstrated interactively during the presentation. A screenshot of such a demonstration is shown in Figure 1. The left plot shows the optimal loading distribution subject to six in-stream nitrate concentration constraints for a risk-neutral stance (risk = 0.5). The right plot demonstrates that risk values such as 0.82 (risk-averse) result in an infeasible optimization problem, i.e., there is no region of decision-variable space that meets all water-quality constraints for such risk values).

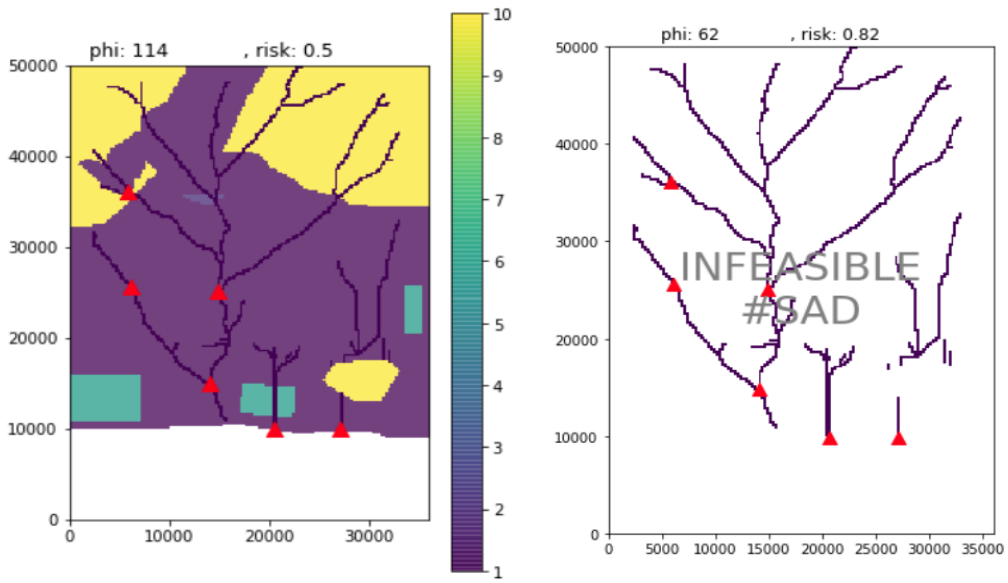

Figure 1: A screen-shot demonstrating the utility of SIRE for optimizing nitrate loading (colours indicate recharge nitrate concentrations) subject to water quality constraints (red triangles) under uncertainty.

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AN ONLINE TOOL TO GUIDE ORCHARDISTS OUTDOOR BURNING ACTIVITIES

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[1]*Hawke's Bay Regional Council*

Air quality in Hawke's Bay is generally very good but at times during winter smoke particulates can build up to unhealthy levels and exceed the National Environment Standard for PM_{10}. The main source of smoke is from domestic fires used for home heating and the Hawke's Bay Regional Council (HBRC) has set rules around domestic burners to help reduce smoke emissions. Outdoor burning in the Napier and Hastings airsheds is not permitted in winter except on horticultural land for specific purposes, namely orchard redevelopment and removal of diseased material.

Rule 19e of the HBRC Air Plan specifies that outdoor burning on horticultural land must not take place in wind speeds less than 3 m/s and in wind directions that cause smoke to move over urban areas of the Napier and Hastings airsheds. The Hawke's Bay Fruitgrowers' Association (HBFA) together with HBRC developed an outdoor burning good practice guide, which includes the wind conditions of Rule 19e and also recommends not burning when a temperature inversion is present.

Outdoor burning produces a highly visible plume and HBRC often receives complaints from members of the public about it. The perception of urban residents is that they are burdened with expensive changes to their method of home heating while orchardists are not restricted and contribute more to poor air quality. In an effort to avoid complaints and prosecution of industry members for burning in unsuitable conditions, the HBFA asked HBRC to assist its members in deciding when the appropriate meteorological conditions are met. This paper describes the progress to date of developing a tool for that purpose.

Aims

The project aims to deliver an online tool that packages real time weather information from climate sites belonging to HBRC and stakeholders in a format that identifies temperature inversions, communicates air quality, maps the airsheds and provides wind speed and direction information for properties where the activity is undertaken. It also has an historic component, providing a timeline of conditions on previous days to allow landowners to review conditions during the activity and for HBRC to review information displayed by the tool in the event of complaints.

Method

A prototype of the tool has been developed using the Shiny Dashboard package in the open source statistical software R. The HBRC climate data are pulled into the tool via the HBRC Hilltop Server public web service. The temperature difference between a low-level and elevated site is used to signal the presence of temperature inversions.

The interpolation of wind data is undertaken using the package Meteoland and Wind Ninja software. The Meteoland package interpolates climate data using details about a location's slope, aspect and elevation. The results are used to display the vector of where smoke is likely to head in relation to the urban airsheds and whether the wind speed fits the criteria for burning.

Results

A demonstration of the tool will be presented, including an assessment of the wind interpolation scheme.

EVALUATION OF HADGEM3 SOUTHERN OCEAN CLOUD USING OBSERVATIONS AND REANALYSES

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Current general circulation models are affected by biases in simulated clouds in the Southern Ocean (SO) which are despite some recent progress are still too large, resulting in biases in shortwave and longwave radiative transfer. These biases are also present in the HadGEM3 model, a UK Met Office model which has been a focus of development in the Deep South National Science Challenge with the aim to more accurately project future climate in New Zealand. The amount of cloud has more ice phase than expected. Satellite observations have been used extensively to study this problem, but the predominantly low level cloud in the SO cannot be reliably observed from space due to the prevalence of overlapping cloud and other limitations such as ground clutter in active instruments. We use observational data from a number of SO voyages to assess clouds in HadGEM3, and contrast it with the MERRA-2 reanalysis, which provides very different cloud phase and cloud occurrence results in the SO. We use ceilometer observations collected on voyages to assess cloud vertical distribution, mini micropulse lidar observations to assess cloud phase and radiosonde observations to assess tropospheric stability and humidity profiles. The ceilometer observations cannot be compared directly with the model due to attenuation of the lidar beam in thick cloud, and we use a ceilometer simulator developed for this project for a like-for-like comparison. We also apply this evaluation to a number of experimental HadGEM3 runs produced with different choices of cloud scheme parameters in order to fix the SO cloud bias.

SPATIAL AND TEMPORAL CHARACTERISTICS OF RAIN-SPELLS IN NEW ZEALAND

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[1]University of Haifa, [2]Visiting professor at the University of Haifa, [3]University of Otago

Aims

The purpose of the present study is to analyze the spatial and temporal distributions of rain-spells and their characteristics in New Zealand. Various rain-spell's parameters such as their average number (NRS), average yield (RSY), average intensity (RSI) and average duration (RSD) and the inter-correlations among all variables are analysed. Intra-annual variability and the rain-spells' characteristics during dry and wet years are presented.

Method

Daily rainfall totals from 19 stations on both islands for the period 1965-2017 were used. Rain-spell characteristics were defined using a daily rainfall threshold (DRT) of 1.0 mm. Data were subject to analysis using the rainfall uncertainty evaluation model (RUEM) developed at the laboratory of climatology at the University of Haifa. Various functions were fitted to represent the relationship between rain-spell characteristics and their duration-RSD. Dry and wet years were defined according to their standardized departures from the long-term mean:

Very Dry (VD)	when	$z<-1.0$
Dry (D)	when	$-1.0\le z<-0.5$
Normal (N)	when	$-0.5\le z\le 0.5$
Wet (W)	when	$0.5<z\le 1.0$
Very Wet (VW)	when	$1.0<z$

Rainfall totals in the different years were subject to cluster analysis (CA) and the various clusters were mapped. Temporal intra-annual uncertainty was estimated in two ways: 1-by calculating the mid-season date (MSD) and the variability from year to year around this date and 2- by calculating the range of percentages accumulated by the MSD.

Results

The main results can be summarized as follows:

1. RSY is the main factor that differentiates between dry and wet years whereas, NRS has only a very limited impact on the annual rainfall.

- The relationship between NRS and RSD is best described by an exponential curve, between the RSY and the RSD by a linear function and by a power function for the relationship between RSI and RSD. An example for Hokitika is presented in Figure 1. The coefficients of the various correlations in all stations serve to prepare charts of iso-lines of equal NRS, RSY and RSI respectively for various selected RSDs.

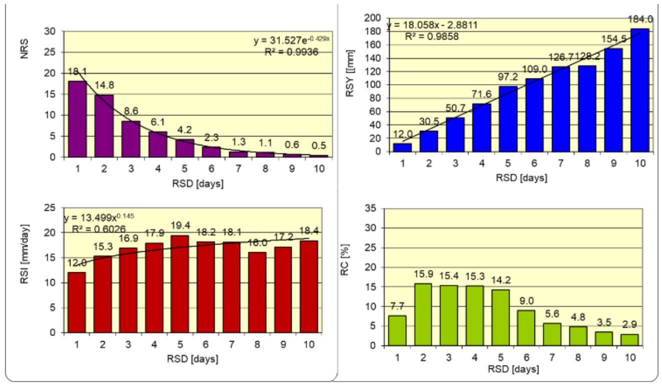

Figure 1: The distribution of rain-spells' characteristics, NRS, RSY, RSI and the relative contribution-RC according to rain-spell duration (RSD) in Hokitika.

- Most year were clustered into five different clusters according to their spatial distribution and their return period were calculated. Each cluster presents a different spatial distribution. Two clusters showing *Dry North-Wet South* (cluster c) and *Wet North-Dry South* (cluster d) and are shown in Figure 2. For each cluster, the appropriate synoptic type according to Kidson classification (Kidson 2000) was attributed.

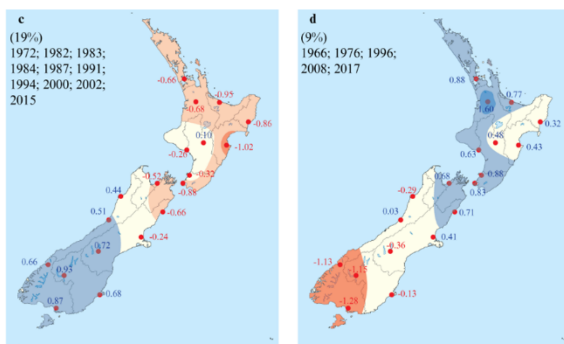

Figure 2: Example of two clusters of years according to their spatial distribution. *DN-WS* cluster (c), *WN-DS* cluster (d). The years belonging to each cluster and their probability appears on each map. Values in blue represent positive standardized departures from the long-term average, in red, negative departures.

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PARTIAL AREA CONTRIBUTION AND OVERLAND FLOW DISCONTINUITY

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Aims

The aim is to review the application of the concept of "partial area contribution" that was developed in humid areas, to arid and semi-arid areas.

Abstract

The phenomenon that not all the area of even small watersheds is participating in contributing runoff to the outlet was shown by Betson (1964), Ragan (1968), Dickinson & Whiteley (1970), Dunne & Black (1970), and others, in humid zones, where overland flow is generated on saturated areas. This phenomenon is known as the "partial area contribution" concept, that later was developed to "variable source area" (Hewlett & Hibbert 1967).

Based on studies executed in the Sinai desert, the Negev desert and the Judean desert, this concept was applied to arid and semi-arid areas, where overland flow is generated by rainfall intensity excess over infiltration rate (Horton overland flow). The partial area contribution in these areas is not connected to the spatial distribution of saturated areas but to the discontinuity of overland flow that is controlled by two main factors:

1. Rainfall properties:

a. The typical short rain events (rain showers of 5 - 30 minutes) in which overland flow that was generated on the hillslopes at a distance of more than 30m from the near channel has almost no chance to reach the channel and to contribute to the channel flow as it infiltrates into the soil on the hillslope before reaching the channel and therefrom evaporates (Lavee & Yair 1990).

b. The fact that the actual rain amount reaching the ground and its intensity are higher near the channel and the adjacent lower part of the hillslopes (Sharon 1980).

2. The spatial distribution of the soil properties which determine infiltration rate:

a. Lateral variations such as the intermittently existence of gullies and interfluves on the lower part of scree slopes. The gullies are characterized by big blocks that have rolled down from upslope and are partly buried in a matrix of fine particles (sand, silt and clay), whereas the interfluves are composed of loose smaller blocks with a very high void ratio and small amounts of fines. Overland flow is generated only in the gullies (Yair & Lavee 1974).

b. Vertical variations such as the existence of colluvium at the lower part of the hillslope, in which infiltration rate is usually higher than in the upper part of the hillslope (Yair, Sharon & Lavee 1978).

c. Spatial distribution of different types of patches such as bare soil covered by mechanical crust or big stones, especially when partly embedded in the topsoil (Lavee & poesen 1991), that function as source areas of overland flow, and shrubs, mosses or small stones that lie on the soil surface that function as sinks for the direct rainfall and for the overland flow from adjacent source patches (Lavee, Imeson & Sarah 1998).

The result is that the channel flow in arid and semi-arid areas is fed by overland flow from a relatively narrow belt at the bottom of the hillslopes on both sides of the channel.

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COMPREHENSIVE APPROACH TO FLOOD FREQUENCY ANALYSIS

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Aims

This paper aims to present and promote a considered, comprehensive general approach for flood frequency analysis. Current practice in NZ is limited and traditionally confined to a few standard distributions. The approach has involved broad consideration of each element of the flood frequency analysis process, covering data checking, plotting position formulae, flood series types, frequency distributions, fitting methods and goodness-of-fit testing, as well as a strategy for decision-making and distribution selection. It builds on the pilot study by Environment Canterbury (Steel, 2016). This approach has been developed for Environment Canterbury and has been used in the assessment of 29 gauged rivers in the Canterbury region plus 13 sites with no data.

Method

- Brief review of current and traditional practices
- Consider each element of the flood frequency analysis process:
  - Review of data quality/reliability and gap analysis
  - Plotting position formula, and inclusion of non-sequential historic flood peaks
  - Flood series type e.g. partial duration, series drawn from annual, biennial and longer time intervals, etc.
  - Frequency distribution – ten different types of distributions assessed, with between two and five parameters
  - Fitting method e.g. PWM, product moments, etc.
  - Goodness-of-fit testing – Anderson and Darling (1952) test and a specific new test developed as part of our study
- Develop strategy for flood estimation based on flood frequency analysis, including selection of preferred distributions, tailored for length of record and whether historic data exists
- Apply method to 29 sites with record length from 5 years to 52 years, with some sites having up to 28 additional historic floods, to estimate floods with ARI of up to 1000 years

Results

- Up to 36 different distributions were fitted to some sites – combination of frequency distribution type and flood series type
- Given the distant extrapolation required (up to 1000 year ARI), frequency curves that had a strong concave (upwards) curvature, which have a tendency to over-predict (and thus violate the concept of a limiting maximum flood), were accorded reduced weight

- For the Canterbury rivers assessed, the most commonly adopted frequency distributions were the TCEV, EV1 (annual), EV1 (biennial) and LP3
- For distant extrapolation of the flood frequency curve, the uncertainty related to the choice of the frequency distribution can be as great as or greater than the intrinsic uncertainty in the frequency distribution
- The approach, strategy and tools that have been developed are generally recommended for comprehensive flood frequency analysis

References

Steel, K. (2016). *Flood frequency analysis pilot study: Orari, Temuka, and Waimakariri Rivers*. Report No. R15/129, Environment Canterbury, Christchurch.

PUMP TESTING AN UNCONFINED SAND AQUIFER, MAHIA, HAWKE'S BAY

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Introduction

Lattey Group was engaged to assist with an application for a new Water Permit to abstract groundwater for municipal supply for the Blue Bay subdivision in Opoutama. The proposed abstraction well, No. 5458 (125mm diameter), is located on Blue Bay Road, approximately 400m north of the coast. The well's total depth is 6.90m and it is screened at a depth of 4.5m, within blue sands. The Static Water Level (SWL) is 3.74m below top of casing (toc). The proposed volumes are 2,462m^3/28 days, and 25,711m^3/year. The proposed maximum abstraction rate is 1.5L/s.

Aims

To determine the capabilities of the proposed abstraction bore (No. 5458)

To determine the aquifer properties in the area

To assess the impact of the proposed abstraction on surrounding wells

Method

A three-step aquifer test (step test) was conducted on the proposed abstraction bore in order to determine its capabilities. The step test was followed by a 24 hour constant discharge pump test, where groundwater levels were measured in the pumped well and four monitoring wells. The drawdown data was analysed using the Neuman (1974) solution for unconfined aquifers. The calculated aquifer parameters were then used to model the impact of the application on surrounding wells.

Results

1. The maximum abstraction rate during the step test was 1.5L/s. The maximum drawdown measured during the step test was 1.35m. The Transmissivity (T) values calculated from the drawdown and recovery data were 188.35m^2/day and 239.57m^2/day, respectively.

- The rate during the constant discharge pump test was 1.5L/s. The maximum drawdown in the pumped well was 1.45m. The highest drawdown in the observation wells was 0.295m, measured in a well located 5m away (No. 5455). The drawdown in the remaining wells was <0.01m. The impact of tidal and atmospheric pressure fluctuations on groundwater levels was negligible.

- The test results were analysed with the Neuman (1974) solution for unconfined aquifers using the drawdown data from Well No. 5455. The calculated aquifer parameters were

T=225.9m^2/day, Storativity (S)=0.005, and β=0.0009. It was not possible to accurately determine the Specific Yield (S_y), as the fitting between the observed and modelled data did not significantly change when S_y exceeded 0.15. Two values for S_y, 0.15 and 0.30, were therefore considered.

- The impact of the proposed abstraction on surrounding wells was modelled in Aqtesolv using two abstraction scenarios: pumping the 28days volume at the maximum rate and pumping at the average daily volume over 1 year. The maximum predicted drawdown in surrounding wells was <0.4m, which is substantially lower than the seasonal groundwater level fluctuations in the area. The predictions for the lower S_y value exceeded those of the higher value by a maximum of 0.05m.

References

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ZERO CARBON BILL – DOES METHANE DESERVE A REPRIEVE?

Ben Liley[1], Sara Mikaloff-Fletcher[1], Mike Harvey[1]
[1]*NIWA*

Aims

To explore the implications of the different possible targets in New Zealand's Zero Carbon Bill (ZCB), especially the question of whether methane emissions should only be 'stabilised'.

Method

Prompted by questions about how to interpret the three alternative targets in the MfE discussion document on the Zero Carbon Bill (Ministry for the Environment, 2018b), we reviewed New Zealand's greenhouse gas (GHG) emissions (Ministry for the Environment, 2018a), their contribution to global emissions, and the implications for global temperature. We considered both the familiar Global Warming Potential (GWP) and the alternative Global Temperature change Potential (GTP, Allen et al., 2018), which may be more relevant to mitigation policy. We calculated the required forest sink to achieve net zero emissions with different scenarios for reduction in fossil emissions and plausible changes in non-CO_2 GHG emissions. We also used a simple climate model together with a plausible "shared socio-economic pathway" (O'Neill et al., 2017) to explore the impact on global temperatures if the same approach to different gases were adopted worldwide.

Results

The three suggested targets in 2050 for the ZCB were: net zero carbon dioxide; net zero long-lived gases and stabilised short-lived gases; and net zero emissions of all GHG. The first is straightforward, excusing the gases from pastoral agriculture that is the mainstay of our economy. The third option gives them equal weight, according to GWP, as in the Kyoto Protocol and much IPCC analysis. Without major breakthroughs, or massive destocking, it would require a very large amount of carbon capture.

The middle option requires some interpretation. Stabilisation of NZ methane emissions effectively means the status quo, as they have increased only 4.4% since 1990, mostly through conversion of formerly forested land to farming. The increase in dairy cows came at the expense of sheep numbers, which have halved since 1990. Cattle and sheep produce similar amounts of methane from the same amount of pasture.

By contrast with methane, gross carbon dioxide emissions rose by 35% over this period.

Whether the atmospheric concentration of methane can be stabilised near the present ~1870 ppb is not a question for NZ, which produces only 0.38% (1.4 Tg) of global anthropogenic emissions (~370 Tg). New Zealand leads research on reducing emissions from pastoral agriculture, and if it succeeds then export of technology might reduce global ruminant emissions. They are still just 15% of total methane emissions, and realistically would only be reduced by a minority of that.

The 90 Tg methane per year emitted by the world's livestock is little more than global emissions of landfills and waste treatment, and less than fossil fuel leakage. Waste accounts for 13% of NZ anthropogenic methane emissions (5% of total GHG), but the amount has decreased since 1990.

Beyond disaggregating the different GHG within mitigation policy, it is clearly important to separate sources of each gas, as of course happens with CO_2.

Methane from enteric fermentation, animal waste, rice cultivation, natural wetlands, biomass burning, and most waste disposal is biogenic, so the carbon in it has recently been removed from the atmosphere by photosynthesis. Thus the CO_2 molecule produced when each CH_4 molecule oxidises does not add to atmospheric CO_2. In contrast, methane leakage from fossil fuel extraction or use does increase atmospheric CO_2, so its GWP is greater by 44/16 = 2.75 (GWP is by weight of gas, not per molecule). The difference is small relative to the methane GWP of 28 or 34 (IPCC AR5, without or with indirect effects), but the distinction is important. New Zealand might decide not to target agricultural emissions until there are viable means to reduce them. Methane from waste and fossil fuel leakage has no economic or social benefits, so there is no reason not to act on them promptly.

With only 0.17% of global GHG emissions, NZ action may seem largely symbolic; our action as good global citizens. Against that, our emissions come from only 0.06% of the world's population, so we are nearly three times the global average (albeit less than two times for CO_2 alone), and 30% of global emissions are from economies of similar size.

To consider the NZ ZCB in this context of the global need for action, it is again worth considering how we compare the relative importance of the different GHG.

To a very large degree, the problem of anthropogenic global warming begins and ends with fossil carbon. Had humanity never released billions of tonnes of 300-million-year-old carbon into the atmosphere, the global warming effect of all other gases would have been small and probably undetectable. Correspondingly, if we could reduce global non-CO_2 GHG emissions to zero, we would remove less than 10% of the additional heating 100 years hence (e.g., IPCC, 2013, Fig 8.34(a)). It would also do nothing to reduce ocean acidification, which is all from CO_2.

Nonetheless, because humanity has burned 300 Gt of fossil carbon, the other gases do matter, especially in the 20-year horizon (IPCC, 2013, Fig 8.34(b)). If New Zealand can help other countries to reduce agricultural emissions, it could speed progress toward global temperature stabilisation.

If New Zealand were to reduce net carbon dioxide emissions to zero (the first scenario), while holding methane emissions steady at 2016 levels, it would have little impact on warming over the first 20 years. However, it would dramatically reduce our contribution to global warming after that. If net carbon dioxide emissions were reduced to zero, while methane emissions were halved (the second scenario), New Zealand's contribution to global warming would be halved on the twenty-year time horizon.

To look at the global context we use an example from the latest generation of future climate scenarios or "shared socio-economic pathways", with a middle-of-the-road scenario and a mitigation effort towards low greenhouse gas impact (SSP2-2.6) consistent with COP21 INDCs. (Riahi et al., 2017). With the MAGICC6 (Meinshausen et al., 2011) simple climate model, we consider a modified pathway with additional reduction of 50 Mt CH_4 either early or mid 21st century. A relatively rapid reduction in radiative forcing due to methane is possible because it is "short-lived". Consequently, there is a rapid response to lowering global warming that might have the most beneficial impact around the time of peak temperature.

Our analysis shows the importance of separate consideration of the different GHGs. The UNFCC's objective, to "prevent dangerous anthropogenic interference with the climate system", now seems possible and affordable with complete elimination of fossil-fuel burning. If feasible, action to reduce short-lived GHG can make an important contribution to reduce temperature change this century.

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CATCHMENT SCALE SURFACE WATER MANAGEMENT IN THE WAIMAKARIRI WATER ZONE

Carey Lintott[1]
[1]*Beca*

Aims

Environment Canterbury is currently working with the Waimakariri Zone Committee and wider community to set flow and allocation limits for the Waimakariri Water Zone.

We took the opportunity presented by the limit setting process to investigate how well the current surface water management regime was meeting its intended purpose and to recommend adjustments as necessary. A potentially complicating character of the regime was the number of Surface Water Management Zones (SWAZ) which were nested within a single hydrological catchment. Having multiple management zones aimed at achieving different outcomes within a single catchment can lead to unintended consequences.

Provided here is a summary of the investigations we undertook to assess the continued need for, and effects of, nested regimes. The findings of this work are not for direct adoption by decision makers, but rather to inform the Zone Committee so that they can make clear recommendations on water management in the zone they represent, in balance with a range of other competing recommendations.

Method

Surface water is currently managed across 16 Surface Water Allocation Zones (SWAZ) within the Waimakariri Zone; the key catchment within this case study being the Cam River/Ruataniwha which drains the area around Rangiora.

Cam River/Ruataniwha has a flat, lowland catchment including both rural and urban landcover. It is an important waterway for local rūnanga, being close to Tuahiwi Marae. Four spring-fed tributaries, the upper Cam River/Ruataniwha, North Brook, Middle Brook, and South Brook meet to form the slow flowing main stem of the Cam River south of Marsh Road, Rangiora. These streams are currently managed as four independent SWAZ despite being part of a single hydrological catchment (Figure 1). We use the Cam River/Ruataniwha catchment as a case study to investigate the spatial and temporal interactions between flows in each of the SWAZ, and the effects of these interactions on the main stem of the river downstream.

We analysed the main parts of the current flow management regime; minimum flows and allocation. Firstly we compared minimum flows in each of the tributaries, using flow duration curves and recession analysis, to understand the temporal relationship between minimum flows in the catchment, and look for patterns of occurrence.

We then assessed the allocation regime, summing total allocation for upstream management zones and comparing this to the current allocation limits, as well as to ecological and cultural allocation recommendations. This allowed us to look at the cumulative effects of upstream takes on the main stem of the river downstream.

Using these analyses options for future flow management at catchment scale were developed for consideration by the zone committee, as part of their recommendations process.

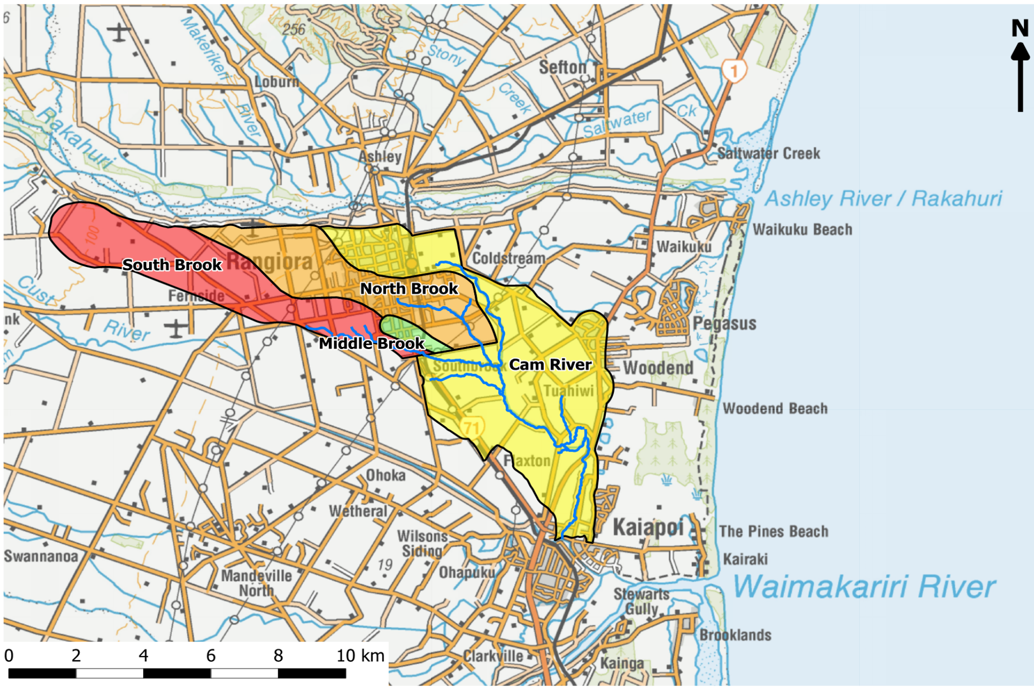

Figure 7: Existing surface water allocation zones in the Cam River catchment. Surface water allocation zones from Waimakariri River Regional Plan (Environment Canterbury, 2011).

Results

This work identified a mismatch in minimum flow onset across the SWAZ; it showed that it can be as much as a month after the Cam River first drops below its minimum flow before North Brook and South Brook reach their minimum flows. The implication of this is that the values being protected by the Cam River minimum flow could be potentially degraded because abstractions upstream can continue to occur. We identified that a large part of this mismatch is created because the minimum flows were set for different management reasons (general instream health vs. effluent dilution).

Our analysis of the allocated water showed a large cumulative abstraction which, if fully implemented, could have adverse effects on the lower reaches of the river.

The management of catchments with nested SWAZ is a complex undertaking, especially when different values are being manged for. Having a number of SWAZ within a single hydrological catchment is not an inappropriate management technique, however the limit setting process needs to be thought through carefully to ensure the consequences of management decisions are acceptable across the catchment.

Our findings, along with the potential implications of various management regimes, are currently being presented to the Zone Committee. The Zone Committee then needs to assess this information in the wider context of their remit to make balanced recommendations for water management across the Zone.

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GROUNDWATER SOURCED AIR CONDITIONING SYSTEMS IN THE CHRISTCHURCH CBD

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[1]*Pattle Delamore Partners*

Aims

Groundwater sourced air conditioning systems in the Christchurch CBD are an energy efficient technology that usually has minimal environmental impact. An unprecedented uptake of these systems has occurred in the Christchurch CBD. This has in part been enabled under a permitted activity rule in Chapter 9 of the Land and Water Regional Plan, although many of the systems draw from aquifers deeper than those included in the permitted activity rule, so resource consents have been required.

The groundwater sourced air conditioning systems in the Christchurch CBD draw water from deeper aquifers, usually from the more productive Wainoni Gravels at around 120 m below ground level, and discharge this water back to groundwater, usually to the first main aquifer, the Riccarton Gravels.

Due to the large number of these systems, the scale of abstraction and reinjection for some of the individual systems, and an already very shallow water table beneath the central city, careful consideration and testing is required to evaluate the potential environmental effects of the systems.

Detailed monitoring during the tests has been undertaken to better understand and address the following potential issues:

- seepage into basements and to surface around stone columns, old bore casings, deep tree roots, deep foundations or cracks in the confining layer (from earthquakes or other reasons),
- increased spring flows or seepage into the Avon River,
- heated groundwater entering the Avon River, and
- increased susceptibility for liquefaction in the overlying Christchurch Formation, due to an increase in pore pressures.

Method

To assess the potential for environmental effects, a number of combined abstraction and reinjection aquifer tests have been undertaken for previous groundwater sourced air conditioning projects within the CBD. A key difference with the testing PDP has been involved with in the last 24 months, is the monitoring of effects at the water table, both within the confining layer or in locations where a shallow unconfined aquifer exists above the reinjection aquifer. This included the installation of dedicated monitoring bores within the reinjection aquifer, and at varying depths within the upper confining strata.

Results

This paper will discuss the tests where detailed monitoring for mounding within the shallow confining strata has occurred. This propagation of groundwater pressures, and potentially heat, through the confining strata requires careful control to avoid adverse effects.

A REVIEW OF FIELD DRAINAGE LYSIMETER RESEARCH IN NEW ZEALAND

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Aims

Field drainage lysimeters are widely used throughout New Zealand, predominantly to measure rainfall and/or irrigation recharge to groundwater. At least two recharge monitoring sites are installed in Auckland, Bay of Plenty, Hawke's Bay, Canterbury, and Southland Regions. Dryland sites are operated by regional councils and NIWA provides support for operation of irrigated sites. Additional recharge monitoring sites, such as those in Waikato, are operated by research institutes and private companies. The primary aim of this paper was to present a summary of groundwater recharge sites including current monitoring objectives, data applications, and emerging challenges. To achieve this, a review of all known drainage lysimeter sites throughout New Zealand was undertaken.

Method

For all known recharge monitoring sites in New Zealand, information such as location, duration of datasets, and site purpose were compiled. All regional councils and other organisations known to operate these sites were contacted to confirm the accuracy of the compiled information. In addition, the following questions were presented to each organisation:

1. What are the primary aims and objectives of the recharge monitoring sites?
2. To what extent does recharge data inform science, policy, and management decisions?
3. How widely are datasets and information from recharge monitoring sites distributed among stakeholders including public?
4. What is the current role of CRI's and other science providers in developing the usefulness and application of the recharge monitoring?
5. Are there any emerging issues that you would like addressed using recharge monitoring sites?

Results

The results of the review will be presented in the context of land use and water resource management, application of recharge data for validation of nutrient and water budgeting models, and challenges faced un the up-scaling of datasets from the point to farm and regional scales.

FORECASTING CYCLONES FEHI, GITA AND HOLA FROM A NZ SEVERE WEATHER PERSPECTIVE

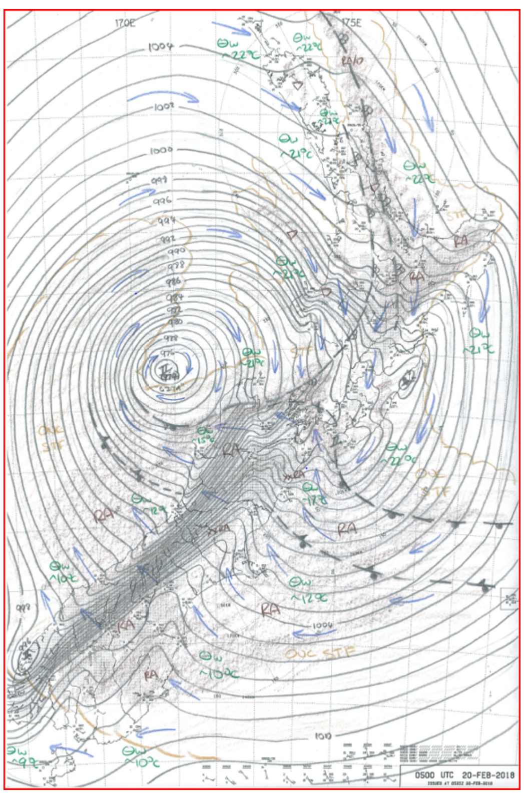
Fulong Lu[1]
[1]*MetService*

Tropical cyclones are one of the most dangerous weather hazards, and the severe gales, heavy rain and storm surges associated with them can cause loss of life and considerable damage to property and infrastructure. After tropical cyclones have transitioned into extra-tropical cyclones, they can still cause significant damage and disruption to mid-latitude countries, such as New Zealand. During the 2017-18 La Niña summer, there were three such cyclones that affected New Zealand: Fehi, Gita and Hola.

When transitioned cyclones move onto New Zealand, they often interact with mid-latitude weather systems, bringing widespread heavy rain, gale force winds and storm surges.

When forecasting the potential impacts of these systems, forecasters look at NWP model guidance combined with diagnosis of the current situation and conditions. Although remote sensing technologies and computer guidance continue to improve, accurately forecasting the tracks of tropical cyclones and extra-tropical cyclones, and their associated severe weather distributions, remain a challenge for the modern meteorologist.

In this paper, cyclones Fehi, Gita and Hola will be reviewed from the perspective of forecasting their tracks and severe weather effects on New Zealand. Up to 48 hours prior to affecting New Zealand, MetService forecast the tracks of cyclones Fehi and Gita very well, along with the associated distributions of heavy rain and gale force winds. These two systems crossed the South Island on 1 and 20 February, respectively. It was notable that, as the cyclones moved over the Tasman Sea, the sea surface temperature in that region was 6 degrees above normal.



MetService Mean Sea Level analysis (working chart, Isobars are 1hPa spacing) of ex-Cyclone Gita, 0500 UTC 20 Feb 2018

Cyclone Hola followed a more easterly track. Upper-level blocking slowed the system to the north of the North Island on 11 March, and the cyclone became cut-off aloft. This process was not well captured by NWP models. The subsequent impact on New Zealand was less than of Fehi and Gita, due to its offshore track to the northeast of the North Island.

At the conclusion of this paper, a brief comparison will be made with cyclones Ita (2014) and Bola (1988).

GROUPING AND RANKINGS IN NIWA'S CLIMATE REPORTING

Gregor Macara[1], Raghav Srinivasan[1]
[1]*Niwa*

NIWA routinely produces monthly, seasonal and annual climate summaries. These provide historical context for contemporary observations of temperature, rainfall, sunshine and max gust speed throughout the country. New Zealand's climate station network comprises hundreds of automatic and manual observation stations, some of which date back to the mid-1800s. In many locations, stations have closed, and new stations have subsequently been established. To rank contemporary climate observations (i.e. to determine their relative extremity), we need a way of using all these historic data. NIWA uses a grouping method, where observations from open and nearby closed stations are grouped together to produce historical location-relevant datasets. The process involved in this grouping and ranking methodology will be described. Also, notable observations of climate extremes over the past decade will be explored.

"LOOPED RATING" EFFECT IN WHANGANUI RIVER RATED FLOWS

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Aims

River flow ratings rely on a one-to-one relationship between river stage and flow. This assumption can be inaccurate due to various causes, including a "looped rating" due to the progression of the flood wave. . NEMS (2016) notes that "'loop' ratings are most commonly encountered in low-gradient sand-bed rivers, .. particularly if .. [the] rate of change of stage is relatively rapid during high flow events". If looped ratings are not allowed for, under-estimates of flow on the rising limb and over-estimates on the falling limb

The two flow-recording sites on the lower Whanganui River (Paetawa and Te Rewa) both exhibit looped ratings over a wide range of flows (Figure 1). The two sites together, just 2.3 km apart, provide an opportunity to test two methods for adjusting rated flows. If the methods are successful with the Whanganui data, more accurate flow ratings could be derived from adjusted gaugings, and the two methods then applied in real time, which would assist HRC in managing Whanganui flood events.

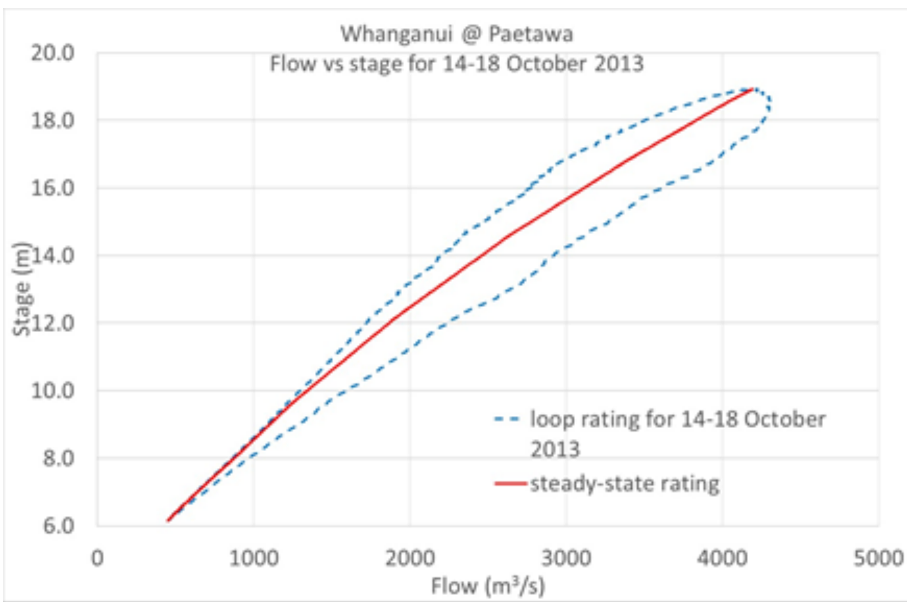

Figure 1: Looped rating (modelled) in a major event, Whanganui River

Here we describe the testing of the two methods on historical data from the two sites. To be successful, the adjustments need to give a plausible and stable flow hydrograph.

Method

A looped rating occurs when, during a flood wave, the water-depth gradient dy/dx is not negligible compared to the bed and friction slopes S_0 and S_f. The Manning equation can then be written:

$S_0 – dy/dx = S_f = v^2n^2/R^{4/3}$ Equation 1

This leads to (equation (9-88) in Henderson (1966),

$Q/Q_0 = \{1- (1/ S_0)dy/dx\}^{0.5}$ Equation 2

where Q is the true flow rate and Q_0 is the rated flow rate, applicable to steady flow. The adjustment can be made in two directions: from Q to Q_0 when processing individual gaugings to get a steady-state stage-flow rating, and from Q_0 to Q to derive the true flow from the stage record and the rating. There are long-established approaches for applying these adjustments using measured water surface slope, and NEMS (2016) refers to one of these, the Boyer method. There are two practical difficulties: First, in a non-uniform channel, dy/dx may be non-zero in steady flow. Some trial-and-error may be needed to determine the steady-state value of dy/dx. Second, the time series of dy/dx is obtained from the stage difference between the two sites, and is sensitive to noise and error in the stage measurements.

The adjustment can also be determined from a single stage record, by assuming the flood wave approximates a kinematic wave. Then:

$dy/dx = -c.dy/dt$ Equation 3

where c is the kinematic wave celerity, which can be calculated from the cross-section shape and the resistance equation. This leads to (equation 9-90, Henderson (1966)):

$Q/Q_0 = \{1- (1/ cS_0)dy/dt\}^{0.5}$ Equation 4

Equation (4) defines the looped-rating adjustment in terms of the rate of change of stage, which can be obtained from the stage record. However, the practical difficulty of noisy data applies to this method also. Henderson (1966) refers to this method as the “well-known Jones formula”.

Results

Both methods were applied to three flood events in 2013-2015, generally resulting in plausible adjustments to the rated flow records at Paetawa and Te Rewa. To achieve this, some trial-and-error was needed to determine the likely steady-state water surface slope and to filter out noise in the time series of dy/dx and dy/dt, to provide reasonably smooth hydrographs of adjusted flow.

The rated flow hydrograph is compared in Figure 8 with hydrographs adjusted by each of the two methods. Figure 8 also shows the relative magnitude of the flow adjustment, which on the rising limb briefly exceeds 20%. The single-site method (blue line in Figure 8) consistently gave a smoother hydrograph then the slope method (black line). However, the slope method could be more practicable for real-time application to the Paetawa site, because the estimate of slope, obtained from the reach upstream to Te Rewa, is obtained earlier than needed.

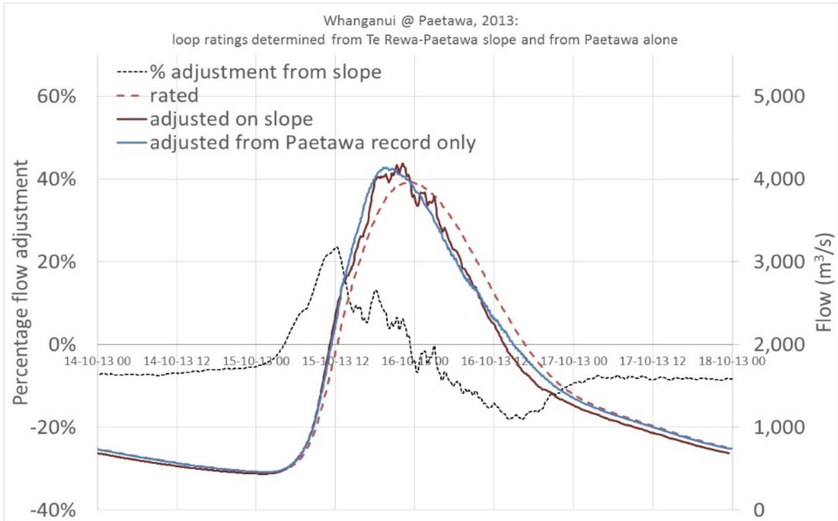

Figure 8: Calculated flow adjustment for looped rating effect, Whanganui R. @ Paetawa, 14-18 October 2013

This retrospective exercise has shown that the looped rating effect on the Whanganui River in large events is significant enough to warrant adjustment, and that either of two methods can be applied at the two flow sites. The adjustment should first be applied to individual gaugings, so that a more accurate rating curve can be derived. Our hope now is that the adjustment can then be applied to real-time data at both the two Whanganui sites, to obtain more accurate rated flows either side of the flood peak.

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CHEMICAL COMPOSITION OF ALPINE RIVERS IN THE SOUTHERN ALPS, NEW ZEALAND

Sophie Horton[1], Sarah Mager[1], Simon Cox[2]
[1]University of Otago, [2]GNS Science

Aims

The geomorphologic instability of the Southern Alps provides a distinct environment for examining chemical and physical denudation. The aim of this research was to determine the elemental partitioning of weathered material as particulate and dissolved (solute) loads; that is, we are interested in understanding whether elements are under or over represented in loads relative to catchment lithology. Secondly, we evaluated the proportion of weathered mass that is evacuated as dissolved river load to previously reported physical weathering fluxes in the Southern Alps.

Method

The particulate river bed-sand and the solute river load were sampled at 74 locations along the Southern Alps. Hydrochemical (solute) samples were analysed for anions (F^-, Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, PO_4^{3-}), cations (Na^+, K^+, Mg^{2+}, Ca^{2+} Al^{3+}, Ba^{2+}, Fe^T, Mn^{2+}, Sr^{2+} Zn^{2+}) and bulk geochemical composition (of 36 elements) of physical weathering products (bed-sand) were determined through portable X-ray fluorescence (and verified compositionally through X-ray diffraction). Predictive discriminant analysis was used to provide an end-member model to infer whether different lithological units influenced the bed-sand geochemistry and/or dissolved load hydrochemistry, and characteristic composition signatures were used to determine whether different lithological units could be detected through the river loadings.

Results

The chemistry of the particulate bed-sand and dissolved load is different; that silica oxide (53–82 wt %) and aluminium oxide (6–19 wt %) dominated the bed-sand, and calcium-bicarbonate (10–39 mg L^{-1}) dominated the dissolved load. Lithological influences on particulate geochemistry and solute hydrochemistry were classified using an end-member model of select ion concentrations, however, in some locations there is little or no coherence between chemistry composition and lithology (Fig. 1). The presence of permanent snow and ice coverage exerted a strong influence on the dissolved load composition and concentration along with other catchment characteristics, whereas lithology and soil type were the main influences on particulate bed-sand geochemistry. Areas of rapid uplift concomitant with high precipitation are recognised as fundamental drivers of high physical weathering yields; however, these drivers are also key factors in producing high chemical weathering yields; specifically along the central portion of the Southern Alps (draining to the west coast). Aggregated multi-year observations of dissolved load concentrations, when combined with modelled discharge were used to determine an annual yield of dissolved solids; which is a proxy measure of the chemical weathering yields. From the monitored catchments the chemical weathering yield was determined to range from 24 to 538 t km^{-2} a^{-1}, illustrating that there exists strong spatial variability in fluxes that are contingent on catchment characteristics. Catchment scale differences reflected specific influences of landslides, sediment stores, glaciation, vegetation, and soil development as key attenuating factors of sediment mobilisation and transport. Overall, the chemical weathering yield was estimated to equate to around 4% of the Southern Alps suspended sediment yield. Relative to global studies, these dissolved yields, particularly through the central portion of the Southern Alps, are among the highest reported globally. Although the material flux via dissolved load is relatively small compared with suspended sediment, it is an important, and often overlooked, contributor of denudation to the oceans and a small, but significant, component of the weathering of the Southern Alps.

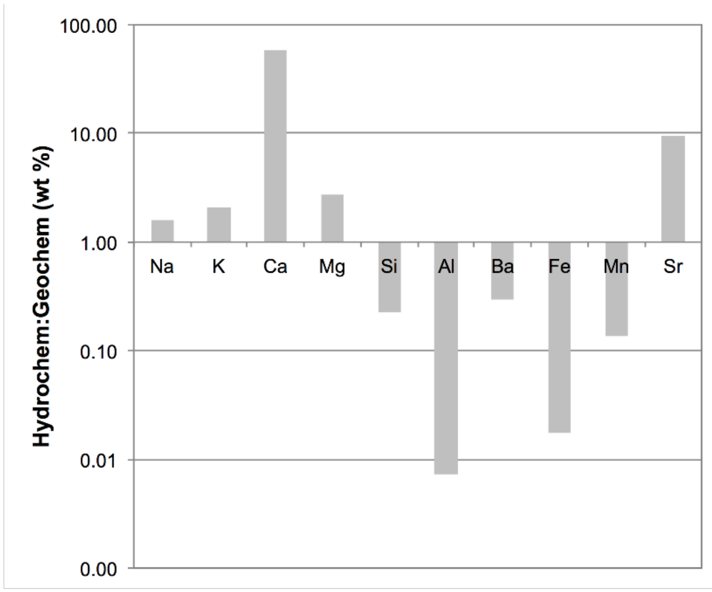

Figure 1: Normalisation diagram of the hydrochemistry concentrations to bed-sand geochemistry abundances. The elements included are common to both the dissolved load and to the particulate load (assuming a 5.3 wt % for Na_2O and 2.0 wt % for MgO) and compared as a wt % abundance. The pattern shows the higher mobility of elements in weathering and transport processes in the base cations (i.e., > 1) and Sr, and lower mobility in the transition metals and Si.

THE INFLUENCE OF STORM ORIGIN, INTENSITY, AND DURATION ON RUNOFF PROCESSES IN TUSSOCK GRASSLANDS IN EASTERN OTAGO

Sarah Mager[1], Sophie Horton[1], Josie Cairns[1], Christina Bright[1]
[1]*University of Otago*

Aims

Upland tussock grasslands are important for the provisioning of high water yields relative to other land covers and for providing a range of ecosystem services. Indigenous snow tussock grasses are adapted to higher altitude conditions including high tolerance for water-logging, snow-burial, low transpiration rates, and low requirements for water under drought conditions. The aim of this paper is to summarise recent work examining 1) the air mass origins of significant-sized precipitation events observed at the GH1 Glendhu Experiment Catchment; 2) how soil moisture responds to the onset of different scaled precipitation events; and 3) the timing and phasing of peak stream flow in relation to soil moisture to inform hillslope connectivity and runoff generation processes.

Method

The field site, GH1, in the Glendhu Experimental catchments of Eastern Otago have been the site of on-going hydrological measurements since 1980. GH1, is a small headwater catchment 2.1 km^2 in area, retained in indigenous snow tussock and retired from light ovine grazing since 2000. Gradual vegetation change in the catchment has been observed since the mid 1980s, so that as of 2016, 35% of the catchment (in the steep north facing gullies) is now covered in mānuka stands. The incursion of mānuka into the catchment has altered the catchment water balance, with a small, but notable, decline in water yield associated with increased evapotranspiration rates of the mānuka. Despite these vegetation transformations the catchment is still mostly snow tussock and provides an ideal field site to study the hydrological ecosystem services provided by indigenous grasslands, given its 35-year flow and rainfall records. Daily flow and rainfall data (1980–2017) was provided by Manaaki Whenua Landcare and analysed to identify the magnitude of the large 24, 48, and 72 hr long storms and their respective rainfall depth. These events were characterised using back-trajectory analysis to determine the main air mass source areas around New Zealand.

Soil moisture has been monitored in the middle portion of the GH1 catchment since September 2016; and provides a 2-year high-resolution record of soil moisture responses to precipitation events, as well as seasonal fluctuations. When these data are combined with stream flow records, it is used to examine how antecedent soil moisture conditions (as an antecedent precipitation index, API), as well as variations in soil moisture with depth may, in part, explain runoff generation, and hydrographic response. The soil moisture response to precipitation onset were categorised as either ‘typical’ or ‘atypical’, designated by whether the response in the shallow zone (SZ) (<0.10) occurred rapidly (i.e., <2 hours), or slowly (>6 hours), as well as examining the soil moisture response through the vertical profile.

Results

The high country of Eastern Otago is typically mild and temperate, with mean annual rainfall of 1330 mm. Rainfall is typically frequent, characterised by small events of long duration and low intensity (Fahey and Payne, 2017). Between 1980–2018 there were 8 storms where precipitation >80 mm d^{-1} (25-Oct-82, 27-Apr-06, 13-May-09, 24-Feb-12, 04-Jun-15, 23-Jan-17, 21-Jul-17, 02-Feb-18) illustrating that intense rainfall events may occur in any season. These large storms originated in the ocean sector to the SW/SSW of

New Zealand and correlate to the prevailing south and south westerly winds that dominate the local climate (Fig. 1a). The exceptions, were 1) the storm of 25-Oct-82 that generated 102 mm over 24-hours and >130 mm over 72-hrs, which originated from the N/NE; and 2) the winter storm of 21-Jul-17 that produced 86 mm over 24-hrs and originated from the N/NE, producing intense rain for 46-hrs (Fig. 1b).

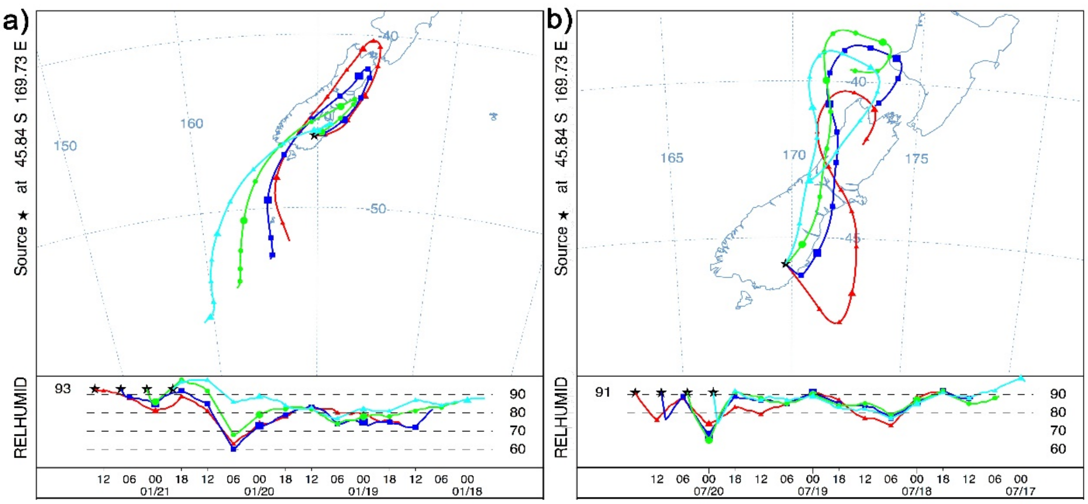

Figure 1: Back trajectory analysis of high rainfall events in Glendhu Experimental Forests for a) Typical SSW storm that occurred on 22-Jan-17, and b) N/NE storm that occurred on 21-Jul-17.

Three soil moisture states were observed, a ‘dry period’ where P ≈ E; a ‘wet period’ where P > E; and a ‘very wet period; where P >> E. Reduced summer soil moisture due to increased plant demand and evaporation from the soil surface was observed in Dec-16 and Feb-17, when P ≈ E. High winter soil moisture values are associated with reduced evaporative potential during winter (25 to 31 mm per month), but is offset by excess precipitation that recharges soil water storage reservoirs, i.e., P > E. Despite increased water demand for plant growth during spring, the period is characterised by ‘wet’ to ‘very wet’ conditions during the austral spring so that P >> E.

The Glendhu soils have a distinct two-layer soil moisture response regime. The upper layer 0–30 cm depth is dynamic, responding quickly to precipitation events. The lower layer 30–70 cm is characterised by slow, or no, response to precipitation events and is a function of the heavy clay soils. The two-layer soil mechanism suggests that the upper layer is dominated by vertical movement in water driven largely by discrete precipitation events, whereas the lower layer appears largely unresponsive to even the largest of precipitation events.

Phasing of peaks in soil moisture with event stream flow peak discharge showed three possible combinations 1) stream flow peaks after root zone soil moisture; 2) stream flow peaks concurrent with root zone soil moisture; and 3) stream flow peaks before root zone soil moisture. The most common phasing observed between soil moisture and stream flow was for discharge to peak 2–4 hours after root zone peak soil moisture was observed. The typical runoff generation pathway under these circumstances is from subsurface flow, indicated by a rapid increase in shallow zone soil moisture, and absorption of infiltrated rain into storage in the root zone.

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RESTORING THE TANIWHA SPRING: A PARTNERSHIP PROJECT BETWEEN ROTORUA LAKES COUNCIL AND NGĀTI RANGIWEWEHI

Clare Maginness[1], Louis Bidois[2], Te Rangikaheke Bidois[3], Greg Manzano[4]
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Summary

Rotorua Lakes Council (RLC) and the Ngāti Rangiwewehi Pekehaua Puna Reserve Trust (the Trust) are working in partnership to restore the Taniwha Spring water supply. This project highlights best practice principles and is relevant to other projects in New Zealand in the following areas:

- Co-management and joint resource consenting
- Challenges of restoring an operational spring water supply
- Principles of kaitiaki flow (cultural limit setting)

Cultural significance and history

The springs that feed the Awahou Stream north-west of Rotorua are precious taonga to Ngāti Rangiwewehi, both as the home of the great taniwha Pekehaua and as a water resource. According to Ngāti Rangiwewehi kaumatua, 'life springs forth for the tribe' through the river that emerges from the largest spring known as Te Waro Uri ('the dark chasm'). In 1966, Te Waro Uri site was forcibly, and without permission, taken from Ngāti Rangiwewehi for waterworks purposes under the Public Works Act 1928. A concrete Pump House was built over the top of Te Waro Uri.

In 2008, following an Environment Court appeal, RLC was granted resource consent to take water from the spring. A short consent duration of ten years was provided to allow RLC time to implement an alternative supply due to the significant adverse cultural effects.

The land containing Te Waro Uri has now been returned to the ownership of Ngāti Rangiwewehi.

In the ten years since the consent was granted, RLC and Ngāti Rangiwewehi have worked together and entered into a Co-Management Agreement. This was a major milestone and signifies a common intention to work in partnership to apply for a joint resource consent to continue supplying water for public supply from Te Waro Uri. A fundamental inclusion in the Agreement is the relocation of the existing Pump House and restoration of Te Waro Uri and the water supply site.

Replacement consent application

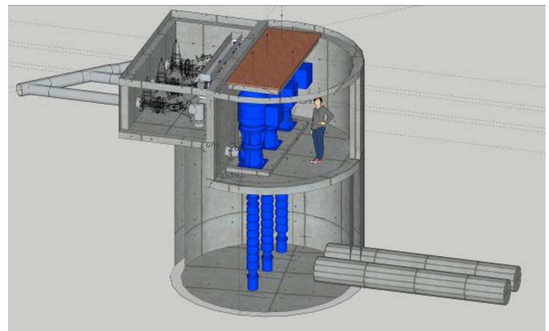
Consistent with the spirit and intent of the Co-Management Agreement, a joint application has been made by the Trust and RLC to replace the existing Resource Consent and apply for new consents for the restoration of Te Waro Uri.

The proposed restoration comprises:

- Removal of the existing Pump House that covers Te Waro Uri;
- Construction of a new underground Pump Station together with a new spring intake; and
- Restoration of Te Waro Uri and site landscaping within the existing water supply site.

Restoration of spring water supply

Engineering design work for the new underground Pump Station is being undertaken. Risks including the stability of the surrounding embankments and liquefaction potential are being evaluated and assessed. The design will also seek to minimise and avoid detrimental effects (both flows and water quality) on Te Waro Uri and the stream, during construction and in the longer term.



Te Waro Uri is the only drinking water supply for the RLC Western Supply Zone. It is anticipated that the water supply will need to remain fully operational during construction, subject to storage capacities and minimum shut-down periods.

A geotechnical investigation was undertaken in September 2018. This will provide geotechnical and hydrogeological information to support the design. A Water Quality Risk Management Plan was implemented during drilling to mitigate potential adverse effects on the water supply.

Assessment of Environmental Effects

An assessment of the environmental effects of the proposed activities has been undertaken including assessment against the Bay of Plenty Regional Council interim (Plan Change 9) allocation limits.

A "kaitiaki flow" limit will be agreed by Ngāti Rangiwewehi. GNS Science and Ngāti Rangiwewehi are working together on the Ka Tu Te Taniwha and Kaitiaki Flows research programmes (c. 2013 - 2018) (Lovett et al, 2016). The objective of the kaitiaki flow is to ensure that the flow in the Awahou is protected, both for the ecological requirements, and the cultural recognition of the water resource as a taonga-tuku-iho, and providing for social and economic use and development by and for Ngāti Rangiwewehi. The proposed consent will incorporate the kaitiaki flow through a consent condition.

Partnership approach

RLC and Ngāti Rangiwewehi are working as partners in a spirit of goodwill and collaboration. The team approach ensures that the mauri of Te Waro Uri and the wider Awahou catchment can be restored while ensuring that the public water supply from the spring can continue into the future, thus providing significant benefits for future generations.

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A QUANTITATIVE ANALYSIS OF AUCKLAND'S ATMOSPHERIC BOUNDARY LAYER IN RELATION TO BROWN HAZE

Hannah Marley[1], Dr Kim Dirks[1], Dr Lena Weissert[1], Dr Nick Talbot[2], Dr Jennifer Salmond[1]
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Aims

A brown air pollution haze that forms over Auckland City on occasional winter mornings has been found to be associated with a significant increase in hospital admissions (Dirks et al., 2017). To better predict and prepare for these events, it is necessary to improve our understanding of the conditions under which they occur. It is widely recognised that the depth of the atmospheric boundary layer influences surface air pollution, as it controls the volume into which pollutants are emitted (Kotthaus & Grimmond, 2018; Pal et al., 2013; Wagner & Schafer, 2017). However, the interactions between the dynamic behaviour of the boundary layer and surface air pollution are complex (Kotthaus & Grimmond, 2018; Li et al. 2017). As yet, very little research has been conducted in relation to Auckland City's atmospheric boundary layer and its influence on air pollution. This study aims to address this gap by performing a quantitative analysis of the boundary layer over Central Auckland and exploring its relationship to the formation of brown haze. The results are expected to aid in a more accurate understanding and prediction of haze events.

Method

Ceilometer data were used to determine boundary layer depth over Auckland City for the winter months (May – August) of 2013, 2014, and 2015. These boundary layer depths were checked for validity using a set of criteria (presence of instrumental artefacts, weak gradients, and low cloud or rain) and the valid boundary layer depths were evaluated against those retrieved from radiosonde data. The effects of length of day, cloud type, and cloud cover on the dynamics of the boundary layer were explored. Finally, the relations between boundary layer depth and brown haze events were investigated.

Results

Provisional results show significant variability in boundary layer depth during the winter months. Figure 1 provides an example of the difference between two calm, clear days during the study period, showing the initial boundary layer depth estimates (green/yellow lines) over the ceilometer backscatter profiles for these days. While the boundary layer depth on 21 July 2015 is estimated to be higher than 500 m during most of the day and reaching above 1000 m in the afternoon (Figure 1a), the boundary layer depth on 14 May 2013 remains under 250 m all day (Figure 1b). Haze days were associated with the development of shallow boundary layers (e.g. a moderate haze event was observed on 14 May 2013, Figure 1b), although very shallow boundary layers (less than 150 m above the ceilometer location) could not always be detected by the ceilometer.

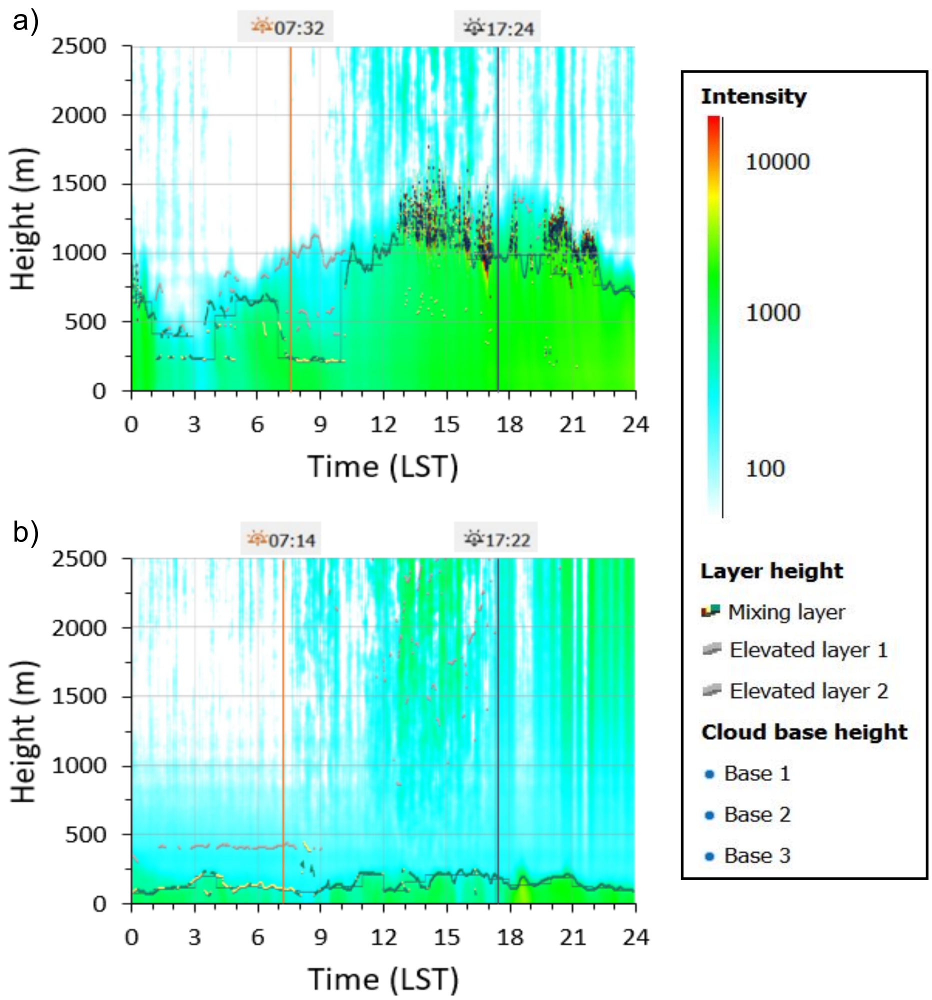

Figure 1: Twenty-four hour ceilometer backscatter profiles for: a) a clear day with no haze (21/07/15), and b) a clear day with moderate brown haze (14/05/13). Colours in the intensity legend indicate the intensity of the ceilometer backscatter signal in units of 10^{-9} m^{-1} sr^{-1}. Initial boundary layer depth estimates are shown as green/yellow lines, estimated elevated layers as grey lines, and cloud base height in blue, however boundary layer depths are subsequently checked for quality. Height is in metres above the ceilometer location (located on the roof of a six-story building in Central Auckland).

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KM-SCALE NUMERICAL WEATHER PREDICTION AND ENSEMBLE METHODS – PROBLEMS, SOLUTIONS, EXAMPLES AND FUTURE PROSPECTS

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Numerical Prediction is an integral part of earth system science. The accuracy of earth system models has gradually improved over the last 30 years, through resolution increase, coupling of different components of the earth system, improvements in data assimilation and physical parameterisations, and refined numerical methods.
Global Numerical Weather Prediction (NWP) models already have horizontal resolutions close to 10 km. Meanwhile, operational limited area models (LAMs) have reached resolutions of 1 to 4 km and sub-km scale LAMs are being tested for operational implementation. Global NWP models with resolutions of 1-10 km face complex problems, since they are running in the so-called 'convective grey-zone'. Very high-resolution LAMs with resolutions <1 km are generally regarded as being able to resolve convection explicitly, but latest research suggests that, even at those scales, models struggle to accurately simulate the spatial and temporal characteristics of convection.
In a changing climate, with ever improving earth system models, increasing amounts of data and more sophisticated automated systems to interpret the available data, the role of the human forecaster is likely to change fundamentally in the next decade or so.
This talk will provide an overview of leading-edge global and limited area NWP, and then address the following key points:
• the problems and solutions of NWP running in the convective grey zone,
• the need for ensemble techniques at resolutions of 1 km or less, and
• the future role of the human forecaster.

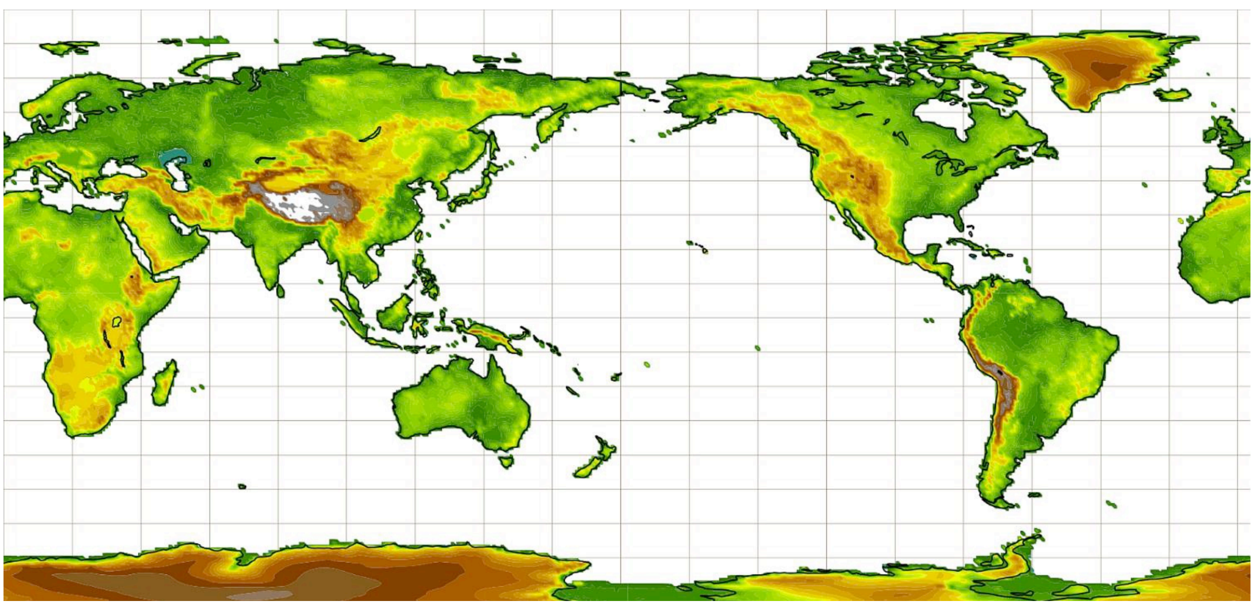

Figure 1: ECMWF Integrated Forecast System 9-km horizontal resolution model orography

References:
Will be provided before the conference.

MEASURING ACTUAL DENITRIFICATION TO UNDERSTAND NITROGEN LOADS THROUGH AQUIFERS

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Aims

Denitrification is a natural process by which dissolved nitrate is eventually reduced to nitrogen gas (N_2). However, the extent of denitrification occurring within New Zealand's groundwater systems is largely unknown. Much emphasis has been placed on identifying where optimal redox conditions are present to allow for the facilitation of denitrification[4].

Unfortunately, assessment of the redox status of the groundwater only suggests whether denitrification may be possible in an aquifer, not whether it has actually occurred[1]. For example, a comparison of groundwater age versus redox status suggests that many reduced (anoxic) zones are, in effect, stagnant or very slow moving[2], and hence any potential for denitrification may have little effect on reducing nitrogen loads to receiving waters because the water does not flow through these zones.

Measurement of 'excess N_2', the product of the denitrification reaction, is the most promising method for directly measuring denitrification that has occurred in an aquifer[5,6]. All groundwaters contain dissolved gases derived from the atmosphere during recharge, including N_2. In addition to the dissolved atmospheric N_2, groundwaters can also contain excess N_2 that has accumulated from denitrification reactions. Measurement of a third gas, neon (Ne), can give the recharge temperature and excess air component by comparing the ratio of Ar and Ne dissolved in the groundwater. This enables differentiating the excess N_2 produced via denitrification reactions from atmospherically derived dissolved N_2 (Figure 1).

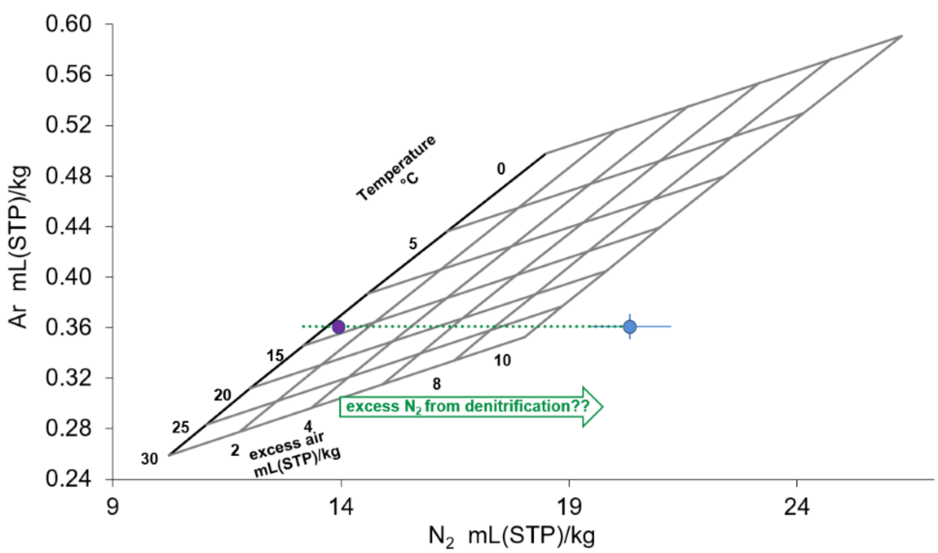

Figure 1: Example of initial contribution of N_2 (purple) calculated using the Ar Ne relationship and the total measured N_2 (blue) in a groundwater sample. The difference between the two N_2 concentrations is the contribution of N_2 from denitrification.

The aim of this study was to validates a method for identification of denitrification in an aquifer and quantification of the extent of any denitrification that actually has taken place.

Method

To validate the use of applying the Ne technique for measuring denitrification in groundwater systems, groundwater samples for Ne were collected from 27 piezometers in the Waikato, Canterbury and Horizons Region following the method described in Martindale et al. (2018)[3]. Many of the piezometers were sampled in pairs, where one piezometer was closely located next to the other but went to different depths. Other proxies for measuring denitrification, or for measuring that there is potential for denitrification to occur, were sampled in conjunction with the Ne samples. In the Canterbury Region these proxies included dissolved oxygen, $\delta^{15}N$ and chemistry. In the Horizons and Waikato Region in addition to $\delta^{15}N$ and chemistry, samples were collected for DNA analysis for the abundance of the *nirS*, *nirK* and *nosZ* genes. Additionally, Child's tests were carried out at the Waikato Region sampling sites. Age tracers, including tritium, CFC and SF_6 samples were also collected from some of the piezometers.

Results

Of the 27 sites sampled, 19 had N_2 in excess above the range of uncertainty. (eg. Figure 2). Of the 19 sites identified as having accumulated the product of active denitrification, 12 were highly anoxic. This is not unexpected. However, 5 of the sites had dissolved oxygen between 2.5 mg L^{-1} and 5.79 mg L^{-1}, indicating that complex flow pathways between the oxic and anoxic zones in the aquifer or in the well exist. Age tracers from the paired piezometers confirm this with groundwater ages differing between piezometers with depths varying by less than a metre.

The other proxies for identifying denitrification including $\delta^{15}N$ isotopic ratios, DNA analysis, chemistry and Child's test support the findings of the simultaneous measurement of Ne, Ar and N_2.

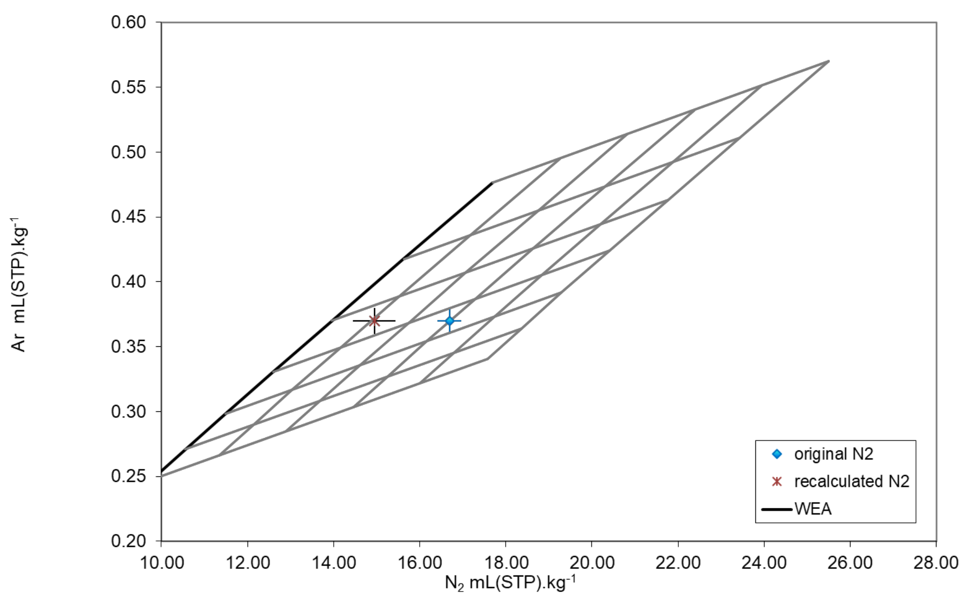

Figure 2: Initial contribution of N_2 (red), from 72_4970 in the Waikato Region, calculated using the Ar Ne relationship and the total measured N_2 (blue) in a groundwater sample.

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USING ECOLOGICAL INFRASTRUCTURE TO REDUCE FLOODING

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Aims

The purpose of this presentation is to demonstrate the potential of using ecological infrastructure solutions to reduce flood hazards for the Piako catchment in the Waikato region. Ecological or green infrastructure is broadly defined as high quality natural and semi-natural areas, which are strategically planned and placed with the aim of protecting ecosystem services. They can deliver a variety of social and environmental benefits: e.g. provision of clean water, rain water retention, better human health and well-being, flood alleviation, carbon storage etc (European Commission, 2013; da Silva and Wheeler, 2017).

Method

Using the Land Utilisation and Capability Indicator (LUCI), an ecosystem service decision support tool, baseline conditions were modelled and mapped for the catchment and then compared against historic wetland conditions (obtained by modifying land cover inputs to reflect our best understanding of historic wetland extent). Differences in flood risk and water quality are explored. Three mitigation scenarios were then developed that reflected various potentially feasible options for using different ecological infrastructure to improve ecosystem service provision. The first targeted indigenous tree planting in upload areas where significant flood benefits were expected along with at least two further environmental co-benefits. The second and third scenarios assumed the same upland tree planting had occurred, but further targeted lowland wetland restoration or establishment. Scenario 2 rewarded wetland establishment of >0.5 ha anywhere, but prioritised riparian wetland planting above off-stream planting, while Scenario 3 included a scheme to widen the river corridor via moving stopbanks, and establishing connected riparian planting. Flood risk and water quality were again modelled for these scenarios, along with flood peaks, and the differences compared to baseline conditions.

Results

All scenarios produced significant reductions in flood peaks compared to the current baseline for all return period rainfall events, although their effectiveness decreased as climate change and/or return period increased. Notably, the third scenario actually exceeded the effectiveness of the historic wetland extend scenario in protecting against 2-10 year floods, presumably mostly a consequence of the significantly increased storage within the river system and its additional capacity to attenuate (dampen) the flow peaks as they moved downwards through the catchment.

There appears to be significant scope for use of green infrastructure in the catchment to protect the catchment from “terrestrially-sourced” flooding generated in its hill country. These can be targeted to obtain additional improvements to water quality and sediment. Specifically, there are many areas where tree planting or wetland restoration in LUCI’s targeted areas for flood mitigation with associated co-benefits can be established.

CONSISTENCY OF SURFACE WINDS IN MULTIPLE REANALYSES PRODUCTS OVER THE ROSS SEA/ROSS ICE SHELF

Adrian Mcdonald[1]
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Abstract

We compare statistics of surface winds in four reanalyses, namely, the ERA--Interim, MERRA2, JRA55, and 20th Century Reanalysis V2c datasets. Direct comparison of daily scale zonal and meridional winds from these reanalyses shows that the winds in all four are highly positively correlated and that the underlying distributions are very similar over the period 1980--2000. We then examine the frequency of representative weather patterns in the five reanalyses to determine whether changes in the occurrence of these patterns is the underlying cause of differences observed. In particular, we use the Self Organizing Map technique on ERA--Interim output to identify representative wind regimes over the Ross Sea region. The frequency of occurrence of the patterns for the four different reanalyses are then derived and shown to be very similar. We then plot the frequency of occurrence as a function of time in each dataset to determine any trends. Analysis shows that all four reanalyses display similar time variations relative to the mean occurrence of that particular node in the common period (1980--2000). We also see that the JRA55 and 20th Century Reanalysis V2c datasets and the ensemble members within that reanalyses display larger variations and some trends previous to 1979. However, the level of divergence in terms of frequencies are clearly largest previous to the International Geophysical Year (1957). This strong trend after that period corroborates recent studies suggesting that previous to the assimilation of manned observations around the Antarctic continent that the 20th Century Reanalysis V2c output does not produce representative patterns of circulation over this region and that artefacts are dominant.

Method

A 4x3 self-organizing map was derived from the ERA-Interim reanalysis because it has been well validated previously. Rather than apply the SOM technique directly to all the ERA-Interim observations between 1980-2000 it was necessary to reduce the quantity of the data input into the SOM and reduce 'weather noise' in the input data. This data reduction step was completed by applying Empirical Orthogonal Function analysis to the space-time cube of the surface winds (both zonal and meridional winds) and then applying the SOM technique to the largest Principal Components (PCs) only. In particular, we truncated the set of PCs when the explained variance reached a threshold of 90% of the total variance. We used the SOMPAK system to derive the Self Organizing Map from the most important PCs over the period 1980-2000. It is worthy of note that we choose to mask out all regions with topography above 500m in our geographic domain (60-90ºS, 140-220ºE) because of the varying spatial resolution of the various reanalyses. This ensured that changes in the representation of distinct topographic features did not impact our analysis significantly. The relative frequency of occurrence of each node within the 4x3 SOM was derived by comparing daily wind fields with the SOM derived patterns using a simple Euclidean distance metric.

Initial Results

The relative frequency of occurrence (%) for each node for the four different reanalyses are displayed in Figure 1. The frequency of occurrence of the patterns for the four different reanalyses over the period 1980-2000 inclusive are extremely similar. This result implies that the general weather regimes represented in the different reanalyses have very similar frequencies of occurrence and thus that the reanalyses are very consistent over this period. Note that the ERA-Interim results and the MERRA2 results are more similar than those when comparing the ERA-Interim values with the 20CRV2c or JRA55 values.

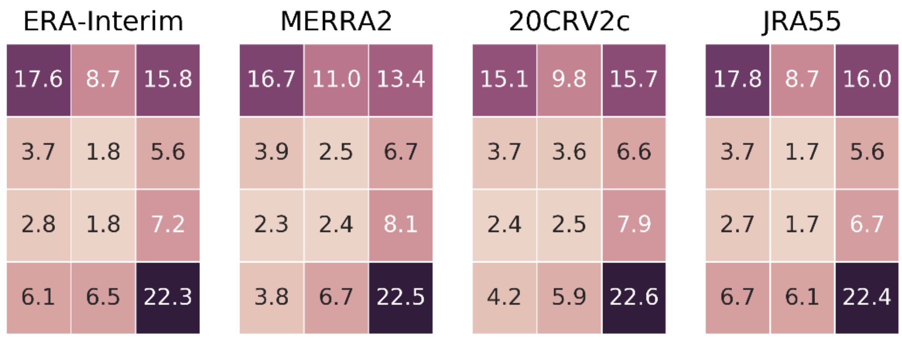

Figure 1: Relative Frequency of Occurrence of the various representative weather patterns derived from the SOM analysis over the period 1980-2000 in the various reanalyses examined.

The normalized difference in the frequency of occurrence of the various reanalyses as a function of time for all 12 nodes is displayed in Figure 2. Examination shows that all four reanalyses display similar time variations relative to the mean occurrence of that particular node in the common period (1980-2000 inclusive), though the 20CRV2c show some small differences compared to the other reanalyses. We also see that the 20th Century Reanalysis V2c dataset displays large variations and trends before 1980. However, these variations are clearly largest previous to the International Geophysical Year (1957). The small quantity of data assimilated at high Southern latitudes previous to 1957 likely means that this is an artefact rather than a true trend.

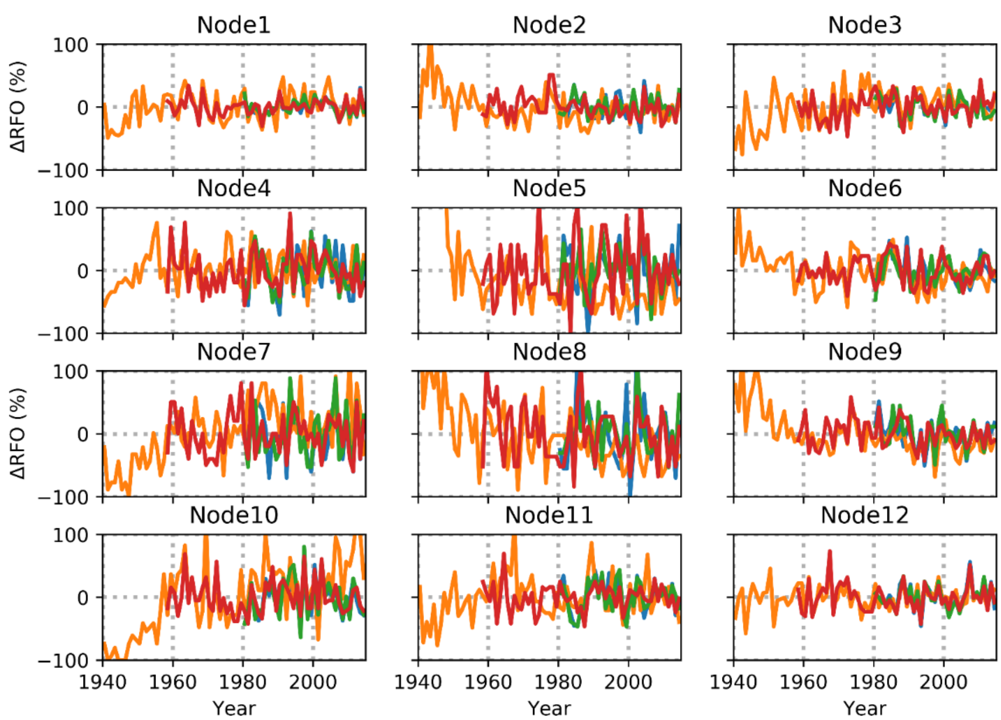

Figure 2: Normalized relative frequency of occurrence differences (relative to mean for 1980-2000) for the following reanalyses: ERA-Interim (blue line), MERRA2 (green line), 20th Century Reanalysis V2c ensemble mean (orange line), and JRA55 (red line).

THE INTERNET OF THINGS – WHAT WE DID, WHAT WORKED, AND WHAT DIDN'T

Rodney McKay[1]
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Aims

Recent developments in technologies associated with the Internet of Things (IoT) bring the opportunity for a potentially revolutionary and disruptive change to traditional data collection and telemetry systems and methods. A number of new wireless network technologies are enabling the development of the IoT, as these new technologies promise:

- Smaller electronic footprints
- Lower hardware costs
- Lower power consumption
- Lower running costs
- Simpler provisioning and network deployment

As leaders in environmental data, NIWA sought to learn about newly available IoT networks, and how they might be leveraged for better and more economic data collection. All new technologies arrive with a degree of hype and promise that must be filtered and tempered, and it was with this objective that NIWA embarked on a series of linked projects and developments in the IoT space. This presentation summarises NIWA's initial foray into IoT through a several internal and external projects.

Method

An IoT device is pretty much any device connected to an IP (Internet Protocol) network, including more traditional WiFi, cellular and satellite data connections. Among the new technologies emerging that offer significant advantage over traditional telemetry systems, NIWA tested LoRaWAN, as NZ telco Spark were looking to invest in that technology. We investigated both public and private implementations of LoRaWAN networks.

In a field situation, a sensor is connected wirelessly to a storage/application layer via access points and gateway and interface layers. The public and private networks enable this pathway from the sensor to the application layer. We examined the range, reliability, ease of set up and use, and cost of the networks.

Results

1. LoRaWAN network coverage range is not what was promised but is better than expected. While not seeing through hills and underground as was initially promised, the technology is better than line of sight, and has some tolerance of obstructions. It is also more tolerant of vegetation than 2.4GHz technologies such as WiFi and ZigBee.

- The network technology is relatively robust and reliable, although there have been issues.
- Rural deployments, especially where the terrain is hilly will remain a challenge. LoRaWAN is not a “magic bullet” that is going to solve coverage issues behind hills or up steep gullies. The sparsity of current coverage of a public network does not provide an immediate solution to this, which strengthens the need for private networks to meet specific coverage needs.
- Private networks are relatively easy to deploy and no more expensive to deploy and manage than funding a public network extension.
- As a public network expands, the footprint and service need of private networks may diminish, though how quickly and likely the public network will replace private is yet to be answered.

Our initial foray into the IoT has identified several further opportunities for development, such as strategies to improve data transfer resilience, which is a limitation in basic applications. Opportunities also exist to further streamline device provisioning and deployment processes, which are a remaining area of cost that is now proportionally higher than the hardware cost that was previously the barrier for many applications.

RIVER FLOW VS WAVES: PROCESSES CONTROLLING RIVER MOUTH LAGOON DYNAMICS

Richard Measures[1], Diedre Hart[2], Tom Cochrane[2], Murray Hicks[1]
[1]NIWA, [2]University of Canterbury

Aims

The Māori term 'hapua' has been applied scientifically to identify a type of river-mouth lagoon which form at the mouths of braided rivers and are common on the East Coast of the South Island. Hapua have a mixed sand and gravel barrier enclosing a shore-parallel lagoon, connected to the ocean via a highly-dynamic outlet channel that can rapidly change position and length or, in some cases, close completely. This study aims to better understand the interacting effects of river flow, waves, and tides on hapua morphology, with the aim of being able to predict how changes in drivers will affect hapua. For example: how will changing river flow regimes associated with water extraction influence hapua behaviour?

Method

Two time-lapse cameras, facing in opposite directions along the shoreline, were installed on top of the cliffed backshore of the Hurunui hapua in June 2015 (see Figure 1 for location and aerial photo of the hapua). The cameras record high resolution images every 15 minutes. Automated image analysis routines were developed to identify the lagoon water's edge in the images, project it onto a map view, and measure the lagoon width and location of the lagoon outlet channel (Figure 2). The image analysis data was pared with lagoon water level, river flow, sea level, and wave data to generate a concurrent two-year timeseries of the drivers and responses of river mouth morphology. This detailed timeseries was used to identify and describe the key processes influencing hapua morphology and their causes.

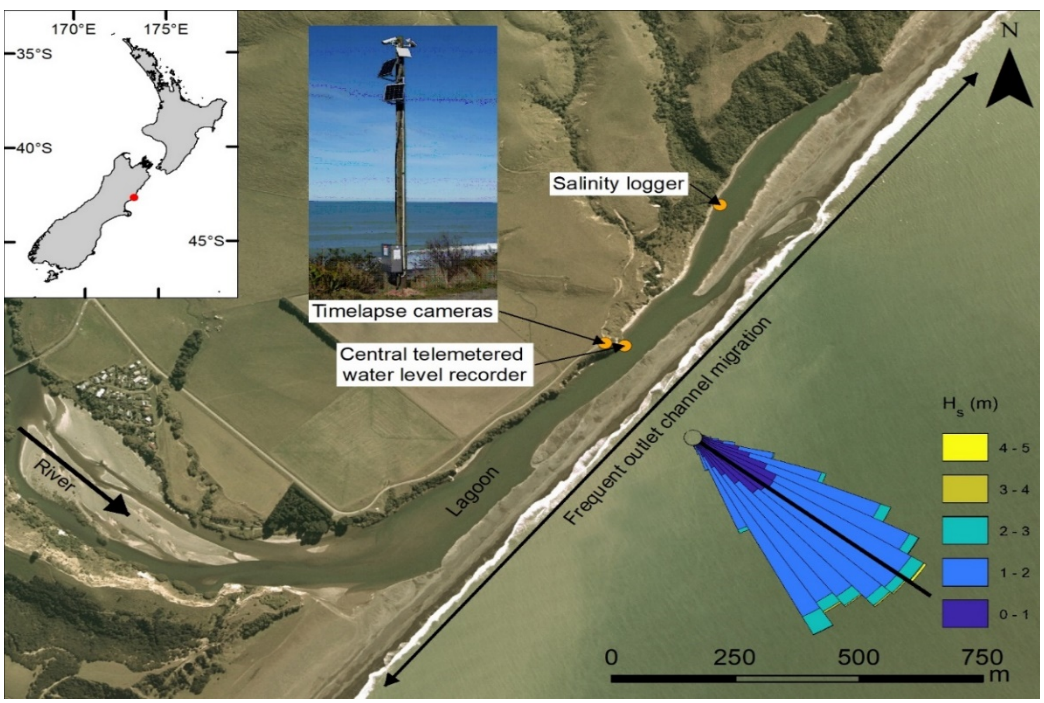

Figure 1: Hurunui hapua location, monitoring instrumentation, and wave climate. Wave rose shows the distribution of significant wave height (Hs) and direction at the 10 m depth contour outside the hapua, the black line on the wave rose indicates the shore normal direction.

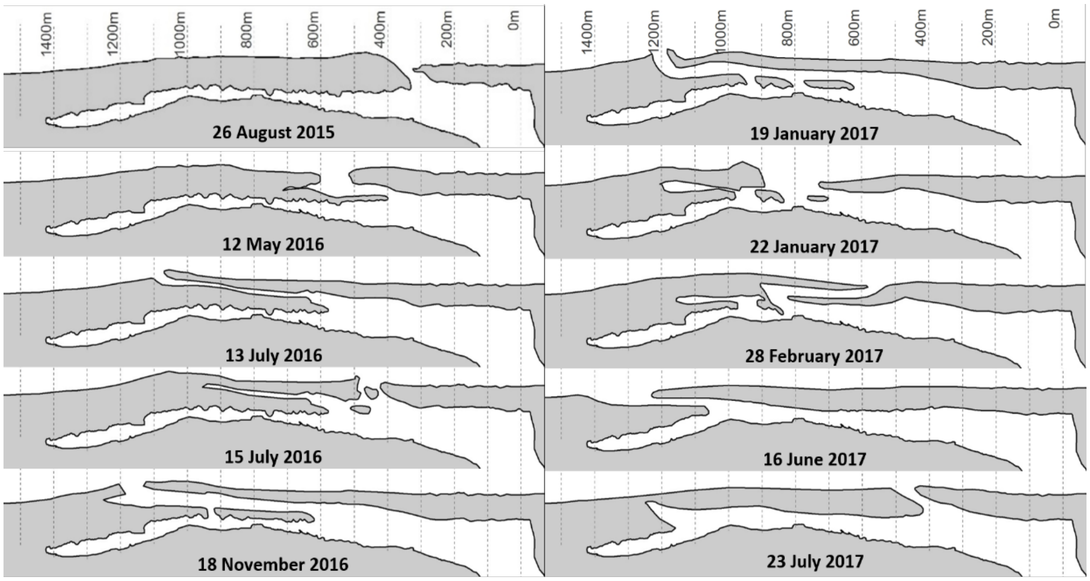

Figure 2: Timeseries of lagoon evolution extracted from imagery.

Results

Over the course of the two-year monitoring period, the outlet channel moved approximately 1 km alongshore before returning to a position nearly opposite the river. The length of the outlet channel through the barrier varied repeatedly over much shorter timeframes and reached up to 800 m several times during the monitoring period.

A new, more detailed conceptual model of hapua behaviour has been developed building on previous work by Kirk (1991), Patterson et al. (2001) and Hart (2009). New processing understanding included in the model includes:

- The likelihood of 'primary breaching' of the lagoon barrier opposite the river increases as river sediment is deposited within the lagoon, raising flood levels at the point the river enters the lagoon. This indicates that river sediment supply could have a strong influence on the frequency of primary breaching.
- Outlet channel migration maintains lagoon size by (a) resetting beach barrier width and position (clearly visible in Figure 2), and (b) offsetting the outlet channel, enabling floods to erode sediment from the backshore and bed of the lagoon. If outlet channel offsetting is reduced (for example by artificial mouth openings) then hapua length and width will reduce (due to waves washing gravel into the lagoon).
- Following a flood, onshore movement of sediment deposits is responsible for initial rapid narrowing and offsetting of the outlet channel by building a 'weak' barrier across the wide flood outlet channel. Under this condition the outlet channel experiences very rapid elongation but is frequently truncated by wave overtopping or small flow variations. Weak barriers can persist for weeks to months until wave overtopping builds a 'strong' barrier which experiences slower but more long lasting outlet channel migration, with less frequent truncation.

During the next stage of the study a physically based model of hapua behaviour is being developed which will be validated using the monitoring data from the Hurunui. The model will be used to test hapua responses to changing river flow regime, sea level and wave climate.

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DETERMINING GROUNDWATER FLOW PATHS AND VELOCITIES USING ELECTRICAL RESISTIVITY TOMOGRAPHY IN CONJUNCTION WITH SALT TRACER INJECTION

Richard Mellis[1], Lee Burbery[2], Phillip Abraham[2]

[1]Southern Geophysical, [2]ESR (Institute of Environmental Science and Research)

Background and Aims

Hydrogeophysics is an interdisciplinary field that focuses on developing an improved understanding of hydrological processes through geophysical observations. Ground penetrating radar (GPR) and electrical resistivity tomography (ERT) are two non-invasive geophysical field methods that are increasingly being used to examine groundwater systems in New Zealand (NZ), mainly in the role of mapping the geological structure of aquifers and predicting the depth of the water table. NZ's hydrogeological landscape is dominated by alluvial gravel aquifers that are inherently heterogeneous and demonstrate a dual permeability characteristic. Following their study of connectivity of open framework gravel facies in such an aquifer on the Canterbury Plains, Burbery et al (2016) proposed time-lapse geophysical methods should be explored as a practical tool for furthering study of preferential flow phenomena in NZ gravel aquifer systems.

Accordingly, in this work we reveal how hydrogeophysical methods have been applied in characterising the hydrogeological setting and examining preferential flow phenomena at Silverstream Reserve in North Canterbury. A denitrifying permeable reactive barrier (PRB) is planned to be built at the site in the near future, as part of the SSIF-funded 'Enhanced Mitigation of Nitrate in Groundwater' programme led by ESR in collaboration with Lincoln Agritech Ltd, Aqualinc Research Ltd, Southern Geophysical, and University of Canterbury. The objective of the hydrogeophysical study was to identify the groundwater flow direction; locate any preferential groundwater flow paths, and determine groundwater velocities along these paths, in the vicinity of where the PRB is planned. Time-lapse ERT was used for this purpose, carried out in conjunction with a salt tracer test. Such hydrogeological information is required to inform design of the PRB and geophysics provides a means by which it could be obtained in a cost-effective manner and without the use of large scale invasive testing.

Method

Subsurface conditions at the 35 ha reserve site were initially examined using GPR, followed by conventional borehole drilling (initially 7 bores drilled to 6 m depth) and installation of monitoring wells (who's function was also as a tracer injection wells). From this the geological profile of the shallow alluvial aquifer was logged, the piezometric gradient was measured and a general groundwater flow direction determined. This prior knowledge of groundwater flow direction informed positioning of the surface-mounted electrode lines required for the ERT survey. The ERT testing was undertaken in two stages.

The first stage of testing was designed to locate any preferential flow paths within the survey area. Three survey lines were set up 0.5 m, 5 m and 15 m hydraulically-down gradient of the injection (test) well. Lines consisted of 64 electrodes, set at 1 m spacing and aligned perpendicular to the presumed direction of flow. After background resistivity measurements had been made, 9000 L of saline solution was injected down the test well over a period of 48 hours. Resistivity measurements were made across the survey lines during and after completion of the salt tracer injection. Mathematical inversion of the ERT data yielded resistivity images of where the salt tracer migrated beneath the survey lines, from which precise groundwater direction was determined. With the groundwater flow paths identified, stage two of testing was designed to determine groundwater velocity. This involved repeating the salt tracer injection test, but this time making more frequent resistivity measurements between fewer electrodes (i.e. along a shorter survey line) spanning directly over the top of where we knew the salt tracer would migrate. Only one survey line – that nearest to (5.5 m down gradient of) the test well – was operated in this case

Results

The results from the first ERT test showed a distinct lower resistance zone where the saline water was concentrated. This was interpreted as a high transmission zone associated with a highly permeable facies in the alluvial sand and gravel underlying the site and which facilitated preferential groundwater flow (Figure 1). By reducing the size of the resistivity array in stage 2 we were able to focus measurement over the flowpath of interest and reduce the time of surveying from two hours per survey to 20 minutes. This faster measurement time enabled the rapid series of resistivity surveys in stage two to capture the saline water in closer to real time as it migrated through the aquifer. From this we were able to estimate groundwater velocity at the precise location the PRB will be sited. The ERT results showed a gradual reduction in resistance within the pathway from approximately 45 minutes after injection to full saturation after approximately 3 hours and 45 minutes (Figure 2). We assumed a value of half the maximum concentration (or half the reduction in resistance) would mark the arrival of the advective front of the salt plume as it migrated under the survey. With this assumption we deduced it took 2 hours and 45 minutes for the plume to travel 5.5 m. From this, we predict a horizontal groundwater velocity of 48 m/day within the preferential flow path that passes through where the denitrifying PRB will be emplaced.

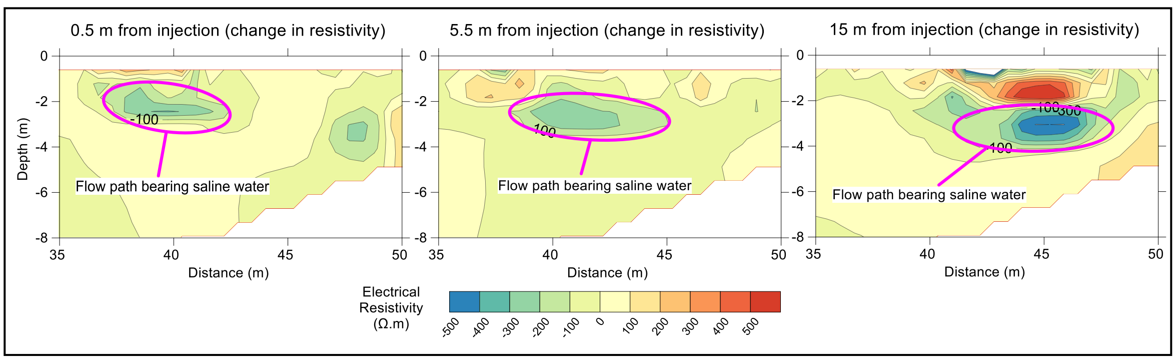

Figure 1: Locating the groundwater flow path: Change in electrical resistance of three parallel resistivity survey lines from background levels after 48 hours of saline water injection.

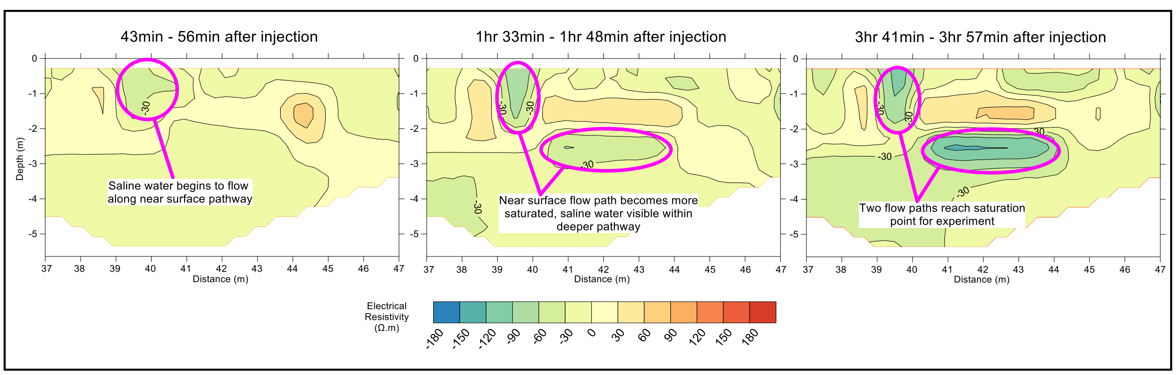

Figure 2: Velocity data collection: Change in electrical resistance through time of one resistivity survey line from background levels during saline water injection.

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ASSESSING THE IMPACT OF OVER-ALLOCATION ON THE FLOW REGIME: RAPARAPAWAI STREAM CASE STUDY

Raelene Mercer[1], Brent Watson[1], Amy Lennard[1]

[1]*Horizons Regional Council*

Background

The Raparapawai is a small sub-catchment (73.4 km^2) in the upper Manawatu catchment. Historically, allocation levels in the Raparapawai have been high relative to the size of the stream with almost one hundred percent of the water being allocated for dairy farming stockwater and irrigation.

During the development of the Horizons Regional Plan (One Plan) allocation framework it became clear that the sustainable core allocation limit was actually much lower than the current allocation level. Setting the One Plan allocation limit at 1,296 m^3/day rendered the catchment "over-allocated" with the then allocation totalling 175% of the One Plan limit.

Over the last 10 years, Horizons has worked with the irrigation consent holders to identify alternatives to taking water from the Raparapawai Stream. Recent consenting processes have required two of the three irrigators to move their takes out of the Raparapawai Stream and into the main stem of the Manawatu River, some 2km away. This move will see the Raparapawai Stream allocation back within the core allocation limit for the first time, albeit it at significant expense to the consent holders. Ultimately it is believed that the move will give all three abstractors increased surety of supply.

Aims

This piece of work seeks to quantify the degree of change in the hydrological regime of the Raparapawai Stream pre and post a change in the allocation status of the stream, as the consenting regime is adjusted to manage the stream within its previously exceeded core allocation limit.

Specifically, the investigation aims to assess how certain ecologically significant features of the flow regime could be expected to change with a reduction in the total abstracted volume, and how these changes could impact on habitat availability and primary production of the Raparapawai Stream.

Method

The Raparapawai Stream lends itself to this type of assessment, not only because of its history of over-allocation and abstraction, but because there were only 3 main abstractors operating from the stream, all of whom provided near real-time water use data via Horizons' telemetered water metering programme.

Flow time-series data are also available for a site downstream of all abstractions from December 2002, approximately 16 years of record.

The water abstraction data and downstream flow records were used to generate a synthetic naturalised flow record, and a record synthesising flow under the current allocation regime prescribed by Horizons' Regional Plan allocation framework.

At the time of writing, this work is still in progress. The intention from here is to undertake analysis to determine the degree of departure from the synthesised “natural” flow regime that would have existed under: a) the previous over-allocated status of the catchment, and; b) under the current regional allocation framework.

The plan is to use the public domain Indicators of Hydrologic Alteration (Version 7.1) software (IHA) (The Nature Conservancy, 2009).

This software allows the comparison of flow records between two distinct time periods (i.e. before and after a step-change), or alternatively, two flow datasets can be compared.

IHA calculates a total of 67 statistical parameters that are known to be ecologically relevant, including frequency and duration of extremes, timing of events, rates of change, annual minima and maxima. It may be that only some of these parameters are relevant to the Raparapawai Stream, but it is anticipated that the exercise will provide some useful measure of the relative impact of the regimes analysed.

Results

Anticipated results include answers to some or all of the following key questions:

- What does the naturalised flow regime look like for the Raparapawai Stream over the available flow record?
- How did the abstraction from the Raparapawai Stream that occurred between 2006 and 2018 change the natural flow regime?
- Which statistical parameters were altered to the greatest degree?
- Are any of the flow regime changes likely to have impacted or influenced the ecological character of the stream, and to what degree?
- How will the currently consented abstraction (within the core allocation limit, but with a lower minimum flow) cause the flow characteristics to differ from the natural regime? From the previous over-allocated scenario?

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THE PROSPECTS FOR PRODUCING A RELIABLE FLOOD FORECAST: A RAINFALL-RUNOFF INVESTIGATION

Dr. Magdy Mohssen[1]
[1]*Otago Regional Council*

Aims

Flood forecasting is quite important for flood warning. However, the ability to produce a reliable flood forecasting model is dependent on the available data/information. This study presents a simple data analysis method using existing rainfall and flow data to test the reliability of any potential flood forecasting model before going through the full modelling process.

Method

The main assumption driving this method is that total observed rainfall and total runoff (effective rainfall) for all events should exhibit a well-defined relationship in order to produce a reliable forecasting model, otherwise it is a strong indication that it will be difficult to achieve a reliable flood forecast model.

Available hourly rainfall and flow data for significant flow events for the Silver Stream at Gordon road (Mosgiel, Otago) and the Manuherikia River at Ophir (Otago) have been analyzed to estimate the corresponding runoff volumes for each event. The corresponding average areal effective rainfall over the catchment has also been estimated for each event. Nineteen significant events for the Silver Stream catchment, with peak flows exceeding 40 m^3/s, were selected along with their corresponding rainfalls at four gauging sites (Sullivans dam, Pine Hill, Swampy Spur and Taieri Depot) for the rainfall-runoff analysis. For the Manuherikia River catchment, twenty significant events with peak flows exceeding 100 m^3/s were selected, along with their corresponding rainfalls at four gauging sites (Dunstan Peaks, Tunnel Hill, Hills Creek and Merino ridges). Baseflow was estimated and separated so that runoff from each event was calculated. A multiple regression was carried out to estimate the weights for rainfall sites which would produce the best fit between observed rainfalls at these sites and their corresponding estimated runoffs.

Results

Figures 1 and 2 show the relationship between the estimated runoffs and their corresponding areal rainfalls for the Silver Stream and the Manuherikia River, respectively.

The relationship between the estimated areal rainfalls for Silver Stream and their corresponding effective rainfalls (or total runoff) show a strong linear relationship. This indicates that observed rainfalls at available gauging sites properly represent rainfall over the whole catchment, and in turn can be used to produce a reliable flood forecast model. On the other hand, this relationship is very poor for the Manuherikia River which, in turn, is expected to be reflected in any flood forecast model developed for this catchment which is dependent on the data of these rainfall sites.

This simple analysis can be used to identify whether the existing rainfall sites are representative enough of the catchment rain to produce a reliable flood forecasting model or if more rainfall sites or rain radar data are needed for the catchment. Moreover, this analysis would give an idea about the reliability of any potential flood forecast model before going through the full modelling process.

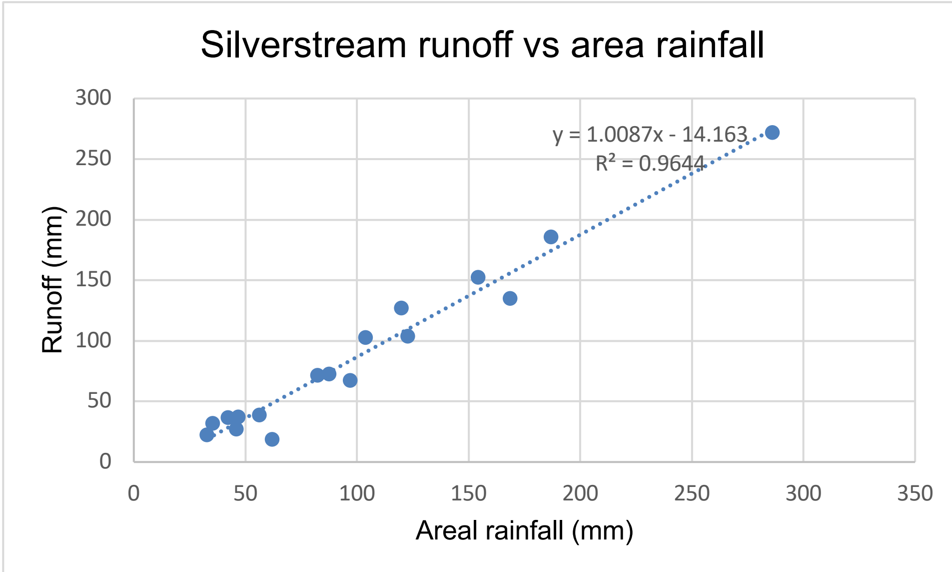


Figure 1: Silverstream runoff vs areal rainfall

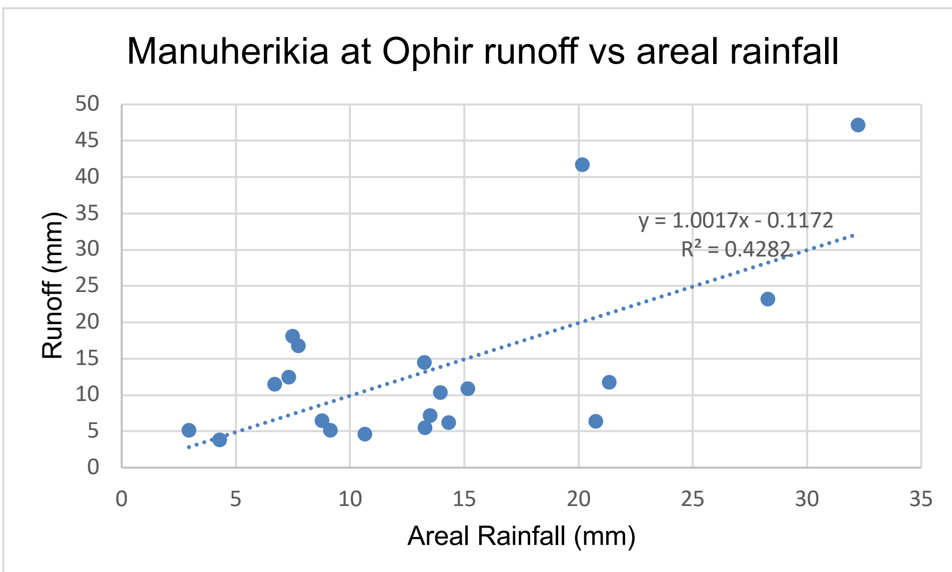


Figure 2: Manuherikia at Ophir runoff vs areal rainfall

ASSESSING DRIVERS OF ENSEMBLE FLOOD FORECASTING UNCERTAINTIES DURING EX-CYCLONE DEBBIE

Kelsey Montgomery[1], Celine Cattoen[1], Stuart Moore[2], Trevor Carey-Smith[2]
[1]NIWA, [2]NIWA

Aims

Flood forecasting is a vital component of emergency preparedness strategies, providing early warnings for adequate preparation time and reducing the impacts of flooding (Bevere et al., 2012, Kunreuther et al., 2011). Forecasting flood risk associated with extreme events is challenging due to large uncertainties associated with initial conditions, model configuration, and model parameters. Therefore, ensemble-based predictions are increasingly used to minimise the effects of these uncertainties and instead generate probabilistic flood forecasts (Cloke and Pappenberger, 2009).

This study is a first step towards a methodology to produce ensemble flood forecasts with improved uncertainty representation. In this phase of the project, we assess key drivers of uncertainty in flood predictions forced with convective-permitting ensemble weather forecasts by conducting a hindcast analysis during ex-cyclone Debbie when, April 2017, the Rangitaiki River stop banks breached in Edgecumbe. We investigate the impact of perturbed physics weather ensembles based on different weather initial conditions and model configurations, and statistically perturbed precipitation scenarios on the flow forecasts. In addition, we compare the effect of flow data initial conditions and flow data assimilation on the hydrological model.

Method

Meteorological forecasts from NIWA's New Zealand Convective-Scale Model (NZCSM) were coupled to the hydrological model, TopNet, to generate ensemble flow forecasts. The TopNet distributed hydrological model (Clark et al., 2008) was developed at NIWA and is based on TOPMODEL processes (Beven et al., 1995) to model the physical processes over different sub-catchments, including a streamflow routing component from each sub-catchment to the basin outlet (Mendoza et al., 2012).

The hydrological model was initialized using the gridded Virtual Climate Station Network (VCSN) (Tait et al., 2006). VCSN interpolates observed meteorological values onto a grid covering New Zealand at a 5km spatial resolution.

NZCSM is a local implementation of the UK Met Office Unified Model, covering New Zealand with a grid resolution of 1.5km allowing for a more accurate representation of the topography and convective rainfall processes. NZCSM forecasts from six different model configurations and four different initial conditions (lagged ensemble) were used to force the hydrological model producing perturbed physics ensembles for the Rangitaiki River. The NZCSM configurations used in this experiment were different convective-scale science configurations of the Unified Model that were used in three consecutive operational suites (ukvos36, ukvos37 and ukvos38) at the UK Met Office. They differ in their handling of turbulent mixing schemes, ice microphysics settings and, in the case of ukvos38, the application of stochastic perturbations to both theta and moisture fields in the boundary layer. A second level of model comparison was achieved by driving NZCSM with lateral boundary conditions obtained directly from a 17km resolution global model and from an intermediate 12km resolution limited area model.

For each weather forecast ensemble member, we applied a statistical perturbation to generate a 50-member statistical flow ensemble to assess the uncertainty obtained from running precipitation scenarios based on a given rainfall forecast.

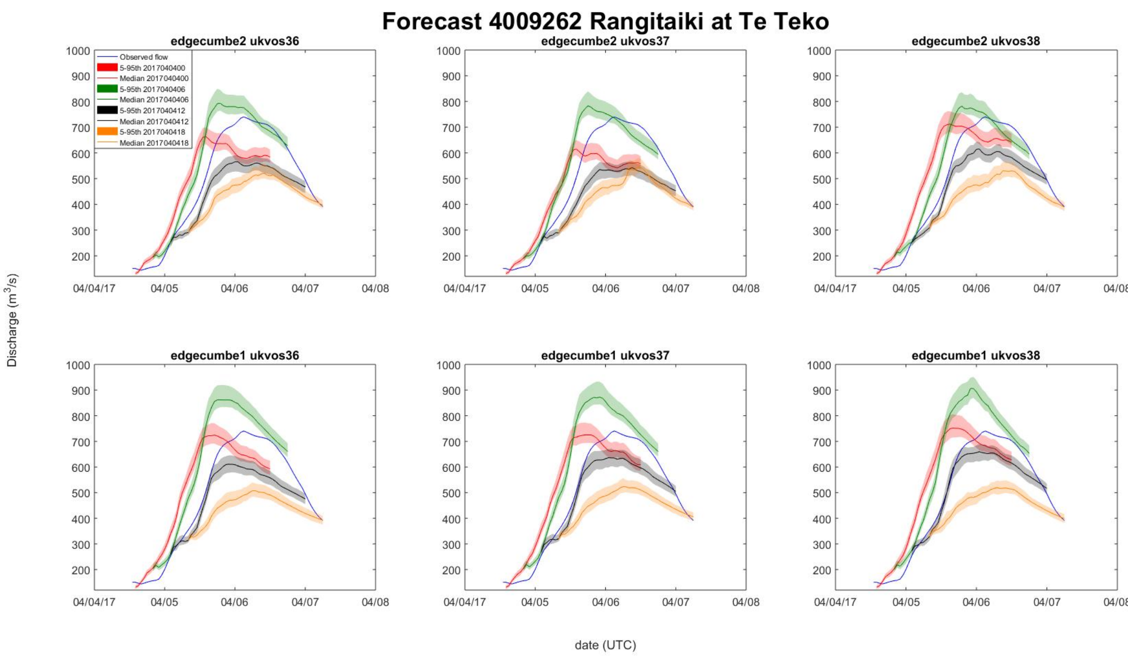
Four sub-basins within the Rangitaiki River of different size and orographic characteristics (e.g. plains in Murupara and mountain ranges in Waihua Gorge) were assessed. We were particularly interested in the steep topography in the eastern portion of the catchment near Waihua Gorge to test the convective-permitting aspect of the meteorological models. We also evaluated the impact of data assimilation on the peak flow for each model configuration.

Results

Preliminary results in Figure 1 show the largest flow forecast uncertainty in order of importance stems from the physical weather initial conditions (lagged ensemble), the hydrological model initial conditions (not shown), initial and lateral boundary conditions (Figure 1, top vs. bottom subplots), flow data assimilation (not shown), weather model configurations, and finally, with the least impact, the statistical perturbation applied to each rainfall forecast.

Future work will include assessing larger weather ensembles (16-18 members) with different initial conditions at the same issue time and at different weather model resolution, for example 4 km versus 1.5 km with a smaller set of ensemble members due to computational constraints. These next steps will inform the long-term goal of producing a methodology to generate ensemble flood forecasts with more accurate uncertainty representation.

Figure 1: Forecast and observed flow at Rangitaiki at Te Teko for each of the six different model configurations. Top row is based on the global model while the bottom row is based on intermediate 12km limited area model.



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A CONVECTIVE-SCALE REANALYSIS FOR NEW ZEALAND

Stuart Moore[1], Trevor Carey-Smith[1], Chun-Hsu Su[2], Nathan Eizenberg[2]
[1]NIWA, [2]Bureau of Meteorology

Aims

Consideration of extreme weather events such as convective cells and thunderstorms, frontal systems, cut off lows and downslope wind storms and their related impacts, such as flooding, is very important when it comes to characterising the past climate and providing a baseline for understanding what might be different in the future under the auspices of climate change.

Recent advances in both the science of Numerical Weather Prediction (NWP) and in the computational hardware available has meant reanalysis projects have been initiated at increasingly higher horizontal resolutions that can begin to explicitly resolve the processes involved in these types of weather events. Some recent examples are the UERRA (Borsche et al., 2015 and references therein) and BARRA (Jakob et al., 2017) regional reanalysis projects, covering western Europe and Australia respectively.

In this presentation, we describe the beginnings of a project to generate a New Zealand focused regional reanalysis dataset.

Method

The New Zealand landscape, which varies from high snow-covered alpine mountains to lush temperate rain forests at sea-level and everything in between, often over very short distances, provides a stern challenge for NWP. NIWA has, since late 2013, been running a NWP model, called the New Zealand Convective-Scale Model (NZCSM) with a horizontal resolution of 1.5 km that is a local configuration of the Met Office Unified Model (Davies et al. 2005). In this time, New Zealand has been subject to a number of extreme weather events, including the passage of many damage-causing ex-Tropical Cyclones and shown itself to be more than capable of forecasting well such events. Indeed, while some biases still exist, it has been shown to be a valuable improvement over NIWA's mesoscale 12 km resolution New Zealand Limited Area Model (NZLAM). For example, Figure 9 compares the total annual precipitation as predicted by NZLAM and NZCSM against NIWA's observation-based Virtual Climate Station Network (VCSN) (Tait et al. 2006) product. It is clear how the landscape resolving nature of the NZCSM, compared to NZLAM, allows it to capture the higher precipitation totals around the high-altitude areas of the North Island and has increased spatial accuracy along the Southern Alps of the South Island.

Confident that NZCSM can simulate the weather over New Zealand's complex landscape, NIWA, in collaboration with the Bureau of Meteorology, plans to generate a convective-scale (approx. 1.5 km resolution) regional reanalysis dataset that will allow the characterisation of New Zealand's historical extreme weather experienced in the years since 1979 through to the present day. Figure 2 shows the domains on which the BARRA and New Zealand regional reanalyses are being and will be produced on. In the future, forcing the same models with data from the Deep South National Science Challenge climate modelling output could allow for a first attempt at convective-scale regional climate projections over New Zealand. This information, of both past and future climate, will enable New Zealand users of the climate system to make informed decisions as to how best to prepare for and mitigate the impacts of climate change and the nature of future extreme weather hazards.

Results

This project is only now just starting. In this presentation, the challenges of convective-scale modelling over New Zealand will be discussed and the proposed modelling and reanalysis methodology to be used will be detailed with some initial results presented.

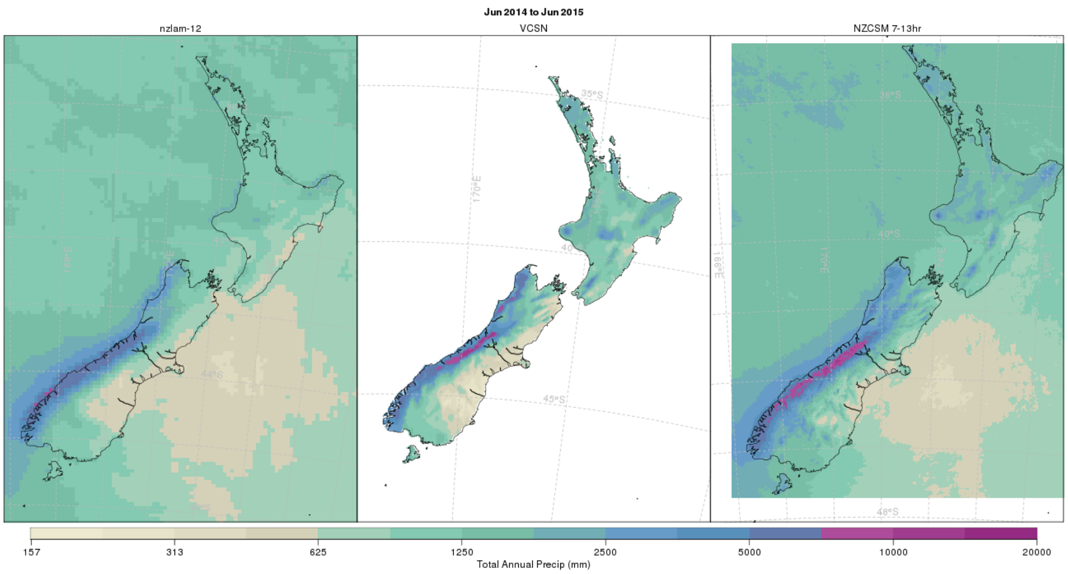

Figure 9: Comparison of NZLAM (left panel), VCSN (centre panel) and NZCSM (right panel) total annual precipitation for the period June 2014 to June 2015.

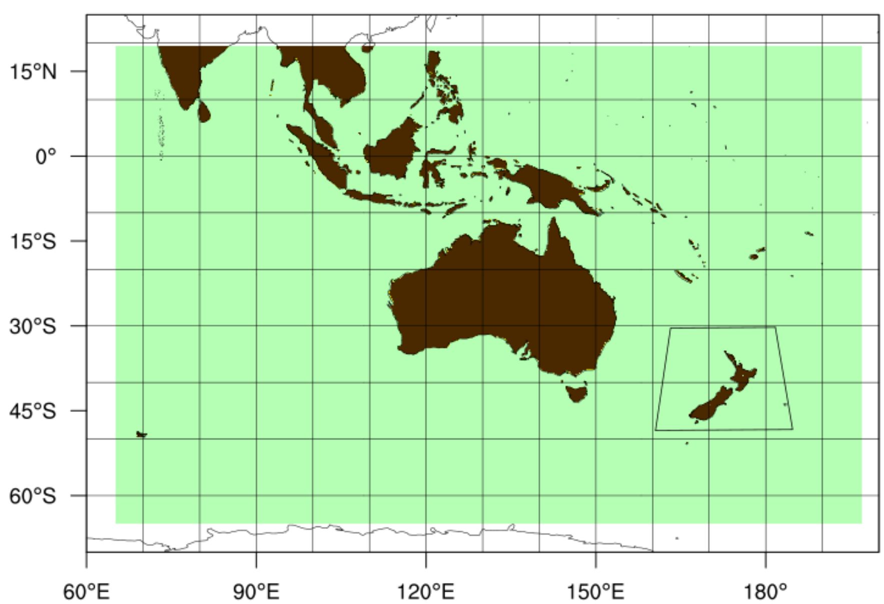

Figure 2: Map showing the domain covered by the 12 km data assimilating NWP model used in the BARRA regional reanalysis project (green shaded area) and the area over New Zealand to be covered in the New Zealand convective-scale reanalysis dataset. The 12 km model used in BARRA provides the initial and lateral boundary conditions for the 1.5 km used over New Zealand.

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EMERGING ORGANIC CONTAMINANTS IN NEW ZEALAND GROUNDWATERS: PILOT ASSESSMENT IN THE WAIKATO REGION

Magali Moreau[1], John Hadfield[2], John Hughey[2], Fiona Sanders[1], Daniel Lapworth[3], Debbie White[3], Wayne Civil[4]

[1]GNS Science, [2]Waikato Regional Council, [3]British Geological Survey, [4]National Laboratory Services

Aims

Synthetic organic compounds used for a range of purposes are a rising concern for freshwater quality, human and aquatic health. These compounds are classed as "emerging" owing to their detection using recent advances in analytical techniques. Overseas surveys have demonstrated that many emerging organic contaminants (EOCs) occur in groundwater (Lapworth et al., 2012; Lamastra et al. 2016). An increasing number of these are being restricted or banned as their associated environmental effects are characterised. In New Zealand, apart from selected agricultural pesticides, EOCs are not being measured in groundwaters. Selecting monitoring strategies of EOCs in groundwater has been identified as both a knowledge gap and a research priority regionally and nationally (Ministry of Business, Innovation, Employment, Science and Innovation. 2017). The very limited amount of existing EOC studies have a strong focus on surface waters, particularly waste-water and coastal receiving environments. This paper presents the results of the first assessment of EOC occurrence in New Zealand groundwaters and related implications for future monitoring.

Method

Samples were collected from 61 groundwater sites across the Waikato region between April and May 2018. Most of the sampled sites (84%) were randomly selected from Waikato Regional Council's State of the Environment monitoring network to encompass a range of groundwater age (sites were grouped into three categories of 1-11, 11-50 or 50-250 years mean residence time) and diverse hydrogeological settings. The survey also included targeted sites, located close to likely EOC sources (waste-water treatment plant, urban and industrial areas), and the collection of blanks and replicates for quality assurance. The samples were analysed for a broad screen of 723 EOC compounds by Liquid Chromatography / Quadrupole-Time-of-Flight Mass Spectrometry (LC/Q-TOF-MS) at National Laboratory Services, UK. Many of the screened compounds have multiple uses, so for interpretation purposes they were categorized according to published references as pesticides, pharmaceuticals, or industrial and life-style compounds.

Results

EOC or EOC degradates were detected at 91% of the SOE sites at concentrations ranging from 0.0001 to 11 ug/L with a maximum of 31 compounds at a given site (for comparison, the EU drinking-water maximum admissible value for pesticides is set at 0.1 ug/L). Multiple groups of EOC were encountered: pharmaceuticals (49 compounds), pesticides (20), industrial (10), preservatives/food additives (3) and life-style (1). Chloridazon-desphenyl-methyl (herbicide) was the most frequently detected EOC. Similar diversity and concentration range for the EOCs were observed at the targeted sites, with the addition of endocrine disruptors (1 measured compound). EOC detections occurred across all three groundwater age categories, with higher concentrations and more types of EOCs detected at sites in the youngest age category (mean residence time of 1-11 years).

Concentrations of detected compounds were comparable to those found in overseas groundwaters. Most of the detected compounds do not presently have environmental or drinking-water thresholds or guideline values. Some of the detected compounds (diclofenac, clothianidin, and imidacloprid) are currently listed by the EU as priority substances for the development of associated drinking-water standards. The large number of non-detects (81% of the analytical suite), illustrates the difficulty in pre-selecting contaminants for long-term monitoring. The list of detected compounds from this survey may be used to inform the development of analytical suites for groundwater.

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THE ONSHORE INFLUENCE OF OFFSHORE FRESH GROUNDWATER - A GLOBAL-SCALE ANALYSIS

Leanne Morgan[1]

[1]*Waterways*

Aims

This study provides the first attempt to examine the likely prevalence of situations where offshore freshwater influences onshore salinities, considering various sites from around the world.

Method

Twenty-seven confined and semi-confined coastal aquifers with plausible connections to inferred or observed offshore freshwater were considered. The study used available onshore salinities and groundwater levels, and offshore salinity knowledge, in combination with analytical modelling, to develop simplified conceptual models of the study sites. Seven different conceptual models are proposed based on the freshwater-saltwater extent and insights gained from analytical modelling. Both present-day and pre-development conditions were considered in assessing potential modern contributions to offshore fresh groundwater. The conceptual models also include interpretations of whether offshore freshwater is a significant factor influencing onshore salinities and well pumping sustainability.

Results

Onshore water levels had declined between pre-development and present-day conditions in fourteen of the fifteen regions, for which pre-development data were available. The change in steady-state freshwater extent associated with these head declines suggest a considerable reduction in offshore fresh groundwater. In all cases where adequate offshore salinity data exist, both present-day and pre-development heads are insufficient to account for the observed offshore freshwater extent. This suggests that paleo-freshwater and/or aquifer heterogeneities contribute significantly to offshore freshwater extent. Present-day heads indicate that active seawater intrusion will eventually impact onshore pumping wells at fourteen of the twenty-seven sites, while passive seawater intrusion is expected onshore in an additional ten regions. While the number of sites considered in this study is limited, the study suggests that when offshore freshwater has an onshore linkage, it is being mined either passively or actively by onshore use. Thus, offshore freshwater should be assessed in coastal water balances presuming that it serves as an existing freshwater input, rather than as a new potential freshwater resource.

For further details of this study, please refer to:

Knight AC, Werner AD, Morgan LK (2018) The onshore influence of offshore fresh groundwater, Journal of Hydrology 561: 724-736, doi:10.1016/j.jhydrol.2018.03.028

GROUNDWATER DYNAMICS IN THE COASTAL WAIRAU PLAIN AQUIFER

Uwe Morgenstern[1], Peter Davidson[2], Paul White[1], Dougal Townsend[1], Rob van der Raaij[1], Michael Stewart[3], Magali Moreau[1], Chris Daughney[1]

[1]Gns Science, [2]Marlborough District Council, [3]Aquifer Dynamics & GNS Science

Aim

Tracers methods are used to obtain a better understanding of the groundwater flow, from recharge to discharge and interaction with surface water, and hydrochemical processes in the aquifers of the Wairau Plain.

Method

Age tracers (tritium, SF_6), oxygen-18, temperature, gas tracers (Ar, N_2, CH_4, radon), and hydrochemistry were measured in ground- and surface water from about 200 sites. Age tracers with long-term time dependent tracer input concentrations in the atmosphere, or that exhibit radioactive decay, allow for groundwater dating in the age range 1-100 years. Tracing seasonal variability signals from the source through the aquifer allow for dating over shorter time scales 0-1 years.

Results

Extremely young water (<1y) was found in most of the sites within the Holocene gravel deposits, in contrast to very old water (>100y) within the Pleistocene deposits (Figure 1). Toward the coast where the aquifer becomes confined, groundwaters have intermediate ages. In the coastal area near Rarangi, a mix of old and young groundwaters occur, depending on the depth of the well and if they draw water from the deeper confined or from the shallow unconfined aquifer.

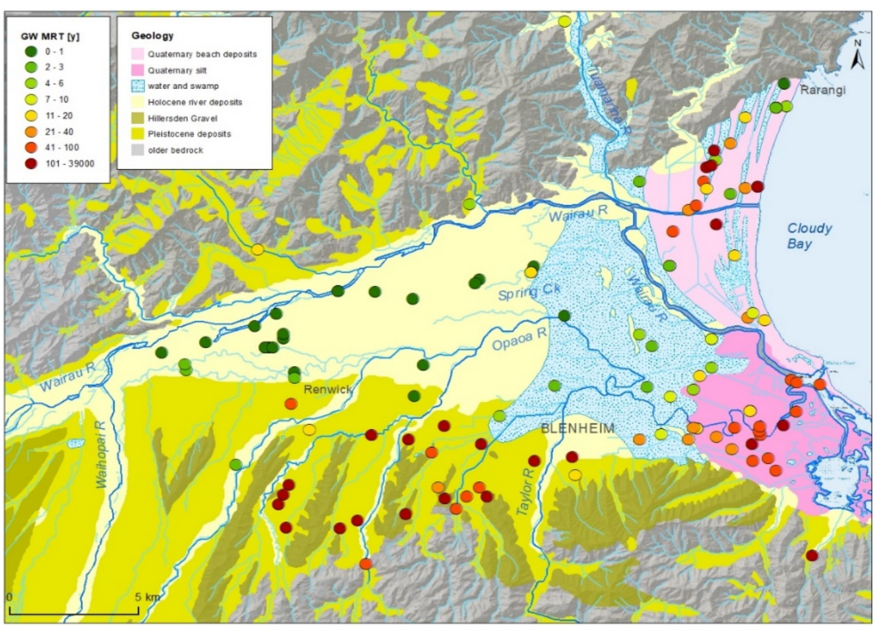


Figure 1: Wairau Plain – Geology and mean groundwater ages

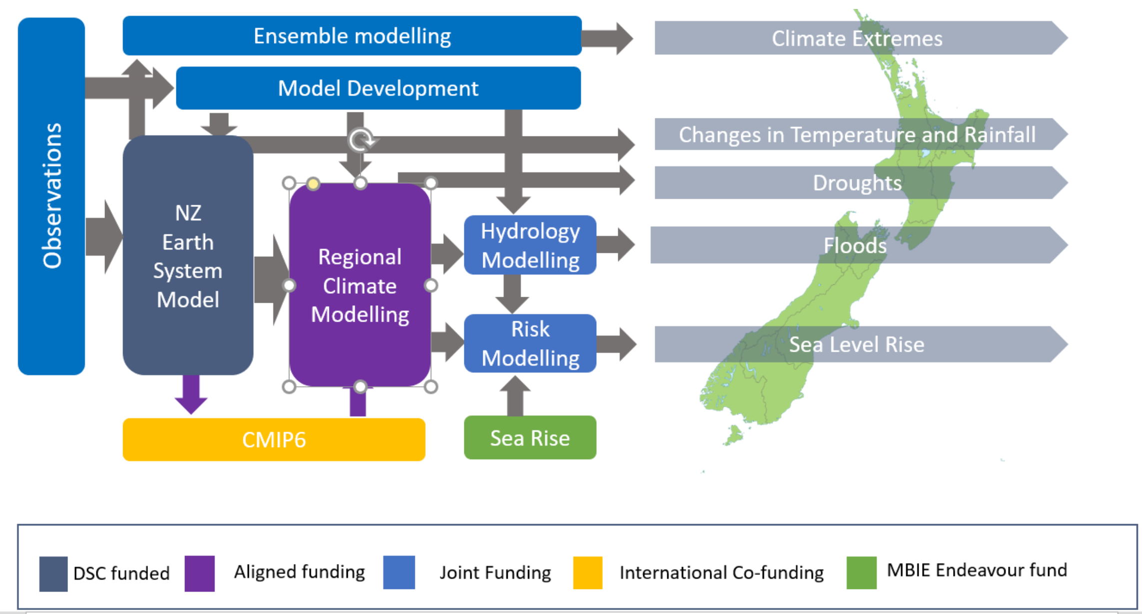
Conclusion

Groundwater ages can robustly be established over the entire age range 0-100 years. Groundwater was found strongly correlated to geology and lithology. Relatively young groundwater in the confined aquifer in the centre of the valley near the coast indicates active groundwater discharge out to the sea.

CLIMATE MODELLING UNDER THE DEEP SOUTH NATIONAL SCIENCE CHALLENGE: A STATUS UPDATE

Olaf Morgenstern[1], M Williams[1]
[1]*NIWA*

The mission of the Deep South National Science Challenge is to "enable New Zealanders to adapt, manage risk and thrive in a changing climate". Key to achieving this mission is a chain of models (illustrated below) which will produce state-of-the-art climate projection data that will satisfy the needs of various stakeholder groups. At one end of this chain is the New Zealand Earth System Model (NZESM). It will produce high-frequency lateral boundary data that drive the New Zealand Regional Climate Model, which in turn will inform hydrology and other impact modelling needed to prepare for climate change. In addition to setting up this chain of models, the Deep South National Science Challenge is involved in several model development projects targeting the NZESM. We will present highlights from these projects and outline the plan for model development and data delivery as the Deep South National Science Challenge enters its second 5-year phase.



OPTIMISING WATER MANAGEMENT BASED ON UNDERSTANDING OF FLOW SOURCES, PATHWAYS AND LAGS

Uwe Morgenstern[1], Catherine Moore[1], Chris Daughney[1], Stewart Cameron[1]
[1]*GNS Science*

Aims

This new 5-year MBIE programme aims to develop the world's first nationally continuous maps of groundwater age, origin and flow paths, useable for all institutions involved in water management. This programme is also called 'Te Whakaheke o Te Wai' - a holistic description of the flow sources, pathways and lags of water on its journey. New Zealand lacks this knowledge, so current water management strategies cannot prevent land use degradation of rivers and aquifers, impacting cultural values, drinking water supplies, agriculture and tourism.

We will derive the whakaheke of groundwater and baseflows in New Zealand's 200 major aquifer systems and the rivers that drain them. We will measure age tracers, which integrate all flow velocities (of water and contaminants) above any measurement point. We will use complementary hydrogeological, chemical and isotope data to understand origin of recharge and flow pathways, effects of geology, seasonality and stream order. New modelling approaches will integrate the tracer and other data across scales. Working with hapū, iwi and national Māori partners, we will incorporate mātauranga-a-iwi/hapū into our models alongside the tracer and other related data. Applications will include setting national policies, managing catchment scale contaminant inflows to groundwater-fed rivers, protecting local potable water supplies (e.g. Havelock North), and water allocation.

Our approach will advance the 'call to action', issued just four years ago by the international hydrological community, urging a new generation of models constrained by water age tracers such as tritium. New numerical modelling approaches, with input of Māori knowledge about surface water flows gained over centuries, will be implemented within industry-standard software to integrate the tracer and other data across scales. We will use nested local scale groundwater models to represent complex flow paths which can dominate pathogen transport. We will also build fast-running metamodels to statistically summarise and transfer larger scale information nationwide to support catchment scale management of water resources. Our programme will materially enhance understanding of how water moves through catchments.

GROUNDWATER SUPPLY PROTECTION ZONES IN FRANCE: CASE STUDY AND PERSPECTIVES IN NEW ZEALAND

Frederika Mourot[1]
[1]*GNS*

Drinking water security has rapidly become a top environmental and health priority for New Zealand, as evidenced by the discussions at the July 2017 Special Interest Group Research Strategy Workshop (MBIE, 2017). Several perspectives can be used to assess the benefits of setting up water supply protection zones, such as human health, ecology, or economics.

This issue is not new nor unique to NZ. The concept of drinking water source "protection zones" was first introduced in French Water Law in 1902. Yet, it was not until 1964 that the establishment of protection zones (Figure 1) around community drinking water abstraction points became compulsory for new supplies, and in 1992 that this obligation was extended to all the existing water takes. By 2013, 33,524 community drinking water supplies were identified across France, of which approximately 68% had formalised protection zones in place (DREAL, 2013).

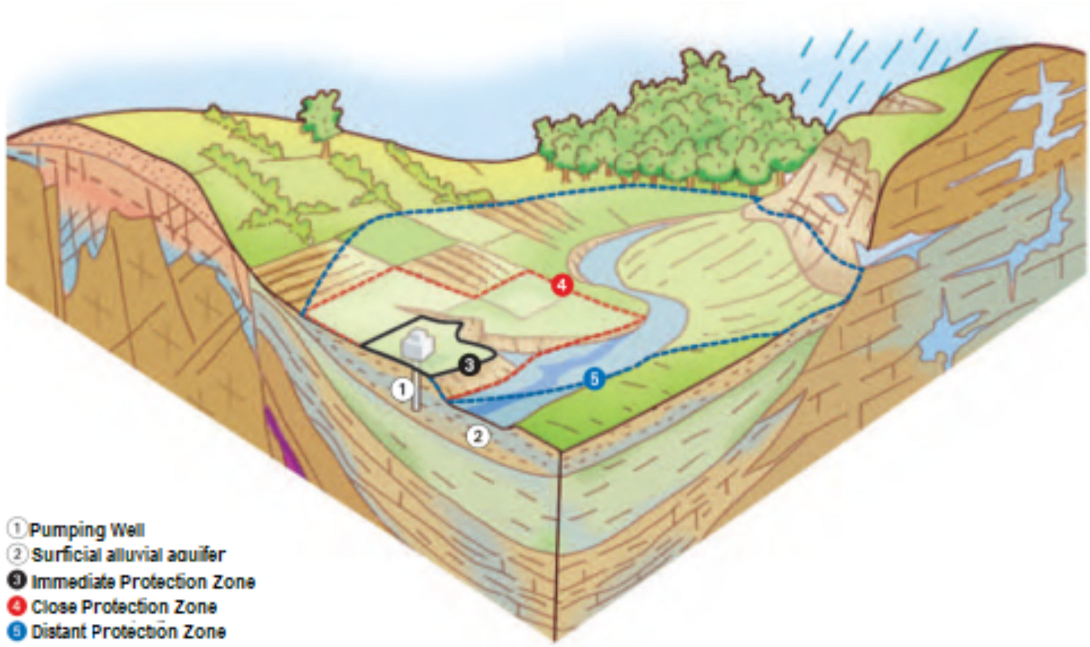


Figure 1: Groundwater Supply Protection Zones (adapted from BRGM, 2009)

This talk presents the French case study in the context of emerging source protection concerns of authorities responsible for delivering drinking water in New Zealand, and the need to improve drinking water supply protection nation-wide. This talk also follows on from the 2013 Capture Zone Guideline work carried out by GNS, ESR and Waikato Regional Council (Moreau and al., 2014; Nokes and al., 2013).

A comparative summary of the relevant French regulations (falling under the broader European regulatory framework) and delineation tools is presented alongside the existing New Zealand source protection framework. Specifically, the cost of protection versus remediation, and the success and limitations of the French groundwater supply protection system are provided through case study examples.

The French water supply protection framework (in accordance with the Water Law) includes tools and methods to delineate protection zones against multiple threats (e.g. microbial, point source, accidental incidents). These methodologies cover different hydrogeological contexts and can be adjusted according to budget. In addition, complementary protection zones at the aquifer scale have been introduced in 2006 (Law on Water and Aquatic Environments) to address the issues related to diffuse pollutants.

Presented case studies outline the necessity of adopting an integrated management approach at the aquifer scale and of involving a large panel of stakeholders. In most cases, efforts need to be sustained in the long term to significantly improve water quality. Many of these case study examples are directly relevant and transferable to the New Zealand context.

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TWO UNPRECEDENTED MARINE AND LAND HEATWAVES IN NEW ZEALAND: SUMMERS OF 1934/35 AND 2017/18 COMPARED

Jim Salinger[1], Brett Mullan[2], James Renwick[3], Howard Diamond[4], Phil Sutton[2]

[1]University of Haifa, [2]National Institute of Water and Atmospheric Research, [3]Victoria University of Wellington, [4]National Oceanic and Atmospheric Administration, [5]University of New South Wales

Aims

During the summers (DJF) of 1934/35 and 2017/18, the New Zealand region experienced unprecedented coupled ocean-land heatwaves that exceeded any that have occurred in the last 150 years, the latter covering a huge area up to 4 million km^2. This study examines the 1934/35 and 2017/18 New Zealand regional land heat waves (LHW) and marine heatwaves (MHW) from observations and diagnostics. The event is described from long land surface temperature observations, SST measurements and sub-surface marine observations, and climate diagnostics.

Method

The New Zealand mean temperature series anomalies (NZT) of Salinger (1980) from (Mullan *et al* 2010) used the 1981 – 2010 normal. Climate extremes for maximum temperatures above the 90th percentile (TX90p), minimum temperatures above the 90th percentile (TN90p) and summer days ≥25ºC used the Climpact2 v1.2.1 software (Alexander and Herold 2015), .

Monthly SST observations are obtained from the National Oceanic and Atmospheric Administration (NOAA) Extended Reconstructed Sea Surface Temperature (ERSST) version 5 data set (Huang *et al* 2017). SSTs for the region calculated spatially averaging SST anomalies between long.100ºE, 150ºW and lat.60ºS, the equator. The Argo temperature anomaly for the eastern Tasman (160-172ºE, 35-45ºS) used all regional Argo data.

Monthly mean sea level pressure (MSLP) data are obtained from the NCEP/NCAR Reanalysis project (Kalnay *et al* 1996) and the 20th century reanalysis project (CR) (Compo *et al* 2011). Changes in atmospheric circulation and other climate parameters are assessed using Trenberth (1976) circulation indices averaged over five months centred on October, the three month Southern Oscillation Index (SOI), and an index of the Southern Annular Mode (SAM) (Marshall 2003). For 1934/35 Kidson (1994) regime and weather types are absent.

Results

For the 1934/35 LHW (Kidson 1935), DJF mean temperature anomalies were 1.9ºC above normal, compared with 2.2 ºC for 2017/18 (Fig. 1a). These were the highest in records back to 1867 (Salinger 1980). TX90p and TN90p were 34 and 31% each for the earlier and 36 and 33% for the later LHW, with a New Zealand average of 23 and 26 days ≥25ºC respectively for each.

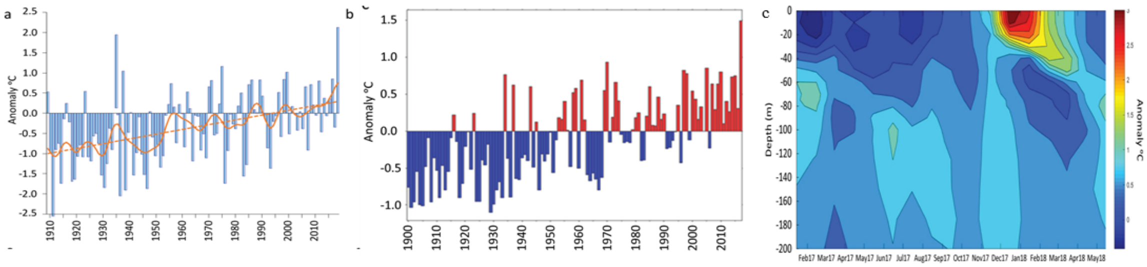

Figure 1: The 1934/35 and 2017/18 New Zealand LHW and MHW. a. The New Zealand temperature (NZT) series 1909 – 2018 summer (DJF) anomaly (1981 – 2010 normal). The red curve is a 15-term filtered average, red dotted line the trend. **b**. DJF SST anomalies 1900-2018 (ERSSTv5) averaged over the Tasman Sea region (26°S–46°S, 150°E–174°E) using 1961 – 1990 normal. c. ARGO float measurements for the eastern Tasman Sea (35 - 45°S, 160 – 172.5°E) of the mean sub surface temperature anomaly.

Argo float measurements (Fig. 1c) averaged over the eastern Tasman Sea confirmed a strong surface warming peaking with a 3ºC mean anomaly over this eastern Tasman region. The anomaly was shallow, mainly confined to the upper 20m but deepened as it eroded.

For the Tasman Sea (26º–48°S, 150º–174°E) SSTs for the MHWs were 0.8ºC (Fig. 2a) above average for the 1934/35 summer and 1.5 ºC for 2017/18, the largest anomaly on record. In the former LHW anomalies of 1ºC covered an area from 160°E-180°W (Fig. 2a), for the latter the 1ºC anomaly covered an area from 145°E-180°W, 35°-50°S, a huge area of 4 million km^2.

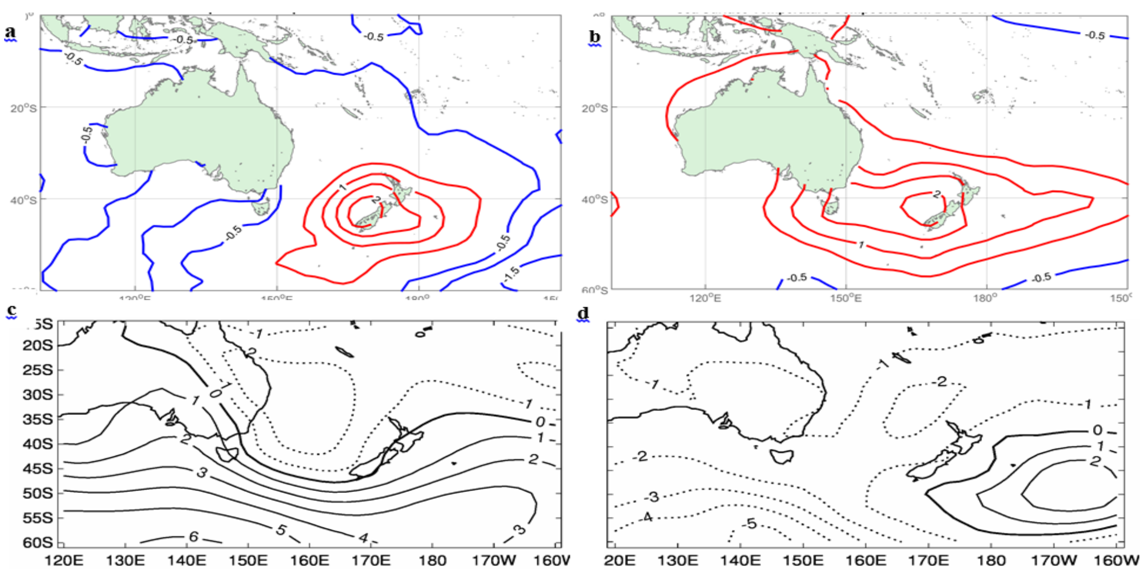

Figure 2: SST and mean sea level pressure (MSLP) patterns. a. Composite DJF 1934/35 and **b.** 2017/18 SST anomalies (from NOAA OI SST (ERSSTv5) using the 1981 – 2010 normal. **c**.DJF 1934/35 from CR project and **d.** NCEP DJF 2017/18 MSLP anomalies using the 1981-2010 reference period.

Atmospheric circulation anomalies for 1934/35 (Fig. 2c) displayed a pattern of strong blocking across the south Tasman Sea and to the east and southeast of New Zealand with troughing in the central Tasman Sea. The 2017/18 event (Fig. 2d) showed a pattern of strong blocking to the east and southeast of New Zealand, with negative pressure anomalies to the northwest.

For DJF 1934/35 there was a strong La Niña event (SOI in spring -3.0, summer -1.2) with a positive SAM (OND +1.27 and JFM +0.31): a good fit with the MSLP pattern (Fig. 2c) giving north to north easterly airflow anomalies over the eastern Tasman Sea and New Zealand. Trenberth indices for Aug – Dec 1934 record the most negative year of all for M1 (representing northerly flow) and in decile 3 for Z1 (representing easterly flow). In comparison for 2017/18 SON and DJF displayed a weak La Niña pattern (SON SOI of +0.9 and

DJF +0.1). The SAM was positive (spring +0.99, summer +1.73. The resultant MSLP airflow anomalies (Fig. 2d) match well with the La Niña event and positive SAM, with the contraction of the southern westerlies towards Antarctica. Trenberth circulation indices for Aug-Oct 2017 are in the 4th decile for M1 and the 3rd decile for Z1, resulting in more northeasterly flow for the period. The Kidson weather types show a predominance of the blocking and lack of the zonal regime resulting in low wind situations.

The drivers of the two LHWs and MHWs included La Niña and positive SAM conditions. The increased blocking in New Zealand latitudes forced the summer storm tracks poleward. The increased atmospheric blocking much reduced the normal wind speeds, with the atmospheric heating allowing significant warming of the surface layers of waters in the New Zealand region.

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WHERE SCIENCE & COMMUNICATION MEET – FOCUSING ON SEVERE WEATHER EVENTS

Lisa Murray[1]
[1]*Metservice, Meteorological Service Of New Zealand Ltd*

Communication has become a vital part of the weather forecasting process. You may have written the perfect forecast, but if no one hears or sees it, what use is it?

In this presentation I will share how MetService reaches out to people in times of severe weather and what are some of the barriers we face engaging our audience. To do this we will focus on two major weather events which occurred early in 2018, when New Zealand was affected by two extra-tropical cyclones arriving on our shores within weeks of each other, with significant impacts to many communities in Aotearoa.

Public communication is an ever-changing environment, much like the weather. We will explore how, as New Zealand's national weather service, we have used social media, alongside traditional media and official channels, to enhance our ability to get the message out to the public and clients during severe weather events.

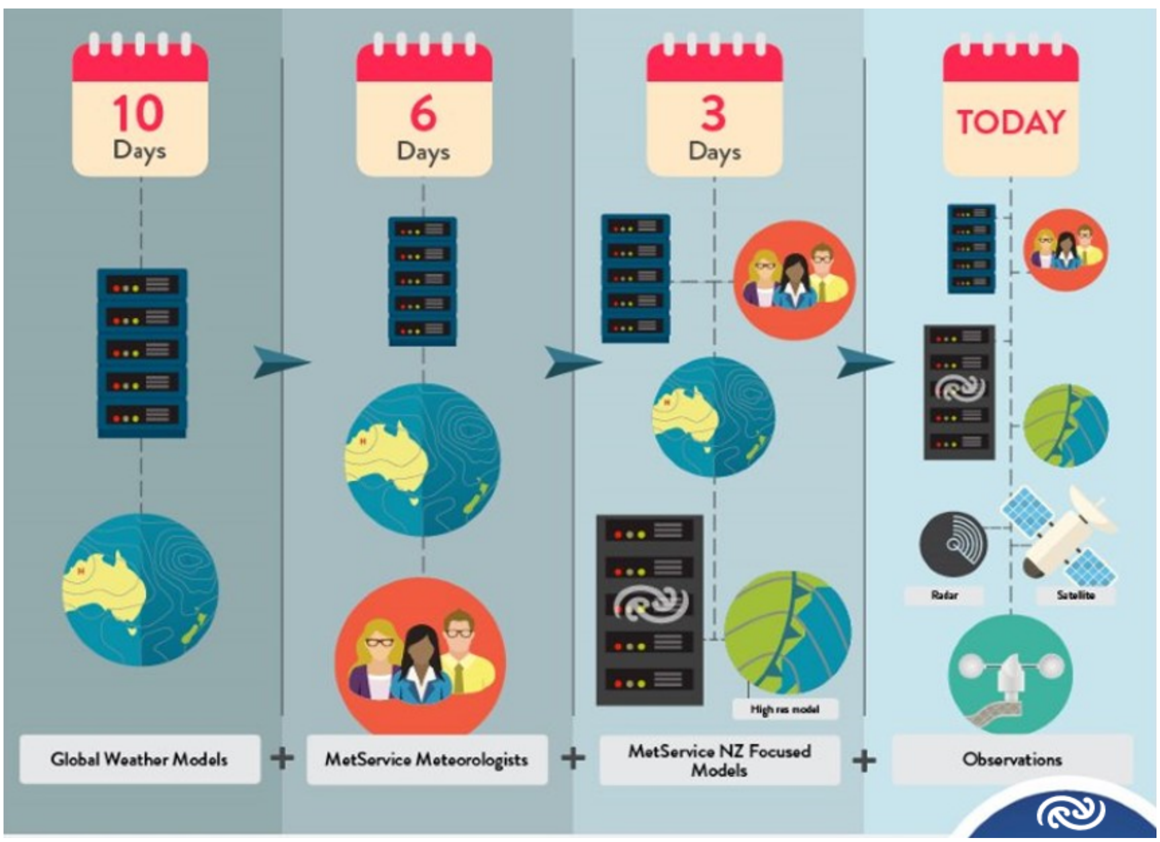

Figure 1: Communicating the forecasting process

BENEATH THE SURFACE: ESTIMATING SEDIMENTATION IN A WATER RESERVOIR

Ryan Nicol[1]
[1]*Pattle Delamore Partners*

Aims

Water reservoirs, as the name suggests, are used to provide an on demand source of stored water and serve a number of purposes such as irrigation, dust suppression, potable supply etc. The available storage in a reservoir can be reduced by sedimentation from upstream sources. During the design stage of a reservoir, the potential for sedimentation is usually estimated and allowances made to accommodate any predicted sedimentation to reduce the need or frequency for sediment removal. However, unpredicted weather events and/or erosion in the upstream catchment can result in sedimentation at much higher rates than anticipated.

The reservoir that is subject of this paper is an in-stream reservoir located within a high erosion catchment. However, the reservoir has experienced a much higher rate of sedimentation than expected and as a result, the available storage in the reservoir has visibly been reduced with subsequent impacts on water quality in the reservoir such as sub-merged macrophyte weed growth and water clarity. The reservoir was constructed in 2006 for general irrigation purposes and consists of an earth embankment dam and a compacted clay liner. The as-built design for the reservoir provides a calculated storage volume of 42,095 m³ with a maximum depth of approximately 7 m.

To determine the level of sediment and whether any sediment removal is required, an estimate of how much sedimentation has accumulated in the reservoir and the remaining storage volume is needed. Estimating the quantity of sedimentation is also useful for resource consenting purposes if the sediment is to be removed, as well as planning any sediment removal methods.

The aim of the investigation was to:

1. Measure the depth between the sedimentation surface and the water surface;
- Calculate the volume of sediment that has infilled the reservoir; and
- Calculate the remaining water storage volume in the reservoir.

Method

A bathymetric survey was undertaken in 2016 which involved measuring the depth to the sediment surface from the water surface of the reservoir using an Acoustic Doppler Profiler (ADP). The ADP was placed on a floatable platform and towed behind a small water craft. The ADP has a depth measurement accuracy of 20 mm and a resolution of 1 mm, recording depth measurements every second with the location of each measurement recorded using an onboard GPS built into the ADP. Data collected by the ADP was sent via radio link to a base station setup on the bank of the reservoir allowing the data to be saved and also viewed in real time.

The bathymetric survey initially involved towing the ADP around the perimeter of the reservoir before following an 8 m by 8 m grid pattern to maximise coverage. The location of any sedimentation surface anomalies such as submerged trees, pipes etc were noted during the survey for removal during the data processing stage. All depth measurements collected were made relative to the water level in the reservoir on the day of survey. The water level in the reservoir was measured prior to the survey being undertaken from a benchmark located at the reservoir spillway. The survey was undertaken during a period of stable weather with no rainfall and low winds to ensure that the water levels in the reservoir would remain constant throughout the survey.

The bathymetric data and associated GPS co-ordinates obtained using the ADP were used to develop a digital elevation model (DEM) of the sediment surface which was then compared to a DEM developed from the as-built plans. The difference between the DEM based on the bathymetric data obtained by ADP (i.e. depth to the sediment surface) and the DEM based on the as-built data was then used to determine the sedimentation volume and also the remaining water storage within the reservoir.

Results

Based on a depth comparison using the as-built data and the bathymetry data from the survey, the following outputs were obtained.

- A sedimentation thickness of up to 5 m has occurred in the deepest section of the reservoir (depth from water surface to the base of reservoir based on the as-built plans was 7 m);
- The volume of sediment infilling the original, as-built reservoir was calculated to be 24,400 m^3, or approximately 57% of the original reservoir volume; and
- The available water storage in the reservoir at the time of bathymetric survey was calculated to be 18,700 m^3, or approximately 43% of the original reservoir volume based on the as-built plans.

Sediment accumulation within the reservoir has resulted in the depth of the reservoir being reduced with more than half of the reservoir volume filled with sediment within approximately 10 years following the reservoir being commissioned.

At the time of writing, the reservoir still has sufficient water storage to continue to operate for its designed purpose (irrigation supply) but the reservoir is still displaying water quality issues. As a result, an additional bathymetric survey is being considered to determine whether there has been any additional sedimentation following the 2016 survey and subsequent high rainfall events that occurred in early 2018.

THE ROLE OF ANTHROPOGENIC FORCING IN EXTREME RAINFALL DURING EARLY MARCH 2014 IN CHRISTCHURCH

Ben Nistor[1], James Renwick[1], Suzanne Rosier[2], Mitchell Black[3], Sarah Sparrow[4]
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Aims

Torrential rainfall over a 48-hour period on the 4th and 5th of March 2014 saw Christchurch, New Zealand, endure widespread severe flooding. Christchurch Gardens received 246% of normal March rainfall within a period of 24 hours - the largest one-day March rainfall since records began in 1873. Resulting damages are estimated to have cost NZD $22.5 million in insurance claims relating to more than 100 homes that were inundated with water. This study investigates whether, and to what degree, there was an anthropogenic influence on extreme 1-day March rainfall in Christchurch as observed in 2014.

Method

Simulation-based approaches using global climate models (GCMs) allow for the generation of large ensembles of realisations from which statistics of rare events (e.g. rainfall extremes) can be evaluated. Using this approach questions such as 'how has the likelihood of this event changed due to anthropogenic forcings?' can be quantitatively investigated. Very large ensembles of 'weather@home Australia-New Zealand' regional model simulations for 2014 are used to quantify and evaluate changes in likelihood of extreme March rainfall. The ensemble distribution of one-day rainfall total is compared between the current climate and a counterfactual climate where anthropogenic forcings have been removed allowing estimates of changing event probability to be obtained. These are assessed against the context of historical observations from which the event return period is discerned.

Results

Low pressure to the northeast of the city in combination with a moisture-laden air mass fuelled the extreme rainfall as a conveyor belt of moist air was driven onshore by strong south-easterly flows. Model simulations show evidence of increased March maximum one-day rainfall for Christchurch in the anthropogenic world, a result which is found to be robust across different spatial averaging areas. The most extreme rainfall events appear to be typified by synoptic conditions much like those observed in early March 2014, with strong onshore winds and a deep low centred in close proximity (within ~ 400 km).

USING PREDICTIVE UNCERTAINTY ANALYSIS TO OPTIMISE DATA ACQUISITION FOR STREAM DEPLETION PREDICTIONS

Tess Op Den Kelder[1,2], Catherine Moore[1], Matthew Knowling[1], Mike Toews[1], Jeremy White[1]
[1]GNS Science, [2]Stockholm University

Aims

To facilitate robust understanding of a groundwater system and its processes and properties, managers need to make difficult decisions about what types of data to collect and where and when to collect it. Monitoring is expensive and time consuming, therefore it is important that the most cost-effective data, is obtained. This is where data worth analysis, which is based on predictive uncertainty analyses, can play an important role. The 'worth' of data is defined here as the reduction in uncertainty of a specific prediction of interest that is achieved as a result of data collection. With the use of data worth analysis the optimal data types, sample locations, and sampling frequencies can be determined for a specific prediction (e.g., Wallis et al., 2014). In this study we used the data worth method to optimize data collection when predicting pumping-induced stream depletion, and specifically we employ the First Order Second Moment (FOSM) based data worth method (Kikuchi, 2017). This study builds upon the work by Fienen et al. (2010), by exploring the impacts of spatial model parameterisation on the performance of the data worth analysis in the context of stream depletion assessments.

Method

A transient groundwater model, using the MODFLOW-NWT (Niswonger et al., 2011) software was developed for the mid-Mataura catchment located in Southland. Model predictions were based on simulating the stream depletion effects from additional pumping wells (the "predictive" model) and comparing these with the model with no additional pumping wells (the "base case" model). The predictions considered are as follows: 1) difference in the number of days below Q95 between the base case model and the predictive model (S1), 2) difference in the number of consecutive days below Q95 between the base case model and the predictive model (S2), 3) maximum difference in discharge between the base case model and the predictive model (S3). These predictions were made at 2 key locations: (i) the catchment outlet at Gore and (ii) the outlet of a spring fed stream (McKellar Stream).

The worth of both existing and additional potential monitoring data is investigated. In addition three spatial hydraulic parameter density scenarios were investigated: 1) distributed pilot point parameters, 2) homogeneous parameters, and 3) cell based parameters.

The uncertainty analysis is performed using a combination of PEST software (PREDUNC5) and the Python package pyEMU. Both software employs the FOSM based data worth method.

Results

The results show that in general the existing groundwater telemetry data resulted in the largest reduction in uncertainty for the predictions examined. The impact in terms of reducing prediction uncertainty, from adding new observation wells in every 10th cell with daily data for the year 2014 is shown in figure 1 for all predictions. The largest dots and yellow-red colouring indicate the areas were monitoring data has the greatest value. For all predictions (s1, s2, s3) at Gore, observation data in upstream reaches of the catchment appear most important; this is related to the outlet at Gore essentially integrating the entire catchment system. In contrast, the observations which reduce the predictive uncertainty for predictions s1, s2, s3 at McKellar Stream are all located around the stream itself, and relate to McKellar Stream being a spring fed stream.

If it is assumed that all existing monitoring networks are retained, then the worth of each new additional possible measurement must take into account the correlation of each new measurement with the existing monitoring network. When this is done, the pattern of the “next best measurement” is altered from those indicated initially by the size of the dots and the yellow-red colouring, so that each numbered location indicates the next best ten new monitoring locations (see numbered boxes; figure 1).

The impact of parameter simplification experiments showed that data worth analysis based on a grid based parameterisation were very similar to those using pilot points. However when using the homogeneous parameterization the data worth results became corrupted by the lack of spatial variability available in the parameterisation.

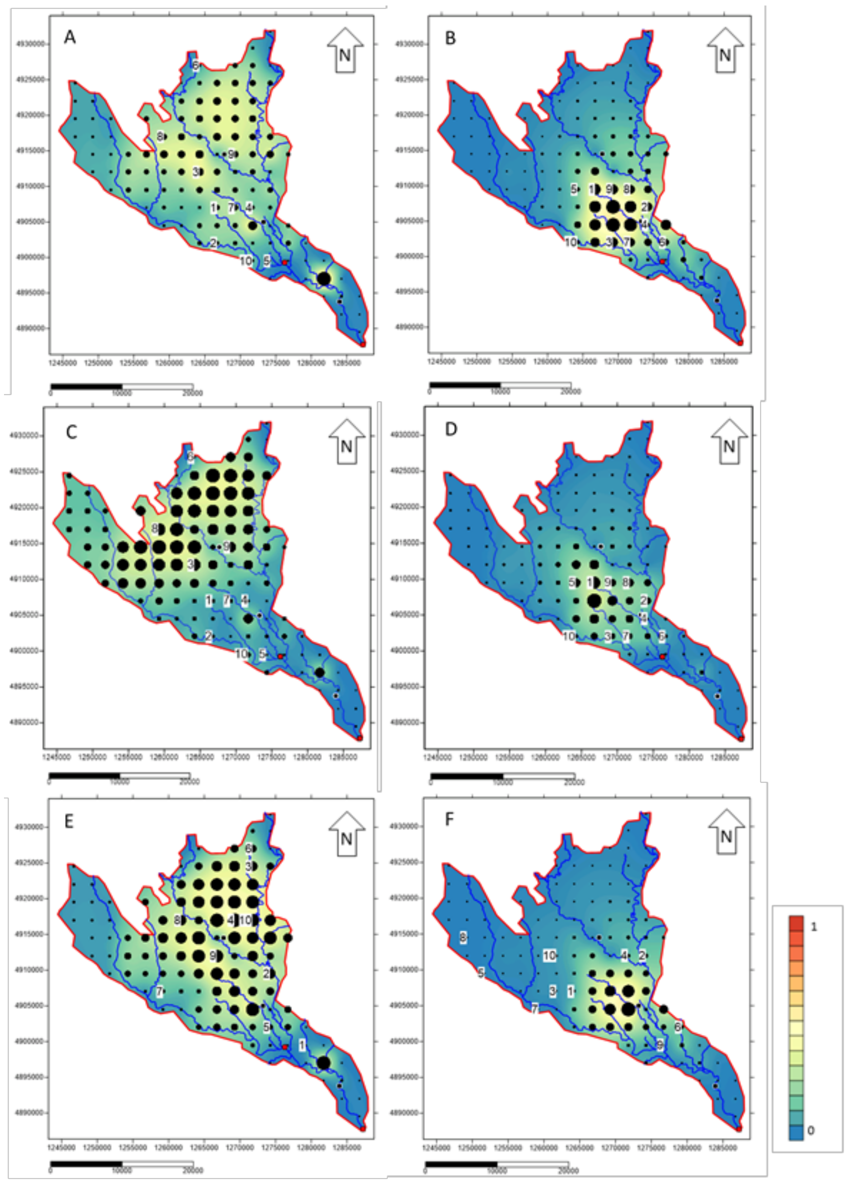

Figure 5.8: Reduction in uncertainty as a fraction of the prior after the addition of the new additional groundwater telemetry wells for A) s1 at Gore, B) s1 at McKellar Stream, C) s2 at Gore, D) s2 at McKellar Stream, E) s3 at Gore, and F) s3 at McKellar Stream. The colours are on a scale from 0 (blue) to 1 (red) and the same scale is used for all figures. The black dots show the location of the new additional well and the sized of the dots are proportional to the reduction in uncertainty and are prediction specific. The numbers show the next new observation that will reduce the uncertainty the most. The black dots with white circles around them are the additional wells and the red dots are the prediction locations

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SPATIALLY EXPLICIT ANALYSIS OF WATER SCARCITY LEVELS RELATED TO AGRICULTURAL POLICY IN BRAZIL

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Aims

Expanding irrigated cropping areas is one of Brazil's strategies to increase agricultural production. This expansion is constrained by water policy goals to restrict water scarcity to acceptable levels. Here the trade-off between levels of acceptable water scarcity, and feasible expansions of irrigation is assessed. In addressing this issue, we restrict the analysis to irrigation expansion on current cropping areas. Our assessment consists of the following steps: (i) the spatial-explicit calculation of green (soil moisture due to rainfall) and blue (here: irrigation using surface water) water consumption for the main crops cultivated in Brazil for both rain-fed and irrigated production systems, (ii) the estimation of the potential blue water resources required to achieve full irrigation on rain-fed areas, (iii) and a comparison of blue water requirements with available fresh water resources corresponding to scarcity levels. Our overall objective is to evaluate the feasible irrigation expansions in Brazil. We thereby test the hypothesis that available freshwater resources limit the further expansion of irrigation in light of sustainable water use in Brazil.

Method

In order to assess water demands of potential expansions of irrigation, impacts on water scarcity, and limits to irrigation expansion under scarcity thresholds, we applied the site-specific crop water balance model SPARE:WATER (Multsch et al., 2013) on the micro-basin scale. To this end, high resolution gridded data on climate and soil were combined with statistical information on irrigation management to run a daily detailed crop water balance model for 166,842 sub-basins in Brazil. The crops considered are cotton, rice, sugarcane, Vigna and Phaseolus beans, cassava, corn, soybean and wheat. Together, these nine crops account for 96% of the harvested area and 98% of the production mass of agricultural products in Brazil. The contribution of crop production to the regional water balance at the level of municipalities was derived by multiplying crop water consumption per growing season, averaged over the grids in the municipality, with the respective municipal cropping area. The total water consumption was aggregated over the catchments to the level of Brazil's regions.

The viability of strategies to expand the irrigated area is analysed in three steps. First, the potential blue water requirement for full expansion of irrigation is calculated for all rain-fed areas. Second, the sustainability of such a strategy is estimated by comparing potential blue water consumption and sustainable blue water availability following Hoekstra et al. (2012). Third, the viable expansion of irrigated area over rain-fed cropping areas is assessed under assumptions of the policy support for available water to be used for irrigation purposes.

Results

Figure 1 shows blue water availability (Figure 1a) and scarcity (Figures 1b and 1c). The available water flows have been classified according to seven groups between 80 mm/a and greater than 2,560 mm/a. The highest values are located in the North closed to the Amazonas River with a median Q95 of 765 mm/a. Q95 decreases in particular in the eastern areas with 26 mm/a and 197 mm/a in the North-East and South-East. The Cerrado area has also comparably low values with a median of 177 mm/a.

The blue water scarcity for current irrigated areas (Figure 1b) shows a specific regional pattern. Most of the agricultural areas are classified as to either meet excellent or very critical water scarcity with 35% and 38%, respectively. A relative shift to the category excellent can be found in the Cerrado region with 44% and 23% for these categories. The highest number of very critical catchments is located in the North-East and South with 64% and 49%. The North and Center-West are characterized by the highest fraction of catchments classified as excellent with 94% and 65%.

The situation could dramatically change when also rain-fed areas are assumed to become irrigated as shown in Figure 1c, with a vast increase of the category very critical with a high percentage of 48% and only a lower fraction in the class excellent with 24%. A similar change can be observed for the Cerrado region with 38% of very critical catchments. The catchments with a higher scarcity are located in the southern and eastern area of the Cerrado, as well as in the eastern part of the Cerrado itself. Note that, due to the exclusion of capillary rise in the calculations, results for specific regions like the Pantanal (Center-West, west of the Cerrado) indicate criticality although water is not scarce in reality.

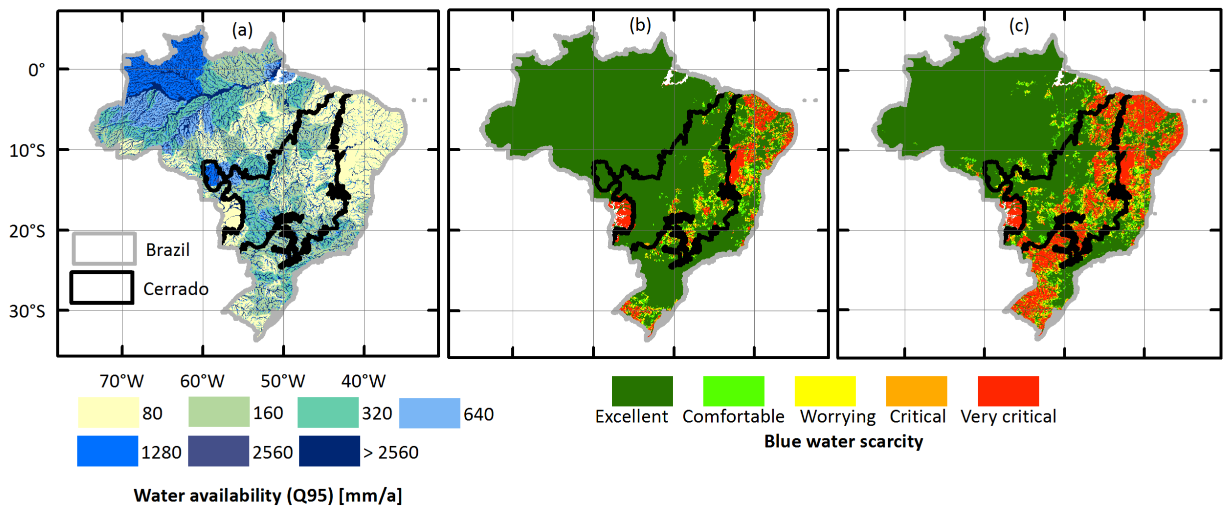

Figure 1: Sustainability evaluation of 166,844 catchments across Brazil. (a) Annual average water availability related to Q95. (b) Blue water scarcity classification of irrigated areas. (c) Potential blue water scarcity classification of rain-fed areas.

Even under current conditions a number of catchments with an area of 0.47 Mha were classified to experience critical and very critical (area 1.63 Mha) water scarcity. Reductions of current irrigated areas of about 35% (to 2.78 Mha) would be necessary to keep all catchments below critical water scarcity, with restrictions mainly required in the North-East and South. An expansion of irrigated areas by irrigating all 45.5 Mha of rain-fed area may severely exhaust water resources, resulting in 26 Mha above critical water scarcity. The expansion of irrigated areas keeping all catchments below critical scarcity level, could allow to irrigate 24.9 Mha, mainly in the South-East and western part of Center-West Brazil.

The results show in a spatially differentiated manner that potential future decisions regarding expanding irrigated cropping areas in Brazil must, while pursuing to intensify production practices, consider the likely regional effects on water scarcity levels, in order to reach sustainable agricultural production. Combining sustainable water management with ecological intensification may provide a way forward that not only leads to economic benefit, but also supports social, environmental and ecological well-being.

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WATER MANAGEMENT KI UTA KI TAI FOR THE SELWYN RIVER SYSTEM

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Aims

The aims of this research are to further improve understanding of the Waikirikiri / Selwyn River system and to implement actions that assist Canterbury Water Management Strategy objectives in an integrated and collaborative manner.

Method

The overarching vision of the Canterbury Water Management Strategy - CWMS is 'to gain the greatest cultural, economic, environmental, recreational and social benefits from our water resources within a sustainable framework both now and for future generations'. A sound hydrological understanding of Canterbury's catchments is a very important aspect of implementing the CWMS, however this knowledge needs to be integrated with many other types of knowledge and value sets. The process of continuous community co-learning in relation to the Selwyn River system has been described as Participatory Action Research in Painter and Memon (2007).

Since CWMS implementation began in 2010, the Selwyn Waihora CWMS Zone Committee has followed a similar process, with initial focus on 'participatory' and 'research' aspects to agree on their recommendations to Plan Change 1 to the Canterbury Land and Water Regional Plan (LWRP). Plan Change 1 introduced policies, rules and limits into the LWRP to manage water quality and water quantity in the Selwyn-Waihora Zone, with particular emphasis on the long-term health of Te Waihora/Lake Ellesmere. Plan Change 1 focusses on reducing negative human induced impacts on the catchment. In addition to the regulatory changes, further actions are required to respond to the additional challenges caused by rising sea levels and a changing climate. The 'action' part of Participatory Action Research has thus increased in prominence recently, though the 'participatory' and 'research' aspects remain crucial to ensure the actions are consistent with all relevant CWMS objectives.The Targeted Stream Augmentation project is a key action to improve the dry period resilience of Selwyn Waihora waterways and the life they support. Early project phases are reported in Painter (2017). The purpose of this presentation is to focus on recent project progress to construct / commission the Broadacres pilot site as well as planning and initial construction for the Waikirikiri / Selwyn Near River Recharge project. These sites are shown as "1" and "2", respectively, in Figure 1.

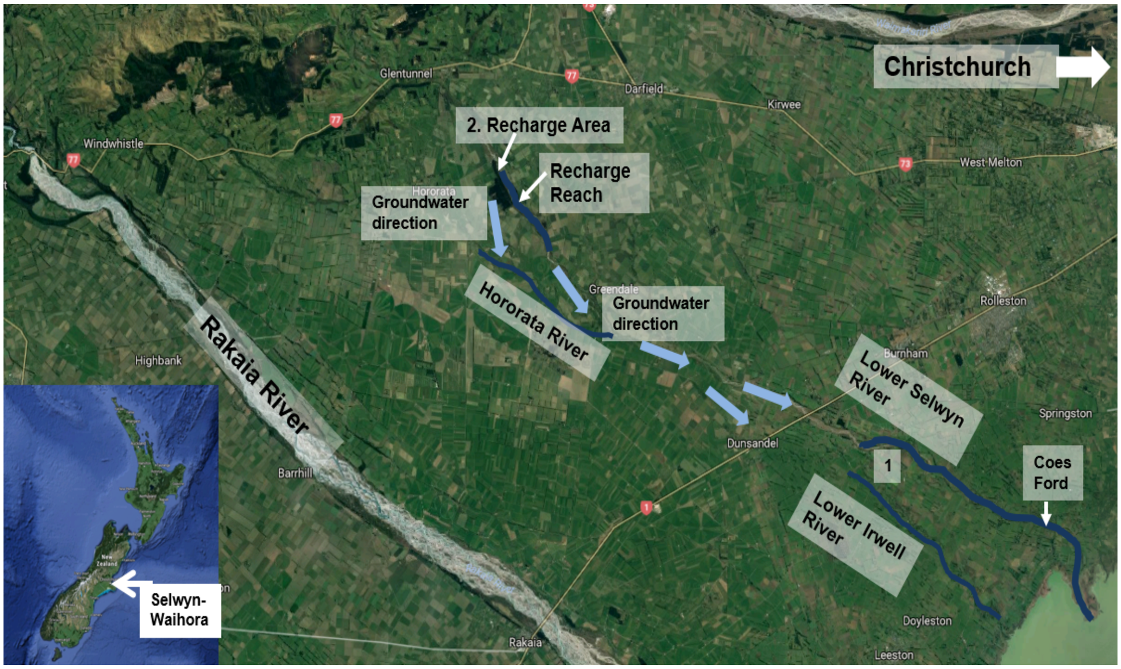

Figure 1: Targeted Stream Augmentation Project – Key components.

Results

The Broadacres TSA project has been designed to keep the upper section of a spring-fed tributary of the Selwyn River flowing when the springs are not flowing naturally. This tributary was historically a stronghold for Canterbury Mudfish (a native galaxiid with ‘‘At Risk: Nationally Critical’’ status), freshwater mussels and freshwater crayfish, but it suffered total loss of life during a recent 18-month dry spell (late 2015 to Autumn 2017). Preliminary assessments sized the expected requirements for the production bore, pump and solar panels. Infrastructure commissioning at the end of the dry spell suggested that the upper section of the tributary could be kept flowing during low groundwater conditions. Learnings to date will be presented on how this project is performing.

The Waikirikiri / Selwyn Near River Recharge Project aims to significantly enhance the state of the Waikirikiri / Selwyn River system through creating an off-take for long term access to water from the Central Plains Water (CPW) scheme pipeline. This off-take will connect to a recharge basin with overflow to dry braids of the Selwyn River. As the source water has different properties from the Selwyn water, filtering through river bed material is important to avoid any negative effects from directly mixing alpine and rain fed waters. Previous research has analysed the interactions between the Selwyn, Hororata and Irwell Rivers along with their connecting groundwater. To inform consenting processes, additional analyses and computer modelling has estimated potential basin recharge rates, shallow groundwater mounding and system wide effects of an extensive operational scenario. Off-take construction was completed as part of CPW pipeline installation in early 2018. Remaining construction is anticipated to be completed in 2019. This presentation will focus on system analysis and design aspects.

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BUCKET SCIENCE IN THE BARN [SOIL HYDRAULIC CONDUCTIVITY]

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Context

Liquid flows down an energy gradient, at a speed limited by the resistance. Hydraulic conductivity is the parameter that links the hydraulic gradient applied, to the flow that occurs, as a property of the medium through which flow occurs. What could be simpler? The concept is applied in contexts from dampness migrating through rock and concrete to groundwater passing through free-flowing gravels and so values of saturated hydraulic conductivity range over about 15 orders of magnitude [10^{-15} to 1 m/s] (Smith & Leslie 1992).

Hydraulic conductivity is particularly significant in water transport between "Groundwater and surface water processes" – a Conference theme. It is explicitly or implicitly involved in: infiltration; exfiltration; losing or gaining streams; transmissivity; recharge; leaching; and in soil and groundwater flow modelling.

This paper is primarily in the context of determining saturated hydraulic conductivity of agricultural soil and using it to investigate leakage from a pond or wetland, but applies more generally. The answer to "What could be simpler?", related to both measurement and application of hydraulic conductivity, is that a lot of things are simpler!

Derivation

The rate at which water flows through a porous medium is a result of a balance of forces: a pressure force; a body force, usually gravity; and a frictional resistance. Conservation of momentum assuming incompressible, laminar flow leads to a vector equation involving these three forces, so [as stresses]:

= 0

PRESSURE GRAVITY FRICTION

p pressure; ρ density; *g* gravitational acceleration; $\hat{g}$ unit direction vector; μ dynamic viscosity; $\bar{u}$ velocity

'cd^2' is included to represent an 'area' on which a frictional force acts. This is comparable to the role of surface area of a sphere in the Stokes law for a sphere moving in a fluid, or the pipe wall area in Poiseuille's formula for laminar flow in a pipe. However, it is clear that the geometry of the passages in connected pores of a medium like soil or an aquifer is not as simple as that of a sphere or a hollow cylinder! So the scalar 'constant', *c*, represents very complex geometry with some representative length dimension, *d*, which is also complex.

The vector stress balance above is more recognisable when written in terms of 'head', $h=p/\rho g$, and hydraulic conductivity, κ:

Darcy's Law

This shows that κ contains both medium and fluid properties, some of which [*c, d*] are already complex before complications such as unsaturated pores and gas content are added, and others [ρ, μ] which can be expected to have values which change with temperature, pressure and solutes.

Unless values are available which apply to a medium nearly identical to that in the application, in a similar state [e.g. of compaction and moisture content for a soil], and under nearly the same ambient conditions, it might be appropriate to measure κ directly in a laboratory or field context.

Measurement

There are empirical methods available which relate saturated and unsaturated hydraulic conductivity to more readily measured soil properties: soil water retention, bulk density, soil texture or even just clay content. Values obtained can differ by one or two orders of magnitude from laboratory measured values. Hydraulic conductivity is one of the most difficult soil properties to measure directly. It is not simple to reproduce the required geometric conditions in the field; nor is it simple to reproduce porous medium properties in a laboratory. It is also not usually reliable to adopt 'text book tabulated' values, even if there is an entry that seems to resemble the material being considered. However, there are field methods which give approximate values of κ and laboratory methods which give more accurate values, but often under more artificial conditions.

It is when these options are either insufficient or unavailable [e.g. expensive] that 'bucket science in the barn' might be appropriate.

The following method [a 'falling head' permeameter test] was applied to two soils [A: silt loam and B: clay loam (Milne *et al.* 1995)] being considered as pond or wetland lining materials. In Figure 1: h_w was initially about 0.4 m; A was 0.008 m^2 [100 mm diameter pipes]; h_s was about 0.15 m and T was chosen to be several periods once the relationship between T and had become linear, i.e. constant, after about 12 days. The test took place over 18 days, in temperatures varying from 3°C to 16°C. The soil columns were compacted at a pre-determined 'optimum' water content. It took 4 days for the soil columns to be nearly saturated, most air expelled and flow to begin.

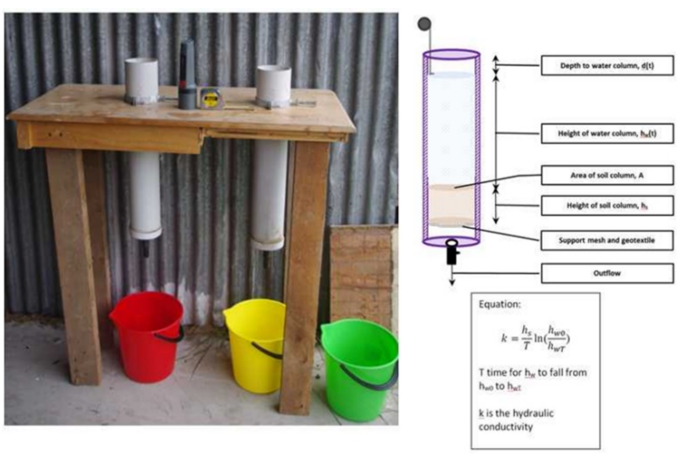

Figure 1. 'Bucket science' measurement of saturated hydraulic conductivity by falling head permeameter.

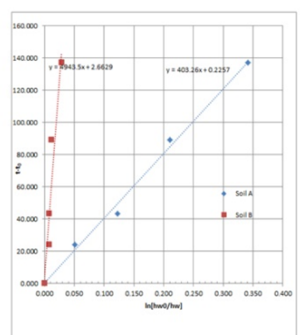

Figure 2. Linear relationships with slopes $\frac{h_S}{K}$

Results and Application

Values of saturated hydraulic conductivity are in Table 1.

Table 1: Measured values of saturated hydraulic conductivity [ms^{-1}] compared with other estimates.

	Measured	**From Texture**	**From Texture and Bulk Density**	**From Field Measured***
Soil A Silt Loam	1.1×10^{-7}	1.8×10^{-6}	1.4×10^{-7}	5.9×10^{-6}
Soil B Clay Loam	6.0×10^{-9}	1.0×10^{-6}	2.0×10^{-7}	2.0×10^{-5}
Reference	This study	'Rosetta' Model 2 Schaap *et al.* (2001)	'Rosetta' Model 3 Schaap *et al.* (2001)	Watt & Burgham (1992)
* These values were measured by twin-ring method (Scotter *et al.* 1982) on excavated subsoil of a Lismore shallow silt loam and by permeameter on a shaved subsoil core for a Temuka deep clay loam.				

Measured values were for samples compacted at suitable water content. What the values would be from a more sophisticated laboratory test [de-aerated water, pre-flushed at high pressure, upward flow, temperature controlled, etc.] is unknown, but my contention is that values would be similar to those measured by the 'bucket science in the barn'. The Rosetta Model 3 value differs from the measured value for Soil A by only 27%; but it assigns a similar value to Soil B; the measured value is 18 times smaller.

The significant result for the application was that Soil B was about 18 times less permeable than Soil A under the test conditions. If used as the flow-limiting component of a natural pond or wetland lining, it could be expected to leak at a rate [< 1 mm/day for 1 m depth over 0.5 m layer] less than evaporation.

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TRACKING GROUNDWATER CONTAMINATION USING DNA TRACERS

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With intensification of land-use activities in New Zealand, groundwater resources (often used for drinking water) are increasingly exposed to pollution from animal and human faecal wastes. This has resulted in an increased need for investigating the contamination sources and their pathways in groundwater using effective tracing techniques.

We have recently developed novel and environmentally friendly DNA tracers for the purposes of tracking water contamination sources and pathways. Field groundwater studies were carried out to evaluate these DNA tracers in two groundwater systems in Canterbury and Waikato. The Canterbury aquifer comprises coarse alluvial gravel and has fast groundwater flow whereas the Waikato aquifer consists of fine coastal sand where groundwater flow is much slower.

Field validation at the Canterbury site demonstrated the utility of DNA tracers in the most vulnerable groundwater conditions. The permeable alluvial gravel aquifer media has poor attenuation capacity and fast groundwater flow at 60-100 m/day. We applied 20 different DNA tracers in the Canterbury field site, each in a quantity of less than the weight of a single eyelash. This was 7-9 orders of magnitude less than salt and dye tracers previously used at the same experimental site. All the DNA tracers were directly detectable in a well 21 m downstream of the injection well. With concentration of one litre of sample and DNA extraction, most DNA tracers were detectable in the furthest monitoring well at 87 m downstream of the injection well.

Field validation at the Waikato site demonstrated the utility of DNA tracers in the groundwater condition most protected from contamination. The groundwater flow rate was relatively slow in the coastal sand aquifer, moving on average only 19 cm a day, and the fine sand is superior in absorbing negatively charged particles such as DNA. We injected four DNA tracers, each in a quantity of less than the weight of a single eyelash. With concentration of one litre of sample and DNA extraction, we were able to detect the DNA tracers in all the monitoring wells, which were distributed within 3 m distance. However, the log-reduction rates of DNA tracers were very high. The relative reduction of DNA tracers was consistent in all 3 wells and also consistent with the results of laboratory degradation tests. DNA tracers were retarded compared to the dye tracer due to significant adsorption onto the fine sand.

Field soil experiments were also conducted applying DNA tracers to lysimeters (0.5 m diameter and 0.7 m depth) that contained undisturbed soil extracted from the Canterbury Plains. Experimental results showed that all the 20 DNA tracers were detectable in soil leachate after the irrigation of DNA tracer-containing water. Experimental results derived from three different lysimeters were consistent under similar experimental conditions, suggesting that experimental results were reproducible. We established the log-removal rates of 20 DNA tracers during their transport through the soil lysimeters. These results suggest that DNA tracers were transported largely through preferential flow paths in the intact cores, which had a higher permeability than the matrix.

Our field studies suggest that the new DNA tracers that we have developed show great promise for use as a tracking tool in groundwater. The next step is to validate these tracers in surface water systems. We will continue to work with end-users to further validate these new DNA tracers in the field conditions. With future up-scaling, the new DNA tracer techniques could provide a useful tool for concurrently tracking multiple pollution sources and pathways in freshwater environments. The impact of this research will be the development of better mitigation strategies for the protection of New Zealand's precious freshwater resources.

NEW ZEALAND SWAT: SEDIMENT MODEL IMPLEMENTATION

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Introduction

The Soil and Water Assessment Tool (SWAT) is a popular (over 1200 peer-reviewed journal articles), physically-based, catchment hydrological-transport model used world-wide, for quantifying the impact of land management practices on streamflow and water quality in large, complex catchments. The major components of the model include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, agricultural management, channel routing, and reservoir routing. The model may be coupled to a surface-subsurface hydrologic model, and an advanced lake and reservoir model. It has also been used recently to indicate the fate and transport of pathogen loads in catchments. SWAT is a public domain model actively supported by USDA. Information on SWAT may be obtained from https://swat.tamu.edu/.

Outputs of modelling sediment transport include stream flows into and out of a reach during a time step, total sediment transported into and out of a reach during a time step, sediment concentrations in a reach, total suspended sediment (TSS) concentrations, and sediment yields from a catchment. Model outputs also include sand, silt, clay, small aggregates, large aggregates, and gravel aggregates in and out of a reach during a time step.

The SWAT model operates on readily available data which enables model applications for both well monitored catchments and more data-sparse catchments. The SWAT model requires a large amount of spatial and tabular input data. Pre-processing of critical data for the SWAT model, such as soils can be laborious and time-consuming. Numerous countries already have pre-processed soils data for use in physically-based hydrological transport models such as SWAT. A methodology is necessary for preparing land use/cover, topography and climate data for input into the model from available New Zealand databases.

Aims

The aim of this work is to develop the methodology for using the Soil and Water Assessment Tool (SWAT) to model soil erosion (mass soil loss to freshwater), sediment deposition in freshwater, sediment loads and yields from fresh water to coastal waters in New Zealand. The model is to be run on a daily time step and output for every sub-catchment in New Zealand may be daily, monthly or annual.

Method

Input data to the SWAT model includes: i) Soil types – Soil type is a key determinant of how well water infiltrates into the soil. Poorly drained clay soils have low infiltration rates and thus high runoff potential, ii) Elevation data – These data are used in model set up to delineate sub-catchments, identify flow paths, and define slopes, which are another key determinant of runoff potential, iii) Land use data – Land use impacts the manner in which water moves through the landscape, and different land uses (forested, agricultural, urban) produce different amounts of runoff, iv) Climate data – Daily temperatures and the amounts and timing of precipitation are key drivers of many catchment processes, including crop growth and runoff, and v) Land management actions – Models include information about crop rotations, tillage and fertilizer application methods, and locations of intervention practices like wetlands and riparian buffers.

The specific input database requirements are i) Digital Elevation Model (DEM), ii) Land cover spatial layers, iii) Soil type spatial layers, iv) Soil profile information, v) Meteorological data (rainfall, temperature, wind speed, relative humidity and solar radiation)

A 15m (2002) hydrologically consistent DEM, accessed from Landcare Research was used. The area threshold required to match, if necessary, SWAT-delineated sub-catchments to REC2 delineated sub-catchments was determined by a process of trial and error. Details on how the DEMs are used for creating a stream network and for sub-catchment delineation is given by Parshotam (2018c).

Deriving a soils dataset for use in SWAT is discussed by Parshotam (2018a). A New Zealand-wide soils dataset was derived from the NZ-NSD for use in SWAT. These variables include soil texture, bulk density, hydrological groups, available water capacity, saturated hydraulic conductivity, erodibility factors, carbon, and soil albedo for individual horizons in the soil profile. The NZ-NSD contains legacy soil data from over 1500 sampling sites from the 1950s and was created in the 1980s. The NZ-NSD was joined to the New Zealand Fundamental Soils Layer (FSL) soil polygons by New Zealand Soil Classification (NZSC) codes. Methods for quality control and for filling missing data are developed and documented. Although the method was developed primarily in order to obtain a soils dataset to be used in the SWAT model, it prepares (and documents) a new GIS soils layer with more useful fields than are currently available in the FSL.

Deriving landuse, slope and climate data for New Zealand for use in SWAT is discussed by Parshotam (2018b). The LCDB v4.1 New Zealand Land Cover Database classes were reclassified to (mostly generic) SWAT land cover/use classes. Some new classes were created, and SWAT land cover databases were updated to include local parameter values given in the literature. It is expected that some of these parameter values will be refined over time. A lookup land use/cover classification table was created with the full land cover class description used as a guide. Slope classes required classification based on multiple classes within SWAT and these ranges are usually determined by the area and region modelled. Slope classes based on New Zealand slope class descriptions were assigned and SWAT model slope class identifiers given. The same class ranges were used across all regions in New Zealand. New Zealand Weather Data for SWAT and in SWAT file format is available through the Global Weather Data for SWAT website (See https://globalweather.tamu.edu/). This website allows one to download daily Climate Forecast System Reanalysis (CFSR) data created from data supplied by New Zealand Meteorological Services (precipitation, wind, relative humidity, and solar) in SWAT file format for a given location and time period. There are 619 stations available across New Zealand with climate data over a 36-year period and these were spot-checked. To acquire the daily SWAT input data, a statistical weather generator was applied. This was obtained by downloading the CFSR_World weather database from https://swat.tamu.edu/media/99082/csfr_world.zip. Details of the preparation of New Zealand Weather data for SWAT are given by Parshotam (2018b).

The setting up and running of the SWAT model from prepared inputs is presented by Parshotam (2018c, d, e), together with a data dictionary to understand output results (Parshotam 2018f). Results are given as a time series of relevant data for every sub-catchment delineated on a region basis. SWAT model sediment output results are available as MS-Access database files. There has been no calibration of the model or validation of results with measurement data but this may be achieved within the SWAT modelling framework and implemented on a catchment-by-catchment basis.

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DIGITISING NEW ZEALAND AND PACIFIC CLIMATE DATA – UNDERSTANDING NIWA'S ARCHIVE AND PREPARING FOR THE FUTURE

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NIWA is the custodian of New Zealand's official climate observation data, as well as data from several Pacific Island countries. Many of these data have been keyed and are stored in NIWA's National Climate Database (www.cliflo.niwa.co.nz). There are large amounts of paper data in the NIWA archive that have not been digitized, including daily data used for understanding trends in extremes of temperature and rainfall. Most of these data exist only on paper (i.e. they have not been photographed) and are potentially at risk of deterioration due to their age (some sheets are over 100 years old). We have designed a strategy to audit the original paper data within the NIWA archive and prioritise it for photographing and database ingestion. The strategy involves 1. Prioritising locations based on length and age of record as well as physical condition of the paper, 2. Methodically checking and recording the contents of each box (including site details, climate variables recorded, and date coverage), 3. Photographing the paper copies, and 4. Repacking into high-quality archive boxes and labelled correctly. Digitising the significant amount of historic climate data that NIWA holds will also support improved reanalysis depiction for New Zealand and the Pacific.

EXAMINING THE STABLE ISOTOPIC COMPOSITION OF WATER VAPOUR OVER SOUTHERN NEW ZEALAND

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The stable isotopic composition of atmospheric water vapour is modified by fractionation during phase changes. As a result, measurements of the isotopic composition provide useful information about the cumulative history of phase changes in an airmass.(Risi, Noone et al. 2012; Galewsky, Steen-Larsen et al. 2016)

The Total Carbon Column Observing Network (TCCON) site operated by NIWA at Lauder has been making retrievals of the column abundances of various trace gases, including H_2O and HDO, from near infrared solar absorption spectra since 2004.(Wunch, Toon et al. 2011; Pollard, Sherlock et al. 2017)

In this work, we present an analysis of the 14-year time-series of total column dry-air mole fraction of water vapour (XH_2O) and the HDO/H2O ratio R quantified by δD in ‰:

Where R_{VSMOW} is the Vienna Standard Mean Ocean Water isotopic ratio. We find that while there is no statistically significant trend in the time-series of XH_2O, δD is seen to reduce in magnitude by 0.27% yr^{-1} as well as having a seasonal cycle.

We shall attempt to explain this trend in terms of changing water vapour pathways.

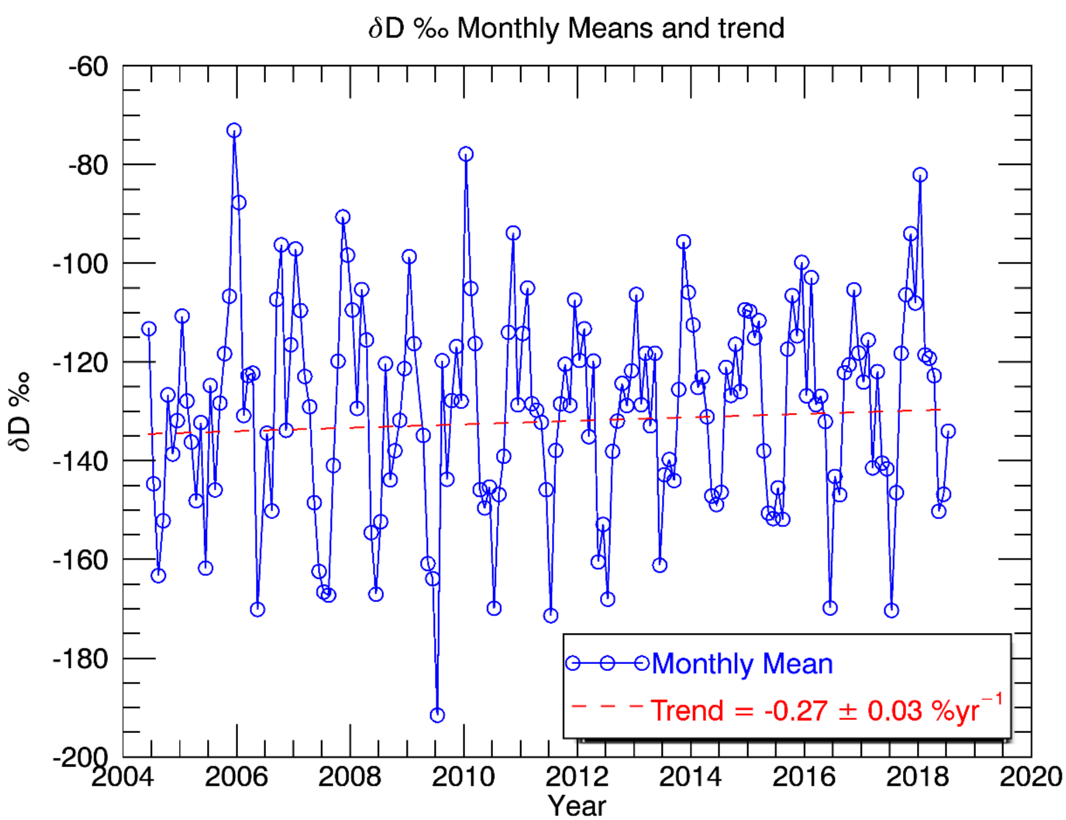

Figure 1: δD time-series

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SNOW HYDROLOGY OF THE SOUTHERN ALPS: A REVIEW

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Aims

Snow in the mountains is a natural water reservoir providing water for more than one billion people across the globe (Barnett et al., 2005, Mankin et al., 2015). In a warming climate, with a shift in precipitation from snow-dominated to rain-dominated regimes, a robust understanding of snow hydrology is important for water management strategies. The knowledge of snow hydrology is a key factor in the Southern Alps of New Zealand because of its role in hydroelectricity schemes where snow contributes up to 24 % of the inflows to the major hydroelectricity lakes (McKerchar et al., 1998). Snow is also a valuable source of water for New Zealand's agricultural sectors (Hendrikx and Harper, 2013). A greater proportion and influence of rainfall to snowfall caused by a maritime setting as well as major differences in the water balance (e.g. runoff behaviour) make the hydrology of the Southern Alps distinctive from many other alpine catchments in European Alps, North America, South America and Himalaya. These differences provide an opportunity to study the physical processes associated with snow hydrology in the maritime Southern Alps. Our objective is to review the literature devoted to snow hydrology in the Southern Alps in order to collate the existing knowledge, and identify significant gaps in the research. We reviewed previously published journal articles, industry reports and unpublished theses that focus on seasonal snow cover and snow hydrology in the Southern Alps. Selected studies were compared and summarized on the basis of the authors' experience and areas for further research have been highlighted.

Results

Snow hydrology research in the last 60 year in the Southern Alps shows that: (1) Because of the substantial influence of energy fluxes on snowmelt generation, efforts have been made to better understand the contributions of energy fluxes to snowmelt in the Southern Alps. These studies have indicated that the contributions of the energy balance components are site-specific and vary significantly over time and space. Even though the turbulent heat flux is believed to be the most important driver of the melt in the maritime Southern Alps (e.g. up to 80% in Canterbury region), measurements of energy balance components at Mueller Hut (east side of the Main Divide) and Brewster Glacier (west side of the Main Divide) have shown that radiative flux could be a major contributor accounting for up to 64% of the snowmelt energy. It is known that synoptic climatology has a great impact on both magnitude and partitioning of the energy balance. However, there is still a need to downscale these large-scale circulation patterns to alpine catchments in order to assess the hydrological responses to the general circulation models. Despite frequent rain-on-snow (ROS) events in the Southern Alps (Moore and Owens, 1984), little is known about the effects of such events on snowpack energy flux and snowmelt discharge. ROS events are highly important in mountain hydrology because of their potential ability to cause major floods. The influence of different controlling factors on rain-on-snow formation such as meteorology, snow pack properties and topography should be investigated during the ROS events in the Southern Alps. Snowpack models and snowmelt runoff models can be used to generate estimations of the snowpack water balance and water available for runoff during ROS events. (2) Our understanding of the contribution of snowmelt to flow in the Southern Alps is partly hindered by poor river gauging systems in upper catchments and sparse climate data at high altitudes. Previous efforts to study the impacts of snow melt on water resources in Southern Alps (McKerchar et al., 1998, Fitzharris and Grimmond, 1982, Kerr, 2013) have indicated that even though compared to European Alps (Penna et al., 2016, Coppola et al., 2016) and Himalayan catchments (Siderius et al., 2013, Adnan et al., 2016) the contribution of meltwater to runoff in the Southern Alps rivers is lower but this proportion can reach up to 40% in upper alpine catchments which feed major rivers in the Southern Alps. There is a need to research the relative contribution of snow at the seasonal scale throughout the alpine basins. Distributed or semi-distributed hydrological models with snow modules are a good tool to help improve estimations of snow contribution to flow in alpine catchments of the Southern Alps. (3) Recent efforts have been made to use remotely sensed data in several alpine catchments of the Southern Alps (Sirguey et al., 2009, Sirguey et al., 2016). The potential use of snow cover data for calibrating and validating hydrological models requires more research in the Southern Alps. Satellite data coupled with in-situ observations can help fill the temporal and spatial gaps of snow observations. This information can be used to better characterize the snow distribution across the Southern Alps. (4) There are large knowledge gaps in some components of the hydrological system in alpine catchments. The role of soil moisture and groundwater in headwaters of such regions, for instance, is poorly understood and needs to be investigated. Information on soil moisture and groundwater data is valuable to conceptualize the runoff generation processes in mountain hydrology. Since the physical processes affecting groundwater recharge are not well understood in sloping terrains, advances in studies of snowmelt recharge of groundwater and its delayed release in the Southern Alps may, therefore, improve our understanding of such phenomena in other alpine regions.

Comprehensive field-based research needs to be conducted to address all components of the hydrologic system, including soil moisture and groundwater. Understanding the flow, storage and pathways of the groundwater will help understand characteristics of alpine aquifers. Different factors influencing subsurface water storage, including soil depth, sub-glacial and proglacial aquifers, geological and geomorphological characteristics of the catchments, and hydrological properties of the land cover materials (e.g. talus and moraine) need to be investigated in complex alpine terrains of the Southern Alps. Experimental studies in catchments with different alpine characteristics have proven the potential use of isotope tracers for separating snow-fed, rain-fed and groundwater-fed sources. Such studies can be done in the Southern Alps for hydrograph separation purposes and flow paths investigations.

This review of published research on snow hydrology in the Southern Alps indicated that despite advances in understanding of snow accumulation and snowmelt processes, there are many areas in the field of snow hydrology in the Southern Alps which require further investigation. The role of hydrological processes such as rain-on-snow events, snowmelt contribution to flow, the link between snowmelt and soil moisture and between snowmelt and groundwater is an open field for future research in the Southern Alps.

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MAKING THE MOST OF LONG-SCREENED WELLS IN GROUNDWATER INVESTIGATIONS

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Introduction

Effective groundwater management depends on understanding aquifer characteristics, flow dynamics and water quality at a representative scale. Wells are expensive to install, so the economical approach is to use available infrastructure where possible. However, wells installed for other purposes (e.g. water production) often have much longer screened or open intervals than wells designed for collecting scientific data. This means that, with traditional methods, key data – like hydraulic properties, water level and water quality – are averaged over an unhelpfully large interval of the aquifer system. So, such wells tend to be underused or even misused in groundwater investigations. The aim of this talk is to show that, with a little extra work and appropriate methods of measurement and analysis, long-screened wells can in fact provide valuable scientific data and insight for groundwater investigations. In particular, it is possible to determine the intersected hydraulic conductivity and head distribution and obtain native groundwater samples from discrete zones.

Method

This talk draws on knowledge developed for a study that used environmental tracers to examine groundwater recharge processes and residences time in the complex geological setting of the Pilbara region of Western Australia. In this study we: (1) numerically modelled the effects of intraborehole flow on purging and sampling long-screened or open wells (Poulsen et al. 2018); (2) measured the in-well flow regime in ambient and pumped conditions with a borehole electromagnetic (EM) flowmeter; (3) developed and tested a new constant-rate tracer dilution method to determine the in-well flow regime in pumped conditions (Poulsen et al. in prep.); (4) developed a depth-specific sampling strategy, exploiting the ambient and pumped in-well flow regimes to target discrete zones that produce native groundwater (Poulsen et al. in prep.); and (5) sampled environmental tracers from long-screened wells and a multi-depth nest of piezometers to investigate groundwater residence times.

Results

The wells used in this work had been un-pumped for several years, so the intraborehole flow plumes were large and it was more practical to avoid sampling them, rather than attempt purging. While pumping, the in-well flow profiles measured with the EM flowmeter clearly showed the main inflow zones, and the proportion from each zone. We produced very similar flow profiles with the new constant-rate tracer dilution method. This involved constantly injecting a tracer at one end of the screen while constantly pumping from the other end. The tracer was drawn towards the pump and diluted in proportion to each inflow. Tracer concentration profiles were collected at regular intervals, and at steady-state they were translated into flows by applying a solute mass balance model. Significant vertical heterogeneity was observed, with the majority of yield sourced from sub-intervals within the wells. Two had strong ambient flows (6-7 L/min) that could be sampled simply by placing the low-rate (0.5 L/min) sampling pump in the higher head zone. Purging was unnecessary because native groundwater was constantly flowing through the well. One well had weak upward ambient flow (<1 L/min), which was enhanced by pumping. Another had negligible ambient flow, so it would produce native groundwater after a modest purge. Preliminary results of sampling show no clear stratification of basic water chemistry, some significant differences of Radon, while Carbon-14 indicates consistently old (10-14k years) groundwater at all depths. CFC and Helium samples are being analysed at GNS Science Water Dating Lab and University of Utah respectively (at the time of writing).

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MODELLING GLACIAL MASS BALANCE WITH AN ENHANCED TEMPERATURE-INDEX MODEL

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Monitoring and modelling the mass balance of temperate glaciers is crucial to understanding how seasonal and multi-annual climate variations are altering the cryosphere. Constraining the mass balance of the New Zealand cryosphere provides a valuable resource on how climate variations at all scales may influence local hydrological regimes. Developing glacial mass balance models is also a crucial step in assessing the longevity of glaciers and ice caps and estimations of global sea level rise. New Zealand glacial mass balance studies are sparse and under-represented in global cryosphere monitoring due the lack of meteorological data from alpine environments. The first multi-annual (22 month) meteorological record from within the ablation zone of New Zealand glacier was recorded on Brewster Glacier in 2012 (Cullen and Conway, 2015). A sophisticated point-based energy balance model (EBM) was developed to calculate the glacial mass balance, producing results congruent with *in-situ* stake and snow-pit measurements (Cullen and Conway, 2015). Such a model is only applicable with high quality measurements of the surface energy balance limiting the temporal and spatial scope of the point-based EBM to the 22-month period.

Aims

The aim of this project is to develop an empirically based distributed mass balance model for Brewster Glacier. The simplicity of an enhanced temperature-index ablation model (ETI) provides the basis of a mass balance model with a low data requirement. Statistical downscaling has been used to reproduce basic meteorological parameters for Brewster Glacier from 1980 through to present (Hofer *et al*., 2017). The simplicity of an ETI will allows for the assessment of glacial mass balance using the statically downscaled dataset.

1. The first objective is to optimize a point-based ETI to the 22-month (2010-2012) EBM mass balance calculations.
- The second objective is to compare distributed ETI results to seasonal mass balance measurements (2005-2018) based on an extensive *in-situ* snow stake observation campaign (Cullen *et al*., 2016).
- The third objective is to compare annual mass balance calculations from the ETI to reconstructed mass balance measurements based on the photographic record of end-of-summer snowlines from 1980 to 2017 (Sirguey *et al*., 2016).

Method

An ETI was combined with an accumulation model to develop a full glacial mass balance model. The ETI model calculates daily melt ():

where is the temperature factor, is the positive degree days, is the shortwave radiation factor, is the modelled albedo and is the modelled extra-terrestrial solar irradiance. The positive degree days were used rather than an equation threshold to allow for solar irradiance to cause melt during periods of negative temperatures. Measured incoming shortwave radiation values were tested in the early stages of model development and the inclusion of modelled solar irradiance barely lowered the model efficiency. An albedo model was developed for Brewster based on observed albedo measurements (Conway and Cullen). The empirical factors (and) were calibrated to the daily melt rates from the 22-month EBM measurements. A least square method was used to optimize the two factors. The Nash-Sutcliffe efficiency coefficient (NS), RMSE and the mean bias difference (MBD) were used as performance criteria. The optimal factors selected as the values that produced the lowest RMSE and the highest NS.

A linear double threshold model was used to model accumulation, assuming that accumulation is equal to solid precipitation. The amount of snowfall () is defined by a lower air temperature (T_1) where precipitation () falls completely as snow and an upper air temperature (T_2), where precipitation falls completely as rain. The amount of snowfall in between the thresholds is proportional to a linear regression. The accumulation model was optimized to the 22-month EBM accumulation measurements at daily time steps producing thresholds of T_1 = 0.2 °C and T_2 = 2.6 °C with a NS of 0.78. Mass balance was then calculated as the sum of ablation and accumulation.

Results

The point based ETI models daily melt rates during the 22-month period with a NS of 0.75, a RMSE of 7.13 and a MBD of 0.23. The MBD greater than 0 suggests that the optimal ETI slightly over predicts the daily melt rates. The albedo model appears to reproduce observed values well and responding to snowfall events in a suitable manner. There appears to be some divergence at the start of the model that may indicate the importance of initial snow depth and age of snow pack. The relative proportion of shortwave radiation that is used in the ETI melt equation is tied closely to albedo; increasing in the winter during large snow depths and decreasing in the summer (Figure 1).

The distributed ETI model does not appear to accurately capture the variation in mass balance from 2004 to 2018 (Figure 2). While the modelled winter mass balance appears to match the observations reasonably well, the modelled summer mass balance underestimates ablation. The empirical factors used in the distributed model were generated from the point based observations over a 22 month period and so the temporal and spatial transferability of these values must be questioned. The ETI under predicted ablation in the 2011 and 2012 mass balance years suggesting that there are significant errors involved in the spatial distribution of empirical factors given the high NS value generated at the point scale.

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STATISTICAL MODELS FORECASTING DAILY RIVER FLOWS FOR OPERAIONAL USE IN HYDRO ELECTRICITY CATCHMENT

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Aims

The aim of this research was to produce automated daily lake inflow forecasts with a 1-7 day lag for all sub-catchments in the Waitaki and Waiau catchments, South Island, New Zealand, with skill over climatology. The first use for these forecasts is as inputs to "HOP", a river flow and hydro generation optimisation model. The second requirement is to enable more optimal electricity generation offers into the NZ electricity market (NZEM) from the hydro generation plant on these rivers.

Method

Multiple linear regression was used to forecast future daily average flows for several sub-catchments. Independent variables included antecedent flows, rainfall, temperatures, and snow melt, as well as forecast local rainfall from Met Service. K-fold cross validation (k=5) was used to estimate confidence intervals and model skill.

Results

Skill over climatology was found to occur in models forecasting flows with lags of 1-5 days in all catchments, and for longer forecast lags in some catchments. For operational purposes, climatology (long term average for the time of year) is therefore used as a "forecast" for days 6 and 7. Table 1 shows the skill (error) statistics from cross-validation for the Lake Ohau catchment, compared to climatology. Models are now being trialled by the generation control team. Forecasts are automatically displayed in front of operators and automatically loaded into HOP, the river optimisation model, which is used by operators in 24 x 7 river flow and generation management. Overall generation efficiency gains as a result of these forecasts have not yet been quantified.

	Climatology as predictor - all forecast lags	Today 1 day lag	Tomorrow 2 day lag	Day after tomorrow 3 day lag	4 day lag	5 day lag
(Mean Absolute Percentage Error)	(0.5)	(0.22)	(0.27)	(0.3)	(0.37)	(0.41)
Correlation coefficient	0.30	0.87	0.82	0.68	0.43	0.36
Explained variance	0.08	0.77	0.68	0.47	0.18	0.13

Table 1: Forecast skill (error) for Lake Ohau tributary inflow forecast for models with forecast lag of 1-5 days, compared with climatology (long term average inflow for the time of year).

Figure 1 shows an example of 5 day ahead inflow forecasts of daily average lake inflows made in the days leading up to a significant inflow event into Lake Ohau in late December 2010.

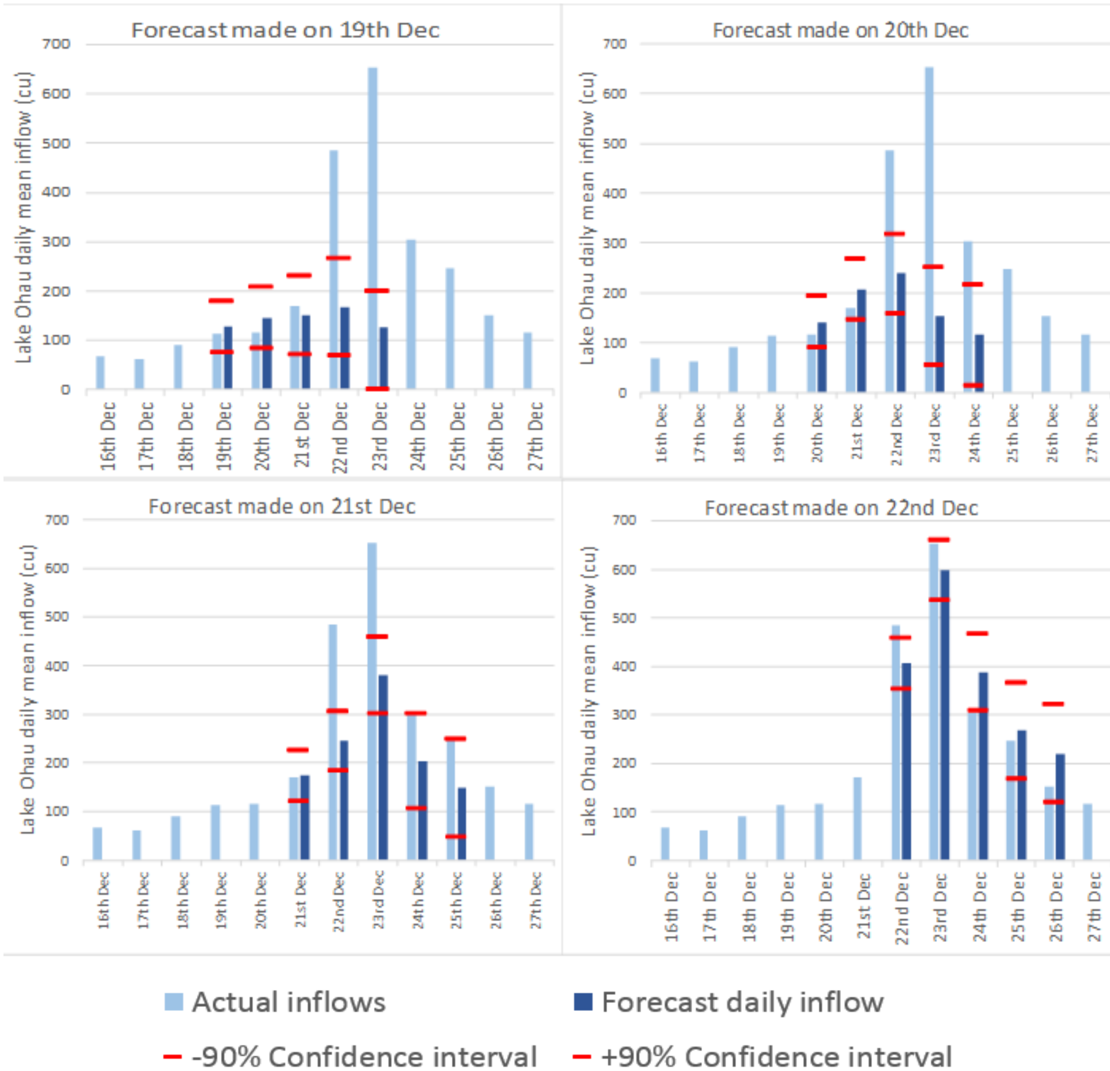

Figure 1: Lake Ohau tributary inflow forecasts for 5 day lags, made on four consecutive days in December 2010, with forecast values, 90% confidence limits, and actual inflows shown.

ASSESSING THE IMPACT OF MODEL SIMPLIFICATION ON RIVER FLOW RELIABILITY PREDICTIONS: A SYNTHETIC EXAMPLE

Channa Rajanayaka[1], Christian Zammit[2], Matthew Knowling[2], Catherine Moore[2], Jing Yang[1]
[1]Niwa, [2]GNS

Aims

Integrated surface and groundwater numerical models are being used extensively for water resource management. The complexity of these models vary considerably from simple lumped models to highly parameterised numerical models. Development of a simple model generally requires less data, information and resources. However, such models can typically only represent limited features and processes, whereas complex models allow representation of more detailed processes, requiring a larger number of parameters. The run-time of complex models is therefore generally higher and they are often numerically unstable. The challenge is therefore to construct a model that is sufficiently complex enough to answer a specific objective(s). As part of the GNS-led Smart Model Aquifer Management program, using a hypothetical catchment, we investigated the impact of using different levels of complexity of integrated surface and groundwater models on predicting river flow reliability, particularly in low flow conditions.

Method

A synthetic model was developed specifically for the purpose of this investigation. This hypothetical catchment covers approximately 1,500 km^2, and simulates a typical New Zealand catchment setting of hillslope catchment discharging to coastal plains. The modelled catchment consists of 50 sub-catchments, a wetland and a river network that discharges water to the ocean. The land-use type varies from forests in the upper sub-catchments and pastoral lands at lower levels, including irrigated dairying.

Firstly, a detailed model of the catchment was developed using HydroGeoSphere (HGS, 2006). As the model simulates transient three-dimensional flow in the surface water and groundwater domains in a fully integrated manner, it is treated here as a “synthetic reality”, providing a rigorous basis for judging various simplified models. The HGS model was used to develop mean daily river flow time-series “observations” at 10 different locations in the catchment.

Based on a conceptual understanding of the catchment, a TopNet-GW model was also developed, constituting a “simple model”. TopNet-GW is a semi-distributed physically-based model and simulates the physical characteristics of the hydrogeological system at sub-catchment level. The TopNet-GW model was run using both calibrated and uncalibrated parameter sets, and was then assessed against the HGS model (“reality”) to evaluate the predictive error and uncertainty, and the outcome of these factors in the decision-making context. The prediction of interest considered here is the number of days that river flow is below Q_{95} (representing low-flows). The model uncertainty was assessed using the GLUE method (Beven and Binley, 1992).

Results

Figure 1 shows the TopNet-GW predictions of low flow days below Q_{95} at the main catchment outflow based on 10,000 prior simulations. Similar analysis is currently being conducted for post-calibration.

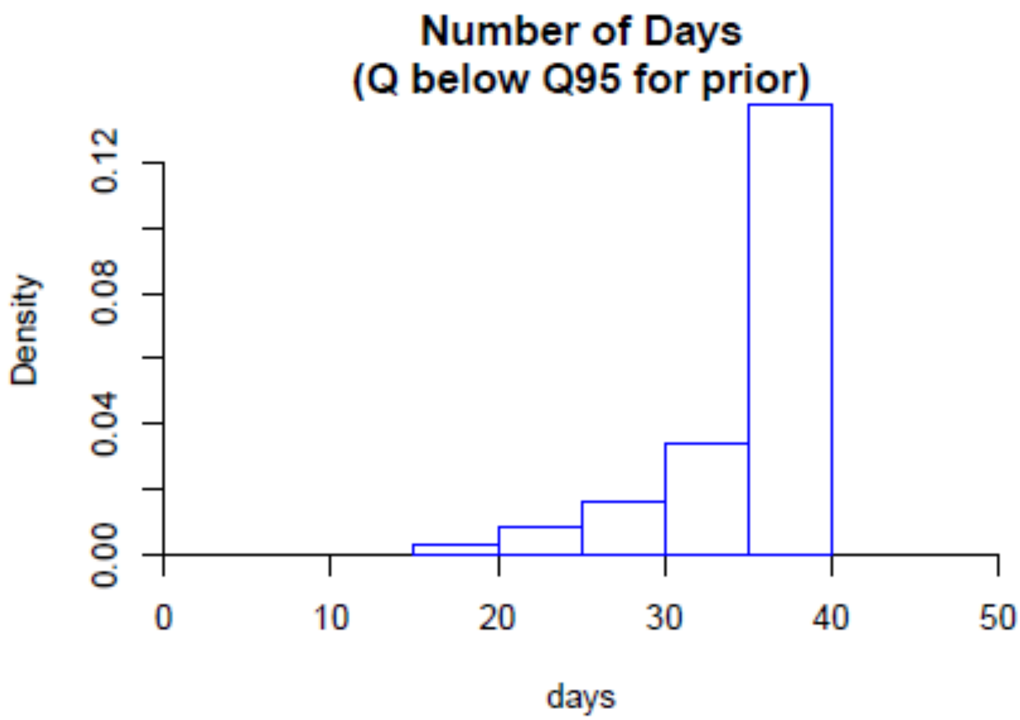

Figure 1: Number of days the flow is below Q_{95} at the main catchment outflow for the prior parameter probability distribution, based on 10,000 TopNet-GW simulations.

Further results, including the river flow hydrographs at the locations used for calibration and verification will be discussed at the presentation.

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STOCHASTIC RESPONSE FUNCTION FOR STREAM DEPLETION ASSESSMENT - PRACTICAL IMPLEMENTATION IN HAWKE'S BAY

Pawel Rakowski[1], Matthew Knowling[2], Jeremy White[2]
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Aims

Aim of the study was a development of user friendly, web based tool for stochastic estimation of stream depletion caused by groundwater pumping.

Method

The Heretaunga Aquifer is a deep sedimentary basin in the Hawke's Bay region of New Zealand. The aquifer comprises unconsolidated, highly conductive gravels and is a major source of water in the region. The aquifer is characterised by significant groundwater-surface water interaction, including substantial river losses that provide the majority of aquifer recharge, along with a number of valued spring fed streams. Increasing groundwater use has resulted in declining surface water flows and groundwater levels.

A groundwater model has been developed to inform management of the Heretaunga Aquifer. The objectives of the model included predicting impacts of groundwater pumping on surface water flows. The model has been developed using MODFLOW 2005 code, along with PEST methodology for calibration and uncertainty analysis.

The model was later converted into a stream depletion response function. This was achieved by running a series of simulations for groundwater pumping from a large number of locations in the model. For each simulation, the pumping impact on surface water flows was compared with flows under the base case of no groundwater pumping. With this method, the spatial distribution of spring flow responses to groundwater pumping was established. This allows for calculation of stream depletion anywhere in the model domain without running the model.

The work included development of a stochastic response function, based on calibration constrained Monte Carlo uncertainty analysis. This has been undertaken using PEST and required a supercomputer due to significant computing time demands (estimated 25,000 processing hours). This allow for stochastic calculation of stream depletion.

Results

The result has been developed into a web-enabled application, using Shiny R software, that can be used by non-technical users for implementing water allocation rules.

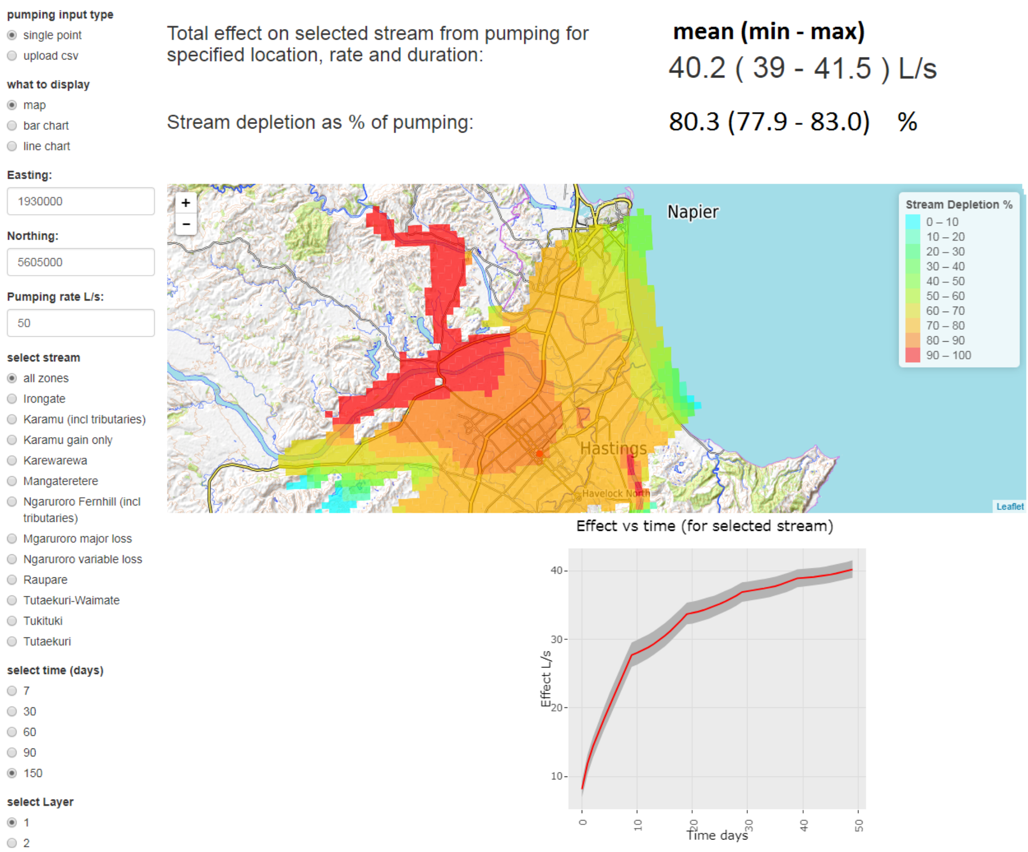

Figure 1

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CHARACTERISTICS AND CONTROLS OF SNOW COVER VARIABILITY IN THE CLUTHA CATCHMENT, REVEALED BY REMOTE SENSING

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Aims

A lack of routine observational data has been a significant historical limitation in characterising and understanding seasonal snow processes in New Zealand (Fitzharris *et al.*, 1999; Clark *et al.*, 2009). In turn, this limits our understanding of processes influencing spatio-temporal variability, and our ability to contextualize and constrain snow models. Here, these shortcomings are addressed by exploiting a 16-year series of MODIS imagery to map daily snow-covered area and produce a regional scale snow cover climatology for New Zealand's largest catchment, the Clutha. This record provides a basis for understanding spatio-temporal variability in seasonal snow cover, and combined with climatic data, provides insight into the controls of this variability.

Method

MODIS imagery was processed to map daily snow-covered area (SCA) for hydrological years 2001 – 2016 using MODImLab (Sirguey *et al.*, 2009). Key metrics including mean snow cover duration (SCD), annual SCD anomaly and daily snowline elevation were derived and assessed for temporal trends using linear regression. Spatial Principal Components Analysis (sPCA) was applied to maps of annual SCD anomaly to characterise modes of spatial variability. Semi-distributed regression analysis between SCD and temperature and precipitation anomalies (from Jobst, 2017; Jobst *et al.*, 2017) allowed the of SCD to climatic forcings to be assessed in the spatial context. Multiple linear regression (MLE) was used to assess the influence of anomalous winter air flow, as characterised by HYSPLIT back-trajectories, on inter-annual spatial variability of seasonal snow cover.

Results

On average, SCA peaks in late June, at around 30% of the catchment area, with 10% of the catchment area sustaining snow cover for > 120 days per year. A reduction in snow cover through July, before a second peak in August is a persistent feature throughout the time series. No significant temporal trend in snow-covered area (SCA), duration (SCD) or snowline elevation (SLE) was detected over the 16 year period, but substantial spatial and temporal variability was revealed. SPCA identified six distinct modes of spatial variability, characterising 77% of the observed variability in snow cover duration (SCD). The spatial structure of principal components extends beyond that associated with topographic controls on snow distribution, highlighting the influence of winter synoptic scale circulation variability, particularly anomalous flow from the North-East and East. SCD was found to have greater sensitivity to temperature than precipitation. Importantly, the relationships between SCD and temperature and precipitation anomalies were spatially variable. Temperature sensitivity was statistically significant ($p \leq 0.05$) for most ranges within the catchment, and greatest on and near the main divide, exceeding 30 d °C^{-1}. Associated R^2 values ranged from 0.40 – 0.55. Temperature sensitivity decreased in strength and significance in the eastern part of the catchment. While precipitation sensitivity of SCD was weaker for all mountain ranges, maximum sensitivity occurred for ranges between 40 and 60 km east of the divide. The spatial relationship between temperature and SCD is interpreted as highlighting the roles of solar radiation and wind. This observation suggests that using a simple degree-day model to reconstruct snow cover and snow pack within the catchment could be challenging. While the spatial precipitation-SCD relationship is relatively weak, it may reflect the role of enhanced spillover during winters with anomalously strong westerly air flow. This study shows that interannual variability in SCD exceeds any signal of longer term climate change over the study period, which stands in contrast to other regions globally (e.g., Saavedra *et al.*, 2018). Improved context is also provided for understanding snowmelt runoff, as well as informing ongoing efforts to improve the modelling of seasonal snow within the Southern Alps.

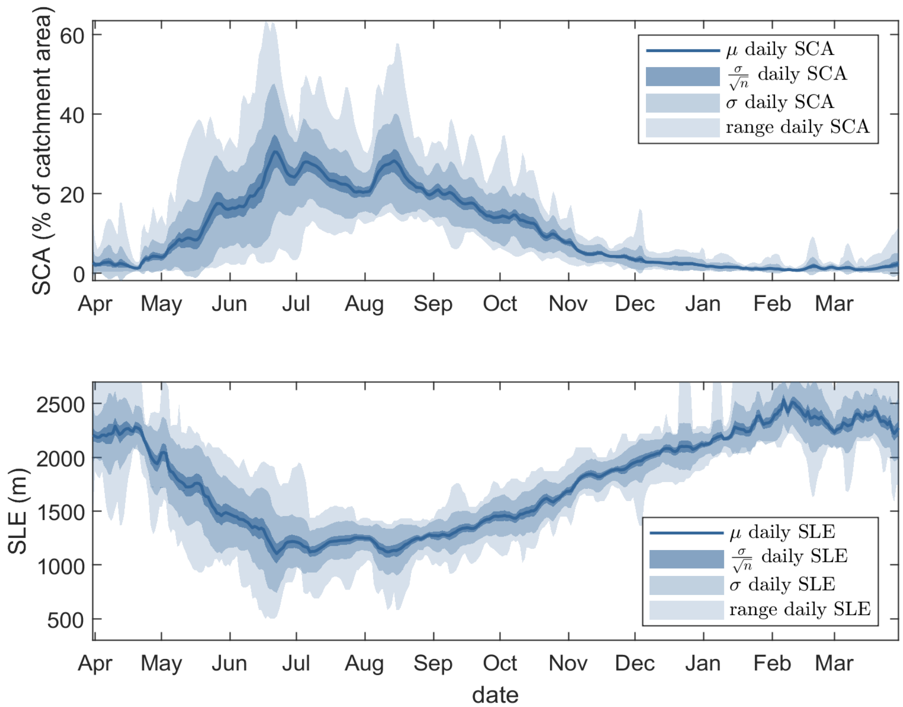

Figure 1: Mean daily snow cover (as a % of catchment area) and snow line elevation (SLE) for the Clutha Catchment for the period 2001 – 2016.

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WHY DID THE CLUTHA HAVE RECORD FLOWS IN 1957/58?

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Aims

This presentation is an exploration of the very high flows in the Clutha river during the 1957/58 year. The year period was notable for a number of storms and flooding events that affected Otago and several regions across the country. Such storms were often associated with the negative polarity of the Southern Annular Mode and occurred during a moderate El Niño event. The 1957/58 flows stand out in the historical record especially as they occurred during a 30-year spell of the negative Pacific Decadal Oscillation which on average is associated with weaker westerly winds over New Zealand, below-normal precipitation in the Southern Alps and headwaters of the main South Island rivers, and reduced average flows in the Clutha and other South Island rivers.

Method

This work was initiated during a study of the effects of the Pacific Decadal Oscillation (PDO, Mantua et al, 1997) upon New Zealand river flows, in particular a time series of annual mean flows in the Clutha River generated by Alastair McKerchar from Contact Energy data (Fig. 1). It is clear that the 1957/58 year stands out as the highest mean flow in the Clutha in the period from the late 1940s.

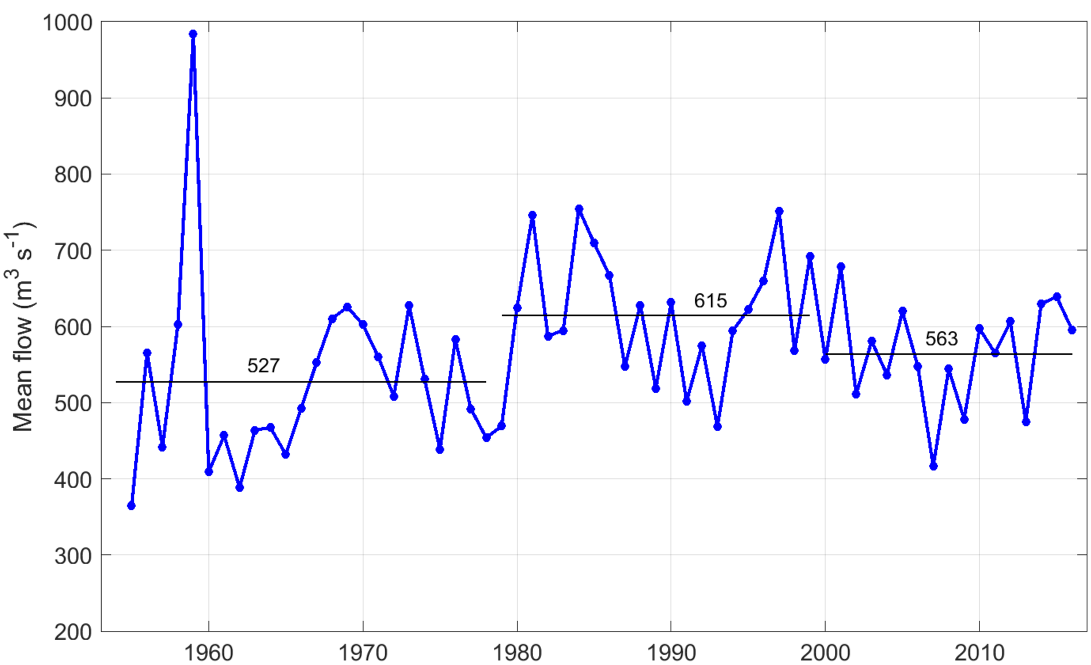

Figure 1: Annual mean flows (Oct-Sep) in the Clutha River, measured at Balclutha. The year is the year of the September (the end of the 12-month period). The horizontal lines indicate mean flows for different polarities of the PDO: negative before 1978, positive 1978-1999, negative since 2000. Data courtesy of Contact Energy.

The high flow in 1957/58 has been analysed in terms of precipitation in the Southern Alps and monthly flows in the Clutha, using observational data obtained from NIWA. The large-scale setting was analysed using fields from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis (Kalnay et al 1996). Indices of the Southern Annular Mode (SAM, Marshall 2003) were obtained from the British Antarctic Survey (https://legacy.bas.ac.uk/met/gjma/sam.html), and the Southern Oscillation Index (SOI, a measure of ENSO activity, Troup 1965) was obtained from the Australian Bureau of Meteorology (ftp://ftp.bom.gov.au/anon/home/ncc/www/sco/soi/soiplaintext.html).

Results

High flows in the Clutha occurred through the period November 1957 to June 1958, during which time the monthly flows stayed above 150% of normal. The highest flows and heaviest precipitation occurred during February 1958. Milford Sound recorded 1.75m of rainfall for the month of February 1958, and recorded over 1m in November 1957, March 1958, and May 1958. The SAM had one of its most negative excursions on record in November 1957 and was almost continuously negative from October 1957 to July 1958.

The meteorological conditions during 1957/58 will be outlined, along with the larger-scale setting. Details of individual flood events will be described using observational records and using contemporary newspaper reports.

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CHANGES IN SOUTHERN HEMISPHERE PRECIPITATION PATTERNS THROUGH THE 21ST CENTURY IN GLOBAL CHEMISTRY-CLIMATE MODELS

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Aims

Through the 21st century, the intensity and distribution of rainfall is expected to change as atmospheric composition continues to evolve. As greenhouse gases (GHGs) accumulate in the atmosphere, precipitation is projected to increase on average in a warmer climate (Boucher *et al.,* 2013). Furthermore the Antarctic ozone hole is projected to recover from the effects of chlorine- and bromine-containing ozone-depleting substances (ODSs), following the Montreal Protocol for Substances that Deplete the Ozone Layer. Antarctic ozone depletion increases the Southern Annular Mode index, which in turn impacts the storm tracks and rainfall patterns over the Southern Ocean (Arblaster *et al.,* 2014). Finally, anthropogenic aerosol emissions may impact precipitation patterns via changes in radiative forcing and through their role as cloud condensation nuclei.

Method

To disentangle the influences of greenhouse gases, aerosols and ozone-depleting substances on precipitation, we analysed sensitivity simulations from six coupled atmosphere-ocean chemistry-climate models which participated in the joint SPARC/IGAC (Stratosphere-Troposphere Processes and their Role in Climate/International Global Atmospheric Chemistry) activity, the Chemistry-Climate Model Initiative (CCMI; Morgenstern *et al.,* 2017). Comparing sensitivity simulations with a future reference simulation of the 21st century allows the individual influences of GHGs, aerosols and ODSs to be identified.

Results

As an example, Fig. 1a shows that Southern Hemisphere precipitation increases by up to 0.5 mm day^{-1} (approximately a 50% increase) in one of the CCMI models, WACCM (Whole-Atmosphere Community Climate Model). By comparing the 2090s precipitation pattern in the reference simulation with a simulation with constant 1960s GHG concentrations, it can be seen that most of the increase in precipitation in the reference simulation is due to increased GHGs (Fig. 1b).

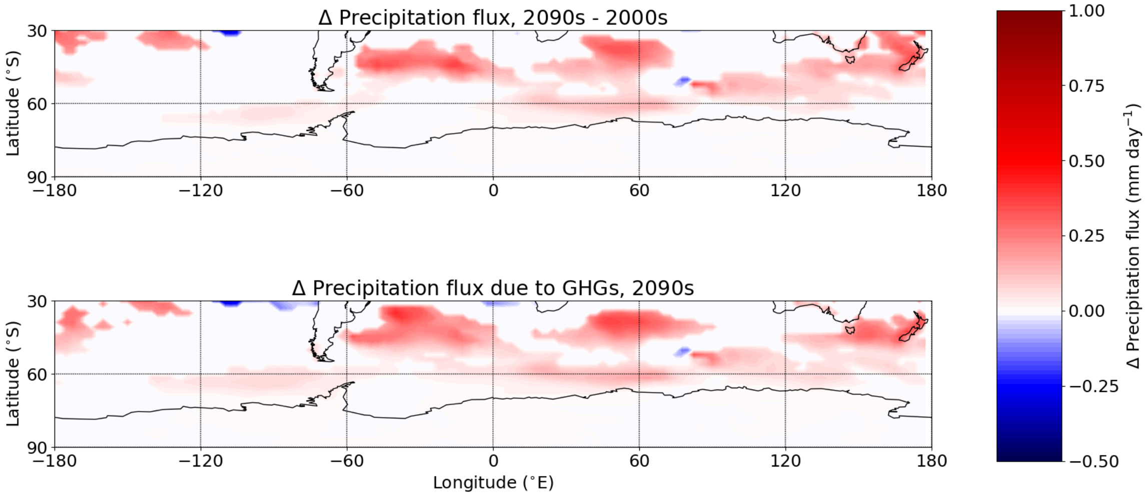

Figure 1: Change in precipitation flux (liquid and solid phases from all types of clouds) in the WACCM model between: (a) the 2000s and the 2090s, for a "future reference" simulation (2090s minus 2000s); (b) 2090s rainfall in the reference simulation compared with a sensitivity simulation with greenhouse gas concentrations fixed at constant 1960 levels (reference minus fixed GHGs). For each simulation, three ensemble members were performed, and the ensemble mean is shown here. Regions in which the difference is not statistically significant at the 95% level of confidence (as calculated with Student's t test, $p < 0.05$) are set to zero.

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UNDERSTANDING THE DYNAMICS OF SHALLOW GROUNDWATER: THE CHRISTCHURCH EXPERIENCE

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Following the 2010/2011 Canterbury Earthquake Sequence, EQC installed thousands of holes to inform geotechnical engineers about soil conditions. Subsequently, ~1000 were used to monitor shallow groundwater and inform modelling of the water table. This modelling of the water table, together with the detailed geotechnical studies, has led to greater understanding of liquefaction vulnerability, through generation of statistical representations of depth to groundwater.

In 2016, the groundwater network was rationalised to ~250 sites and instrumented with transducers, logging water level and temperature every 10 minutes. This improved efficiency data collection, but also resulted in more accurate monitoring. The new high-resolution dataset is a game changer. It provides insight into the short-term groundwater response to rainfall, tides and river flows, and has enabled the generation of tens of thousands of surfaces to characterise, spatially, the variability of groundwater levels and flow.

It has highlighted the highly dynamic response of the water table to drivers such as rainfall, river flow, tides, and even evapotranspiration. This has huge potential value in understanding the variability of groundwater levels, and hence the consequent effects on liquefaction potential, antecedent conditions to flooding and general issues of rising groundwater with sea level rise and climate change. Rainfall events can cause a short-lived spike in groundwater level of up to a metre higher than usual in some areas, but a much more damped and delayed response in others (see Figure 10). These responses are missed with a single weekly or monthly measurement, as illustrated in Figure 11.

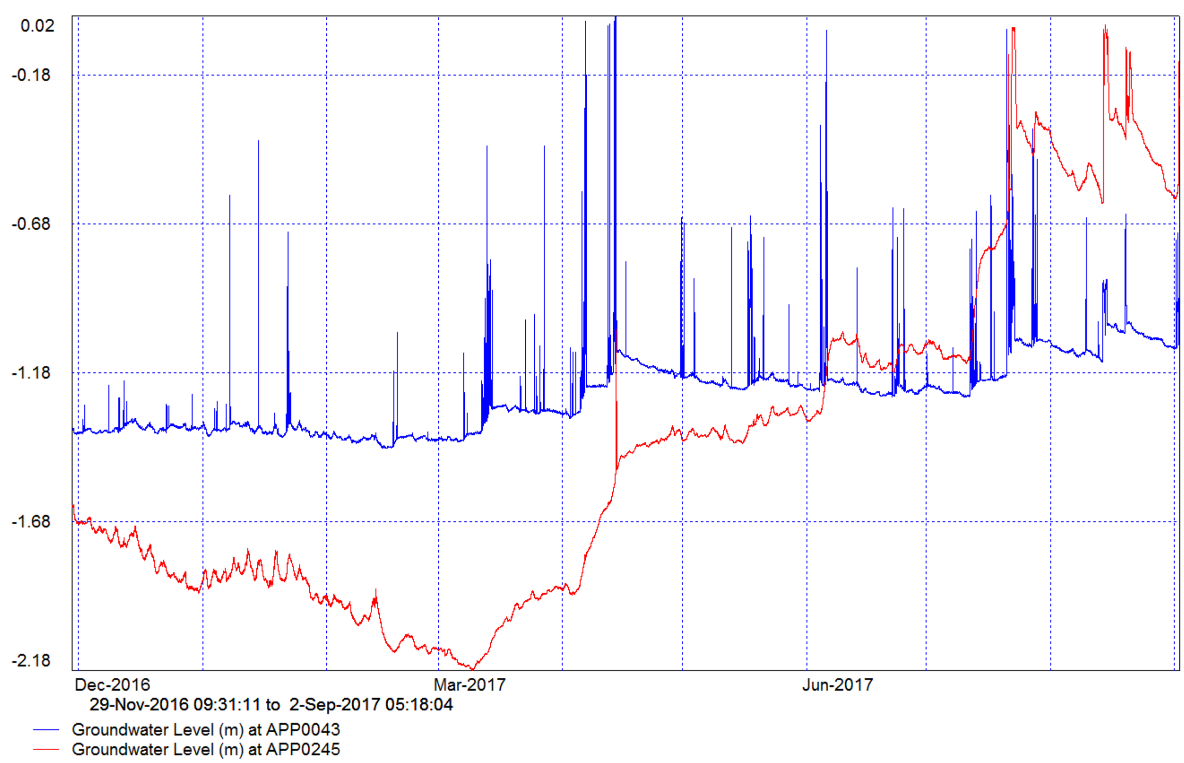

Figure 10: Contrasting responses to rainfall events in APP043 and APP245

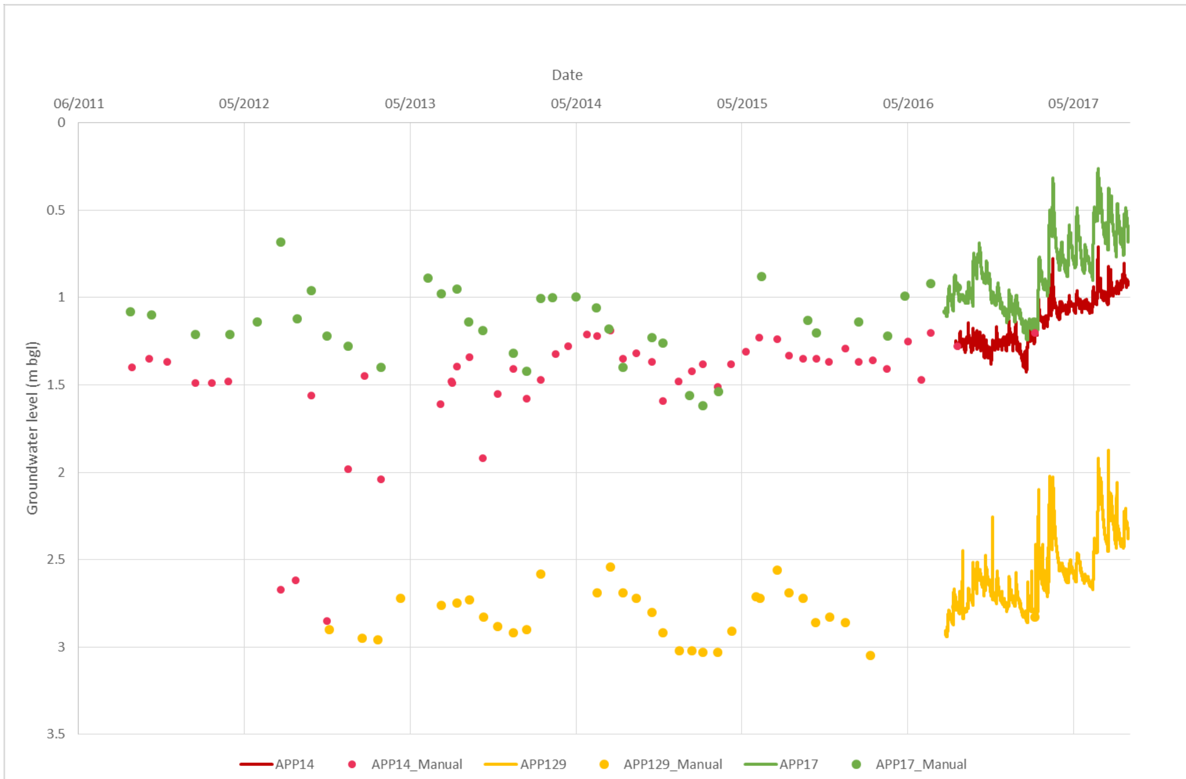

Figure 11: Dipped and high resolution data for three piezometers

The data sets a new standard of monitoring for urban areas constructed on shallow groundwater, where hazards such as liquefaction and flooding are driven by changes in groundwater level that can occur over hours or days. This rich dataset, together with further research and analysis, will inform the management of groundwater related natural hazards in Canterbury (and other hydrogeologically similar areas of New Zealand).

EIGENMODELLING TO PREDICT THE IMPACTS OF CLIMATE AND IRRIGATION

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Aims

In Canterbury, the winters of 2015/2016 were characterised by low rainfall recharge, resulting in record low groundwater levels in some wells across Canterbury at the end of the 2016/2017 summer. The aim of this work was to assess whether declining groundwater levels at the end of 2016 and start of 2017 were being driven by climate or abstraction.

Method

For the Selwyn and Ashburton zones, eigenmodels (Bidwell & Morgan, 2002; Bidwell, 2003) for 23 wells were developed (Rutter, 2018). The models were calibrated to measured groundwater levels and then used to separate the impacts of groundwater abstraction (and subsequent irrigation) and climatic influences on groundwater levels.

Eigenmodels incorporate bulk aquifer parameters which are calibrated to match the measured groundwater level response at specific wells. Spatial variation across the catchment is accommodated by the inclusion of zones, each with differing aquifer stresses (land surface recharge (LSR) and pumping).

Time series of land use over the model domain was generated primarily from Environment Canterbury's consents and wells databases, and included the development of irrigation (and the underlying increase in abstraction and increase in recharge) through the years.

To help understand whether the low groundwater levels in 2017 have been exacerbated by pumping, the effects of pumping were removed from the eigenmodel predictions for the wells that were reasonably well calibrated. Additional recharge occurs on irrigated land, due to the fact that soil moisture deficits are higher compared to dry land conditions. And the additional LSR under border dyke irrigation is much larger than under the same land spray irrigated. Therefore, the effects of additional recharge due to irrigation were also removed (reverted to dryland LSR).

Results and Discussion

The modelled relative influences of climate versus pumping were quite variable. In the southwest area (near Ashburton), the predicted groundwater levels without abstraction and with dryland recharge were lower than measured. This is due to the historical dominance of border dyke irrigation in this area, which results in artificially high groundwater levels. Normally, the hydraulic effects of removing irrigation recharge and pumping would be partially rebalanced by interactions with the Ashburton River. However, due to the simplicity of the eigenmodel method, it does not hydraulically rebalance as it would in reality. Therefore, while a reduction in predicted groundwater levels in this area is likely to be correct, the magnitude of the change is likely to be overstated by the model.

In general, for the rest of the study area, abstraction appears to have resulted in lower groundwater levels, in some cases by up to 10 m. Often the effects of removing pumping and irrigation is to reduce the seasonal variability from the signal. This is particularly noticeable in the coastal zone south of the Rakaia River. Comparing the modelled and measured groundwater levels illustrates how abstraction enhances the seasonal variability, with more extreme lows in the measured data than what might have occurred without pumping (see Figure 12 and Figure 13). Winter groundwater levels are still well represented in most cases. Though in some wells there appears to be a general decline in groundwater levels compared with what would have been expected without abstraction. This would very likely have been the case with L36/1226, L36/0064 and L36/0058 except that groundwater levels in the vicinity of these bores were positively offset as a result of the September 2010 earthquake.

In some cases, measured groundwater levels have shown little recovery in recent years, but have benefitted from a positive offset from the September earthquake, meaning that their levels are not currently exceptionally low. Where there are well calibrated eigenmodels, it is can be seen that the predicted groundwater levels would have been at record lows without this offset.

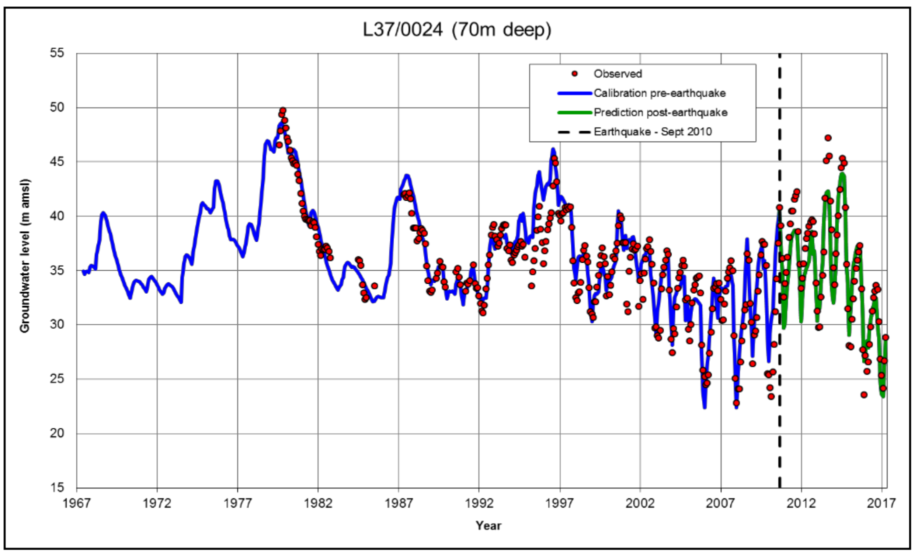

Figure 12: Calibrated eigen model for L37/0024 with abstraction and irrigation

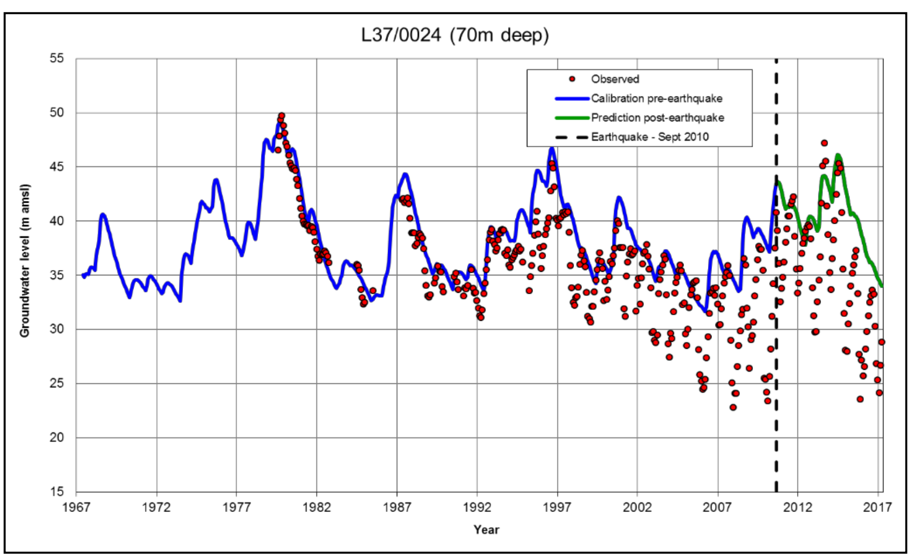

Figure 13: Dryland eigen model for L37/0024

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Acknowledgements

This work must acknowledge and thank Environment Canterbury for funding the investigation of the ongoing impacts of the Darfield EQ on groundwater levels.

NEW ZEALAND GUST CLIMATOLOGY PART II: REVISING NEW ZEALAND REGIONAL WIND SPEEDS

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[1]The University Of Auckland, [2]NIWA

Aims

Proper design and construction for wind-resistant buildings and infrastructure are crucial to minimise the direct loss of lives, properties, and the subsequent broader-scale economic impact after severe wind events. On the other hand, in any design project for large structures, safety considerations must be balanced against the additional cost of over-design. Therefore, the correct determination of design wind speeds has a crucial role in achieving appropriate structural design. All buildings and structures in New Zealand are designed to resist the effects of the wind speeds specified in the wind-loading standard (AS/NZS1170.2, 2011). While much of the content of AS/NZS1170.2 (2011) has been prepared in Australia, the design wind speeds for New Zealand are the responsibility of New Zealand researchers and practitioners.

The regional wind speeds given in AS/NZS1170.2 (2011) were mostly calculated based on the wind measurements taken in Australia before the 1990s. However, there are substantial differences in both wind climate of the two countries and the instrumentation used in Australia and New Zealand. Currently, the regional wind speeds for the whole of New Zealand, except Wellington region, are exactly the same as the regional wind speeds for the majority of Australia.

This paper emphasises the analysis of the existing and historical weather database of wind speeds at few selected sites around New Zealand, correcting them for site exposure, and determining gust speeds as a function of wind direction for various return periods.

It is also of great interest to know the possible effects of climate changes, particularly increasing sea surface temperature, on intensity and frequency of extreme winds, and subsequent influences on regional wind speeds. Although introducing higher design wind speeds seems to be a global solution to allow for the increasing trends in tropical cyclone/hurricane cat 4 and 5 occurrences, there is a great deal of uncertainty in the estimations, and regulators may resist imposing additional economic costs of higher design wind loads without more evidence and confidence in the trends (Holmes, 2015). Therefore, it is crucial to carefully study extreme events and accurately estimate the appropriate design wind loads.

In this paper, the wind data recorded at a number of selected stations in New Zealand are subjected to a robust homogenisation algorithm (See Part I, and Safaei Pirooz, Flay, and Azorin-Molina 2018; Safaei Pirooz, Flay, and Turner 2018) and then the extreme value analysis is carried out using the maximum gust speeds, and the magnitudes of regional wind speeds for different return periods and also the directional multipliers are computed and compared with values given in (AS/NZS1170.2, 2011).

Method

The selected stations for this paper are Auckland Aero, Pukekohe, Wellington Aero, Paraparaumu, Christchurch, and Tiwai Point, which are chosen from the three defined regions in AS/NZS1170.2 (2011), namely A6, A7, and W. Maximum daily and annual gust wind speeds recorded at each station are extracted from NIWA's climate database (NIWA 2018), and subjected to a robust quality control and homogenisation algorithm to eliminate all the breakpoints resulted from changes in instruments and data acquisition process, site relocation and other systematic errors (see Part I for more details). The extreme value analysis is carried out for each of 8 wind sectors an also combined directions in order to compute the directional multipliers.

For calculating extreme winds at different return periods, two approaches are employed to estimate the parameters of the Generalised Extreme Value (GEV) distribution (Eq. 1).

$$F_U(U) = \exp\{-[1 - k(U-u)/a]^{1/k}\} \tag{1}$$

First, assuming the parent data has Type I distribution (i.e. k = 0), the mode of extreme value distribution (u) and the scale parameter (a) are found using Gumbel method (Gumbel 1958). Second, a numerical method, Maximum Likelihood (ML) approach, is used to calculate k, u, and a. Type I distribution is unbounded at the upper end, thus provides conservative regional wind speeds. However, calculating k, as opposed to assuming it to be zero, provides more realistic values. The distributions of real data and fitting Type I and ML results will be provided in the full paper.

Results

The results of this paper are compared with the current regional wind speeds given in (AS/NZS1170.2, 2011), and some changes and recommendations for both regional wind speeds and directional multiplier are proposed to be considered in the future version of the standard.

As an example, the results of the Wellington region, including the Wellington Aero and Paraparaumu stations, are shown in Figures 1 and 2. Figure 1 shows that both approaches give higher regional wind speeds, particularly at low return periods, compared to the values given in AS/NZS1170.2 (2011). Also, there are discrepancies between the computed directional multipliers and AS/NZS1170.2 (2011), which will be discussed in detail in the full conference paper.

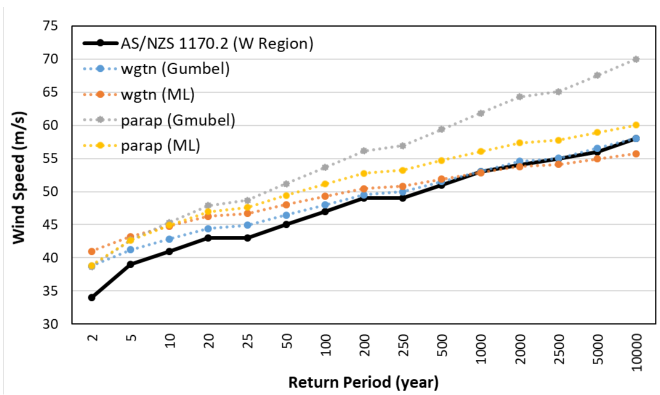

Figure 14: The all-direction regional wind speeds for W region stations

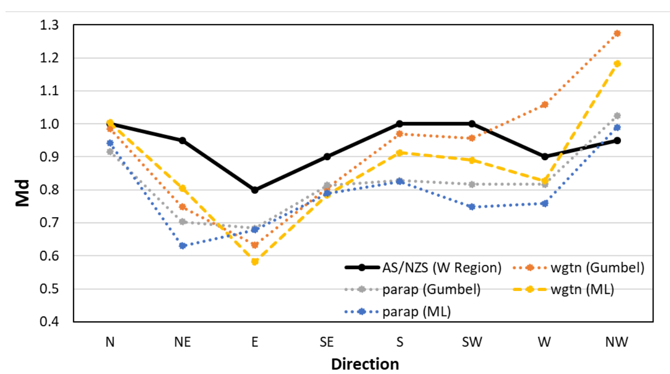

Figure 15: Directional multipliers computed for W region stations

Analysing the extreme wind speeds of different regions in New Zealand showed that there are areas within the defined regions (i.e. A6, A7, and W) that have higher regional wind speeds and different directional multipliers than those provided in the current version of AS/NZS1170.2 (2011). Therefore, this paper also discusses the possibility of adding a new region to the future version of AS/NZS1170.2 for New Zealand.

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SOUTHERN ALPS SNOW AND ICE LOSSES FOR SUMMER 2017/18: FROM REMOTE SENSING AND MODELLING

Jim Salinger[1], Blair Fitzharris[2], Pascal Sirguey[3], Nicolas Cullen[2]
[1]*University of Haifa,* [2]*University of Otago,* [3]*University of Otago*

Aims

The goal of this research is to provide ice volume and seasonal snow estimates of the Southern Alps mountain system in response to the 2017/18 summer (DJF) from remote sensing methods, and estimates seasonal snow deposition, ablation and accumulation from conceptual modelling. This past summer was the warmest in the instrumental record. Results are then related to a glacier inventory to calculate changes in ice volume for the whole Southern Alps. High resolution SENTINEL-2 satellite images are used to derive the End of Summer Snowline EOSS of the Tasman Glacier ($EOSS_{TAS}$) and the Southern Alps ($EOSS_{ALPS)}$, and ice volume loss.

Method

Chinn *et al* (2012) from $EOSS_{ALPS}$ has estimated the mass balance and ice volume of small and medium size glaciers of the Southern Alps from 1977-2008, and $EOSS_{ALPS}$ has recently been updated to 2017 (Willsman 2018). $EOSS_{Tas}$ was assessed using a time series of SENTINEL-2 satellite images capturing the rise of the snowline to its highest observed altitude using maps from 14 March 2018 (NZDT). Changes to Southern Alps ice volume in 2018, are estimated from variations of $EOSS_{TAS}$ using its strong relationship with that of the Southern Alps ($EOSS_{ALPS}$). The $EOSS_{Tas}$ values are used to extend the volume changes prior to 1977 back to 1961 so that the 2018 ice loss can be placed in historical context. Systematic monitoring of glacier-wide albedo at Brewster Glacier with MODIS (Sirguey *et al.,* 2016) and related linearly to its mass balance (Cullen *et al.,* 2017) provided an alternative linear model relating the mass balance of Brewster Glacier to that of the Southern Alps (R^2=0.85). Uncertainties are obtained via propagating the standard error in the regression parameters to the predicted values. A conceptual model (SnowSim, Fitzharris and Garr 1995, Kerr 2005), was developed that calculates seasonal snow deposition, ablation and accumulation. The model has been tested against observations of snow.

Results

The SENTINEL-2 satellite images placed $EOSS_{Tas}$ at 2238m (Figure 1), the highest on record, which translated to an $EOSS_{ALPS}$ of 2204m, 386m above the 1981-2010 average. It shows that there was an estimated 3.4±0.6 km^3 water equivalent (w.e) loss of ice in the small to medium glaciers. Allowing for the proglacial lake growth and downwasting in the 12 large glaciers of 0.2 km^3 makes the 2018 loss 3.6 ±0.6 km^3 w.e., from 40.6 in 2017 to 37.0 km^3 in 2018. The total volume change since 1961 from all glaciers was from a volume of 61.0 km^3 to 37.0 km^3, a loss of 24.0 km^3 w.e., a loss of 39.4% (Figure 2a). The summer of 2018 caused the largest annual volume loss of permanent ice in the last 57 years. This was confirmed by observations of surface albedo at Brewster Glacier with Moderate Resolution Imaging Spectroradiometer (MODIS) (Sirguey *et al* 2016, Cullen *et al* 2017) which, related estimated for the Southern Alps by Willsman (2018) yielded an ice volume loss of -3.1±0.7 km^3. The albedo method revealed the fast and uninterrupted depletion of the winter snowpack compared to the long-term trajectory (Figure 2b), leading to an exceptionally early exposure of the glacier in December 2017. Despite short-lived snow to low levels brought by cyclone Gita in February 2018, surface albedo decayed further to its lowest since 2000 and captured the EOSS rising to an unprecedented level close to or above the top of the glacier.

Although there has been a steady loss from the 12 large glaciers since 1961 at a rate of about 0.2 km^3 per glacier year, the largest fluctuations are driven by the small to medium glaciers. A change in climate regime around 1998 heralded the commencement of a period of rapid ice loss. The total ice loss from the small/medium glaciers was 13.1 km^3, and the large glaciers 11.0 km^3. The SnowSim model of Fitzharris and Garr (1995) (Fig. 5c) showed that the water stored as seasonal snow leading up to August and from mid-December 2018 was the lowest on record. From mid-January it became "negative', indicating all the seasonal snow had melted, with extraordinary loss of permanent glacier snow and ice.

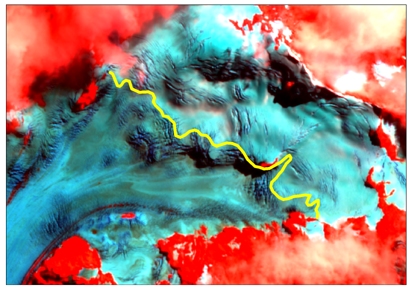

Figure 1: SENTINAL-2 satellite image. This satellite image is from 14 March 2018, enhanced to display contrast in the accumulation area of the Tasman Glacier. The line shows the End of Summer Snowline for the Tasman Glacier ($EOSS_{TAS}$) for 2018.

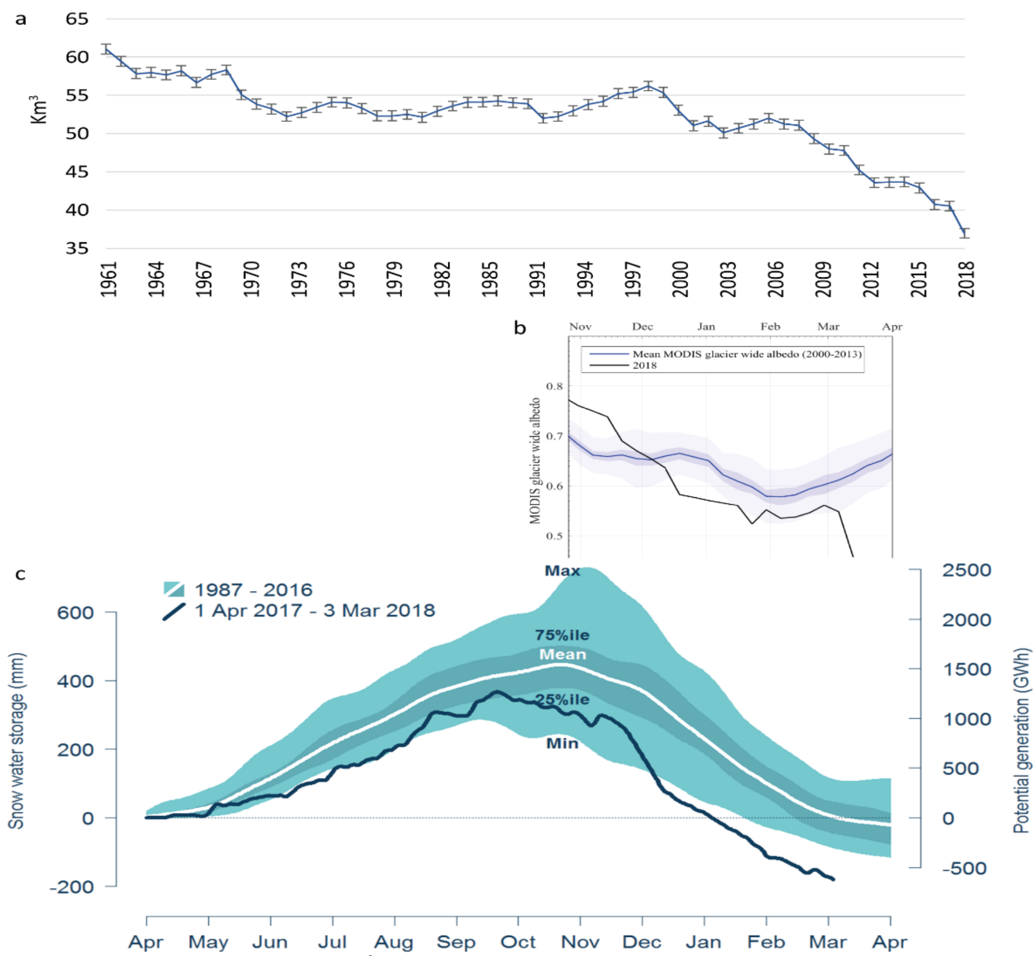

Figure 2: (a.) Southern Alps ice volume (km^3 of water equivalent), with error bars, for all glaciers of the Southern Alps from 1961 to 2018, **(b)** mean (blue) MODIS glacier wide albedo (2000-2013) and the 2017/18 season (black), **c**. water stored as seasonal snow (mm) for the period 1987 – 2016. The season from 1 Apr 2017 – 3 Mar 2018 is shown as the blue line.

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DENITRIFICATION RATE INPUTS TO GROUNDWATER MODELS

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Aims

In New Zealand, recent increases in land use intensity associated with farming and dairying have resulted in significant increase of nitrate levels in groundwater and surface water systems. A key removal process for nitrate is denitrification, which requires four conditions, namely: anoxic or low oxygen conditions; provision of a suitable electron donor; microbial consortia capable of carrying out denitrification; and sufficient nitrate. Reducing conditions are necessary for denitrification, thus the groundwater redox status can be used to identify subsurface zones where potentially significant nitrate reduction can occur. The aims of this work are to a) estimate spatially distributed redox status at the basin scale b) quantify denitrification rate uncertainty at the numerical grid scale and c) to quantify the effects of aggregation scaling and spatial averaging on denitrification parameter uncertainty and on model predictive uncertainties.

Method

The denitrification zones (“Oxic”, “Mixed” and “Reduced”) are derived using discriminant analysis, and the discriminant model prediction uncertainty is used to characterize redox condition uncertainty, at the numerical grid scale. We implement a Monte Carlo scheme, where the redox state is considered a random variable and each realization is recalibrated against measured nitrate concentrations. All other flow and transport parameters are retained from the deterministic calibrated model, so that no other sources of uncertainty can be contributing to our assessment results. Within each zone denitrification processes are assumed to follow a first- order irreversible mass reduction relationship.

The multinomial probability mass functions of the redox class occurrences were upscaled from the grid scale (250 m) to scales ranging from 500 m to 10000 m. These upscaled probability functions were used as the basis for the upscaled Monte Carlo scheme. Two distinct cases of spatial averaging are considered. In the first case denitrification rates are considered to be spatially distributed categorical parameters, with their physical values determined at the grid scale. Alternatively, in the second case, the denitrification rate is considered to be a model parameter, calibrated to the observations comprising the model calibration dataset.

Results

Calibrated “Mixed” and “Reduced” denitrification rates distributions are found to be skewed towards lower values, resulting in averages smaller than the calibrated deterministic equivalents. The “Oxic” zone calibrated denitrification rates are more symmetrically distributed and approximately 3 orders of magnitude lower than the mixed and reduced rates. Using the calibrated denitrification standard deviation as a measure of their uncertainty the “Oxic” and “Mixed” zone rates are more uncertain than the “Reduced” ones.

Spatial averaging of the class membership probabilistic fields results in decreasing uncertainty of the average catchment denitrification potential (as calculated from the average denitrification rate). When denitrification rate is considered as a model parameter (calibrated to the observations comprising the model calibration dataset) spatial averaging of the class membership probabilistic fields results in increasing uncertainty of the average calibrated denitrification rates for all three zones. Similarly, the average of the denitrification rate standard deviation calculated at each grid location also increases with aggregation scale.

Finally, the model predictive uncertainty also increases with scale. When the scaling effect of the calibrated denitrification rates is ignored and only the class membership probabilistic fields are aggregated, predictive uncertainty remains relatively stable with increasing scale.

This work is part of the MBIE-funded ‘Smart Aquifer Management’ programme led by GNS.

OPTIMISING THE PERFORMANCE OF AN IN-STREAM WOODCHIP DENITRIFYING BIOREACTOR UNDER UNCERTAIN HYDROLOGICAL CONDITIONS

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Aims

Nitrate pollution of surface water systems from farming activities is a global environmental problem. In most parts of New Zealand, over the past 20 years there has been rapid intensification of farming which is forecasted to continue. Thin alluvial soils prone to nitrogen leaching, overlie fast flowing, highly permeable gravel aquifers. Being unconfined and aerobic the aquifers themselves have poor capacity to attenuate nitrate, the result being detrimental effects on the region's water quality.

Woodchip denitrifying bioreactors (WDBs) that target filtration of nitrate from farm drainage water, are low-key, passive water treatment systems, that are gaining recognition as an efficient tool for tackling the issue of diffuse nitrate pollution from agricultural landscapes. Whilst the hydraulic regime and concentration of nitrate in the drainage water constitute two fundamental environmental variables that determine the size of a denitrifying bioreactor, the issue of over- or under-treatment of water that might otherwise promote undesirable pollution swapping phenomena and construction costs also need to be factored into the overall design process. Conventional methods for optimizing the design of denitrifying bioreactors generally rely on deterministic models, even though many of the design parameters are not known with confidence.

Method

In this work we apply an alternative design philosophy and demonstrate how the bioreactor design process can be improved through application of stochastic methods. The design aspect of an 'in-stream' WDB planned for installation on a farm in South Canterbury is structured as a multi-objective performance optimization problem that is solved in a stochastic framework, using freely available open source tools.

The optimization objective in this work is to find out the geometric dimensions of the bioreactor (Figure 1) that lead to the best long term performance, translated in terms of cost and nitrate removal, without releasing unwanted by-products to the environment. These objectives can be summarized as:

- Minimize: Installation cost
- Minimize: Over and under treatment
- Maximize: Total nitrate mass treated
- Minimize: Outflow concentration
- Subject to:
    - Source flow rate and nitrate concentration
    - Permissible reactor dimensions
    - Reactor flow interception capacity
    - Reactor treatment capacity
    - Maximum reactor height

The in-stream reaction mathematical model is structured around the assumption of zero-order kinetics, while the through flow is assumed uniform, following Darcy's law. Uncertainty considerations regarding values of physical parameters that govern bioreactor performance are incorporated into the optimization problem through the substitution of the model deterministic variables with random variable equivalents. Each parameter value is sampled from a statistical distribution in accordance with site observations and previously published data. The stochastic objective functions are numerically calculated using a Monte Carlo scheme and their averages are used to generate the deterministic objective functions equivalents. Finally, the multi objective deterministic problem is reduced to a two objective one, using the weighting sum method allowing the representation of an optimal solution set in a two dimensional plot, where the decision maker can better visualize and comprehend the decision related trade-offs.

Results

The proposed design methodology for the 'in-stream' WDB improves significantly over conventional methods, incorporating in the decision making the uncertainty of physical parameters that are not known with confidence, while allowing the decision maker to weight the trade-offs between competing objectives before a final design is selected.

In the current study, a preferred reactor design, 75 m in length and 1.5 m in height was selected from the optimal Pareto set. Over the projected 10-year operational lifetime, it is forecasted that the reactor will achieve approximately 33.9% average nitrate removal of the expected nitrate mass in the drain (±0.1% for the 99% confidence interval around the mean), or 56% of the nitrate in the bioreactor intercepted drain flows. It is predicted that the cost of N-removal offered by the denitrifying bioreactor will be NZ$9.70/kg-N.

Objective uncertainties are sourced from the uncertainty of different parameters. Intercepted flow, outlet concentration and average treatment percentage uncertainties are dominated by the uncertainties related to the woodchip hydraulic conductivity and its anticipated reduction over time, while uncertainties regarding the over or under treatment of drain flows and the total mass of nitrate removed are dominated by uncertainties in the woodchip reactivity and its time dependent decay.

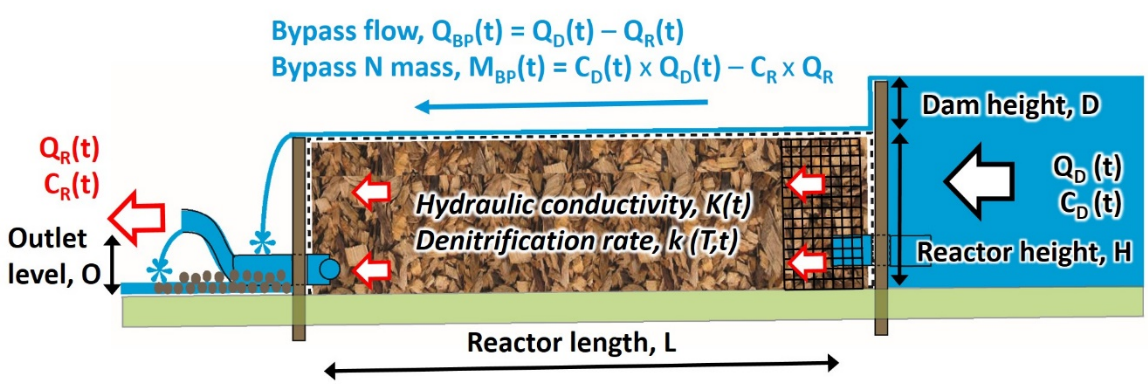

Figure 16: Schematic design of the in-stream WDB planned at Barkers Creek. The woodchip-filled reactor is a sealed unit, lined with EPDM rubber. Drain water enters the reactor and flows through woodchip-filled gabion baskets that act as serviceable sediment traps/pre-filters, before passing through more woodchip that fuels denitrification reactions. Drain flows that the WDB cannot handle spill over the bioreactor and bypass any treatment.

MANAGED AQUIFER RECHARGE IN SUPPORT OF FISHERIES AND AGRICULTURE: A CASE STUDY FROM NORTHWEST USA

Jake Scherberg[1], Jason Keller[2], Mike Milczarek[2], Troy Baker[3], Steven Patten[3]
[1]Williamson Water Advisory, [2]GeoSystems Analysis, [3]Walla Walla Basin Watershed Council

Aims

This presentation aims to provide a case study of water management strategies utilizing managed aquifer recharge (MAR) in the Walla Walla Basin (WWB), located in a semi-arid region of Eastern Washington and Oregon, receiving an average of 430 mm of annual rainfall, primarily over the winter and spring months. The WWB has extensive agricultural lands and the Walla Walla River (WWR) is the primary source of water for irrigation during the spring and early summer. Groundwater is the dominant water source for irrigation during the dry summer months spanning from late June through October.

Gradually declining groundwater elevations in the WWB due to increasing groundwater use, and anthropogenic changes to surface hydrology and efforts at groundwater recharge have been recorded for over 60 years with no abatement expected under current water management practices (Patten 2010; Bower and Lindsey, 2010). Conversion of unlined canals to piped systems to eliminate canal seepage and optimize irrigation efficiency has reduced canal seepage and resulted in reduced recharge of the alluvial aquifer. Groundwater losses have resulted in reduced groundwater return flows to the WWR, contributing to low summer flows that limit fish passage and lead to high stream temperatures that degrade fish habitat.

Since 2004 MAR has been practiced in the WWB. MAR is achieved by diverting water from the WWR through the existing irrigation canal and pipe network when flows are high relative to irrigation demand, typically mid-November to mid-May, to infiltration basins or underground perforated pipes where the water then percolates into the underlying alluvial aquifer. There are currently seven active MAR sites in the basin. MAR has been demonstrated to increase groundwater storage, thereby increasing groundwater available to irrigators and also increasing groundwater return flows to some streams (Bower and Lindsey, 2010; Henry, 2013). However, the effects of the MAR program are primarily observed in the proximity of the recharge sites. It is hypothesized that more widely distributed MAR sites will have a more widespread effect on the groundwater resources, and possibly benefit surface water resources (Scherberg et al., 2014).

Method

A numerical groundwater-surface water model was developed using the Integrated Water Flow Model (IWFM) code, a code developed by the California Department of Water Resources with particular strength in calculating groundwater-surface water interactions and agricultural water use. The model was calibrated to observed hydrological conditions and applied to predict future conditions under current management practices in the Baseline Forward Model (BFM). Four alternative water management scenarios were developed to predict how lining canals and concurrently reducing irrigation diversions from the WWR (a practice referred to as water savings) with varying levels of MAR would impact stream flows and groundwater storage (Geosystems Analysis, 2016).

Results

Model results predict that seasonal low flows in the WWR at the downstream reference location will increase an average of 0.13 m^3/s (10%) relative to baseline conditions due conversion of unlined canals to pipelines (Current MAR-Piped). With MAR increased to 18.0 Mm^3/y and 29.9 Mm^3/y and an additional 58 km piping (Increased MAR-Piped and Maximum MAR-Piped scenarios), the predicted flow increases in the WWR averaged 0.16 m^3/s (11%) and 0.26 m^3/s (18%), respectively, over the summer months. Without MAR (No MAR-Piped), flow is predicted to decrease for the months of August and September relative to baseline conditions. The "No MAR-Piped" and "Current MAR-Piped" scenarios are predicted to reduce groundwater storage relative to the baseline model due to reduced recharge from canal seepage. The "Maximum MAR-Piped" scenario is predicted to yield groundwater storage that is greater than baseline conditions while groundwater storage is predicted to be similar to baseline conditions in the "Increased MAR-Piped" scenario.

Water management scenarios showed a strong impact on predicted net groundwater discharge to surface water in the model area. Conversion of canals to pipelines eliminated seepage losses from those canals and was predicted to lower groundwater elevations and decrease stream baseflows. This was counteracted by increasing MAR which was predicted to have an increasing effect on stream baseflows with distance downstream. An increase in baseflows would likely have potential ecological benefits in the form of increased summer flow rates, lower stream temperature, and improved riparian habitat.

Water savings from increased piping is estimated to result in an approximately 30,500 m^3/d reduction in surface water diversions into the primary irrigation canals for the months of July through October, an 11.7 % decrease from the BFM. This translates to 0.53 m^3/day of reduced diversions from the WWR per meter of additional pipeline. Relative to the BFM the Current MAR-Piped scenario predicts approximately 7,800 m^3/d less net groundwater discharge to surface water over the model area from July through October, a 4.3 % decrease. Therefore, the model predicts that with the continuation of current MAR practices the net water savings in the WWR following pipe installation would be approximately 22,700 m^3/d after factoring for reduced groundwater discharge. This reduction in groundwater discharge would effectively offset 25.5 % of the pipeline water savings in the WWR. Pipeline installation and MAR site development and operation are estimated to cost approximately US$600 per meter of pipeline and US$90,000 per MAR site. The costs translate to approximately US$27.1 million per 0.1 m^3/s of increased flow (July through October) at Touchet for pipeline installation and US$3.7 million USD per 0.1 m^3/s of increased flow for MAR installation.

Water management scenario results indicate that converting canals into pipelines is likely to have a negative impact on groundwater resources and limit instream water savings if undertaken in isolation. However, if combined with increased application of MAR there is potential to mitigate the impact of the canal piping by enhancing groundwater storage and groundwater discharge. The Maximum MAR-Piped scenario is predicted to provide the most widespread benefits to both fish habitat and groundwater resources by allowing for significantly increased summer flows in the WWR and some tributaries while stabilizing aquifer storage.

The use of MAR in the WWB is an opportunity to practice conjunctive management of groundwater and surface water resources to meet conflicting water demands in the basin. Model results suggest that increasing application of MAR as a basin water management strategy will increase summer time stream flows at a cost less than converting canals to pipelines. Direct water savings with pipe installation is predicted to increase summer flow in the WWR; however model predictions indicate that without MAR decreased groundwater discharge will reduce this benefit. As MAR development proceeds in the WWB it is important that recharge water and groundwater quality monitoring is continued to ensure that water quality standards are maintained, as is required by law.

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RMA PLAN REVIEW AS HYPOTHESIS TESTING – A SOCIO-HYDROLOGY PERSPECTIVE

David Scott[1], Fouad Alkhaier[2]

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The development of RMA Plans typically involves the use of models to support the evaluation of environmental management strategies. Hydrologists often contribute to the plan development process by developing models of groundwater and surface water systems and then use these models to explore alternative scenarios. Such models are inherently uncertain and it has become increasingly expected that model outputs should be accompanied by a description of prediction uncertainty. Typically, the outputs of these hydrological models provide inputs to other models (e.g. ecologic, economic, social) which are arguably even more uncertain yet those uncertainties are less commonly addressed. In the final outcome the multiple model-based scenario evaluations are commonly used to inform the development and adoption of an RMA Plan.

The agreed objectives and measures incorporated in an adopted Plan inevitably involve compromises which reflect the range of interests and values of the various stakeholders. The process is essentially a political one yet the final outcome can reasonably be characterized as the adoption of an agreed 'model' and the Plan measures can be seen as hypotheses, e.g. 'if groundwater abstraction adjacent to streams is constrained then the frequency of low flows will be reduced', or 'land use controls on nitrate will lead to improved water quality'.

Once the exhaustive RMA Plan preparation process has run its course it is understandable that hydrologists will naturally be inclined to return to their 'day job' involving monitoring of the environment and improving the reliability of models with the objective of reducing the uncertainty of predictions. This monitoring and investigation can be justified on the basis that within the next 10 years a Plan review will be required and, presumably, improved knowledge and more certain models will be useful and possibly necessary.

The socio-hydrology perspective, which is the focus of this paper, suggests an alternative approach. Garcia et al. (2016) draw attention to the coupling of human and hydrological systems noting that 'human activity impacts the hydrological cycle and hydrological conditions can, but do not always, trigger changes in human systems.' It is important to note that RMA Plans also influence human activity, or at least they are intended to. In preparing to answer the question 'Has the Plan worked?' it is vitally important that human activity is observed along with hydrological conditions.

When planning on-going monitoring and investigations a socio-hydrology perspective encourages us to consider questions such as:

1. What are the Plan objectives? Have quantitative targets been established? Are they measurable?

- Have the objectives been met? Or, at least, are things heading in the right direction?
- To what extent has the Plan been implemented? (e.g. have relevant consent conditions been applied and complied with? Have the expected developments taken place?)
- Have the assumptions implicit in the plan been valid (e.g. climate scenarios and irrigation efficiencies?)

- What are the main sources of uncertainty in model predictions? And what potential exists to reduce uncertainty in a strategically useful way?
- And so on…

This line of enquiry encourages a broad multi-disciplinary approach to the design of future monitoring and investigation programmes. Ideally this design would be undertaken in conjunction with Plan development and the identified requirements would be included amongst the Plan measures.

This paper will describe how the socio-hydrology perspective is able to contribute to the design of a comprehensive monitoring and investigation programme for the Te Waihora/Lake Ellesmere catchment. Plan Change 1 of the Canterbury Land and Water Regional Plan introduced policies, rules and limits to manage water quality and quantity in the catchment. A 5-year effectiveness and efficiency review of the plan change and associated non-statutory provisions is scheduled for 2021 and a 10-year plan review is due in 2026. By focusing on the hypotheses implicit in the Plan, the socio-hydrology perspective is expected to encourage a holistic approach to the development of the information base required for these planned reviews.

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END-MEMBER MIXING ANALYSIS OF RECHARGE SOURCES IN THE CHRISTCHURCH AQUIFER SYSTEM

Lisa Scott[1], Zeb Etheridge[1], Matt Hanson[1]
[1]*Environment Canterbury*

Aims

The aim of this work was to estimate the recharge source contributions, especially the proportion of Waimakariri River water, to the water supply aquifer for Christchurch. This was needed to evaluate the potential for nitrate concentrations to increase if high nitrate land surface recharge water from intensively farmed land north of the Waimakariri River flowed under the river into the Christchurch aquifer system.

Method

We used chloride concentrations (Cl) and oxygen stable isotope ratios ($\delta^{18}O$) as natural tracers in a probabilistic ternary end-member mixing analysis (EMMA) to estimate the proportions of contributing recharge sources at target locations across the Christchurch groundwater system. The Cl and $\delta^{18}O$ data were sourced from water quality databases (Environment Canterbury and Christchurch City Council); research investigations (Cronin, 2012; Tutbury, 2015); and drilling and sampling additional wells to fill spatial gaps.

First, we characterised three end-members: coastal land surface recharge (LSR), inland LSR and Waimakariri River recharge. Rainfall near the coast has higher chloride concentrations and more enriched $\delta^{18}O$ than rainfall on the higher inland plains, so we split the LSR component into two end-members. We combined the data from several representative sites including river sites, wells, and lysimeter soil drainage samples to determine a probability density function (PDF) for each of the tracers and recharge source end-members (Figure 1).

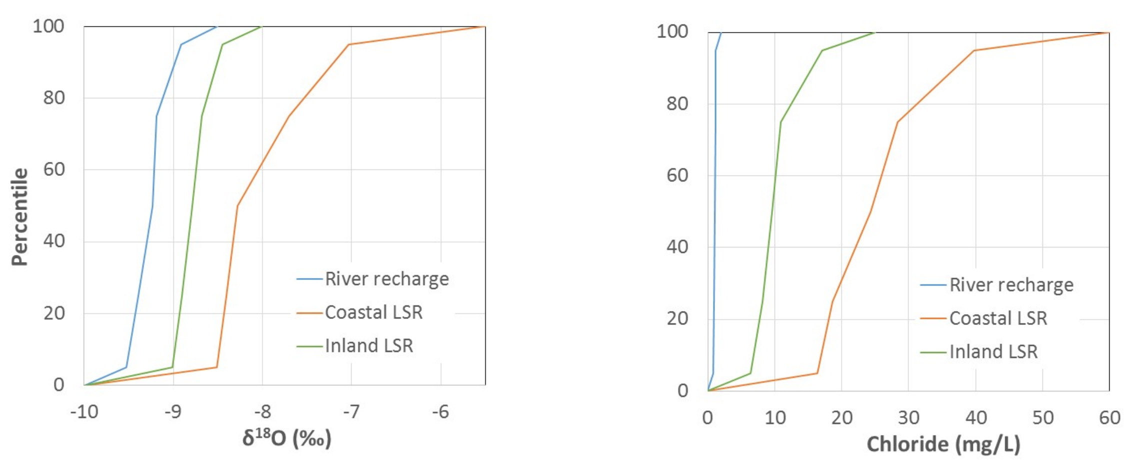

Figure 1: Probability density functions for $\delta^{18}O$ and Cl concentrations in recharge end-members

Next, we identified mixing target locations, each assumed to contain a mixture of the three end-members. We grouped wells into spatially proximal clusters of similar depth and tracer concentrations and used the available Cl and $\delta^{18}O$ data to define PDFs for the target sites.

Finally, we set up a system of simultaneous equations based on the concentrations of two tracers and the fact that the three recharge sources must add to 100%. We used a probabilistic method (Monte Carlo) to repeatedly sample the distribution of input parameters, solving each time for the three unknowns: the proportions of each of the three end members in our target groundwater. We generated PDFs of the proportions of river recharge, coastal LSR and inland LSR at each target location (Locations A to M, Figure 2).

Results

The Monte Carlo approach has advantages over a deterministic model because it allows us to consider the uncertainties of our estimates. In Figure 2 we show an example where we summarise median proportions and estimated ranges of river recharge reaching shallow wells, less than 30 m deep. From these results, we can visualise a tongue of groundwater dominated by Waimakariri river water extending across the city from Mcleans Island Forest (J) across to Redwood (I). Higher proportions of LSR occur to the north (Belfast, G and Kainga, H) and across the central city. At well depths of 100 to 200 m we saw evidence of higher proportions of river recharge contributing to groundwater in the south west of Christchurch city (areas B to F).

The results of this work were presented with other evidence – hydrogeochemistry, water levels and aquifer test parameters (Etheridge *et al*., 2018) – to an expert panel tasked with assessing the likelihood of groundwater flow and nitrate transport occurring beneath the Waimakariri River. The EMMA results were also used for filtering of a suite of groundwater models developed via a calibration-constrained Monte Carlo uncertainty analysis process (see Hemmings *et al*, 2018).

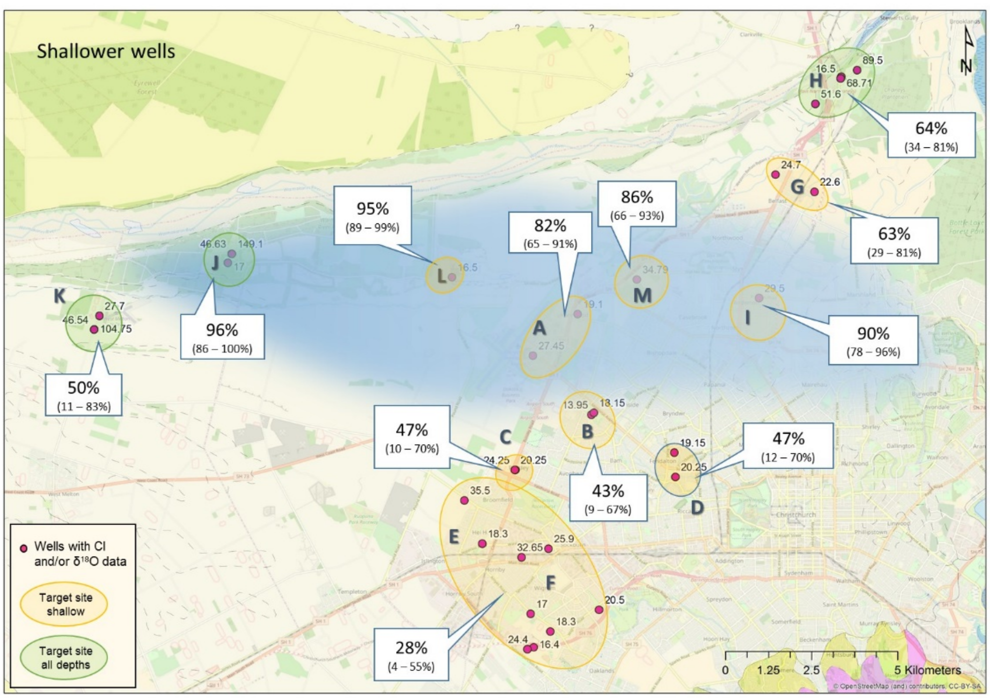

Figure 2: Median (and 90% confidence interval ranges) for the fraction of Waimakariri River recharge contributing to groundwater as calculated from 2 tracer EMMA for target sites with shallower wells. The well locations are labelled by mid-screen depths.

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APPLICATION OF GIBBS' MODEL TO DRAINAGE NETWORKS AND ITS IMPLICATION ON FLOOD MITIGATION IN URBAN CATCHMENTS

Junshik Hwang[1], Gyung Jae Kim[1], Yongwon Seo[1,2]

[1]*Yeungnam University,* [2]*KWRA*

Drainage network is an essential component in an urban infrastructure system for the purpose of collection and drainage of surface runoff. Topological characteristics of urban drainage networks has not received much attention in spite of its impacts on flooding and peak flows. In this study, we introduced stochastic network models to evaluate the urban drainage networks and its implication to flood mitigation in urban catchments. Gibbs' model was used to analyze the network configuration of 31 urban catchments with various slope ranges. The results showed that urban drainage networks can be less efficient than river in nature in terms of the drainage time, which is counter-intuitive. On the other hand, the analysis showed that efficient networks have risks of flood concentration and, hence, increase potential flood risks. This study showed that efficient networks tend to have higher peak flows at the outlet and vice versa. Therefore, an alternative drainage network layout, which is less efficient and more sinuous, was introduced and it resulted in reduced peak flows and flooding. This result shows managing a proper drainage network layout can contribute to flood mitigation in urban catchments.

Aims

This study aims to evaluate urban drainage networks in terms of network configuration and its implication to peak flows and flood mitigation measures in urban catchments. We applied Gibb's model to analyse network configuration. A sample catchment (Seocho4) was selected among 31 catchment to demonstrate the effect of drainage network layout on peak flows of the resulting hydrographs by comparing hydrographs from the original network and Gibbs' model. Actual rainfall records in 2011 was used for this purpose to show how network layout affects the peak flows and floods.

Method

Network topology has been an interesting topic due to its implication on hydrologic response of a catchment (Rodriguez-Iturbe and Valdes, 1978). We applied Gibbs' model (Troutman and Karlinger, 1992) to urbanized catchments in Seoul, South Korea and also South-Eastern Chicago area to examine the network characteristics in terms of the value of beta. The network characteristics are related to the value of beta (Seo and Schmidt, 2012; 2013; 2014). Figure 1 shows the relation between the value of beta and the sinuosity of simulated networks. As the beta decreases, the network becomes more and more sinuous. In contrast, the network becomes less sinuous as the beta increases to infinity.

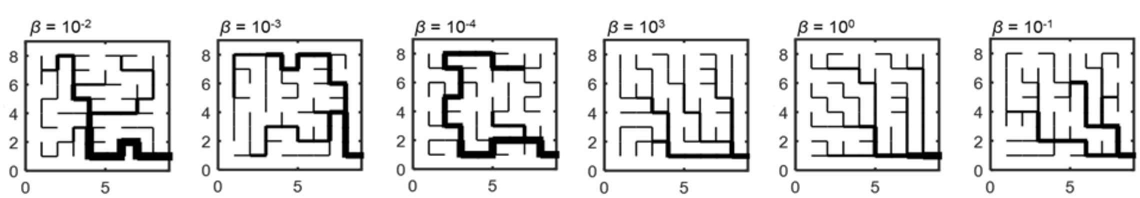

Figure 1: Gibbs' model with different values of a parameter β

Results

The result shows that the configuration of urban drainage network layout has little relation with catchment properties, such as catchment slope. It is important because it means that the configuration of layout is not automatically or naturally determined following topography. It also means it is necessary to think of configuration of drainage network layout intentionally because it has a great relation with flooding or peak flows of drainage network runoff hydrographs. Figure 2 shows an alternative layout of a drainage network in Seoul (Seocho 4), which was obtained from Gibbs' model with different value of β (10^{-4}). The catchment had serious flood damage in 2011 and three sample storms were applied including the same amount of storm of 2011 to evaluate the alternative drainage network layout without any other changes in catchment properties. SWMM was used to evaluate the impact of the alternative layout as shown in Figure 2.

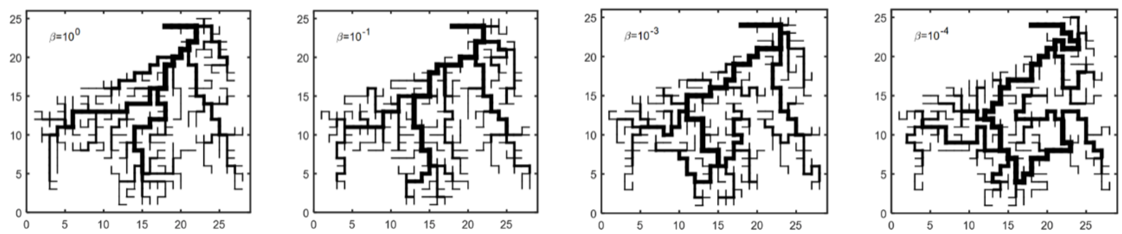

Figure 2: Application of alternative drainage network layout from Gibbs' model with different values of a parameter *β*

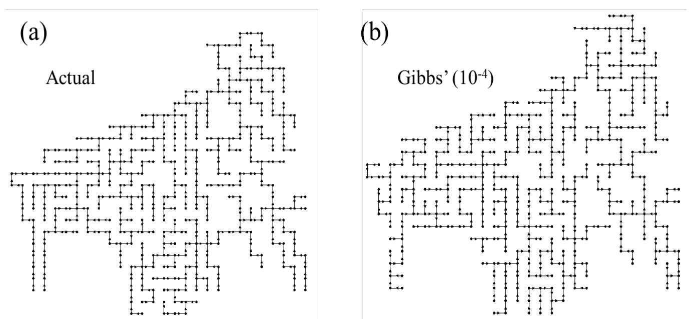

Figure 3: SWMM layouts of (a) the existing actual network and (b) an alternative network

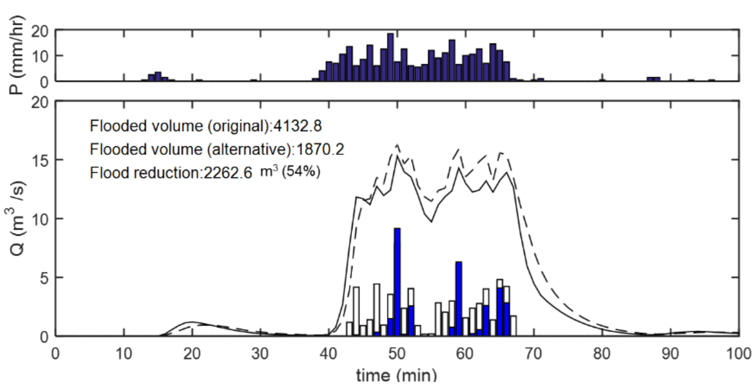

Figure 3: Reduction of flooded volume of water with a heavy storm of 2011

The result was interesting that the alternative layout reduced the volume of flooding or peak flows for the three storm cases. These results imply the configuration of a drainage network layout is crucial because it does have a strong impact on flooding or peak flows of drainage network runoff hydrographs. The case study of Seoul suggests the need to seek for alternative drainage network layout, but not just for efficiency in terms of reducing flood risks. Typically, a drainage system is designed to drain water from developed areas as prompt as possible. However, the analysis showed that efficiency of network can exacerbate flooding. The results show that efficient networks tend to have higher peak flows at the outlet. Changing drainage network layout of a test catchment resulted in reduced peak flows and flooded volume amount. In this regard, drainage network layout can be an alternative measure for efficient flood mitigation that reduces the peak flows of urban drainage network hydrographs.

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HOW CAN A STABLE ATMOSPHERE IMPACT EXTREME FIRE BEHAVIOR?

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Aims

Prediction of continuously evolving and in some cases rapidly changing fire behaviour requires a wide range of knowledge in complex interaction between wildfire and atmosphere, on top of relatively static influences of topography and vegetative fuels. While a considerable amount of research has focused on fire-atmosphere interactions, considerably less investigation has been undertaken on the structure of fire-induced flow circulations under the influence of various atmospheric stability. In particular, an inversion, a density interface between well-mixed turbulent layer and non-turbulent air in the capping stably layer, commonly forms in the atmospheric planetary boundary layer (PBL), with much drier air typically found above the inversion. Primary aims of this study is first to characterise the flow circulations and second to investigate the influence of atmospheric stability on the fire-induced circulations and resulting surface heat fluxes.

Method

A series of numerical experiments was conducted using idealised two-dimensional atmospheric simulations. Wildfire was represented using a prescribed stationary constant surface temperature in the simulations. The initial potential temperature soundings, $\theta(z)$, were constructed from a three-layer structure; a mixed layer with a constant potential temperature θ, a free atmosphere with a uniform potential temperature lapse rate (5K km^{-1}), and a capping inversion with a sharp θ jump (0.8, 4, or 8K/100 m) across the interface between the mixed layer and free atmosphere. Sensitivity tests were performed by changing two atmospheric stability parameters, z_i (mixed layer height) and $\Delta\theta_i$ (inversion strength capping the mixed layer), and two fire parameters, θ_f (strong surface heating representative of wildfire) and W_f (width of the θ_f) independently to investigate how each parameter controls the strength of fire-induced flow circulation. All simulations were conducted in dry and initially calm atmosphere.

Results

Simulated fire-induced flow circulation showed similar characteristics with density currents across all experiments, as relatively dense inflows towards the centre of the heat source and overlying return flow away from the heat source produced Kelvin Helmholtz billows. Results indicate that internal head circulation of the fire-induced flow with low pressure centre plays a role in surface wind variations near the heat source (Figure 1). In particular, periodic pulsations in surface horizontal winds within the inflow resulted from a rapid downward transfer of momentum. Higher z_i resulted in deeper inflow head circulation and surface wind speed maxima farther away from the heat source correspondingly. Stronger θ_f produced more vigorous circulations with convection penetrating higher into the free atmosphere (Figure 2). Implication of these results for the prediction of wildfire behaviour will be discussed.

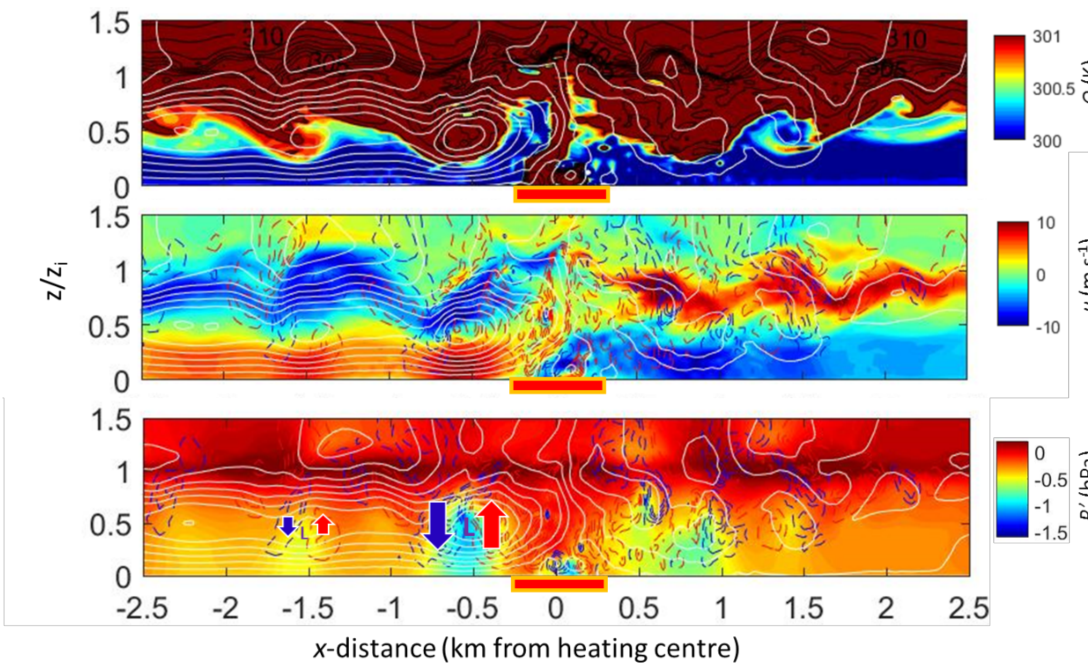

Figure 1: Contour plots of (top) potential temperature (black solid; color shaded between 300 and 301K), (middle) *u*-velocity (color shaded) and *w*-velocities (dashed, positive: red, negative: blue), and (bottom) pressure perturbations (color shaded) and the *w*-velocities at 133 min for the initial surface heating of 1500 K. Streamlines are shown with white solid lines. The initial mixed layer height was 1500 m AGL, initial inversion of 8K/100 m and free atmosphere potential temperature lapse rate for 5K km^{-1} for the simulation. The location of the stationary heat source is indicated by orange boxes on the bottom plots.

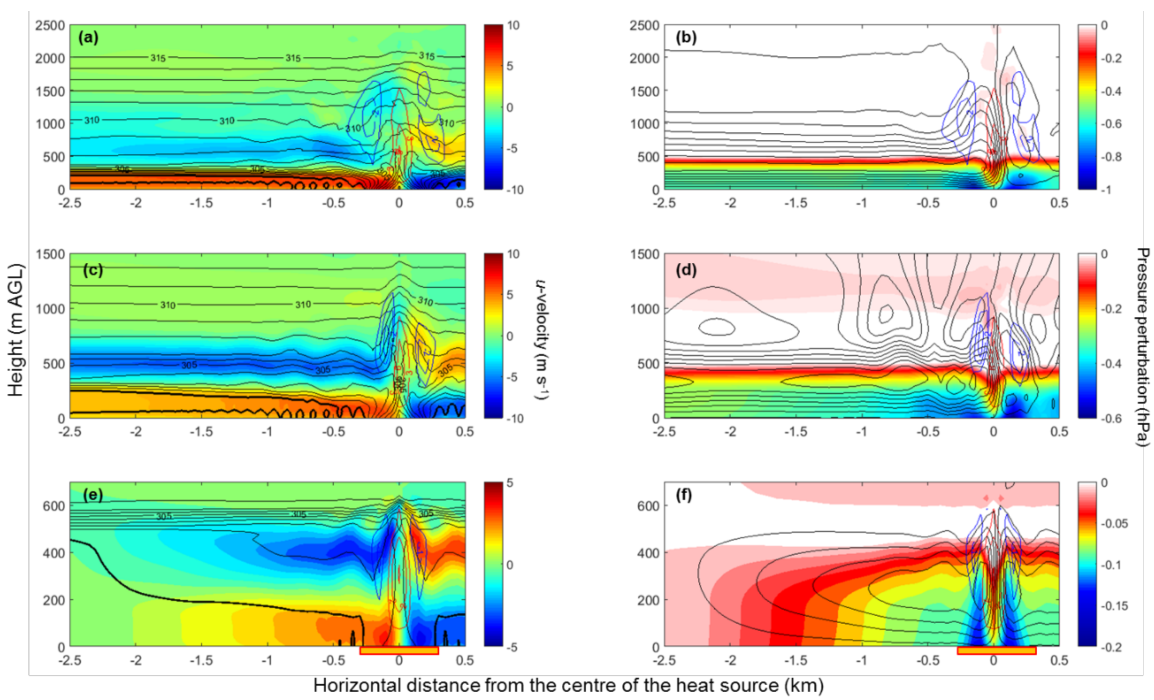

Figure 2: Contour plots of (left) mean *u*-velocity (color shaded), vertical velocities (dashed; red: positive; blue, negative), and potential temperature (solid black; 1K interval) and (right) mean temporal pressure perturbations (color shaded) and streamlines (black solid) averaged between 60 and 120 min for the initial surface heating of (top) 2500 K, (middle) 1500 K, and (bottom) 500 K. The initial mixed layer height was 500 m AGL for the three simulations. The location of the stationary heat source is indicated by orange boxes on the bottom plots.

APPLICATION OF WATHNET MODEL FOR ASSESSMNET OF IRRIGATION SHORTFALL

Shailesh Kumar Singh[1], Richard Ibbitt[1]
[1]*NIWA*

Knowledge of the likely rainfall and river flow for a coming season can improve management of an overall water resources system without unduly compromising either the environmental or productive behavior of the system. The objective of this study has been to assess the probability of irrigation demand shortfalls, i.e. soil moisture deficits, for a typical "run of the river" irrigation scheme so as to identify the duration and severity of potential shortfalls and to focus future infrastructure design considerations on where they are most likely to be effective. For the scheme considered, the impacts of shortfalls on four soil types with different water holding capacities have been examined, subject to constraints on the water that may be taken from the local river.

To do this a multi objective linear programming tool WATHNET has been used to build and run a model of the irrigation scheme. The model has then been used to calculate, from daily river flow, rainfall, and potential evaporation (which acts as pseudo demand), the likely amount of irrigation water that can be taken each day from the river. Part of the model's output is information on where and when shortfalls in irrigation requirements might occur. While the model has a number of potential uses, the one focused on in this study has been how to use predictions of 3-monthly rainfall and temperature to estimate potential daily water available for irrigation.

The method uses Monte-Carlo simulations, to produce multiple replicates of equally likely sequences of river flows, rainfall and potential evaporation values. A sub-set of the equally likely sequences is then selected using prediction information of the likely seasonal climate outlook from NIWA's Climate Update. The selected sequences, which are biased towards the seasonal climate prediction, are then used as inputs to multiple model runs. Each model run produces a set of outputs that show how the scheme would be expected to perform for each set of inputs. By using the output from all the "biased" model runs a probability distribution can be made of water availability for irrigation. By using the probability distributions for different components of the scheme, irrigators can assess how they may be affected by the predicted "weather" over the irrigation season.

The methodology has been demonstrated using the Shag River Irrigation Scheme located in the Otago region of New Zealand. The results compare the predicted soil moisture variation over two three-month periods with retrospective simulations based on the observed rainfalls, river flows and potential evaporation values. It has been found that WATHNET is able to simulate the 3-month soil moisture dynamic. In order to develop WATHNET as a tool to assess probabilities of irrigation shortfall it needs to be validated using measurements of soil moisture variations over an irrigation season at sites with different soil types.

LIDAR RESOLUTION FOR FLOOD MODELS

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Aims

LiDAR is used in hydrodynamic modelling for determining topography, ground cover, surface roughness and channel networks and for revealing hydraulic controls such as bridges, structure crest levels and levees. Scan densities from LiDAR sorties for hydraulic modelling typically range from 1-20 points/m^2. LiDAR "hits" may be from the ground, buildings or vegetation. For numerical hydraulic modelling purposes, LiDAR hits are converted to digital elevation models (DEMs) of the topography and may be used for roughness mapping [1]. While DEMs have been resampled at different resolutions to evaluate the effects of different grid cell sizes on flood simulations [2, 3] there is little information on the minimum resolution of raw LiDAR to supply sufficient information for accurate flood mapping at a given cell size.

Rain-on-grid hydrodynamic models now allow model domains to be extended into catchment areas [1] but the high LiDAR scan densities required for urban areas with infrastructure are unlikely to be necessary for e.g. hill country catchments. This research investigates the effects of LiDAR resolution in relation to flood models.

Method

Appropriate LiDAR resolution is investigated with case studies in an area that is representative of a wide range of New Zealand conditions. Three LiDAR resolutions with nominal point densities of 1, 4 and 8 points per square metre are investigated. The point cloud LiDAR data at the different resolutions is used to extract representative hydraulic modelling DEMs and representative hydraulic modelling roughness maps. The DEMs are studied to investigate narrow channel continuity, hydraulic controls and structure crest levels and to examine variations and errors in the respective DEMs. The different DEMs and roughness maps from LiDAR collected at different densities are evaluated with a hydrodynamic flood model.

LiDAR at nominal 1 point/m^2 density was supplied by Greater Wellington Regional Council and LiDAR at 4 and 8 points/m^2 was commissioned by Land Inventory New Zealand (LINZ) specifically for this study. The three data sets are called 'low', 'medium' and 'high' resolution in the following analyses.

Individual point co-ordinates (x,y,z) and reflected LiDAR intensity (i) of the point cloud data was analysed to extract ground elevation (Z) and ground roughness (Zo). This process used a search footprint. The ground elevation was determined to be the lowest z elevation within the footprint (Figure 1). The ground roughness was determined by an algorithm which analyses variation and absorption of returns within the local search footprint. The roughness algorithm was pre-trained for each LiDAR data sortie using reference surfaces such as roads, gravel areas, fields, scrub, etc. In order to correctly extract ground level and roughness there must be sufficient returns within a search footprint. The extraction process is computationally demanding because neighbouring LiDAR hits on the ground may be from different LiDAR flight path scans and widely separated in a data file.

Results

The unrefined LiDAR point data was supplied in "tiles" measuring 480 m x 720 m. Analysis of the data-sets revealed that the LiDAR point densities were significantly higher than the nominated densities. Table 1 shows actual point densities from a random sample of non-sequential LiDAR tiles.

Table 1: Nominal and actual LiDAR point densities**.**

Quality	Low resolution	Medium resolution	High resolution
Nominal density [points/m^2]	1	4	8
Actual density range [points/m^2]	0 - 16	1 - 50	6 - 251
Most common number points/m^2	3	9	Bimodal: 17 & 29

Using the most common point densities from Table 1, search footprint radii of 1 m, 0.5 m and 0.375 m are suitable to achieve around 7-9 points per search footprint. This number of points is sufficient for roughness determination as shown in Figure 2.

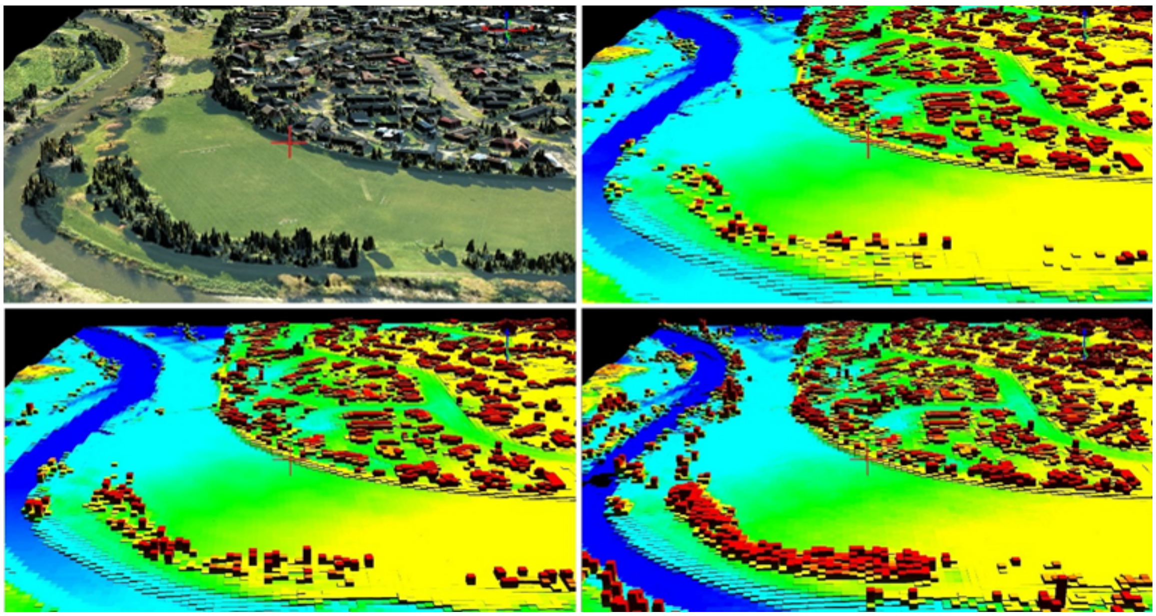

Figure 1: Urban and riverside area showing air photo on raw LiDAR points (top left) and 3m DEM grids derived from (clockwise) high, low and medium resolution LiDAR. Grid elevations from low to high are shown by blue<green<yellow<red respectively.

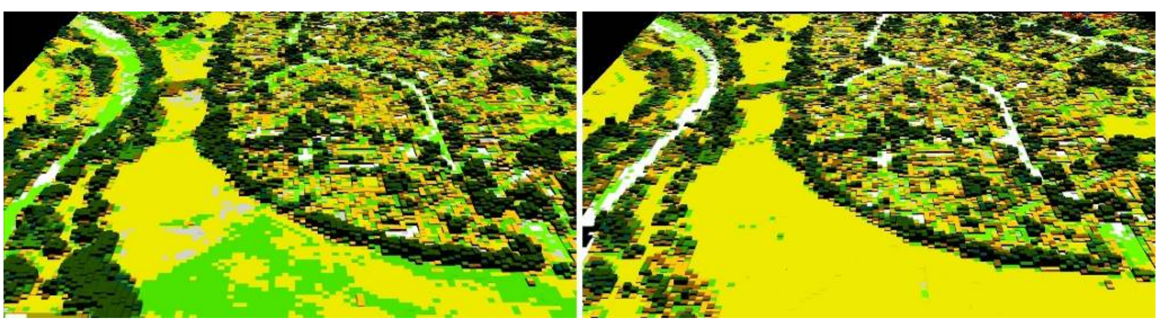

Figure 2: Urban and riverside 3m roughness grid derived from high resolution (left) and low resolution LiDAR (right). Roughness levels from low to high are shown by white< grey< yellow< light-green< orange< brown< dark-green. The stop bank is rough because it is covered by vegetation.

The "medium resolution" LiDAR provided elevation and roughness grids sufficiently accurate for hydrodynamic flood mapping of urban and rural floodplains. Note that while this LiDAR had a nominal point density of 4 points per metre^2 the most common density for the delivered "medium resolution" LiDAR was 9 points per metre^2. So the delivered LiDAR should have around 9 hits per metre^2. The low resolution LiDAR (delivered at 3 points per metre^2) is considered adequate for hill catchments. Scrutiny may be required where narrow-crested control structures exist. LiDAR collection specification details should exclude double counting of multiple coincident returns and avoid widely varying point densities across a target area.

This research is funded by NIWA, LINZ and the NZ Natural Hazards Research Platform. Greater Wellington Regional council provided historic flood and background information.

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INVESTIGATING NEW ZEALAND'S DROUGHTS IN THE 20TH AND 21ST CENTURIES

Dr Abha Sood[1], Dr Brett Mullan[1]

[1]*NIWA*

Aims

Droughts in New Zealand can cause over billion-dollar annual losses to the primary sector and impose severe and conflicting demands on limited water resources. The aim is to examine the 21st century climate change which may considerably alter the nature of droughts and compound risks for major stakeholders in New Zealand such as regional councils and industry.

Method

In this study, a widely used drought index relevant to the agricultural sector, "Potential Evapotranspiration Deficit (PED)" index which quantifies the gap between water demand and water availability is computed from regional climate model data for New Zealand. It is first validated for the 20th century and readjusted to match the prevalent conditions for a historically realistic simulation. Applying these adjustments to climate data, we gain confidence in the future changes in PED derived from the regional projections which characterize changes in the future drought conditions. The spatiotemporal characteristics such as spatial patterns and seasonal and interannual variability of the regional changes are discussed and several risky future "hot spots" identified linking them to the underlying climate drivers.

Results

The changes PED index is largely based on, and consistent with, the bias corrected temperature change patterns of the regional climate model (RCM). Changes in other uncorrected climate variables (radiation, relative humidity and wind) also influence derived PED changes, but to a lesser degree. The spatial variability of PED (Fig 1.) is mostly well captured over most of New Zealand (Ministry for the Environment, 2016), but since the critical climate variables relative humidity and solar radiation are significantly biased, local spatial details deviate considerably from observation-based patterns. Readjusting these variables to the "observation derived" values results in reduction in PED biases. Some impacts of PED correction on the 21st century climate signals for different external forcings are discussed. The added value of PED derived from the corresponding next generation very high resolution (12km-4 km) RCM climate data is also discussed.

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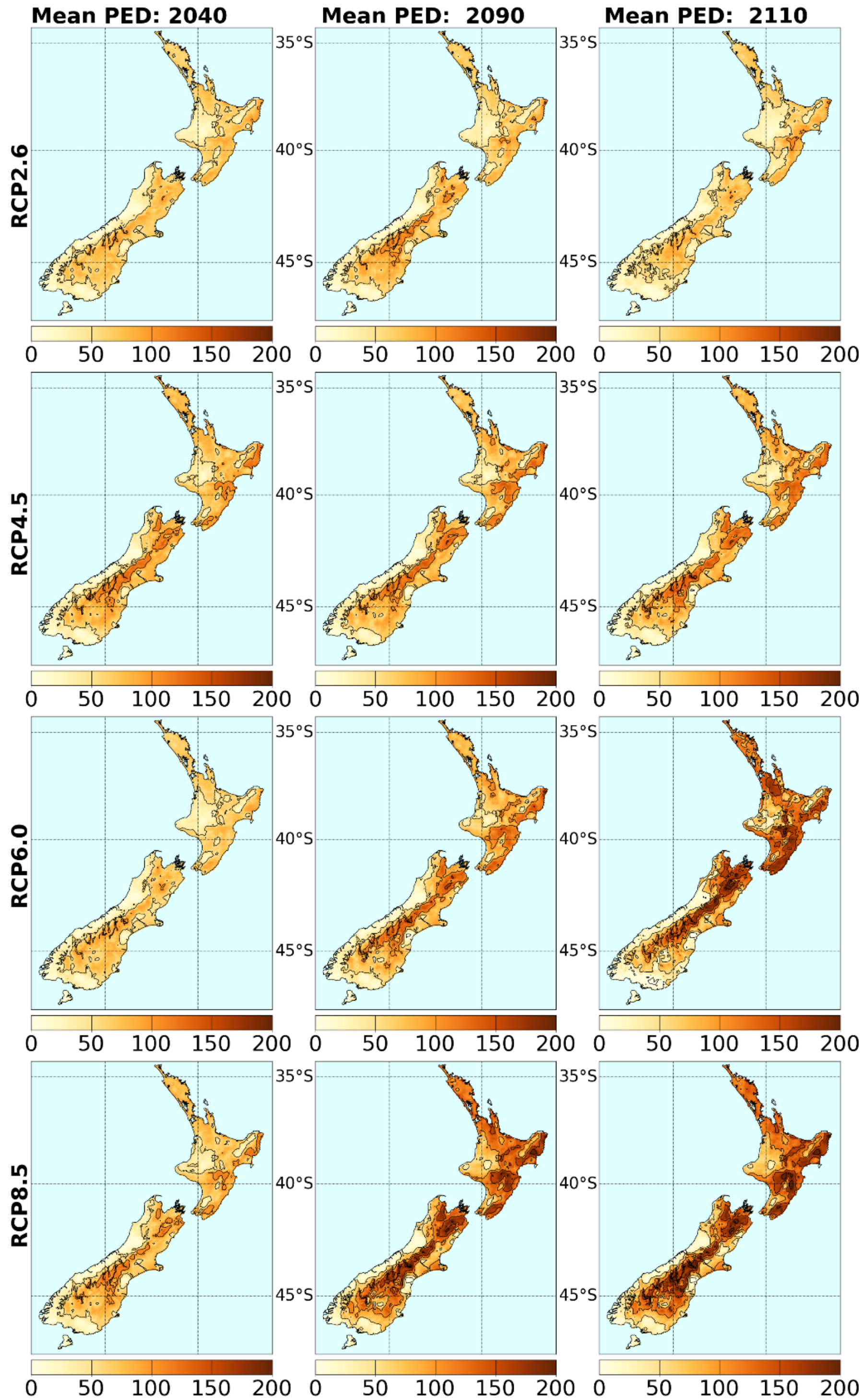

Figure 1: RCM-projected changes in potential evapotranspiration deficit (PED) (in millimetres accumulation over the July–June 'water year'), with respect to the baseline 1995 period, for all four RCPs and three future time periods.

BARRIERS TO THE UPTAKE OF BUILDING-SCALE WATER SENSITIVE URBAN DESIGN TECHNOLOGIES IN CHRISTCHURCH

Vicky Southworth[1], Eric Pawson[1], Tom Cochrane[1]
[1]*University Of Canterbury*

Aims

The long-term strategy for accommodating Christchurch's growing population is to densify the city centre and suburbs. Traditionally increased runoff comes with densification. Contamination of waterways and flooding are already associated with stormwater runoff in Christchurch. Climate change is expected to challenge the existing stormwater system further. Building-scale solutions to reduce runoff become increasingly important as the space for larger scale options such as swales and wetlands diminishes (Charlesworth & Warwick 2011). Textbooks describe the 'WSUD treatment train' which starts with at source options and progresses to larger scale options such as wetlands , but in Christchurch the first part of the train is often missed out, limiting the opportunity to minimise contaminants flushed into the natural environment and reduce runoff volume. In addition, the use of rainwater tanks offers not just a solution to managing excess runoff, but also an opportunity to build resilience when the demand for water is increasing with a growing population and a warming climate (Lawton et al. 2007).

Finding opportunities to include WSUD solutions at the building-scale in both new build and retrofit projects is imperative, given that many buildings in existence today will still be with in decades to come. Local government programmes in the States and Australia, such as Seattle's 700 Million Gallons project (www.700milliongallons.org), educate and incentivise householders and businesses to incorporate low tech rainwater management solutions on individual properties, such as DIY rain gardens, cisterns for irrigating gardens or just planting more trees and mulching regularly.

The aim of this research was to identify the barriers to increasing uptake of building-scale stormwater management solutions in Christchurch, and subsequently to propose options to overcome the barriers.

Method

Twenty-nine interviews with a broad range of local decision makers and stakeholders such as architects, landscape architects, developers, planners, engineers, and community groups have been carried out to provide insights into the barriers to WSUD uptake here in Christchurch. Several interviewees were also selected to provide a Maori perspective.

Interview questions were developed based on those identified in the research literature. There is much commonality between barriers found in Australia and the US for example, despite differences in governing structures and environmental priorities and legislation (Roy et al. 2008). Open-ended questions provided an opportunity to explore whether barriers exist that are unique to Christchurch.

Solutions will be proposed based on a review of policies and programmes that have been used elsewhere nationally and internationally to enhance the use of WSUD, together with findings from the interviews to ensure solutions address the local context.

Results

Cost - The interviews identified cost to be the most commonly cited barrier.

Technical resistance - Some key decision-makers inhibit the selection of devices for on-site inclusion of WSUD devices. In particular permeable paving systems (PPS), which provide very positive reductions in runoff volume and contaminants (Drake et al. 2013), are avoided because of uncertainty relating to long term maintenance. Other considerations limiting uptake are a perception that rain tanks are ugly, that soils are only suitable for infiltration in the west of Christchurch, green roofs are unsuitable in earthquake zones, and that devices on private sites are at risk of failure from poor maintenance practices. Stormwater management devices are ranked in Christchurch City Council's Surface Water Strategy (Christchurch City Council 2009). The focus on a limited selection of 'preferred' devices may explain the low uptake of less favoured devices, such as PPS, compared with devices that are more commonly included in developments currently, i.e. rain gardens.

Lack of knowledge – Includes different groups in the decision-making chain such as developers/home builders and architects. There is insufficient sharing of knowledge. Some professions, such as landscape architects, can be excluded from early decision-making, and design responsibilities for the building (architects) and the exterior (landscape architect) reduces the opportunity for integration, meaning that WSUD options can be identified too late to be included in a development. There is a lack of knowledge among some builders and plumbers who don't have the skills to install WSUD technologies.

Mindset – The majority of people don't want to spend to achieve a desired outcome of healthier waterways. The huge increase in average property sizes since 1980s indicates size has been prioritised over environmentally sensitive development. The Te Whariki subdivision, a Ngai Tahu development in Lincoln, was profitable but did forego profit to enhance the environmental footprint to include wetlands (https://tewhariki.co.nz/live-here/about-te-whariki). Developers produce what is demanded - sustainable features are not a key selling point. Politicians, since they are the representatives of society, prioritise spending and policies to meet citizen expectations. The Maori culture prioritises ecosystem health and long term protection/enhancement valued sufficiently to offset profit.

Conclusion

Shifting mindsets and building knowledge - Education is paramount so that the population as a whole values water sufficiently to invest in technologies that reduce impacts on the waterways. This is essential for reducing impacts from existing properties. This is a long term action.

Breaking down technical resistance - Providing good and publicised demonstration projects, supported by research establishments and ongoing monitoring, will help to build confidence and knowledge amongst stormwater practitioners, developers and architects. Research into the full range of devices by local universities or crown institutions is particularly important as research carried out by suppliers is less trusted.

Mandate or incentivise – to capture benefits of current technologies that can be incorporated into new buildings now. There should be less emphasis placed on which devices developers and homeowners use, but rather focus on the desired outcomes in terms of volume reduction and quality improvement, leaving designers to select the solutions that are most appropriate to the site and their client. Incentivising uptake can be effective and addresses the issue of retrofit, but has a cost. A loan scheme through rates to spread the cost of benefits that also benefit society may be viable.

Professions and organisations – need to collaborate and work together earlier and more effectively, working towards common goals. Local authorities could support early adopters by fast-tracking the consent process to minimise the risk of time delays which are off-putting to developers.

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COMPARISON OF SUNSHINE MEASUREMENT INSTRUMENTS IN NEW ZEALAND

Raghav Srinivasan[1], Gregor Macara[1]
[1] *Niwa*

Sunshine duration in New Zealand is typically measured by one of two methods. Historically, measurements have been obtained using a *Campbell-Stokes* instrument. This instrument uses a glass sphere to concentrate the sun's rays, and burns a trace onto a suncard. A manual observer then performs a visual inspection of the suncard, and records the duration of sunshine to a resolution of six minutes. Although *Campbell-Stokes* instruments remain in operation throughout New Zealand, contemporary station changes have resulted in the use of electronic *Kipp and Zonen* instruments to record sunshine hours. These electronic sensors are more sensitive to solar radiation, which may enable them to record higher sunshine hour totals compared to a *Campbell-Stokes* instrument.

Both manual and electronic instruments are operating side-by-side at four climate stations located throughout New Zealand, which allows a comparison of the two measurement methods. The observations obtained at these sites have been compared to determine whether an electronic sensor measures higher sunshine hours than a Campbell-Stokes sensor due to its sensitivity. Results from this investigation will be presented, and reasons for differences between the two instruments explored.

A TOOL TO COMPARE VARIOUS IRRIGATION SCENARIOS APPROACHES UNDER DIVERSE SOIL PLANT AVAILABLE WATER CONDITIONS

M S Srinivasan[1], Carla Muller[2], Mark Neal[3], Richard Measures[1], Channa Rajanayaka[1], Graham Elley[1]
[1]NIWA, [2]NIWA, [3]DairyNZ

Aims

The MBIE funded Irrigation Insight programme aims to optimise the environmental and economic benefits of irrigation through the use of better irrigation scheduling practices and high-resolution weather forecasting, A daily water balance model was developed to understand the hydrological impact of irrigation on soil moisture, evaporation and drainage. The model was applied to a North Canterbury site, comparing three contrasting scenarios - dryland (no irrigation), rostered irrigation schedules and justintime irrigation. The best irrigation strategy to optimise soil moisture availability for pasture growth, while minimising the amount of irrigation and drainage, was investigated for two distinct plant available water (PAW) capacities (low and high, 69 and 149 mm PAW for 600 mm depth.

Method

An Excel-based daily water balance model was developed to compare the various irrigation scheduling approaches against a dryland scenario. The inputs to the model were measured rainfall and estimated potential evaporation (Penman). Three scenarios were considered:

1. dryland (no irrigation),

1. rostered irrigation, where 15 mm of irrigation was simulated every four days from October 1 to April 30, irrespective of soil and weather conditions, and

2. just-in-time irrigation, where 10 mm of irrigation was simulated whenever soil water content dropped to 55% PAW in October, November, March and April, (shoulder seasons) and 60% PAW from December to February.

The rostered irrigation approach represented a supply-based scenario, while just-in-time is a demand-based scenario. The two irrigation approaches are typical of those used in Canterbury, though the rostering interval may vary across the region. The model was applied retrospectively for 18 irrigation seasons, and the frequency and amount of irrigation applied and water lost from root zone owing to soil PAW exceeded (≥ field capacity) were compared between the approaches. No water supply limits were considered.

Results

The model results are for the irrigation season only (October to April), and are averaged over 18 irrigation seasons:

- Under both rostered and just-in-time irrigation scenarios, for both soil PAWs, the soil moisture remained at or above 50% PAW for 99.9% of the irrigation season. In contrast, under the dryland scenario, the soil was at or above 50% PAW for only 24% of the season.
- Since the available soil moisture in dryland soil was less than that of irrigated, the actual evapotranspiration from dryland soil was 49% less than that of irrigation scenarios.
- As the amount of water input varied across the three scenarios, the dryland soil recorded the lowest total drainage per irrigation season (20.4 mm; all rainfall drainage). This increased to 55.4 mm (rainfall + irrigation drainage; averaged between the two soil PAWs) under the just-in-time scenario and 444.5 mm under the rostered scenario.
- The rostered scenario resulted in more irrigation events (53, averaged between the two soil PAWs) and total irrigation applied per season (799 mm) compared with the just-in-time scenario (39 irrigation events and 394 mm, respectively)
- When irrigating two soil types with two different PAWs -
    - if minimising irrigation-drainage is the primary objective, then scheduling irrigation based on the soil with high PAW is advised. However, this can lead to soils with low PAW experiencing soil moisture stress (soil moisture at or below 50% PAW) for more than a third of the irrigation season.
    - if minimising soil moisture stress (maintaining soil moisture at or above 50% PAW) is the primary objective, then scheduling irrigation based on a soil with low PAW is advised. However, this could result in three times more irrigation-drainage than likely when high PAW soil is used for irrigation scheduling.

EFFECT OF VARYING FLOWPATH CONTRIBUTIONS ON LONGITUDINAL BASEFLOW STREAM CHEMISTRY PATTERNS

Roland Stenger[1], Juliet Clague[1], Uwe Morgenstern[2]
[1]Lincoln Agritech, [2]GNS

Aims

To establish why spatial patterns of stream solute concentrations and loads showed marked differences between two longitudinal stream samplings carried out under baseflow conditions in June 2016 and June 2017.

Method

Kopuhurihuri Stream is located in the Reporoa Basin, where nitrogen and phosphorus transfers from dairying land to surface waters are investigated in the MBIE-funded Transfer Pathways Programme (Clague et al, this issue; McDowell et al., 2018). Stream water sampling and concurrent flow gauging were carried out on 01/06/16 and 08/06/17 under baseflow conditions. Here, we focus on six main stem sampling sites (from K1 near the confluence with Waiotapu Stream in the west to the headwater site K6 in the east, Fig. 1). The suite of analytes comprised a range of nitrogen, phosphorus, and carbon species, major ions, nitrate isotopes and tritium.

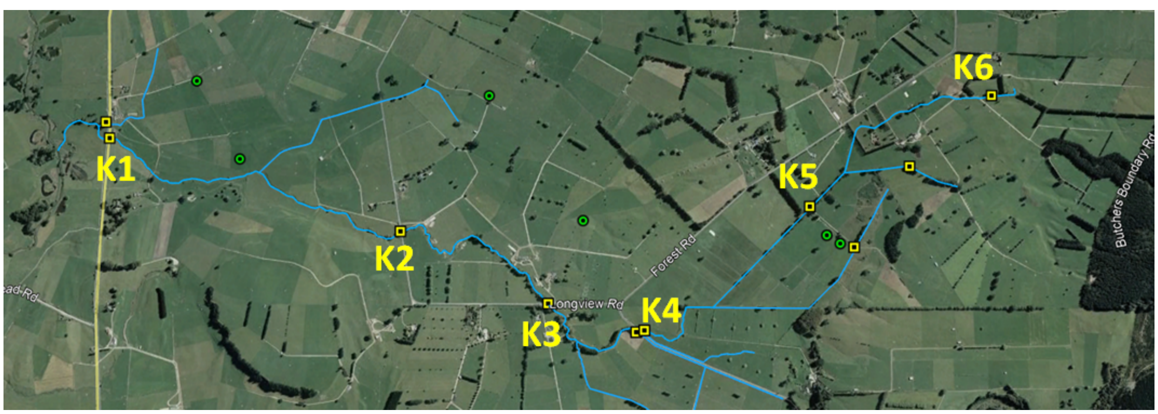

Figure 1: Sampling sites on Kopuhurihuri Stream shown as yellow squares, main stem sites K1 – K6. Green circles mark associated shallow groundwater monitoring sites (Clague et al., this issue).

Results

Nitrate concentrations at the June 2016 sampling were relatively low (1.1 – 1.6 mg L^{-1} NO_3-N) and showed little spatial variation (Fig. 2a). The vast majority of the low nitrate load discharged into Waiotapu Stream near K1 (10 kg d^{-1} NO_3-N) was already in the stream at K3, i.e. the load arose from the eastern headwater part of the catchment (Fig. 2b). Nitrate concentrations were markedly higher and more variable at the June 2017 sampling (3.3 – 7.5 mg L^{-1} NO_3-N) and nearly 90% of the much greater total load (69 kg d^{-1} NO_3-N) entered the stream between K4 and K1, i.e. in the western half of the catchment. Fig. 2c demonstrates that the measured stream flow was reasonably similar between the sampling sites in the eastern headwater area, but distinctly different in the western half (K4 to K1), where strong flow increases were observed in 2017. Concurrent groundwater monitoring revealed that water tables were substantially higher at the 2017 sampling date compared to the 2016 sampling date (not shown). This was particularly the case in the western part of the catchment. The markedly higher water tables (by 1 – 2 m) facilitated a substantially greater contribution of local shallow groundwater flow into Kopuhurihuri Stream and its tributaries in the western part of the catchment. This activation of short, lateral pathways is also reflected in the estimated MRTs of the stream water, which ranged from 23 – 28 years in 2016, but were only 1.5 – 9.7 years in 2017 (Fig. 2 d).

Conclusions

While stream flow and nitrate loads at the 2016 sampling date were largely generated in the eastern headwater area, the much wetter summer/autumn 2017 activated shallow lateral pathways in the western part of the catchment, which resulted in much greater discharge of local shallow groundwater than what was observed in 2016.

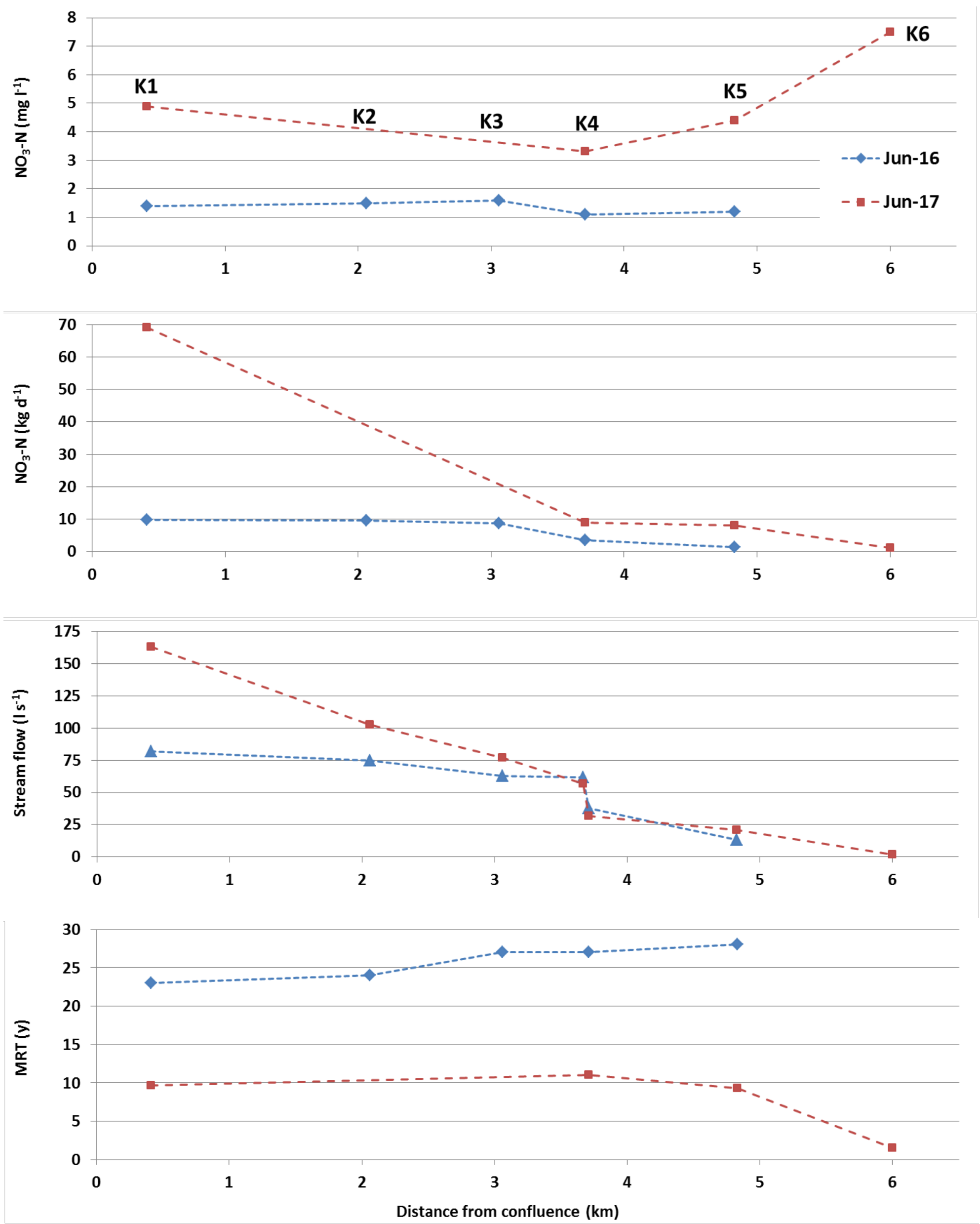

Figure 2: Nitrate nitrogen concentrations and loads, stream flow, and Mean Residence Times (MRT) of baseflow stream samples (June 2016 and June 2017).

Acknowledgement

This work was carried out under the MBIE "Transfer Pathways Programme" and co-funded by Waikato Regional Council and DairyNZ Ltd. We thank Brian Moorhead and Tasman McKelvey for invaluable technical support and gratefully acknowledge our collaborating farmers.

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SUBSURFACE FLOWPATHS OF CHRISTCHURCH SPRINGS

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Aims

To investigate the sources and flowpaths of springs in Christchurch using geochemical indicators, such as the chemical and stable isotope concentrations, and tritium and dissolved gas age-dating methods.

Methods

Samples were collected from the springs between 8 and 10 December 2017. They were analysed using standard methods at GNS Science in New Zealand, and at the Faculty of Life and Environmental Science, University of Tsukuba in Japan. The spring locations are shown in Fig. 1.

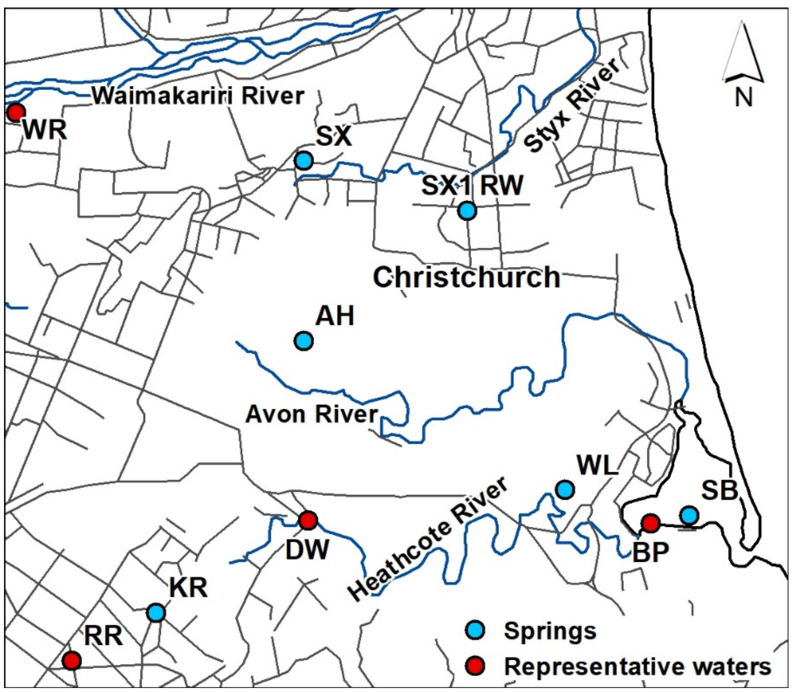

Figure 1: Map of Christchurch showing spring locations in blue (SX – Styx River, RW – Redwood, AH – Avonhead, KR – Knights Reserve, SB – Sandbar, WL – Wetland Springs). Representative water locations are shown in red (WR – Waimakariri River, RR – rainfall recharge, DW – deep groundwater from a 175 m deep well, BP – Banks Peninsula spring).

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Results

The chemical compositions of the springs were compared with those of representative waters from Christchurch. The spring compositions were intermediate between those of the representative recharge waters to the upper Quaternary fluvial gravel aquifers under Christchurch (WR Waimakariri River and RR rainfall recharge), and were quite different from groundwater in fractures, joints, and fissures in the Miocene volcanic rock of Banks Peninsula (BP), showing that all of the spring waters came from the Quaternary system. SB showed strong similarity to DW (deep groundwater).

The stable isotope compositions show that WR is the main source of water to all of the springs, with smaller and variable contributions from RR.

Tritium concentrations are given in Table 1. The mean residence times (MRT) have been calculated using the exponential piston flow model (EPM) with exponential fraction f = 0.7 (the use of the EPM to estimate MRTs is explained in Stewart, 2012). The Styx River sample has the youngest age of 2 years. Redwood Spring has age about 9 years, and Avonhead and Knights Reserve Springs have ages around 8-14 years. The Sandbar and Wetland Springs are much older with ages of >180 and 150 years respectively.

Table 1: Tritium concentrations and estimated mean residence times (MRT) in years, and gas concentrations in air in equilibrium with the samples. Yellow shaded rows indicate young water, blue shaded rows much older water.

Symbol	Tritium (TU)	Tritium MRT (yrs)	SF_6 (pptv)	Halon (pptv)	CFC-11 (pptv)	CFC-12 (pptv)	CFC-113 (pptv)
SX	2.167	2	--	--	--	--	--
RW	1.525	9	6.46	1.93	105	778	28.1
AH	1.650	8	6.51	2.22	497	1914	48.8
KR	1.222	14	6.45	2.03	361	537	38.9
SB	-0.028	>180	0.16	0.04	2.7	7	1.4
WL	0.233	150	--	--	--	--	--

The table also shows the concentrations of SF_6, Halon-1301, CFC-11, CFC-12, and CFC-113 in air in equilibrium with the samples when they were recharged (Beyer et al., 2014). Because the concentrations of these anthropogenic gases have increased in the atmosphere in time, the concentrations are related to the ages of the samples. The young samples gave air concentrations similar to present-day values, while the old sample (SB) gave much lower concentrations signifying a much older age.

So why are the eastern springs (SB, WL) so much older than the western springs (SX, RW, AH, KR)?

Many authors (e.g. Cameron, 1992) have noted that most, and certainly the most substantial, springs have historically been located on the western side of Christchurch, where the aquifers become confined because of the thickening of interleaved marine layers towards the east. The first artesian aquifer provides groundwater pressure that enables the springs to flow. The four western springs, which existed before the 2010 earthquake, produce this young water. However, new springs were identified following the earthquake away from the western 'spring line' (Cox et al., 2012). The new springs were distributed in the catchments of the Avon/Ōtākaro and Heathcote Rivers, where there was substantial disturbance of the sediments. The two springs with old ages are from this group and therefore have a clear association with the earthquakes. Their very old ages indicate enhanced vertical permeability caused by the earthquakes (Cox et al., 2012).

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MAPPING GRAPEVINE-CLIMATE RELATIONSHIPS AT HIGH RESOLUTION IN VINEYARD REGIONS IN THE CONTEXT OF CLIMATE CHANGE

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Aims

It is well-known that wine style and quality is strongly influenced by the climate of the vineyard region within which it is produced (Chuine et al. 2004, Coombe 1987). Understanding the spatial and temporal variability of the climate in vineyard regions is therefore important, particularly in the contemporary context of climate change (Hall and Jones 2009, Jones et al. 2012, Webb et al. 2012). Climate analysis and modeling at the global and synoptic scales are not accurate enough to take into account the local variability that is important for viticulture. Relationships therefore need to be established between local, regional and global scale climate in order to propose adaptation responses to climate change for wine growers (Quénol et al. 2014). The application of weather/climate models using nested scales (e.g. global > synoptic > regional > local) allows an improved framework for developing adaptation options in response to future climate change.

The aims of the research presented here are therefore to: 1) apply mesoscale numerical models (in this case, the Weather Research and Forecasting model) and high-resolution data networks to investigate weather and climate variability at fine scale in New Zealand vineyard regions; 2) use the model output data to assess the influence of fine scale climate variability on grapevine response; and 3) help develop adaptation strategies in response to observed spatial and temporal climate variability in vineyard regions.

Methods

In this study, the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008) has been used to simulate local weather and climate in New Zealand vineyard regions in complex terrain in order to investigate vineyard scale climate variability at 1 km resolution, using an hourly time frame (Sturman et al. 2017). WRF model runs were completed for a number of growing seasons for three vineyard regions in New Zealand, including 10 growing seasons (2008-9 to 2017-18) for Marlborough; 5 growing seasons (2013-14 to 2017-18) for Waipara, and 10 growing seasons (2007-08 to 2016-17) for Central Otago. The datasets provided by the model allow investigation of the major influences on local weather and climate (sea breezes, foehn winds, cold air drainage and ponding, etc.) in the three vineyard regions. They also allow analysis of the relationship between local weather/climate and grapevine response (e.g. through phenological relationships), as well as evaluation of climate risk factors (e.g. frost, high temperatures, or strong winds). By running the model over multi-year periods, it is possible to identify optimal climate regions for different grapevine cultivars as the basis for developing climate change adaptation strategies.

Installation of high-resolution instrumentation networks has been undertaken in parallel with the modelling work in order to allow model validation and downscaling to even finer scales within the vineyards (e.g. 50-100 m) (Le Roux et al. 2018a).

Bioclimatic indices typically applied to the development and management of vineyard regions have been mapped using the WRF model output. The indices used include: 1) mean growing season temperature (1 October to 30 April); 2) accumulated Growing Degree Days (GDD) using a 10ºC base temperature (1 October to 30 April); 3) the Huglin index (1 October to 31 March) (Huglin and Schneider, 1998); 4) the Grapevine Flowering Véraison (GFV) model using a 0ºC base temperature (29 August to 30 April) (Parker et al. 2011); and 5) the cool nights index (March mean minimum temperature) (Tonietto and Carbonneau 2004). The GFV model was used specifically to investigate spatial variability in the timing of particular climate-controlled phenological phases of the grapevine, such as flowering and véraison.

Model calibration and validation tests were conducted for the 2013-14 and 2014-15 growing seasons using data from the Marlborough automatic weather station (AWS) network (Le Roux et al. 2018b), and for Central

Otago for 2015-16, focusing particularly on air temperature and bioclimatic indices. Maps of the important climatic and bioclimatic variables for viticulture have been produced for each area, allowing inter-comparison of the climatic environment of these three important South Island vineyard regions.

Results

The research has demonstrated the usefulness of mesoscale weather/climate models in combination with measurement networks to investigate key local features of the weather/climate (sea breezes, foehn winds, mountain/valley winds, cold air ponding, etc.) and their contribution to the 'terroir' in vineyard regions. These models also provide a good basis for analysis of the relationship between weather/climate and key phases of grapevine development at vineyard scale within wine-producing regions in order to improve crop modelling. They also allow investigation of the variability of climate across vineyard regions at high resolution, including identification of optimal/marginal areas for wine grape production for different cultivars, and climate risk assessment based on various bioclimatic indices and climate variables. Finally, the new knowledge of climate-grapevine relationships allows improved assessment of the robustness of vineyard regions to longer term climate change, specifically in evaluating how much change it would take to make a region unsustainable with respect to specific grape varieties.

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RAIN RADAR NOWCASTING FOR SMALL CATCHMENT HYDROLOGY IN NEW ZEALAND USING STEPS

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Aims

New Zealand has historically focused much of its attention on the hazards associated with big rivers. However increasingly territorial authorities around the country are seeking to manage the pluvial flooding risks to residential and commercial properties in small, often steep, catchments. Recent short-duration / high-intensity rainfall events in both Auckland and Wellington have resulted in notable flooding damage to property and increased awareness of the risk of injury or loss of life. While Insurance and infrastructure will play an important part in the management of these risks, some of the biggest gains can be made through increasing the communities' preparedness for flooding and in enhancing the operational response. Numerical Weather Prediction tools are useful for helping inform the community and response crews in advance of events, however increased detailed information about the spatial distribution and intensity of rainfall as it occurs, or even potentially in advance of flooding, the ability to respond is enhanced.

Rainfall radar provides probably the best method for measurement of the spatial distribution of the short-duration / high-intensity rainfall events which in many urban catchments are the most likely to cause damaging flooding. In order to better make use of the available national rain radar observations from the NZ MetService network, the authors have already collaborated to establish a real-time GIS platform for regional radar-derived Quantitative Precipitation Estimation (QPE). To extend the operational usefulness of the radar data, a Quantitative Precipitation Forecast (QPF) based on a radar echo extrapolation nowcasting method has also been implemented to provide ensemble estimates of possible rainfall distributions up to 2 hours into the future.

Method

The radar nowcast QPF is generated by the Short Term Ensemble Precipitation System or "STEPS" (Bowler et. al. 2006). STEPS uses a scale decomposition technique to account for the lack of predictability of smaller scale rainfall features- which is very important when considering the impact of individual convective systems on small catchments. The existing Auckland Council / Wellington Water radar QPE product, which includes clutter suppression, attenuation corrections, advection-interpolation and gauge scaling (Sutherland-Stacey et. al. 2017) provides the input data for STEPS. The radar QPE and radar nowcast QPF are combined on-the-fly in a web-based GIS portal which allows for treatment of antecedent condition and intensity/duration accumulation-based alarming in target catchments.

Results

In order to characterise the operational performance of the catchment alarming system, the QPE analysis and radar nowcast QPF have been run in hindcast mode covering the last 2 years. The radar QPE is validated against independent rain gauge measurements and in turn, the radar nowcast QPF is validated against the radar QPE. We present the results of the validation showing the radar QPE to be unbiased and able to detect localised short-duration/high-intensity rainfall events in ungauged catchments. The radar nowcast QPF is found to provide useful forecasts at the catchment scale and achieves the highest skill at shorter lead times. This is the expected result given the chaotic nature and limits of prediction of the evolution of convective systems. Case studies of the (hindcast) performance of STEPS for the recent flooding events are also presented and implications for operational hydrology and hydraulic modeling are discussed.

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ENHANCING VCSN RAINFALL ESTIMATES FOR HYDROLOGICAL MODELLING

Dr Andrew Tait[1], Dr Christian Zammit[2], Ms Kathy Walter[2], Mr John-Mark Woolley[3], Mr John Powell[1]
[1]Niwa, [2]Niwa, [3]NIWA

Aims

Accurate estimates of spatially- and temporally-complete rainfall are fundamental for hydrological modelling, particularly in ungauged catchments. In this project the aim is to test the influence of including Regional Council rainfall data, in addition to rainfall data stored in the NIWA National Climate database, in the interpolation of daily rainfalls and the subsequent impact these additional data have on river flow estimation.

Method

The Virtual Climate Station Network (VCSN) daily rainfall estimates provide this input for NIWA's Topnet hydrological model. However, it is well known that these rainfall estimates in areas of high elevation of New Zealand have a relatively low accuracy. Since many catchments have their headwaters in these same areas, the resultant Topnet flow estimations often have large bias, compared with observed flows, requiring bias correction.

The major source of VCSN rainfall estimation error is associated with the sparsity of observations in the high elevation areas. And yet, there are many hundreds of Regional Council-owned rainfall observation sites located in the hills and mountains that are not used for the VCSN simply because the data are not entered into NIWA's national climate database. Through a programme of bulk collection of these Regional Council data, we test the level of error reduction (measured as a function of the bias in modelled flows) associated with:

1. Augmenting the daily rainfall data stored in the NIWA climate database sites with all the Regional Council daily rainfalls, then re-running the VCSN interpolations;
2. Enhancing the spatial resolution of the VCSN from ~5km to ~500m; and
3. Performing interpolations of hourly rainfall.

Results

The results of these tests will be presented and a plan for the ongoing enhancement of the VCSN rainfall estimates will be discussed.

GROUNDWATER FLOW MODEL DEVELOPMENT FOR THE RANGITAIKI, TARAWERA, AND WHAKATANE WATER MANAGEMENT AREAS

Mauricio Taulis[1]

[1]*Jacobs NZ*

Aims

Jacobs New Zealand Limited (Jacobs) was engaged by Bay of Plenty Regional Council (BoPRC) to develop a steady state groundwater flow model of the main catchment covering the Rangitaiki, Tarawera, and Whakatane Water Management Areas (WMAs). This catchment is delimited by the ridges to the west of the Tarawera River, the ridges to the east of the Whakatane River, and the upper reaches of the Rangitaiki River. The Rangitaiki-Tarawera-Whakatane steady state model (RTW Model) will be used to support the development of allocation limits for freshwater resources. The model includes the basins shown in **Error! Reference source not found.**. The aim of the RTW Model is to provide a better understanding of the connectivity of the groundwater systems and a better understanding of the groundwater-surface water interaction, as well as providing the ability to estimate allocable groundwater, and to allow for future simulations for groundwater management scenarios.

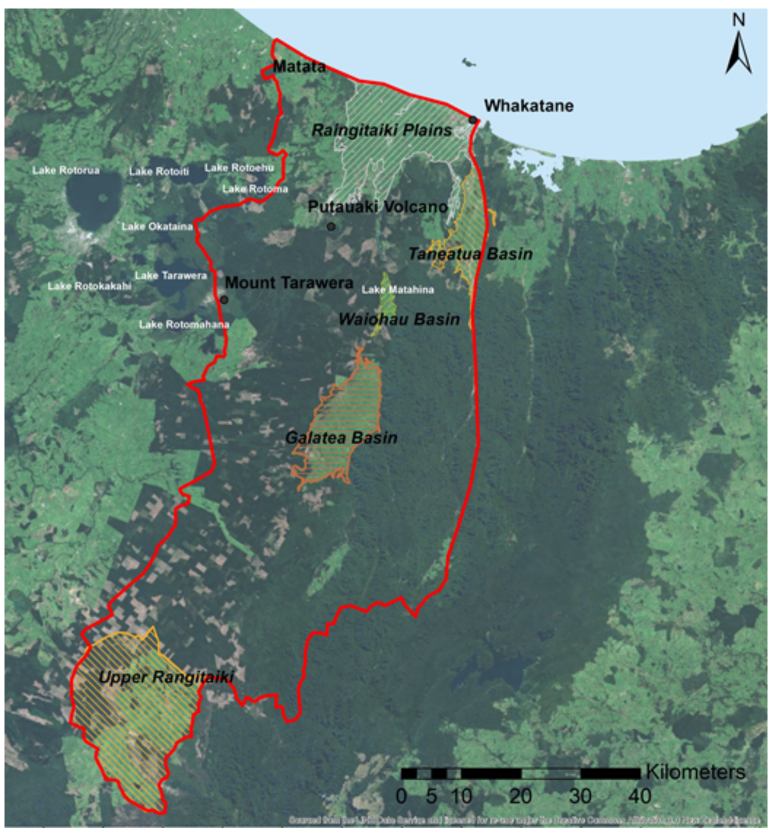

Figure 17: Rangitaiki-Tarawera-Whakatane Model area (outlined in red).

Method

Model conceptualisation focused on reviewing existing information on the Rangitaiki, Tarawera, and Whakatane WMAs, including an assessment of the data quality and its limitations. Once the initial data review was completed, the work progressed towards developing a conceptual understanding of the hydrogeological processes that the groundwater model needed to include. These included replicating groundwater flow directions, the hydraulic connection between groundwater and surface water bodies, recharge and discharge, and the spatial distribution of hydrogeological units and their properties.

A 3D hydrogeological model was assembled based on the GNS geological models of the Kaituna, Rangitaiki, Tarawera, and Whakatane WMAs (areas covered by the model). This model was used as the framework to develop the RTW groundwater flow model, which was developed using the three-dimensional (3D) finite difference MODFLOW simulation code. The model framework was constructed with Hydrostratigraphic Unit (HSU) vertical discretization and the simulation was executed using the NWT solver. The model domain comprises the RTW model area covering the basins of interest and is approximately 4,720 km^2 with a nearly north-south alignment. The model is subdivided into 681 rows and 347 columns to create square grid cells of 200 m x 200 m, with 1,180,199 active cells. The model consists of 10 layers which are used to host the HSUs present within the RTW model area.

The model was calibrated by comparing modelled and measured hydraulic heads, as well as baseflow in steady state for a model run with actual pumping. Standing water level data from both Transient and Static data sets (provided by BoPRC) was analysed to determine adequate calibration targets. A total of 47 wells were selected as calibration targets. In addition, the daily records of 5 stream gauging sites were examined to estimate baseflow averages to use as calibration targets. Stream flows were provided by BoPRC and these data were analysed using the baseflow separation method. Calibration was achieved through manual trial and error by adjusting the aquifer properties and conductance of simulated rivers from the initial estimates. The calculated vs measured groundwater level results show reasonable agreement with the line of best fit - the NRMS error associated with this calibration is 1.9%.

Results

A series of five model predictions (scenarios) were defined, in consultation with BoPRC, in order to investigate potential impacts of groundwater abstraction on groundwater levels and surface water levels (base flow) in the RTW Model area. These predictions were designed to simulate changes in the groundwater system under various pumping conditions:

- Model Prediction 1. This prediction represents current conditions (calibrated model) with an average annual recharge of 46% and actual pumping rates. This model run shows that, in general, the current extraction pumping rates do not exceed the limits of sustainable water extraction.
- Model Prediction 2. This prediction is identical to Model Prediction 1 except that in this case wells are pumping at their maximum consented rate. This model run suggests that, as in the previous prediction, the current extraction rates do not exceed the limits of sustainable water extraction.
- Model Prediction 3 was set up by gradually increasing the Bore Pumping rate for all bores to the limit of sustainable extraction. This limit was established by ensuring the shallowest confined aquifer had positive heads above sea level, at a distance of 400m from the coast (south). These model runs suggest that the limit of sustainable water extraction is exceeded at twice the maximum consented pumping rates.
- Model Prediction 4 represents the effects of groundwater extraction during the summer period (low recharge conditions). This model run was set up by considering average precipitation during

the summer months (December – February) and 8% of precipitation as recharge. This model showed that, under these recharge conditions, drawdown tends to increase within the first 50 m.

- Model Prediction 5 represents the effects of groundwater extraction during the winter period (high recharge conditions). This model run was set up by considering average precipitation during the winter months (June – August) and 76% of precipitation as recharge. This model run showed exhibited lower drawdown than the one for previous scenarios and thus represents sustainable water extraction under these recharge conditions.

DID THE HAVELOCK NORTH CONTAMINATION TRANSFORM BUSINESS OWNERS' PERSPECTIVE OF WATER?

Rachel Teen[1], Dr Lin Robers[2], Dr Ed Challies[3]
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Safe drinking water is essential to public health. In August 2016 an outbreak of gastroentenitis in Havelock North, New Zealand, shook the public's trust in the water supply service. Over 5,500 of the town's 14,000 residents were estimated to have fallen ill with campylobacteriosis, and 45 people were hospitalised. There were three attributable deaths and an unknown number still suffer on-going health issues. Consequently business owners were detrimentally affected – financially, operationally and emotionaly. Their perceptions of water were immediately affected, particularly with the application of chlorine to the water supply, and their trust in their local government bodies diminished. Transformational Learning Theory was the lens used to ascertain if the contamination event transformed Havelock North business owners' perspective of water. Perspective change is most likely to occur when people experience a series of sensory perceptionary encounters, also critically reflect on the complete context of those physical and mental perceptions, and additionally, critically *self*-reflect on how they can transform the context or situation and then take action.

Aim is to determine if Havelock North business owners

1) Are aware their business is connected to and dependent on natural water eco-systems?

2) Are aware of their own cumulative water usage and the consequential, long-term effects on natural water ecosystems?

3) Are open to changes in their hydrosocial contract?

4) Have undergone a transformative change in their perspective of water?

Qualitative Research Methodology

Using a case study approach twenty local business owners participated in semi-structured interviews twelve months after the August 2016 contamination. Manual sorting and NVivo coding were used to analyse the recorded data. A combination of inductive and deductive analysis was used to determine the degree of alignment to Mezirow's (1978) Transformative Learning Theory.

Results

All business owners underwent perception changes in their water supply and all critically reflected on the context of the contamination event. However, none were deemed to have undergone a transformation in their perspective of water because they did not engage in any critical self-reflection. The various causes of the contamination were all external to Havelock North business owners, they perceived there was no need for them to critically self-reflect on themselves nor their business strategies. Their perceptions in regard to the importance of water did change because the event made many of them realise how integral water was to trading and remaining operational. The disruption triggered them to think about the connectivity of water to natural ecosystems, including humanity. Business owners unquestioningly accepted the unwritten hydrosocial contract with the local councils, and none had experienced a transformational perspective change whereby they sought to implement an alternative hydrosocial contract.

References

Mezirow (1978), Sofoulis & Strengers (2011) . Shove (2010), Sofoulis (2005) ,Termeer et al (2017)

OPTIMIZED RAKAIA RIVER MANAGEMENT THROUGH MODELLING THE RIVER'S FLOW REGIME AND INTERACTION WITH ITS WATER USERS

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[1]*Environment Canterbury Regional Council*

The Rakaia River is the largest braided river in New Zealand and has been recognised as having an "outstanding natural characteristic in the form of a braided river" in the National Water Conservation Order (Rakaia River) 1988 (WCO). The Rakaia is one of the most highly valued recreational water resources in Canterbury, being directly used for activities such as fishing, jetboating and white-water sports as well as indirectly as part of a landscape and ecosystems valued for cycling, walking and ecotourism.
The WCO provides up to 70 m^3/s to be abstracted from the Rakaia, provided that an equivalent amount of water is left instream above the defined monthly minimum flows. In 1989, the North Canterbury Catchment Board and Regional Water Board granted several consents to take water from the Rakaia River and in so doing created an informal approach that grouped consents into 'bands' with a common reliability of supply. Taking water for out-of-stream use, particularly irrigation, has increased over time. The "Lake Coleridge Project" defined in the WCO Amendment Order 2013 came into effect on the 7th of March 2013. This amendment specifies additional rules to the WCO about damming, diversion, takes, and discharge of water, as well as rules about "stored water" for irrigation use.
Over the last few years river users have expressed concerns that flow/water levels in the Rakaia River have at times been lower than they have previously observed. This potentially has a negative impact on the river's recreational water use (e.g. fisheries), flows required to maintain in-stream values, sedimentation, river mouth health and water availability for irrigation purposes and may reduce the ability of the river to flush itself, leading to gravel build-up downstream and flooding.

Aims

Given the complexity of the Rakaia River's hydrology in the alpine catchments, together with the large amount of consent holders, there is a need to systematically update our understanding of Rakaia's water balance. Therefore, this study aims to:

- Model and understand the natural hydrological state of the Rakaia River
- Compare river management and state with the WCO and other river values
- Get a detailed overview/list of active consents
- Develop a mechanism to quickly/easily compare water use data with consented rates and volumes
- Enable active and proposed consent changes to be assessed effectively

Method

Since this is work in progress, and not all seven work packages are relevant for this conference, the focus of this presentation will be on biophysical data processing and analysis, and the water balance model itself. To be more specific:

- Gridded precipitation based on bias-corrected remote sensing data
- Spatially distributed hydrological modelling of the (naturally behaving) alpine catchments
- Water allocation modelling of the lower sections of the Rakaia River

The Rakaia River is an alpine catchment, and therefore a substantial amount of winter precipitation is stored as snow and released during spring/early summer. For this reason, it is crucial to have accurate precipitation estimates, and model the amount stored as snow which is then released later in the year. The distribution of rain gauges is sparse, especially in the mountainous regions where precipitation intensities are highest. To overcome this issue, we have used a combination of remotely sensed precipitation (TRMM 3B42) for its temporal and spatial coverage, and in-situ rain gauge measurements to create a gridded bias-corrected precipitation product based on a methodology by Terink et al. (2010).

Because the tributaries upstream of Lake Coleridge still behave as a “natural system” (almost no interaction with water users), and the catchment downstream of Lake Coleridge is affected by the actions of consent holders, a two-step modelling approach is carried out:

1. Spatially distributed hydrological model (SPHY, Terink et al. (2015)) for the upstream “natural” catchments.
2. Water Allocation model (WEAP, Sieber and Yates (2015)) for catchments downstream of Lake Coleridge.

SPHY will be calibrated using MODIS remotely sensed snow cover, proxies for average annual glacier mass balance change, and observed streamflow. The Water Allocation Model will be forced with the simulated streamflow from SPHY and populated with all the consents and their conditions/restrictions, i.e. WCO minimum flow requirements and the banding system. Once this set-up has been accomplished, Environment Canterbury will have a tool that allows for optimized Rakaia river management.

First results

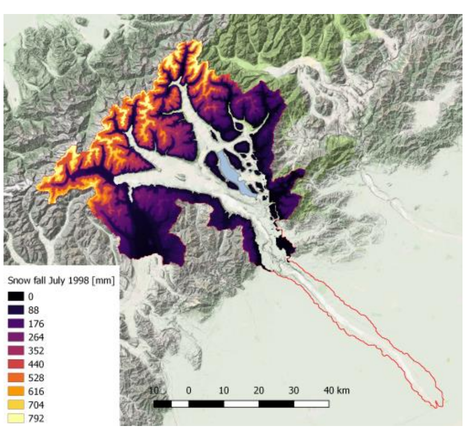

Figure 1: Simulated snowfall for July 1998.

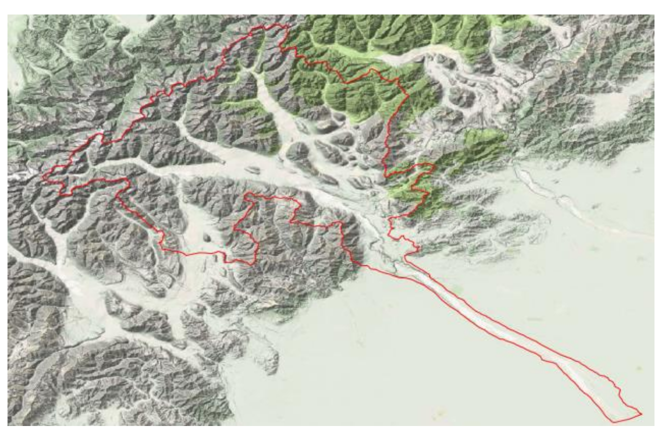
Figure 2: Two-set modelling approach and their domains.

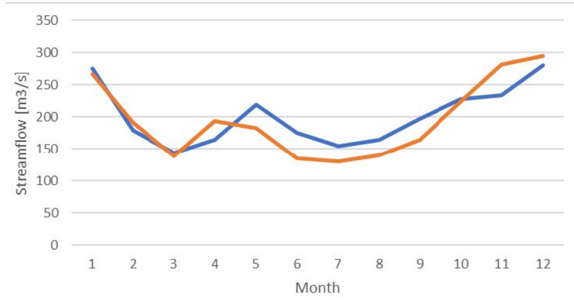

Figure 3: Uncalibrated (orange line) versus observed (blue line) streamflow at Fighting Hill.

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CHRISTCHURCH'S RIVERS AND THEIR COMMUNITIES. SWAMP TO CITY.

Hugh Thorpe[1]
[1]*Independent*

Aims

To give a general account of the nature and changes to the forms, physical, environmental, historical and geographic of Christchurch's urban rivers, and the interactions of citizen groups with them.

This paper properly falls into the theme of "Catchments and Communities" although it could also classify as "Social Hydrology"

We should not forget that to Kai Tahu, the manawhenua of the area the rivers were just as important, maybe more important, than they are to the present population. But this paper is focussed on the present urban catchments of Christchurch which have been and continue to be absolutely integral to the development and future wellbeing of the city.

The catchments concerned are: Opawaho (Heathcote), Otakaro (Avon), Puharakeke (Styx), Otukaikino and perhaps the upper reaches of the Huritini (Halswell) into which the city has expanded. These rivers are unusual in that they are all short enough that they can each easily be traversed by car (or bicycle) from source to sea in a day or less and the full hydrological and environmental transformations within the urban setting appreciated. It is a fascinating experience.

Because of their small population and limited technology Kai Tahu were unable to make significant changes to these waterways but the arrival of Europeans in numbers, beginning in 1850, together with their technology and animals quickly wrought large changes and in a few decades the rivers, particularly the Heathcote were severely degraded. This situation continued largely unquestioned until maybe the last 40-50years. But now, the urban population of Christchurch is around 400,000 and the there is an increasing realisation of the economic value of water resources. This, together with a heightened appreciation of the social and environmental values of Christchurch's rivers has led the City Council, with strong support from a large number of interest groups throughout the city, to devote significant resources to the maintenance and restoration of our urban waterways.

This paper touches on the major features of the rivers and the recent works to begin restoration.

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USING VULNERABILITY ASSESSMENT TO DESIGN "BIG RIVER" FLOW STUDIES IN CATCHMENTS INVOLVING MULTIPLE HAPU

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[1]Tipa And Associates Ltd, [2]Te Runanga o Arowhenua

Aims of the research

The aim of the research was to undertake a "big river" flow study. The catchment we chose was the Waitaki catchment. A secondary aim, however, before we could undertake a big river study, was to identify the sub-catchments that were to be the focus of our flow investigations. Our final aim therefore was to undertake a vulnerability assessment for all 50 sites assessed by whanau and hapu using the Cultural Health Index, and to identify those that are categorized as highly vulnerable. This first step would ensure that the hapu, in preparing a flow study to inform the future review of the Waitaki Catchment Allocation Plan were focusing their attention on the sub-catchments that were highly vulnerable. A structured objective process was important given that the catchment is shared by three runanga.

Methods

Secondary sources were utilized. The Cultural Health Index has been applied at more than 50 sites in the catchment. A report card for the catchment, reporting against 45 indicators, was also available. A series of climate change reports, prepared by NIWA for Te Runanga o Ngai Tahu in 2016, were also accessed. Finally, we had access to all the Cultural Impact Assessments that had been prepared by Ngai Tahu. We had a rich database of qualitative and quantitative data that included contemporary photographs and historic paintings, survey maps and photographs.

Results

We compiled a matrix that started with the Ngai Tahu aspirations for a selection of sites ki uta ki tai - from Aoraki to Korotuaheka (a reserve) at the river mouth. We then used expert opinion and analysed CIAs, CHI results, whanau evidence, climate change reports, and technical reports to identify the likelihood of these aspirations being realized, focusing on the factors that could limit realization. This information then enabled us to calculate the risk. We used a whanau based expert panel to rate the consequence. Whanau and hapu are already active in the Waitaki and are implementing a range of strategies and policies that could loosely be described as adaptation strategies. Once again, we used a whanau based expert panel to rate adaptive capacity. Once we had estimated risk, consequence and adaptive capacity we had the components to determine the vulnerability of the respective sub-catchments. This assessment also identified a number of areas of significance to whanau, such as groundwater, spring fed streams, and wetlands, where there is limited data.

GROUNDWATER FLOW AND TRANSPORT MODEL SIMPLIFICATIONS USING EQUILIBRIUM WATER TABLE AND PARTICLE PATHLINE METHODS

Mike Toews[1], Catherine Moore[1], Rogier Westerhoff[1]
[1]GNS Science

Aims

Groundwater models are used to help support resource management decisions, but often numerical models are developed that are too complex and time consuming to allow meaningful assessment and quantification of uncertainties that are inherent in all numerical representation of natural systems. This abstract presents a case study from the SAM (Smart Models for Aquifer Management) research programme to investigate model simplification strategies.

This case study uses a groundwater flow and transport model from the mid-Mataura area of the Southland region. A complex version of the model uses MODFLOW-NWT with MT3D-USGS to simulate groundwater flow with nitrate transport, incorporating surface water-groundwater exchanges of both water and contaminants.

The first simplification experiment is to use an equilibrium water table (EWT) method to approximate groundwater flow and levels from aquifer transmissivity and recharge values. The second simplification experiment is to use forward-tracking particle pathlines to approximate groundwater transport of nitrate to surface water and groundwater observations.

Methods

This work extends on previous modelling (Phreatos, 2007). The modelling domain is in the alluvial plains north of Gore, and includes Mataura River, Waikai River, and Waimea Stream. The base of the aquifer was determined with the assistance of a 3D geological model for the region (Tschritter et al. 2016). All model grids have a uniform 250 m resolution.

A rich set of observation data was provided by Environment Southland, and includes groundwater levels (manual readings and continuous telemetry), groundwater chemistry, stream gauge, stream gain-loss estimates, stream chemistry, and rainfall chemistry. These datasets were used either to establish calibration targets, or to provide input concentrations for rainfall and streamflow entering the groundwater domain.

Nitrate losses were provided by Environment Southland from OVERSEER, in combination with land use spatial data. Denitrification rates were approximated using a linear discriminant analysis provided by ESR (Wilson et al., 2018), which predicts redox conditions within the aquifer domain. Physiographic units were also used to assess their ability to help constrain potential denitrification areas.

The complex, three-layer, mid-Mataura groundwater flow and transport model uses 350 pilot points per layer to spatially parameterise hydraulic properties. Surface water courses were extracted from a REC3 dataset provided by NIWA, and used to define 33 reaches of a streamflow-routing network for MODFLOW. Surface water flow from a TopNet model were used to establish incoming surface water flows and runoff to each stream reach. TopNet's catchment drainage rates were used to define spatial recharge across the domain. Nitrate transport was simulated using MT3D-USG with a steady-state version of the groundwater flow model, using average nitrate loading between 2011–2015.

A simplified groundwater flow model using the EWT method was determined from national datasets of aquifer transmissivities and groundwater recharge (Westerhoff & White, 2014). These datasets were also processed through a one-layer MODFLOW-NWT model to provide groundwater heads, routed streamflows and gain-loss fluxes to compare to observed values.

Particle pathlines were simulated using MODPATH, using forward-tracking particles distributed on the water table. Nitrate was transported along each pathline using the land-source nitrate concentrations, and first-order decay rates were applied along each pathline trace. Aquifer concentrations were determined by aggregating the mean of each pathline contribution within each cell.

Because pathline transport models only simulate advection without diffusion, distance-based exponential weighting functions were used to influence pathline concentrations to nearby observations during calibration. Groundwater concentration observations were assessed using a radial exponential weighting function through the full aquifer domain, such that nearby pathlines have the greatest influence. Surface water concentrations were assessed by allowing equal weighting in all upstream reaches of a location, and exponentially decreasing weights downstream of the location, which may allow pathlines to intercept parts of the stream locations to aggregate a concentration average matching the observation.

Results

Complex models with nearly 4,000 parameters and 20,000 transient observations were calibrated in parallel on high-performance computers, requiring significant resources (approx. 300 CPU hours for a calibration). In comparison, EWT models with fewer parameters were run in a few seconds, and water table elevation estimates (Figure 1) are adequate depictions of the potentiometric surface simulated with complex MODFLOW results. Observed heads and flows have reasonable correlations to the EWT results, however stream gain-loss observations were poorly characterised by EWT results.

The pathline transport model (Figure 2) was used to simulate nitrate concentrations to groundwater wells and surface water locations. Generally, these results resemble the main characteristics from the complex MT3D-USG results. However, pathlines stop at stream boundaries, thus a detailed stream network cannot be implemented in this type of transport model. Surface water concentration observations had better calibration results than groundwater concentration observations.

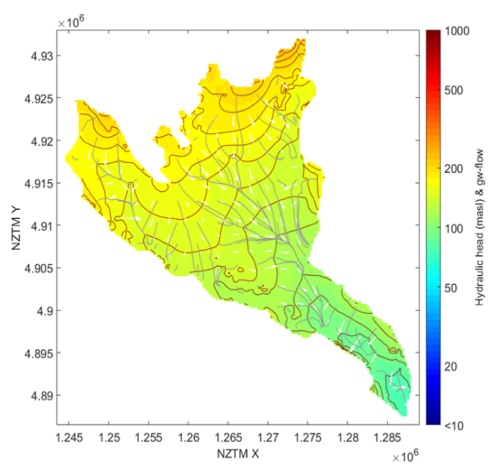

Figure 1: EWT result water table and selected pathlines.

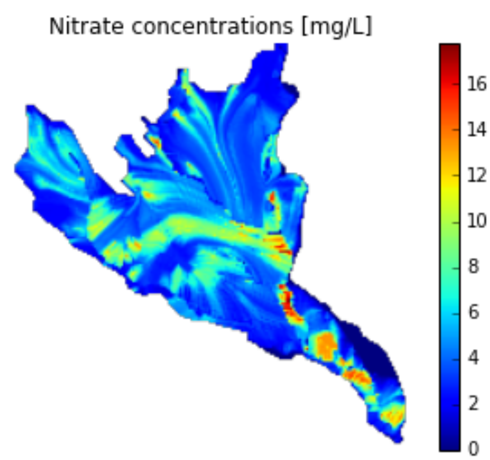

Figure 2: Pathline transport model with nitrate concentration traces, with denitrification applied.

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INCLUSION OF SUBSURFACE HYDRAULIC PROPERTIES IN THE NEW ZEALAND WATER MODEL-HYDROLOGY PROJECT

Dr Rogier Westerhoff[1], Constanze Tschritter[1], Dr Christian Zammit[2]
[1]*GNS Science,* [2]*NIWA*

Aims

The 'New Zealand Water Model-HydrologyProject' (NZWaM-Hydrology) aims to develop hydrological understanding across the New Zealand landscape with a combination of data on surface water, soil, subsurface (geology), and groundwater. GNS Science has been sub-contracted to provide subsurface and groundwater information to NIWA, with the long-term aim to enable a better coupling of groundwater to surface water in the NZWaM-Hydrology (TopNet).

The aim of this research is to set up and test the inclusion of subsurface hydraulic properties (hydraulic conductivity K; depth to hydrogeological basement Z_{HGB}; and effective porosity φ_e) into the geospatial framework of NZWaM.

Method

A nationwide estimate of K near the surface was developed by using the 1:250,000 geological map of New Zealand (QMAP, Heron et al, 2012) and a look-up table approach with internationally recognized permeabilities of rock types (Gleeson et al., 2012), improved for the New Zealand geology (Tschritter et al., 2017). Hydraulic conductivity over depth was estimated as an exponential decrease over depth as suggested in previous research (Fan et al., 2013). A cut-off value of 0.1 m/day was used to define Z_{HGB}.

Nationwide estimates of φ_e were estimated by a similar approach, with look-up tables suggested by multiple international and New Zealand studies and exponential decrease of porosity over depth as proposed by, e.g., Beven and Kirkby (1979) and Ramm and Bjorlykke (1994).

Results

We present the current estimated hydraulic properties. Throughout the project, these estimates are improved and updated annually with new research insights.

At the national scale, the resulting datasets of K, φ_e and Z_{HGB} follow the expected patterns, e.g., high values in the alluvial plains, medium values in the central volcanic region and low values in basement and Tertiary rocks.

The results were evaluated in the Southland region using a 3D geological model previously developed by GNS Science, and field data provided by Environment Southland. This evaluation showed that the estimates of K and depth to hydrogeological basement of this study followed the same spatial pattern as the 3D geological model, but showing more spatial detail than previsouly existed. Furthermore, field-observed K values are typically highly variant, where NHP K values are more constant, caused by the simple look-up table approach.

The nationwide and regional findings lead to the conclusion that the methods used for this nationwide approach are warranted, but that input parameters should be adjusted. Specifically, future research is recommended to include more K values from pumping tests; to have a better definition of 'depth to hydrogeological basement'; and to use additional information on hydrogeological system knowledge.

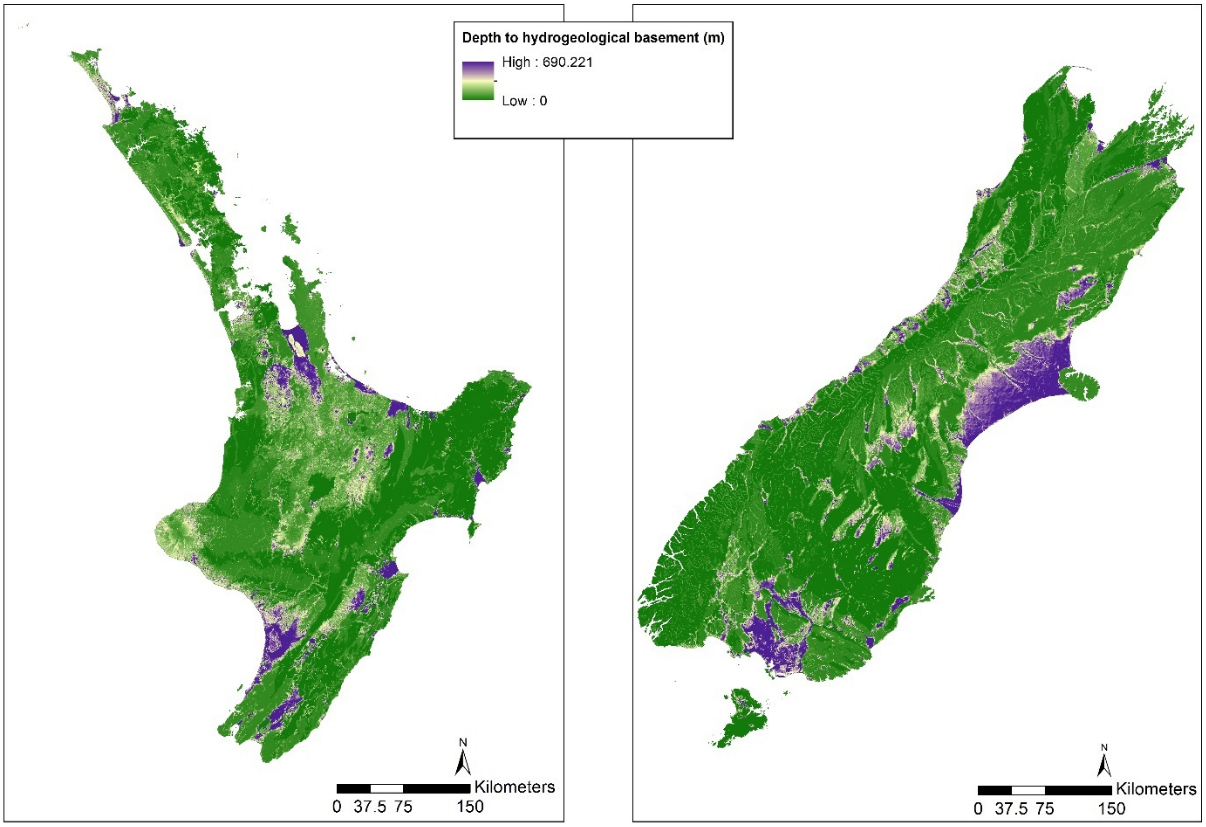

Figure 1: Estimated depth to hydrogeological basement at the national scale.

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FORECASTING THE AERIAL SPREAD OF MYRTLE-RUST (AUSTROPUCCINIA PSIDII) TO NEW ZEALAND FROM AUSTRALIA, NEW CALEDONIA AND RAOUL ISLAND

Dr Richard Turner[1], Dr Stuart Moore[1], Mr Vijay Paul[1]
[1]*NIWA*

Aims and background

Myrtle rust (Austropuccinia psidii) is a fungus that produces microscopic spores that can easily spread on the wind and which attacks various species of plants in the Myrtacaea family such as Pohutukawa and Manuka and represents a major invasive pest risk to New Zealand. Myrtle rust was discovered in Raoul Island in early 2017 and then Northland in late April 2017 and shortly after in Taranaki (early May). Subsequent discoveries have been made in many locations including Waikato, Bay of Plenty, Auckland, and Tasman District.

Due to the potential aerial spread of the Myrtle rust spores, NIWA has conducted comprehensive modelling assessment of long-range aerial transport opportunities for spores to be blown to New Zealand from possible sources in the East Coast of Australia and New Caledonia, where Myrtle Rust is established, as well as from Raoul Island. The assessment for determining the primary introductory pathway was carried out for the period July 1, 2016 to April 30, 2017. NIWA has since then been monitoring possible ongoing airborne transport to New Zealand from external sources and to also model possible aerial transport from infected sites within New Zealand. The output provided to MPI is intended to provide guidance for surveillance efforts by identifying areas of potentially greater exposure to Myrtle Rust spores and it aid decisions around long-term management.

Given the very large distances involved in modelling the transport of the fungal spores, NIWA's Numerical Weather Model NZLAM was used to provide the necessary meteorological and UV radiation inputs into the long-range aerial transport model. NZLAM has a horizontal grid spacing of 12 km and is the highest resolution NWP model available globally that has a domain that includes all of East Australia, New Caledonia, Raoul Island, and New Zealand.

Method and assumptions

The aim of the aerial spread modelling is to try and identify the dates of possible introduction of Myrtle Rust to New Zealand and Raoul Island and the areas exposed to highest risk in New Zealand. In doing the calculations and in interpreting the results of the modelling, many assumptions are made and a number of uncertainties identified, these were;

- The most suitable weather conditions for high numbers of spores to reach New Zealand are characterized by low or moderate turbulence and the shortest path. Low turbulence conditions are associated with the maintenance of high concentrations within plumes and spores are more likely to be viable if transit times are shorter due to generally lower exposure to UV radiation, and flat low-altitude flights also generally avoid freezing and thawing cycles which are likely to damage the spores. For this reason, and for practical computational considerations, it was deemed reasonable to stop calculations after 63 hours or when the calculated altitude of the spores exceeded 2 km.
- High spore densities are maintained if spores were exposed to low levels of UV radiation which is a function of cloudiness, solar zenith angle, total column ozone, altitude, and aerosol optical depth.

UV radiation is calculated as part of routine daily operations at NIWA for the NZLAM domain and were available for the assessments here.

- High spore densities are maintained if precipitation is absent or light and scattered. The most important spores type for long distance transmission are urediniospores which are 14-27 x 14-29 m in dimension; smaller spores are released at night (Glen et al 2000). These dimensions mean that spores can blow with the wind and not settle too quickly, however this size means they are easily washed out by rain.
- The NIWA modelling described here assumed no dry deposition, and the risk of exposure for a point location is conservatively assumed to be proportional to the total column (0-2 km) count of spores passing over that point. This means that favourable conditions for dry deposition existing at destination sites was not accounted for but that any spore in the column could be deposited.
- The density of spore concentrations at each source was the same and prescribed to be at a level of 107 spores/km2/day. The magnitude here is somewhat arbitrary, as the relative risk for one destination compared to another would remain the same regardless of the choice made.
- No diurnal cycle in sporulation was assumed, although there is evidence for the most abundant spore counts to occur around 2 pm (Zauza et al 2014).
- The height of the starting point for each spore trajectory was 10 m above ground level, and it is assumed that spores are present at the source at this altitude all the time. Note, the trajectory calculations include vertical motions so spores are allowed to move up and down during transit.
- No wind speed threshold at which spores are lifted off was assumed. This is conservative, but not thought to be serious because under light wind conditions the spores would not drift far and would only start to move far from the source when speeds increases.
- The precipitation is modelled over the 12 km NZLAM grid box, and often (especially in tropics) there can be dry areas besides areas of intense rain and estimates over a 12 km x 12 km grid cell can smooth such features out. The current modelling option is to discount the effects of precipitation scavenging of spores unless heavy precipitation is occurring over large areas.
- Similarly to precipitation, UV estimates are based on modelled NZLAM cloud fields. Different lethal doses of an accumulated UV intensity are quoted in the literature. Here, we scale UV-B index (to the whole solar radiation band) and use the threshold of 1.2 MJ/m2 value (Kim and Beresford (2008)).
- Effects of temperature and humidity on spore survival during transit are only crudely accounted for in that they are assumed to be non-viable if transported aloft to altitudes higher than 2 km.
- As it is possible that viable spores can be present, but inactive, at a location for several months, until environmental conditions become favourable, the long-range dispersal modelling was extended back to cover the period July 1, 2016 onwards.

The assumptions and uncertainties listed above mean that the results are by no means exhaustive, but we are confident, given their conservatism, that all significant dispersal opportunities and at risk areas were identified.

Results

The key results from the modelling to date are that Australia (East Coast) was likely the main source of risk and Raoul Island and New Caledonia present a much lower source of risk of infection . The highest risk period for aerial introduction in the period July 2016 through June 2017 was from mid-July to early August and October 2016, while moderate risk periods occurred in January, February, and May 2017. A high risk for additional introductions was also modelled for July through September 2017.

The five most exposed areas, based on counts of modelled high exposure episodes, were Northland, Taranaki, Tasman, Bay of Plenty and Southland. In July, 2017 all but Tasman and Southland had confirmed infections but Tasman was found to be infected by early 2018 and the Southland climate is thought to be less favourable for establishment of the disease. The second-most exposed set of four areas were Auckland, Waikato, Wellington and West Coast. All of these areas, except the West Coast have now confirmed infections.

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DESIGN AND IMPACT ASSESSMENT OF COASTAL WETLAND USING AN INTEGRATED CATCHMENT MODEL

Dragan Tutulic[1], Patrick Durney[1], Kalyan Chakravarthy[1]
[1]*DHI Water and Environment Ltd*

Aims

Wetlands are recognised as a critical part of our natural environment, with unique hydrological features, providing important habitat for native plants and animals. They serve as a moderator of hydrologic variability—storing flood flows and reducing flow velocities during wet weather. They also play a role in keeping streams and rivers clean by trapping sediments, nutrients, and other pollutants.
The Lower Kaituna Wetland Management Reserve (close to the town of Maketu), is the biggest area of original wetlands in the Bay of Plenty region. Bay of Plenty Regional Council (BoPRC) is proposing to extend the wetland to include a parcel of land between the existing wetland, Kaituna River and Tauranga Eastern Link. The existing wetland, with an approximate area of 243 ha, is tidally influenced. The proposed project will add 45-80 hectares of new wetland.
Hydrological understanding is central to the success of wetland creation and management. Firstly, hydrological processes influence the physical, chemical and biological characteristics of wetlands. Secondly, hydrological modifications such as raising water levels or diverting drainage channels impact the habitat conditions of desirable wetland plant and animal species. Thirdly, the ability to predict the impacts of such modifications is required to develop management schemes to achieve target goals, avoid undesirable outcomes, and sustainably utilise the limited resources available for wetland management and conservation. A modelling system can be used to investigate the resultant hydrological and biochemical characteristics of the new wetland. Hence, BoPRC commissioned DHI Water and Environment Ltd (DHI) to carry out a numerical modelling study for this wetland reserve. This modelling system will not only help design and optimise the new wetland but will also form part of an Assessment of Environmental Effects (AEE) study to obtain a resource consent for the wetland extension.

Method

Conceptually, a numerical model of the wetland is required to represent the following processes, all dynamically linked:

- Surface water flow: the movement of water as it enters the wetland from the river through flap gated culverts and moves throughout the wetland.
- Precipitation, evapotranspiration and infiltration to groundwater: spatially distributed rainfall-runoff flow of water on the surface, loss of water through evapotranspiration from the surface and the root zone (most likely the biggest loss of water from the system), and infiltration of water from the surface through the root zone into the aquifer.
- Groundwater flow: sub-surface water movement.
- Impact of these processes on the potential water quality for the new wetland, with emphasis on salinity, temperature, and Dissolved Oxygen (DO).

It is proposed that an integrated catchment type water movement and quality model is the only way to properly simulate all the important processes that occur within the lower Kaituna catchment that will have significant impact on the existing wetland and its potential extension.

In this project, DHI's MIKE SHE modelling system was chosen to simulate the integrated hydrological and water quality characteristics. MIKE SHE is a physically based, surface-subsurface integrated, unsaturated-saturated flow coupled distributed hydrological and water quality modelling system (DHI 2017). It is one of the most extensively used physically based distributed hydrological modelling systems capable of simulating eco-hydrological processes.

The biggest advantage offered by MIKE SHE is its modular structure comprising six process-oriented components, which describe the major physical processes of the land phase of the hydrological cycle. The modular structure allows for spatial distribution of catchment parameters, climate variables, and hydrological response through an orthogonal grid network and column of horizontal layers at each grid square in three dimensions. The flexibility in MIKE SHE's framework allows each process to be solved at its own relevant spatial and temporal scale.

Results

In this presentation, we will discuss the objectives of the study, data analysis, model framework, and model results, and their suitability for subsequent investigations. Initial model results highlight the complexity of the hydraulic processes within the study area, specifically regarding the backwater effects of the tidal process and low topography terrain. These complexities all but eliminate the use of implicit overland flow solvers and validate the choice of MIKE SHE with its explicit solvers to capture the hydraulics of the study area. While we are still in the model calibration phase, our initial modelling has been able to replicate stage elevation in the Kaituna River and the broad water level fluctuations with both the surface waters of the wetland and the groundwater system (Figure 1).

References

DHI, 2017. MIKE SHE User Manual, Volume 1: User Guide. DHI.

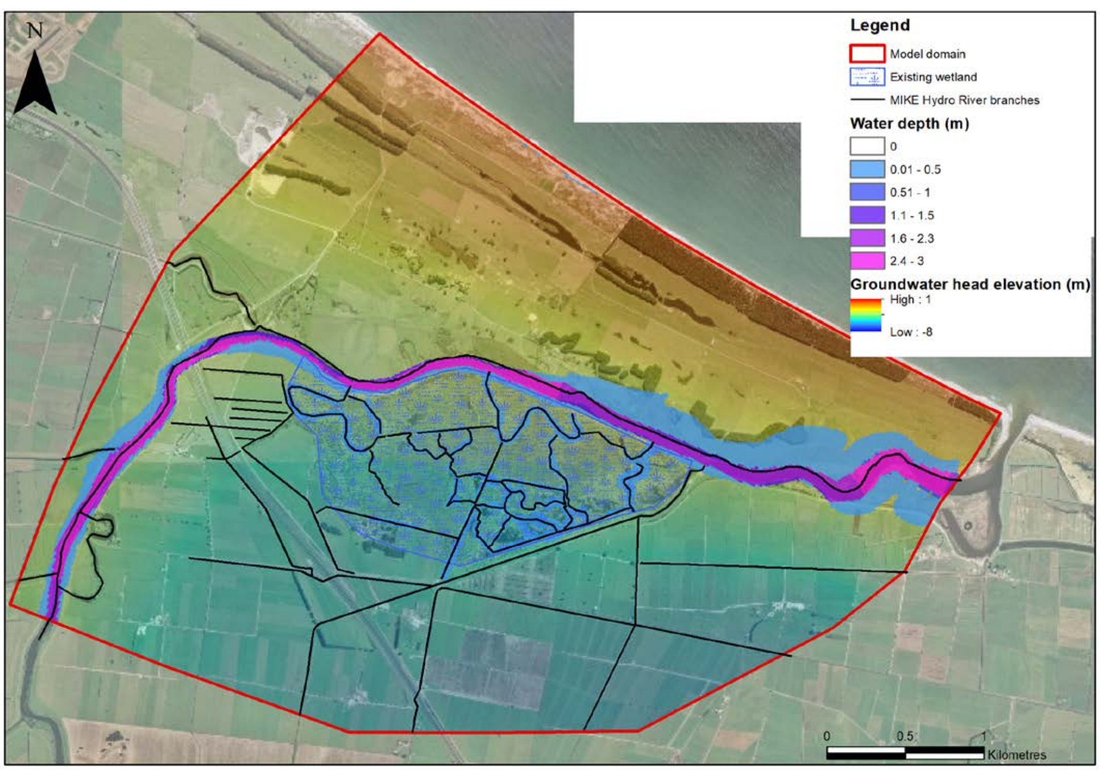

Figure 1: Model set-up and preliminary results.

GISBORNE MANAGED AQUIFER RECHARGE PROJECT – STAGE 2 INJECTION TRIAL

Eric Van Nieuwkerk[1], Peter Hancock[2], Niels Hartog[3]
[1]Golder Associates (NZ) Ltd, [2]Gisborne District Council, [3]KWR Watercycle Research Institute

Aims

The long-term water availability in the Poverty Bay area, Gisborne, is a potentially limiting factor in future regional development. Irrigation for horticultural purposes is one of the main uses of water across the Poverty Bay Flats and a substantial proportion is derived from groundwater. Gisborne District Council (GDC) identified declining groundwater level trends in the Poverty Bay area as an environmental and water supply reliability issue. These trends are linked to increasing groundwater abstraction for irrigation purposes.

Method

MAR is one option under consideration to improve water security and involves the replenishment of the aquifer ensuring sustained yields from the aquifers beneath the Poverty Bay Flats. The Makauri Aquifer was selected for the MAR pilot project due to its relatively high usage, declining groundwater level trends, broad extent and good transmissivity.

Figure 1: Gisborne MAR injection well

Results

The installation of a Makauri Aquifer injection well (Figure 1), headworks and filter system was completed in May 2017 and injection trial undertaken between June – September 2017. Waipaoa River water is sourced via an existing infiltration gallery at Kaiaponi Farms and after filtering injected into the Makauri Aquifer at the MAR site. The 2017 injection trial (Golder, 2017) showed that augmentation of the Makauri Aquifer is technically viable (73,000 m^3 was injected in 59 days, approximate injection rate was 15 L/s). An increase in groundwater levels during injection is clearly visible, with mounding effects recorded up to 1,500 m away from injection well.

A full scheme could potentially have both a stabilising effect on Makauri Aquifer groundwater levels enhancing aquifer yield, as well as beneficial effects on water quality. However, there are risks associated with the Gisborne MAR project that need to be understood and effective management and mitigation strategies put in place. Key risks include well clogging associated with the injection of oxic river water into the anoxic Makauri Aquifer, and risks of contamination of groundwater. Further investigations and trialling are scheduled for the 2018 – 2020 period, to better understand the significance of the key risks and the optimal design for developing a full-scale MAR scheme. The results from 2017 – 2018 period will be presented at the conference.

References

Golder, 2017, Poverty Bay Managed Aquifer Recharge Pilot, Results 2017 Injection Trail, report number 1415771_7403-025-R-Rev1, December 2017.

TO CALIBRATE OR NOT TO CALIBRATE? THAT IS THE QUESTION!

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

The short answer to the question is Yes! Of course you should calibrate a sensor if you want to get meaningful data out of it. But there is also a longer answer which is less clear cut and full of variables and uncertainties. Up for discussion are some of these such as, acceptable serviceability of equipment, threshold of accuracy, requirement of accuracy, environmental conditions, calibration tools and environment, expected range of fluctuation, frequency of calibration, user competence and training.

Also up for discussion is bump testing or verification - How often should it be done? How important is the method of verification? What tolerance of error can be applied?

These are all questions that should be considered before pushing the calibrate button.

WAITOHI CATCHMENT INTEGRATED SURFACE WATER AND GROUNDWATER INVESTIGATION

Mr Bas Veendrick[1], Neil Thomas[1], Suzanne Gabites[2], Hamish Graham[2]
[1]Pattle Delamore Partners, [2]Environment Canterbury

Aims

Environment Canterbury is developing sub-regional plans (zone specific chapters of the Canterbury Land and Water Regional Plan) for each Canterbury Water Management Strategy (CWMS) zone, including the upcoming Hurunui-Waiau Zone. The plan will focus on water quality and quantity limit setting. To support the plan development, technical work on surface-water and groundwater interaction is being carried out.

Method

To assist with this limit setting process and to gain a better understanding of the surface and groundwater system in the area Environment Canterbury collected a variety of water quantity and water quality data in the Waitohi Catchment and Amuri Reach of the Hurunui River between October 2016 and July 2017. This monitoring programme included undertaking gaugings and water quality sampling in the Waitohi and Hurunui Rivers along with visual observations of flowing, ponding and drying reaches at different locations along the Waitohi River. Groundwater quantity and quality data was also collected along with a piezometric survey during the 2017 winter. The work aimed to answer a series of particular questions including:

1. What is the minimum flow required to maintain flow along the length of the Waitohi River?
1. Where does the water in the lower Waitohi River originate from once it re-emerges downstream of Dalziels Road?
2. Where would be the most effective minimum flow site for protecting the values in the river?
3. Is the catchment over-allocated with respect to groundwater and surface water?
4. Should all groundwater takes be restricted by minimum flows in the river?
5. How often and why are shallow bores alongside the river drying up?

Various approaches were employed to help answer these questions, including surface water flow naturalisation, analyses of gains and losses, assessment of frequency, extent and duration of dry river reaches, various water quality analysis techniques including cluster analysis and stiff plots, as well as piezometric contouring and groundwater balance assessments.

Results

Groundwater data (i.e. groundwater levels and water quality) collected for this work represented a time of higher groundwater levels and higher surface water flows. Consequently, the data may not be representative of times of lower flows and lower groundwater levels. However, initial groundwater analysis indicated that generally, the sources of water in the lower Waitohi River, (defined as the reaches downstream of Medbury Road) are likely to be land surface recharge and seepage losses from the Waitohi River. Water quality data did not indicate a clear component of Hurunui River water and groundwater contours did not indicate a clear loss from the Hurunui River towards the Waitohi River at the time the measurements were made.

Analyses of concurrent gauging surveys along the Waitohi River at low flows show a consistent losing pattern when the Waitohi River emerges from the foothills onto the Amuri Plains down as far as Bakers Road Ford. The Waitohi River gains flow in the lower reaches before its confluence with the Hurunui River mainstem. Loss rates during low flow conditions vary greatly and the maximum loss rate appears to be in the order of 220 L/s, indicating that a flow greater than this is required to maintain a continuous flow along the length of the Waitohi River. The most effective minimum flow site for the Waitohi is where the river emerges onto the plains (Lake Sumner Road Bridge flow recorder). Due to the varying nature of the loss rates, consideration should be given to a minimum flow site at Lake Sumner Road Bridge in combination with flow measurements in the vicinity of Bakers Road Ford (where relative loss rates are greatest).

The catchment is currently considered over-allocated with respect to groundwater, as allocation of groundwater south of the Hurunui River is likely to be greater than 50% of annual average recharge. Review of relatively short-period groundwater levels do not appear to show significant declining trends. When comparing the current surface water allocation with the limits set in the relevant sub regional plan the Waitohi River, which were set at current allocation when the plan was written, there is a small amount of water available. However, with respect to NES guidelines, the sustainable allocation limit would be significantly less.

The management approach defined under Schedule 9 of the Land and Water Regional Plan is likely to be appropriate with respect to restricting groundwater takes based on minimum flows in the Waitohi or Hurunui Rivers. Shallow bores dry up alongside the river due to both low flows in the Waitohi River as well as the length of time over which low flows occur. Visual observations were used to provide an indication of the extent and duration of dry, ponding and flowing reaches of the Waitohi River. This information was used to map the sequence of the increase in the extent of drying (and ponding) in the Waitohi River during the 2016/2017 low flow period. A low flow period of more than 40 days is likely to be required before shallow bores dry up, although the rate of decline in flows at the lake Sumner Road Bridge may impact that estimate.

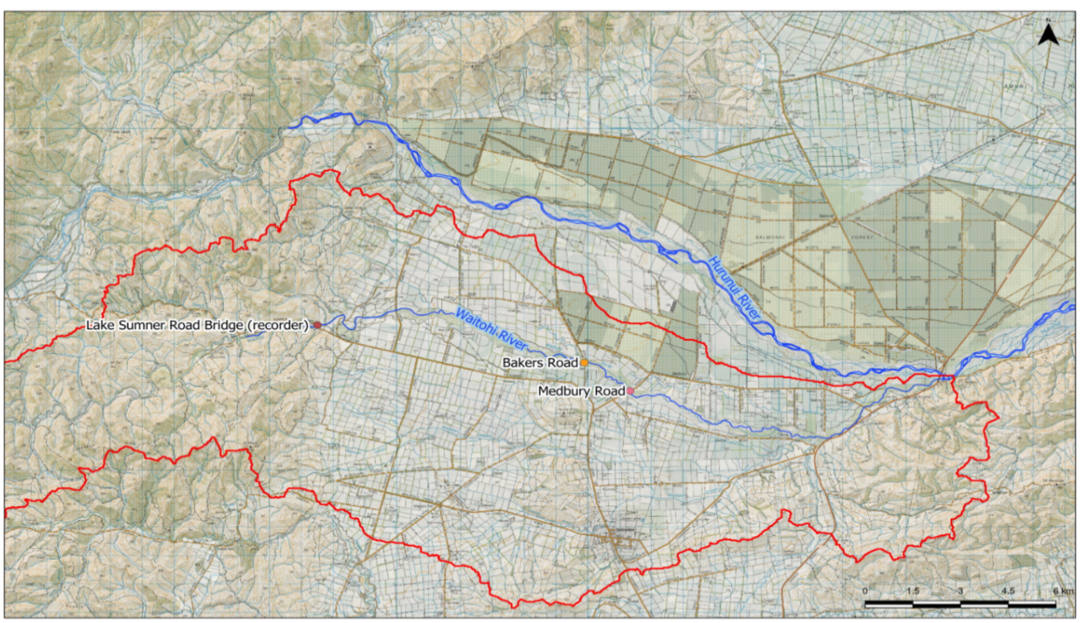

Figure 1: Map showing the location of the gauging points on the Waitohi River. The Waitohi River catchment is outlined in red

WAIMAPU STREAM (TAURANGA) – THE PERILS OF EXTRA CALIBRATION

Philip Wallace[1], Peter West[2]
[1]DHI Water & Environment Ltd, [2]Blue Duck Design Ltd

Aims

Tauranga City Council (TCC) convened a working group to review hydrological assumptions used in a hydraulic model of the Waimapu Stream catchment, after a recent review of hydrology assumptions for the adjacent Kopurererua Stream led to a significant lowering of design flows there.

Method

Previously, the hydrology of the upper catchment of the Waimapu had been represented with the "Model A" (Time-Area method) option of the MIKE 11 RR (rainfall-runoff) module. The model was calibrated to the flood event of 29 January 2011, as recorded at the McCarroll's Farm flow recorder. The hydrological model produced a good match to the recorder data, albeit representing only one subcatchment. The hydrological parameters were then applied to the other subcatchments and used in modelling the 100-year ARI design flood.

Data from four flood events were available for calibration in the current study:

- 29 January 2011 (Cyclone Wilma)
- 11 June 2014
- 5 April 2017 (Cyclone Debbie)
- 13 April 2017 (Cyclone Cook)

Flow data at the McCarroll's Farm recorder were available for all events. Rain radar and rain gauge data were also available, with which to refine the model inputs. Each event was modelled with the original hydrological model assumptions and then with variations on a UHM approach.

Results

Rerunning the original hydrology assumptions confirmed the good fit of the original model to the recorded flow data (Figure 1) for the January 2011 event. However, use of a UHM with a proportional loss of 0.28 also gave a good match to the recorder data. (For comparison, a UHM with a 0.20 proportional loss was the method finally adopted for the Kopurererua catchment.)

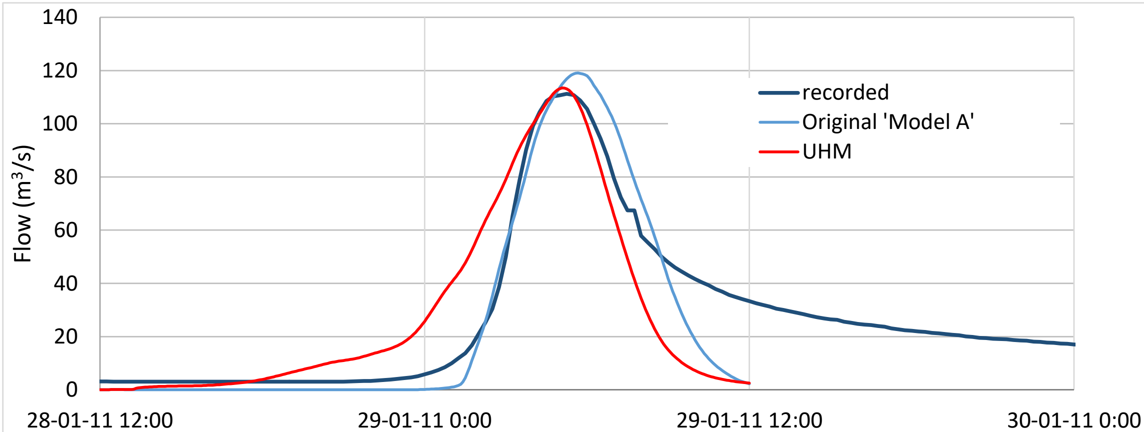

Figure 1: Calibration results – flows at McCarroll's Farm recorder, 29 January 2011 storm

In the June 2014 event, the peak flow recorded at McCarroll's Farm was 203 m^3/s, close to the 100 year ARI flow of 212 m^3/s. At the time of the event, the observed flood levels took TCC staff by surprise, given the rainfall recorder data being received. Retrospective radar analysis showed that the heaviest rainfall had missed the rain gauges, and so it was hoped that using the rain radar data in the modelling would produce a satisfactory match to the recorded flows. This did not prove to be the case however. Peak flows could only be reproduced by the model with assumptions that would later prove to vastly overestimate design floods (Figure 2). Further analysis of rain radar data shed no light on why the recorded flows were so high (Figure 3).

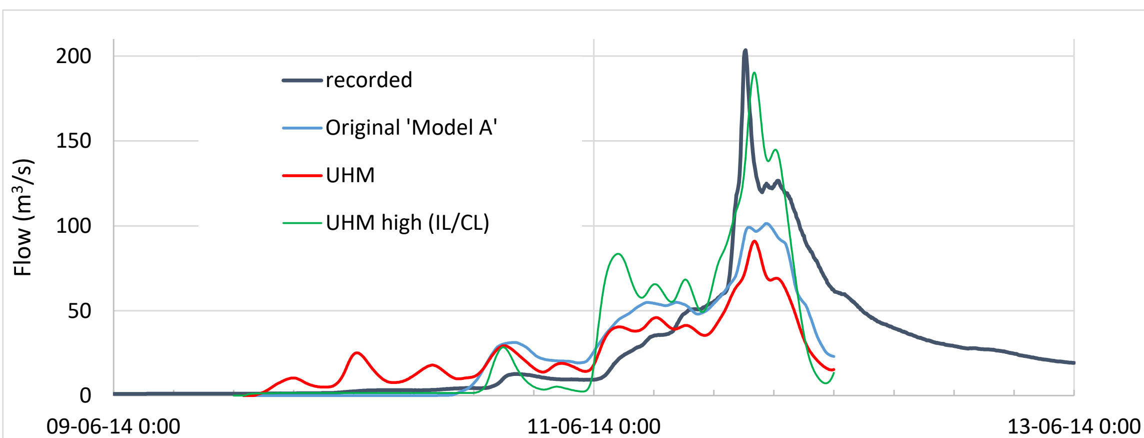

Figure 2: Calibration results – flows at McCarroll's Farm recorder, 11 June 2014 storm

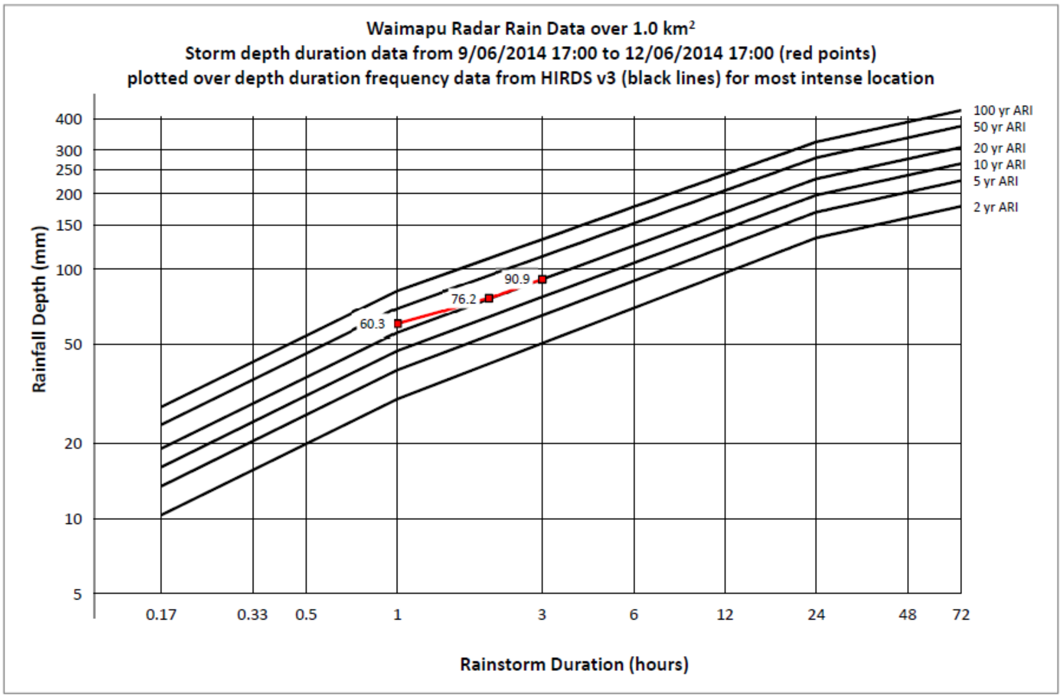

Figure 3: June 2014 storm rain radar data compared to Intensity-Duration-Frequency plots

For the two remaining calibration events, the models could not reproduce the pattern of the recorded flows for the 5 April 2017 event but a reasonable fit to the 13 April 2017 was obtained.

Thus, calibration remains inconclusive, with the model not consistently producing reasonable matches to recorded flows.

Encouragingly however, both the original hydrology model and a UHM approach gave peak design flows close to the current 100-year ARI flow estimate (from a flood frequency analysis). The study concluded with a recommendation that, until such time as either the currently adopted rating curve for the McCarroll's Farm recorder changes significantly or additional calibration data are collected, the original hydrological model will be used for design simulations.

SHORT-TERM RESERVOIR INFLOW FORECASTING, MODELLING WATER AVAILABILITY FOR THE CLUTHA HYDRO POWER SCHEME

AMY WATERS[1], William Earl Bardsley[1], Malcolm Taylor[2]
[1]The University of Waikato, [2]Contact Energy

Short-term reservoir inflow forecasting is a crucial component of hydro power generation, when there is a limited storage buffer, allowing the operator to know how much water will be available in the following days. The accuracy of the inflow forecast ensures maximising the operational efficiency of the hydro-scheme, by directly influencing power production scheduling and market offers, as well as increasing benefits gained from water as a renewable energy source.

The operation of the Clutha River hydro scheme, which supplies around 10% of New Zealand's electrical energy, relies heavily on an existing model which forecasts inflows into two small head pond reservoirs (Lake Dunstan and Lake Roxburgh).

Aims

The aim of this study is to develop an improved model for forecasting the inflows into these reservoirs, improving the overall operational efficiency of the Clutha River hydro scheme. The model will aim to have minimal forecasting uncertainty and have application to estimating missing data.

Method

The inflow model will be developed by analysing precipitation, temperature and flow data from within the Clutha catchment. A series of empirical equations will be developed for forecasting water flows for the main arms of the Upper Clutha catchment. A main aim of model development will be to accurately forecast the levels of Lakes Wakatipu and Wanaka, as together their outflows make up over 80% of the uncontrolled inflow into Lake Dunstan. The independent forecasts will then be added together to give the forecasted inflows for Lake Dunstan and Lake Roxburgh.

Results

Work is presently ongoing and results to date will be outlined at the conference.

A PROBABILISTIC MODEL OF AQUIFER SUSCEPTIBILITY TO EARTHQUAKE-INDUCED GROUNDWATER-LEVEL CHANGES

Weaver, K. C.,[1] Arnold, R., [1] Townend, J.,[1] Cox, S. C., [2]

[1]*Victoria University of Wellington*

[2]*GNS Science*

A probabilistic model for earthquake-induced groundwater response as a function of Modified Mercalli (MM) shaking intensity has been constructed using an internationally significant catalogue of monitoring well observations during earthquakes. The study constitutes a regional-scale multi-site multi-earthquake investigation encompassing the occurrence and absence of responses, over a decade of seismic shaking. Persistent groundwater-level changes, or absence of change, have been quantified in 495 monitoring wells in response to one or more of 11 recent New Zealand earthquakes larger than M_w 5.4 between 2008 and 2017. A binary logistic regression model with random effects has been applied to the dataset using three predictors: earthquake shaking (peak ground velocity), degree of confinement (monitoring well depth) and rock strength (site average shear-wave velocity). Random effects were included as a partial proxy for variations in monitoring wells' susceptibilities to earthquake-induced persistent water-level change. Marginal probabilities have been calculated as a function of PGV and MM intensity, and the likelihood of persistent water-level changes computed for MM intensities II to VIII. This study is the first attempt at incorporating both seismic and hydrogeological factors into a probabilistic framework for earthquake-induced groundwater level changes. The framework is a novel and more generalizable approach to quantifying responses than alternative metrics based on epicentral distance, magnitude and seismic energy density. It has potential to enable better comparison of international studies and to inform practitioners making decisions around investment to mitigate risk and increase the resilience of water supply infrastructure.

AN EIGENMODEL APPROACH FOR GROUNDWATER LEVEL PREDICTION

Julian Weir[1], Dr Birendra KC[1], Stephen Collins[2], Abby Matthews[2], Dr Helen Rutter[1]
[1]Aqualinc, [2]Horizons Regional Council

Eigenmodels have previously been used to better understand the relative impacts of climate and groundwater abstraction, but their application as a predictive tool has not been widely tested. Aqualinc has developed eigenmodels to simulate the response in groundwater levels as a result of changes in land surface recharge (LSR) and groundwater abstraction, and then used these models to forecast future groundwater levels.

A pilot study was completed in the Manawatū-Whanganui region for Horizons Regional Council (Horizons). Spatial variation was accommodated by the inclusion of two zones (north and south) as divided by the Manawatū River. These zones were further divided between the coast and the inland foothills based on the proximity of climate stations, land use, soil properties and monitoring bores. Two areas of interest were supplied by Horizons. Two example bores in each of these areas of interest were chosen, one to represent shallower groundwater levels and one to represent deeper groundwater levels.

The key eigenmodel inputs are LSR, groundwater abstraction and proportion of irrigated area within each zone. LSR was modelled for 58 years (from January 1960 through to April 2018) using the IrriCalc water balance model based on historical climate data (under both irrigation and dryland scenarios) for the dominant crop type and soil plant available water. Aqualinc's Climate Time Series Extension method (Kerr, 2017) has been used to extend and gap-fill measured rainfall and PET time series. Seven climate stations have been used to represent rainfall. For PET, a single climate station (NIWA's Palmerston North station) has been used, as this is the only local station that has a long-term PET record in the study area. Groundwater abstraction has been estimated by considering consents and irrigated area data along with crop water demands calculated by IrriCalc. Irrigated area within each zone was derived from irrigated area mapping that was completed by Aqualinc for the Ministry for the Environment (Dark *et al.,* 2017).

Eigenmodels were constructed and then calibrated to measured groundwater levels for each of the four bores. Once calibrated, the historical modelled response was then used to predict a range of future responses accommodating simple climate forecasts. The forecasting component of the model first requires the user to specify a target prediction date and a length of prediction. The methodology then classifies forecasted climate into nine different classes comprising three classes of temperature (warm, average and cold) and three classes of rainfall (wet, average, dry). Each temperature and rainfall class spans one-third of the corresponding range in historical records. The top one-third of the temperature records have been classified as 'warm'; the top one-third of rainfall has been classified as 'wet'; etc. Users select both the temperature and rainfall forecast, which could be based on an external climate forecast provider, or their own local knowledge.

Figure 1 demonstrates the result of calibrating the eigenmodel against the measured groundwater level data for the period November 1996 to February 2018 in bore 345009 located in south zone. The calibrated model captures the majority of the measured groundwater level response. Figure 2 shows measured groundwater levels for the same bore with a mean 30-day prediction beyond the last date of measurement for an average rainfall and average temperature forecast. Also shown in the graph are 5-percentile and 95-percentile predicted groundwater levels.

The method provides water managers with guidance as to what groundwater conditions might be expected at a desired date, based on the measured groundwater levels and response to historical recharge and abstraction patterns. The method can predict groundwater levels over shorter time periods (say, up to 30 days beyond a measurement date) with relatively good confidence. However, predictions beyond 90 days would have less confidence as climate predictions become increasingly uncertain. By being able to forecast groundwater levels at the end of a summer, water resource managers would be able to communicate likely issues, and users would be able to better manage their allocation, particularly during dry conditions when water conservation may be needed.

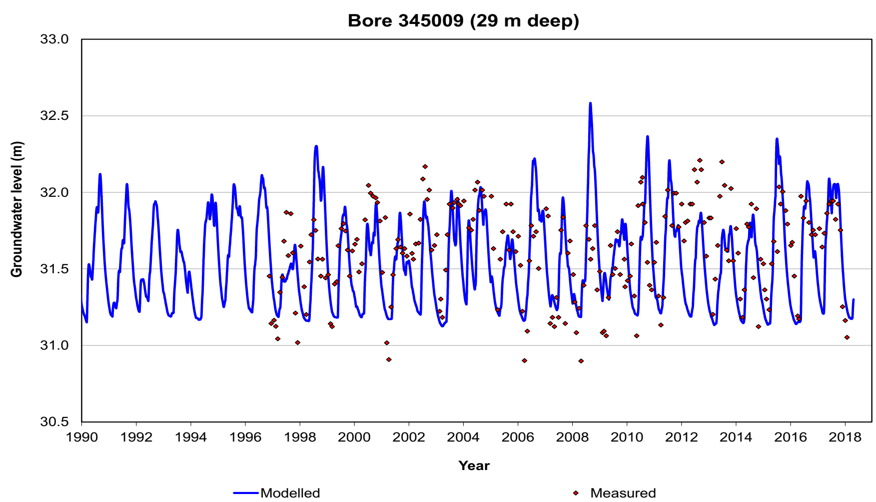

Figure 1: Calibrated model for a bore 345009 over the period November 1996 to February 2018

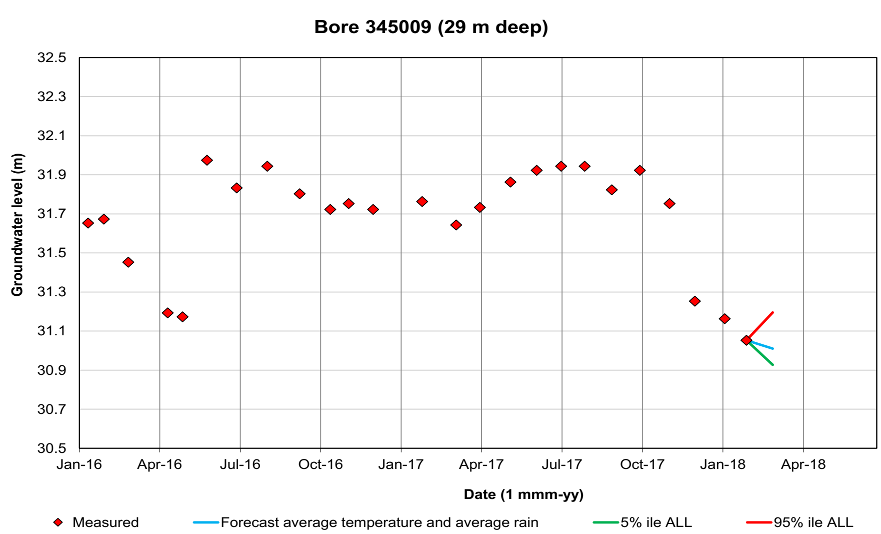

Figure 2: Measured and forecasted groundwater levels for bore 345009

From this pilot study, the following future improvements are suggested:

1. Extend this work to other areas of the region by selecting wells representing alternative hydrogeological settings (e.g. shallow versus deep groundwater; adjacent to rivers versus further away; inland versus coastal).

- Include additional attributes for forecasting, such as antecedent soil moisture conditions and groundwater levels.
- The model has been developed using an Excel spreadsheet. This could be converted to a coded platform (such as 'R' or 'Python') to improve calculation speeds. This could also lead to an internet-hosted model for wider access and availability.
- Automate the prediction with real-time climate data and groundwater levels.

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GROUNDWATER ALLOCATION REGIME FOR ALL CATCHMENTS IN THE BAY OF PLENTY REGION 2005 - 2018

Paul White[1], Glenys Kroon[2], Dougall Gordon[3], Conny Tschritter[1], Daniel Collins[4], Raoul Fernandes[2]

[1]Gns Science, [2]Bay of Plenty Regional Council, [3]Wellington Regional Council, [4]NIWA

Aims

Bay of Plenty Regional Council (BOPRC) set out, in 2005, to identify groundwater allocation limits for all its aquifers. This aim came on a background of rising demand for groundwater and a lack of groundwater allocation limits in the region. In addition, the community was concerned to maintain stream flows. Therefore, limits had to consider the effects of groundwater use on stream flow because of the predominance of baseflow-dominated streams in the region, principally in large areas of volcanic terrain. However, aquifer characteristics (e.g., aquifer distribution, hydraulic links to spring-fed streams and groundwater catchment boundaries) were poorly understood.

BOPRC aimed to characterise the groundwater system and calculate groundwater allocation limits for each aquifer in the region; these limits aim to preserve surface water baseflow from the effects of groundwater use and provide interim allocation limits for groundwater. BOPRC has given effect to these limits via the region-wide Plan Change 9 (PC9; Bay of Plenty Regional Council. 2018). PC9 is the first step in a two-step process that BOPRC is undertaking to set environmental flows and levels under the National Policy Statement for Freshwater Management (NPSFM). This first step is to ‘hold the line’ with conservative region-wide interim limits before undertaking more detailed assessments, in accordance with the NPSFM, to determine the final sub-regional limits.

Method

Conceptual groundwater models (i.e., geology and flow) were developed of groundwater systems to calculate average annual groundwater flow in all Bay of Plenty catchments and zones (Figure 1). Characterisation of the groundwater system used sub-regional 3D geological models to assess the distribution of aquifers, identify likely groundwater flow directions and inform the definition of groundwater catchment boundaries. These models collated all relevant material such as geological maps, well logs, reports (published and unpublished) and geophysics from all sectors such as groundwater, geothermal, engineering and geotechnical; identifying geological units (aquifers, aquitards and aquicludes) and relevant geological structural information, such as faults.

Steady-state water budgets were used to characterise groundwater flows, including groundwater outflow to surface water (i.e., baseflow). These budgets assessed all relevant flow components (e.g., rainfall, evaporation, groundwater use and surface water flow), using data from BOPRC and the National Institute of Water and Atmospheric Research.

Average annual groundwater flow was partitioned into an allocation to sustain stream flow and ‘Residual Average Annual Recharge’ (RAAR). The allocation to sustain stream flow was based, largely, on baseflow calculations and is relevant where groundwater is connected to surface water (Bay of Plenty Regional Council, 2018). Generally, this allocation was less than groundwater flow, i.e., RAAR was greater than zero. However, in some cases this allocation was equal to groundwater flow, i.e., RAAR equalled zero.

RAAR was divided into an 'Interim Allocation Limit' (IAL), which was set at 35% of RAAR, and an allocation to sustain aquifer pressure. Note that IAL defined here is more conservative than the proposed National Environmental Standard for Ecological Flows and Water Levels, i.e., that 35% of total aquifer recharge be available for allocation in non-coastal aquifers. The use of conservative IALs aims to 'hold the line' and reduces the prospect that future sub-regional plan changes will need to claw back allocation, as well as taking into account the uncertainty in the calculation and protecting the hydraulic heads to prevent the likelihood of saltwater intrusion. PC9 also included separate IALs for surface water.

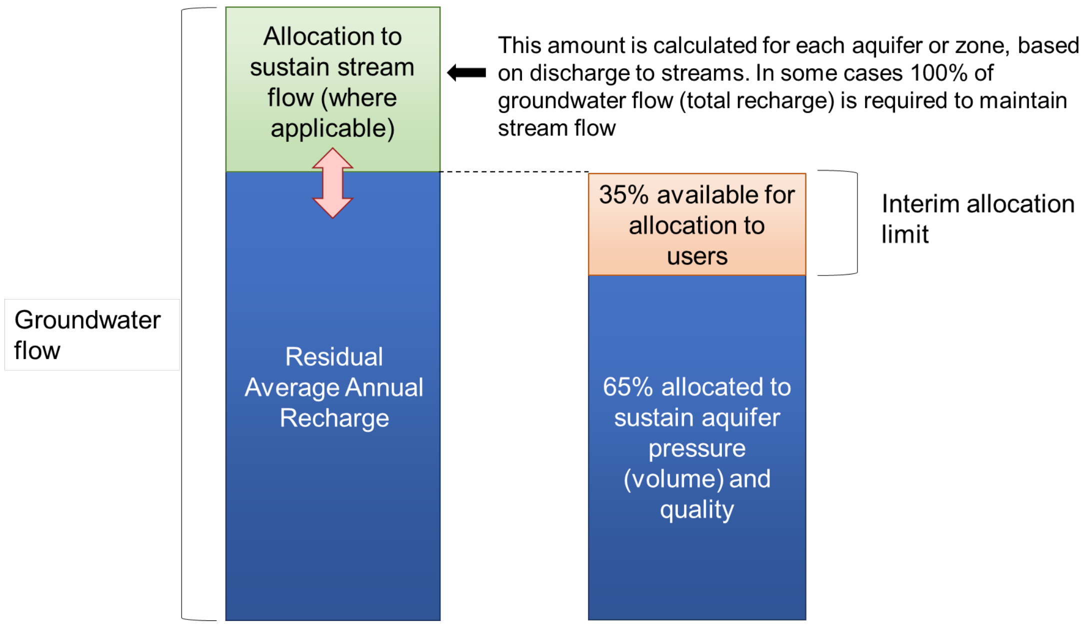

Figure 1: Schematic of groundwater allocation in PC9 (Bay of Plenty Regional Council, 2018).

The development of PC9 included extensive public consultation, including more than 30 meetings with stakeholder groups (iwi, community water users) and several workshops with Councillors prior to notification in October 2016. As part of this development, Council produced a set of publicly-accessible water accounts that, in combination with PC9, set water availability and described the methods used to calculate IALs.

Results

This year, 2018, saw the completion, of PC9 for groundwater and surface water in the Bay of Plenty region. The policy is a significant milestone for the region because it contains a schedule of IALs for groundwater that were based on GAA calculations and featured transparent policy decisions on allocation and extensive community engagement. Calculation of GAA has also produced an extensive knowledge base of the Bay of Plenty region's aquifers (e.g., White et al., 2008).

The PC9 process has determined interim groundwater limits that will now form the basis of allocation decisions. Future plan changes will review these limits, and in some cases, require additional science. For now, the combination of scientific assessments and the Resource Management Act planning process has resulted in the establishment of region-wide limits to groundwater allocation in the Bay of Plenty, thereby contributing to the sustainable management of this important resource.

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DATA ASSIMULATION FOR A HYDROLOGICAL FLOOD FORECASTING MODEL

Greg Whyte[1]
[1]*DHI Water & Environment*

Aims

This case study of the Hutt River Flood Forecasting system aims to demonstrate the benefit of using data assimilation for a hydrological model in addition using data assimilation for a hydrodynamic model. Hydrological and hydraulic predictions are affected by various sources of uncertainty which degrade the performance and predictive capabilities of such models. Data assimilation techniques can be used to improve model predictions.

Method

The Hutt River Flood Forecasting system has been in operation since 2016 and is configured to run 3 simulations every 3 hours that predict water levels and flows across the catchment. The base simulation uses a Metservice forecast rainfall prediction and additionally a 0.8 and 1.2 Metservice forecast is run to produce an envelope of predictions every 3 hours. A simulation consists of a 2 day hindcast period and a 2 day forecast period. The period separating the hindcast and forecast period is referred to the Time of Forecast (TOF). Currently the Hutt River system uses data assimilation in the hydrodynamic model where state variables are updated over the hindcast period to force the model at certain locations to closely match observed discharge. This is to ensure the model at the TOF is up to date in terms of antecedent conditions so the best possible predictions can be made. The effects of hydrodynamic model state updating are reasonably quickly transferred downstream and therefore has limited effect on the future model state whereas hydrological model states are more persistent in time due to the hydrological memory and can increase the forecast lead time.

Data assimilation for the hydrological model has been implemented in the NAM model of MIKE HYDRO (the replacement for MIKE 11). The NAM rainfall-runoff model includes different internal states corresponding to the water content in the conceptual storages (1) surface storage, (2) overland flow reservoir 1, (3) Overland flow reservoir 2, (4) Interflow reservoir, (5) Lower zone (root zone) storage, and (6) groundwater storage.

Results

Evaluation of the internal states of the hydrological model was not possible because they are unobservable, only the combined rainfall-runoff can be directly compared to observations. The oral presentation will present the results of using no data assimilation, hydrodynamic data assimilation and hydrologic data assimilation for the Hutt River catchment.

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PLANKTON TO PLANETARY WAVES, SIMULATING THE 'EARTH SYSTEM'

Jonny Williams[1], Olaf Morgenstern[1], Vidya Varma[1], Fraser Dennison[1]
[1]*NIWA*

Aims

The mission of the New Zealand Government's Deep South National Science Challenge is '…to enable New Zealanders to adapt, manage risk, and thrive in a changing climate.' Under this Challenge, we contribute to the development of an 'earth system' model in collaboration with international partners. When complete, this model will simulate the global atmosphere, ocean, sea ice, land surface, atmospheric chemistry, ocean biogeochemistry, and marine ice sheets.

We will provide a brief introduction to earth system modelling in general and will then concentrate on the specific modelling and capability building which is being carried out in New Zealand.

The presentation will also showcase first results from the new supercomputing facilities which have been installed in New Zealand over the last year or so. This new resource has enabled us to simulate more model processes than ever before and has brought New Zealand to the forefront of global geophysical modelling capability.

Finally, we will give an overview of what type of results you can expect to see over the coming years which are now possible due to the availability of a global earth system model for Kiwi researchers.

Method

We use the high-performance computing (or 'supercomputing') resources managed by NIWA and NeSI (the New Zealand eScience Infrastructure). Specifically, we use the Kupe and Māui machines.

Results

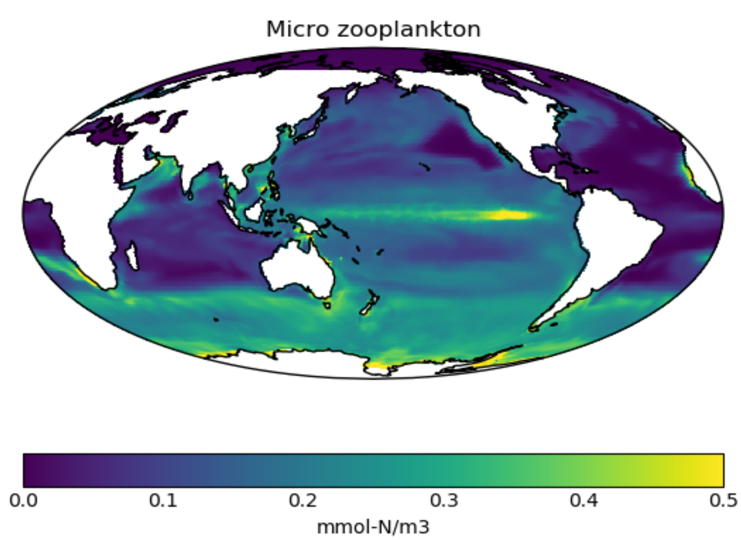

Figure 1: An example of the modelling capability of the earth system model; the micro zooplankton concentration in the global ocean.

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WATER QUALITY MODEL PERFORMANCE EVALUATION METHODS

Jon Williamson[1], Hangjian Zhao[1]
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Aims

The analysis was aimed at enhancing the understanding of a largely non-technical team involved in the process of selecting appropriate performance measures (PMs) for evaluating water quality model calibration accuracy. The need for the work arose because of the disparate view between modellers and non-technical members of the project team with regard to model accuracy. The modeller being of the view that the calibration was generally good "given the data available (length of record and quality)", while the project team were of the view that the "statistics indicate the model is not good".

In performing model performance evaluation, it is assumed that the observation dataset is error free and all error variance is contained in the simulation results (Willmott, 1981). However, measured data are inherently uncertain (Moriasi et al, 2007). Therefore, what is good model performance, when the data the model is being evaluated against is imperfect itself.

The analysis aimed to test two similar hypotheses in slightly different ways:

1. Does sample size have a bearing on "model performance"; and

- Does sample size matter with model of known performance (i.e. a data trained model).

Background

The analysis was undertaken as part of the work program for two comprehensive catchment water quality modelling projects of the Kaituna and Rangitāiki catchments for the Bay of Plenty Regional Council. The models were developed using the eWater SOURCE catchment model and the water quality parameters being investigated were Total Nitrogen (TN), Total Phosphorus (TP), E. coli and Total Suspended Solids (TSS).

Method

The analyses performed in this study used the Nash–Sutcliffe efficiency (NSE) coefficient as a PM. NSE is defined as:

where is the mean of observed discharges, and are the modelled and observed discharge at time t, respectively.

Two case studies were undertaken to address the disparity outlined above. Both case studies utilised simulated and observed flow data for the Rangitikei River at Te Teko. This site was selected because it has relatively larger sample size comprising 14,536 observations and was one of the better performing flow calibrations.

Case Study 1 – Influence of Sample Size on PM

The same number of observations were randomly selected between the start and end dates of the measured data at Te Teko 1,000 times (also ensuring each data point in the sample was unique i.e. no duplicates). NSE was performed on each realisation. The procedure was repeated incrementally with increasing number of observations selected, as follows:

- Randomly select a number of observations with size (n), between the start and the end of the record;
- Perform NSE analysis on the selection (size n);
- Repeat above two step 1,000 times and record the NSE value each time;
- Compute the mean, standard deviation, standard error and relative standard error of the 1,000 NSE outputs.
- Repeat the process for the different selection sizes (n).

Case Study 2 – Influence of Model Accuracy on Importance of Sample Size

A R scripted model was provided by Ton Snelder from Land and Water People Ltd, which we adapted for this analysis in Python. The method comprises generation or “simulation” of a sub-dataset from an observation dataset (Te Teko flow). The simulation was constructed based on the selected observation data, a fixed bias constraint and a random error derived from a normal distribution (e.g. Obs+Bia+Error). The bias represents the systematic error of the model, hence the smaller the bias, the closer the simulation will resemble the observation.

Four models of different predictive ability were constructed, and sample data pairs (obs and sim) of 10, 15, 20, 30, 40, 50 100, 200 and 500 in size were randomly extracted for each of the four models. The NSE was calculated on each sample and the same process was repeated 1,000 times per sample size. From the 1,000 repeats, the average NSE value was calculated.

Results

The results for Case Study 1 are as shown in **Figure 1**, which provides the following conclusions:

- With increasing sample size, the standard deviation (or variability) and the relative standard error of the NSE decrease (i.e. the randomness of the dates selected is overcome by population size);
- At approximately 500 samples, there is no significant change in all statistical measures, indicating that increasing the population size will not necessarily improve the statistical results (all other external variables remaining equal);
- Where the sample population is <30 the variation in the NSE results exceed the mean NSE value (Std Dev > mean).

The results from Case Study 2 are shown in **Figure 2** and conclusions from this analysis are as follows:

- sample size becomes increasingly important for models of moderate to low accuracy;
- for highly accurate models, sample size is not a factor in determining the accuracy of the model (but us modellers will say it is near impossible to get this level of accuracy in "real-world" modelling).

While increasing the sample size is likely to increase the likelihood of being able to increase your model performance, it does not guarantee it. This depends on a range of factors including how good the model is, how good the modeller is. how good the data is and how complex the flow system is? This is a really interesting topic and we hope this paper provides fuel for thought.

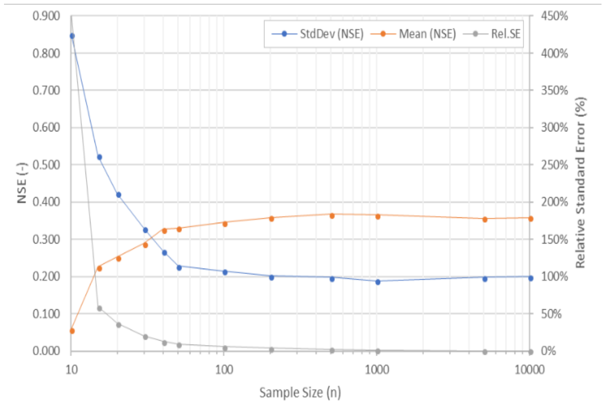

Figure 18: Sensitivity of NSE to Sample Size.

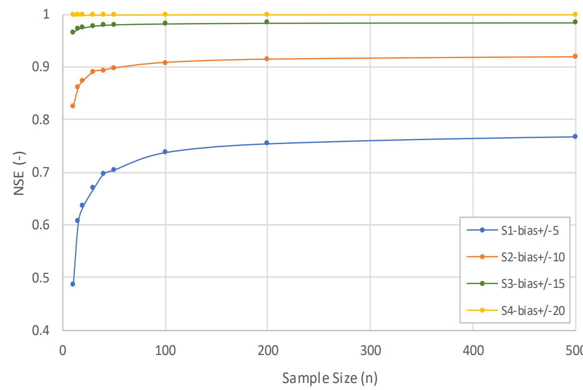

Figure 19: Sensitivity of NSE to Sample Size.

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AQUIFERWATCH – TOWARDS AN OPERATIONAL TOOL TO PREDICT WAIRAU PLAIN AQUIFER DEPLETION

Thomas Wöhling[1,2], Moritz Gosses[1], Peter Davidson[3]
[1]Technische Universität Dresden, [2]Lincoln Agritech Ltd., [3]Marlborough District Council

Aims

The Upper Wairau Plain Aquifer serves as the major resource for drinking water and irrigation in the Blenheim region. In the past decade, the aquifer has been several times severely depleted during summer and water take restrictions had to be imposed by the Marlborough District Council (MDC) who manages the groundwater resource. A numerical model has been set up for the Wairau Plain to better understand the surface water – groundwater interaction and flow processes in the Wairau Plain Aquifer and to predict several quantities of interest (Wöhling et al. 2018). A comprehensive list of daily model inputs is required to run the complex model. This includes Wairau River flows but also the outputs from a distributed soil water balance model which itself requires inputs of spatially distributed meteorological inputs (that are not available in real-time). In addition, the run-times of the model can be up to several minutes. These issues together makes it very challenging to use the complex model for real-time operational forecasts that are required to support decision making at the MDC.
The aim of this contribution is to develop and present a prototype of an operational model to forecast Wairau Plains Aquifer storage levels in case of naturally occurring recession events. The tool predicts aquifer depletion for the projected (worst) case that the Wairau catchment does not receive rainfall in the forecasting period. This will create more lead time for the MDC in decision making and adaptive management of the Wairau Plain groundwater resources.

Method

Since we face practical restrictions in using the existing numerical model of the Wairau Plain Aquifer for operational management purposes, we utilize data-driven surrogate modelling of groundwater levels in our approach together easily attainable inputs that could be derived directly by an automated database query of the MDC monitoring network. Wairau River flow recession time periods are predicted based using statistics from historic (observed) time series. Aquifer storage is then predicted with lead times of days to weeks based on the river flow recession predictions, predicted groundwater levels and a hydrogeological model of the Upper Wairau Plain Aquifer. In our analysis we also include a robust, data-driven uncertainty analysis to provide confidence bounds for the groundwater head and aquifer storage predictions.

Results

The surrogate models to predict groundwater levels at selected locations of the Wairau Plain perform very well in predicting (hind-casting) historic observations. The models are efficient and extremely fast and exhibit a low model simplification error. This allows to predict groundwater surface and aquifer storage with extremely short computer times. The “real-time” predictions were a prerequisite for the operational management support tool. The aquifer depletion was successfully tested on historic time series. Naturally, the confidence bounds increase with lead time, but generally include the observations. Since the tool is based on historic data, it would be – following fundamental modelling theory - only be applicable to low-flow periods similar to the ones occurred in the past. However, the Wairau Plain Aquifer system has shown a remarkable resilience in some important hydrogeological features which allows to put trust in the prediction of low flows. In any case, new data (or projections) could be easily incorporated in the tool as it becomes available or at regular intervals. Overall, the AquiferWatch prototype is promising for implementation into operational management by the MDC.

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HYDROGRAPH SEPARATION AND NUTRIENT LOAD PREDICTION USING MONTHLY STREAM PHOSPHORUS AND NITROGEN DATA

Simon Woodward[1], Roland Stenger[2]
[1]DairyNZ Ltd, [2]Lincoln Agritech Ltd

Introduction

Hydrograph separation techniques are used to estimate the proportion of stream flow attributable to base flow (assumed to represent groundwater discharge) as opposed to quick flow (assumed to represent surface and near-surface runoff). These techniques commonly rely on either hydrograph analysis or chemograph analysis. The former methods are suitable for analysis of long term hydrograph data but are rather subjective, whereas the latter methods require intensive sampling, and so are usually only practicable for analysis of individual storm events. The ability to perform objective hydrograph separation using low-resolution, long-term data sets would be highly useful for understanding the importance of near-surface vs groundwater flow paths for water and nutrient discharge in rural catchments.

Methods

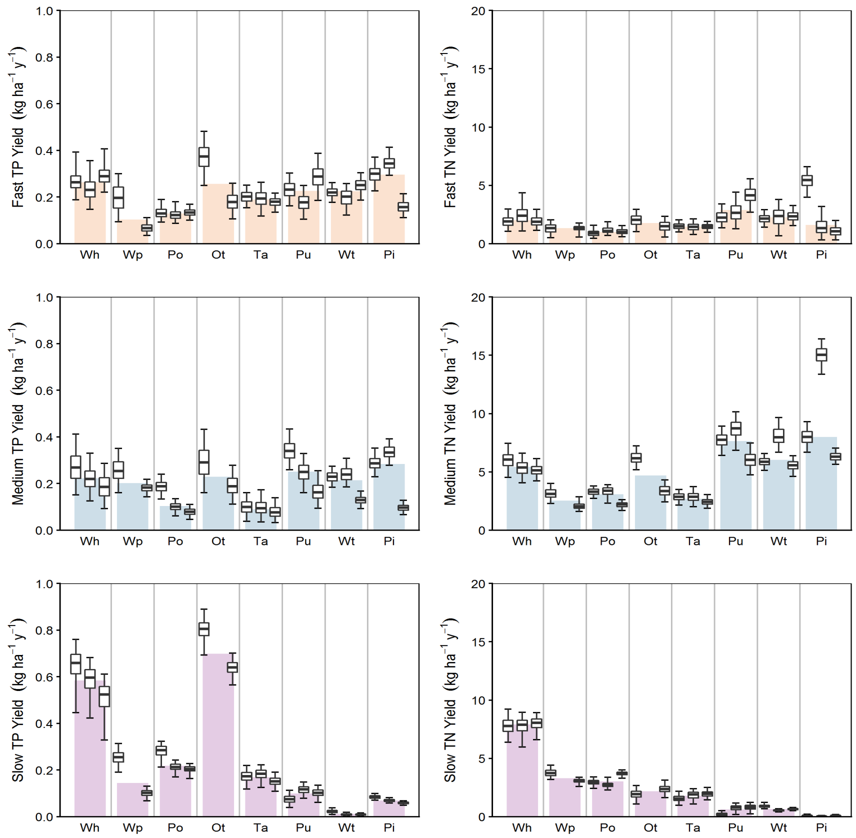
The BACH method was developed to perform hydrograph separation and nutrient flux estimation from water quality and stream flow data routinely collected by Regional Councils throughout New Zealand. The model consists of a simple recursive digital filter (Su et al., 2016), applied twice, combined with a simple end-member mixing assumption (Adams et al., 2009). The model takes daily stream flow as input, and is calibrated to monthly concentration data using a Bayesian method, to infer fast (near-surface storm flow), medium (seasonal shallow groundwater) and slow (deeper groundwater) discharges, concentrations and nutrient yields, as well as the uncertainties associated with these predictions. The method was applied to 15 years of monthly TP (total phosphorus) and TN (total nitrogen) concentrations from 8 mesoscale catchments in the Waikato Region: the Waiotapu (Wp), Otamakokore (Ot), Tahunaatara (Ta) and Pokaiwhenua (Po) in the Upper Waikato, the Puniu (Pu) in the Waipa District, and the Piako (Pi), Waitoa (Wt) and Waihou (Wh) in the Upper Hauraki Plains. The data from each catchment were split into three 5-year subperiods (2002-2006, 2007-2011, and 2012-2016), each analysed separately to provide validation of the results. The method is described in full in Woodward and Stenger (2018).

Results

Bayesian model calibration achieved a good fit to the monthly TP and TN data for all catchments and subperiods. Although the digital filter parameters were poorly identified (i.e., had high uncertainty), the flow path concentrations, flow proportions, and yield partitioning were generally well identified for the fast, medium and slow flow paths in each catchment and consistent between subperiods (Figure 1). This implies that the monthly TP and TN data contains sufficient information content to infer these catchments properties with a useful degree of uncertainty.

Conclusion

Based on these results, the catchments could be grouped into three types: firstly, slow flow-dominated catchments (Wh, Wp, Po, Ot, Ta) with Fast:Medium:Slow flow contributions approximately in the ratio 10:25:65, secondly, an intermediate catchment (Pu) with flow components approximately in the ratio 20:55:25, and thirdly, flashy catchments (Wt, Pi) with Fast:Medium:Slow flow contributions approximately in the ratio 25:60:15. These proportions were consistent despite large differences in annual flow, differences in concentration ranges, and despite the large proportion of spring flow in the Waihou catchment. Our analysis also highlighted that the deeper groundwater pathway is very important for both P and N load delivery in the slow flow-dominated catchments, as the high flow volumes overshadow the low concentrations. The ability to quantify the nutrient load delivered via the fast flowpath, which was similar across these rural catchments, was also notable. Application of the method across a wider range of geological and climatic conditions is planned to see if additional “catchment hydro-types” can be identified.



Acknowledgement

This work was carried out under the MBIE “Transfer Pathways Programme” and co-funded by Waikato Regional Council and DairyNZ Ltd.

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PROGRESS ON NATIONAL SURFACE-GROUNDWATER MODELLING: MODEL DEVELOPMENT, PARAMETERISATION AND REGIONALISATION

Jing Yang[1], Christian Zammit[1], James Griffiths[1], Channa Rajanayaka[1], Paul White[2]
[1]NIWA, [2]GNS

Aims

"The National Policy Statement for Freshwater Management (NPS-FM) provides direction on how local authorities should carry out their responsibilities for managing fresh water" (www.mfe.govt.nz/fresh-water/acts-and-regulations/national-policy-statement-freshwater-management). To effectively apply NPS-FM, it is important to know how much water is available, how it varies seasonally, and how it will change for different scenarios (e.g. climate change, land use change, etc), for both surface water and groundwater. To address these problems, NIWA is developing, parameterising and regionalising a national surface water-groundwater model in New Zealand within National Hydrologic Program (NHP) funded by Ministry of Business, Innovation and Employment (MBIE), with an emphasis on lowland areas where groundwater strongly interacts with surface water and water resources are of importance to ecological and economic development.

Method

We have been parameterising the integrated surface water and groundwater model TopNet-Groundwater (i.e. Topnet-GW; Yang et al., 2017) through collaborations with regional councils/districts, GNS, and University of Bristol, UK. To parameterise TopNet-GW, we aim to build national datasets that combine the expert knowledge (e.g., of surface water and of groundwater) of scientists (i.e., national research institutes and regional and district councils), Yang et al. (2018). These datasets include: groundwater-surface water interactions (i.e., loss, and gain, of stream flow to, and from, groundwater); riverbed characteristics such as bed sediments and bed-wetted area; and water budgets.

Techniques for model regionalization are under development, e.g., to areas where there is insufficient groundwater measurements and knowledges. Model applications are beginning with Topnet-GW trials in three regions: Southland, Greater Wellington, and Gisborne.

Results

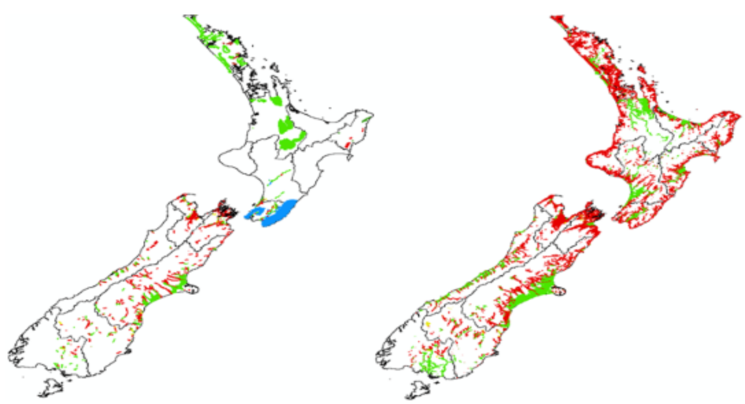

Figure 1: National loss and gain streams in New Zealand (left: expert knowledge from regional and district councils; right: statistical prediction based on expert knowledge in the left plot; red – loss stream; green – gain stream; blue – natural). (Yang et al. 2018)

Figure 1 shows there is a strong interaction between surface water and groundwater, as loss and gain streams in Figure. Left plot in Figure 1 shows the loss and gain streams based on knowledges of surface water and groundwater scientists from regional and district councils. Based on this, a statistical model was constructed to give predictions to streams there is no loss and gain information (right plot in Figure 1).

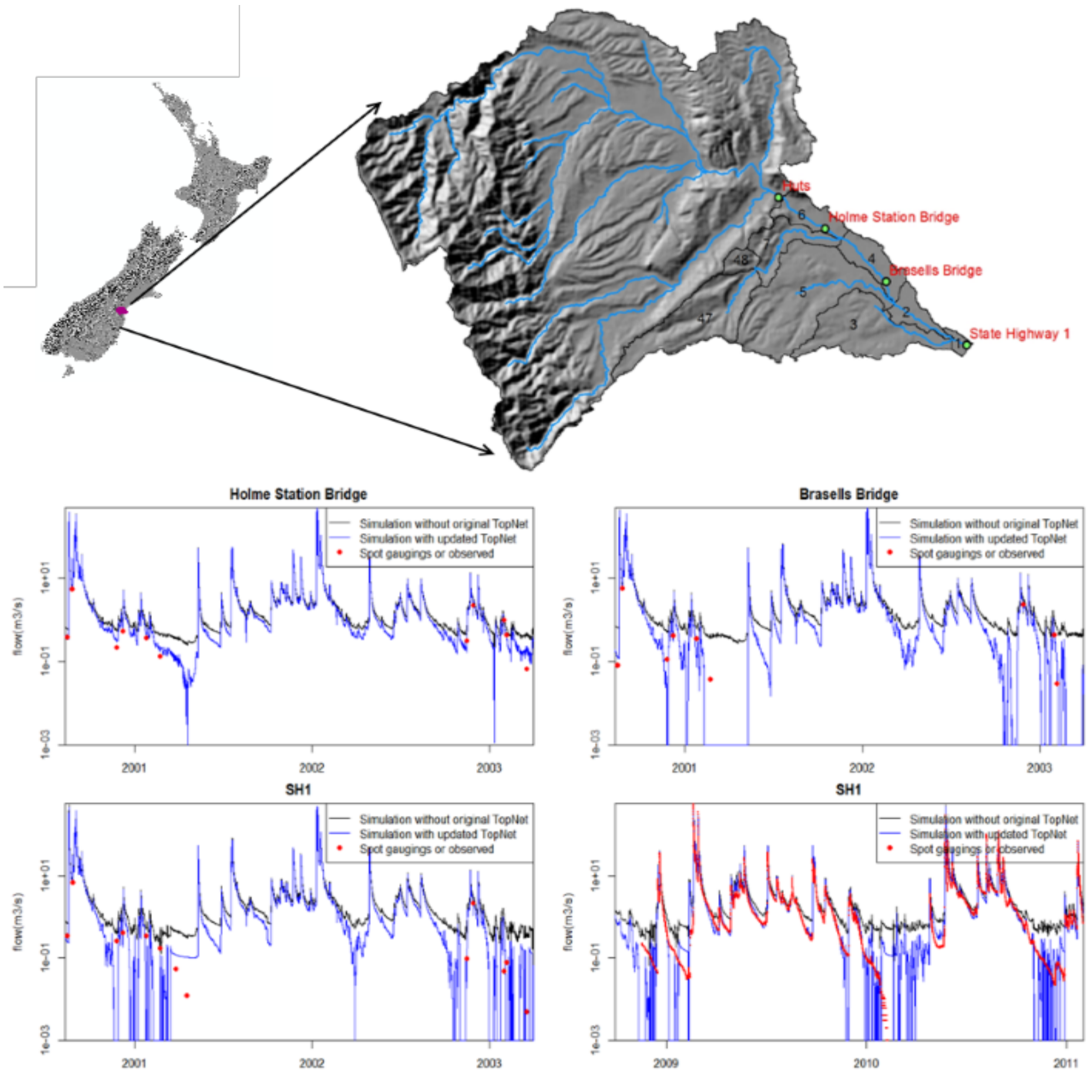

Figure 2: Comparison of model simulations of TopNet (original TopNet) and TopNet-GW (updated TopNet) applications in the Pareora catchment, Canterbury (Top – study location; Other – flow simulation at three locations) (Yang et al., 2017)

Figure 2 demonstrates one TopNet-GW application in the Pareora catchment, Canterbury. Spot gauged flow data at these three sites before 2002 were used for model calibration and from 2002 to 2011 were used for model validation. Its performance was compared to original TopNet. Significant improvement can be observed in the lowflow period. This will be important for local water management.

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INVESTIGATION OF THE TWO WIND PEAKS IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE DURING DEEPWAVE

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[1]*Niwa*

Aims

DEEPWAVE (Deep Propagating Gravity Wave Experiment over New Zealand) was conducted over and around New Zealand from 4 June – 20 July 2014 (Frits et al. 2015). Its aim was to study the dynamics of gravity waves from the surface of the Earth to the upper level of the atmosphere and to improve the parameterization schemes for gravity waves, During DEEPWAVE, a total of 162 radiosondes were launched from Haast (50), Hokitika (121), and Lauder (91). In the wind profiles of the radiosondes, sometimes two maxima in the zonal wind speed were found: one in the upper troposphere, the other in the lower stratosphere (Fig. 1a). It is hypothesized that the former wind peak was associated with the upper-level jet, and the latter was due to wave activity. The objective of this work is to test this hypothesis, to investigate whether the waves were mountain waves or inertia gravity waves, and to identify their source.

Method

The radiosondes had a temporal resolution of one second. This allowed a vertical resolution of 1 – 6 m for the observations. These high-resolution data were noisy due to random errors and very fine-scale turbulence. In addition, mathematical analysis and calculation cannot be done using these raw data with non-uniform vertical resolution. Thus, we created 100 m resolution radiosonde data from the surface to 25 km from the raw sonde data using linear vertical interpolation.

In addition to radiosonde observations, numerical simulation by NZLAM was also used. The NZLAM is configured from the UM and has a domain size of 324 by 324 horizontal grid points with a horizontal grid spacing of 0.11° (~ 12 km). It has 70 levels in the vertical and the top level is 80 km above mean sea level. The matching simulated radiosonde data were created from model level data using linear interpolation following the path of the balloons. Hourly model outputs were used for this interpolation.

To isolate and better understand the gravity waves in the lower stratosphere, a Lanczos band-pass filter was applied to the observations and simulations in one dimension. Wavelengths between 1.5 km and 10 km were allowed to pass through the filter (Fig. 1b). A similar approach has been used in previous publications (e.g., Scavuzzo et al. 1998).

To isolate the inertia gravity waves, a filter for horizontal wavelengths of 200 – 400 km was used for NZLAM simulation (Fig. 2).

To identify the source of the inertia gravity waves, NZLAM was run again but this time removing the New Zealand mountains (Fig. 2).

Wave parameters (intrinsic frequency, periods, wavelength, wave kinetic energy and potential energy) were calculated based on linear theory (Sawer 1961) using both radiosonde observations and simulated radiosonde data.

Results

Analysis showed that the wind speed peak in the upper troposphere was associated with the upper-level jet at around 11.5 km. The wind peak in the lower stratosphere around 15 km was due to the activity of inertial gravity waves. These inertia gravity waves had vertical wavelength of ~3 km, horizontal wavelength of ~ 300 – 400 km, periods of ~ 8 – 10 hours, and wave speed of 11 – 12 m/s.

When a balloon was launched in the early afternoon on 29 June 2014, it shifted eastward while ascending. The first wind peak was observed when it reached ~ 11.5 km, the upper-level jet. The second wind speed peak was observed when it reached ~ 15 km (Fig. 2), the strong westward tilted winds associated with the activity of the inertia gravity waves.

The westward tilted regions of strong zonal wind speed (Fig. 2) were due to the background zonal winds enhanced by the westerly perturbed winds. These perturbations have the signature of inertia gravity waves, because the horizontal perturbed wind vector turned counter clockwise with height in the Southern Hemisphere.

Analysis suggested that the source of the inertia gravity waves in the lower stratosphere was very likely due to the geostrophic adjustment at the exit region of the upper-level jet streak. Flow over New Zealand mountains was not the main source for these inertia gravity waves.

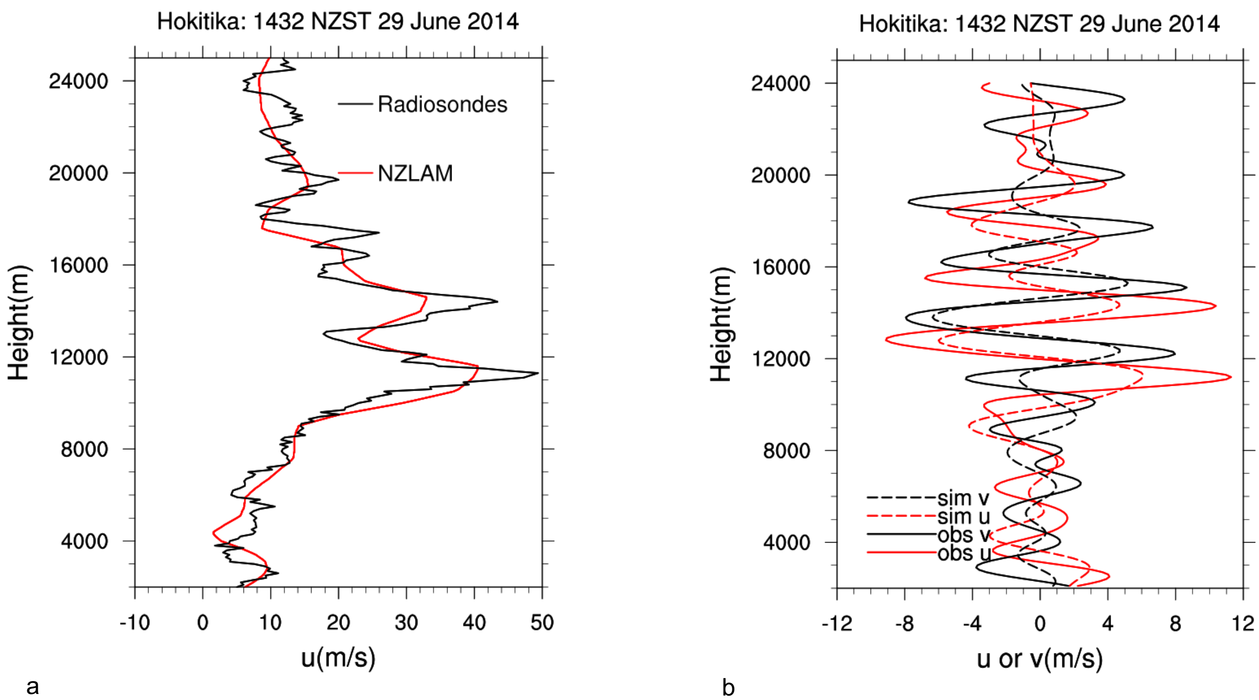
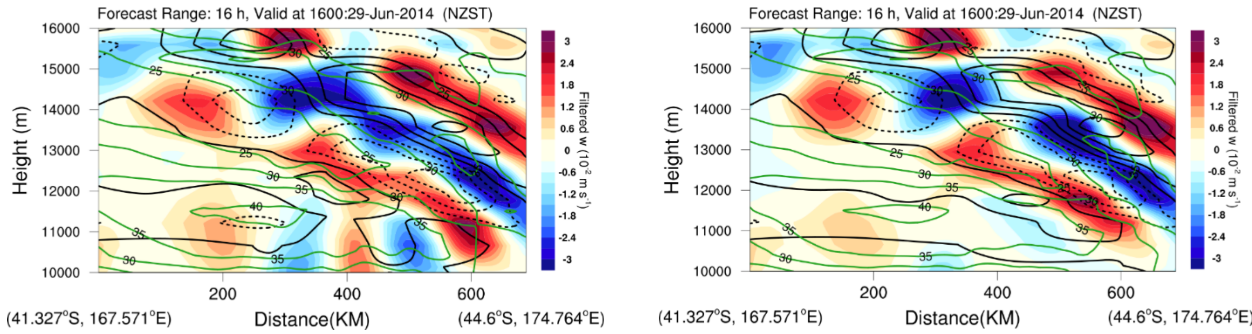


Figure 1: (a) Observed (black) and simulated zonal wind profiles at Hokitika and (b) band-passed (1.5 – 10 km) zonal and meridional winds from radiosonde observations and the corresponding radiosondes simulated by NZLAM at 29 June 2014 at Hokitika.



a b

Figure 2: Simulated zonal wind speed (green contours), band-passed (200 – 400 km) potential temperature (black contours with 1 K interval, solid for positive and dotted for negative), and band-passed vertical velocity (shading) along the north transect in Fig. 6c (left panel) at 1600 NZST 29 June 2014 (the Low-Ri case). (a) Simulations with terrain, and (b) simulations without terrain. The overall similar wave structure and patterns for simulations with and without mountains indicated that the inertia gravity waves were not mountain waves.

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UPDATE ON THE NEW ZEALAND WATER MODEL-HYDROLOGY PROJECT

Dr Christian Zammit[1], Dr Rogier Westerhoff[3], Dr Linda Lilburne[2], Dr James Griffiths[1]
[1]Niwa, [2]Manaaki Whenua Landcare Research, [3]GNS Science

Aims

Over-allocation of water and water quality degradation are key issues in New Zealand. To address these issues, the National Policy Statement for Freshwater Management requires Regional Councils, in collaboration with iwi and communities, to set limits on water use and water quality, and establish allocations to stay within these limits.

Effective and efficient limit-setting and allocation require tools that can accurately predict the transport of water and contaminants, such as nutrients or sediment, from their source areas to the receiving water bodies where their effects occur. The scarcity of direct measurements of surface and groundwater flows and contaminant concentrations at spatial and temporal scales suitable for limit setting, means simulation models are urgently needed. These models are used to make predictions and develop scenarios of the future by combining scarce measurement data, information about processes like runoff and nutrient leaching, and detailed maps of streams, aquifers, soils and other catchment properties.

One of the challenges for modelling flows and contaminants is the complex arrangement of land and receiving waters in NZ catchments. Another challenge is posed by the time and effort needed to build models for the many places that require limit setting. The New Zealand Water Model – Hydrology (NZWaM-Hydrology) was set up by NIWA in December 2016 to answer those challenges and needs, through the development of a single, highly adaptable system focused on determining the key environmental controls of water movement across the landscape at relevant scales. Another objective is to develop a model that is transferable, scalable and can be simplified based on data availability. The NZWaM-Hydrology will provide essential information for the implementation of the NPS-FM, as well as key knowledge for the success of the National Science Challenge programmes that aim to relate pressure on New Zealand eco-systems to ecosystem responses (e.g. Our Land and Water Challenge and Deep South Challenge).

The aim of this paper is to report the progress made during the second year of the project and future developments of this project.

Method

The NZWaM-Hydrology aims to develop a catchment-scale combined surface water and groundwater model coupled to a model of age of surface water and groundwater, that can be applied and parametrized at the national scale. It primarily focusses on water quantity, extending existing models, as well as providing a framework to ingest new model developments and conceptualisations. These goals will be accomplished through

- Development of a "living" geospatial database targeting catchment scale hydrological processes, linking geospatial data layers to their hydrological interpretation through key mechanistic and empirical relationships and parameters;
- Development of a national scale surface water-groundwater model, coupling existing national scale surface water and groundwater models through an integrated modelling framework;
- Development of a water age model, i.e., a conceptualisation of water age in the surface water and groundwater models. The water age model will be based on a national scale understanding of hydro-geochemistry as well as observed young and old water isotope signatures;

- On-going co-development and implementation with key regional council partners and iwi. Programme interactions with these various partners will allow exploration of the effects on model outputs of different levels of 'data availability' to drive such a model. This will result in a better understanding of the potential uses and limitations associated with model simulations and prediction.

The NZWaM-Hydrology structure is presented in the diagram below (Figure 1).

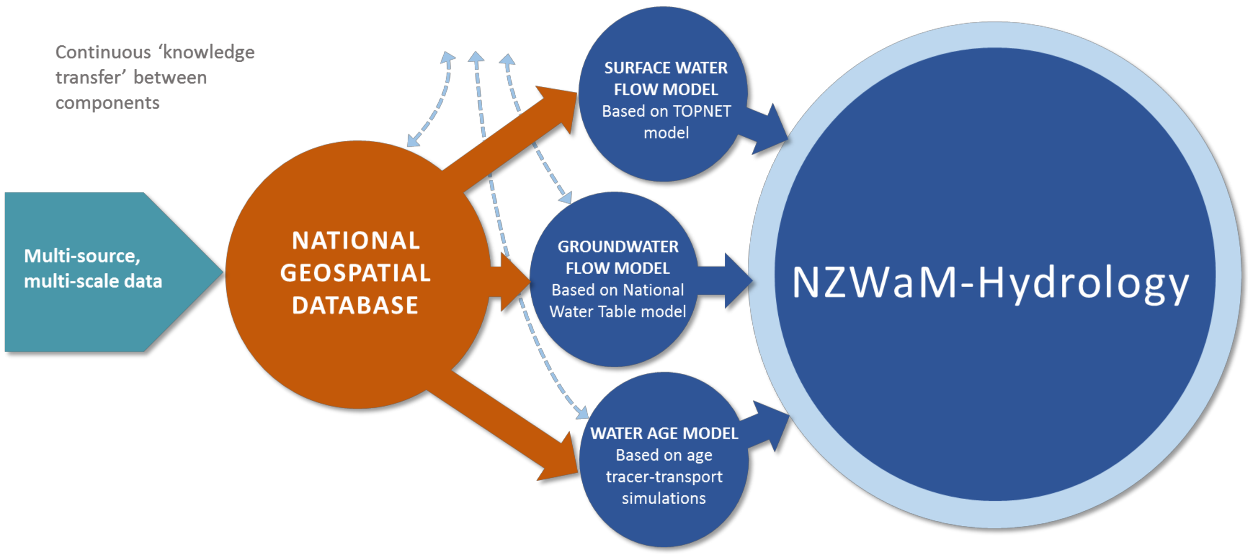

Figure 1: Conceptual organisation of the NZWaM-Hydrology project.

Results

A large component of the NZWaM-Hydrology work over the period 2017-2018 focused on developing the basic components of the model. As a result, the development of the geospatial framework includes the following components:

- Geospatial database (Hydro-Geofabric) containing up-to-date and harmonised datasets relevant to parameterise the national hydrological model for different applications and scales (e.g., rainfall, soil, topography, geology).

- New Digital River Network combining advances in national scale DEM and availability of Lidar information.

- National scale soil characterisation combining Fundamental Soil Layer information with advances in soil mapping (S-map and S-map Next Gen MBIE contestable program) in collaboration with Manaaki Whenua Landcare Research.

- National-scale groundwater related information based on aquifer characteristics in collaboration with GNS Science (effective porosity, depth to groundwater basement, subsurface hydraulic conductivity).

- Static and dynamic mapping of gaining and losing streams across New Zealand (in collaboration with GNS Science and all regional councils).

Additional work was carried out across other objectives on:

- Development of a benchmarking procedure to test model development, conceptualisation and parametrisation across New Zealand;
- Incorporation of a National Water Table model, based on the Equilibrium Water Table concepts, into the national hydrological model;
- Collection of surface water and groundwater isotope information to inform the development, conceptualisation and assessment of the water age module across the regions of three partners (Environment Southland, Gisborne District Council and Horizons Regional Council);
- Provision of information generated by the program to end users.

BUILDING A FINER DIGITAL RIVER NETWORK FROM A HYBRID LIDAR-15MDEM MODEL

Dr Christian Zammit[1], Dr Ude Shankar[1]
[1]*Niwa*

Aims

River networks are fundamental to modelling the movement of water and contaminants from their sources through to waterways, lakes and estuaries. Networks are derived from digital elevation models by employing algorithms that calculate pixel slope gradients and establish headwaters of streams through threshold setting or drainage area and valley slope relationships. Improving the accuracy of the digital elevation model will, therefore, be expected to reduce derivation errors and lead to more representative networks. This can be a step towards better prediction of water movement to assist water managers with limit setting for freshwater use and quality through to allocation of water takes, all requirements of the recent NPS-FM.

This paper describes the derivation of a high resolution digital network (DN3) which improves on previous river networks (REC1 & 2) created by NIWA.

Method

The network is created from a hybrid LIDAR-NZSoSDEM (Otago University, Columbus et al., 2011) DEM at 8m resolution. Lidar data points, where available, are used to replace data from NzSoSDEM. The combined dataset is processed within ArcMap ('Topo to Raster' tool), together with the 'blue-lines' of rivers and lakes from LINZ, to produce a flow-enforced DEM at 8m. This step is highly dependent on data density and complexity of the landscape contours, and can place high demands on computer resources. It may take several attempts to produce a successful DEM at 8m, usually done by adjusting the processing extent of the map. DEMs are then combined for each region by using the mosaic tool.

The workflow then proceeds with the use of ArcHydro tools within ArcMap to produce the river networks and associated catchment boundaries, after conditioning or 'burning in' of the DEM with the 'blue-lines'. Visual comparison of the river network with existing topo maps is used to readjust, if necessary, the threshold value to minimise the appearance of non-perennial streams.

Results

The finished DN3 river network is of a higher density, and shows an improvement in headwater delineation and a significantly better representation of streams in flatter landscapes with low relief.

Noted improvements are:

1. More accurate headwater reaches
   - Higher density and more accurate in flat areas when Lidar is available
   - Closer representation of LINZ's 'blue-lines'
   - Higher density has resulted in more outlets observed for small lakes and ponds not previously captured in REC1&2

A draft network was provided to regional council for internal check and review. The updated version 1 of the network will be released to regional councils and central government agencies by August 2019.

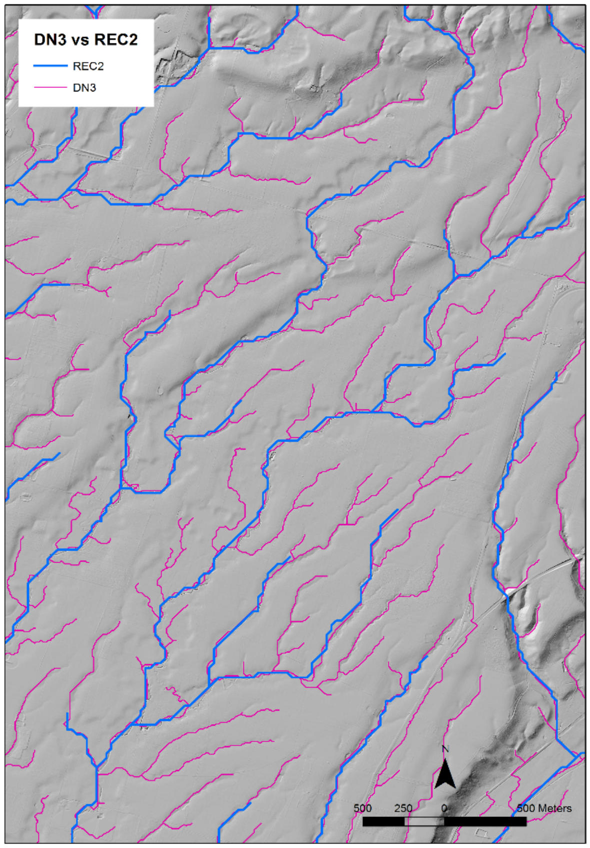

Figure 1: DN3 (in pink) and REC2 (in blue) networks compared on a hillshaded view of a Lidar based DEM. DN3 shows denser network and better representation of headwater reaches.

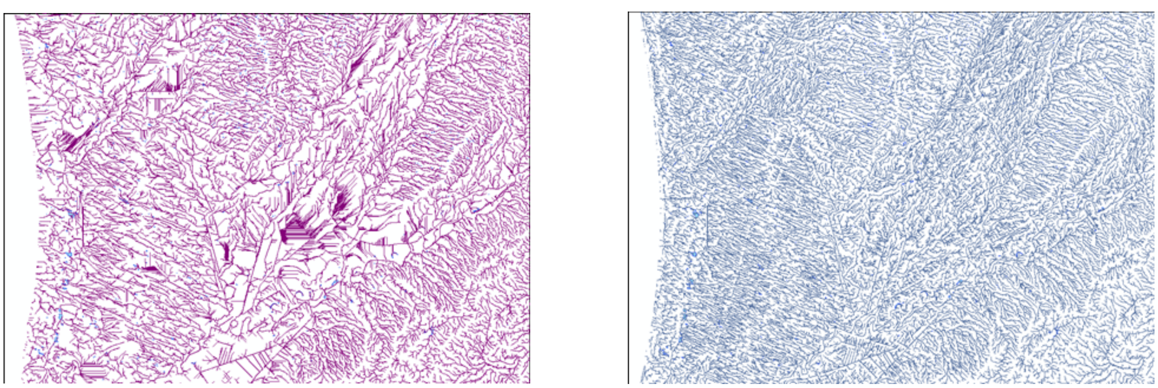

Figure 2: Network without Lidar on the left shows characteristic 'feathering' of reaches in flat areas. Figure on the right shows this has been corrected once Lidar data is incorporated and reaches are formed as 'regular' streams.

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THE INFLUENCE OF BOUNDARY LAYER TURBULENCE TO WILDFIRE SPREAD BEHAVIOUR

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Aims

Wildfires have direct economic and safety impacts on human society both in New Zealand and worldwide (Doherty et al., 2008; Thompson and Calkin, 2011). Many numerical models have been developed and used for operational wildfire risk management. Most of these operational models use highly parameterized empirical fire spread schemes which ignore important atmospheric boundary layer (ABL) turbulent feedback processes (Coen et al., 2013; Sullivan, 2009), which can influence the fire spread behaviour (Potter, 2012; Werth et al., 2011). These processes can also modulate wildfire spread behaviour and impact fuel combustion efficiency and fire flame dynamics and other factors. This work aims to develop a new understanding of coupled fire-atmospheric interaction by focusing on resolved turbulence scales at the fire front and their potential impact on fire spread behaviour. The outcome of this work can be used to identify fire spread regimes influenced by near-fire atmospheric turbulence, and thus can be applied to wildfire spread scheme and fire hazard management.

Method

A large eddy simulation (LES) model is used in this study to resolve grid scale turbulence in the ABL. An infinite hot patch line in the spanwise direction is set on the surface to represent an idealized line fire. The work also deployed a cuboid shaped block in the upwind position before the hot patch to establish local turbulence in the simulation (Fig. 1). Different turbulence intensities and frequencies are produced when flow with different windspeed pass and interact with the block.

Four simulation cases with same settings except different initial horizontal wind speed (case 1: 1, case 2: 2 , case 3: 4 , and case4: 8) have been performed and analysed in this work. The total simulated time is 60 minutes, and the fire line is set after 30 minutes spin-up time in each simulation. To focus on the turbulence perspective of the ABL characteristics, the neutral atmospheric stability is used in all these simulation cases.

According to the position of the hot patch and the turbulence field, near fire region, fire region and fire spread region are identified as regions of interest (ROI). The centre point of each ROI (shown in Fig. 1 as Point 1, 2, and 3) is picked and used to perform wavelet analysis. The production and advection part of the ABL turbulence will be identified to determine the cause of the changes in turbulence field.

Results

It is found that turbulence flow in low windspeed (case 1 and 2) simulations changes significantly after passing the fire region (shown in Fig.2). Compared to Point 1, more high frequency signals can be seen at Point 3. This suggests that wildfire might influence the ABL by inducing more high frequency turbulence into the field. These high frequency turbulences might be produced by the extreme temperature conditions of the fire region since the advection part from the upstream region does not contain high frequency turbulence.

The simulation with 4 initial windspeed (case 3) on the other hand, shows less change after getting through the fire region (due to the length limit, figures cannot be shown in this abstract). When increasing the initial windspeed to 8 (case 4), the turbulence signal remains almost unchanged after passing the fire region.

Results from the four cases suggest that ABL with different turbulence characteristics can influence the wildfire spread differently. Based on these results, two wildfire spread types can be defined. ABL which has more high frequency turbulence might influence the fire spread behaviour significantly and directly. Wildfire spread behaviour under this type of ABL condition can be classified as ABL dominant spread. The ABL processes is crucial for fire spread prediction and fire risk management.

Another type can be classified as multi-factor spread type. ABL under this type lacks high frequency turbulence and can be influenced by wildfire while passing through it. Thus, both ABL turbulence and fire dynamics are needed to predict fire spread behaviour in this situation. The work will compare production and advection part of the ABL turbulence field to quantify the influence of ABL versus fire dynamics in this type.

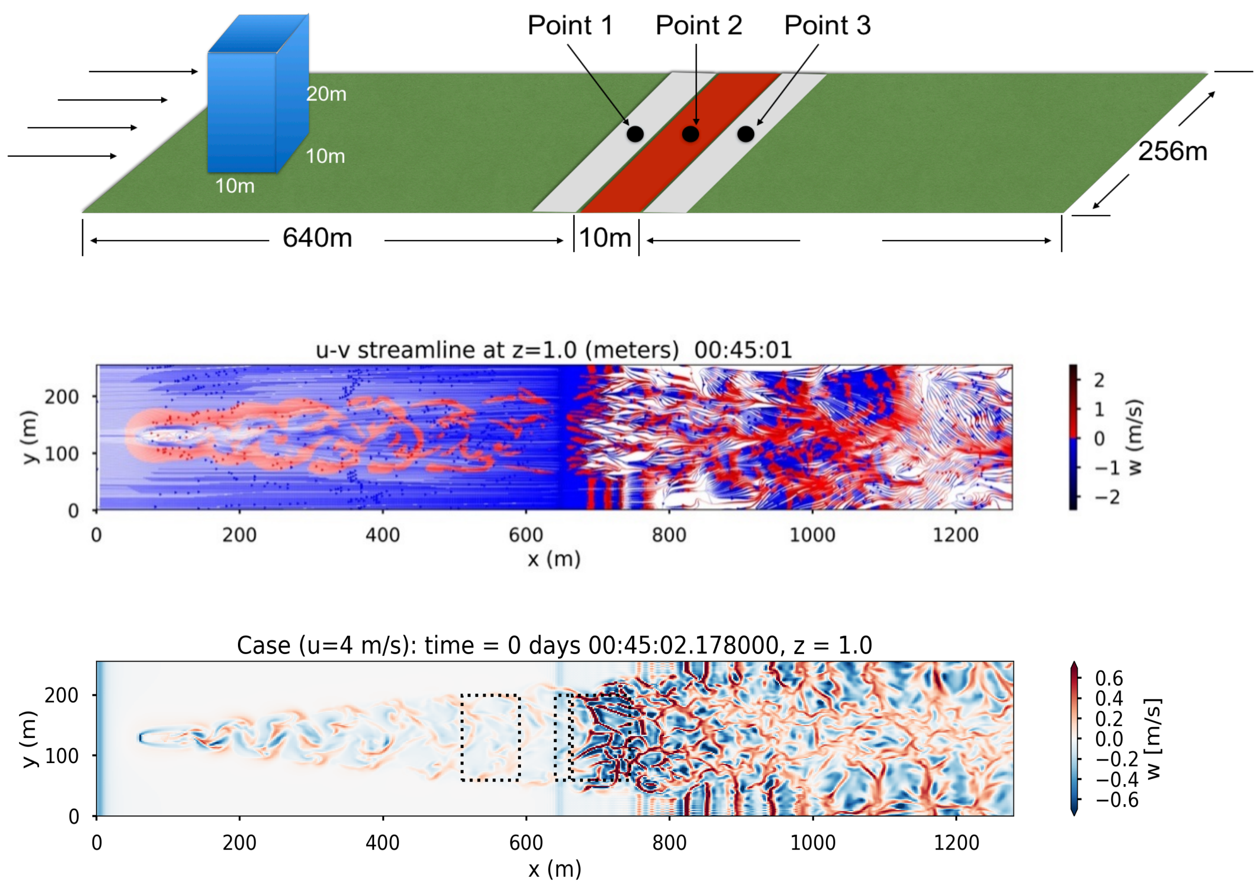

Figure 1: Model setup. Open boundary condition at streamwise (left and right) direction and cyclic boundary condition at spanwise (north and south) direction.

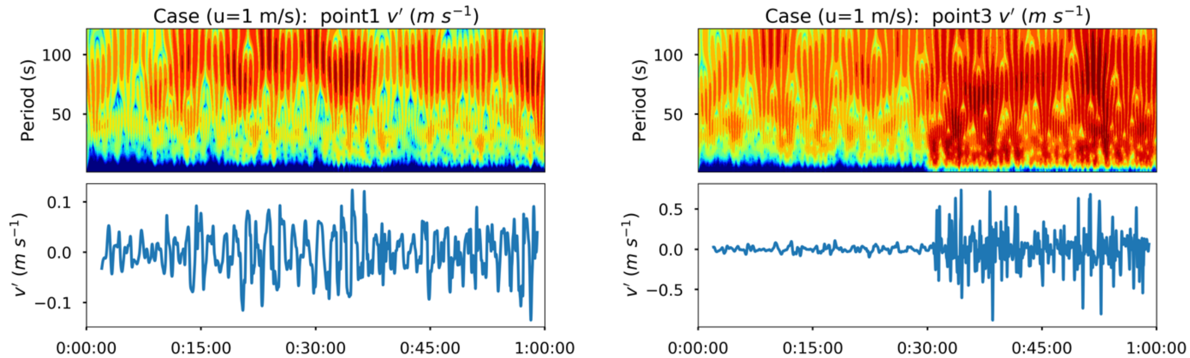

Figure 2: Wavelet analysis of at Point 1 (before fire region) and Point 3 (fire spread region) for 1 windspeed simulations.

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UNCERTAINTIES IN HISTORICAL CHANGES AND FUTURE PROJECTIONS OF DROUGHT

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Abstract
Precipitation, streamflow and drought indices suggest drying since 1950 over many land areas, and models project more frequent and intense drought in the 21st century. Here, we examine the uncertainties in estimating historical drought changes, and further compare the model-simulated drought changes with observation-based estimates since 1900 and their future projections using the self-calibrated Palmer Drought Severity Index with the Penman-Monteith potential evapotranspiration (PET) (sc_PDSI_pm) based on the simulations from both the Coupled Model Intercomparison Project Phase 3 (CMIP3) and Phase 5 (CMIP5). Consistent with our previous analyses, precipitation and streamflow data and the calculated sc_PDSI_pm all show consistent drying during 1950-2012 over most Africa, East and South Asia, southern Europe, eastern Australia, and many parts of the Americas. Furthermore, long-term changes in global and hemispheric drought areas from 1900-2014 are consistent with the CMIP3 and CMIP5 model-simulated response to historical greenhouse gas and other external forcing, with the short-term variations within the model spread of internal variability, despite that historical changes over many regions are still dominated by internal variations. Based on the sc_PDSI_pm, both the CMIP3 and CMIP5 models project continued increases (by 50-200% in a relative sense) in the 21st century in global drought frequency and area even under low-moderate emissions scenarios, resulting from a decrease in the mean and flattening of the probability distribution functions (PDFs) of the sc_PDSI_pm. This flattening is especially pronounced over the Northern Hemisphere land, leading to increased drought frequency even over areas with increasing sc_PDSI_pm. While warming-induced ubiquitous PET increases and precipitation decreases over subtropical land are responsible for the sc_PDSI_pm decrease, the exact cause of its PDF flattening needs further investigation.

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