Oral Abstracts

In order of presenter's last name

UNDERSTANDING THE EFFECTS OF EIFFELTON IRRIGATION'S TARGETED STREAM AUGMENTATION

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The Eiffelton Community Group Irrigation Scheme (ECGIS) is a small owner-operated irrigation scheme located near the Canterbury coast near Ashburton. The scheme area is crossed by drainage channels which maintain the water table below ground level. These drains historically flowed perennially with discharging groundwater. Increased abstraction (from connected groundwater) and decreased recharge (from greater irrigation efficiency) has lessened their flow reliability. These drains are used to provide and convey irrigation water to members. ECGIS operates using targeted stream augmentation, where deep groundwater (≥50 m) is pumped from bores into surface drains, which then transport the water to scheme members. Though the scheme has been operational for 30 years, its operational effects have never been quantified.

Aim

To understand operational effects of ECGIS on Windermere Drain, the largest and centremost drain used by ECGIS.

Methods

To understand the effects of targeted stream augmentation a field programme of groundwater and surface water quality and quantity monitoring was undertaken. Data was collected from March 2018 to April 2019, capturing the tail end of the 2017-18 irrigation season, the 2018-19 irrigation season, and the period between. Monthly sample runs were conducted to collect water quality samples, undertake stream gaugings, and take groundwater level measurements. The core monitoring network consisted of five arrays (Newtons, Boundary, Surveyors, Poplar and Lower Beach; Table 1 and Figure 1), each containing a surface water site and two piezometers, one in the bed of Windermere Drain and one approximately 10 m from the drain. Four ECGIS augmentation bores were also included in this sampling ('Scheme' Figure 1 and Table 1). Complementary data included ECGIS operational data (pumping data for augmentation bores and for drain abstractions) and Windermere Drain flow data.

Results

Results suggested that ECGIS operation has maintained drain discharge at a rate typically greater than that experienced before irrigation commenced. They also suggest that without this augmentation, Windermere Drain would flow intermittently. Annual average discharge estimates were compared to estimates from pre-ECGIS as presented by Middleditch (1983). Annual average discharge across the monitoring period was lower at Newtons (-38%) and higher at Boundary (+128%), Surveyors (41%), Poplar (33%), and Lower Beach (4%), than pre-ECGIS estimates. Considering Windermere Drain flow data alongside ECGIS operational data enabled estimation of drain flow in the absence of targeted stream augmentation. Estimation suggested that Windermere Drain could have experienced significant periods of no flow across the monitoring period had ECGIS not been augmenting flow. This is consistent with trends seen in other drains in the wider coastal area that do not have their flows augmented.

Results also suggested that targeted stream augmentation contributed to lower dissolved oxygen (DO), lower electrical conductivity (EC), and lower nitrate-N concentrations in Windermere Drain and shallow groundwater across the 2018/19 irrigation season. Median water quality parameter concentrations during the 2018-19 irrigation season were considered against pre-irrigation concentrations (Table 1). DO medians generally decreased during irrigation season compared to pre-irrigation data. This may reflect the introduction of deeper, lower DO water from Scheme bores to the drains and shallow groundwater. Changes in median EC during the 2018-19 irrigation season generally reflected changes in median nitrate-N, suggesting nitrogen as the dominant ion. The most significant change between pre-irrigation and irrigation medians was the reduction in nitrate-N concentrations in monitoring arrays. This was due to dilution by augmentation water from lower nitrate-N Scheme bores. DRP and E. Coli concentrations generally either increased or had no significant difference on pre-irrigation season values. As Scheme bore concentrations of these parameters were generally lower than that at other investigation sites, this suggests an external source, most likely land use.

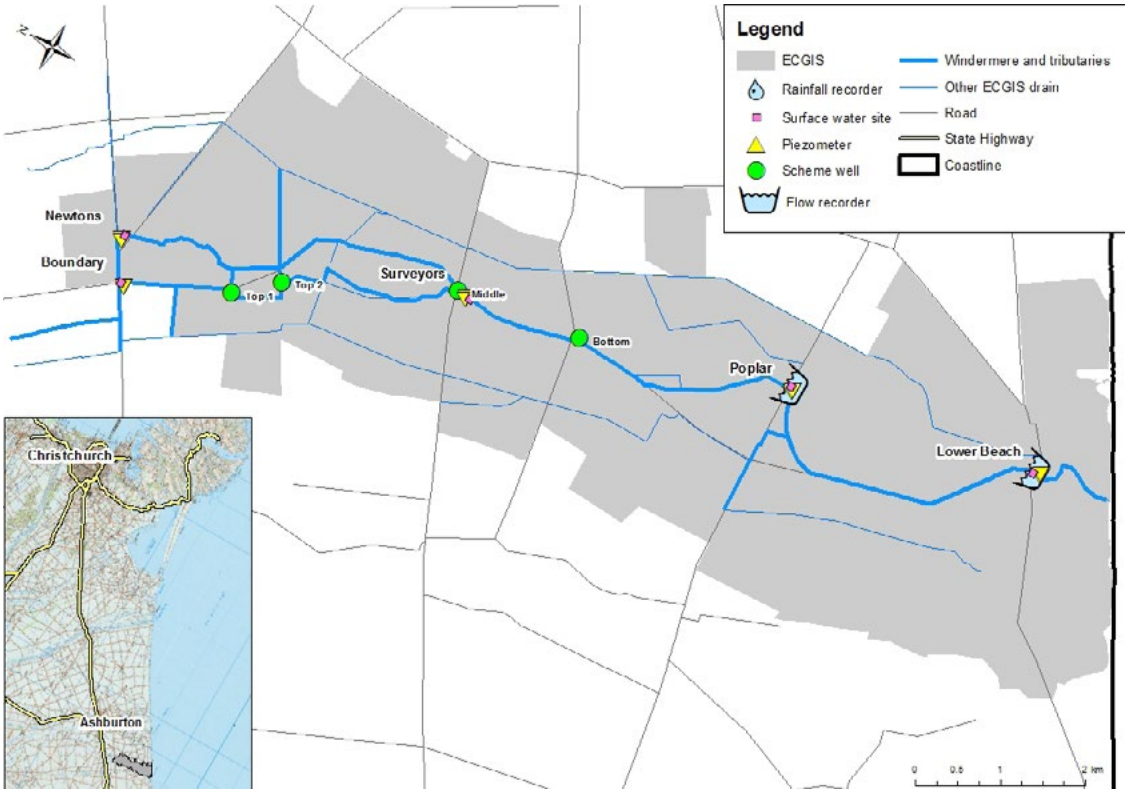

Figure 1: Investigation Location and Monitoring Sites. Large Labels are Array Names, Small Labels are Scheme Wells, Inset Shows Regional Location of Scheme

		Temp.	DO	EC	Nitrate-N	DRP	*E. coli*
Newtons	Bank Piezo	▲	▼	▼	▼	=	▲
	Bed Piezo	▲	▼	▼	▼	=	=
	Drain	▲	▼	=	=	▲	▼
Boundary	Bank Piezo	▲	=	▼	=	=	▲
	Bed Piezo	▲	=	▼	▼	=	▼
	Drain	▲	▼	▼	▼	▲	▲
Scheme	Top 1	▲	▼	▲	=	▲	▲
	Top 2	▲	=	▲	▲	=	▲
	Middle	▲	▲	▲	▼	=	=
	Bottom	▲	=	▲	=	=	▲
Surveyors	Bank Piezo	▲	▼	▼	▲	=	=
	Bed Piezo	▲	▼	=	=	▼	▲
	Drain	▲	▼	▼	▼	▲	▲
Poplar	Bank Piezo	▲	▼	▼	▼	▲	▲
	Bed Piezo	▲	▼	▼	▼	=	▲
	Drain	▲	▼	▼	▼	▲	▲
Lower Beach	Bank Piezo	▲	▼	▼	▼	▲	▲
	Bed Piezo	▲	▼	▼	▼	=	▲
	Drain	▲	▼	▼	▼	▲	▲

▲ Higher
▼ Lower
= No significant difference

Table 1: Relative Change in Median Values During Operation of Eiffelton Community Group Irrigation Scheme Relative to Pre-Irrigation Values

Reference

Middleditch, W. (1983). Eiffelton Community Group Irrigation Scheme – Final Report. Water and Soil Irrigation, Christchurch for the National Water and Soil Conservation Organisation. Report No WS 826.

MICROBIAL TRANSPORT THROUGH VARIABLY SATURATED HETEROGENEOUS INTACT ALLUVIAL GRAVEL VADOSE ZONE CORES

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Groundwater, which is an important source of drinking water worldwide, is vulnerable to contamination by pathogenic microbes with a disparate number of reported waterborne outbreaks (i.e., diarrhoea, gastrointestinal illness) associated with groundwater (Jin and Flury, 2002). The source of this contamination is often due to farming activities such as effluent application to land and grazing of pasture animals, and on-site wastewater treatment systems. The risk of transport of microbes through the subsurface is dependent on whether the soil surface becomes saturated or not (Close et al., 2010). Knowledge of the factors that influence the fate and transport of bacteria and viruses in soil and aquifers is critical to ensure that proper management of pathogen sources is undertaken to protect public health. While studies on microbial transport through groundwater have shown that microbial pathogens (e.g. Escherichia coli) are relatively stable in groundwater (Schijven and Hassanizadeh, 2000; Pang et al., 2004), there is still considerable knowledge gaps regarding the transport and fate of microbes through the heterogeneous subsurface to groundwater (i.e., variably saturated media in the vadose zone).

Aims

In this study, we aim to determine the transport of faecal indicator species (E.*coli*, F-RNA bacteriophage MS2) and a tracer (bromide (Br)) through typical gravel vadose zone materials at variable levels of water content (saturated vs. unsaturated flow).

Method

Three 'intact' cores (C1-C3) of undisturbed heterogeneous alluvial gravel vadose zone material were collected at two sites (Burnham, Lincoln) south of Christchurch, NZ. By using intact cores, the natural structure was preserved; macropore and micropore flow remain viable. Image data derived from X-ray computed tomography scans was used to analyse the structure, heterogeneity and macroporosity of the cores (Figure 1). C1 contained sandy gravel (SG) overlying a sand lens (SL). C2 contained a heterogeneous SG mix, while C3 contained SG with an open framework gravel (OFG) lens through the middle of the core. The average saturated hydraulic conductivity (K_{sat}) for C1, C2 and C3 was 4.38 m/d, 4.45 m/d and 4.2 m/d, respectively.

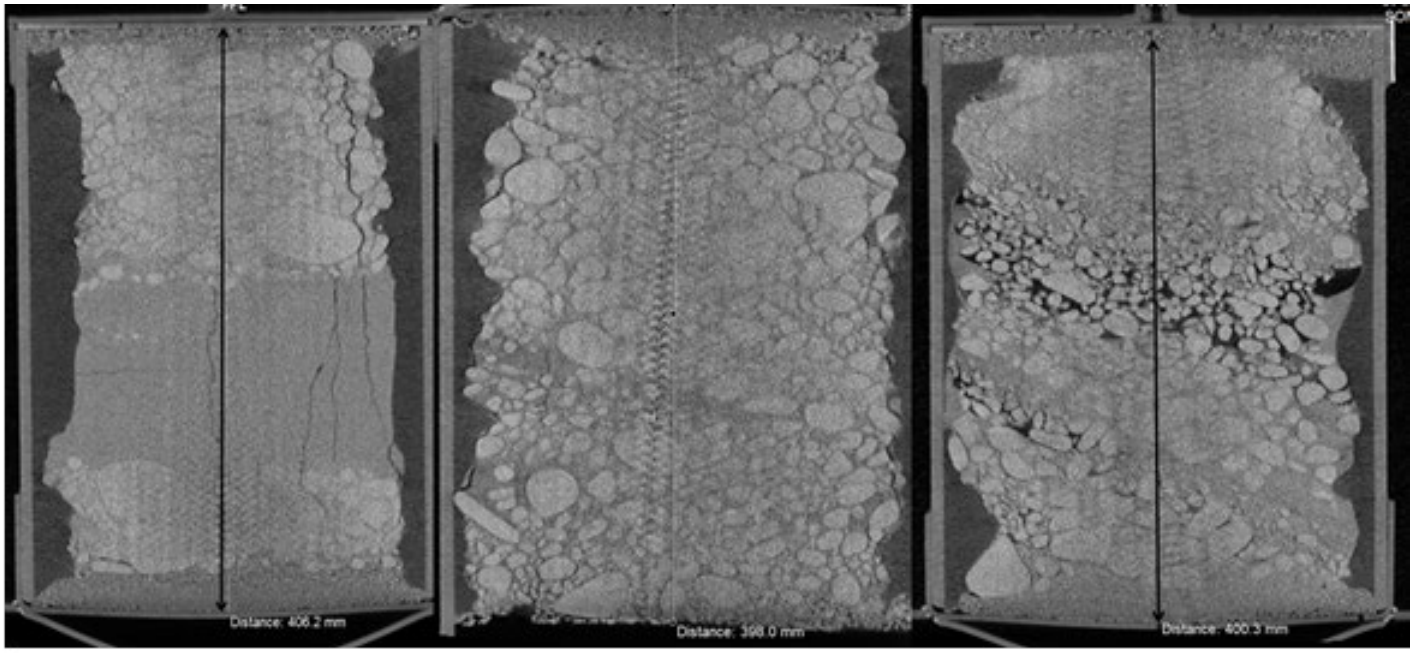

Figure 1: X-ray computed tomography (CT) images of cores (~ 400 mm length).

In the first set of experiments each core was run under saturated flow conditions with a constant head of 25 mm. The second set of experiments were run under high flow (7.5-10 mm/hr) unsaturated flow to simulate heavy rainfall, irrigation or septic tank effluent discharge, for which vadose zone media are often under saturation. The third set of experiments were run under low flow (0.5 mm/hr) unsaturated conditions. The cores were irrigated for ~ 3 days prior

to tracer injection to ensure steady conditions. Water and tracers (Br 50 mg/L, *E. coli* 1 × 10^5 cfu/mL, MS2 phage 1 × 10^5 pfu/mL) were supplied to the top of the cores via a logger-controlled solenoid valve, through three equally spaced fine sprayers. Solution samples were extracted at set times from a collection cup manually during working hours and via an auto sampler after hours. The removal of Br, *E.coli* and MS2 phage was evaluated using peak breakthrough attenuation, spatial removal rate, and normalised mass recovery (moments analysis). Transport and attenuation of microbes was described using an advection-dispersion equilibrium model. The CXTFIT optimisation package Version 2 (Toride et al., 1995) was used for deriving values of average pore-water velocity (V), dispersion coefficient (D), and first-order removal rate (λ).

Results

Retention of microbes in the vadose zone is highly dependent on flow rates and degree of saturation. Figure 2 shows reasonable matches between experiment data and fitted breakthrough curves (BTCs) for Br and *E.coli* under saturated conditions. C1, containing SG and SL, had the fastest BTC. Br and *E. coli* were transported at similar velocities through each core as reflected in the overlapping rising limbs of the BTCs. E. coli was attenuated compared to Br with maximum *E. coli* C/C_0 to maximum Br C/C_0 ratios of 0.67, 0.49 and 0.60 for C1, C2 and C3, respectively, possibly indicating that SG is better at attenuating microbes under saturated conditions. The three flow regimes resulted in different transport characteristics i.e., cores with sand increased retention of microbes and increased dispersion of solutes. Microbial removal was much less under saturated conditions than under unsaturated conditions, with *E.coli* removal generally greater than that of MS2, which is consistent with results in Weaver et al. (2016). Under saturated conditions, *E. coli* transport showed velocity enhancement (microbial tracers move quicker than solute tracers) in C1 and C2 but retardation in C3. The presence of OFG or the SL did not appear to effect vertical transport of the contaminants, suggesting that all vertical movement of Br, bacteria and bacteriophages through the vadose zone was controlled by SG (finer material and finer pores).

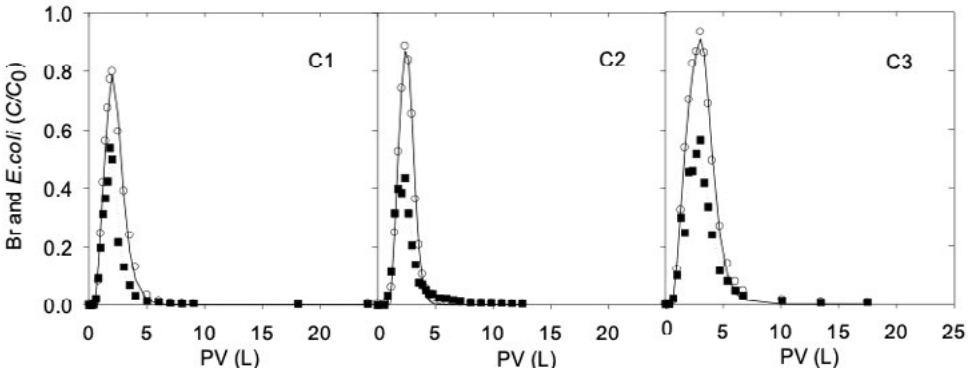

Figure 2: Breakthrough curves of the saturated cores with moments predicted curves for bromide (○ observed, - fitted) and *E. coli* (■ observed, -- fitted).

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ENVIRONMENTAL IMPLICATIONS OF END-OF-LIFE TYRES ON GROUNDWATER AND THEIR REUSE IN CIVIL ENGINEERING APPLICATIONS

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The disposal of over 3.5 million end-of-life tyres (ELTs) per year in landfill, stockpiles and via illegal dumping is a serious socio-economic and environmental concern for New Zealand (NZ). Problems associated with ELTs disposal include solid waste management in landfills, tyres as breeding grounds for pests, tyre leachate and tyre fires.
While tyre rubber itself can be considered relatively inert, tyres contain approximately 1.5% by weight of hazardous compounds and the additives used in the manufacture of tyres are potentially harmful to the environment (e.g. organohalogen compounds, acidic solutions). In addition, steel fibres within the tyres can leach heavy metals. Due to these environmental issues and the increasing volume of ELT production in NZ, it is becoming imperative to investigate more sustainable and large-scale initiatives for the recycling of ELTs. Aimed at addressing the problem of ELTs in NZ, a joint research project between the Institute of Environmental Science and Research Ltd (ESR) and the University of Canterbury proposes to recycle ELTs (in the form of granulated tyre rubber) mixed with gravelly soils and concrete to develop cost-effective seismic-isolation foundation systems for low-rise buildings for residential housing. However, the suitability of ELTs for such an application needs investigating due to potential leaching of contaminants to ground and surface water.

Aims

The overarching objective of the project is to provide an environmentally-friendly, cost-effective way of recycling ELTs (i.e. 'eco-rubber' foundation system), providing substantial environmental and socio-economic benefits for NZ. The specific aim of this project is to determine the leaching potential of the proposed gravel-rubber mixtures to be used in the foundation system.

Method

A comprehensive literature review has been undertaken to determine if the tyre rubber-gravel mixtures are likely to be hazardous, what contaminants could leach from the tyres and whether or not it needs to undergo approval by the NZ Environmental Protection Authority. There has been extensive research on the leaching of contaminants from waste tyres in laboratory (Kanematsu et al., 2009; Selbes et al., 2015) and field (Garga and O'Shaughnessy, 2000; Humphrey and Katz, 2001) studies and the toxicity of this leachate to aquatic organisms (Birkholz et al., 2003; Wik, 2007). Zinc has been identified as an element of concern in tyre leachate studies (Smolders and Degryse, 2002). If the steel components of the tyres are exposed, there may be elevated manganese and iron levels within the leachate (Garga and O'Shaughnessy, 2000). Mercury and lead may be elevated in tyre leachate; however many studies have reported negligible levels (Nelson et al., 1994). Studies have also shown that tyres can leach chemicals that display estrogenic activity (Li et al., 2006), causing endocrine disrupting activity in aquatic organisms.

Environmental laboratory tests will be undertaken to identify the degradation profile of the shredded rubber, and the potential for soil/groundwater contamination from the use of the proposed gravel-rubber mix. Batch leaching tests of the selected rubber-gravel mixture will be conducted under controlled pH conditions to determine if it contains leachable contaminants that may cause an environmental harm if released. There are a number of factors that can influence the rate of tyre leaching and the concentration of leachate compounds in soil, surface water and groundwater including the size of the tyre chips (Rhodes et al., 2012), the amount of steel exposed (MWH, 2004), the aquatic environment in which the tyre is exposed, contact time between the tyre chips and water (Azizian et al., 2003), permeability of the surrounding soil, distance to groundwater table, vertical and horizontal water flow through the soil. Therefore, it is important to understand the relationship between these factors and the chemical characteristics of the leachate. The factors that will be tested in the batch tests will be the rubber content (20-40% content by volume), size of the tyre chips (three different sizes), the amount of steel exposed and the contact time with the aqueous solution. In the batch tests a certain volume of (1) rubber and (2) rubber-gravel mixture will be placed in glass containers containing deionised water with zero head space at a neutral pH for a time period of 24 hrs (following EP-Toxicity test guidelines). The extract from the leaching tests will be filtered, combined and analysed for the components of interest (i.e. organic carbon and heavy metals). The test results will be assessed by comparison to NZ landfill waste acceptance criteria (WAC) for Class A and B total concentration and leachability limits criteria (Ministry for the Environment, 2004).

If the results from these batch tests indicate leaching of harmful contaminants, more detailed assessment will be required. This will be done by using data from less conservative (more realistic) leaching column tests which include site parameters (e.g. geometry and hydrology) to model the release, transport and fate of the contaminants over time from the source to the potential receiving environments/receptors. In addition, a suitable engineering countermeasure (e.g. use of a reactive geomembrane to remove contaminants that would pollute the groundwater) to remediate or to contain the leaching material will be carefully selected and tested.

The successful completion of this research will result in a sustainable engineering solution to increase the seismic resilience of low-rise buildings while reusing/recycling waste tyres with great environmental and socio-economic benefits (new jobs, improved products, increased revenues) for NZ. This work is part of the Ministry of Business, Innovation and Employment of NZ (MBIE) Smart Ideas Research Grant No. 56289.

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100% CARBON-FREE POWER IN NON-NORMAL HYDROLOGICAL YEARS: THE ROLE OF WATER IN NEW ZEALAND AND THE WORLD

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[1] University of Waikato

Given current concerns about the future global environment, the 2019 conference committee is topical in the bold theme of *Challenges facing civilization*. This encourages some speculative presentations which might be a little beyond the usual content of New Zealand Hydrological Society conferences.

In that spirit, this presentation first revisits Onslow pumped storage as the only option for maintaining renewable power in New Zealand in non-normal hydrological years (leaving aside the mathematical impossibility of defining normal hydrological years in a situation of climate change). Interestingly, the Interim Climate Change Committee (ICCC) chose to redefine its original mandate on how to achieve 100% renewable electricity, claiming that getting the last few percent would lead to unreasonably high power prices. In fact, any casual observer of the electricity market knows that the highest wholesale power prices are frequently associated with lower storage levels in the hydro lakes.

This effect is illustrated in Fig. 1, showing the fall in electricity prices following the 2019 March flood inflows into the South Island hydro lakes.

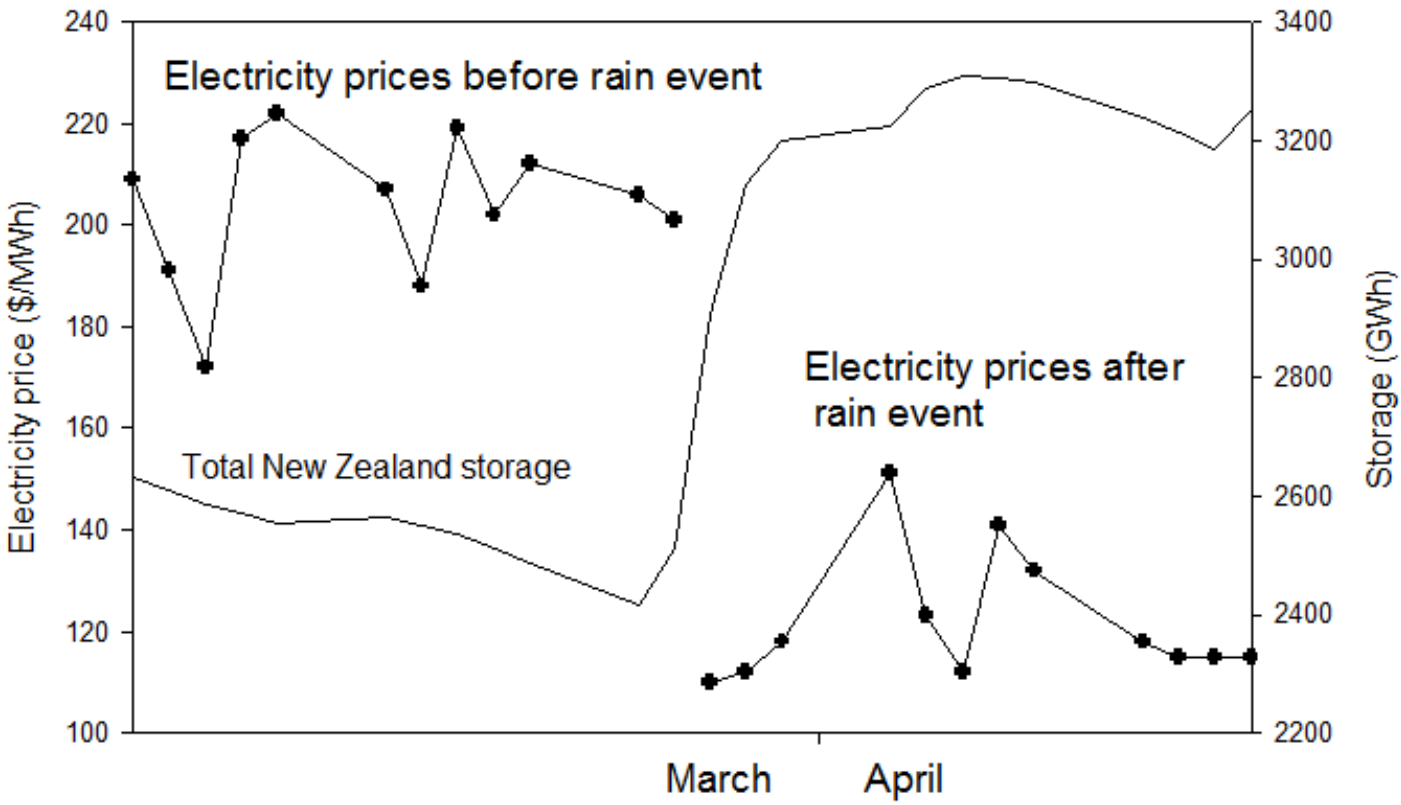

Figure 1: Effect of theMarch 26 Westland rain event on New Zealand wholesale electricity prices. Prices are daily median values at Haywards node (excluding weekends). Daily storage values provided by NZX.

The message is clear: increasing national total storage by a climate-buffering major pumped storage scheme at Onslow will result in gaining the last few percent of renewable power and give long-term electricity prices which are lower, not higher. It is even a little better than that because Onslow can act as a power source and not a power sink. This is because more power is able to be derived from the Waitaki stations through reduced spill events. Such spills are rare but represent significant energy loss when they do occur.

The ICCC panel included among its recommendations that pumped storage in New Zealand should be investigated as a matter of priority. In response, the Minister announced that agencies would be identified before the end of 2019 who could carry out such work. More information may be available by the time of the conference. Hopefully, the Onslow scheme will proceed after all necessary consultations and environmental considerations. Otherwise the proposed national electrification as part of the Paris agreement will be doubtful even in a “normal” hydrological year.

The second part of the presentation offers an entirely speculative future scenario on the role of New Zealand hydro power beyond 2050 – identified as a critical target year for mitigating against climate change. Contrary to current government policy, a case is argued that in the long term there could/should be a goal of significant reduction in the electricity contribution from renewable sources.

There is national pride in our present high proportion of power from renewable energy sources. However, issues arise in the long view, assuming no future nuclear power or undersea power cable link. In this view, outside of geothermal energy and roof-top solar panels, renewable energy should in fact be both avoided and reduced as far as possible because it is (i) unsustainable, and (ii) produces significantly detrimental environmental impacts. The unsustainable aspect is obvious in the long view. Our hydro rivers are already largely used up and we cannot keep going forever building wind generators on ridges or out to sea to match an inevitably increasing power demand. Environmental impacts are there already for all to see, with past hydro developments leaving a legacy of diverted rivers, dried rapids, eroding lake shorelines, and flooded geothermal fields.

One mode of solving the planetary issue of global warming could offer a unique opportunity for New Zealand's power future. What is required globally is a solid fuel coal alternative for baseload thermal power stations, which is both free and emission-free. There are any number of solid fuel options but silicon fuel created from massive development of Arabian nuclear power stations has attraction. Like hydrogen, silicon is an energy vector (not an energy source) but, lump for lump, has almost exactly the same energy content as high-grade coal. Silicon (as quartz sand) is also abundant so a range of different ship cargoes can be carried on the return trip to the Middle East, as opposed to just returning the power station oxide "ash" to source for reprocessing.

But why Arabia and how could the fuel be free? Saudi Arabia is in a unique position in that (i) it has accumulated considerable capital, (ii) it requires a sustainable future income source as alternative to its petroleum exports, and (iii) it runs the risk of becoming temperature-unlivable under future global warming. Their one further national requirement is water, which returns to the title of the presentation. The industrial chemistry of the silicon production would use nuclear power to reduce silicon oxide to silicon via a magnesium (not carbon) intermediary. This process is energy-inefficient so, for example, it might require four Arabian nuclear power stations to maintain just one silicon power station replacing a coal-fired station somewhere in the world. However, inefficiency is at the Arabian end and the resulting waste heat would be of value when incorporated into water-generating desalination plants.

The silicon fuel would be free because it has to be, if there is no other alternative to avoid going forward into a coal-fired overheated planet. For example, there would be little point for anyone to import coal for power generation if free silicon fuel is available. The cost-free nature of the fuel would derive in part from subsidies coming from the richer nations in proportion to the amount of carbon dioxide they have already contributed to the current atmospheric load. Reliable within-border security of electricity supply is fundamental to national economies so in the initial years there would be silicon stockpiling by nations importing more than required. The technological requirement for constructing silicon-fueled power stations is not a great hurdle and should be quickly achievable. Heated silicon oxidises slowly because it is diffusion-limited, so there would be a need to pre-mill the particles down to optimal fine shards. However, such technical issues are infinitely simpler than wasting time and time money seeking nuclear fusion, which must be the classic example of energy scientists fiddling while the atmosphere burns.

Suppose then there really is a future shift in New Zealand to baseload power from silicon or some other acceptable imported fuel. Seasonal power demands and dry years would no longer be of concern, making hydro lake storage irrelevant beyond a few days. There would remain a need for daily peaking so pumped storage and some hydro would still be needed, though reduced. For example, the Tongariro scheme Whanganui diversions would no longer be required, and Tokaanu and Rangipo would operate only for short periods for peak demands. All wind power would be deconstructed. Individual hydro lakes would either revert or be maintained for other purposes. For example, Lake Dunstan might be eliminated and the Cromwell Gorge apricot orchards restored, but Karapiro maintained for recreation. Whatever happens finally, perhaps a student at the 2050 Hydrological Society conference might give a presentation on how remarkably correct (or hopelessly wrong) the predictions were from the distant past of 2019.

HOW IMPORTANT IS THE SHALLOW GROUNDWATER PATHWAY FOR CONTAMINANT EXPORTS FROM ARTIFICIALLY DRAINED PASTORAL LAND?

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Introduction

In artificially drained land, subsurface drains are well recognised as being a significant transfer pathway for agricultural contaminants into surface waters. Discharges from artificial drainage can bypass the soil matrix, potentially allowing very fast and un-attenuated nitrogen (N) and phosphorus (P) transfers from the paddock directly into adjacent surface waters. However, the actual importance of lateral subsurface drainage discharge vs. vertical discharges into the underlying shallow groundwater under varying hydrological and hydrogeochemical conditions around New Zealand remains poorly understood and rarely quantified. Moreover, the fate of vertically recharged nutrients has rarely been investigated. However, it is recognized that the fate of recharged nitrate is largely determined by the redox status of the shallow groundwater system.

Aim

To understand and describe the contaminant loads of N and P that are exported along the various export flow paths, under artificially drained pastoral agriculture.

Method

Artificial drainage flows from grazed pasture on two dairy farms on the Hauraki Plains, Tatuanui and Waharoa, were routed through surface water monitoring weirs, enabling the drainage flows to be continuously monitored. Flow based proportional samplers were 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. Hydrological balance equations along with supporting information from measured subsoil hydraulic conductivities and hydraulic gradients were used to estimate the shallow groundwater's hydraulic export. These estimates were combined with groundwater contaminant concentrations to estimate nutrient export via this pathway.

Results

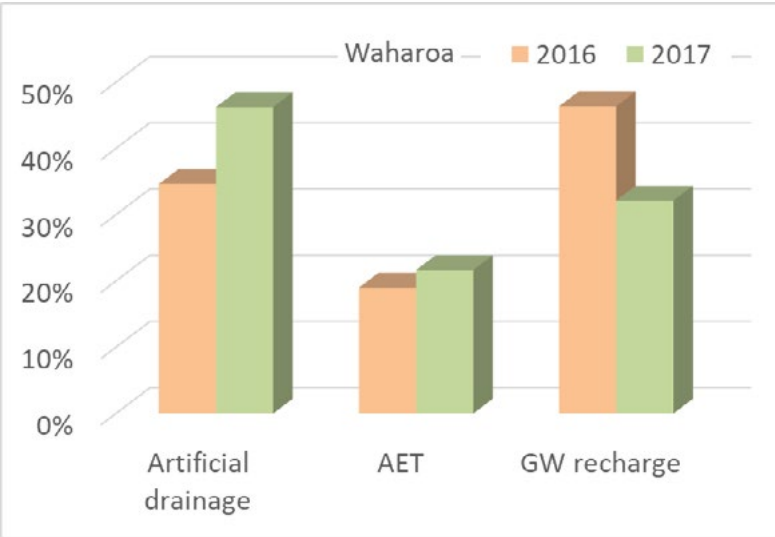

Fig 1: Hydraulic exports from Waharoa site in 2016 & 2017

At Waharoa, over the two years of monitoring, lateral artificial drainage and vertical shallow groundwater recharge both accounted for similar volumes, approx. 40% of the rainfall received during the drainage season (Fig. 1).

At Tatuanui over 80% of the rainfall over the drainage season was discharged via artificial drainage, with the remainder accounting for evapotranspiration. Accordingly, there was no detectable groundwater export from this site.

The annual total (lateral + vertical) organic N, ammoniacal N, and nitrate N yields (kg N/ha) for 2016 and 2017 are presented in Figure 2.

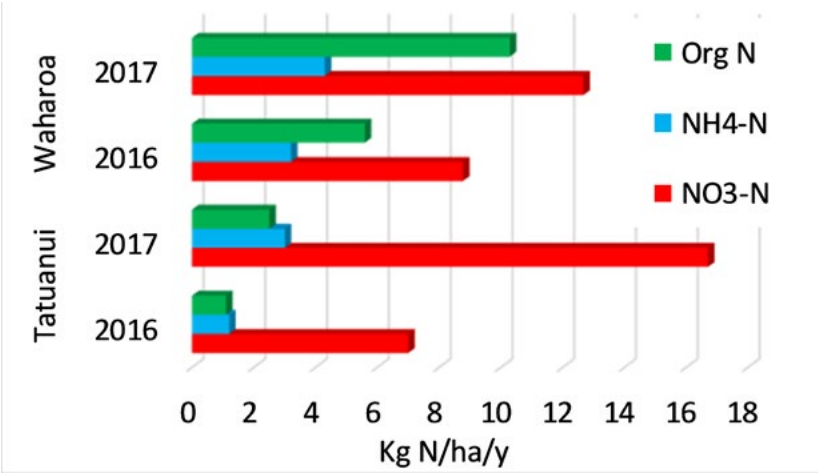

Fig 2: Total N exports from the two sites in 2016 & 2017

As all excess water was exported from the Tatuanui site via the artifical drainage system, this pathway is also responsible for all the N and P exported from the site. Averaged over the two years, the artifical drainage pathway accounted for 62% of the total N exports at Waharoa, with the remaining 38% of N exported on the shallow groundwater pathway.

While artifical drainage was the predominant pathway for nitrate N exports at Waharoa, organic N and ammonicial N were largely exported through the shallow groundwater(Fig. 3).

As the shallow groundwater at both sites was found to be in a reduced redox state, this strongly decreased the nitrate loads exported via this pathway.

As overland flow was not an active pathway at Waharoa (or Tatuanui), the dominant pathway for the export of various forms of P was related to the hydrology of the drainage season. However, both the shallow groundwater and artificial drainage are important mechanisms that need to be considered in the export of P from a drained site (Fig 4).

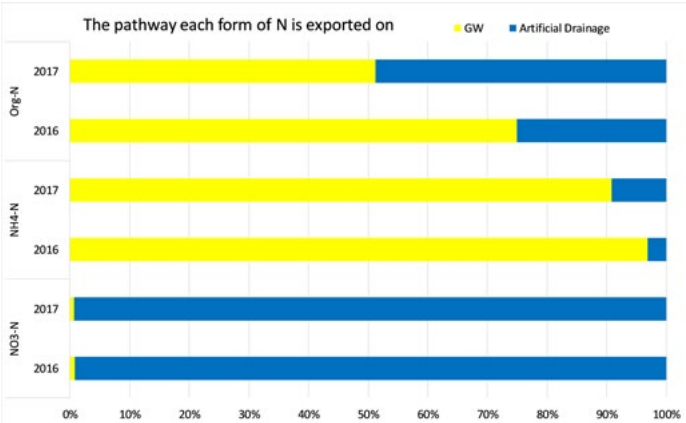

Fig 3: Form of N exported via groundwater or artificial drainage from Waharoa 2016 and 2017

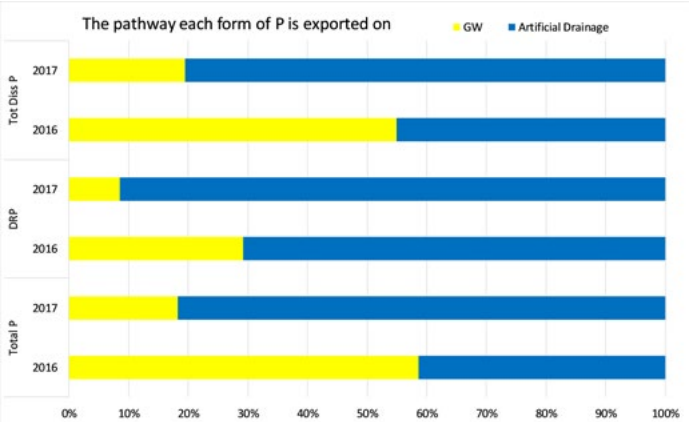

Fig 4: Form of P exported via groundwater or artificial drainage from Waharoa 2016 and 2017

Conclusion

Subject to site-specific conditions, the shallow groundwater can be an important pathway for contaminant exports from pastoral land even under poorly or imperfectly drained soils.

Acknowledgement

This work was carried out as part of the MBIE-funded Critical Pathways Programme and its predecessor Transfer Pathways Programme. We gratefully acknowledge the co-funding by Waikato Regional Council and the co-operation of the Allen and Hedley families of the Hauraki Plains.

INSIDER INFORMATION ON BIOREACTOR FUNCTIONING AND IDENTIFYING IMPROVEMENTS FOR THE REMOVAL OF NITRATE FROM ARTIFICIAL SUBSURFACE DRAINAGE FROM PASTORAL AGRICULTURE

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[4]University of Waikato

Aims

Artificial subsurface drainage controlling seasonally high groundwater levels has been found to be a substantial pathway for nutrients from agricultural lands into surface waters. Thus, mitigating the impacts of agriculture on surface water quality needs to address nutrient transport via subsurface drainage. Woodchip bioreactors are a promising mitigation option as demonstrated in arable agriculture in the US. However, research is needed to understand their efficiency in removing nutrients from very flashy drainage flows and concomitant high nitrate concentrations from NZ pastoral agriculture, possible pollution swapping and options for increasing nitrate removal rates.

Method

A lined 78-m^3 woodchip bioreactor was constructed on a dairy farm in the Hauraki Plains (Waikato). Rainfall, flow, hydrochemistry and dissolved gases in the inflow and outflow were monitored for two drainage seasons (part of 2017, 2018). During a 30-day period in Aug/Sept 2018, the inlet/outlet sampling regime was supplemented with a more comprehensive intensive sampling within the bioreactor. This sampling methodology utilised multilevel wells installed into the bioreactor at 6, 25, 36, 48, 66, 76 and 97% of the distance from the inlet to the outlet manifold. A multi-plexer system collected water samples from the bioreactor and reticulated them to a spectrophotometer where they were analysed for nitrate and carbon concentrations. The time series of nitrate-N concentrations at the inlet and outlet and three intensive sampling wells, through the bioreactor are shown in Fig 1. Peak nitrate concentrations, decreasing with travel distance, for three elevated nitrate drainage events of 23rd and 31st August and 2nd September 2018 are highlighted in this same figure.

Results

The mean nitrate-N concentrations in the inflow and outflow respectively, were 5.6 and 0.01 mg/L in 2017, and 13.7 and 7.5 mg/L in 2018. Based on the nitrate-N fluxes, the estimated nitrate removal efficiency of the bioreactor was 99 and 48% in 2017 and 2018, respectively. The higher removal efficiency in 2017 could be attributed to; the much longer residence time of the water in the bioreactor (mean=21 days vs 5 days in 2018) allowing more opportunity for microorganisms to reduce the nitrate in the water; and the availability of electron donor (DOC) to support denitrification. In 2017, greater DOC available within the bioreactor was confirmed by the higher DOC flux from the bioreactor (17.9 kg vs 9.3 kg in 2018).

Reduction in the peak NO_3-N concentrations with distance travelled, from three elevated drainage events in 2018 is well described (R^2= 0.96 to 0.99) by similar quadratic relationships, with the fraction of distance travelled in the bioreactor, as shown in Fig 2. The result of the nitrate removal rate decreasing somewhat with distance travelled through the bioreactor, concomitant with decreasing nitrate concentrations, tentatively indicates that the removal rate is related to the concentration on the nitrate substrate.

Very long residence times in 2017 promoted strongly reduced conditions, resulting in the production of hydrogen sulphide and methane. However, short residence times constrained complete reduction of nitrate resulting in higher nitrous oxide concentrations in the outflow vs inflow in 2018. Elevated discharges of DOC and DRP were evident during the start-up phase of the bioreactor in 2017. However, significant removal (89%) of DRP was observed in 2018.

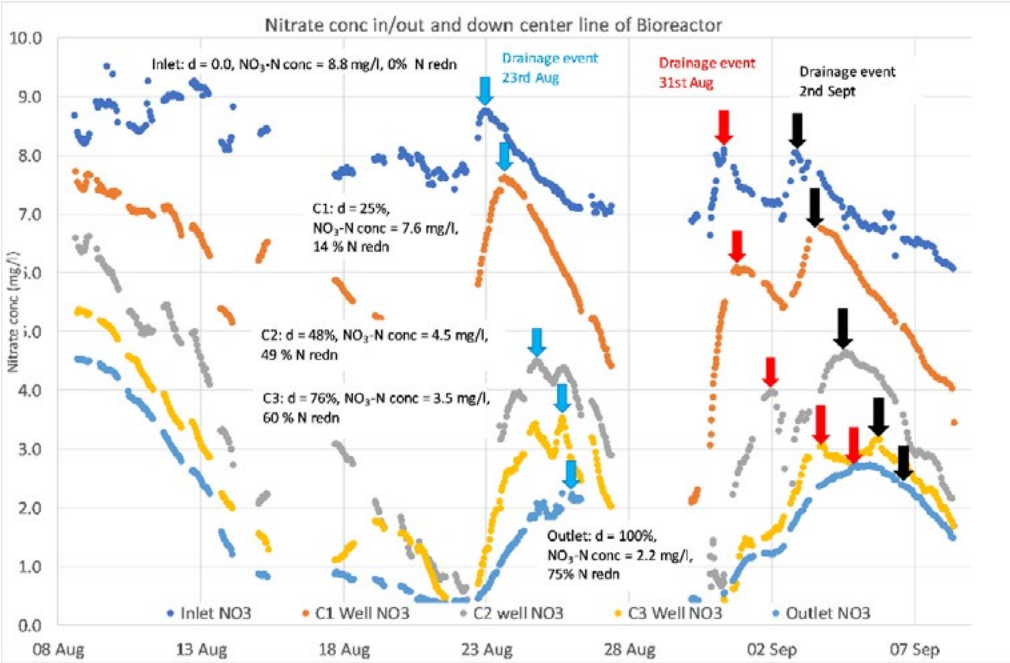

Figure 1: Nitrate-N concentrations (mg-N/l) with time at five intensive sampling points through the bioreactor. The reduction in peak nitrate concentrations for the event of 23rd August 2018 is described in terms of fraction of distance travelled through the bioreactor, for events of 31st August and 2nd September events peak concentrations only are highlighted.

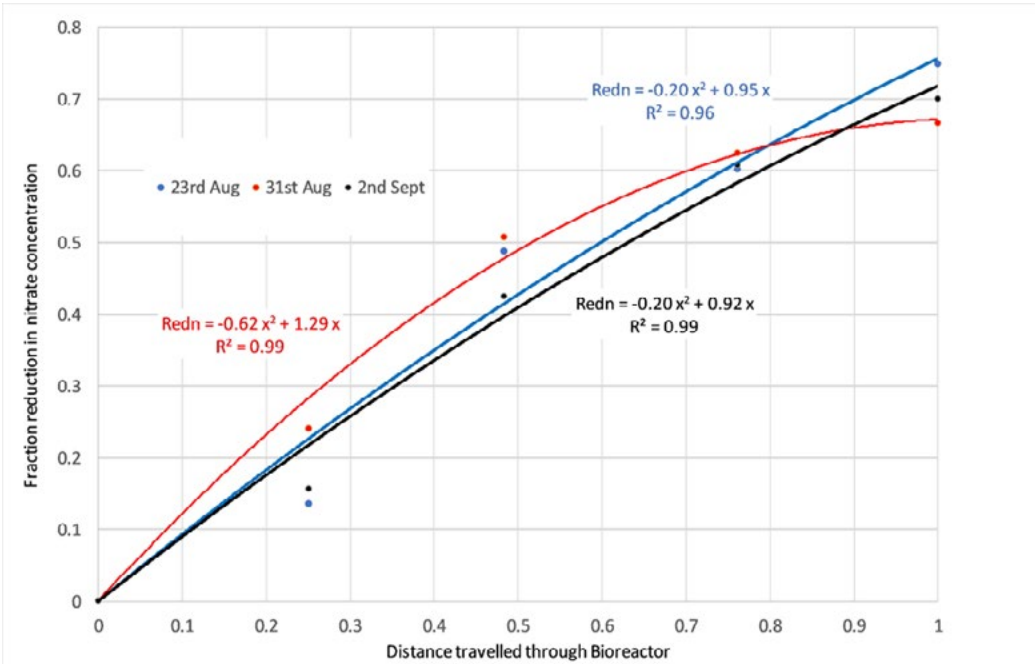

Figure 2: Fraction reduction in peak nitrate-N concentrations with distance travelled through the bioreactor for three drainage events of 23rd and 31st Aug and 2nd Sept 2018.

Conclusions

Woodchip bioreactors are a useful tool in removing nitrate, and possibly DRP, from subsurface drainage water. The fraction reduction in peak nitrate-N concentrations was well described by a second order relationship with the fraction of distance travelled through the bioreactor, tentatively indicating the removal rate decreases with decreasing nitrate concentration.

Enhancing efficiencies of bioreactors may require a combination of; adding another electron donor (e.g. methanol) to promote complete denitrification during higher flow and concomitant N load peaks, and additionally preventing very long residence times to minimise the production of odorous or greenhouse gases.

Acknowledgement

This work is part of the SSIF-funded 'Enhanced Mitigation of Nitrate in Groundwater' programme led by ESR. We gratefully acknowledge the co-funding by Waikato Regional Council and the co-operation of the Mourits family, Tatuanui.

CLIMATOLOGY OF VAPOUR TRANSPORT ASSOCIATED WITH NEW ZEALAND DROUGHTS

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Droughts are widely recognised as one of the most costly environmental hazards, impacting an area socially, economically and ecologically (Mishra and Singh, 2010). The exact definition of a drought remains an area of research which is of yet unanswered, although in general terms it can be thought of as the absence of moisture. Research has been directed towards characterising the movement of moisture in the atmosphere during drought events (Liu *et al.*, 2017). Moisture transport has been shown to follow seasonal patterns over numerous study areas, with directional changes linked to the dominate synoptic pattern during the seasonal cycle (Liu *et al.*, 2017). The blocking of such moisture transport is frequently seen as a drought causing mechanism. Throughout New Zealand, the wider synoptic conditions associated with drought development are well understood (Salinger and Porteous, 2014). However, the climatology of moisture transport remains an area which is under-researched.

Aims

The aim of the study is to investigate the transport of vapour across the wider New Zealand region, with a particular focus on investigating this movement during drought events across the country. This will be achieved by characterising vapour transport during drought events, allowing for the identification of possible common characteristics of vapour transport and drought across New Zealand.

Method

The standardised index of precipitation and evapotranspiration (SPEI) over New Zealand for the period July 1979 to December 2010 was used to examine drought events across the country. A three month rolling time step was chosen. Hierarchical cluster analysis using the Wards algorithm was performed to identify drought regions across the country which will be used for further research.

Vapour transport data were obtained from ERA Interim for the period July 1979 to December 2010 (IVT). Data were averaged into monthly mean values to enable easier comparison with the SPEI data. Composite analysis was performed on IVT fields to identify common characteristics of IVT during drought events. Preliminary analysis of IVT fields was also performed using self-organizing maps.

Results

Initial results illustrate unique characteristics of IVT for drought events across New Zealand, with composite analysis revealing a weakening of the westerly movement of moisture across New Zealand associated with drought across New Zealand. Decreases in moisture fluxes were greatest over the west coast and north of the North Island.

Analysis of extreme events (95% quantile) reveal the occurrence of all events during the winter season. Seasonally, anomalous conditions associated with winter droughts can be characterised by a weakening westerly movement and associated flux over Northland, with increased flux over the lower South Island associated with a strengthening of this westerly movement (Figure 1). Stronger changes in direction and magnitude are witnessed during spring and summer (Figure 1). The contrast illustrates the significance and relative scarcity of moisture during the winter period.

Further research is to be directed towards characterising moisture fluxes with drought on a regional scale, alongside a possible examination of teleconnections between IVT and Trenberth indices.

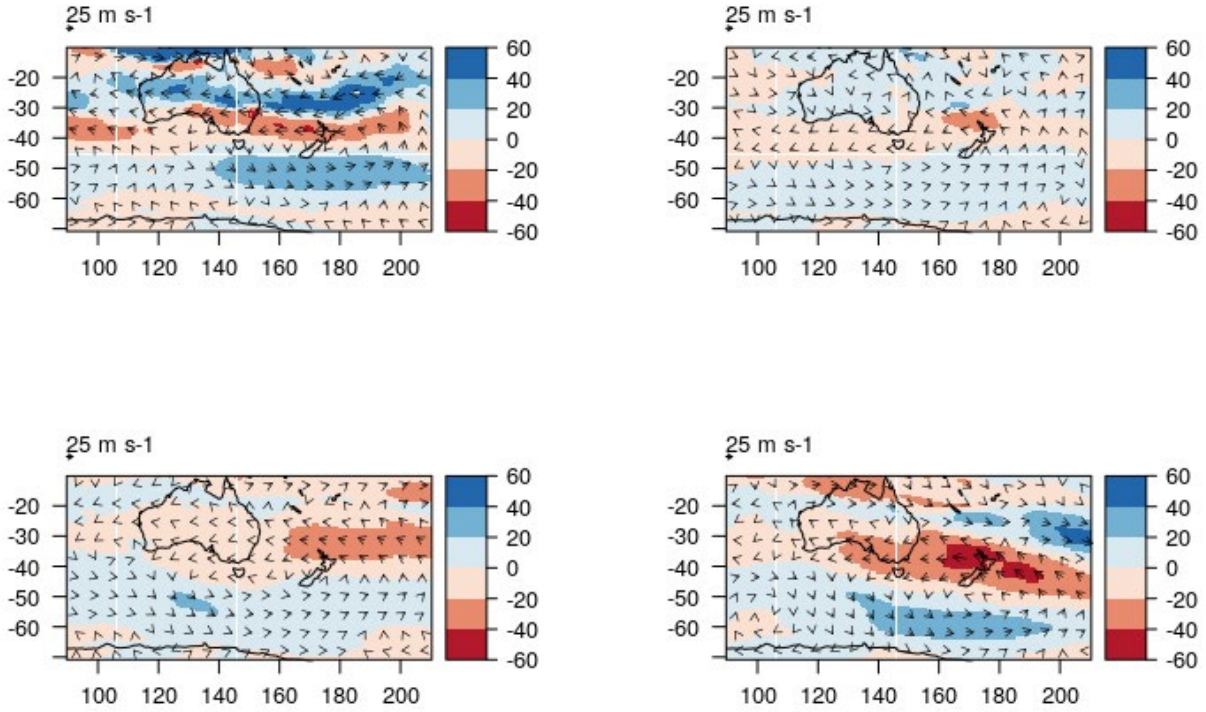

Figure 1: Anomalous IVT movement associated with seasonal drought over New Zealand for the period July 1979 to December 2010, showing summer (top left), autumn (top right), winter (bottom left) and spring (bottom right) seasons.

References

Liu, Z., Lu, G., He, H., Wu, Z. and He, J. 2017. Understanding Atmospheric Anomalies Associated With Seasonal Pluvial-Drought Processes Using Southwest China as an Example. *Journal of Geophysical Research: Atmospheres* 122 (22), 12,210-12,225.

Mishra, A.K. and Singh, V.P. 2010. A review of drought concepts. Journal of Hydrology 391 (1), 212-216.

Salinger, M.J. and Porteous, A.S. 2014. New Zealand climate: patterns of drought 1941/42 – 2012/13. Weather and Climate 34 (9), 2-19.

CHRYSTALLS BEND STOPBANK SEEPAGE ASSESSMENT, ŌTAKI

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[1] WSP Opus

Aims

Gravel has been excavated from the Ōtaki River and the adjacent floodplain for many years. Recently, however, excavation of gravel has commenced from the floodplain outside of the stopbank on Ashford Park. Gravel extraction is permitted by resource consents which include a number of conditions to safeguard the integrity of the Chrystalls Bend Stopbank (Figure 1).

During quarrying operations, the seepage of turbid water has been observed under the Chrystalls Bend Stopbank; from Ashford Park into the 'Main Lake' formed by previous gravel extraction operations. This raised questions regarding the integrity of the stopbank.

Consequently, hydrological and geotechnical investigations were undertaken to understand the origin, nature and characteristics of the discharge, and whether the seepage poses any risk to the stopbank from either piping failure or slope instability during a large flood event.

Method

To understand the cause and controls on any seepage beneath the Chrystalls Bend Stopbank, electronic water level sensors were installed in the Ōtaki River, the three quarry lakes (i.e. the Main Lake, Ashford Park, and the Canoe Polo Lake) and two shallow bores within Ashford Park (Figure 1). All water levels were reduced to a common datum.

Daily inspections were undertaken for any potential discharge beneath the stopbank, and potential flow paths were investigated using both turbid water (from quarrying operations) and fluorescein dye. Two trial pits were excavated adjacent to the stopbank to confirm the sub-surface stratigraphy.

These data were used to update seepage and stability models developed previously to support the application for resource consents.

Results

The water level data show that the Ōtaki River, the various lakes associated with the quarry, and the shallow bores are all hydraulically-connected and form one interacting surface water-groundwater system. The shallow unconfined aquifer beneath the floodplain has a direct hydraulic connection to the Ōtaki River. Water flows from the Ōtaki River (upstream of the quarry), into the shallow unconfined aquifer, and then laterally beneath the stopbank. The seepage observed is the result of natural groundwater flow within a paleochannel of coarse gravel which is acting as a preferential flow path.

The quarry operations in Ashford Park generate a source of turbid water. This water then flows within the natural groundwater system, beneath the stopbank, and into the Main Lake as a result of the difference in head. Groundwater flow is then to the northwest, parallel to the Ōtaki River. The turbid water does not indicate 'new seepage', or a change to the groundwater dynamics, rather it highlights an existing natural seepage process.

Under 'normal conditions', groundwater flows from Ashford Park to the Main Lake; however, no seepage above the water level is expected and the groundwater is at least 3.5m below the base of the stopbank (Figure 2). A maximum exit gradient of ~0.04 was calculated which is significantly less than the accepted seepage-exit gradient factor of safety (<0.5). The calculated seepage velocity of 0.0006m/s is also significantly lower than the critical velocity for alluvial materials and therefore too slow to entrain any material from within the stopbank. Similarly, during a 1% AEP design event, no seepage is modelled to occur on the landward side of the stopbank and all exit gradients remain <0.5 for the duration of the flood.

The consented setback between the edge of any gravel excavation and the toe of the stopbank is conservative. The crown scarp of the critical slope failure surface is >35m from the toe of the stopbank and the FoS does not drop below 1.5 closer than 30m from the toe of the stopbank (Figure 3).

Therefore, the updated seepage and stability analyses show that the seepage has no effect on the stability of the Chrystalls Bend Stopbank, both under normal conditions and during a 1%AEP design flood event.

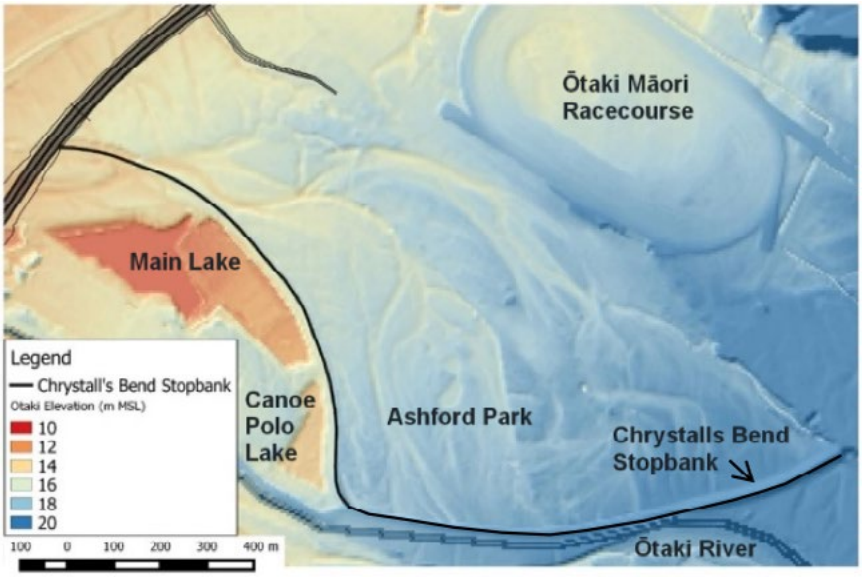

Figure 1: The quarry is on the floodplain of the Ōtaki River which shows numerous paleochannels. Also visible are the stopbank, and the ponds formed by the excavation of gravel.

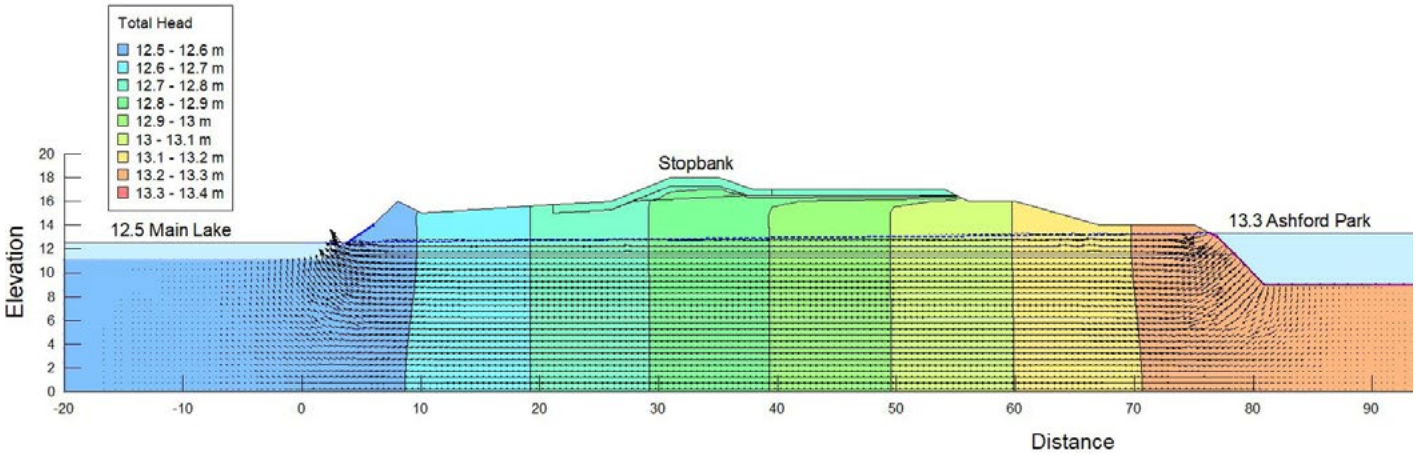

Figure 2: SEEP/W™ analysis of groundwater movement from Ashford Park, beneath the stopbank, and into the Main Lake.

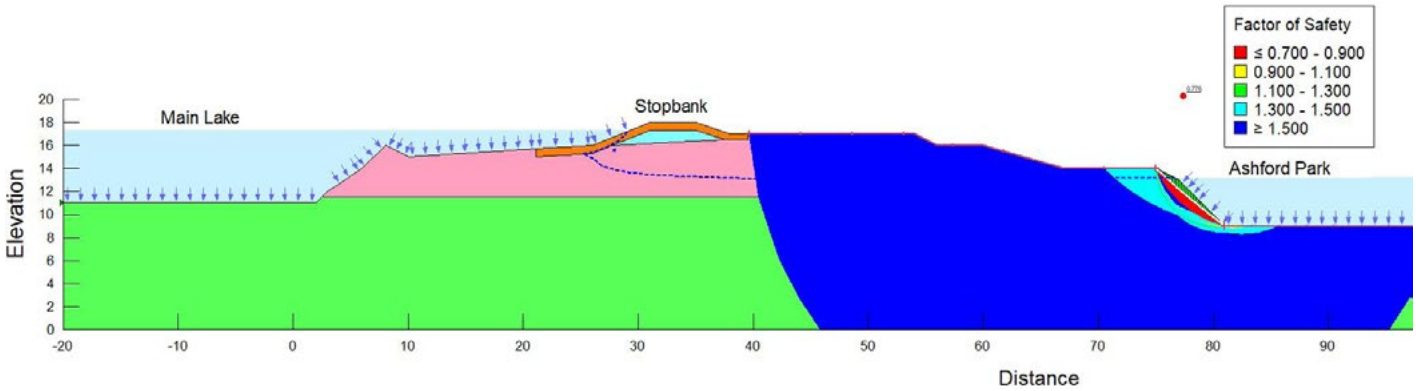

Figure 3: Slope stability FoS zone map during the 1% AEP design flood. The FoS only drops below 1.5 30m from the toe of the stopbank.

QUANTIFYING STREAMFLOW DEPLETION FROM GROUNDWATER ABSTRACTION IN THE SELWYN RIVER

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[2] Environment Canterbury, Christchruch

Background

Streamflows support many in-stream values such as cultural values, recreational needs, flow connectivity for fish passage, and limiting of nuisance algae growth. It is therefore important to effectively manage water abstraction within sustainable limits. Quantification of streamflow depletion resulting from groundwater abstraction is required for this task.

The Selwyn is a hill-fed catchment that crosses the Canterbury plains and then drains into Te Waihora/Lake Ellesmere. There is little surface water abstraction, but there are many groundwater takes in the mid-to-lower reaches. Start dates of existing consents from the catchment suggest that abstractions increased in the lower catchment during the mid-to-late 1990's. However, inter-annual variations in climate mean that analysis of flow data alone cannot be used to assess the influence of abstraction on streamflow. Furthermore, water-balance calculations and application of physically-based hydrological models are complicated by uncertain catchment boundaries due to flat topography, possible lateral groundwater exchanges with adjacent catchments, and lack of long-term recorded abstraction time-series.

Aims

The aim of this work was to quantify streamflow depletion from groundwater abstraction in the Selwyn. A secondary objective was to demonstrate the utility of regression models such as those used in machine learning when addressing hydrological research questions.

Methods

Long-term flow data from two gauges were available. The Whitecliffs flow gauge is located at the foothills in the mid-catchment upstream of most abstractions. The Coes Ford catchment is located at the downstream outlet of the catchment. Both gauges have been collecting continuous streamflow data since at least 1984. These data were analysed to quantity the degree to which groundwater abstraction has depleted river flows in the lower Selwyn River. The analysis consisted of several steps:

a) Obtain mean daily flow data and apply a Box-Cox transformation to each record (Figure 1).
b) Extract time-series of evaporation and precipitation from NIWA's Virtual Climate Station Network (VCSN) averaged over the catchments upstream of each gauging station (Figure 1).
c) Split data into pre-abstraction and post-abstraction periods (Figure 1).
d) Train models to predict mean-daily-flow from antecedent meteorological conditions at each gauging station for the pre-abstraction period and post-abstraction period separately.
e) Apply cross-validation within the pre-abstraction and post-abstraction periods by leaving out data from each water year in-turn. Each water year starts 1st October.
f) The hypothesis that there has been a depleting effect of abstraction will be supported if:
    a. The pre-abstraction trained Whitecliffs model predicts the post-abstraction period well.
    b. The post-abstraction trained Whitecliffs model predicts the pre-abstraction period well.
    c. The pre-abstraction trained Coes Ford model overpredicts the post-abstraction period.
    d. The post-abstraction trained Coes Ford model underpredicts the pre-abstraction period.
    e. Between-year cross-validation performance was more consistent within the pre-abstraction period than within the post-abstraction period for Coes Ford.
    f. Between-year cross-validation performance was equally consistent within the pre-abstraction period and the post-abstraction period for Whitecliffs.

Several regression methods were applied, including machine learning algorithms, to complete these steps. Various model performance criteria were applied.

Results

The Whitecliffs models showed similar predictive performance and predicted similar flows across both periods. The cross-validated Whitecliffs models showed similar levels of between-year predictive performance regardless of which year was withheld from within either period. This showed that, for a sub-catchment with no abstraction, models trained to either period could predict flows in the other period despite any between-period differences in climate conditions.

The pre-abstraction trained Coes Ford model over-predicted the post-abstraction observed flows. The post-abstraction trained Coes Ford model under-predicted the pre-abstraction observed flows. The pre-abstraction trained cross-validated Coes Ford models showed consistent between-year predictive performance. The post-abstraction trained cross-validated Coes Ford models showed inconsistent between-year predictive performance. Similar results were found regardless of whether parametric or machine learning regression approaches were applied (Figure 2).

The streamflow depletion can be quantified by comparing pre-abstraction trained and post-abstraction trained predictions of mean-annual-low flow, low-flow series, or duration curves derived. All models indicated that there was a strong streamflow depletion effect.

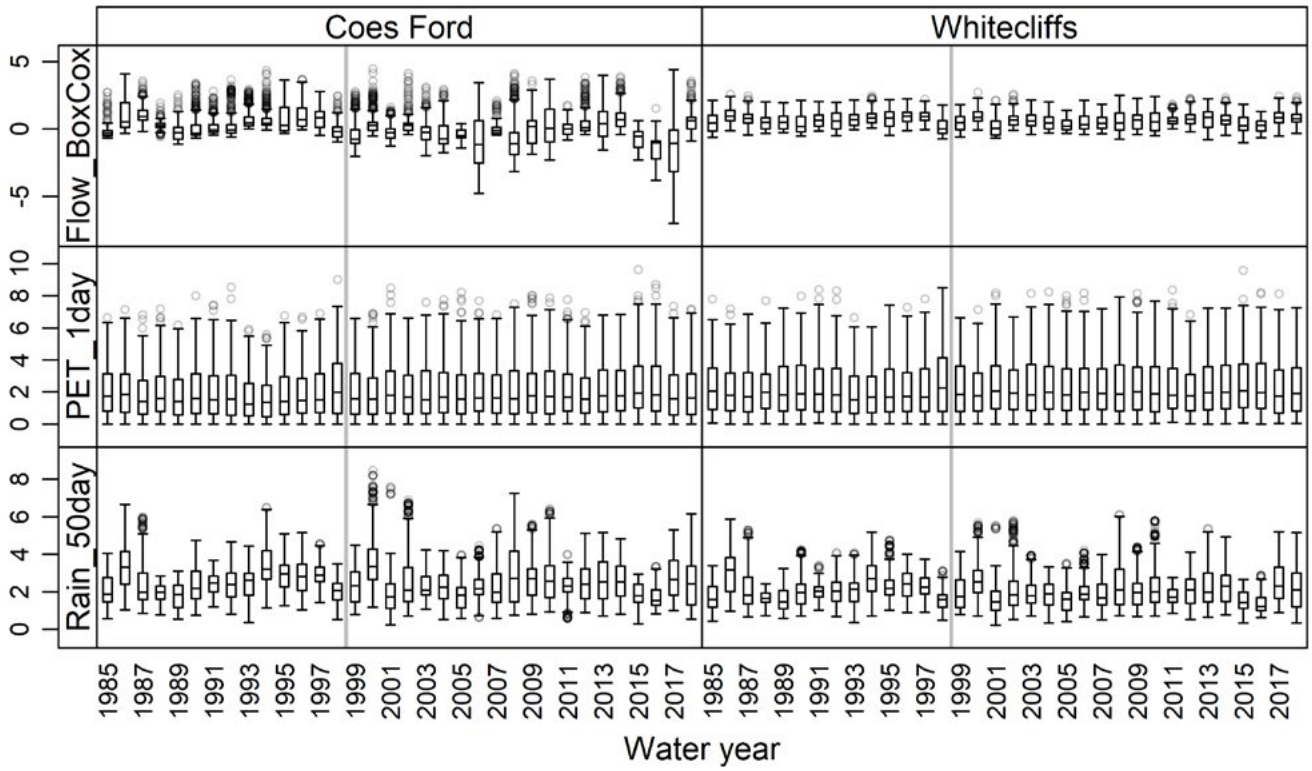

Figure 1: Daily values of observed flow (Box-Cox transformed), estimated 1-day potential evaporation (mm) and 50-day estimated rainfall (mm) for the Whitecliffs and Coes Ford sub-catchments of the Selwyn River. Grey dashed line indicates separation between pre-abstraction and post-abstraction periods.

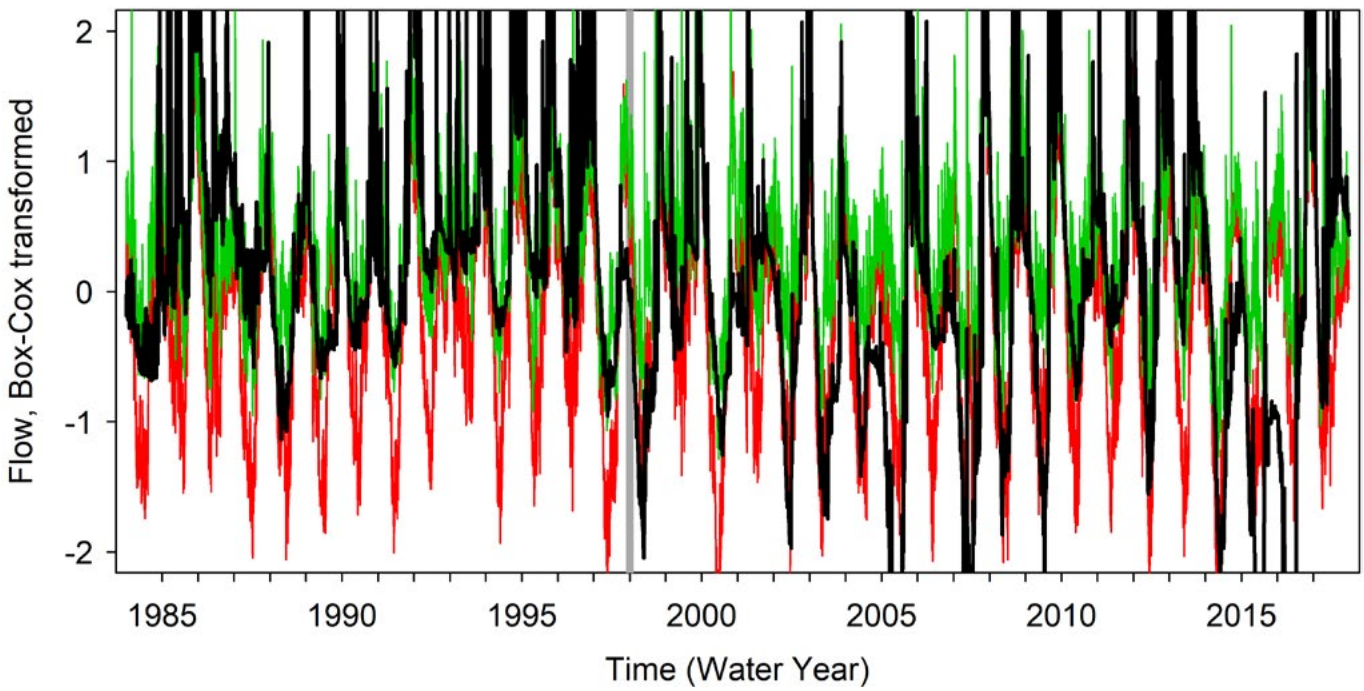

Figure 2: Observed flow (black), pre-abstraction trained predictions (green), and post-abstraction predictions (red) for the Coes Ford sub-catchment of the Selwyn River. Grey line indicates separation between pre-abstraction and post-abstraction periods.

WATER TRADING: IS IT ALREADY HAPPENING? WHAT ARE THE ADVANTAGES? ARE THE REQUIREMENTS FOR WIDESPREAD UPTAKE EASILY MET?

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[1] NIWA, Christchurch
[2] NIWA, Hamilton

Water trading is defined as the process of buying and selling rights to access and use water. Water trading can currently be practiced in New Zealand under the RMA. Many regional authorities apply regional policies and plans that permit water trading through water take consent transfers. Although the RMA technically allows trading of water consents and water trading has been the subject of academic interest in New Zealand for several years, widespread uptake has not occurred. There has been no substantial movement towards setting up an operational system across a region or catchment. This is likely due to a range of reasons, including limited capacity for the temporary or partial transfer of water consents and the complexity of the administration of transfers of water consents under s136 of the RMA.

Several regulators, business initiatives, academics and research organisations have investigated or proposed different water trading frameworks as a pathway toward improving technical efficiency, addressing underutilisation of allocated water, and resolving iwi rights and interests in fresh water and water management. Water trading has been touted as an effective management mechanism because it may deliver economic benefits within environmental limits. Water trading may present the advantage of being a dynamic allocation framework within which water use limits can be more easily altered compared to a static framework. Thus, environmental flow effectiveness can be monitored, evaluated and improved following adaptive management principles. Trading also has the advantage of allowing transfer of water rights to the environment for the purposes of supporting ecological, cultural, aesthetic or recreational values provided that the environment is explicitly recognised as a water user. Water trading can be conducted with a “no injury rule” which requires the assessment of any proposed transfer to confirm that the change in abstraction location or use of the water will not impact other water users. Given these advantages water trading might be used to optimise the benefits of water use by allowing space-time flexibility in water allocation rules without compromising risks to in-stream and aquifer values. However, we apply a critical assessment of the benefits, opportunities and limitations to New Zealand’s environment and economy of deploying water trading approaches.

We present previously documented requirements for implementation of water trading taken from international experiences in regions where it has been applied. We conclude that, whilst there are several advantages, water trading should not be viewed as a ready-made and easily implemented solution for improved water management. New Zealand’s flashy hydrology is not conducive to seasonal water trading and smaller catchments may not contain enough users to constitute functioning markets. A clear co-governance policy framework for water trading has not been devised or agreed by iwi/hapū and the Crown, based on the Treaty of Waitangi. The authority to transfer existing water rights to the environment has not been granted and questions about who would act on behalf of the environment are unresolved. Requirements relating to collection, collation, and communication of hydrological data such as river flows, groundwater levels, and water use are only partially in place. Operational requirements for market operation such as tracking of exchanges and assessment of potential environmental effects have not been devised or deployed. The institutional capacity required for implementation may be lacking but this is hard to assess because the roles that various government agencies and iwi/hapū would play in co-developing and implement water trading are currently unclear.

PROTECTING COASTAL AQUIFERS FROM SALINE INTRUSION

Amandine Bosserelle,[1] Eric van Nieuwkerk[1]
[1] Golder Associates (NZ) Limited

As in many parts of the world, New Zealand's coastal fresh groundwater resources are increasingly susceptible to saline intrusion from land use changes, over-abstraction and sea level rise. There are options available to mitigate adverse effects, but their efficacy is not always clear. Investigation and modelling tools can help assess the scale of the saline intrusion problem and identify mitigation strategies.

New Zealand's fresh groundwater resources are well-established and mostly present in either narrow river valleys or large bays and low-lying coastal plains that all have similar climate and hydrogeological settings. Researches demonstrate that a large range of factors such as groundwater abstraction, land use change, sea-level rise, inundation, erosion and contamination have contributed to saline intrusion. Competition for urban development, agricultural land and natural or restored habitats is already debated as population in most coastal city centres increase and the suitable type of land available to grow food also is needed. The quality and quality of freshwater resources is already impacted by those activities while adaptation and mitigation of saline intrusion constitute a challenge. A review of those processes contributing to salinization identifies potential risks for future availability of fresh groundwater resource.

The key issue is the distribution of water across catchments and analysis derived from previous investigations point towards a net deficit (i.e. lack of recharge) of aquifers at the coastline. The lack or reduction of recharge due to upstream groundwater abstraction, river flood mitigation (and infiltration reduction) and sea-level variations will always drive the salinization of the freshwater systems.

Nowadays numerical models are available to assess changes from external factors, however they often lack site specific parameters, horizontal and vertical refinements in order to simulate specific three-dimensional components of coastal issues. It is a very challenging part of the modelling approach but is not a limiting feature and doesn't limit the reliability of the results. Modelling density driven flow simulates the interaction between freshwater and saline groundwater and is without doubt a powerful tool for understanding, visualising and predicting past, current and future states.

We have reviewed case studies and specific saline intrusion processes in which a sophisticated approach and modelling tools are used to show an increase in salinity of freshwater resources as a result of land use changes, drainage and sea-level rise. We can also demonstrate how modelling tools can be used to develop sustainable solutions to protect further salinization or mitigate existing issues. The primary purpose of Managed Aquifer Recharge (MAR) was to create a freshwater barrier to control the saltwater interface away and maintain abstraction for water supply. Assessing the suitability of MAR in the NZ context is largely unknown to control saline intrusion. We identified that this research is important and would provide potential benefits within an environmental and socio-economical context.

THE EFFECT OF THE FINE PARTICULATES AND PARTICLE SIZE ON NEPHELOMETRIC TURBIDITY

Bright, C.E,[1] Mager, S.M.,[1] Horton, S.L.[1]
[1] School of Geography, University of Otago

Quantifying suspended material is challenging, and standard methods require the collection of discrete grab samples and laboratory analysis. Instead, researchers and environmental managers opt to quantify riverine suspended sediment using turbidity as a proxy by establishing ratings between in situ turbidity and suspended sediment measurements. As such, turbidity is used widely as a surrogate for suspended sediment concentration (SSC), and often used as a regulatory tool and threshold for land use disturbance and environmental protection. However, the physical characteristics of suspended material that is, particle size, shape, colour, density, and refractive index behave differently and produce different optical outputs, which undermine the precision of measured suspended sediment to turbidity relationships. Consequently, turbidity relationships to suspended material can show non-linear responses to particulate organic matter (POM), and changes in particle size distribution (PSD). In this paper we show the influence of ultra-fine particulate matter (UFPM; < 6μm) on specific turbidity and its association with POM in suspended sediment material from alpine rivers in the Southern Alps of New Zealand. Such work is needed to establish the effect of particle size and other interferences (e.g., organic material) on optical water quality and suspended sediment, which is acknowledged but rarely explained. Despite such recognition of these different optical properties, nephelometric turbidity persists as a convenient measure in environmental monitoring programmes, as a proxy indicator of land disturbance and suspended sediment.

Aims

The objective of this paper is twofold: firstly, to examine the importance and contribution of fine particulates (6 – 63 μm) and ultra-fine particulates (< 6 μm) on turbidity and the effect these have on turbidity measurements derived from different nephelometric methods (EPA 180.1 and ISO 7027); and secondly, evaluate whether different size classes produce higher effective turbidity rating equations by examining specific turbidity over different particle size classes.

Method

To explore the links between turbidity, suspended sediment, and particle size, two approaches were employed; firstly, quantifying specific turbidity response over a hydrograph as a measure of natural changes in suspended load optical properties; and secondly, a laboratory-based settling experiment to examine specific particle size class effects on turbidity-suspended sediment relationships. To do this, riverine suspended sediment was collected under storm flow conditions from alpine rivers in southern New Zealand; the Ahuriri River in Southern Canterbury, Haast River on the West Coast, and the Rees, Shotover and Dart/Te Awa Whakatipu rivers in the headwaters of the Clutha Mata-Au catchment in Otago. Our approach emulated the material conditions in which source and transport limitations are observed in natural systems and allows the combined effect of variations in grain mineralogy, size, and shape that occurs in natural systems to be examined and reflect the natural variations in optical properties that are typical of alpine river systems.

Results

Specific turbidity changes over event flow and is particularly sensitive to increasing proportional amounts of sand, UFPM and POM in suspension. Furthermore, the UFPM is the size fraction (< 6 μm) where particulate organic matter becomes substantially more important. The implications are that the slopes of SSC-turbidity relationships are fraught in locations that may be dominated by cyclic release of POM, or distinct pulses of fine-grained material. Locations where the turbidity-SSC slopes approximate 2, POM is usually <10% of the total suspended load. However, when SSC-turbidity slopes are <1 this is likely caused by high amounts of side-scatter from UFPM concomitant with higher proportions of POM. Thus, the use of turbidity as a proxy for determining suspended sediment concentration may have serious implications to the measurement of representative suspended sediment data and to management concerns, particularly in locations where POM may be a significant contributor to overall suspended load.

REDUCING NUTRIENT LOSSES THROUGH IMPROVING IRRIGATION EFFICIENCY

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Aims

The purpose of this pilot study was to answer three important questions:

- How much can drainage and the associated N-loss to water be reduced by increasing irrigation efficiency?
- What changes in irrigation systems and their management would be needed to achieve this?
- What are the primary incentives and barriers to achieving the changes required?

Method

Existing data from twelve representative dairy farms located in Canterbury were used with well-established computer models to build the technical evidence base needed to answer the first two questions. The third question was addressed using the project team's expert knowledge of irrigation systems and their operating requirements, in conjunction with the technical evidence base.

Results

Changing irrigation practices to make more efficient use of both irrigation water and summer-time rainfall reduced N-loss to water by 27% (~19 kg N/ha/year), on average. The percent reduction ranged from 4% to 58%. These reductions in N-loss to water were achieved without significantly reducing modelled average annual pasture production.

To achieve this degree of N-loss reduction the following changes were made to irrigation management practices:

- The irrigation 'trigger level' (the soil water content at which an irrigation application is initiated) was varied from month to month and in some months is significantly lower than current practice. Most farmers use a trigger level of 50% of the soils water holding capacity throughout the irrigation season.
- The irrigation 'target' soil water content was reduced, compared to current practice, so that after each irrigation event there will still be a soil water deficit. The aim of this 'deficit irrigation' is to always have some capacity to store rainfall that occurs during the irrigation season. This reduces the risk of rainfall-induced drainage and N-loss occurring during the irrigation season.

The irrigation management strategy that achieved the N-loss reductions reported above is as follows:

Month	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Irrigation Trigger (% of soil water holding capacity)	20%	40%	50%	50%	50%	40%	30%	20%
Irrigation Target (% of soil water holding capacity)	80%	80%	80%	80%	80%	80%	80%	80%

To implement this strategy it is essential that:

- Soil water content is routinely measured using reputable soil moisture sensors or soil moisture monitoring service provider.
- The irrigation application system can be adjusted to apply relatively small amounts of water (e.g. 15mm). The depth depends on the soil water holding capacity.
- The irrigation application system has a relatively short return period (e.g. 3 days). This depends on the amount of water applied and the evapotranspiration rate.
- The irrigation water supply is 100% reliable.

At present about 72% of irrigation application systems in use in Canterbury are very likely to be able to meet the above application depth and return period requirements. An additional 19% may be able to meet these criteria but probably require a comprehensive irrigation design review and some capital investment in irrigation equipment. The balance almost certainly require replacement of the existing irrigation system.

A recent survey of irrigation management practices indicates that in the area surveyed about 60% of properties have soil moisture sensors installed but that fewer than half of these are actually used to guide day-to-day irrigation decision making.

DENITRIFICATION WALL TRIAL IN A GRAVEL AQUIFER: RESULTS FROM YEAR 1

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Aims

Historically, New Zealand has depended heavily on dilution being the solution for controlling groundwater nitrate pollution. Increased intensification of the land however, has led to a progressive decline in water quality that has triggered freshwater reforms and prompted changes to water quality management strategies. Nitrogen-mitigation measures are one aspect of change being explored, including the idea of eco-engineered solutions, like woodchip denitrifying bioreactors (Schipper et al., 2010). Within parts of the USA at least, such edge-of-field N-mitigation measures have become standard farming practice (USDA, 2015). Whether they are a viable water quality management option for New Zealand conditions has yet to be answered.

Woodchip denitrification walls are a specific class of denitrifying bioreactor that target passive removal of nitrate in shallow groundwater. Whilst denitrification walls have been demonstrated and proven effective groundwater remediation concepts in sandy aquifer systems (e.g. Schipper et al., 2000; Schmidt and Clark, 2012), no reported examples can be found of their application in gravel aquifers, as are the type that constitute the major groundwater systems of New Zealand and are most vulnerable to nitrate leaching. As part of a feasibility study of denitrifying bioreactor technologies for mitigating nitrogen impacts from New Zealand agricultural landscapes, we are piloting a woodchip denitrification wall in a shallow gravel aquifer.

Method

Following a year of site investigation to characterise background conditions and evaluate crucial design parameters, in November 2018 we installed a woodchip denitrification wall in alluvial gravel outwash belonging to the Waimakariri River/Eyre River fan complex, North Canterbury (Figure 1). The experimental wall measures 25 m long x 5 m wide and comprises a 50/50 binary mixture of gravel/woodchip that is entrenched 3 m deep below the land surface or 2.5-2.9 m below the water table. In studying the performance of the denitrification wall, we have routinely been monitoring groundwater quality upstream and downstream of the structure, tracking the development of the redox plume and evaluating pollution-swapping phenomena, such as leaching of dissolved organic matter; mobilisation of iron and arsenic from the greywacke aquifer sediments, as well as production of greenhouse gases. In addition to these observations, we are studying changes in the microbial community structure in and about the wall. Hydrogeophysical methods are being applied to both monitor the hydraulic efficiency of the wall and map complex flow paths through the heterogenous alluvial gravel aquifer.

Whilst it is only 12 months since the denitrification wall was installed, given the high groundwater flux through the alluvial gravel aquifer, we estimate that within this short time our denitrification wall has filtered as much groundwater as pre-existing examples in sand aquifers would achieve over several decades of operation. The implications of this on the ageing process of the woodchip wall and its denitrification capacity in the long-term, form a key component of the pilot study.

Results

The initial hydraulic conductivity of the wall was estimated to be in the region of 20,000-30,000 m/d. Being significantly higher than the natural aquifer sediments, we believe the wall is inducing a significant amount of hydrodynamic dispersion in the aquifer that likely explains why we have failed to identify any horizontal stratification in the water chemistry down-gradient of the wall. This is despite it only partially-penetrating the 5 m thick surficial aquifer. Salt tracer tests conducted in conjunction with time-lapse electrical tomography are planned to test this hypothesis.

The fresh woodchip contained a significant labile fraction of organic carbon (identified as mainly o-alkanes and aromatic/phenolic compounds) that leached from the outset. The highly reactive labile carbon created an anoxic plume of groundwater that resulted in reduced nitrate levels being measured 190 m from the PRB – the most down-gradient of our monitoring wells. A pulse release of metal elements from the greywacke sediments was detected in the process. Five metres down-gradient of the wall, dissolved iron and arsenic concentrations peaked one month after the wall was built, at 6 g/L and 23 ug/L, respectively.

After nine months of operation, the woodchip wall continues to reduce groundwater nitrate to effectively zero, although the oxidation-reduction potential (ORP) of groundwater down-stream of the wall has resumed a positive value. This suggests any denitrification potential is now constrained to within the wall itself. In terms of greenhouse gas pollution-swapping phenonema, based on concentrations of dissolved nitrous oxide and methane measured in the groundwater, it appears the woodchip wall does fuel methanogenesis. How much methane is actually emitted from the subsurface to the atmosphere remains to be quantified. Only negligible (part per billion N) amounts of N_2O measured have been detected in groundwater at the site. Considering the wall reduces nitrate concentrations to effectively zero with no concomitant increase in nitrite, ammonia or nitrous oxide, we conclude that the wall is effective at fueling complete denitrification and assume all nitrogen is converted to nitrogen gas. Evaluation of the performance of the wall is on-going.

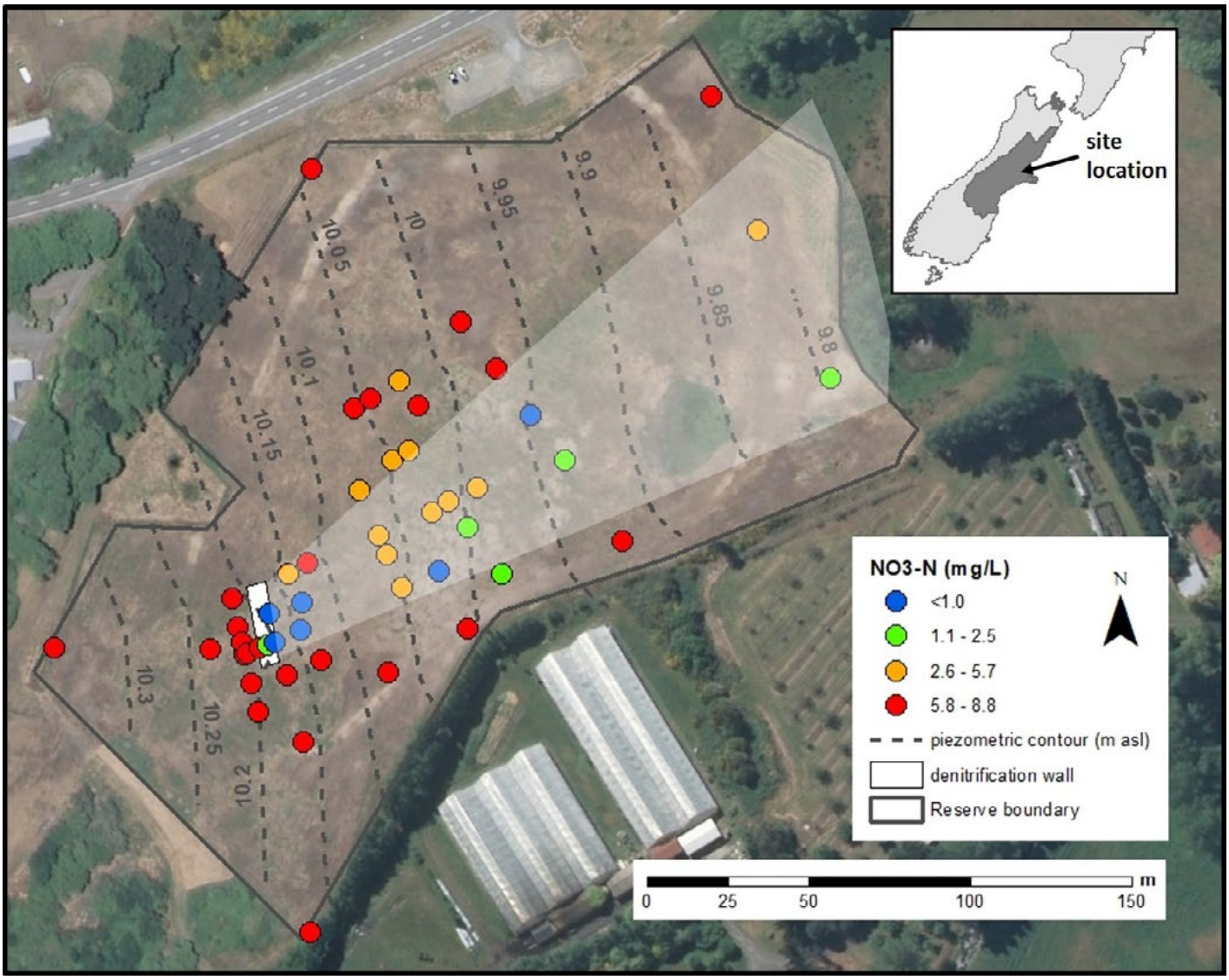

Figure 1: Shallow groundwater nitrate concentrations at the experimental field site, as surveyed May 2019, six months after installation of the woodchip denitrification wall. Groundwater flow direction is to the north-east. The shaded region marks the extent of the plume of treated groundwater, reduced in nitrate.

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DESIGN RAINFALL REGIONALISATION USING A NON-STATIONARY GEV

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Aims

Regional frequency analysis is a common method used in extreme rainfall research when observational records are too short to allow reliable estimation of long recurrence intervals. A region of influence is chosen comprised of a collection of sites with similar extreme rainfall properties that can be used in the estimation of quantiles at the site of interest (Burn 1990). Traditionally, a curve such as the Generalised Extreme Value (GEV) distribution is fitted to each site in the region using an appropriate method such as maximum likelihood or probability weighted moments (Ailliot et al. 2011, Hosking and Wallis 1988). Parameters for the dimensionless regional growth curve are then calculated as a weighted average of those from individual sites. A major deficiency in this approach is that for relatively short records, the uncertainty or variability in parameter estimates can be quite large. For example, there can be a large range of values for a shape parameter that all provide an acceptable fit to a short record. Even though weighted averaging is used, these will have a detrimental effect on the final result.

The aim of this research is to provide a more robust way of estimating regionalised growth curve parameters without sacrificing the additional value relatively short records can contain. An additional goal is to provide more smoothly varying and consistent growth curves between nearby sites and across a range of durations for the location in question.

Method

This work is built upon the rainfall dataset collated for the 2018 update to the High Intensity Rainfall Design System (Carey-Smith et al. 2018, HIRDS 2019). Annual maxima series (AMS) for durations ranging from 10 minutes (~1000 locations) to 5 days (~3000 locations) were produced as part of this HIRDS update.

To provide more robust regional growth curves, instead of estimating parameters for sites separately, a non-stationary GEV distribution has been used so that growth curves can be fitted to multiple AMS at once. Using a non-stationary approach allows the user to choose whether parameters should be completely independent for each AMS, combined to a single value for all AMS, or allowed to vary based on an appropriate covariate. Some example configurations are shown in Table 1.

	Location Parameter		***Coefficient of variation***		***Shape Parameter***	
	Region	**Duration**	**Region**	**Duration**	**Region**	**Duration**
A	Independ.	Independ.	Independ.	Independ.	Independ.	Independ.
B	Independ.	Independ.	Independ.	Independ.	Combined	Independ.
C	Independ.	Independ.	Combined	Combined	Combined	Duration
D	Independ.	Duration	Combined	Duration	Combined	Duration
E	Independ.	Duration	Elevation	Duration	Combined	Duration

Table 1: A selection of possible models showing how the 3 GEV parameters could vary across different sites in the region and between different durations. Parameters can either be independent (having a different value for each site and/or duration), combined (having the same value for all sites and/or durations), or vary as a function of duration, elevation or another covariate.

Results

Preliminary results have been obtained for models A and C as described in Table 1. The shape parameter as estimated for the 24-hour duration AMS for these models is shown in Figure 1. For the shorter duration records, when the estimation is done independently, there are many instances where neighbouring sites have very different shape parameters, and these often have quite large, possibly unrealistic values.

Conversely, when the parameters are regionalised using the non-stationary GEV, there is much more consistency between nearby sites and a more realistic range of values for the shape parameter. Despite the large differences between the results of these two methods, the goodness of fit for individual sites is in most cases not significantly worse.

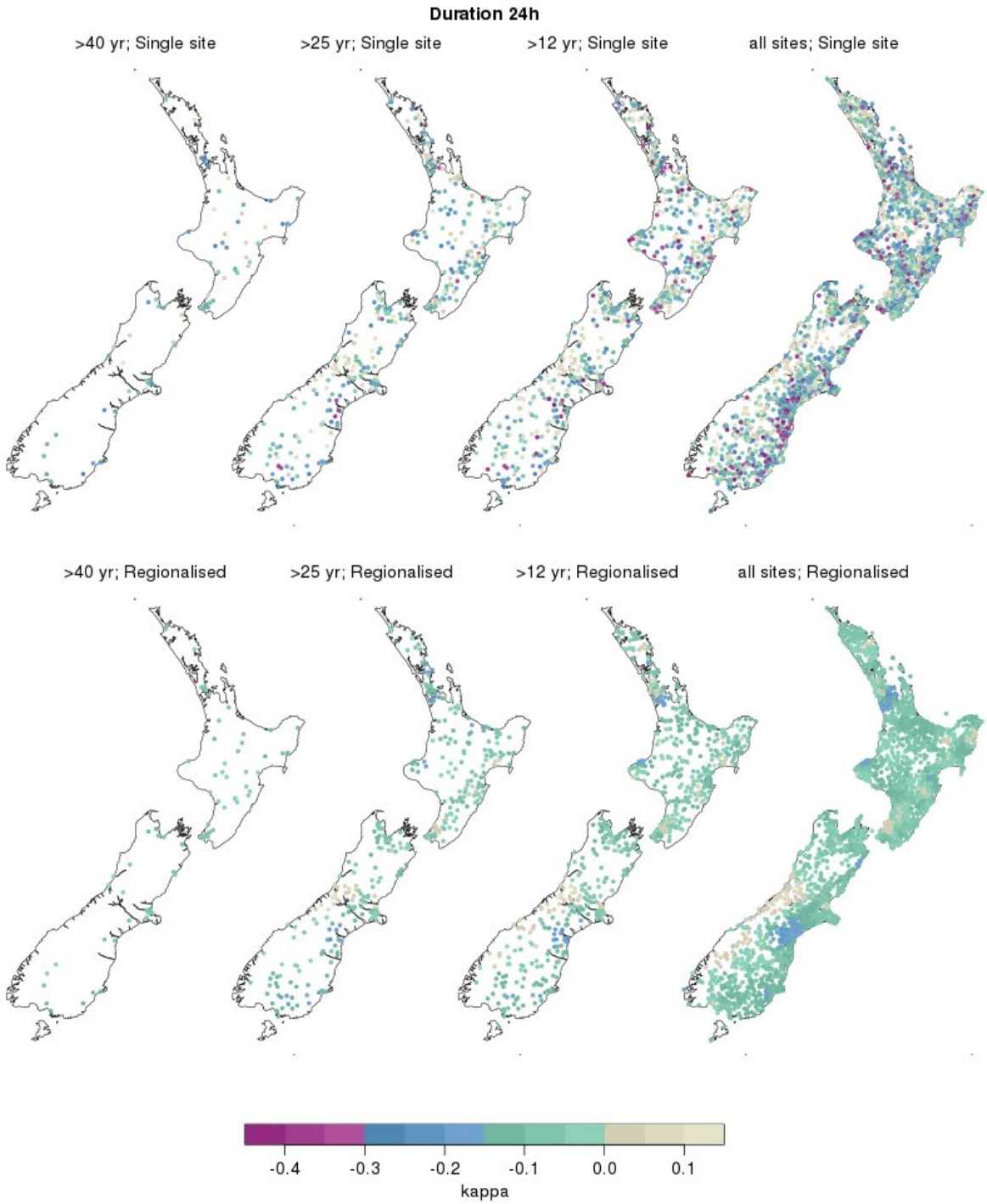

Figure 1: Shape parameter for 24-hour duration annual rainfall maxima when fitted independently to each site (top row) and when using a combined parameter for sites within a region of influence (bottom row). The effect of including additional sites based on their length of record is shown in the left to right progression.

In addition to providing more robust growth curve estimates, this method will also provide more amendable input to procedures, such as the thin-plate spline, used to map parameters across the country. Similarly, combining different storm durations in a continuous way removes the tendency to produce inconsistent predictions where shorter durations are given larger rainfall depth estimates than longer durations.

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IMPACT OF WETLAND EXTENSION ON ECOSYSTEM HEALTH

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New Zealand wetlands host a diverse range of aquatic life, including fish, macro-invertebrates, macrophytes. Dissolved Oxygen (DO) is an important parameter to determine the ecosystem health of the wetland. As DO levels in water drop below 5.0 mg/L, aquatic life is put under stress. The lower the concentration, the greater the stress. Oxygen concentrations <2 mg/L are considered hypoxic. Hypoxia can impair the growth and reproduction of aquatic organisms. Oxygen levels that remain hypoxic for a prolonged period can result in large fish kills. The project team has recently completed modelling of the proposed Kaituna Wetland extension for Bay of Plenty Regional Council (BOPRC). This study sought to understand water quantity and quality outcomes from extending the wetland by approximately 80 ha (~40%). This presentation details a water quality investigation undertaken as part of the ecosystem health assessment.

Aims

A key aim of this investigation was to identify areas of the wetland with low DO, which presents problems for aquatic life. We investigated the impacts of proposed wetland reticulation and vegetation clearance programmes on dissolved oxygen within the wetland.

Method

Flushing time is important as this indicates how rapidly oxygen and other substances (like nutrients or contaminants) will be exchanged within the wetland. Faster flushing will result in more rapid dilution of substances within the wetland. More rapid dilution of substances from incoming flushing waters means that the standing concentration of these substances is reduced. This also means that DO can be more rapidly replenished by the generally higher oxygen concentrations found in the incoming river water, raising the potential sustaining capacity of the wetland (as hypoxic and anoxic waters are flushed out).

Using the integrated water resource modelling platform – MIKE SHE, we developed a calibrated flow and transport model of the wetland. The AD (Advection-dispersion) module was used to calculate how long a conservative tracer takes to be exchanged (flushed out) within and from outside of the wetland. The conservative tracer test involved the introduction of a high concentration non-reactive solute across the model domain. Introduction of the tracer was achieved by specifying a starting condition (concentration) at all locations within the wetland. From the very first model time step, this concentration begins to be displaced by freshwater entering the model domain. The modelled time it took for 95% of the tracer to be removed from the wetland by flushing was used to approximate residence time at each observation site. We recorded the length of time for the tracer to hydraulically flush (Figure 1) from the wetland at various key sites. We then modelled various reticulation system changes and vegetation clearance programmes comparing the changed flushing times using a relative change framework.

Results

Modelling showed that areas of low DO levels (measured data) correlated with the areas of longer flushing time. This suggests that DO levels are directly related to the residence time of water in the wetland. Modelling with increased vegetation clearance frequency and new reticulation channels showed that flushing time could be significantly reduced for the sites of interest. The integrated water resource modelling approach provided a feasible and pragmatic approach to improve water quality and extend habitat areas for aquatic life in the wetland.

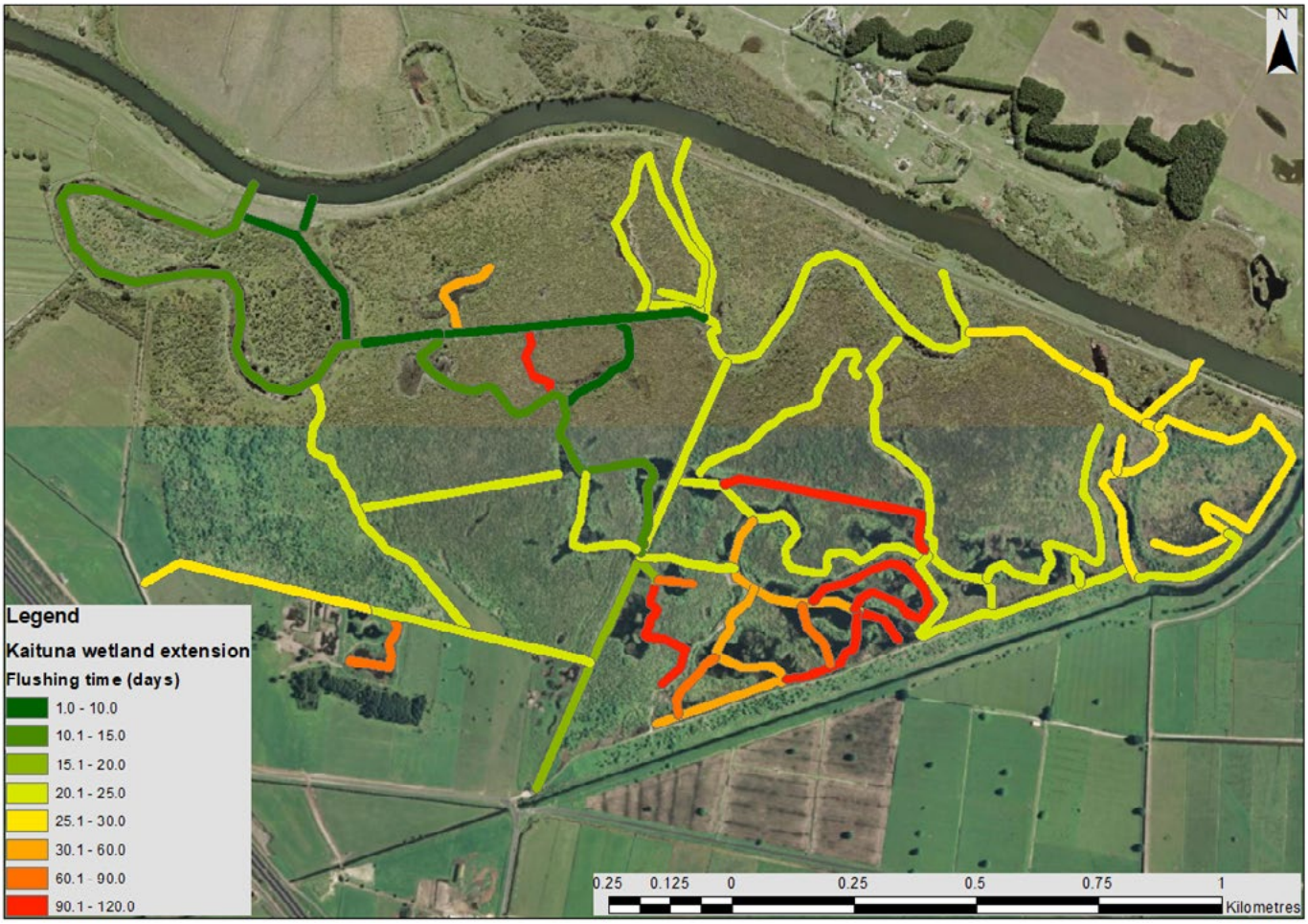

Figure 1: Example of flushing times in various wetland channels

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2018 NATIONAL SURVEY OF PESTICIDES, GLYPHOSATE, AND EMERGING ORGANIC COMPOUNDS (EOCS) IN GROUNDWATER

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Aims

In 2018 ESR co-ordinated a survey of pesticides in groundwater throughout New Zealand, which was the eight such survey since the 4-yearly surveys commenced in 1990. Glyphosate and its metabolites, as well as a suite of EOCs were added to the survey. The aims of the survey were to update the national overview of pesticides in NZ groundwater systems and to investigate temporal variation in pesticides between surveys; to assess whether glyphosate and its metabolites were present in groundwater in NZ; and to carry out the first national assessment of a suite of EOCs in NZ groundwater.

Method

The well sampling was carried out by Regional and Unitary Authorities, generally between September and November 2018. The Waikato Regional council are providing results for an additional 41 wells that have been sampled as part of their regional survey in December 2016 that will be included to give a national perspective. Samples were analysed for acidic herbicides and a suite of organochlorine, organophosphorus and organonitrogen pesticides by AsureQuality. Samples for Glyphosate were separately extracted and analysed for glyphosate and 3 of its metabolites. A suite of 31 EOCs were analysed by Northcott Research Consultants Ltd with detection limits generally between 0.05 and 0.1 ng/L. Wells were selected on the basis of the importance of each aquifer to the region, the application or storage of pesticides in the area, and the vulnerability of the aquifer to contamination, recognising that shallower, unconfined aquifers would be more at risk than deeper aquifers. If possible, where a well had been sampled for previous surveys, it was also included in this survey to give a temporal comparison. The majority of the selected wells were from unconfined aquifers.

Results

There were a total of 167 wells were sampled for standard pesticide suite (88 pesticides) not including the 41 wells from the Waikato Regional Council. Glyphosate & metabolites were analysed in 135 wells; and EOCs were analysed in 121 wells.

The following summary does not include the results from the Waikato Regional Council wells but the conference presentation will include these results. There were 55 detections of pesticides in 36 wells (21%). There were 16 different pesticides detected. The pesticides detected were similar compared to previous surveys. Concentrations in the pesticide suite ranged from 0.01 to 0.91 ug/L (ppb). There were one or more wells with pesticides detected in 12 of the 14 participating regions. Pesticides were not detected in sampled wells from Hawkes Bay (13 wells) and Bay of Plenty (25 wells). There were no pesticide detections exceeding the maximum acceptable value (MAV) for drinking water (Ministry of Health 2018).

There was one well out of 135 wells analysed for glyphosate that had low levels of glyphosate detected. This well had poor wellhead protection and there were chemical containers stored in the vicinity. Repeat sampling of this well and sampling of nearby wells is underway.

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

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MAPPING GROUNDWATER DISCHARGE INTO A LARGE COASTAL LAGOON IN NEW ZEALAND

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Aims

The overall aim of this study was to identify the spatial distribution of groundwater seepage into Te Waihora/Lake Ellesmere, a large (200 km2), shallow coastal lagoon in Canterbury, New Zealand. This lagoon holds important ecological, cultural and recreational value, yet has suffered from significant water quality decline in recent decades. There is currently limited understanding of how groundwater discharge to Te Waihora affects water quality in the lagoon, and this study explores fundamental questions to address this knowledge gap.

Method

This study combined broad-scale methods to qualitatively map groundwater inflow into the lagoon. An airborne thermal infrared imaging survey was flown over the lagoon during summer to identify relative cool patches indicating groundwater inflow. This dataset was compared with high spatial resolution observations of radon-222 (a natural groundwater tracer), conductivity, temperature, and dissolved oxygen.

Results

We found areas of groundwater seepage into Te Waihora at locations previously identified, as well as areas not known before this study. The data identified both point-source springs and diffuse seepage along the shoreline. This initial broad-scale survey of seepage into the lagoon revealed groundwater inflow in locations previously thought to be unlikely. This dataset will allow for follow-up work to improve the estimate of the groundwater proportion of the lagoon's water budget in light of identifying these new seepage locations.

We demonstrate the successful use of broad-scale methods for identifying the spatial distribution of groundwater discharge into a large coastal waterbody. The combination of methods builds confidence in interpretations and allows us to identify anomalies unrelated to groundwater seepage.

IMPACTS OF CLIMATE CHANGE ON THE RETURN PERIODS OF EXTREME PRECIPITATION AND DRY SPELLS IN NEW ZEALAND

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Aims

Global warming is expected to affect precipitation distribution and intensity in New Zealand, with potential impacts on frequency and severity of floods and droughts. Statistical analyses of historical records highlighted significant trends in mean annual precipitation in certain regions of New Zealand, with an overall reduction in the north and east of the North Island, and an increase almost everywhere else, especially on the South Island West Coast. However, the limited time coverage of historical records and the large uncertainties underlying climate model projections impair our ability to identify trends in extreme rainfall and dry spells. Here, we aim to provide a deeper insight into the potential effects of climate change on the return periods of floods and droughts in New Zealand.

Method

Drawing on 60 years of daily precipitation maps provided by the National Institute of Water and Atmospheric Research (Cichota et al., 2008), we quantify the correlations between the rainfall principal components and relevant climate indices, namely, the Interdecadal Pacific Oscillation (IPO) and El Niño Southern Oscillation (ENSO). This procedure allows us to generate a long-term stochastic set of monthly rainfall maps correlated with the projected variations in IPO and ENSO signals (Dominguez et al., 2010). We finally downscale the monthly rainfall maps to daily timescale using the stochastic temporal disaggregation method proposed by Thober et al., 2014.

Results

We analyze the stochastic rainfall set to quantify the expected variations in return periods of extreme rainfall and dry spell in different regions of New Zealand. The results suggest that the North Island and the South Island will overall experience an increase in drought and flood frequencies, respectively. Combining these results with historical records of insurance claims, we finally estimate the potential socio-economic impacts of floods and droughts under different climate change scenarios. These results may guide the implementation of effective adaptation and mitigation strategies against the increasing risk of natural catastrophes.

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DETECTION OF RATING SHIFTS AT HYDROMETRIC STATIONS

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Aims

River discharge time series are usually established using “rating curves” (hereafter called RCs) that approximate the stage-discharge relation. These models are fitted using occasional stage-discharge measurements, also known as gaugings. However, two major problems affect the RC estimation: firstly, gaugings and RCs are both uncertain; secondly, the stage-discharge relation can be unstable and subjected to sudden or transient changes (also known as “rating shifts”). For the first problem many authors have proposed methods for the uncertainty quantification (Kiang et al. 2018). As regards the second issue transient changes require a dynamic approach while sudden changes require detecting the times of shift and estimating an RC for each stable period. We propose some tools for the detection of effective or potential sudden shift times in a retrospective analysis. To do this we use two main sources of information: the gaugings and the water level (or “stage”) record.

Method

The proposed retrospective analysis of rating shifts is based on three principal steps:

1. Detection of some effective rating shifts using direct observations at the hydrometric station (e.g. segmentation of residuals between gaugings and a reference RC; segmentation of the recessions of the stage record).
2. Detection of all the potential (suspected) shifts using a proxy model (e.g. sediment transport model to detect morphogenic events; correlation with a reference discharge time series).
3. Elimination of the false detected shifts of step 2, if direct observations are available for the concerned period.

For the first step we propose two tools. The first tool is based on the segmentation of the time series of the residuals between gaugings and a time-invariant reference RC. The segmentation method accounts for uncertainty of both the gaugings and the RC. It is a multi change point detection method based on a Bayesian framework. The inferred parameters are the mean of each segment and the change point times that separate the segments. During the segmentation estimation the number of change points is fixed. Thus the procedure is iteratively performed for an increasing number of change points until the optimal segmentation is reached according to a criterion (e.g. BIC, Schwarz 1978). The detected shift times are then adjusted to real events causing the shifts (e.g. the peak of the floods). We then re-estimate the reference RC on each sub-period and re-segment the corresponding residuals in a “top-down” recursive way in order to reveal smaller changes. The second tool uses stage record. It estimates the riverbed morphological changes at hydrometric stations through the analysis of stage recessions. This method assumes that stage asymptotically tends to the river bed elevation as discharge tends to zero (Łapuszek & Lenar-Matyas 2015). After the identification of stage recessions, a Bayesian regression is performed to each recession using a two-exponential model and an asymptotic parameter. The time series of the asymptotic parameter is then segmented through the same method applied to the gaugings residuals. A change in the asymptotic parameter, strictly correlated to the riverbed elevation, may reveal a rating shift. This tool also provides important information about the magnitude of the shift. Finally, a verification of the consistence of the results from the two tools is performed.

While the first step searches for the “observed” shifts and would miss any shift not evidenced by gaugings or recessions, the second step searches for all potential shifts. To this aim we propose two tools. The first tool uses the stage record to perform a sediment transport analysis. In the absence of direct observations of sediment transport, the model is calibrated against the “observed” shifts of step 1. The analysis requires the knowledge of the temporal behavior of the river bed elevation in order to compute the critical stage for sediment motion. To do that the results of step 1 are used to estimate the RC parameters (among which there is the river bed elevation) for each detected stable period (Mansanarez et al. 2019). A cumulative transport is then computed in order to detect all the other potential morphogenic events. The second tool is based on the correlation analysis between the discharge time series and the output of a simple hydrological rainfall-runoff model. This in an ongoing study and further investigation is needed. A “stable” neighboring station could also be considered in the correlation analysis.

Finally, a second set of potential and effective shifts times is available for the Step 3. An RC is estimated for each period of stability among the shift times. If there is no significant change of the RC parameters between two successive periods, the corresponding shift time is discarded.

Results

The proposed method for rating shifts detection has been applied to two case studies mainly affected by morphological changes: the Ardèche River at Meyras, France and the Wairau River at Barnett's Bank, New Zealand. We report in Figure 1 the results of the first case study only. The results are quite encouraging if compared to the official shift dates (black crosses). However some of the proposed tools are site-specific. Stations also affected by progressive phenomena such as hysteresis, backwater and aquatic vegetation growth may be more challenging. The generalization of the method requires further investigation.

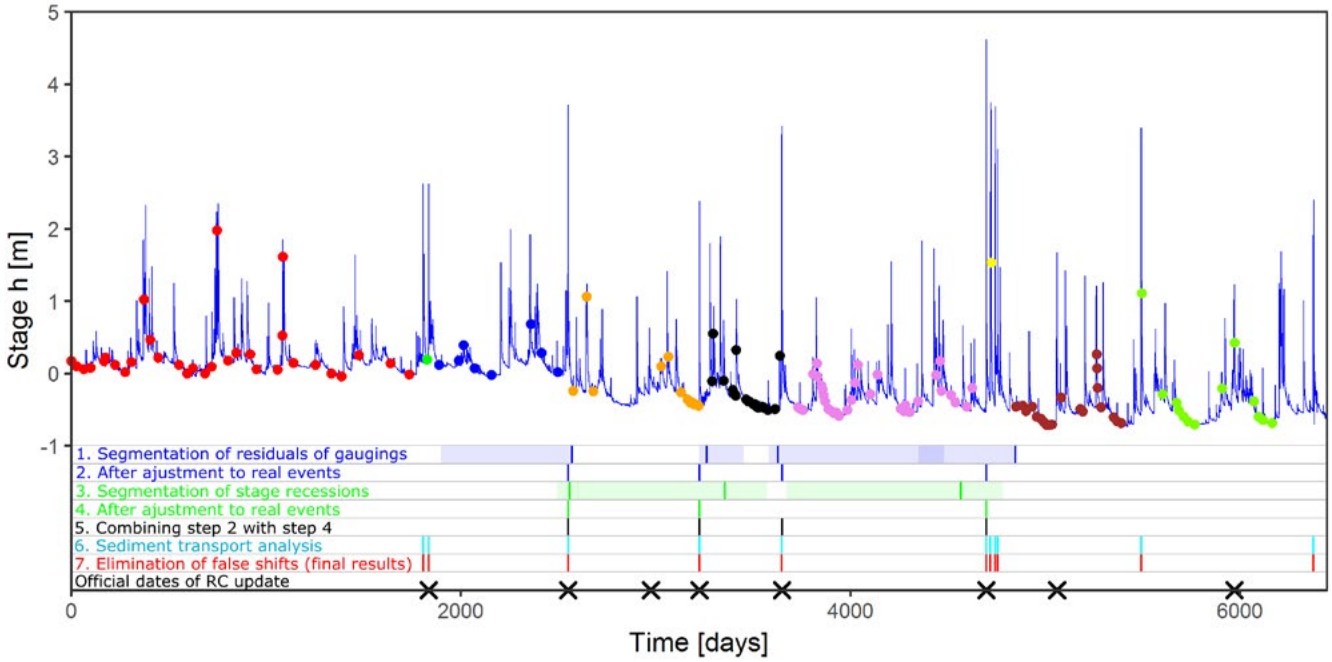

Figure 1: The set of rating shift times for each step of the proposed method plotted against the stage record for the Ardèche River at Meyras, France (period 11/2001-06/2019).

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CONTINUOUS TURBIDITY AS A PROXY FOR WATER QUALITY AT NIWA BENCHMARK RIVER SITES

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Background and Aims

NIWA has run continuous nephelometric turbidity sensors (Forest Technologies DTS-12 units) at 18 of its river benchmark sites since about 2014-16. The sensors were installed to provide a continuous relative measure of suspended matter and water clarity where water quality is measured routinely on monthly visits – so providing potential local calibration data for turbidity to certain water quality variables.

The aim of this research was to assess the utility of these continuous turbidity records as a relative proxy for water quality variables, including visual clarity, total phosphorus, total nitrogen and the indicator bacterium, *E. coli*.

Method

The DTS-12 turbidity sensors measure 90o scattering of near-infra-red (NIR) radiation at 780 nm, so are (nearly) compliant with the international standard for nephelometry (ISO 7027) which specifies side-scattering in the 830-890 nm NIR range. The turbidity sensors were (mostly) installed in housings constructed of plastic waste piping sloping down the channel bank at points close to the hydrometric site – with turbidity being logged on the hydrometric logger.

We compared the available (continuous) field turbidity with discrete (monthly) field measurements of visual clarity, plus discrete (monthly) laboratory measurements of turbidity (Hach2100AN nephelometer) and sediment-related water quality variables (total phosphorus, total nitrogen and *E. coli*), on samples collected from nearby water quality sites.

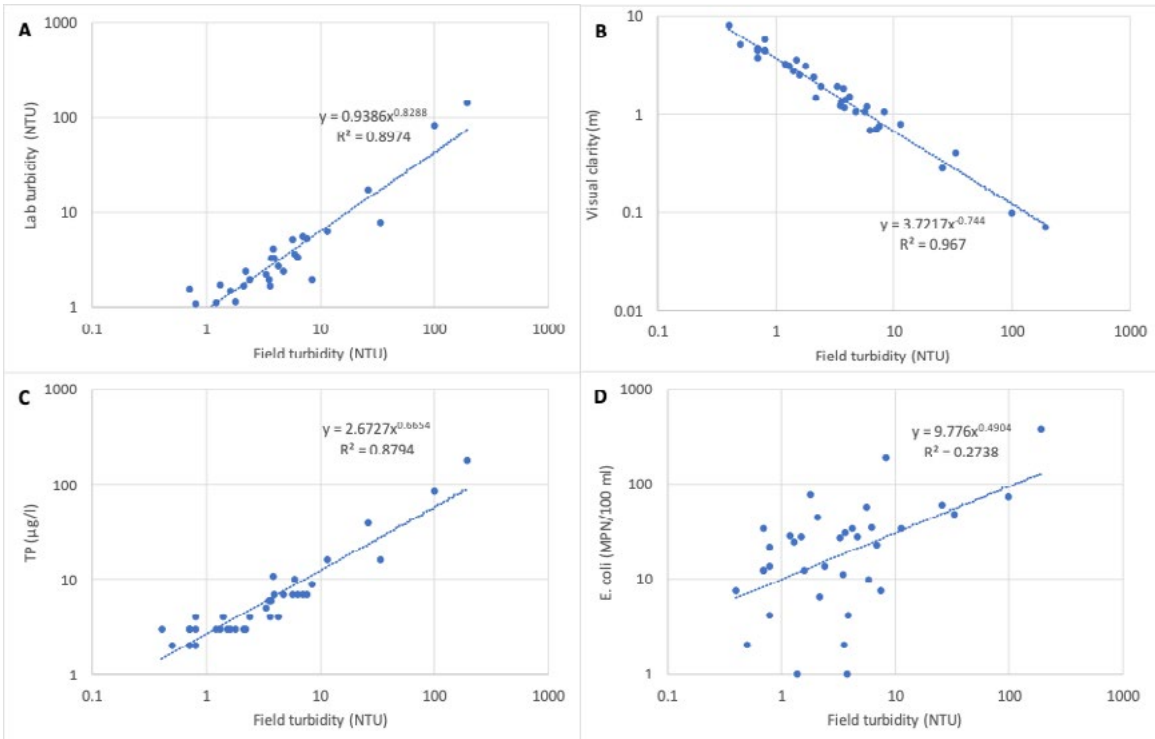

Figure 1: Scatter plots of water quality versus continuous field turbidity for the Hurunui at Mandamus. Water quality variables are: A Laboratory turbidity B. Visual clarity, C. Total phosphorus and D. *E. coli*.

Results

Figure 1 shows scatter plots of four water quality variables versus continuous turbidity – for the Hurunui at Mandamus (site CH1) by way of example. At this site, the close correlation of bench turbidity (and visibility) with continuous turbidity was interpreted as indicating good stationarity of the DTS-12 sensor.

Stationarity of continuous turbidity was judged to be met closely at eleven (out of 18) river benchmark sites. At these sites, visual clarity also correlated closely with field turbidity. The continuous turbidity records also correlated with other water quality variables of interest, particularly total phosphorus, and, to a lesser extent, total nitrogen and *E. coli* – as shown for one example site in Figure 1.

Laboratory turbidity and visual clarity correlated relatively weakly with continuous field turbidity at seven (out of 18) sites, particularly where DTS-12s did not operate reliably. Operational problems with the DTS-12 sensors included wiper failures, communication problems and drift.

Discussion and Ramifications

The operational problems with some DTS-12 turbidity units at several benchmark sites has been disappointing. Furthermore, a recent experiment (Hughes et al. this conference) has shown that different DTS-12 units have widely differing response (despite identical calibration to formazin) – which is problematic if field sensors have to be replaced following failure or loss. In view of these kinds of multiple shortcomings, the US Geological Survey (USGS) is phasing out DTS-12 sensors and we recommend NIWA follow their lead. That said, where DTS-12 sensors continue to operate satisfactorily, they can provide potentially very useful data – as the USGS acknowledges and this work has demonstrated.

Where stationarity was met, the DTS-12 continuous turbidity records provided potentially very useful proxies for certain water quality variables. For example, the field continuous data could be interpreted in terms of visual clarity regime (i.e., frequency distribution of visual clarity) and light attenuation loads can be calculated (Elliott et al. 2013). This would be a very valuable (and novel) application of continuous turbidity data – similar to the (more typical) application to estimating sediment mass concentrations and loads.

A modest, but still potentially useful, correlation with *E. coli* at most river sites (e.g., Figure 1) is consistent with the recent finding (Davies-Colley et al. 2018) that continuous turbidity could be used to inform would-be swimmers of contact recreational suitability (indicated by visual clarity as well as *E. coli*) and protect them from microbial hazards in 'real time'. Similarly, a typically close correlation with total phosphorus (e.g., Figure 1), and modest correlation with total nitrogen, suggests the use of continuous turbidity to estimate nutrient loads.

In ongoing work, we are extending the range of calibration of DTS-12 sensors with some storm-flow sampling at selected benchmark sites. We are also widening the scope of analysis of water samples at 'sediment' sites run by NIWA and collaborators – to include sediment-related water quality rather than merely mass concentrations.

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IS SMALL-SCALE MANAGED AQUIFER RECHARGE ABLE TO ACHIEVE BIG OUTCOMES? LEARNINGS FROM THE HINDS-HEKEAO PLAINS.

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Aims

Managed aquifer recharge (MAR) consists of a collection of physical tools used internationally to proactively recharge groundwater systems. Twelve small-scale (MAR) sites were constructed, hydraulically tested, and operated between 2018 and 2019, as part of the development of a Groundwater Replenishment Scheme (GRS) across the Hinds-Hekeao Plains. The purpose of the small-scale MAR test sites was to improve understanding of the wider MAR potential across the Hinds-Hekeao catchment. A steering committee named Hinds/Hekeao MAR Governance Group (MAR GG), and more recently the Hinds/Hekeo Water Enhancement Trust (HHWET), guides the development of the trial. The following is a list of key programme objectives:

- **Methodology:** Develop a site-selection and monitoring programme methodology that can be used to roll out a GRS programme across the Hinds/Hekeao Plains.
- **Site testing:** Locate and field test standardized MAR sites across the Hinds-Hekeao Plains, to provide the MAR GG with feasibility and scalability information for the development a GRS.
- **Utilise up to 500 L/s:** Combined with the Lagmhor Trial site and the Hekeao/Hinds River Project, demonstrate a capacity to utilise 500 L/s of stock water currently available from Ashburton District Council.
- **Catchment outcomes:** Test MAR sites in different areas ranging from the upper catchment to positions near spring-fed streams/drains, to address various quality and quantity outcomes required of the GRS programme.
- **Outreach/GRS programme momentum:** Utilise the field testing programme as part of outreach efforts to enable more people to become aware and participate in the development of the GRS.
- **Cost effective MAR tool development:** Evaluate different soakage system designs (e.g., soakage pits)

Method

An initial site selection process was developed for the Hinds/Hekeao Plains by evaluating a range of physical and spatial factors. The primary considerations that went into the initial site selections were:

- Access to source water and quality of source water
- Access to site (land ownership) and local community interest
- Distance to natural recharge (e.g., Hekeao/Hinds River)
- Depth to the water table
- Interpreted groundwater flow direction (e.g., local or down-gradient benefits)
- Proximity of historical groundwater nitrogen issues
- Overall location relative to general GRS concepts
- Proximity of community drinking water supplies
- Proximity of potential monitoring bores
- Geostatistical modelling indicative permeability in top 30 metres (i.e. high, medium, low)

Source water was delivered to the test sites utilising the existing open races and piping of the MHV Water Irrigation Scheme and Rangitata Diversion Race. Sites either delivered water for MAR directly from an open race via a siphon, or through existing on-farm ponds (Figure 1).

Figure 1: Small-scale MAR site utilising pond storage and siphon.

A standardised infiltration pit design was used across all twelve sites. Each pit was excavated to a depth of 6.5 m, with a diameter of 1.5 m, and backfilled with clean cobbles. A steel piezometer was installed to the base of the pit, and an additional piezometer nearby, each instrumented with a pressure transducer and data logger. A digital flow meter and valve control flow into the pit.

The hydraulic testing of the sites was conducted using a stepped increase in flow rates, a period of constant flow, and a recovery period where flows had ceased. Following the initial testing and analysis of data to determine suitable flow rates, the sites were then run over twelve months to identify long-term flow rates and clogging risk.

Results

The tested MAR sites typically received long-term flow rates between 15 L/s and 30 L/s. The annual volume of groundwater recharge utilising all twelve test sites was 1,680,336 m^3. This represents approximately one third of overall groundwater recharge from the Hinds/Hekeao MAR trial during Year 3 (2018 to 2019). Many of the test sites were not operational for the full year. As a result, it is anticipated that the annual groundwater recharge of all twelve test sites will increase, in addition to increases from water delivery optimisations and site upgrades.

Hydraulic testing began in early 2018, during a period of elevated rainfall. As a result, elevated groundwater levels influenced the results of the hydraulic testing at some sites by reducing hydraulic head space, thus reducing the maximum infiltration rates. When groundwater levels receded, this allowed greater potential infiltration rates in soakage pits that intersected the groundwater table.

MAR sites supplied directly from an open race generally proved more challenging to manage, compared to those that derive water supply from a pond. Fluctuations of flow in the supplying races might change over a week, causing variation in race head and subsequent MAR flow rates. In comparison, MAR sites that derive water from a pond typically have much steadier flow rates. The irrigation ponds also provide storage, which allows a MAR site to continue operation despite water delivery restrictions (e.g., water restrictions due to low flows in the Rangitata River).

In summary, small-scale MAR sites have proven to be a useful tool for proactively recharging a catchment-scale groundwater system and on-going testing has highlighted a number of challenges for practical management of the soakage systems.

SOUTH CANTERBURY COLLABORATIVE HILLSLOPE PROJECT

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Introduction and aims

The South Canterbury Collaborative Hillslope project was established in 2018 and focuses on improving our understanding of the spatial and temporal controls on hydrological and nutrient fluxes in loess soils. Loess soils cover approximately 5,606 km^2 of land in Canterbury, representing 13% of the land area in the region. The hydraulic characteristics of loess soils are poorly understood, though we know they are different from those of the stony and well-draining soils which are common on the Canterbury Plains (Dodson, 2019).

The broad goals of the South Canterbury Collaborative Hillslope project are 1) improving our estimates of groundwater recharge through loess soils, 2) improving our understanding of containment transport pathways over and through loess soils, and 3) improving our understanding of irrigation management on loess soils.

Method

We have selected a field site on an irrigated dairy farm near Otaio, South Canterbury. The field site is a 4.5 ha paddock comprising a single, zero-order drainage basin, irrigated with a centre pivot. The paddock is in permanent pasture (no winter forage crops). Since November 2018, we have installed a surface and subsurface weir at the drainage basin outlet, more than 30 soil moisture probes, a piezometer and a climate station. Characterisation has so far included soil auger holes, three test pits where soil profiles have been described in detail and soil properties have been measured, and a high-resolution topographic survey via photogrammetry from images acquired by a drone (Johns, 2019).

The purpose of the instrumentation and characterisation is to allow us to measure as many water balance variables as possible and to understand the physical processes occurring at the site.

Where to from here?

We intend to occupy the Otaio field site for approximately 3 to 5 years with the intent of continuing to install instruments (such as more piezometers and runoff plots) and further characterise the site (examining more soil profiles and possibly using geophysics) and to collect data.

With the data we are collecting, we intend to start constructing models of the site to achieve the goals listed above. We are exploring developing a LImburg Soil Erosion Model (LISEM), Agricultural Production Systems sIMulator (APSIM) model and a groundwater model capable of simulating flow in the unsaturated and saturated zones.

Acknowledgements

We would like to acknowledge Rod and Nicola Hayman (Springbank Farm) for allowing us onto their property to undertake this research.

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A STABLE ISOTOPE MAP OF NEW ZEALAND'S SURFACE WATERS

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Aims

Stable hydrogen (δ^2H) and oxygen ($\delta^{18}O$) isotope measurements in surface water provide potentially powerful tools with uses in hydrology, ecology and food science. These uses include identification of groundwater pathways, calculation of connectivity of rivers and groundwater, identification of natal origins of diadromous fish, and tracing the geographical origins of food. While $\delta^{18}O$ and δ^2H values of precipitation across New Zealand have been mapped, isotope values of surface water differ from those of local precipitation due to processes that occur as water flows across landscapes, including mixing, sub-surface flows and surface evaporation. Detailed maps of river water isotope values are lacking. For the New Zealand Water Model, these maps will provide information on hydrological processes at a national scale and provide the physical data necessary for the calculation of young water fraction (i.e. the proportion of water that is less than ~ 2-3 months old) in river reaches across the country. We present a GIS-based model of long-term annual average surface water isotope ratios in New Zealand.

Method

We used gridded precipitation isotope maps produced from published relationships between precipitation isotopes and NIWA Virtual Climate Station Network data (VCSN). We used VCSN precipitation and evapotranspiration data 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 were summed across a flow direction grid which is derived from a DEM.

For validation, we analysed >1000 river water samples from 58 sites on the NIWA National Water Quality Monitoring Network as well as regional water isotope sampling carried out in collaboration with Regional Council partners.

Results

We will present modelled surface water stable isotope values (δ^2H and $\delta^{18}O$) and compare these with measurements of samples from NIWA's National River Water Quality Monitoring Network. We outline our model correction approach and present the corrected, reach-scale map of New Zealand surface water.

EVENT-SCALE SOIL-EROSION AND SEDIMENT-TRANSPORT MODEL FOR PREDICTING WATER QUALITY IN RIVERS

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Introduction

Since European settlement in New Zealand, large-scale catchment disturbance has led to increased erosion rates and delivery of fine sediment to rivers, lakes and estuaries. Excessive sediment loads adversely affect downstream aquatic ecosystems. Riverbeds and benthic habitat are smothered. Fish become susceptible to disease. Periphyton and macrophytes on riverbeds are seriously impacted due to reduced light penetration. To reduce the amount of sediment being delivered to streams and their downstream receiving environments, catchment-wide approaches for reducing soil erosion are required. In recent decades, catchment rehabilitation measures, such as land use change, riparian management, and erosion control planting, have been used to reduce suspended sediment contributions to downstream environments. These measures are costly to implement across whole catchments and so need to be targeted to achieve cost-effectiveness.

Aims

We aim to develop an event-scale catchment model of soil erosion and sediment transport so that the effects of soil erosion on water quality, such as visual clarity (Figure 1), can be predicted. The models will characterise where and when soil erosion occurs, what type of sediment is produced, and how that sediment moves through catchments. High temporal and high spatial resolution will enable regional councils to prioritise where to apply cost-effective erosion control to meet national and regional water quality objectives.

Method

Rainfall and evapotranspiration control pore water pressure in soil which in turn controls landslide failure and earthflow movement. Soil water may be modelled as:

$$\dot{Z} = \dot{P} - \dot{I} - \dot{D} \qquad (1)$$

where Z is soil water (m), P is precipitation (m), I is interception (m), and D is drainage (m), and the dot superscripts represent rate of change (s^{-1}).

During a storm event, soil water may exceed field capacity and build up pore water pressure, u ($N.m^{-1}$), which reduces the shear strength of soil, τ, according to

$$\tau = c + (\sigma - u)\, tan\emptyset \qquad (2)$$

where σ is normal stress, and c and $tan\emptyset$ are constants for a soil type. When shear strength becomes less than shear stress, the soil fails as a landslide or earthflow movement is initiated.

During a storm event, soil water may even exceed profile saturated water and cause overland flow. If that flow is over bare ground then surface soil will be eroded, E (m), as surficial erosion or gully erosion, according to

$$\dot{E} = k\,(\tau - \tau_c) \qquad (3)$$

where τ is the shear stress applied by the depth of overland flow, τ_c is the critical shear stress required for soil erosion, and k is a constant depending on soil type.

Eroded soil and corresponding particle size distributions will be delivered in hourly timesteps to sub-catchments (REC) where they will be routed through river networks according to the one-dimensional advective-diffusion equation

$$\frac{\partial C}{\partial t} + u\,\frac{\partial C}{\partial x} = D\,\frac{\partial^2 C}{\partial x^2} + \frac{(r-p)\,C}{d} \qquad (4)$$

where C is the sediment concentration (kg.m^{-3}), u is the average water speed (m. s^{-1}), which is ~ 2/3 of kinematic wave speed, d is average water depth (m), r is resuspension of sediment from the channel (m. s^{-1}), p is fall velocity of sediment (m. s^{-1}), x is distance down the river (m), t is time (s), and D is a diffusion coefficient (m^2 s^{-1}). The routing of sediment through a reach will consider the deposition and resuspension of sediment, and associated particle size distribution, from a channel store according to

$$r = \varepsilon\,\frac{dC}{dy} \quad (5), \qquad\qquad p = \omega\,C \quad (6)$$

where C is the sediment concentration along a vertical water profile, y (m), and ω is fall velocity of suspended sediment (m. s^{-1}), and ε is the momentum diffusion coefficient, both of which depend on particle size distribution. From the particle size distribution of suspended sediment, the visual clarity of water may be inferred. Calibration of model parameters will be achieved by constraining the model to measured long term soil erosion rates and to measured spatial patterns of particle size distributions in rivers.

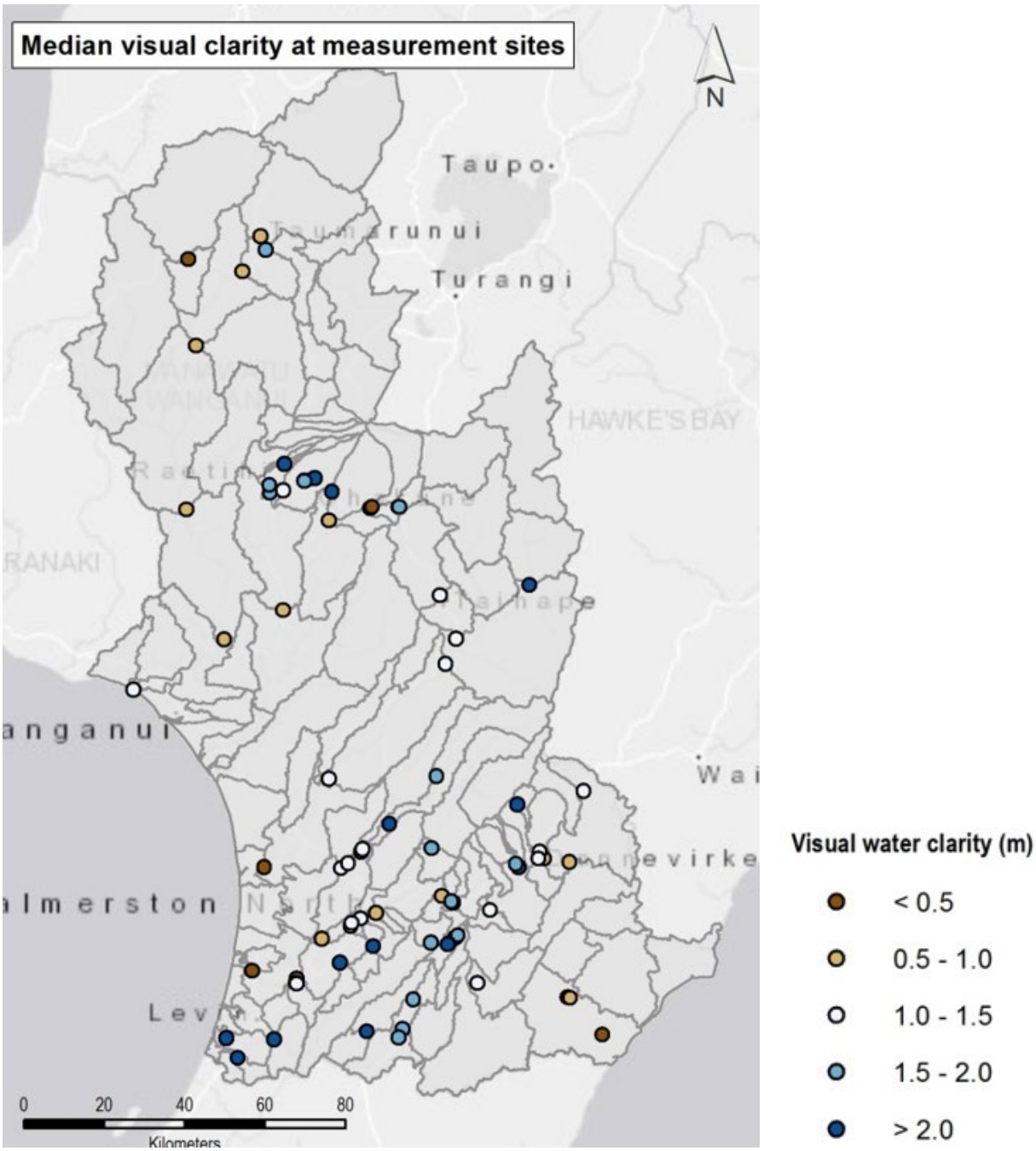

Figure 1: Median visual clarity of rivers in the Manawatu/Wanganui region.

WHEN GROUNDWATER STRIKES: MAPPING SHALLOW GROUNDWATER RISKS

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Aims

The complexity of modelling shallow water table dynamics can be computationally expensive, particularly as integrated surface-subsurface hydrologic models are often required (Bizhanimanzar et al, 2019). In addition, there is often a scarcity of spatially distributed data that makes traditional groundwater flow modelling difficult and leads to greater model parameter uncertainty. The aim of this presentation to show how geostatistical methods provide an appealing alternative by considering data-driven methods that may be able to predict shallow groundwater levels without a deep knowledge of the underlying physical parameters (Goovaerts, 1997; Sahoo et al, 2017).

Methods

Our methods employ readily available data from regional/national authority databases and environmental data sets. We use nonlinear data normalization methods in conjunction with kriging interpolation to predict the depth to groundwater surface. The workflow has been automated using the R statistical computing language allowing for greater efficiency and reproducibility. The methodology supplements depth to shallow groundwater surface mapping methods previously constructed for Christchurch (van Ballegooy et al., 2013) and Hawke's Bay (Rosser and Dellow, 2017).

Results

The resultant groundwater surfaces provide a reasonable approximation of the shallow groundwater and uncertainty surfaces for regional areas. The resulting shallow groundwater level maps can then be used to quantify risks to infrastructure, including liquefaction risks and groundwater inundation. With continuous advances in automated groundwater monitoring and data assimilation methods, there are many opportunities for development of shallow groundwater mapping methods in the future.

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DATA FUSION – MERGING MODEL RESULTS WITH TELEMETRY DATA TO CREATE DESIGN WATER LEVELS, REAL-TIME MONITORING AND VIRTUAL SENSORS

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Aims

Groundwater levels and pore pressure distributions are important input data for many engineering calculations in civil engineering and mining. Direct measurements and numerical models are the main tools for obtaining this input, each having different strengths and drawbacks. Models provide a continuous distribution in space and allow forecasting but are associated with a model-to-measurement misfit. Direct observations are usually very accurate and allow real-time monitoring but are spatially sparsely distributed.

Consequently, optimal knowledge of hydraulic heads requires combining both methods. The standard method is model calibration. This method can – if performed wisely – reduce the model predictive error associated to a minimum. At the end of the process however, the model's output still contains a bias that propagates into further engineering decisions and can reduce their robustness. Also, assimilation of new measurement data into the model that is continuously collected in the field traditionally requires recalibration of the model. This process still requires high effort of labour and time, making it less suitable for real-time monitoring and fast decisions.

Method

To face these challenges, this presentation demonstrates how the results from a calibrated model are augmented using a bias correction method based on geostatistical principles. Based on past performance of the model, the likely spatial and temporal distribution of the model error is estimated at unsampled or forecasted locations. By correcting for this bias, we can estimate the most likely "real" system state based on Bayesian principles including uncertainty margins.

Results

The process is illustrated using case studies on generating design water levels and pore pressure distributions for civil engineering, pit dewatering and slope stability projects.

The presentation shows why augmented estimates are generally more accurate than those of the calibrated model or interpolated data alone, especially in complex hydrogeologic environments like mining areas. Additionally, we obtain confidence intervals for the estimates, which is useful for choosing appropriate safety factors and proposing new measurement locations.

NUTRIENT TRANSPORT AND WATER QUALITY OF BARKERS CREEK CATCHMENT, SOUTH CANTERBURY

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Background

Diffuse nitrogen and phosphorus pollution from farming practices is a water resource management issue throughout New Zealand. Efficient management of diffuse pollutants requires a conceptual understanding of the relationship between groundwater and surface water at a catchment and sub-catchment level. With this knowledge, transfer pathways and problem sub-catchments can be identified. Barkers Creek is a small sub-catchment of the Waihi River, in South Canterbury. Diffuse pollution is causing water quality issues within the Barkers Creek catchment that propagate to Waihi River.

Aims

There were three key components to this study:

a) To characterise the hydrology, hydrogeology and hydrochemistry of Barkers Creek sub-catchment.
1. To determine the main transfer pathways for nitrogen, phosphorus entering Barkers Creek.
2. To understand temporal dynamics of nitrogen, phosphorus and sediment, and in particular the role storm flows have in these processes.

Method

A field campaign was conducted to intensively monitor the surface water and groundwater regime in Barkers Creek over the year 2016-2017. An initial catchment wide survey was undertaken to identify suitable monitoring sites for the 12 month fieldwork program. Four groundwater sites and 19 surface water sites were monitored as part of this study. Data collection occurred at different temporal resolutions, with parameters measured at all sites at a bimonthly interval (nutrients and flow), five of the surface water sites measured at fortnightly interval (nutrients and sediment only) and two surface water and four groundwater sites measured at 5-minute intervals (surface water flow and groundwater level). Nutrients measured included nitrogen species, phosphorus and sediment (surface water only).

Results

About of 44% of the flow in Barkers Creek is attributed to groundwater seepage occurring from the lower catchment, between McKeown Road (5.2 km upstream of the confluence) and the confluence with the Waihi River. Flow paths and residence times between the recharge and discharge zones for groundwater appear to be short.

There is evidence of anthropogenic influence on water quality, particularly on shallow groundwater, with elevated nitrate-nitrogen concentrations observed throughout much of the lower catchment. Nitrate-nitrogen and dissolved reactive phosphorus concentrations are typically higher in groundwater and some of the spring-fed streams than what is observed in Barkers Creek. There is also evidence of a natural phosphorus source in the catchment.

Of the nitrate-nitrogen load exported from the Barkers Creek catchment to the Waihi River, 20% is from diffuse groundwater seepage into the creek bed, 11% is from the Barkers Creek catchment upstream of McKeown Road and the remainder is from stream systems in the lower catchment, most of which are spring-fed (groundwater fed). 56% of the total nitrate-nitrogen load is from the 3 (of 10) spring-fed streams in the lower catchment. Nitrate-nitrogen loads during storm events do not differ significantly from loads during baseflow conditions and the spring-fed streams are a significant transfer pathway under all flow regimes.

Minimal phosphorus load in Barkers Creek comes from diffuse groundwater seepage. Barkers Creek upstream of McKeown Road contributed 13% of the total load export with the remainder attributable to export via spring-fed streams. The hotspots for phosphorus are 4 (of 10) spring-fed streams in the lower catchment. Export of phosphorus and sediment is sensitive to flow regime, with storm events being the major driver for transport from Barkers Creek to the Waihi River.

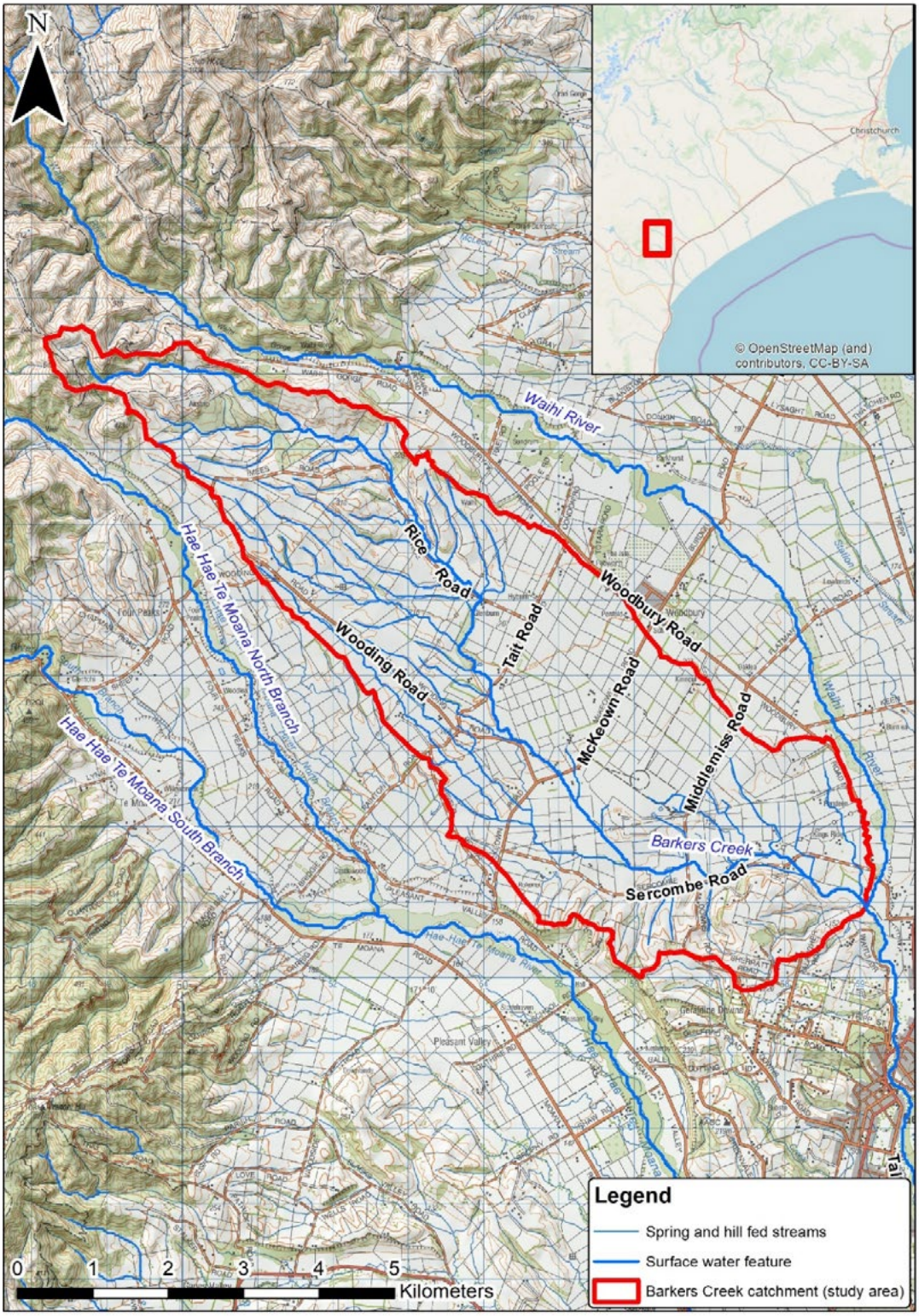

Figure 1: Map of the Barkers Creek catchment

COMPARING SATELLITE AND MODELLED ESTIMATES OF HYDROLOGICAL FLUXES

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[1] NIWA, Christchurch, NZ.

The research compared estimates of soil moisture dynamics from the SMAP Global 3-hourly, 9 km, L4 product, with estimates made using the New Zealand Water Model (NZWaM). Comparison was made of both spatial and temporal patterns of each dataset and the reasons for disparities between the datasets discussed.

SMAP uses a combination of radar and radiometer sensors. Products available include L4 9 km data for surface and root zone soil moisture (cm^3/cm^3). Temporal resolution for the Sentinel constellation is 5 days but image delivery is dependent on cloud cover. Realistically there is a good chance for at least monthly in winter and fortnightly in summer. Surface soil moisture estimates represent only the first 0-5cm, but they can be used to calibrate existing soil moisture models or in conjunction with empirical measurement.

The root zone soil moisture estimates are derived from merging SMAP estimates from a land-surface model in a soil moisture ensemble Kalman data assimilation system. Figure 1 shows estimated root zone soil moisture for a point location at in Southland from 2015 to 2018. Soil moisture data were available as either point-scale or area averages.

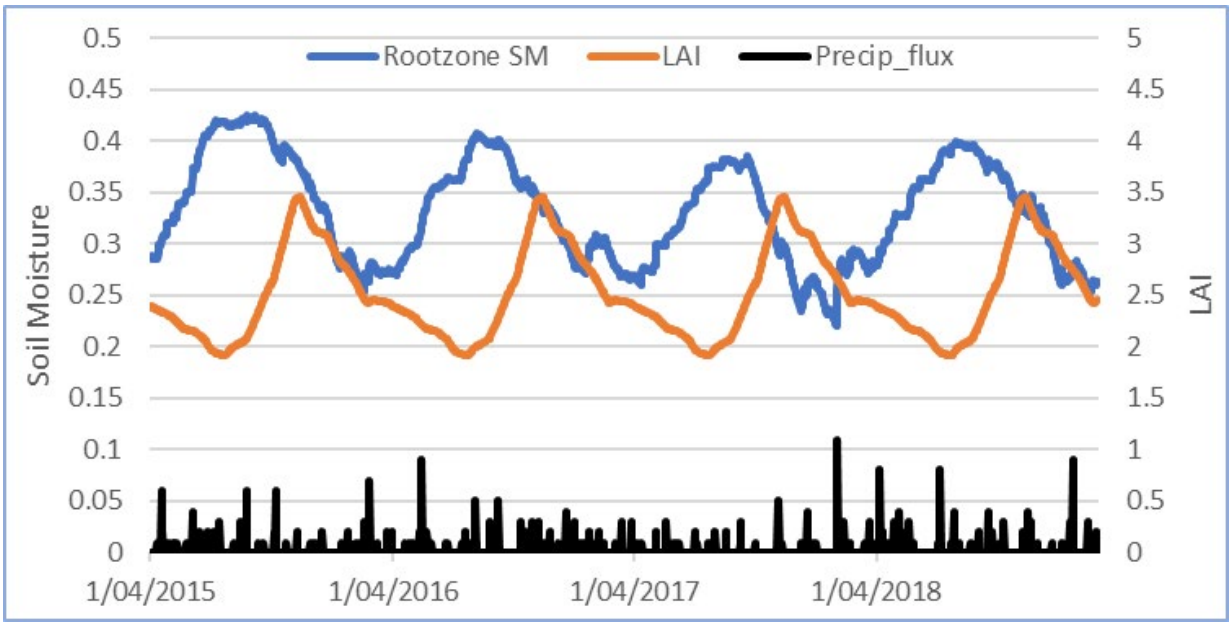

Figure 1: SMAP L4 product root zone soil moisture shown with LAI and precipitation for Mataura, Southland.

In addition to comparison with catchment averaged modelled timeseries (shown for the Southland region between 2000 to 2014 in Figure 2), differences in spatial variability during wet, dry and average conditions will be assessed. The difference between point-scale and area-averaged SMAP data was also investigated.

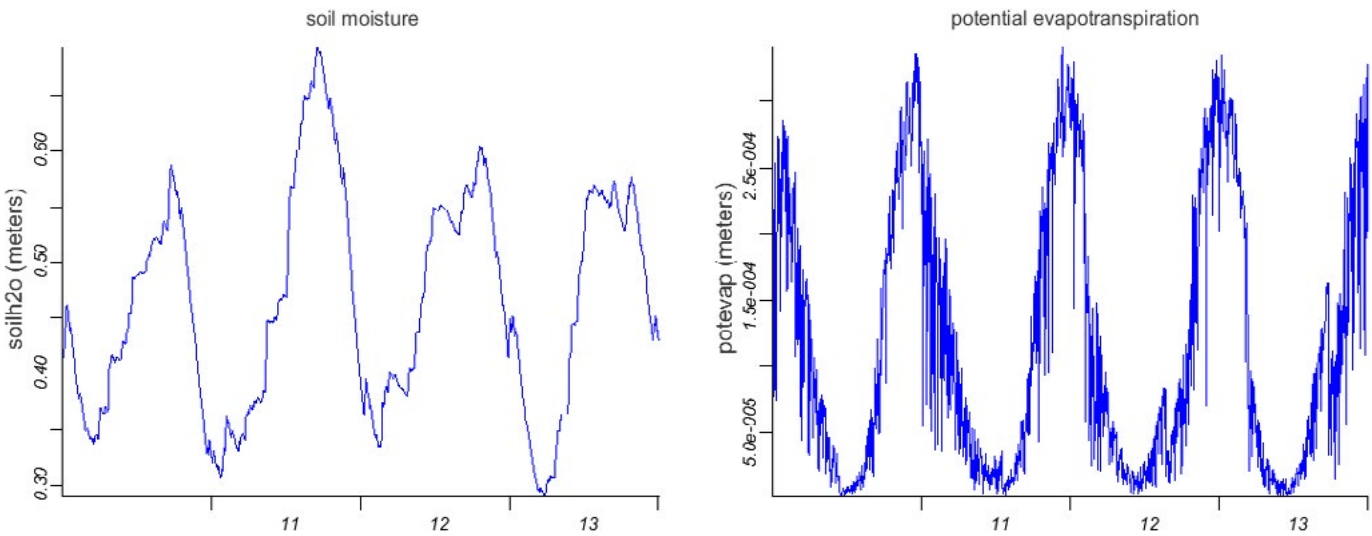

Figure 2: Catchment averaged modelling soil moisture and evapotranspiration for Mataura, Southland.

AN INVESTIGATION INTO NON-FAECAL SOURCED E.COLI IN LANDFILL AND COMMERICAL COMPOSTING LEACHATE

George Hampton,[1] Tim Baker,[1] Dr Jacqui Horswell,[2]
[1] Jacobs New Zealand Limited
[2] ESR (now Massey University)

The Otaihanga Landfill ('the landfill') is a closed landfill managed by Kāpiti Coast District Council (KCDC). Historically, biosolids from Kāpiti Coast District have been disposed of at the landfill, ceasing in 2015. Adjacent to the landfill at its southeastern boundary is a commercial composting facility.

High *Escherichia coli* (*E. coli*) and faecal coliform counts (> 1,000,000 cfu/100 ml) have been repeatedly observed in concentrated leachate at the landfill and the off-site monitoring sites that are monitored as part of the landfill resource consent. *E. coli* is a single bacteria species within the faecal coliform group (i.e. a *E. coli* are a subset of faecal coliforms).

Faecal indicator bacteria, including total and faecal coliforms, *E. coli*, and enterococci are commonly used to indicate the presence of faecal contamination in water used for drinking and recreation. The assumptions behind the concept of using faecal indicator bacteria are that these organisms are normal inhabitants of the gastrointestinal tracts of humans and animals and are incapable of long-term survival or replication outside of their hosts.

The elevated counts observed during routine monitoring had historically been attributed to the landfilling of biosolids. However, even after the biosolids were no longer accepted at the landfill and the area was capped with clay in 2015, elevated counts continued to be observed in the Southern Wetland. A detailed investigation was commissioned by KCDC, which involved high frequency sampling of off-site discharges, detailed sampling of stormwater and compost leachate across the landfill, and faecal source tracking to determine the likely origin of the faecal source markers.

The results from this investigation have demonstrated that the highest concentrations of faecal coliforms and *E. coli* are measured in leachate samples collected from the base of the windrowed compost within the composting operations. The elevated counts were traced across the site through the various parts of the drainage network, eventually moving off-site via the Southern Wetland and Eastern Mazengarb Drain.

When faecal bacteria such as *E. coli* are present in environmental samples, it indicates that a faecal source may be present. The presence of a faecal source generally leads to the conclusion that pathogenic bacteria or viruses may also present, which come from faeces. These microorganisms can introduce disease in humans and animals that come into contact with the environmental sample.

A second phase of investigation was undertaken to determine if the high levels of *E. coli* leaving the landfill site were a potential health risk, and to determine the source of the faecal contamination. Two pathogenic bacteria were included in the laboratory culturing analysis of the samples. If the samples were contaminated by human or animal faeces, *Salmonella* and *Campylobacter* would be the most likely bacterial pathogens to be detected. No *Salmonella* or *Campylobacter* were detected in any of the samples tested.

Faecal source tracking was then undertaken on samples collected from the landfill to try and identify whether the source of the high levels of faecal bacteria was animal, bird or human faeces. The faecal source tracking results mirrored the culturing of the faecal bacteria, in that high levels of general faecal source marker were detected in several samples, particularly the green waste and the green waste leachate. However, importantly, specific faecal source markers for human, dog and avian sources were negative, expect for one sample which indicated low levels of avian faecal source.

Several published scientific studies have shown that faecal indicator organisms such as those used in this study (e.g., *E. coli*) can also be naturally occurring in non-faecal sources such as terrestrial soils, aquatic sediments, and vegetation. As such, the results suggest that in this case, the indicator bacteria are a result of non-faecal sources, most likely decomposing green waste and soil, and as such are unlikely to pose any risk to human health.

CLIMATE CHANGE – A HIGH LEVEL ASSESSMENT OF IMPACT ON FUTURE WATER SUPPLY

Hansford J R[1]
[1]Tonkin + Taylor

Aims

Climate change is expected to affect the assurance of water supply to demand centres in New Zealand. What the effect could be on yields from water resources has been assessed as part of a Deep South Challenge project. This paper presents the approach followed in the study and the results of simulation analyses to assess the projected impact that future climates could have on assurance of water supply from existing and new water resources.

Method

Existing as well as possible future water supply schemes spread across New Zealand were selected for yield assessments. For each location daily streamflow time series were generated using NIWA's un-calibrated TopNet rainfall-runoff model with rainfall data from the six Global Climate Models (GCMs). Each of the six GCMs were used to generate daily streamflow from 1973 to 2005 (historic period) and then from 2006 to 2100 one time series for each Representative Concentration Pathway (RCP) giving 6 daily streamflow time series from 1973 to 2005 and 24 time series from 2006 to 2100.

Constant draft yields were determined for assurance of supply of 99.5, 99, 98 and 95% using a simple mass balance model. Analyses were based hydro-years with the low flow period in the middle of the year and not split into two years (generally July to June). Assurance of supply was calculated as the percentage of years simulated with no shortfalls.

Yields were determined by simulation for the historic period (1973 to 2005) and for each RCP at four future time horizons (2020, 2040, 2060 and 2080). Yields at the four time horizons were based on a 35 year long time slice with the time horizon year in the middle. Storage for each of the six streamflow time series (6 GCM time series) was assumed full at the start of simulations. Assurance of supplying the target draft was calculated as the percentage of years simulated (210 years i.e. 35 years x 6 GCMs) with no shortfall in supply.

Results

The results are based on simulations using daily streamflow generated by NIWA's TopNet model. The yield results were plotted to show possible trends in yield due to projected climate change. Examples of the results are shown in Figure 1 and Figure 2 for the Taranaki and Auckland Regions respectively.

Figure 1: Simulated yield results for a site in Taranaki Region

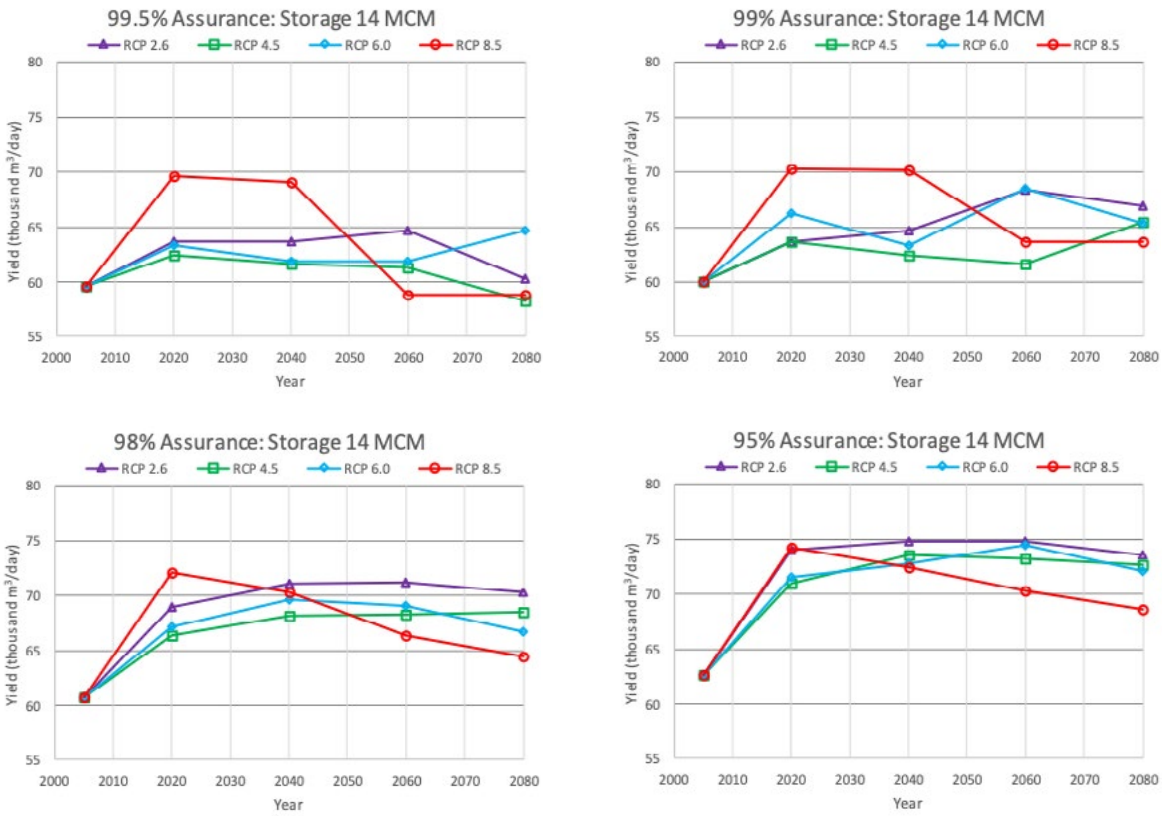

Figure 2: Simulated yield results for a site in Auckland Region

The Taranaki results show a general decline in yield from the resource due to climate change while the results for Auckland Region indicate possible increase in yield from 2005 to 2020 followed by a general slow reduction in yield.

These results are based on simulations using streamflow generated from a single set of rainfall generated by the six GCMs. More rigorous analyses using multiple sets of climate change projections from each of the GCMs are required to add confidence to the results and likely trends in yield due to climate change. Such analyses are outside the scope of the study.

ON REGIONAL GROUNDWATER MODELS AS TOOLS FOR INFORMING MANAGEMENT: AN EXAMPLE OF EFFECTIVE AND EFFICIENT DECISION-SUPPORT MODELLING (WAIRARAPA VALLEY; NZ)

Brioch Hemmings,[1] Matthew J Knowling[1]
[1] GNS Science

Water resources are under pressure globally, from threats including over-production and contamination. The increase in these threats, exacerbated by increased population demand, economic drivers for land-use change, and climate-change, has initiated a rise in resource management strategies. Numerical models are widely used to support decisions pertaining to resource management. Despite wide acceptance that uncertainty quantification underpins model-based decision support, the use of (and reliance on) a single (deterministic) model parameter realisation for informing management decisions is still commonplace. While a deterministic model can provide useful insights into general system behaviour, it is a deficient tool for management decision support, where expression of risk (and therefore uncertainty) is critical.

We present a case study of modelling for decision support, using a highly parameterised, regional-scale, groundwater model of the Ruamahanga catchment, Wairarapa Valley, New Zealand. The model ultimately serves to evaluate the effectiveness of land-use management strategies that aim to improve groundwater and surface-water quality. We explore probabilistically, the desired management strategy outcomes, as represented by decision relevant simulated outputs (DRSO) at key locations of management interest. MODFLOW-NWT/MT3D-USGS is used to simulate flow and nitrate-transport. We first express prior parameter uncertainty for 547,182 model parameters based on literature values, expert knowledge and field data. Using ensemble-based approximations to the model sensitivity (Jacobian) matrix, implemented in the recently developed PESTPP-IES, we conditioned parameters through history matching (or “calibration”). This provides an expression of the posterior parameter uncertainty in just a few-hundred model runs. Model execution for both the prior and posterior parameter ensembles propagates the parameter uncertainty to in-stream (surface water) and groundwater nitrate concentration DRSOs. This probabilistically describes the likely effectiveness of a management decision.

Our results highlight the value and power of deploying stochastic model representations to support decision-making. The results also suggest that the process of history matching may have little effect on the assessment of the likely effectiveness of prospective management strategies; predictions of interest are often not sufficiently informed by the available data experience significant changes in mean values or variances (uncertainty) through history matching. This is especially the case when desired management outcomes relate to relative (change and percent change) predictions. Given that prior uncertainty quantification is relatively rapid, we suggest that this should represent a minimum requirement when modelling for decision support.

SUSPENDED SEDIMENT PARTICLE SIZE MEASUREMENT USING A LASER DIFFRACTION GAUGING INSTRUMENT WITH IMPLICATIONS FOR MEASURING THE SAND COMPONENT OF THE SUSPENDED LOAD

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

Aims

While optical back-scattering (OBS), or turbidity, sensors are widely-used as a surrogate measure of suspended sediment concentration (SSC), they have two important limitations when used for monitoring the suspended load. The first is that their relationship with SSC is highly sensitive to the sediment size-grade, with their response to clay being of order 100X that to sand. The second is that they measure only at-a-point, typically at an accessible streambank location, and so may not represent the spatially averaged SSC, since the sand fractions of the suspended load tend to be located in higher velocity zones near the bed and in mid-channel. The upshot is that while turbidity-based monitoring typically registers the clay and fine silt load well, it may barely register any sand load and so under-represent the total suspended load. Conversely, acoustic back-scatter (ABS) sensors are more responsive to coarse silt and sand than to clay, but they still only measure at a point. Therefore, both OBS and ABS sensor records need to be "calibrated" to the cross-section average suspended load with manual sampling campaigns using depth-integrating samplers, particularly where there is a significant sand component in the suspended load and/or there is particular interest in the sand load, such as when deriving riverine contributions to beach sand budgets. Moreover, even depth-integrated sampling misses some of the sand load that is transported in the "unmeasured zone" between the sampler intake and the riverbed. Here we demonstrate these sampling issues, and how much of the sand load can be missed by fixed-point monitoring, by exploring data on the cross-channel distribution of the suspended load by size fraction using an in-situ laser-diffraction instrument.

Method

We present data collected with a Sequoia LISST-SL2, which is a cable-suspended streamlined bomb that is traversed through the flow depth, continuously measuring depth and velocity and continuously pumping an isokinetically-collected water stream through an on-board laser diffraction device that measures the volumetric sediment concentration across 36 size fractions over the range 1-500 microns. The instrument's data is logged to a laptop via the coaxial suspension cable and gauging reel.

The LISST-SL2 has been used during flood flows at sites on the Mataura and Oreti Rivers, Southland, where optical and acoustic point sensors are installed for continuous monitoring. Depth-integrated sampling accompanied the LISST-SL2 measurements to calibrate the LISST's volumetric concentration results to equivalent mass concentrations. Nether the LISST-SL2 nor the depth-integrating samplers sample the "unmeasured zone" within 0.1 m of the bed surface, where sand concentrations are a maximum; however, we are able to estimate the sand load in this near-bed zone by extrapolating the LISST-measured velocity and concentration profiles down to the bed.

Results

The Oreti and Mataura River LISST-SL2 results show that the suspended load was polymodal, with a typically dominant medium silt mode and smaller clay and sand modes. Comparisons of OBS and ABS records (which track the finer and coarser fractions of the suspended load, respectively) showed that these two fractions were often out of phase during the monitoring events.

The LISST-SL2 data clearly show the theoretically anticipated velocity and concentration profiles, with vertically-uniform mixing of the clay-silt fractions but "bed-hugging" sand profiles, notably at mid-channel verticals where the suspended sand load was maximal.

Comparison of the LISST-SL2's volumetric concentrations with the manually collected samples indicated an apparent sediment density of approximately 1.1 g/cm^3, which is less than the true mineral density because of grain shape effects on laser-diffraction.

Integration of the velocity and concentration profiles between water surface and bed at-a-vertical provided the suspended load by size fraction over the vertical, and also provided comparisons with the load indicated by simply sampling at a single point or by truncating the integration at the top of the unmeasured zone, as depth-integrated sampling is forced to do. This indicated a significant component of the suspended sand load was carried in the unmeasured zone, while surface-based sampling would have missed much of the sand load.

These results stress the general need to calibrate point-measured surrogate records of SSC to cross-section mean SSC measurements, particularly where sand comprises a significant part of the suspended load. The LISST-SL2 represents a precision device to collect such calibration measurements.

SWAT+ APPLICATION IN A TYPICAL DAIRY FARMING CATCHMENT IN NEW ZEALAND

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Dynamic catchment models have capabilities of representing the dynamic behaviours of complex processes and help to gain insights about the complex catchment system where direct measurement are not always feasible at large scales. The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1993) is the dynamic catchment model that has been applied across a wide range of catchment scales and conditions to assess hydrological and environmental issues. SWAT has been successfully applied in the Toenepi catchment, one of the Dairy Best Practice catchments, for predicting water quantity and water quality. It has been proved to be a potentially suitable model for intensively agricultural catchments in New Zealand (Hoang, 2019).

SWAT+, a completely revised version of SWAT, was released recently by the model developers due to the need of managing and maintaining the open source SWAT codes and their future modifications/improvements more efficiently. While the basic algorithms used to calculate the processes in the model have not changed, the structure and organization of both the code and the input files have undergone considerable modification. Compared to SWAT, SWAT+ provides more flexibility in spatial representation of interactions and processes within a catchment that aims at resolving some limitations in SWAT. Therefore, it is possibly a useful tool for catchment management, and is tested in this study.

Aims

This study aims at testing SWAT+, a revised version and the future of the SWAT model, in a typical dairy farming catchment in New Zealand. The Toenepi catchment, Waikato region, North island of New Zealand is used as the tested case study. The improvements implemented in SWAT+ are explored and assessed.

Results

Preliminary results indicate that SWAT+ predicts discharge very well, with Nash Sutcliffe Efficiencies (NSE) of 0.71 and 0.93 at daily and monthly time steps, respectively. Flow duration curves of simulated and measured streamflow are closely fitted. Although flow variation is very well captured, high flows experienced during storm events are underestimated. Subsurface drainage is the main contribution to streamflow, as expected in a pastoral catchment with an extensive tile drain network. The good water quantity predictions imply that SWAT+ adequately represents hydrological processes in the study catchment. More components of SWAT+ will continue to be tested.

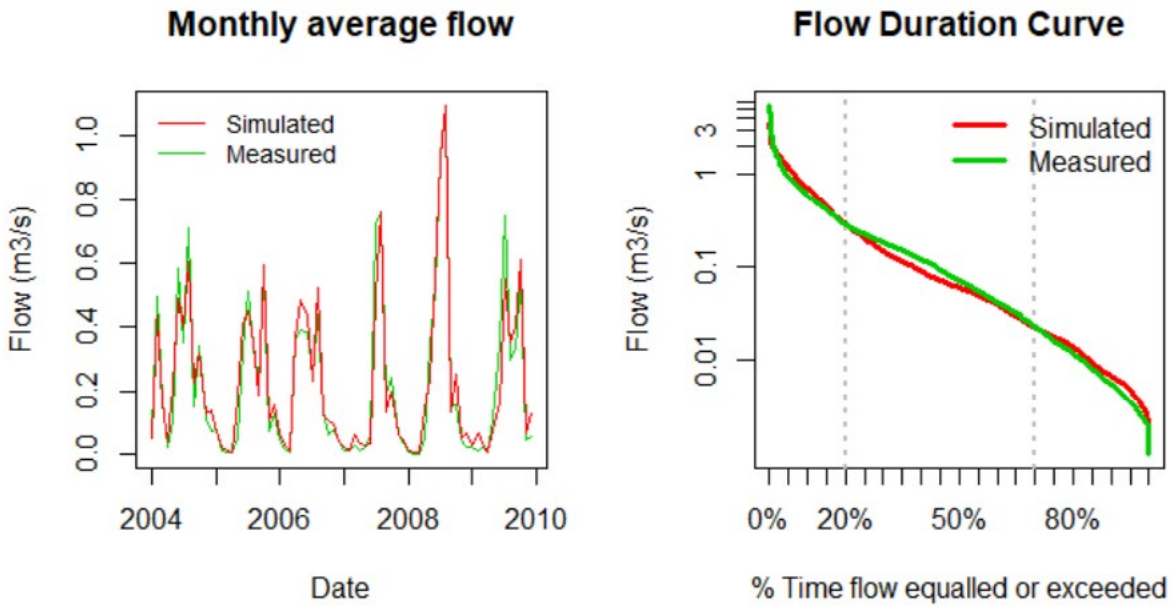

Figure 1: SWAT+ model performance on streamflow prediction in the period 2004-2009

References

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SOUTHERN ALPS IN SUSPENSION: PARTICLE SIZE OF SUSPENDED MATERIAL OF ALPINE RIVERS

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Aims

Hillslopes are transient stores of organic and inorganic material that are ripe for mobilisation into river networks during storm events. Material entrained in rivers as suspended material, should reflect the catchment lithology, but, mineral composition is supply-controlled from rock types that might preferentially fail, and transport-controlled, where some mineral fractions may be more prone to erosion into larger rock clasts (bedload), and others winnowed into finer fractions, like silt and clay. The aim of this study is to explore whether the mineral composition of suspended sediment is uniform across different size fractions, and whether distinct element compositional changes occur as grain size transitions from coarse sand (2 mm) to silt (< 63 µm). Secondly, we consider whether the particle size distribution of bulk suspended sediment differs between catchments of different geomorphological attributes, and over flow events.

Method

The geochemical composition of river sand deposits was determined by collecting sand-sized samples close to the waters edge from lag deposits. These samples were oven dried and sieved into 0.5 phi sized increments. Each sub-sample was analysed using a portable XRF, and normalised into a percentage weight total. The device is not capable of detecting Na_2O and MgO, so these were assumed as static percentages from samples held in the Petlab database. Bulk suspended sediment samples were collected from 6 rivers draining the Southern Alps, and settled for 7 days to partition sediment > 1 µm in size. The bulk suspended sediment was dried at 30ºC and its geochemistry determined using a portable XRF (as above), and measured in triplicate for particle size distribution using a Malvern 3000 particle size analyser fitted with a Hydro 2000 wet sampler.

Results

Geochemical composition of bed sands versus suspended material

Comparison of the bed sand and the suspended sediment geochemistry showed notable differences in the composition of major oxides with marked decreases in the proportion of SiO_2 in suspension (52–55 wt %) compared to bed sand (64–80 wt %). All other major oxides were relatively enriched in the suspended sediment and their wt % consistent between three sampled rivers (e.g., Dart, Rees, and Shotover). Enrichment was observed in all of the trace metals in suspension, with some elements being detected that were previously absent from bed sand analyses, e.g., As and Cr. SiO_2 was likely preferentially transported in the coarser clastic grain sizes, and was therefore over-represented in the sand grains compared to silt and clays; or, that there existed a size differential in the processes governing rock and mineral break down, where the minor elements are relatively enriched in the smaller clastic sizes due to differences in mineral hardness, i.e., SiO_2 was relatively resistant to comminution and abrasion processes compared to feldspathic-derived minerals like CaO and MnO.

Particle size distribution of different rivers

Suspended sediment particle size distributions (PSD) from rivers draining the Southern Alps show that most suspended sediment was silt-sized, with median particle sizes (D_{50}) ranging from 18–30 µm, although there are outliers. In particular, the rivers draining highly glaciated catchments, like Fox, Waiho, Hooker, Tasman, and Godley tended to have a finer particle size distribution with a D_{50} of 6–11 µm. Where glacial lakes are present, the PSD are bi-modal and strongly reflect the influence of coarse-material settling out within the lakes.

Particle size distributions during an event

Suspended sediment PSD was quantified in two catchments: Ahuriri (drainage area of 1284 km^2 – a large alluvial catchment of grasslands with alpine headwaters), and Birch Hill Stream (drainage area of 11 km^2 – a small, steep cascading catchment with alpine headwaters). Over the 25 mm rain event with a peak flow of 50 cumecs, the Ahuriri River had a relatively constant mean suspended sediment particle size (D_{50} of 11–14 µm) with little change in the proportion of sand (7–15%), silt (71–79%), and clay (11–16%). As such in the long alluvial system of the Ahuriri it appears that there was a ready and consistent supply of material in-channel for suspended sediment, and there was no observed exhaustion of fine-grain material over the event. This trend, however, was not observed in Birch Hill Stream, which appears to be fine-grain material limited, as there were significant shifts in the particle size distribution, with a trend of coarsening on the ascending limb of the hydrograph. The proportion of material grades was highly varaible: sand (5–50%), silt (40–66%), and clay (10–30%), and likely reflect both supply and competence-limits on suspended sediment supply in Birch Hill Stream.

CAN WE STORE WATER BELOW GROUND TO PROVIDE RELIABLE WATER SUPPLIES, ORETI BASIN, SOUTHLAND?

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[1] Wallbridge Gilbert Aztec (WGA)

Aims

A feasibility assessment into the application of Managed Aquifer Recharge (MAR) to enhance groundwater storage in the Oreti Basin was initiated by the Oreti MAR Trust during 2019. The main purpose of the Oreti Basin MAR project is to utilise and seasonally replenish stored groundwater to ensure secure and reliable water supplies for a range of land uses whilst maintaining ecological and cultural values. Reliable water supplies provide an opportunity for the primary sector to maximise and maintain economically viable and diverse farm systems. Sustainable management of groundwater storage is necessary to ensure consistent baseflows to springs, streams and rivers.

The Oreti Basin MAR feasibility project is based on assessing the suitability of source water (surface water) for recharge and the groundwater system for storage. The key questions for the assessment have been:

- Is water available and can it be delivered to potential MAR sites?
- Can the aquifer(s) accept and store water?
- What potential rates of recharge and recovery are likely for the basin aquifers?
- Are there water quality effects with mixing source and receiving water?
- Is a MAR pilot trial worth progressing?

Background

The predominant driver for MAR in the Oreti Basin is the need for reliable water storage. While there are large volumes of surface water flowing through the basin every year, low flow conditions during the summer limit seasonal water usage and put pressures on aquatic ecosystems. With the prospect of increasing climate variability, there is a strong incentive to build resilience for the local community (primary industry) through the development of water storage. This MAR feasibility project focuses primarily on actively using two confined aquifers within the basin for water storage. However, there is also opportunity to provide seasonal recharge to shallow unconfined aquifers to help support flows from springs and local stream baseflows and thereby enhance environmental resilience in the basin.

MAR consists of a collection of physical tools used internationally to proactively recharge groundwater systems. These tools can be expanded into a component of a catchment level integrated water management scheme or groundwater replenishment scheme (GRS). Enhanced replenishment works well when it is complimented by the catchment scale management of groundwater abstraction.

Method

A detailed assessment of available reports and environmental monitoring and water use data has been undertaken. Source water availability and seasonality under existing regulatory limits was evaluated. Aquifer characteristics, seasonal variations in groundwater pressures and well performance information was evaluated to determine potential aquifer storage and water production capacity. Source and receiving water quality data was reviewed to identify potential clogging and water quality issues that may require management in a groundwater replenishment scheme.

Results

Our initial feasibility study has confirmed that MAR in the Oreti Basin is viable based on the available information as there is:

1. Suitable quality and quantity of source water for MAR,
2. Storage potential available within the confined aquifers, and
3. Limited water quality effects which can be managed within the operation of a MAR scheme.

The uses of the stored water are yet to be determined by individuals within the community, but initial calculations have shown actively managed aquifer water storage appears to be viable for a range of irrigation application purposes. In addition, analysis of the available bore capacity information indicates that wells have the potential injection capability but that careful well design and positioning will be required. The conceptual Oreti GRS would likely utilise a combination of both existing and new abstraction wells coupled with a series of dedicated specialised MAR sites (basins/wells) to provide sufficient storage for peak irrigation demand.

The graphic presented in Figure 1 provides a conceptualisation of what a GRS for the Oreti Basin could look like at the catchment-scale. This schematic represents a GRS that provides communities with the capacity to capture, deliver, recharge and recover water sustainability from an aquifer system whilst providing strengthening resilience of environmental systems and enhancing the cultural and social values.

Conclusions and Recommendations

WGA has recommended that a trial be progressed including design of a conceptual MAR pilot trial (location, conceptual design, monitoring requirements) and an assessment of environmental effects of the pilot trial.

A pilot trial will further our knowledge on a range of factors including:

- The connectivity between the two confined aquifers in the Oreti Basin.
- The potential rates of injection possible from a purposefully built injection bore
- Groundwater level and water quality responses in the recharged aquifer and connected water bodies.
- Recovery rates for abstraction of recharged water.

In addition, WGA has recommended establishing a diverse, community-based working group of potentially interested stakeholders for workshops covering the implications and potential water use options for improved groundwater storage.

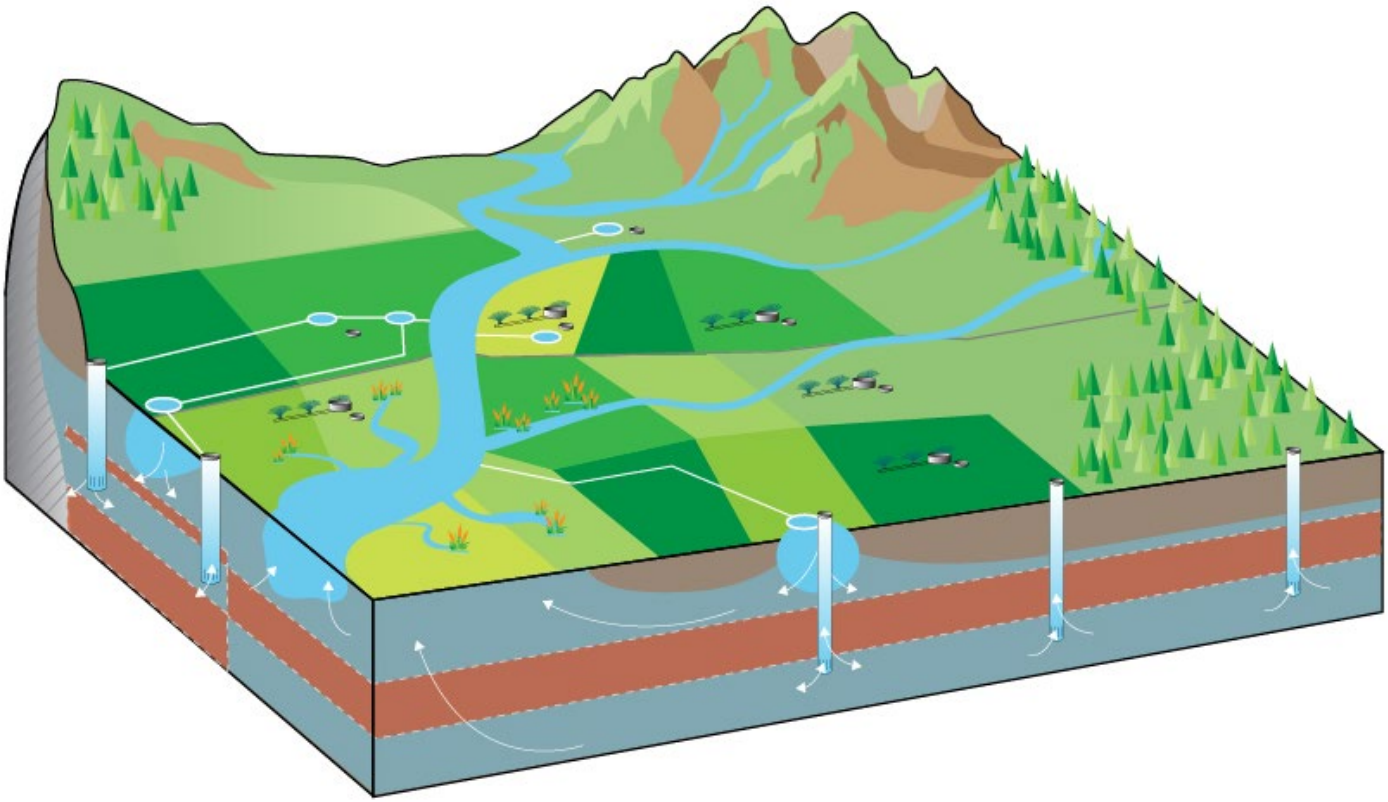

Figure 1: Groundwater Replenishment Scheme conceptualisation for Oreti Basin.

Project Website: https://www.oreti-mar.com/

COMPARABILITY OF THE OUTPUT OF ISO 7027 COMPLIANT TURBIDITY SENSORS

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Background

Nephelometric turbidity is widely used in environmental science as a measure of 'water cloudiness' and as a surrogate of water clarity or suspended particulate matter concentration. Nephelometric turbidity is a very convenient metric, being simple to measure, and sensors are relatively cheap and widely available. However, turbidity measured by different sensors can produce different turbidity unit values on the same water mass containing natural suspended particulate matter. This issue has long been known and turbidity sensor design standards have been developed to improve the comparability of the outputs of different sensors. The ISO 7027 standard has become a popular design standard for many turbidity sensor manufacturers. In New Zealand, the National Environmental Monitoring Standard (NEMS) for turbidity requires use of ISO 7027 sensors for field-based monitoring of turbidity. The NEMS for turbidity also recommends validation of field measurements with ISO 7027 compliant sensors. This recommendation is based on the expectation that the response of different ISO 7027 compliant-sensors should be closely comparable. However, recent NIWA experience as well as recently-published research (e.g. Rymszewicz et al. 2017) suggests that the response of different turbidity sensors, even when ISO 7027-compliant, can vary appreciably.

Aims

The primary aim of this experiment was to test if different turbidity sensors designed to the ISO 7027 standard output comparable turbidity unit values on the same fine sediment suspension. A secondary aim was to test if different units of the same make and model turbidity sensor output comparable turbidity unit values on the same fine sediment suspension – effectively to test sensor 'interchangeability'.

Method

We conducted a laboratory-based experiment to test the comparability of five different ISO 7027 compliant sensors The ISO 7027 compliant sensors used in this experiment were: YSI EXO1 Sonde-turbidity, Observator Analite NEP5000, Hach TL2310 LED, Hach 2100Q-is, and Forest Technology Systems DTS-12 (NB: the DTS-12 DTS-12 has a peak wavelength of 780 nm, slightly outside the range of 830-890 nm specified in the ISO 7027 standard). We also tested whether different units of the same make and model respond identically. Multiple units of three different field-type sensors (Forest Technology Systems DTS-12 (3 units), YSI EXO Sonde-Turbidity (3 units) and Observator Analite NEP5000 (2 units)) were compared. A laboratory recirculation tank was used to test the outputs of the sensors over a wide range of suspended sediment concentrations of a natural river sediment.

Results

The results from our experiment show that different ISO 7027 compliant sensors can output very different numerical turbidity unit values on the same fine sediment suspension (Figure 1). At the highest suspended sediment concentration (SSC) of 339 mg l^{-1} tested in the experimental tank, the turbidity ranged five-fold – from 127.5 FNU on an Observator Analite NEP500 sensor, through to 648 FNU for a handheld Hach 2100Q unit. Differences in the outputs of different sensors to have been attributed to factors such differences in spectral emission of light source, spectral sensitivity of detector, detector angle and beam configuration; combined with the very different optical properties of natural suspended particulate matter in comparison to formazin particles (e.g. McCluney 1975). The results of this experiment suggest that even very subtle differences (e.g., different tolerances used in the manufacture of components) in sensors compliant with the *same* international standard can influence turbidity sensor response.

Our results also indicate that even different units of the same make and model can output different numerical turbidity unit values on the same fine sediment suspension. The EXO1 Sonde-turbidity units were the only tested sensors that produced statistically indistinguishable outputs and could be considered truly 'interchangeable'. The DTS-12 units exhibited the greatest variability. Variability in sensor response presents challenges for obtaining a consistent turbidity record where sensor replacement is required. The two tested Observator units produced broadly similar outputs, however, their response was the least linear out of all the tested sensors.

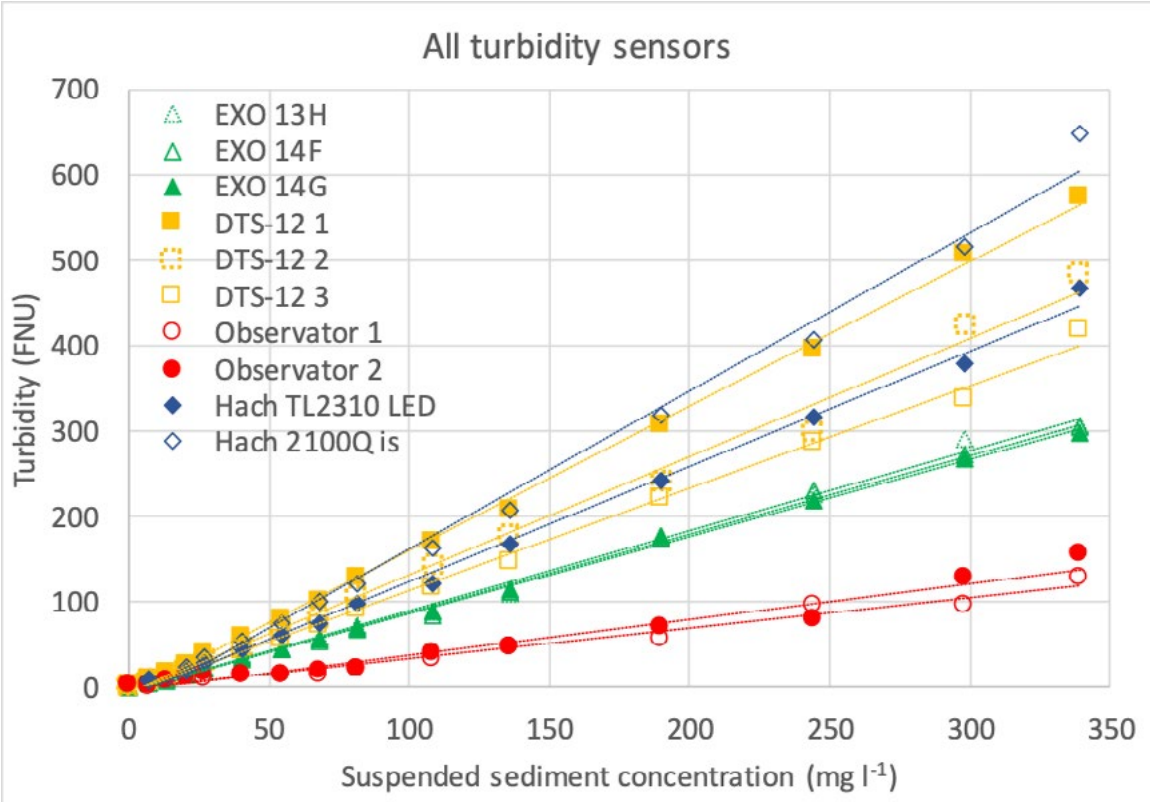

Figure 1: Relationships between suspended sediment concentration of experimental tank water and turbidity as measured by all the turbidity sensors used in the experiment.

Conclusions

Our finding that nephelometric turbidity measurements are instrument-dependent, even for sensors of the same design, and sometimes the same make and model, has important implications. In particular, treatment of nephelometric turbidity as an absolute quantity should be abandoned. Instead, turbidity should be used as a valuable proxy for several sediment-related variables of interest in water quality, provided suitable local calibration is achieved (Davies-Colley and Hughes 2019). We recommend that, instead of reporting FNUs (or other turbidity unit), the turbidity record should be converted to the variable of interest – such as SSC, or visual clarity – based on empirical (local) correlations.

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TARGETED STREAM AUGMENTATION AND MANAGED AQUIFER RECHARGE MODELLING WITHIN THE WAIMAKARIRI IRRIGATION LIMITED COMMAND AREA

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[1] Pattle Delamore Partners Limited

Aims

Managed Aquifer Recharge (MAR) is the infiltration of good quality water into the ground to improve groundwater quantity and/or quality and the flow and quality of springfed streams that emerge from the groundwater. Targeted Stream Augmentation (TSA) is the addition of water to improve the quantity and/or quality of a specific stream. Environment Canterbury (ECan) has projected future nitrate-N concentrations at public drinking water supply wells, private water supply well areas, and streams in the Waimakariri Water Management Zone if current management practices (CMP) continue, or if all farming changes to adopt good management practices (GMP) (Etheridge et al., 2018).

This study sought to utilise these recent and projected nitrate-N concentrations to assess the effects and feasibility of using TSA and MAR to help achieve the Plan Change 7 (PC7) recommended nitrate-N concentration limits via the application of additional fresh water available from the Waimakariri River within the Waimakariri Irrigation Limited (WIL) command area.

Method

Water availability for TSA and MAR was investigated by subtracting the irrigation water demand estimated with a daily soil moisture balance (SMB) model from the total inflow authorised by consent allocations for the Browns Rock intake. The SMB model evaluates soil moisture balance on a daily basis using input data including consented water take restrictions, river flow, storage, rainfall, potential evapotranspiration (PET), soil properties, and irrigation application decision making.

The TSA models use the current and projected in-stream nitrate-N concentrations and the calculated median flow rates from gauging data to estimate the overall increase in median flow with fresh water required for meeting the recommended PC7 limits. Similarly, each analytical MAR mixing model estimates a total MAR requirement by defining a shallow aquifer zone that encompasses active private drinking water supply well depths and applying Darcy's law to solve for long-term median groundwater throughflow and nitrate-N transport within each private water supply well area with projected exceedances. Lateral hydraulic gradients were estimated from ECan's Waimakariri long-term median, pre 2016 shallow wells, piezometric contours and ranges in shallow aquifer zone transmissivity were determined from aquifer test data. Groundwater throughflow areas were determined from interpreted long-term median groundwater flow directions that encompass the extent of active private drinking water wells within each area. Literature values for vertical dispersion informed the estimated ranges of vertical groundwater mixing, while calculated ranges of linear groundwater velocities were used to approximate timeframes to achieve positive outcomes within each area.

Data on *E. coli* concentrations within the Waimakariri River source water in the vicinity of the Browns Rock intake were applied to literature values of decay rates and the estimated linear groundwater velocities to determine the safe spacings of hypothetical MAR features from domestic wells for microbial attenuation. Long-term median and recent seasonal minimum/maximum depth to groundwater conditions were estimated in conjunction with analytics on cumulative mounding effects to assess MAR feasibility and necessary accommodation space within the very shallow aquifer zone with respect to potential drainage problems and sources of contamination such as septic systems.

Sixty potential MAR and TSA site areas were identified along water races away from domestic wells and potential sources of contamination in areas where deeper groundwater conditions with more accommodation space are expected. Seventeen of these potential MAR sites were classified as priority based on a matrix of criteria including the likelihood of positive measurable outcomes in the near future at nitrate-N impacted domestic wells and proximity to areas that, in the long-term, serve larger populations in terms of the overlapping groundwater recharge areas for public supply wells where ECan have projected nitrate-N exceedances of the PC7 targets.

Results

The SMB model underpredicted the measured total abstraction volume for the irrigation scheme over the last three irrigation seasons with a relative percent difference ranging from 4% to 10%. Based on the entire SMB modelling period (1968 – 2018), at least 3.1 cumecs (as a constant-rate) of water is potentially available each year for TSA and MAR. It is also estimated that for every 5 out of 10 years, at least 7.5 cumecs of water is potentially available for TSA and MAR.

The average estimated total current and future TSA and MAR water requirements are within the range of water available from the Waimakariri River (Figure 1). The TSA requirements do not consider improvements to groundwater quality from MAR within stream groundwater recharge zones (Figure 2), so it is possible that future TSA requirements under various MAR scenarios for private well areas (Figure 3) could be less than what are found by this study. Total water race capacities are also within the range of the estimated MAR requirements at potential sites (Figure 4). Predicted cumulative mounding effects suggest that most of the potential MAR sites could support the estimated 8-month rate requirements when water is available and running in tandem.

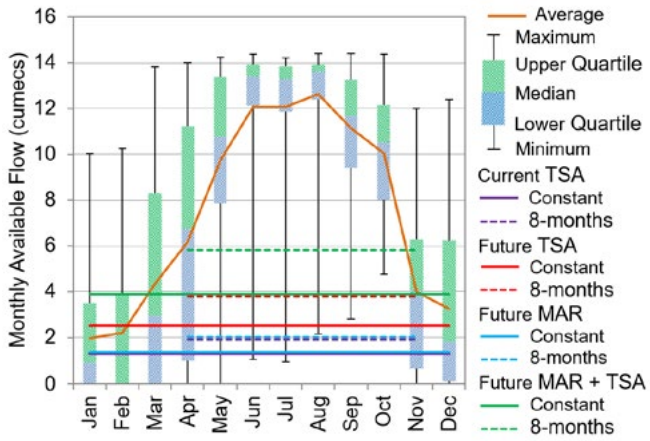

Figure 1: Water Availability and Requirements

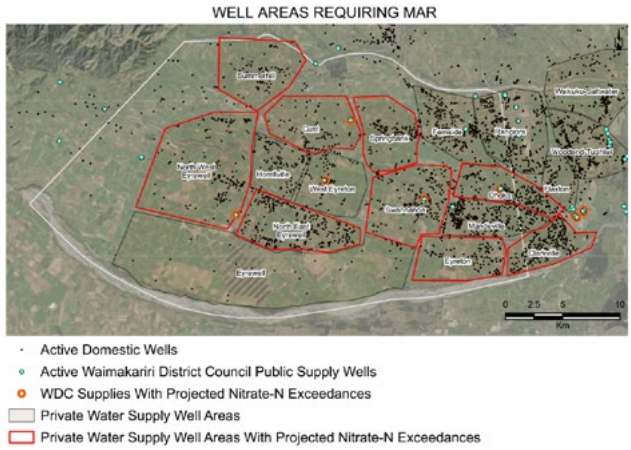

Figure 3: Private Well Areas Requiring MAR

Figure 2: Waterways Requiring TSA

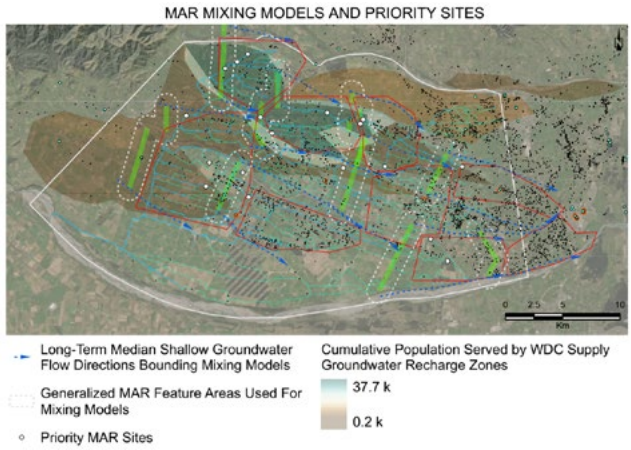

Figure 4: MAR Mixing Models and Priority Sites

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INSTRUMENTATION AND CHARACTERISATION OF THE SOUTH CANTERBURY COLLABORATIVE HILLSLOPE PROJECT FIELD SITE

Tom Johns[1]
[1] Environment Canterbury

Introduction and Aims

The South Canterbury Collaborative Hillslope project focuses on improving our understanding of the spatial and temporal controls on hydrological and nutrient fluxes in loess soils (Dodson *et al*., 2019). For the success of the project, it is essential that the field site is fit for purpose. We aim to design and build a field site which delivers high quality data and requires minimal intervention and maintenance once installed, all while minimising the impact on a working farm.

The project team is made up of workers from Environment Canterbury, Lincoln University, Manaaki Whenua – Landcare Research Ltd, AgResearch Ltd, National Institute of Water and Atmospheric Research Ltd (NIWA), Earth & Environmental Science Ltd and Plant & Food Research Ltd.

Method

To select a field site for the project, we undertook a GIS-based assessment of land use, irrigation and soil type. We then inspected 14 potential field sites before choosing one near Otaio, South Canterbury.

Once we had selected our field site, we developed an instrumentation and characterisation plan which will allow us to calculate a water balance and understand the physical processes occurring at the site. To calculate a water balance and understand the physical processes at the field site, we need to install a range of instruments above and below the surface.

In November 2018, we installed a piezometer with a stand-alone data logger. In January 2019, we built a surface flow weir and H-flume, and our collaborators at NIWA installed a tier II climate station and telemetry system for the field site.

By the end of April 2019, we had completed a high-resolution topographic survey via photogrammetry from images acquired by a drone, and we had installed a sub-surface weir. NIWA had installed nine soil moisture probes and an additional rain gauge to measure the water coming into the catchment from the centre pivot irrigator. Lincoln University described the soil profile in three auger holes to a depth of 6 m, and Plant & Food Research Ltd examined three soil test pits and installed 32 soil moisture sensors.

In spring/summer 2019/2020, Manaaki Whenua – Landcare Research Ltd will be digging three more test pits, Plant & Food Research Ltd will be installing run off plots and Environment Canterbury intends to install more piezometers.

Acknowledgements

We would like to acknowledge Rod and Nicola Hayman (Springbank Farm) for allowing us onto their property to undertake this research.

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TE WHAKAHEKE O TE WAI: IMPROVING UNDERSTANDING OF GROUNDWATER FLOW PATHWAYS IN NEW ZEALAND

Peter Johnson,[1] Uwe Morgenstern,[1] Catherine Moore,[1,2] Stewart Cameron[1]
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[2] CSIRO, Brisbane Australia

Aims

Te Whakaheke o te Wai is a 5-year MBIE Endeavour programme that aims to develop a nationally continuous map of groundwater age, origin, and flow paths. The project aims to develop a holistic approach to water management using a combination of age tracers, numerical modelling and metamodeling, and the mātauranga-a-iwi/hapū. We will constrain the pathways, or *whakaheke*, of water in and around the more than 200 major aquifer systems in New Zealand and the rivers that drain them. In tandem, these observations will strengthen our understanding of water knowledge in New Zealand and help reduce degradation of rivers, lakes and aquifers. These project outcomes will help guide national and regional policies on water allocation, management of catchment scale contaminant inflows to rivers, and protection of potable water supplies.

Method

The whakaheke of water is identified based on a combination of water age, indigenous observations, and modelling of basins at varying scales. Water samples are in the process of being collected from streams and aquifers nationwide. Age distributions determined from tritium and other water chemistry show patterns which help define potential flow pathways. Existing and newly-developed numerical models are implemented that incorporate this age information, along with current and historical mātauranga. Water age and mātauranga provide new datasets for calibration which can help reduce model uncertainty and identify important model parameters that have not been previously considered or incorporated. Based on modelling of a subset of basins nationally, a metamodel will be developed later in the project which will guide identification of te whakaheke o te wai nationally when combined with water age data collected throughout New Zealand.

Results

Tritium sampling of the NIWA monitoring network has been underway for several months, and data analysis is ongoing. Regional tracer sets have been established for groundwater samples from several basins, including Heretaunga Plains, Canterbury, and Northland. In addition, we have updated the numerical MODFLOW model of the Heretaunga Plains region. Incorporation of tritium age data into the models has shown substantial benefits for improving constraints on water flow, provided the model is designed to handle this information without inducing bias in calibration results (Knowling et al. in review). Included in the newly rebuilt model is a new Python tool to automate generation of the surface flow MODFLOW functions based on input shapefiles.

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NATIONAL ASSESSMENT OF SOURCE PROTECTION ZONES FOR DRINKING WATER

Kerr, T.,[1] Cranney, O.,[1] Dark, A.,[1] Young, A.[2]
[1] Aqualinc Research Ltd.
[2] Ministry for the Environment

Aims

To understand what areas in New Zealand might be affected if all drinking water supply sources were required to have source protection zones in place.

Method

All drinking water sources for water supplies serving over 100 people were identified using the coordinates for abstraction points contained in the New Zealand drinking water register.

The source protection zones were delineated using methods described by Pattle Delamore Partners Ltd and ESR Ltd. (2005) and Moreau et al (2014). For surface water sites this involved identifying entire upstream catchments, as well as an "intermediate zone" encompassing areas 25 km upstream with a buffer of 100 m landward of the river edge. For groundwater sites source protection zones were delineated using fixed radius zones based on estimated 50 year and 1 year travel times. The land use of the protection zones was estimated from the Land Cover Database version 4. Current consents within the protection zones were identified using regional council consent databases. The regional impact of protection zone implementation was assessed based on the land use and the number and type of consents within the zones.

Results

Groundwater protection zones for 1 year travel time encompass 665,000 ha nationally, while surface water Intermediate Zone cover 700,000 ha nationally. These mapped areas are shown in Figure 1. Most of the groundwater protection zones are currently in high-producing grassland. Most of the surface water Intermediate Zones land cover was assessed as being low risk for water quality. The spatial variation in affected areas, consents and land cover types indicate the impact of implementation of a national standard for source protection zones would also vary regionally.

The full report (Kerr et al 2018) is available at: https://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/aqualinc-technical-report-drinking-water-source-protection-zones.pdf

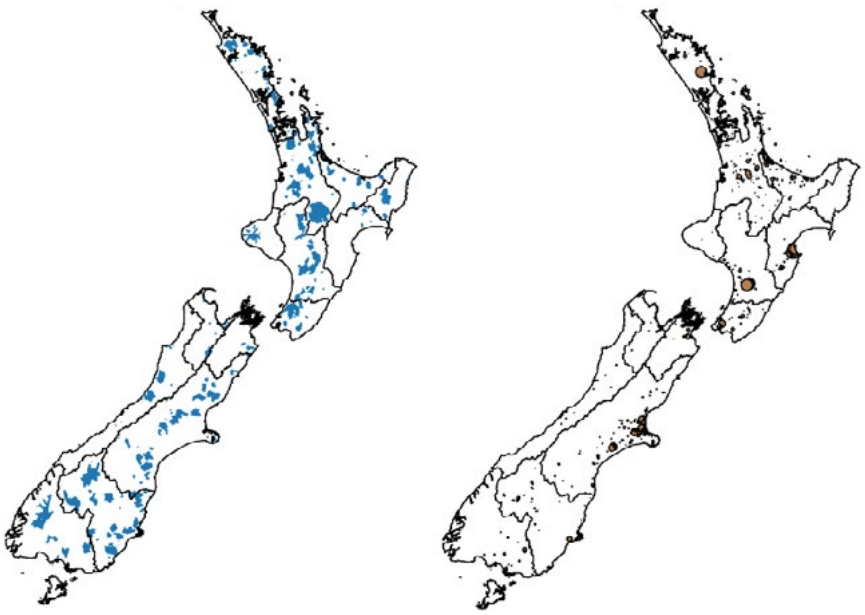

Figure 1: Surface water Intermediate zones (left) and groundwater protection zones for 1 year travel times (right)

References

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CANTERBURY FLOW NATURALISATION TOOL

Mike Kittridge,[1] Wilco Terink[1]
[1] Environment Canterbury, Christchurch

Aims

Flow naturalisation is the process to create a flow dataset that represents what the flow would be if no upstream water abstractions occurred. This naturalised flow is a fundamental dataset used in statistical analyses for water resource planning at both the local and regional scales. Even in its simplest form, flow naturalisation is not trivial and at its most complex a complicated hydrologic model is required.

A practical bridge between the very simple and very complex has been developed at Environment Canterbury (ECan) to utilise much of the available data at ECan to estimate naturalised flows at any monitored flow site by ECan. The python tool is automated, maintained, and available as open-source software.

Method

There are five main modules that are used to ultimately generate the naturalised flows:

a) Querying and/or estimating flow at the flow monitoring site(s)
1. Catchment delineation above the flow monitoring site(s)
2. Selecting the upstream water abstraction sites from the catchment delineation
3. Querying and estimating water usage when the usage doesn't exist
4. Flow naturalisation of adding the water usage back to the monitored flow

The first module queries ECan's flow datasets and determines if a continuous record is available. If only manual flow gaugings are available, then regression analysis is performed against any surrounding flow recorder sites and a new continuous flow record is generated.

The second and third modules identify the locations of the monitoring sites and uses the River Environment Classification Network (REC) to identify the water abstraction sites above each monitoring site.

The fourth module queries the water usage dataset to determine if daily usage data exists at the water abstraction sites. If usage data does not exist, statistical analysis is performed to estimate the missing usage data.

Finally, the actual and estimated water usage is added to the continuous flow records at each monitoring site to produce the naturalised flows.

Results

The output of the tool includes not only the daily naturalised flows, but several intermediate datasets from the modules above. This includes shapefiles of the monitoring sites, the abstraction sites, the upstream catchments, the original water usage and allocation data, and the regression results. The tool can also plot the results for single monitoring sites as shown in Figure 1 for the monitoring site at State Highway 1 on the Ashburton River (68801).

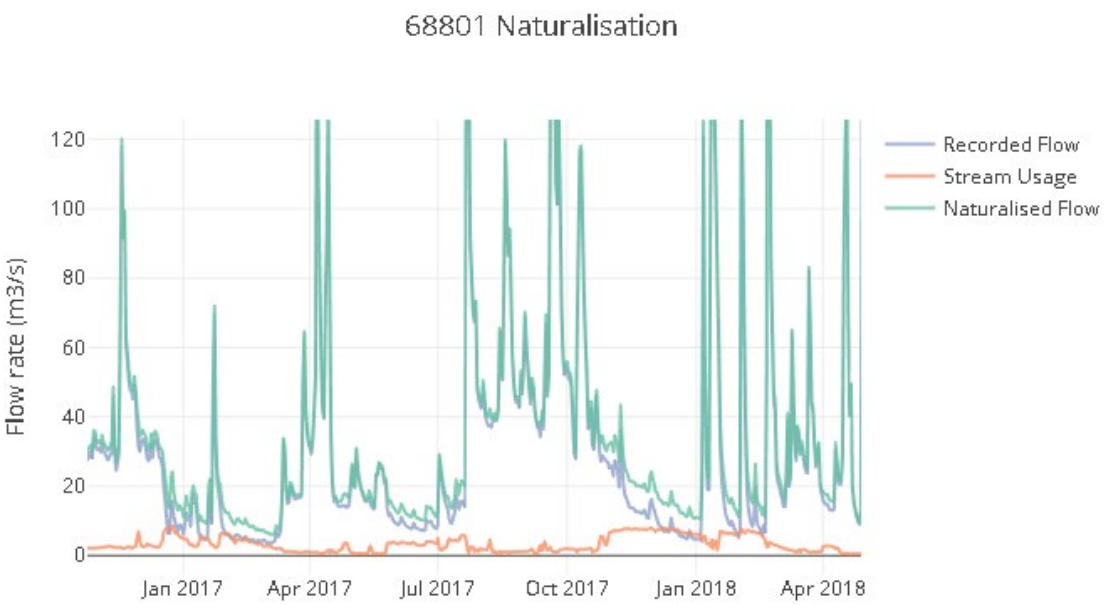

Figure 1: Recorded flow, stream depleting usage, and naturalised flow at State Highway 1 on the Ashburton River (68801). As can be expected, there is more stream depleting usage during the summer months than winter months.

GENERALIZING FLOW DURATION CURVES FOR BIAS CORRECTION OF RIVER FLOW FORECAST

D. Lagrava,[1] C. Cattoën[1]
[1] NIWA, Christchurch

Aims

The New Zealand river flow forecast project aims to produce and communicate qualitative river flow forecasts at national scale for both gauged and ungauged catchments (Cattoën et al., 2018). Absolute flow forecast values are expressed in a relative sense using modelled FDC generated from long-term flow simulations at each river location. The objective of this study is to generate absolute flow forecast at national scale by bias-correcting the modelled FDC with estimated FDC from observed flow time-series and catchment characteristics. FDC bias-corrected daily flow simulations have shown performance increase across hydrological signatures and performance metrics (McMillan et al, 2016).

The estimated FDC can be easily computed from observed flow time-series when available. However, this is not possible on ungauged sites. In order to overcome that problem, there exist several methods in the literature to generalize the FDC for those sites based on similar catchment characteristics. We apply such method to obtain estimated FDC on ungauged sites, so that we are able to perform the bias correction and passage to absolute values for simulated river flows.

Method

The New Zealand river flow forecast is based primarily on the TopNet distributed hydrological model (Clark et al., 2008), developed at NIWA. This model is based on TOPMODEL processes (Beven et al., 1995) to model the physical processes over different sub-catchments. To be consistent for gauged and ungauged catchments, the model is used uncalibrated. As a result, it provides a categorical forecast relative to modelled FDC curves. Those relative forecasts can be mapped to bias-corrected absolute flows expressed in m3/s by using estimated FDC for each basin location.

Estimated FDC are already available for gauged catchments that have flow time-series. For ungauged catchments, we aim at producing hourly-based estimated FDC following the process to obtain daily FDC in Booker et al. 2012. This is a two-step process, where we first approximate the FDC on gauged sites and then we extrapolate those FDC to ungauged sites that have similar hydrological and topological characteristics to known gauged sites.

For the approximation step of the FDC, we have two possible alternatives: using a single parametrized distribution and using multiple distributions. The first case is straightforward to implement: simply perform a fit for a chosen distribution, like the Generalized Extreme Values (GEV). However, in several cases, this approach fails to capture tail events of the FDC like probability of exceedance of flooding or drought. The second case requires the knowledge of relevant distributions that can be used on such extremes of the spectrum.

The generalization step of the FDC uses Machine Learning (ML) techniques. In this case, we have a set of N possible classes, where a class is an FDC generating function with given parameters. Our problem is to assign one of such classes to ungauged sites based on catchment characteristics such as topography, geology, land-use and climate. In this study, we use Random Forests and Multi-Class Logistic Regression.

Finally, to evaluate the effectiveness of the FDC estimation method, we compare FDC bias-corrected flow forecasts with raw forecast values and against observed flows at selected sites.

Results

The first set of results relate to the quality of approximation of FDC using a single parametrized distribution versus using a multi distribution approach.

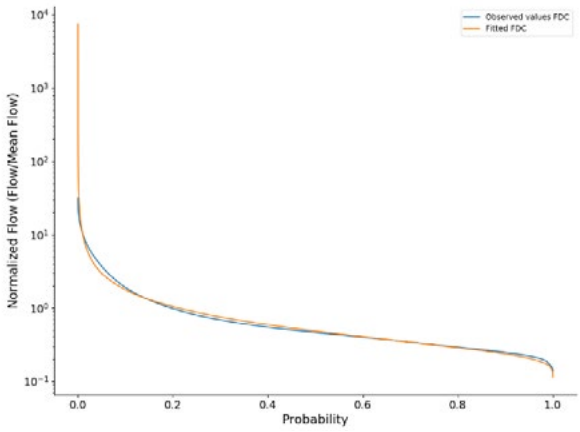

Figure 1: Comparison of observed vs. estimated FDC using a single parametric distribution

Once we have successfully generalized the FDC, we will present preliminary results of the impact of the bias-correction approach by evaluating flow forecast performance with and without bias correction at selected gauged sites for validation.

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SOLUTIONS FOR IMPROVING WATER QUALITY ON HIGH COUNTRY FARMS IN NEW ZEALAND

Lissaman, H.G.,[1] Mager, S.M.,[2] Arbuckle C.A.H.
[1] The University of Otago
[2] Aspiring Environmental Ltd, Wanaka

Aims

Freshwater bodies in New Zealand are of substantial economic, environmental, cultural, and social value (MFE & Stats NZ, 2017). Contaminants from agricultural land use have substantially degraded freshwater quality in New Zealand, and impacted the values accompanying these waterways (McDowell *et al*., 2013). Several mitigation strategies for agricultural pollutants are effective in New Zealand. However, in the high country, these strategies are either inappropriate or their efficacy is poorly understood. To improve freshwater quality effective mitigation strategies must be available for all situations and environments. Therefore, the objective of this study was to determine the effectiveness of mitigation strategies that are promising yet under used on high country farms in New Zealand, primarily riparian buffer strips and constructed wetlands.

Method

Water quality was monitored monthly on two high country farms near Wanaka for 12-months, before, during, and after the implementation of a riparian buffer strip, and five years following the implementation of a constructed wetland. The effectiveness of each mitigation strategy was determined through a longitudinal stream assessment, with water quality samples collected in reaches above and below mitigation landscape features. The water quality of nearby base-line sites represent a mixture of pristine and modified streams for comparison to the mitigation strategy reaches, and provide an indication of what the water quality of mitigated streams should be with attenuation, and what it may have been without attenuation. Following the assessment of attenuation effectiveness, a complementary cost-effectiveness analysis was conducted for each strategy. Additionally, a four day before-after-control-impact (BACI) study was conducted on the constructed wetland and a non-managed stream reach, to determine the capacity of the wetland to attenuate agricultural contaminants from a stock grazing event.

Results

So far, results from the monthly-sampling study indicate that the constructed wetland attenuated *E. coli*, particulate organic matter, and suspended sediment substantially (70%, 67%, and 58% reductions respectively), and sulphate, ammonium, and orthophosphate moderately (47%, 38%, and 14% reductions respectively). Nitrate increased below the wetland (98% increase), potentially due to the intrusion of groundwater, and not a reduction in attenuation. The BACI study indicated that the attenuation capabilities of the constructed wetland responded inconsistently across variables during a sheep grazing event. For example, the concentrations of *E. coli*, nitrate, suspended sediment, and orthophosphate increased noticeably at sites below the wetland following 70 sheep grazing upstream (67%, 29%, 21%, and 17% increases respectively). However, sulphate and particulate organic matter concentrations did not increase downstream following the grazing event, and the concentration of ammonium increased insignificantly downstream (10% and 2% decreases, and an 11% increase respectively). Overall, the findings of the study indicate that constructed wetlands can attenuate agricultural contaminants on high country farms well, if not better than in other environments (with the exception of nitrate) (i.e. Dykes, 2013; Praat *et al*., 2015). It is noted, however, that large high-country grazing events can undermine the attenuation capabilities of constructed wetlands, by overwhelming the system. Therefore, to ensure good water quality, it is important that several mitigation strategies are implemented on any one farm. Moreover, high country farm practice must continue to evolve in support of good water quality outcomes, as mitigation strategies alone cannot improve water quality in such extreme environments.

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TECHNICAL GUIDELINES FOR DRINKING WATER SOURCE PROTECTION ZONES

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In 2005, Pattle Delamore Partners Ltd (PDP) and the Institute of Environmental Science and Research Limited (ESR) prepared the report *Methodology for Delineating Drinking Water Catchments* for the Ministry for the Environment (MfE). The report was prepared to inform the development of the regulations that later became the *Resource Management (National Environmental Standards for Sources of Human Drinking Water) Regulations 2007*, commonly known as the Drinking Water NES.

In 2018, the Ministry for the Environment engaged Pattle Delamore Partners to review and update the 2005 report in order to inform the potential use of source protection zones as a spatial criterion within the Drinking Water NES. The updated report, *Technical Guidelines for Drinking Water Source Protection Zones* ('Technical Guidelines'), produced by PDP for MfE is based on current national and international best practices for delineating and implementing source protection zones for drinking water sources. The Technical Guidelines recommend default source protection zones to which the regulations within the NES could apply. Methods for refining the zones to take into account site-specific circumstances are also outlined.

The Technical Guidelines provide national guidelines for establishing drinking water source protection zones that can be applied consistently across the country for drinking water supplies derived from surface water and groundwater. The primary intention is to support the implementation of the Drinking Water NES and to inform improvements to related policies and practices.

The Technical Guidelines are based on the well accepted method for evaluating contamination risks to drinking water sources, which involves assessing contaminant sources, receptors and pathways. The relevant receptor is a drinking water supply intake. For a risk to be identified, all three aspects (i.e. source, pathway and receptor) must be present. A common method for managing risks to drinking water is to eliminate one of these three components – or to make the pathway between the source of contamination and receptor contain sufficient barriers (e.g. sufficient attenuation of contaminant concentrations), so that the risk of an adverse effect on the drinking water supply is acceptably low.

Defining a drinking water source protection zone involves delineating an area within which risks to a drinking water supply intake from contaminant sources are identified and appropriately managed. The size and shape of the source protection zone takes into account the characteristics of migration pathways that occur over land and through surface water and the subsurface environment.

Longer migration pathways induce greater attenuation of the concentration of a contaminant due to naturally occurring processes of dispersion and dilution; filtration; adsorption and sedimentation; bio-degradation and chemical transformation; evaporation and die-off.

The Technical Guidelines propose three generic drinking water source protection zones, as follows, each recognising different degrees of contaminant attenuation that occur along migration pathways. For all zones, it is important to consider the potential for preferential pathways, which could affect contaminant transport time and attenuation.

Source Protection Zone 1:
This is an immediate zone around the drinking water supply intake, where contaminants could directly impact on the intake structure. Land-use activities in this zone should be strictly controlled. For groundwater supplies this zone is defined on the basis that the well is properly constructed and sited to avoid rainwater and floodwaters from directly entering the well casing.

Source Protection Zone 2:
This intermediate zone is focused on specific land-use activities or discharges that might directly contaminate the water source. For surface water sources, the extent of the zone is based on providing an early warning of a potential contamination event and to limit the concentrations of microbial pathogens in surface water prior to abstraction and treatment. For groundwater sources, the zone's primary purpose is to limit the potential for microbial contaminants to reach the water supply in an infective state. While this zone is primarily intended to provide for sufficient microbial attenuation, where possible, it is also considered sufficiently large to provide protection against many other contaminant discharges, including accidental spills. Zone 1 is contained within Zone 2.

Source Protection Zone 3:
This zone encompasses the entire upper catchment for surface water sources and/or the entire capture zone or catchment for groundwater sources. Within this zone non-point sources arising from general land use, cumulative effects from small point sources and large scale discharges may need to be managed. This zone is also intended to address persistent contaminants that may not attenuate significantly before reaching a water supply intake, such as nitrate, pesticides and some emerging contaminants.

The Technical Guidelines propose default source protection zone sizing, based on an updated literature review, practical experience and a theoretical assessment of contaminant migration. These include default 'conjunctive' zones that relate to situations where both groundwater and hydraulically-connected surface water are drawn into an intake.

In many cases, it may be appropriate to replace the default zones with site specific zones based on the particular water supply intake configurations and the environment in which they are situated. Methods to develop site specific zones need to involve an assessment of contamination risk and contaminant attenuation along migration pathways towards the particular water supply intake. The Technical Guidelines provide information and practical advice on methods for delineating site specific source protection zones.

This presentation on the Technical Guidelines will outline the default source protection zones recommended for potential inclusion in the Drinking Water NES and the recommended process for refining these zones to site specific zones. The background to these zones will be discussed, including the review of national and international literature published since the 2005 guidelines relating both to the delineation of capture zones and contaminant transport behaviour (including transport of different microbes).

DEFINING DRINKING WATER SUPPLY SOURCE PROTECTION ZONES – A CASE STUDY FOR THE HORIZONS REGION

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Aims

The Government inquiry following the Havelock North drinking water supply contamination event in August 2016 identified the multi-barrier approach as a fundamental principle of drinking water safety. Whilst water treatment, monitoring and infrastructure maintenance are all important barriers to the contamination of drinking water supplies, source protection zones (SPZ), with appropriate controls on and responses to activities within them, should form the first line of defence. This paper discusses the importance of defining suitably sized source protection zones which consider the risks of all potential contaminant sources. This has been undertaken for approximately 46 surface water and groundwater drinking supply sources within the Horizons Region.

Method

In response to the recommendations from the Havelock North inquiry, Horizons and the Territorial Authorities within the Horizons region co-sponsored a project considering source protection management for the drinking water supplies in the region that supply more than 500 people. The project involved defining source protection zones for each surface water and groundwater supply, based on three zones of protection:

- Intake Zone (SPZ 1), which is the area in the immediate vicinity of the intake structure.
- Intermediate Zone (SPZ 2), for surface water intakes this is a zone where contaminants can reach the supply in 8 hours; for groundwater intakes this is a zone where microbiological contaminants could reach the intake at potentially harmful concentrations.
- Catchment Zone (SPZ 3), defines the remainder of the catchment that contributes water to the intake.

Traditionally, the method for defining source protection zones involved a zone solely for intake protection and the potential travel time of microbial contaminants (in line with SPZ 1 and 2 above). However, the use of SPZ 3 allows for the risk associated with more persistent contaminants to be more appropriately managed. The work also involved on site inspections of each bore head for the relevant supplies, supplementing desk based assessments of the risks within the zones around each bore.

Results

Source protection zones are ideally developed using site specific considerations such as groundwater and surface water interactions, preferential flow paths and the vertical direction of groundwater movement. The protection zones in the Horizons region have been refined beyond default methods by utilising site specific information. This paper will present information for select supplies where site specific information has been incorporated. For some groundwater supplies, SPZ 3 has been split into two areas due to the presence of upwards hydraulic gradients within the wider catchment. This was undertaken to separate areas where:

- Downwards head gradients occur i.e. the recharge zone where land use activities could contaminate groundwater via direct infiltration; and
- Areas of upwards head gradient (under natural conditions), where contamination could occur due to localised reversals of vertical groundwater gradients due to abstraction, and where vertical migration pathways as can occur around some bore heads and casings could act as a direct contaminant pathway to deeper strata.

This paper also highlights the importance of identifying all types of contaminant sources within each zone and determining who will be responsible for managing the risks. While some information is readily available, such as the HAIL register and consented activity records, some information is less obvious, and will require the ongoing liaison with landowners to raise awareness in areas that are critical to the safety of the water supply.

Site inspections were also crucial in helping to identify risks around each supply and understand the procedures at each site. Combined, this work provided a very useful overall picture of the risks to drinking water supplies across the region and collated a series of recommendations to help mitigate those risks.

BEHAVIOUR OF THE WAIWERA AQUIFER UNDER PRESSURE

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Background

The small township of Waiwera is located approximately 5 km north of Orewa and 40 km north of Auckland. Waiwera is underlain by a low-temperature groundwater-geothermal aquifer which covers an area of *c*. 1 km^2. Hydrogeology of the aquifer is characterised by a shallow (up to 13 m thick) layer of unconsolidated Holocene alluvial sediment (e.g., marine sands, silt, clay, shells). This layer is underlain by Miocene-age Pakiri Formation of the Waitemata Group Sandstone to *c*. 400 m BGL. Waiheke Group greywacke forms the basement in this area with a fault in the greywacke providing a conduit for deeper groundwater circulation. Groundwater originating from rainfall recharge is thermally heated and circulates (via buoyancy) through the greywacke sandstone to reach temperatures of *c*. 50 – 55˚C at the centre of the aquifer.

In pre-European times Waiwera was a significant site for Maori who bathed in the warm water springs that emerged on the beach. From the mid-1800's onwards commercial and private spas were established and made use of the artesian water (ARWB, 1980). Over time, increased use and gradual exploitation of the resource resulted in a decrease in water levels, and from 1969 groundwater water had to be pumped from bores. In the 1980's a water resource management plan was adopted by Auckland Council to protect the reservoir. This included installation of a monitoring bore to better understand the hydrogeological behaviour of the reservoir.

An approximately linear relationship occurs between groundwater abstraction and groundwater level. In late 2018 the primary groundwater user (Waiwera Thermal resort) ceased abstraction of groundwater. As a result groundwater levels have increased substantially, in many cases to elevations above the bore casing. Overflowing bores caused considerable flooding throughout the township and in response landowners have increased the height of casing and/or installed pressure valves onto the bores. The groundwater level in the aquifer has continued to rise through 2018 and 2019. This project was undertaken within and to contribute to a wider collaboration involving Urban Partners, GFZ Potsdam, Auckland Council, and local landowners.

Aims

The primary objective of this project was to better understand the hydrogeology of the Waiwera aquifer so that the resource could be sustainably managed. The primary aims of this project were to better understand the hydrogeological setting, specifically to understand:

a) the current 'state' of the Waiwera aquifer resource;
- Whether high resolution (e.g., 5 min) groundwater level data could be analysed to determine hydraulic properties driven by tidal effects; and
- Temperature gradients and/or preferential fracture location for groundwater flow within the open portion of boreholes.

Method

Daily average and monthly average groundwater levels were plotted on timeseries using the verified dataset provided by Auckland Council. Daily average values were used so that the effects of tidal cycles were removed from groundwater levels. Any instances of changes in groundwater level in the dataset that did not appear to be driven by abstraction were further explored. Fibre Optic Distributed Temperature Sensing (DTS) equipment was deployed down boreholes and analysed to provide high spatial and temporal resolution of temperature at several locations within the aquifer.

Results

Groundwater level over time has increased considerably since the 1980's, from approximately 1 – 2 m below MSL to 2 – 3 m above MSL (Figure 1). Considerable change in groundwater levels were observed following the 7.8 M_W Kaikoura earthquake (November 2016) and more recently following cessation of abstraction from Waiwera Thermal Resort (e.g., 2018 – 2019). Temperature data collected during fieldwork in October and hydraulic properties will also be presented. This data will be analysed to gain a better idea of potential sustainable abstraction rates from the aquifer.

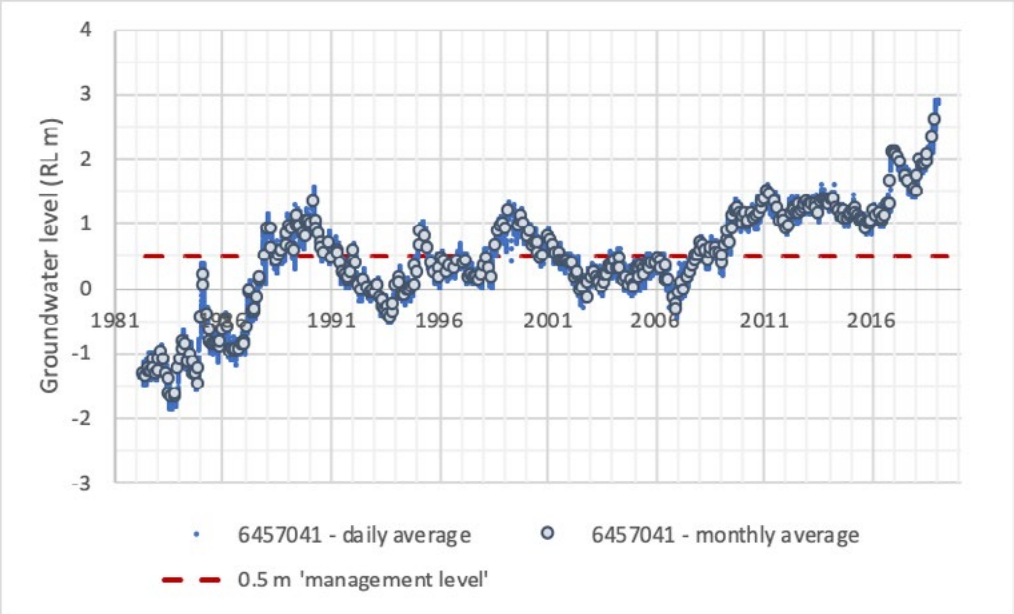

Figure 1: Quality controlled dataset for the Waiwera Beachfront Deep monitoring bore (6457041). Average daily and average monthly groundwater levels are shown for the period 1982 – 2019. The Auckland Council Aquifer Management Level of 0.5 m RL is provided by the dashed line (Auckland Council., 2019).

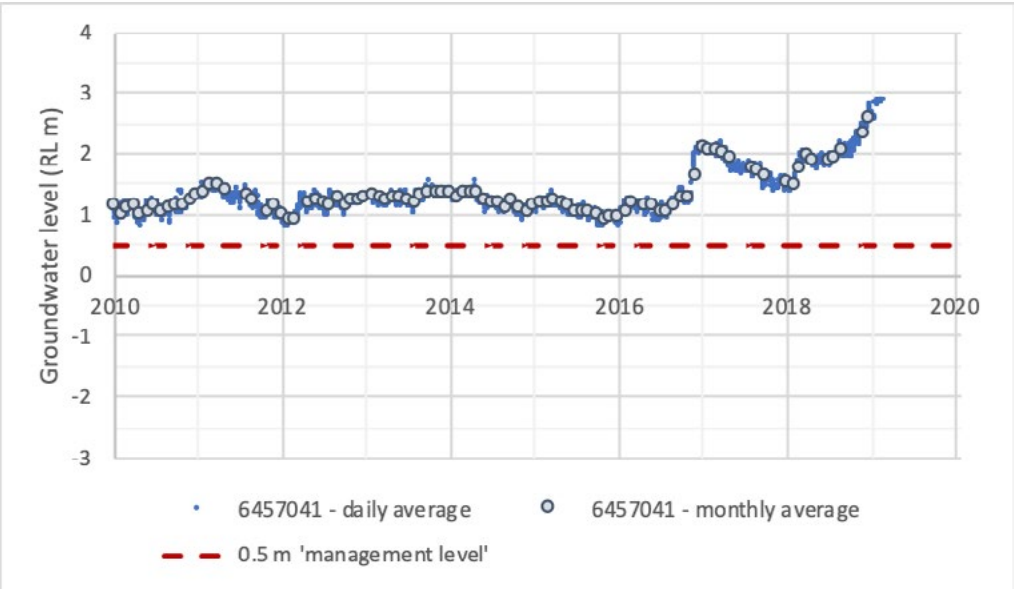

Figure 2: Quality controlled dataset for the Waiwera Beachfront Deep monitoring bore (6457041). Average daily and average monthly groundwater levels are shown for the period 2010 – 2019. The Auckland Council Aquifer Management Level of 0.5 m RL is provided by the dashed line (Auckland Council., 2019).

FOUR DECADES OF SUSPENDED SEDIMENT YIELDS AT GLENDHU

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Aims

The aim of this work is to reconstruct a suspended sediment yield for the Glendhu Experimental Catchments to determine a 36-year-long record. Suspended sediment yields for both experimental catchments (one catchment retained in indigenous tussock grassland and the other planted in exotic *Pinus radiata*) have been undertaken twice before; at the beginning of the experiment by O'Loughlin et al. (1984) for the period 1980–1983 and by Fahey (2012) for 1983–1987. The current assessment is based on the period 2016–2018 during the clearance phase (ORC, and the authors). The amount of sediment transported from the hillslope is dependent on supply-availability, and transport competence. For small headwater catchments, the mobilisation of sediment is mostly controlled by water volume, since at least 90% of suspended sediment is transported during stochastic flow events. Only in instances of frequent storms, with short relaxation periods, is there likely to be a temporary sediment exhaustion. Therefore, the number and intensity of storm events is a good predictor of overall sediment yield in any given year. In this way, runoff is the main control on suspended sediment, so that an increase in annual storminess will inevitably lead to a higher suspended sediment yield.

Method

Turbidity was measured continuously between July 2016 and January 2018 by the Otago Regional Council and rated to suspended sediment using water samples collected using an automatic water sampler. The turbidity rating was derived from 80–110 samples collected at 30-minute intervals during storm events, as well as discrete grab samples collected throughout the period. The combined discharge and suspended sediment record was used to calculate the suspended seidment yield for the observation period. This data, as well as previous suspended sediment yield studies were used to compare two methods for reconstructing suspended sediment yield from flow records. The first method is a standard flow duration curve approach that rates a specific discharge to suspended sediment, and cumulatively summed for each calendar year. The second method used existing suspended sediment data for discrete events and rate the peak runoff of each event relative to measured total event suspended sediment. This approach then ignores the potential issues of hysteretic effects of suspended sediment delivery to the catchment, since peak sediment always occurs prior to peak discharge in the Glendhu Experimental Catchments. Event flows at Glendhu are typically very short-lived, so the maximum hourly runoff for each day was used to rate suspended sediment and then summed to each calendar year.

Results

Forest clearance in Glendhu began in 2014, and changed the availability of suspended sediment within the pine catchment; so a bespoke suspended sediment to discharge rating is used during this period. Over the forest clearance phase, clearance was initiated in the uppermost part of the catchment, so there was only modest changes in runoff observed during this period, and as a result there was no significant difference in suspended sediment yield between the tussock control and the pine forest (when accounting for an uncertainty of ~20%). Comparison to the turbidity-derived suspended sediment yield for 2017 suggests that the flow duration curve, tended to over-estimate suspended sediment yield (heavy line on Figure 1), whereas the event peak flow method was more conservative. On this basis, the event peak flow method was used to derive a 36-year suspended sediment record for both catchments (Figure 2).

There are two points of interest in the long term reconstructed suspended sediment record from Glendhu. Firstly, there is a notable shift in the average SSY with two distinct periods evident in the tussock catchment, firstly a period of higher suspended seidment from 1982–1997, and then a period of lower suspended sediment from 1998–2018. Since there is no change in the sediment rating for this catchment, there is a clear shift in the amount of storminess that is occurring. The early period is associated with a positive phase of the Interdecadal Pacific Oscillation (IPO), whereas the latter phase is a negative phase. Secondly, some years have very high SSY (e.g., 2006), which was marked by 5 unusually large events, and results in anomolously high SSY. The latter is important because it indicates that SSY observations have to occur over multiple years to account for potentially anomously high, or low, storm runoff years. In the pine catchment, the effects of changing runoff on SSY are evident from the pattern of declining SSY over the growth period of the pine forest, and the rapid increase in runoff over the clearance phase. Of interest is the effect of the high storminess in 2006 did not affect runoff generation in the pine catchment, and that the effect of the events on sediment generation were effectively attenuated by the closed canopy of the pine forest, and peak discharges were barely evident in the flow record.

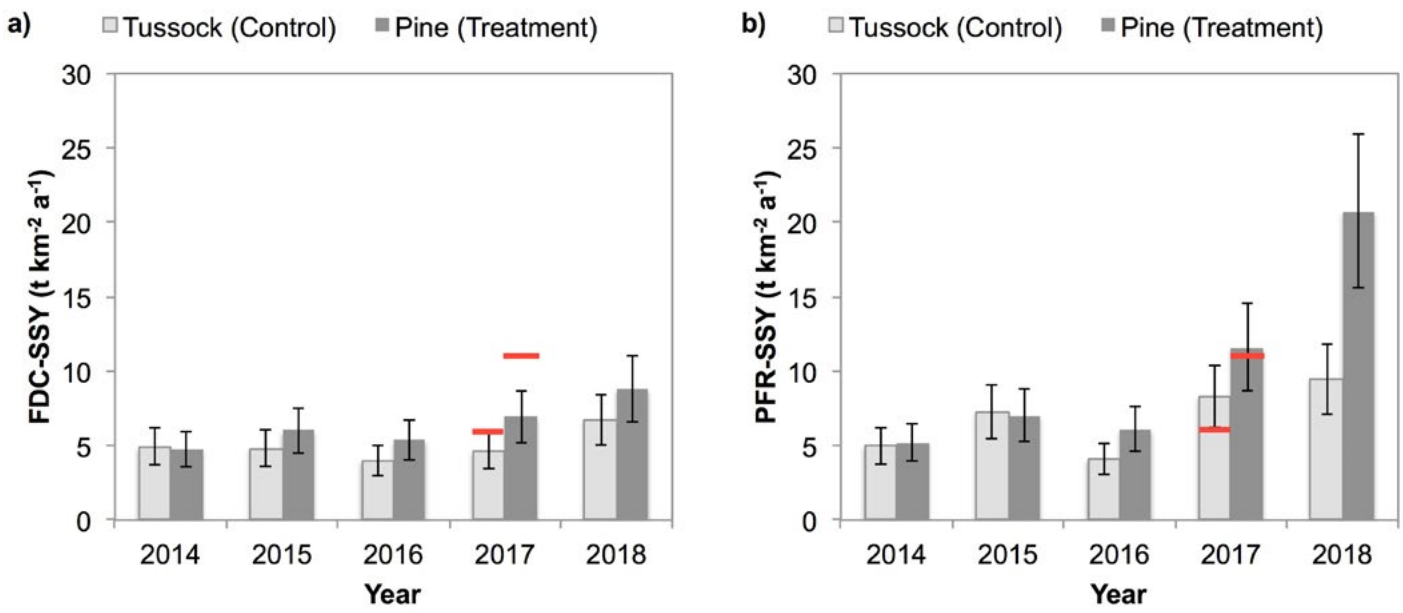

Figure 1: Method comparison for determining suspended sediment yield using a) flow duration curve method and b) event peak flow runoff method. Solid horizontal bars in 2017 are the suspended sediment yield measured continuously using a turbidity rating method.

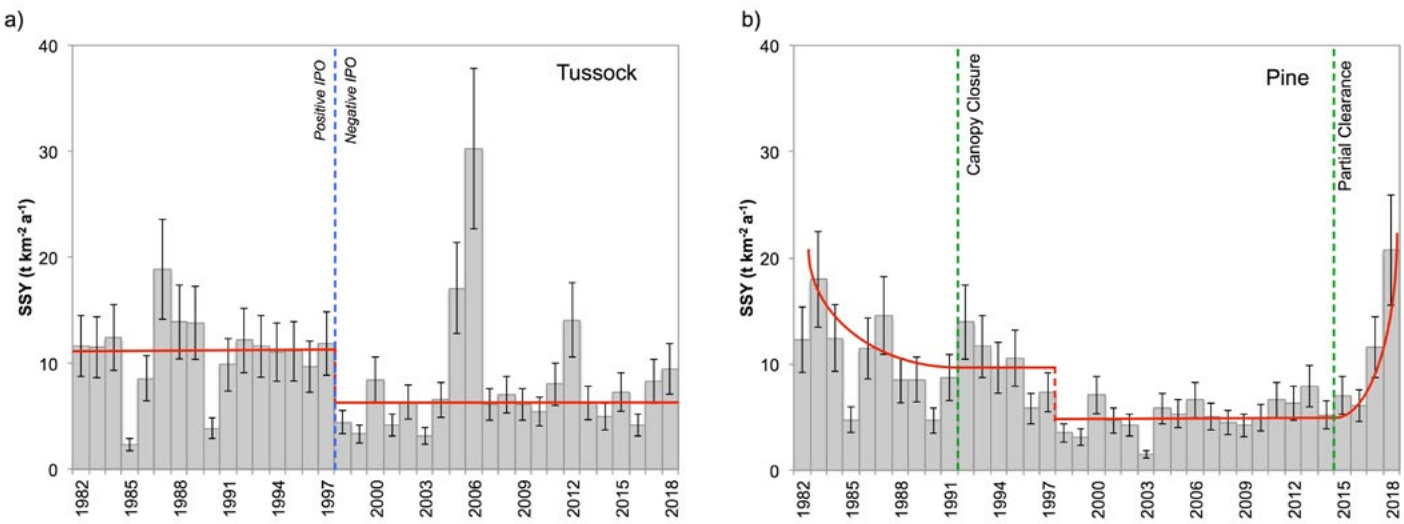

Figure 2: Reconstructing suspended sediment yields at Glendhu Experimental catchments using an event peak flow method.

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WATER WE DO ABOUT THE RIVER? A MIXED METHODOLOGY TO UNDERSTANDING WATER QUALITY AND MANAGEMENT IN A SOUTHLAND CATCHMENT

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Aims

Water quality is a highly contested issue, and poor water quality in New Zealand is often correlated to intensive pastoral agriculture, especially in concentrated farming areas like Southland. The Waikaka Stream is one such catchment that currently does not meet local water quality standards, due to 'very poor' water quality. Water management is regulated by regional councils, however, communities in Southland have been mobilising to form catchment management groups, offering an alternate, bottom up management style. This research will use the Waikaka Stream as a case study, assessing the water quality, community perceptions, and the potential for community catchment management.

Method

Since November 2018, monthly water samples have been collected at 16 sites throughout the Waikaka Catchment, including the mainstream, as well as significant tributaries in the catchment. The sampling strategy reflects different physiographic characteristics in the catchment, as well as different farming types and management techniques. Faecal coliforms and *E.coli* were tested for bi-monthly, to assess the bacterial contamination in the stream, and whether these concentrations are spatially heteorogeneous across the catchment. Samples were also tested for nitrate (NO_3), ammonium (NH_4^+), phosphate (PO_4), total nitrogen (TN), and total phosphorus (TP), to understand the nutrient concentrations across the catchment and seasonal variations. The suspended sediment, particulate organic matter, and turbidity were also quantified at each sampling site.

Quantitative results were collected through semi-structured interviews with community members in the Waikaka Stream. Quantitative results are coupled with qualitative data to understand water quality perceptions, and how these relate to observed key water quality indicators. Interviews also provide local knowledge to inform the quantitative water results. Quantitative data was also used to understand the community catchment groups, and the processes around their formation and operation. These interviews provide information around the barriers to success for community management, and how the groups interact with local government, and the potential for success. 10 farmer interviews were conducted, with a range of farming types and demographics being interviewed, to gain an understanding of the entire catchment.

Results

Preliminary quantitative results show both spatial and temporal variation within the water quality indicators in the Waikaka Stream. Water quality variables do not show the same trends across the catchment; therefore, the likely environmental factors are different within each reach, and affect water quality outcomes in different ways (Figure 1, Figure 2). For most variables, the concentrations exceed the recommended levels in surface water. However, this lies in contrast to the perceptions of the community members, who consider the water quality to be 'quite good'. The difference between the quantitative observations of water quality, and the local stakeholders perceptions potentially illustrates why many communities may feel frustrated with regulatory targets and that a gap exists between their conception of water in their catchment, and the creeping decline in water quality that exists over the catchment, and over time.

Quantitative results show that there are several key reasons for the formation of the community catchment group. Motivation varied between farmers, with some wanting to be involved to look after the environment because they rely on it, while others want to ensure they leave a healthy environment for future generations. Others want to prove that farmers treat the environment well, as they feel constantly blamed for all poor water quality. Every farmer thinks that the community catchment group is a positive management strategy, although levels of involvement and engagement vary.

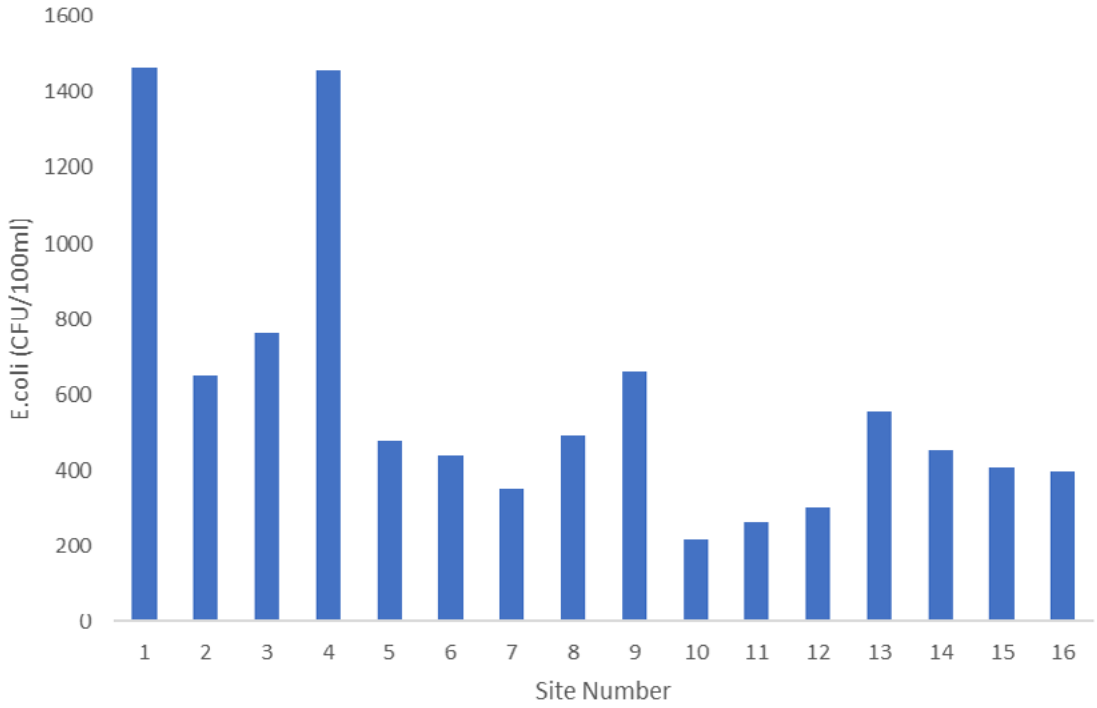

Figure 1: E.coli levels across the catchment

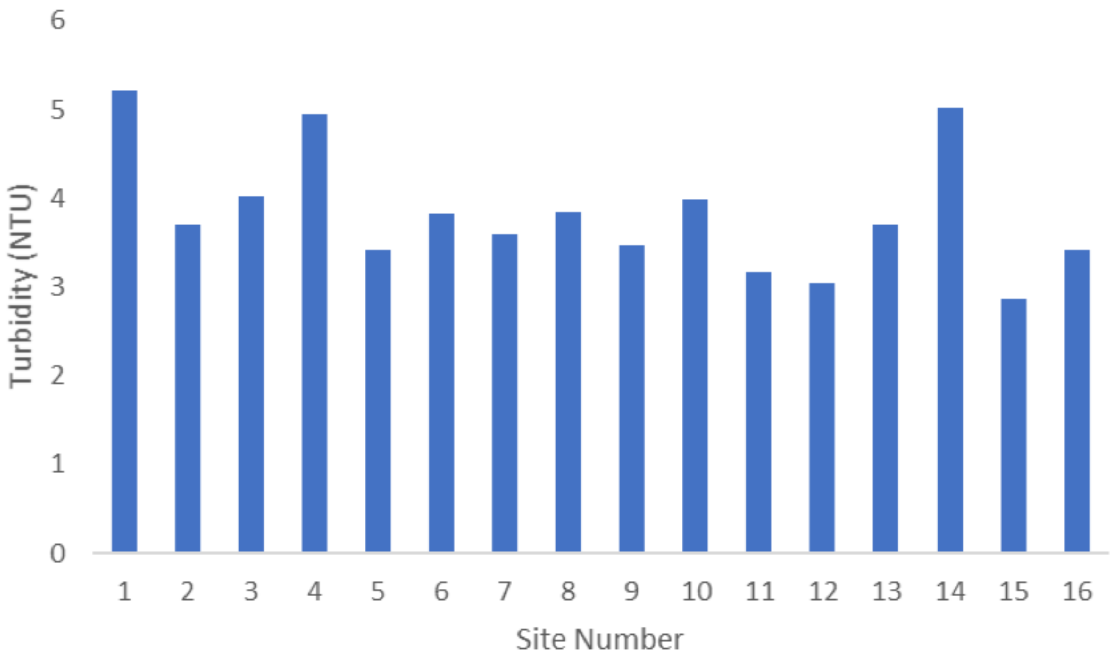

Figure 2: Turbidity levels across the catchment

FLOOD HAZARD ASSESSMENT OF OPHIR, OTAGO

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Aims

Floods are the most common and costly natural disaster. The main aim of this study is to assess the flood hazard of the Manuherikia River at Ophir, Otago. To achieve this assessment, a hydrological study which included frequency analysis has been carried out and a HEC-HMS hydrologic model along with a computational hydraulic model have been developed.

Method

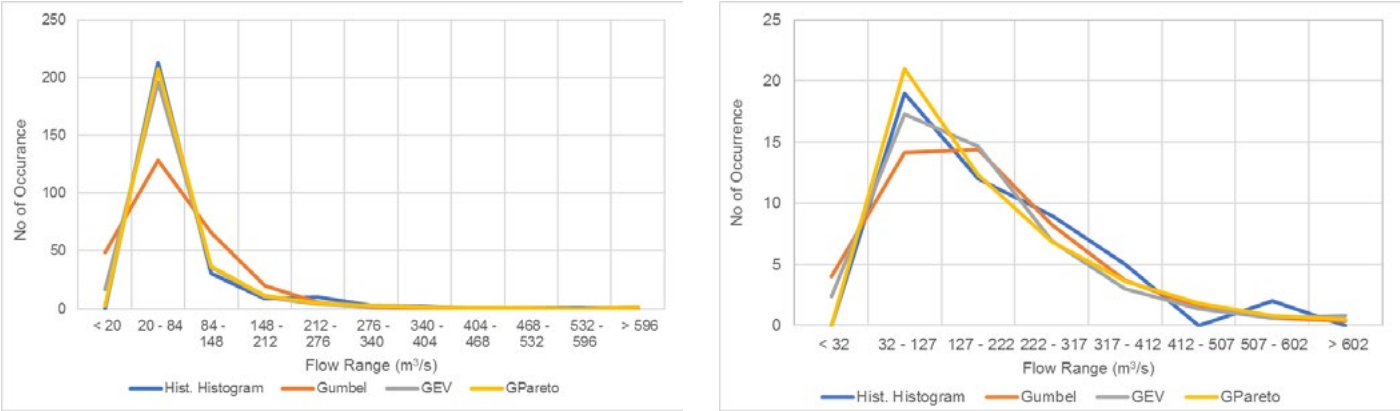
Maximum annual series "MAS" and partial duration series "PDS" were applied to obtain the high flow series for frequency analysis of the Manuherikia River at Ophir. Forty-eight years of flow data at Ophir is available from 1971 until 2018. A threshold of 32 m^3/s, which is the lowest flow in the MAS, was selected to obtain the PDS. A condition of having at least 48 hours between two consecutive peaks was set up, in addition to further inspection to insure independence between selected peaks. Moreover, as base flows were significant for many events, baseflow was separated for the case of the PDS and frequency analysis was carried out to effective peak flows and their corresponding base flows separately. This was based on the assumption that peak flows and base flows are produced by two different hydrological processes. This PDS approach resulted in the selection of 270 high flow events, compared to only 48 events obtained for the MAS. A HEC-HMS model has been set up and calibrated to simulate the July 2017 high flow event and has been validated by testing its performance to simulate the May 2011 high flow event. A rainfall-runoff analysis of 20 high flow events has been carried out to aid the estimation of the initial values for the model's parameters, and to estimate the weights for each rainfall site for estimating areal precipitation in the HEC-HMS model. This HEC-HMS model has been utilized to produce the whole flow hydrographs at the outlets of the Manuherikia River sub-catchments which drain to the Manuherikia River, as needed by the hydraulic model in order to assess the extent of flooding. The flow hydrograph pattern of the 1987 flood event was chosen to produce the design rainfall event which will produce the peak flows associated with different Average Recurrence Intervals (ARI), as it would produce higher water volume for the same peak flow compared to other high flow events.

The hydraulic model of the Manuherikia River at Ophir was setup using HEC-RAS 5.0.3 model. The model was setup as one-dimensional (1D) / two-dimensional (2D) flow areas, with the main river channel, bridges and culverts incorporated into the model as one-dimensional (1D) elements, while the flood plain was configured as two-dimensional flow area. The inflow hydrographs produced by HEC-HMS model were applied to the 1D stream as upstream boundary and as lateral boundary. A rating curve was used as the downstream boundary. The stage values were available for discharges less than 632 m^3/s. For discharges greater than 632m^3/s up to the full bank stage, the existing rating curve was extrapolated using Manning's equation. The model was calibrated for the December 1995 event and validated for the March 1987 and November 2018 events utilizing observed high-water marks, photos, discussions with residents and personal accounts.

Results

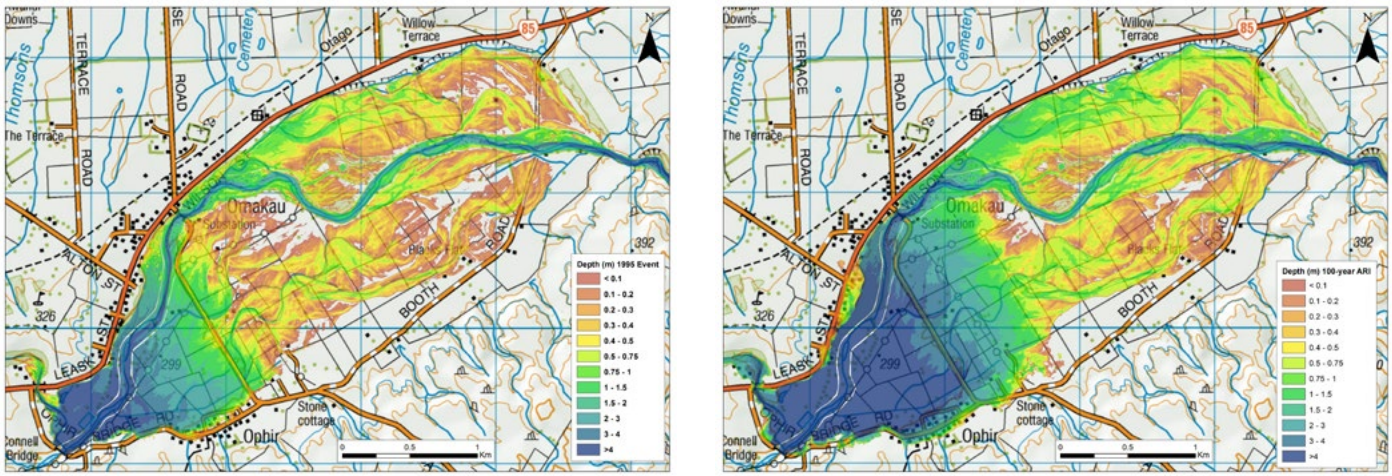
The partial duration series modelling has been considered more reliable as it resulted in models with better fit to the observed statistics, as shown in Figure1. The PDS has produced significantly higher values for the 50- and 100-year ARI flows. The 100-year ARI flow based on the PDS (965 m^3/s) is about 58% higher than the value produced by the MAS, while the PDS 50-year ARI flow (734 m^3/s) was 35% higher than the corresponding MAS value. The rainfall-runoff analysis of 20 high flow events of the Mauherikia River catchment was useful to understand the limitations imposed on the reliability of any developed hydrologic model due to the lack of rainfall sites. This rainfall-runoff analysis also aided the choice of initial values for the HEC-HMS hydrologic model.

The hydraulic model was run for events with 100-year ARI peak flows produced by MAS and PDS series, respectively. Figure 2 presents the flood depth and flood extent for these two 100-year ARI flows produced by using two different approaches. Results suggest that the method used to obtain high flow series "MAS or PDS" for estimation of design peak flows can result in quite different flood depth and extent, which in turn can have significant implication for flood management and planning.



a) Maximum Annual Series (MAS) b) Partial Duration Series (PDS)

Figure 1: Manuherikia River at Ophir observed vs Modelled histograms



a) Maximum Annual Series (MAS) b) Partial Duration Series (PDS)

Figure 2: Modelled maximum flood depth and flood extent for peak flow close to 100-year Average Recurrence Interval flow produced using (a) MAS and (b) PDS.

Acknowledgement

The authors are grateful to NIWA for the availability of the Manuherikia flow data at Ophir

COMMUNICATING NATIONAL SCALE RIVER FLOW FORECASTS: FLOOD EVENT CASE STUDIES AND STAKEHOLDER FEEDBACK

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Aims

Flood forecasting is a vital component of emergency preparedness strategies, providing early warnings to facilitate adequate response and reducing the impacts of flooding (Bevere et al., 2012, Kunreuther et al., 2011). The New Zealand River Flow Forecast project aims to complement and support existing models already used by local authorities (Cattoën, 2018). The aim of the project is to work collaboratively with stakeholders to design a tool that is better designed for decision-makers' needs and priorities. We present several flood event case studies with a qualitative assessment of the flow forecast tool performance during these events. Additionally, we discuss some feedback from stakeholders affected by these events.

Method

NIWA's national river flow forecasting system provides hourly forecasts, two days in advance, for more than 60,000 rivers across New Zealand. The system uses NIWA's High Performance Computing facility to link NIWA's national hydrological model with high-resolution weather model output, satellite and climate station data. The forecasts are displayed as relative flow values based on long-term flow simulations. Simulations are generated from more than 40 years of climate records from hundreds of monitoring sites around the country in NIWA's Virtual Climate Station Network.

River flow forecasts create automated, state of the art, flow forecasting videos at national scales. This user-friendly visual format can be sent out daily via a link to the organizations and people that need to access the information. Every morning a new forecast video is automatically uploaded to a Vimeo account where stakeholders can view the 48-hour forecast. Figure 1 shows a still frame from a video during a West Coast flood.

Results

Within the past year, while the New Zealand River Flow Forecast has been producing beta version forecasts, there have been three large rain events causing flooding. On 7-9 November 2018, persistent heavy rain fell on many western and inland parts of the South Island, heaviest falls were along the West Coast, where widespread surface flooding and slips were reported. Parts of the West Coast received up to 650 mm of rain in 52 hours (Blašković, 2018). The second event occurred on the West Coast on 26-27 March 2019, with over 1000 mm of rain falling in the Cropp River destroying the Waiho Bridge leaving nearly 500 people stranded in Franz Josef (Neilson, 2019). On 29-30 May 2019, the South Island and southern North Island experienced widespread rainfall with totals up to 300 mm in Arthur's Pass in 48 hours (RNZ, 2019).

For all three events, the flow forecast showed extremely high river flows in the affected areas. Feedback we received from stakeholders was overall positive, although forecast information is qualitative, forecast videos offer useful additional spatial and temporal information to the existing pool of observed and forecast information used by decision-makers. Stakeholders also indicated what information was missing and should be included or could be communicated more effectively for decision-making. These interactions with stakeholders are beneficial to shaping a more effective tool and plan future research and development directions to address key priorities.

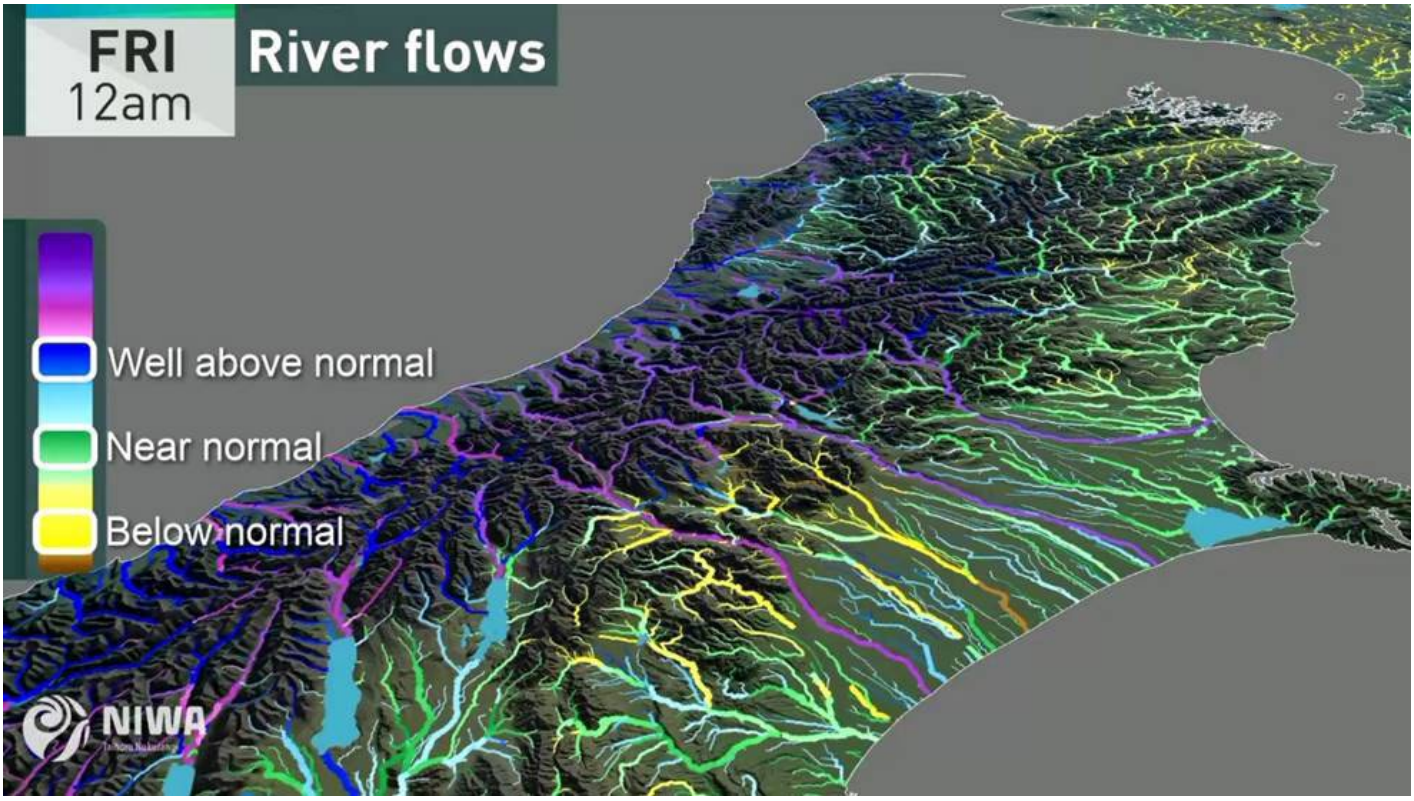

Figure 1: Flow forecasting video still frame using river network layer

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NEW ZEALAND AQUIFERS DIGITAL MAP

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Aims

The national aquifer map aims to represent New Zealand's hydrogeological assets in a digital dataset that includes all the key elements of this important national resource. This paper describes the development of the map and the methods that were used to provide a new national classification of aquifer type and their distribution.

This development, the first update of the national aquifer map since 2001, was undertaken by GNS Science and commissioned by Ministry for the Environment. Many of the datasets used to develop the previous New Zealand aquifer map (White 2001) have since been improved in terms of resolution and coverage (e.g., QMAP, the 1:250,000 geological digital map of New Zealand; Heron 2014). In addition, a nationally-consistent classification of hydrogeological systems was recently developed and applied nationally (Moreau et al. 2019).

Method

The national aquifer map provides national coverage with method that is consistent, transparent and defensible. Firstly, a national classification of subsurface units relevant to groundwater flow (i.e., aquifers, aquitards and aquicludes) was developed. This classification was primarlily geological and based on QMAP. For example, aquifers were identified in Holocene, Quaternary and Tertiary sediments. Then, surface and subsurface layers were represented with a 'stack' of GIS polygons, without any connotation of depth.

Layers were mapped with available information including: the QMAP GIS datasets (polygons, polylines and faults, Heron 2014), the recently-developed national groundwater systems GIS map (Moreau et al., 2019); QMAP geological cross sections; digital topographic contours; and relevant technical publications (by GNS Science and by regional councils; and relevant digital 3D geological models developed by GNS, e.g., White et al., 2016).

Results

The updated digital aquifer map consists of GIS files i.e., a set of overlying polygons representing aquifers, aquitards and aquicludes and the 3D structure of New Zealands aquifers (e.g., Figure 1). The national aquifer map represents much of the detail of aquifer location that was not available in White (2001). For example, the map identifies areas with aquifers in eastern North Island that were not mapped by the 2001 map. The map identifies the 'stack' of aquifers in the eastern North Island including: Holocene gravels and the coastal zone in the Heretaunga Plains; Tertiary units in the area include Pliocene and Miocene sediments in outcrop, and the eastward extension of these to the coast.

This map will be used to produce a 2D aquifer map with summary hydrogeological attributes from the New Zealand Groundwater Atlas project (a project commissioned by MfE and undertaken by GNS Science, in collaboration with NIWA, Aqualinc and ESR). These national datasets will be used by MfE to inform groundwater work-streams related to the Environmental Reporting Act (2015) the National Policy Statement for Freshwater Management, and to increase public awareness about groundwater.

In addition, the national aquifer map provides a consistent framework to connect the considerable information on groundwater systems held by regional regulatory authorities. In particular, regarding standardization of boundary mapping and assigning hydraulic properties. This information should be integrated into future updates of the national aquifer map.

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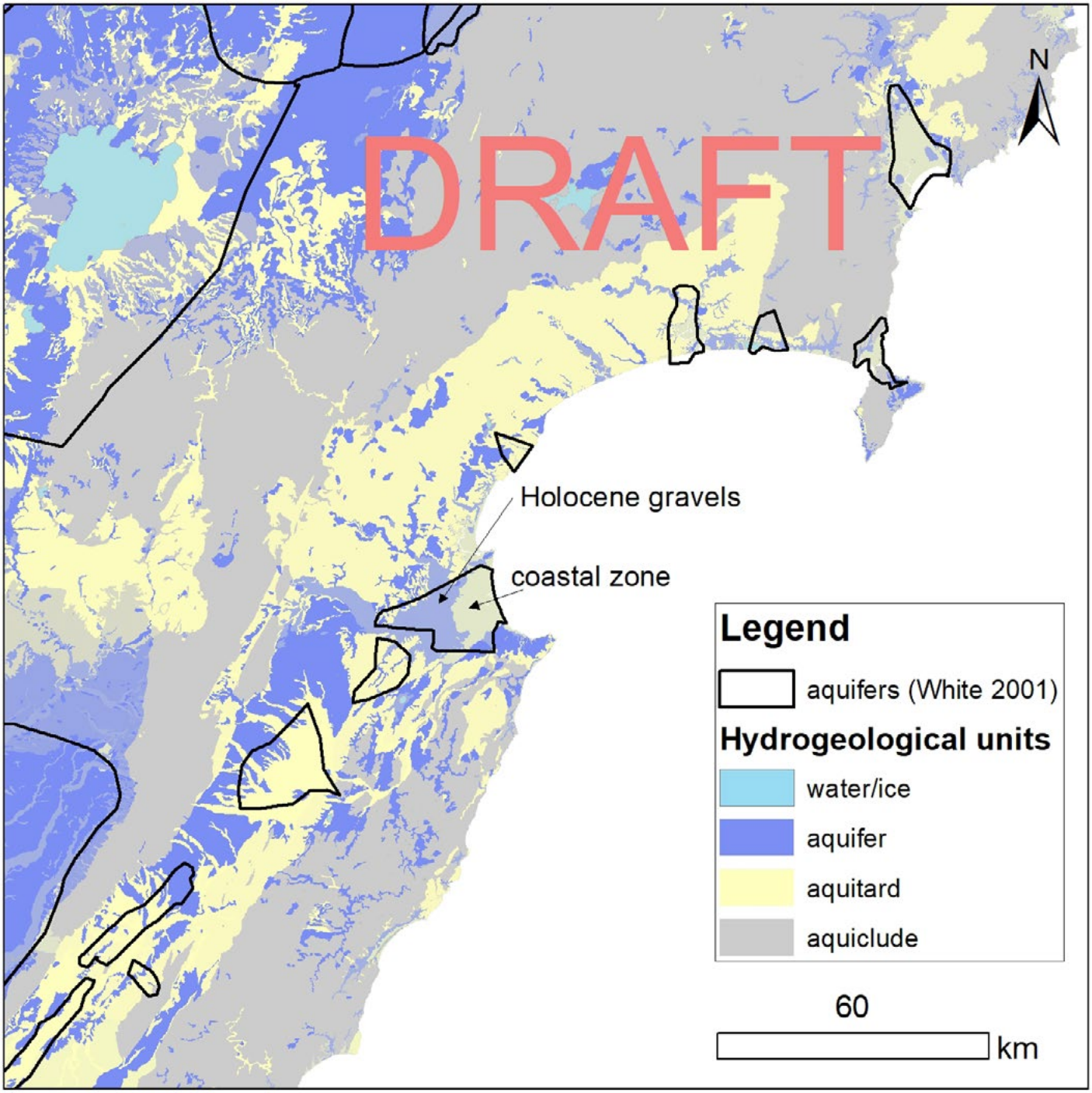

Figure 1: Spatial distribution of hydrogeological units at the ground surface represented as overlapping polygons in the vicinity of the Heretaunga Plains.

GROUNDWATER STORAGE THAT FEEDS THE WAIRAU RIVER AND STREAMS IN THE WAIRAU PLAIN

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Aims

We aim to estimate the groundwater storage that maintains river and stream baseflow through prolonged dry periods. This is required for groundwater abstraction limit setting to maintain sustainable river and stream flows, and for understanding of lag times of contaminants, for example nitrate, from land into the water ways.

Method

The age of the water in stream and river discharges is linked to the age of the water in the groundwater reservoir that feeds the rivers and streams (e.g. Berghuijs and Kirchner 2017, Morgenstern et al. 2010). Most groundwater is exchanged only slowly with the surface and is therefore relatively old.

The hydrogeologic properties of geologic formations, such as the ability of the rainwater to enter a groundwater system or the amount of groundwater storage, can be characterised by the mean transit time (MTT) of the water through these formations. The MTT is the time between rainfall and discharge of the water, for example via springs and seeps into rivers and streams. A longer MTT shows a larger contribution of deeper groundwater flow paths, associated with larger dynamic groundwater volumes

We use tritium dating of stream and river water in the Wairau hydrologic system to estimate the MTT, and groundwater storage that actively feeds the rivers and streams.

Results

The Wairau River was sampled for tritium over a wide range of flow conditions, which overall are representative of average flow. Therefore, the derived MTT of 4 years is representative of average flow. Using the average flow of 51 m^3/s, the groundwater storage that feeds the Wairau River at the Wairau Plain is estimated to be approximately 6,400M m^3.

Four significant spring-fed streams in the Wairau Plain were also sampled, at baseflow, to obtain baseflow MTTs and related baseflow storage. Spring Creek, for its relatively high flow, has a very low water storage of 29M m^3 in the Wairau Fan because of its short transit time of only 0.33 years. Its flow is therefore very dependent on continuous recharge from the Wairau River, and it is likely to mimic the Wairau River flow very closely in the event of extended drought. Murphys Creek has a similar storage of 30M m^3, and with its MTT of 1.5 years would be buffered against a drought of up to a year, but not of more than a year. The drought buffer is similar for Fulton Creek, with a storage of 12M m^3. The estimated storage for Doctors Creek is 51M m^3 which would be able to sustain such low baseflow, over years.

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BETTER SPATIAL CHARACTERISATION OF EVAPOTRANSPIRATION AND RAINFALL RECHARGE ESTIMATES TO GROUNDWATER USING REMOTE SENSING MULTISPECTRAL TECHNIQUES AT LYSIMETER SITES

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[1] GNS Science

Aims

Regional councils have the responsibility to set allocation limits to protect and ensure the sustainable use of their freshwater resources. An important part of allocation limit setting consists in assessing the amount of recharge to groundwater. Improvement of recharge estimates and models and assessments of sustainable allocation limits will become more important in the future, where more variable rainfall input to freshwater systems are expected under climate change.

This study, funded by Envirolink for Hawke's Bay and Bay of Plenty regional councils, used two novel techniques (unmanned aerial vehicle (UAV) and satellite multispectral imagery processing) to improve recharge estimates through better assessment of actual evapotranspiration, in combination with upscaling of local rainfall recharge lysimeter observations in two aquifer recharge areas.

Method

UAV multispectral imagery (MSI) was acquired and mosaicked for six surveys between early April and end of May 2019, three each at two sites located near lysimeters:

- Substation site in the Heretaunga Plains (Hawke's Bay), with an area of 27.3 ha covered by vineyards;
- Collins Lane site in the Lower Kaituna River catchment (Bay of Plenty), with an area of 24 ha covered by dairy farm pasture.

MSI from the Sentinel-2 satellite was also acquired for the two study sites. Both MSI datasets (UAV and satellite) were processed in the Google Earth Engine (GEE) cloud-computing platform (Gorelick et al., 2017). Remote-sensed vegetation parameters such as Normalised Difference Vegetation Index (NDVI) and Leaf Area Index (LAI) were calculated from the Red and Near infrared bands, and subsequently used to estimate relative evapotranspiration (RET).

To show the benefits of using a recharge model that incorporates RET derived from this study, hypothetical long-term recharge was calculated for both sites, using a flat terrestrial model cell, soil inflow generally assumed equal to rainfall, and soil outflow the sum of AET and recharge; outflow through streamflow was considered negligible for flat terrain. MSI processed results were then compared to historical lysimeter data collected at the two sites and of the hydrogeological context.

Results

This study showed that inclusion of spatially detailed evapotranspiration data obtained from UAV and satellite MSI data can lead to significant improvements in recharge estimates in comparison to typical recharge model resolution (Figure 1), which are typically coarse (e.g., 1 km x 1 km, in Westerhoff et al., 2018). The study also found that UAV and satellite-derived RET correlate very well, both spatially and in terms of absolute values. UAV data can be used to complement satellite data, with UAV having higher resolution: incorporation of satellite data leads to a spatial interpolator with 10 m resolution; UAV data can improve this resolution to 10 cm. Data processing through cloud-computing services is also very efficient to reduce the computational burden linked to the use of such high-resolution datasets.

Additionally, UAV and satellite RET datasets can help to refine important factors involved in recharge estimation, such as the placement of lysimeters; the understanding of the impact of human-made features (e.g., roads, roofs and compacted and sealed areas); and the characterisation of the soils.

This study has demonstrated proof of concept for improved parametrisation of rainfall recharge in regional numerical groundwater models (e.g., Heretaunga Plains Groundwater Flow model in Hawke's Bay and the Kaituna, Makatu and Pongakawa Water Management Area groundwater flow model in Bay of Plenty), which will ultimately benefit management of water resources through improved understanding and reduced uncertainty.

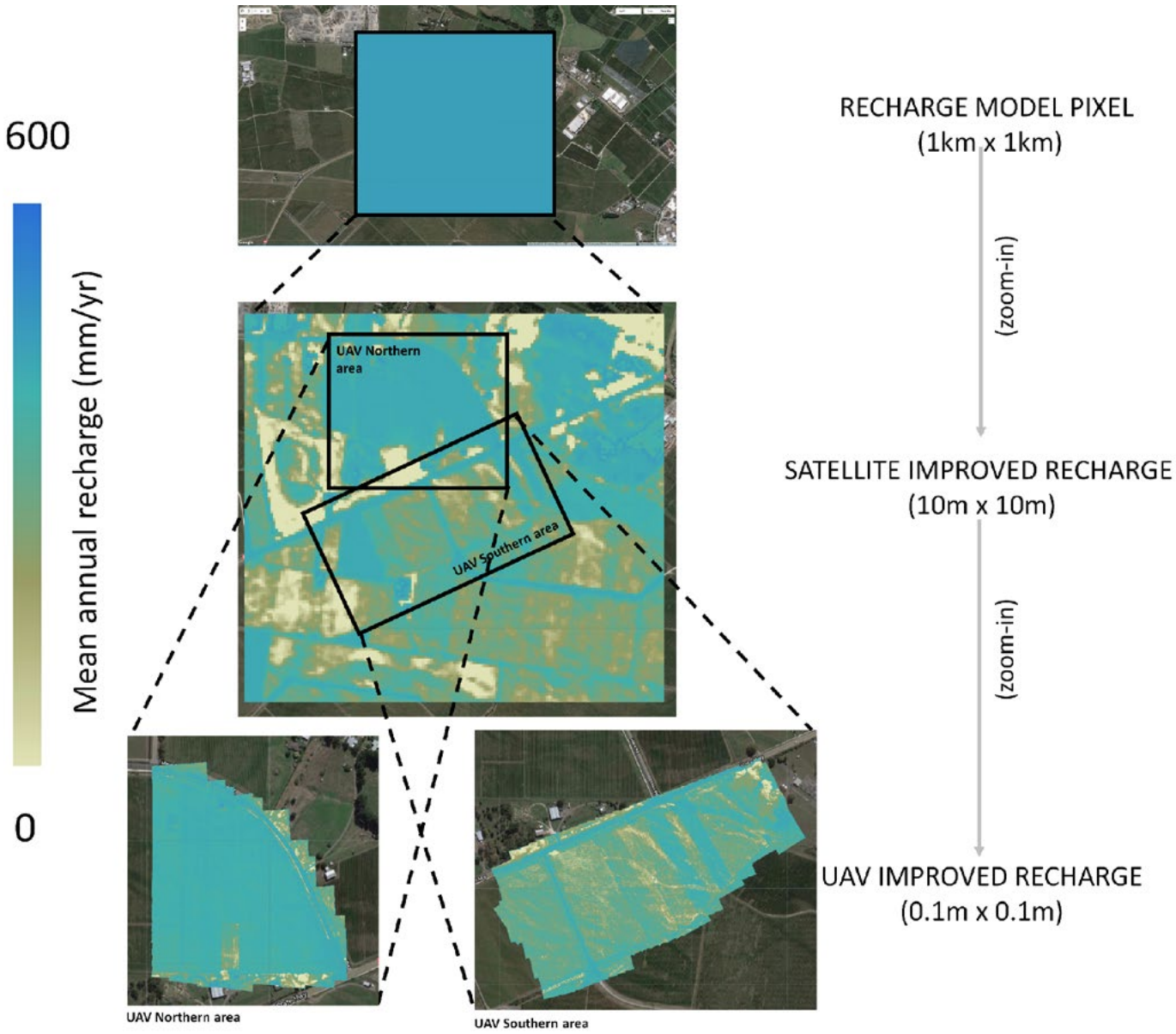

Figure 1 Example of potential refinement of recharge model resolution from: typical existing model resolution (top) satellite data (middle) and UAV data (bottom) at the Substation site (Hawke's Bay).

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UPSCALING OF POINT-SCALE GROUNDWATER RECHARGE MEASUREMENTS USING MACHINE LEARNING: A CANTERBURY CASE STUDY

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Aims

Accurate estimation of groundwater (GW) recharge rates is essential for water resources decision-making, in particular for dynamic regional-scale water allocation. Recharge are typically estimated either based on models that require observed climate and soil data for calibration or through measurements at a lysimeter monitoring site. While lysimeters are a direct method of measuring drainage, utilisation for decision making in regional water management is limited, as merely point-scale measurements of recharge are provided. Machine learning techniques such as artificial neural networks (ANNs) have been identified to be a robust tool for modelling nonlinear groundwater hydrology processes (Krishna et al., 2008; Nayak et al., 2006). ANN was selected in this study in order to develoop a tool to support decision making in groundwater allocation by spatially upscaling lysimeter-measured recharge.

Method

Daily recharge data recorded at three lysimeter stations (Dorie, Dunsandel and Methven) in the Canterbury Plains region of New Zealand were used in this study. A sequence of analysis steps was followed to determine regionalised recharge values. These analysis steps are shown in Figure 1. First the recharge data have been pre-processed following a rigorous quality control procedure. Next time series analysis and model (i.e. the ANN) development was carried out. The ANN was trained and assessed in terms of its predictive performance to match lysimeter-measured recharge. Model uncertainty has been assessed using a “Dropout” Monte Carlo (MC) technique. The results were then upscaled spatially. Such information could then be utilised by decision makers in the groundwater allocation process.

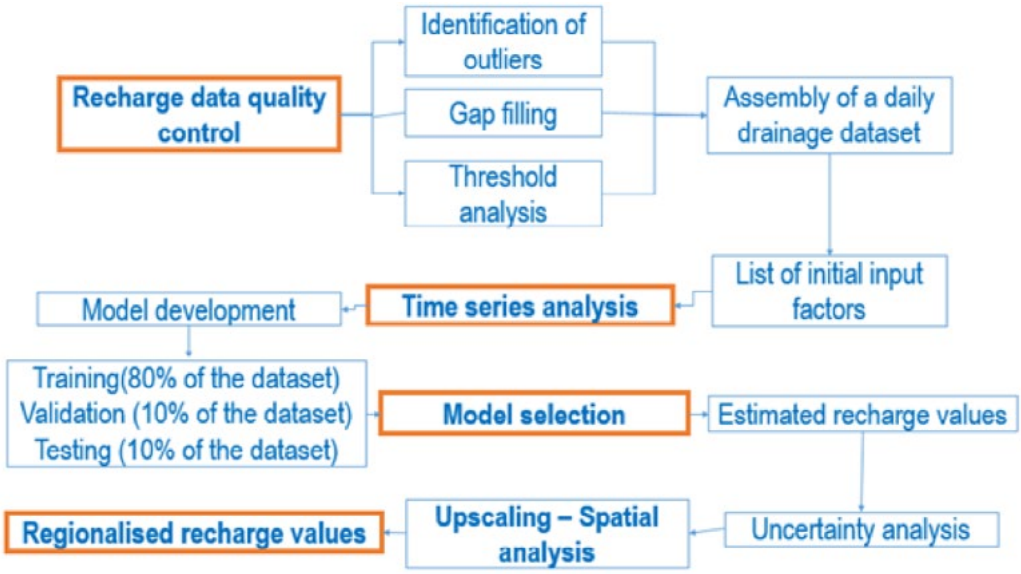

Figure 1: Flowchart of the analysis steps.

Results

Best results were obtained using rainfall, potential evapotranspiration and dominant soil texture data as inputs. Figure 2 shows an example comparison between the predicted and observed drainage at one of the study sites for an arbitrarily chosen time period. Overall, model accuracy was found to yield root mean squared error values ranging from 0.65 up to 0.86, and a mean absolute error ranging from 0.41 to 0.99, with an uncertainty of 6%.

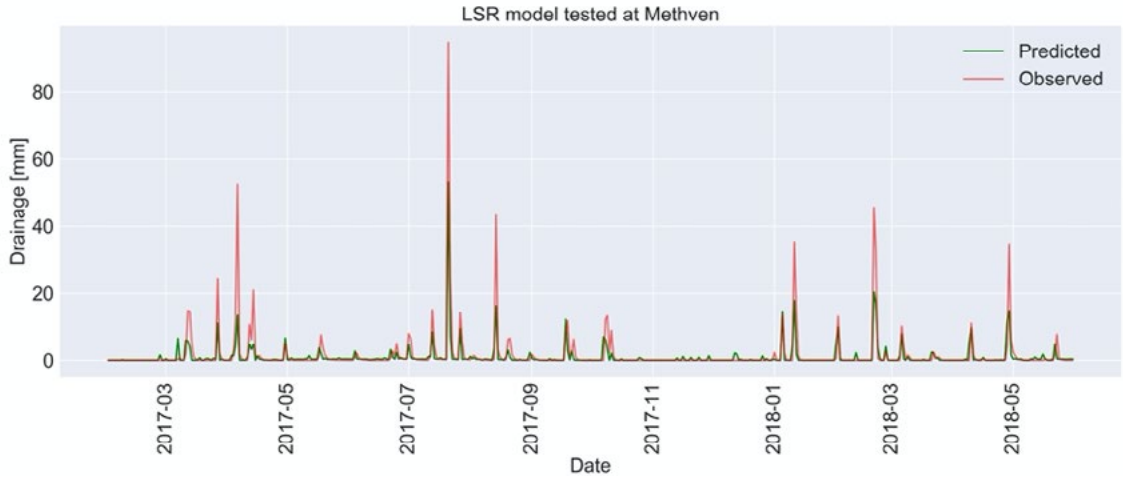

Figure 2: Example model result for daily time step at site Methven.

The model was implemented in a geographic information system (GIS) environment, in order to predict the spatial variability of land surface recharge, and to calculate GW allocation for three of the groundwater allocation zones of the Canterbury Region (i.e. Rakaia-Selwyn, Ashburton and Chertsey).

In summary, the methodology developed in this study couples a supervised machine learning technique with a visualisation tool in a GIS environment to predict land surface recharge. The tool may be utilised by water managers to develop sustainable dynamic regional groundwater allocation strategies.

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TILE DRAINAGE EFFECTS ON HYDROLOGICAL RESPONSES

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Aims

There has been an increase in sub-surface “tile drains” on the Gisborne Flats, especially with the conversion of pastoral land to kiwifruit orchards. Gisborne District Council wanted to investigate the potential influence of increasing horticulture tile drainage on the flood hazard of their surface drainage network. This network has a 5-year ARI design service level.

Method

A review of previous studies was undertaken, along with NZ and US Technical Drainage Guides. HEC-HMS models were developed to simulate a hydrological response on a hypothetical 100ha block to be converted to horticulture with tile drainage. The SCS Curve Number loss method was initially used to provide a “physical basis” to generate a 5-year flood hydrograph, and this model was then replicated with the SCS Initial Loss (IL) Continuing Loss model. The influence of tile drainage was then assessed by increasing the IL and CL to reflect the increased soil water capacity and increased permeability rates. This assessment was also extended to the 3km^2 Tansley Road (surface) drain catchment, which is planned to be upgraded. An assessment is also undertaken on the rainfall, groundwater, surface hydrology and soils for their permeability/infiltration characteristics of the area, and to assist in developing credible catchment rainfall-runoff models.

Results

From the review of previous studies, tile drainage increases rainfall losses to soil water storage. This water drains more effectively, reducing evaporative losses and surface runoff and hence peak flows. Peak flows can be up to 80% lower with tile drainage; the soils, slope, rainfall intensity and tile spacing influencing the surface hydrograph magnitude and shape. There is a “lag” with the tile drainage hydrograph, namely it is longer and flatter than the comparable surface hydrograph.

From the analysis of hydrometric data, measured 5-year ARI flood yields varied from 1.0 m^3/s/km^2 to 2.6 m^3/s/km^2. Comparable “NZ Flood Statistics” flood values for the same locations were 0.64 m^3/s/km^2 and 1.2 m^3/s/km^2 respectively. Soils in the Tansley road catchment, especially the potential horticulture area, are predominantly clay loams or silt loams over clay and are classified as poorly drained with low permeability.

HEC-HMS CN loss model that produced a flood peak of 1.0m^3/s was used for the 100ha agricultural block without drainage (Figure 1). This was matched by an SCS model with an IL of 12mm, and CL of 6mm/hr. Increasing the IL by 2mm and the CL by another 2mm/hr to represent improved soil water storage and permeability rates with tile drainage, reduced the peak flow by 30% to 0.7 m^3/s. Increasing the CL by a further 3mm/hr reduced the flood peak to 0.55 m^3/s. Extending this modelling concept to the larger Tansley Drain catchment, lowered the modelled peak by 16% for the lower increased in modelled losses and by 20% under the larger of the modelled losses.

The theoretical maximum tile drainage flow from the 100ha block will be around 400L/s. However due to the low hydraulic conductivity of the soils and from local practical experience, maximum flows will be less than half of this. The tile drainage flow will occur some hours after the commencement of rainfall, and after the surface hydrograph peak has passed.

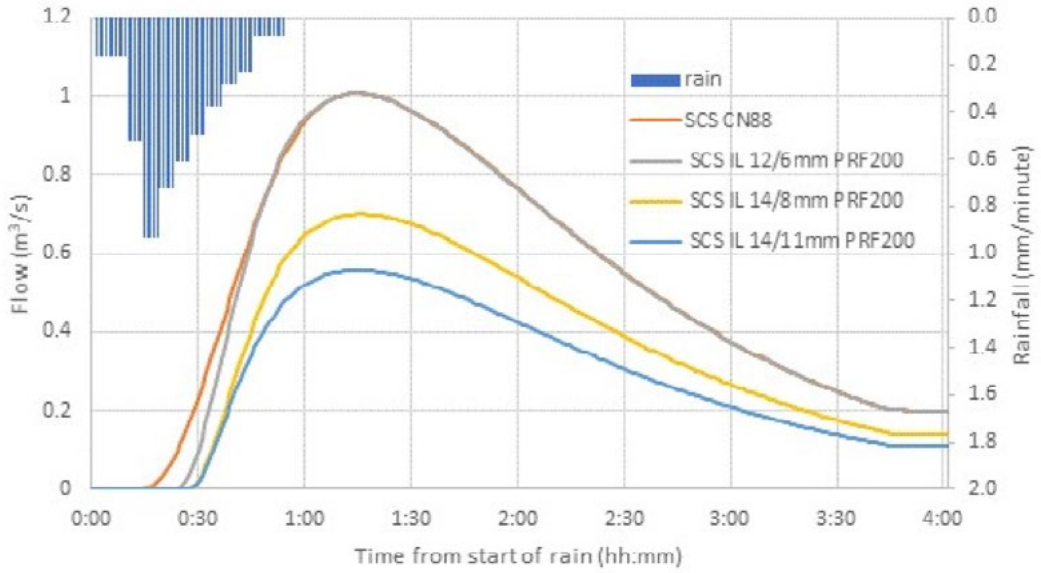

Figure 1: HEC-HMS 5-year flood hydrograph from 100ha using SCS CN88 (and SCS UH initial loss of 12mm and Continuing Loss of 6mm/hour) to represent the "undrained catchment" and increasing the IL and CL to represent improved soil water storage and permeability due to subsurface drainage.

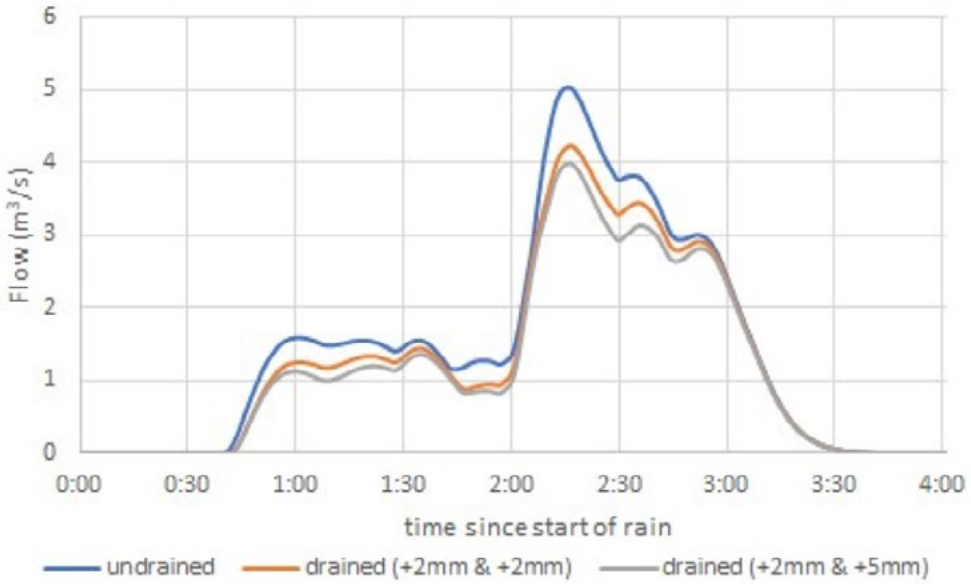

Figure 2: HEC-HMS 5-year flood hydrographs for Tansley Road drain using SCS UH initial and continuing loss models to represent the catchment with and without sub-surface drains.

DEVELOPMENT OF SYNTHETIC DNA TRACERS FOR TRACKING WATER CONTAMINATION

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[3] Environment Canterbury Regional Council
[4] Waikato Regional Council

Better management of water contaminants is urgently needed as the intensification of human activities has significantly polluted New Zealand's freshwater. However, a major barrier to better contaminant management is the lack of effective tools to provide spatially accurate information in tracking the sources of pollution and contamination pathways.

In this project, we have developed novel and environmentally friendly synthetic DNA tracers for the purposes of tracking water contamination sources and pathways. These new DNA tracers are biodegradable and non-toxic, hence, they can be used in ecologically sensitive freshwater environments. A suite of 20 different DNA tracer sequences is now available, each with a unique identifier, and these are available in either free or microencapsulated forms. The free DNA tracers can diffuse into the porous media of soils and aquifers, whereas the microencapsulated DNA tracers are protected from the environmental stresses that are often encountered in surface water and effluent.

We have validated these DNA tracers in undisturbed soil, in two groundwater systems in Canterbury and Waikato, and in a surface water stream in Canterbury. Soil lysimeter experiments used an undisturbed stony silt loam soil extracted from the Canterbury Plains. Properties of the aquifers at the Canterbury (coarse alluvial gravel) and Waikato (fine coastal sand) sites differed markedly as did their groundwater flow characteristics (fast and slow, respectively). Three surface water experiments were conducted in a stream with a fast flow rate of about 270 L/s (44 km/day) and with algae growing in some parts.

We have demonstrated that these DNA tracers are detectable and identifiable in field conditions, and we could track both the free and microencapsulated DNA tracers in the surface stream for a distance of at least 1 km. Compared with the free DNA tracers, the microencapsulated DNA tracers showed significantly lower reductions in their concentrations for the same distance travelled. The quantities of DNA tracers required were 6–8 orders of magnitude less than traditional dye and salt tracers used for water tracking.

We have also conducted laboratory studies investigating the degradation of the DNA tracers in groundwater, stream water, and in domestic and dairy shed effluent, as well as their adsorption in stream sediments, soils and aquifer media collected from field trial sites. These studies have improved our understanding of DNA degradation and adsorption in different environmental conditions.

DNA tracers show great promise as a tracking tool and we will continue to work with end-users to further validate these new tracers in field conditions. With further up-scaling, the new DNA tracer techniques could be used to concurrently track multiple pollution sources and pathways in freshwater environments. This research will lead to the development of better mitigation strategies that will protect New Zealand's precious freshwater resources.

REGIONALISTION OF THE NEW ZEALAND SWAT MODEL

Aroon Parshotam[1]
[1] Aqualinc Research Ltd.

Introduction

The Soil and Water Assessment Tool (SWAT), downloaded from https://swat.tamu.edu/, is a popular (over 3800 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 model is used internationally to assess best management practices and for supporting environmental directives. 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/or an advanced lake and reservoir model. It has also been used recently to indicate the fate and transport of pathogen loads in catchments. 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.

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 fertiliser application methods, and locations of intervention practices like wetlands and riparian buffers.

The aim of this work is to regionalise the national New Zealand SWAT model, which was created for the purposes of obtaining national assessments. These regional SWAT models may be run on a daily time step and output for every sub-catchment in a region may be daily, monthly or annual.

National SWAT model

A national SWAT-based sediment transport model was produced, by pre-processing land use/cover, topography and climate data for input into the model from available New Zealand databases (See Parshotam (2018a, b, c, d, e, f). That work has since been extended to include nutrient transport. Setting up and running 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. There was no calibration of the model or validation of results with measurement data, and this may be achieved within the SWAT modelling framework and implemented on a catchment-by-catchment basis.

Pre-processing of critical data for the SWAT model, such as soils and climate can be laborious and time-consuming, and a national dataset derived from the New Zealand National Soils Database (NZ-NSD) for use in SWAT was prepared (see Parshotam, 2018). Pre-processing climate data is possible by building up a SWAT dataset of data extracted from the National Climate Database through CliFlo. Alternatively, New Zealand Weather Data for SWAT is freely available through the Global Weather Data for SWAT (see https://globalweather.tamu.edu/) through the National Centers for Environmental Prediction (NCEP), Climate Forecast System Reanalysis (CFSR) programme. A weather generator is also a necessary input in the SWAT model and a World CFSR weather generator from CFSR stations including New Zealand ones is available. It is much more convenient to use CFSR data because it is readily available. However, this data needs to be checked against actual station data. Calibration should use actual station data.

Regional SWAT model

The limitations of applying the developed methodology for a nationlised SWAT model and applying it to various regions in New Zealand is given in Parshotam (2019a, b). A process of regionalising the model is necessary to reduce computation time and reflect within a specific region: i) crop factors and regional management practices, ii) soils, iii) range of slopes, iv) water quality issues, and v) “hotspots”. It may also be a necessary process before calibrating the model at a micro- sub-catchment level. The methodology for creating a New Zealand-wide national SWAT model, using available New Zealand databases is refined, with greater weight given to data from a given region and from respective councils.

In Parshotam (2018c), a 15m (2002) hydrologically consistent DEM, accessed from Landcare Research was used. The area threshold required to match SWAT-delineated sub-catchments to REC2 delineated sub-catchments was determined. This small sub-catchment size made computational time considerably large and presented issues with storing large output data files and presenting output results. Parshotam (2019) recommended the importance of burning the REC2 (or more recent digital stream networks such as DN3, if available) into the DEM to create a somewhat 'better' hydrologically corrected DEM. This process may be done automatically within ArcSWAT or QSWAT, which has better output visualization tools.

The method for producing a national soils map from the NZ-NSD did not give additional weight to similar soils in a given region. A regional soils dataset may obtained where similar soils within a region in the NZ-NSD is given additional weight. The same methodology given in Parshotam (2018a) is followed but data that is rated high quality within a region is given precedence.

Gridded weather data (precipitation, wind, relative humidity, and solar) from the CFSR is available in SWAT file format for a given grid location and time period. This climate data needs to be spot checked against regional station data from the national climate database. It is necessary to use actual weather station data and not CFSR data to develop a fully developed regional SWAT model. CSFR gridded data, however, needs to be compared with regional station data from the national climate database. The CFSR data was created using data supplied by NZ Meteorological Services from stations that are predominantly at airports and this should be considered when using CFSR data in various regions that are not low-lying.

Regions in areas where there are huge rivers creates overlay issues between the landcover database (LDCB4.1) and Fundamental Soils Layer (FSL) polygons (Parshotam, 2019b). To address this problem, a new landuse layer along rivers in the SWAT reclassified landcover data layer set, needs to be created.

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MEI TE VAI KI TE VAI: CATCHMENT NUTRIENT AND HYDROLOGICAL PROCESSES AND THEIR INFLUENCE ON MURI LAGOON, RAROTONGA, COOK ISLANDS

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Aims

A fringing reef surrounds the island of Rarotonga, with an associated shallow lagoon located between the reef and the shore (Befus et al., 2014; Tait et al., 2014). The width of the lagoon is at its greatest extent at the location of the Muri Lagoon, where it ranges from approximately 400 m – 900 m wide. Muri Lagoon has an approximate area of 1.75 km2, and an average depth of 1.4 m (Tait et al., 2013).

In recent years' Muri Lagoon has seen episodes of extensive seaweed growth and degradation of water quality. A broad range of potential causes has been suggested, including changes to lagoon hydrodynamics, historical agriculture, commercial development to support tourism and on-site wastewater disposal.

As part of the Mei Te Vai Ki Te Vai (MTVKTV) project, a detailed catchment and lagoon environmental investigation has been carried out to identify the drivers of lagoon degradation and seaweed growth, and inform early and longer-term mitigation options.

This paper presents the findings of the hydrogeological assessment carried out between June 2017 and May 2018.

Method

Assessment of Muri Lagoon and its catchment focussed on water quality, and chemical and physical processes as likely drivers for sea weed growth. A preliminary conceptual model of these conditions and processes was developed through literature review, with this informing gap analysis. The literature reviewed included a range of reports prepared by different ministries of the Cook Islands Government (CIG), reports prepared since the 1960s by technical experts commissioned by the CIG, and scientific journal articles prepared by researchers. In excess of 200 reports and articles were reviewed.

A subsequent suite of field investigations was undertaken in 2017-2018 to address information gaps identified and refine the conceptual model of influences on the lagoon. Investigations covered a wide range of fields including geology; hydrogeology; hydrology and water and sediment chemistry; lagoon ecology; and the lagoon's physical characteristics, such as bathymetry. Focus areas included:

1. Characterisation of freshwater (groundwater and surface water) flow paths to the lagoon, identification of attenuation processes, likely travel times and development of nutrient mass balances for each flow path.
2. Characterisation of physical and chemical processes in the lagoon, including hydrodynamics and sediment influences on water quality.
3. Review of catchment land-use and lagoon physical changes over time.

Results

A complex geological history has been identified in the Muri area, with differing episodes of volcanic activity and changing depositional environments. Three distinct groundwater flow paths have been identified, with these comprising (1) shallow beach deposits, (2) phonolite rock which outcrops as Taakoka Motu within the lagoon and (3) deeper fractured phonolite and basalt. Each groundwater flow path demonstrates distinct chemical and nutrient characteristics, physical properties and connection to the lagoon. Notably, each has different recharge environments and exposure to nutrient sources.

The catchment water balance is dominated by groundwater recharge, with streams and swamps providing areas of groundwater-surface water interaction, but otherwise relatively low freshwater flow to the lagoon. Shallow groundwater within coral sands and limestone of the beach terrace discharges to near shore areas and demonstrates the influence of wastewater discharges.

Deep groundwater, with an average age of 100 years, has been found to be confined at the beach area, but contributes the majority of the freshwater flow and catchment sourced nutrient load to the lagoon as submarine groundwater discharge, upwelling approximately 400-500 m into the lagoon and towards the reef.

Wave setup across the fringing reef creates a water level in the lagoon that's higher than sea level, driving a dominant gradient and generating water flow north and out through the Avana Passage. The lagoon flow patterns under all wave conditions, bar storm events, leave low flow water zones and poorly mixed groundwater, that correlate with areas of seaweed growth.

The investigation findings indicate that the lagoon is nitrogen limited and that shallow groundwater of the beach terrace, whilst not the greatest contributor of nutrients to the broader lagoon, is providing a relatively new and increasing source of nutrients to the more sensitive, low-flow areas, where seaweed growth has become prolific. The investigation emphasises the importance of obtaining a robust conceptual understanding of the dynamic lagoon and catchment processes when investigating causes and solutions for lagoon health.

Figure 1: Muri Lagoon, Rarotonga – Seaweed Growth Event (2016)

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EVALUATION OF THE USE OF STORMWATER ATTENUATION ON URBAN FLOODING

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Urban development often results in an increase in the volume of stormwater runoff causing the stormwater network capacity, including pipes, drains and waterways, to be reached more often and much more quickly. Development also reduces ground soakage and vegetation that would have previously slowed runoff.

In this study, stormwater attenuation, the process of storing storm water on site and releasing it in a controlled manner, was used to mitigate the effects of urban development on floods in the Morningside area, Whangarei. There are a number of ways of stormwater attenuating flow including storage tanks, underground storage and ponds.

The objective of this paper was to evaluate the use of stormwater attenuation on urban flooding and to determine how stormwater attenuation can help to mitigate the effects of urban development on flood risk. It was found thatstormwater attenuation can help to minimise the potential for increased discharge of stormwater runoff from the urban development site to streams and receiving environments.

Key words

Runoff, flood risk, Stormwater Attenuation, Hydraulic Modelling, Urban Development

PREDICTING UNIMODAL WATER RETENTION CURVES OF FINE TEXTURE SOILS FROM TRADITIONAL PARTICLE SIZE DISTRIBUTION DATA

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Aims

Indirect methods for estimating soil hydraulic properties from particle size distribution have been developed due to the difficulty in accurately determining soil hydraulic properties, and the fact that particle size distribution is one piece of basic soil physical information normally available. The similarity of the functions describing the cumulative distribution of particle size and pore size in the soil has been the basis for relating particle size distribution and the water retention function in the soil. Empirical and semi-physical models have been proposed, but these are based on strong assumptions that are not always valid. For example, soil particles are normally assumed to be spherical, with constant density regardless of their size; and the soil pore space has been described by an assembly of capillary tubes, or the pore space in the soil matrix is assumed to be arranged in a similar way regardless of particle size. However, in a natural soil the geometry of the pores may vary with the size of the particles, leading to a variable relation between particle radius and pore radius.

Method

The current work is based on the hypothesis that the geometry of the pore size and the void ratio depends on the size of the soil particles, and that a physically based model can be generalised to predict the water retention curve from particle size distribution. The rearrangement of the soil particles is considered by introducing a mixing parameter that modulates the cumulative particle size distribution, while the total porosity is constrained by the saturated water content.

Results

The model performance is evaluated by comparing the soil water retention curve derived from laboratory measurements with a mean Nash–Sutcliffe model efficiency a value of 0.91 and a standard deviation of 0.14. The model is valid for all soil types, not just those with a marginal clay fraction.

Keywords

Particle size distribution; pore size distribution; water retention curve; soil hydraulic parameters; Kosugi model

RIVERS IN SKIES: BRINGING SNOW TO THE SOUTHERN ALPS

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The Southern Alps are a key landscape feature that shapes the hydrology of alpine rivers in the South Island of New Zealand. Seasonal snow is an important element of water resources in the Southern Alps by influencing the timing and magnitude of the discharge of alpine rivers (Kerr, 2013). Large snowfall events, in particular, control the interannual variability of snow storage during winter and the amount of water released during the melt season. In the maritime Southern Alps, climate warming poses a unique threat to snow hydrology because much of the snowpack accumulates at temperatures near 0 °C.

Despite few studies about climatology of snow on some glaciers in the Southern Alps, the climatological and meteorological features of snowfall events is largely unappreciated across the Southern Alps. One of the areas important for snow hydrology is moisture transport available for winter precipitation. The majority of the poleward moisture transport across the mid-latitudes is carried out by atmospheric rivers (ARs). Strong relationships have been found between ARs and hydrological processes such as precipitation, streamflow and flooding in the mid-latitudes of the western North America, South America, the Norwegian coast and the British Isles. In the western US, for example, it is estimated that 25-50% of the total water supply in California is due to the landfall of ARs. One of the reasons atmospheric rivers has recently gained more attention in regions such as western United States is their potential to put an end to long term droughts (Dettinger *et al*., 2011). Even though previous research has highlighted the potential role of ARs as strong drivers of solid precipitation in alpine terrains (Guan *et al*., 2013; Hansen, 2016; Demaria *et al*., 2017) their role in snow accumulation is still largely unknown in many parts of the world including alpine catchments of the Southern Alps. The results of a recent study by Little et al. (2018) at Brewster glacier, located on the west side of the Main Divide, show significant relationship between ARs and glacier mass gain and loss by influencing snow accumulation and snow ablation. The next step is to examine the role of ARs on large snowfall events at greater spatial scale across the Southern Alps. Of particular interest is the analysis of moisture transport in the South Pacific region over the Tasman Sea and its relationship with large snowfall events in the Southern Alps. There has been a lack of systematic measurements of snow in the Southern Alps despite broad seasonal snow cover. Success in snow measurement, however, has been recently gained by establishing a network of high altitude monitoring sites by the National Institute of Water and Atmospheric Research (NIWA) (Hendrikx & Harper, 2013). The new network has provided an opportunity to collect snow observations especially close to the Main Divide of the Southern Alps which contains the main areas of the snow fields with great importance in contributing to river flows during the melt season.

Aims

This study seeks to investigate the role of ARs in producing large snowfall events across the Southern Alps in order to improve understanding of how large-scale atmospheric processes manifest in local and regional scale snow accumulation.

Data and Method

We utilised daily data of snow depth from three SIN sites across Southern Alps over a period of eight years. To identify the large snowfall events, the value of 90th percentile of daily snow depth at each site was used. The Interim European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis was used to identify ARs. We calculated the integrated water vapour (IVT) fields at 0.5° × 0.5° spatial resolution and 6-hourly temporal resolution. Here, IVT is defined as

$$IVT = \sqrt{\left(\frac{1}{g}\int_{1000\,hPa}^{300\,hPa} qu\,dp\right)^2 + \left(\frac{1}{g}\int_{1000\,hPa}^{300\,hPa} qv\,dp\right)^2} \quad (1)$$

where g is the gravitational acceleration, q is the specific humidity, u is the zonal component of the wind, v is the meridional component of the wind, and p is the pressure. An approach similar to Rutz et al. (2014) was applied to identify atmospheric rivers using IVT values.

Results

It was found that 35% of annual snow accumulation was received during the large events demonstrating the vital contribution of these events to the snow hydrology of the Southern Alps.

While the landfall of ARs can potentially lead to major flooding events in the region, our results show that about 70% of large snowfall events across the Southern Alps during winter are associated with ARs. Strong fields of IVT responsible for moisture transport, accompanied by rapidly deepening pressure systems are the main driver of large snowfall events over the Southern Alps. ARs responsible for the largest snowfall events at three sites are shown in figure 1. The frequent occurrence of ARs during winter precipitation across the Southern Alps indicates the key role of meridional water transport available for precipitation. Our findings demonstrated that moisture transport within a predominantly north-westerly airflow is a significant contributing component during large snowfall events. Also, low and mid-level jet streams play a critical role in transferring moisture across the South Pacific Ocean over Tasman Sea prior to large snowfall events in the Southern Alps. The findings of this study can be used to complement operational forecasting models for predicting large snow events in the maritime conditions. The position and strength of water vapour flux inside an AR impact the magnitude of incoming moisture available for precipitation, therefore, further research is needed to pose new insights into mechanisms of ARs responsible for extreme hydrological events across the Southern Alps.

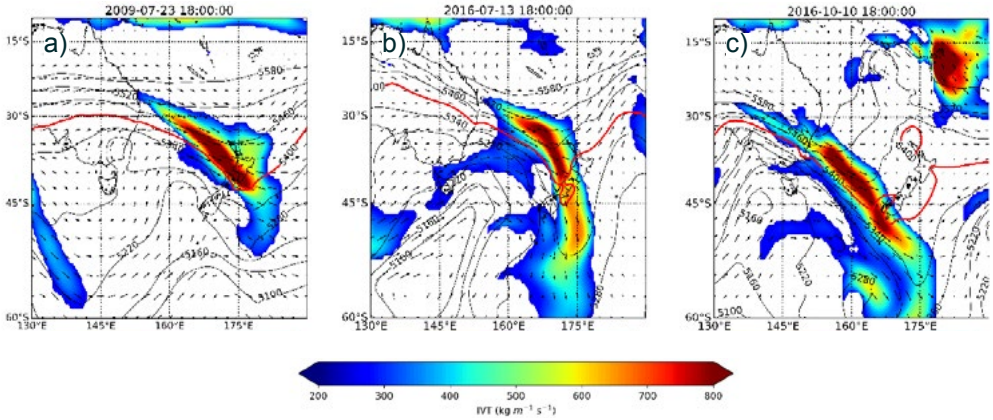

Figure 1. A depiction of ARs associated with the largest snowfall events at a) Mahanga, b) Mueller Hut, and c) Mt Larkins

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FLOODING AND ATMOSPHERIC RIVERS OVER THE LAST 40 YEARS

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Atmospheric Rivers (ARs) are filamentary regions of enhanced atmospheric water vapour transport, responsible for over 90% of the horizontal moisture flux through the midlatitudes. A vast amount of research has been conducted on ARs experienced on the West Coast USA linking these features to extreme precipitation, flooding, drought and snowfall. Comparatively, little work has been conducted on these features in other mid-latitude locations around the world. In the Southern Hemisphere, New Zealand has been recognized as a location where Atmospheric Rivers may be just as influential as they are in the USA, however, research is yet to fully substantiate this connection. Exploratory work by Kingston et al. (2016) demonstrated that the eight largest floods in the headwaters of the Waitaki River were produced by AR events. Recent research by Little et al. (2019) also linked large melt and snowfall events at Brewster Glacier to AR structures. To further understand the role of ARs in New Zealand, automatic detection algorithms need to be run to develop a non-subjective, scientifically robust database of all ARs that have occurred in the New Zealand region. The suitability of detection algorithms and subsequent AR categorizations presents a unique forecast application; by tracking ARs in forecast datasets it is possible to improve the forecasting of the largest floods in New Zealand such as the devastating West Coast floods in March 2019. Developing and communicating the importance of ARs in New Zealand will not only be of interest to scientists, but also to water and emergency managers, media, public and policy makers.

Aims

The main objective of this work is to study the occurrence of Atmospheric Rivers in New Zealand and how well tracking algorithms can detect and track these events. The role of ARs in New Zealand surface water hydrology is also to be addressed by examining precipitation and discharge records during landfalling AR events at different locations within New Zealand.

Method

An object-orientated AR detection algorithm that was developed in the USA (Guan and Waliser, 2015) will be run for to the New Zealand region over the last 40 hydrological years (1980 - 2019). Globally gridded datasets from Era-Interim (ECMWF) are used to identify filamentary regions of high integrated vapour transport (IVT) over New Zealand. The historical occurrence of extreme vapour flux is analysed and return periods of such events are produced. The purpose of calculating return periods is to communicate the magnitude of individual storms in a quantitative manner, allowing for a simple comparison between storm events. Extreme vapour events are also characterized based on new definitions (from the USA), dependent on the magnitude and duration of extreme vapour events at individual grid cells in the New Zealand region (Ralph et al., 2019). The seasonality of different category events is presented for different locations in New Zealand and the link between ARs and precipitation/river discharge is established.

Results

A primary outcome of AR tracking algorithms is the ability to categorize individual storms. A storm of particular interest is the event that produced the disastrous flooding on the West Coast in March 2019. The tracking algorithm classified this storm as a Category 5 event (the largest possible event) due to the intensity of the atmospheric vapour flux and the duration that storm persisted for in that location (Figure 1). Historical analysis of the last 40 years indicates that the 2019 West Coast flood was a ‘1 in 5-year’ event. The West Coast floods set the record of maximum 48-hour precipitation, producing 1086 mm of rain, an extremely high precipitation for what is being classified as a ‘one in five’ year storm through the analysis presented. The relationship between atmospheric vapour flux and precipitation in nontrivial and high vapour does not necessarily produce high precipitation. In the case of the West Coast storm, the atmospheric conditions were not abnormal, these atmospheric conditions occur regularly (approximately every 5 years). The interpretation is that these events only generate conditions conducive to extremely high precipitation events. Interestingly, the previous 48-hour precipitation record in New Zealand (also record at the Cropp River weather station) was also a Category 5 Atmospheric River. Historical analysis of precipitation records will be compared to the 40-year dataset of ARs to establish the relationship between ARs and high precipitation, proving the use of a detection algorithm that can be run on forecast data with the hope of improving the forecasting and understanding of such extreme floods.

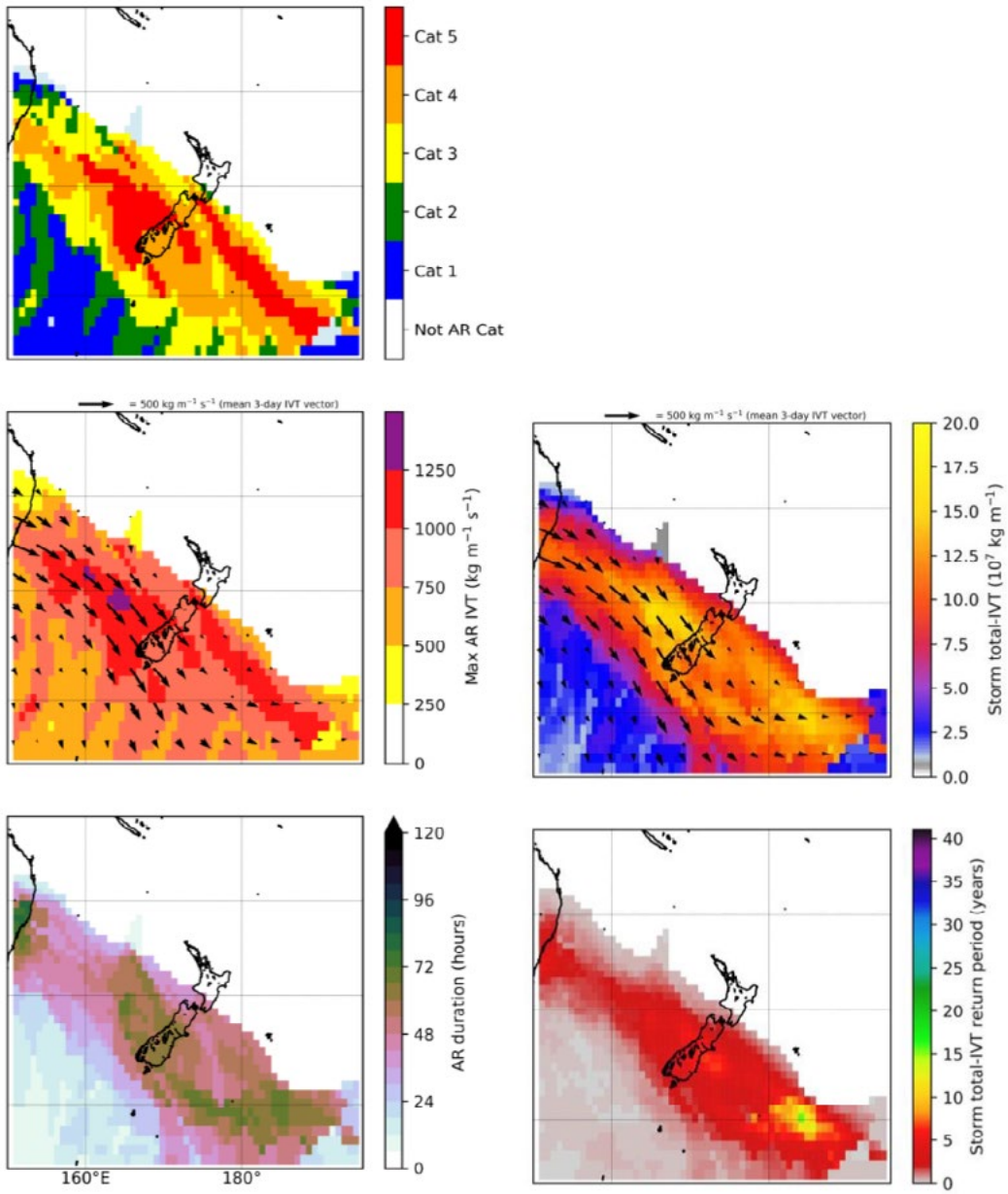

Figure 1: Storm characteristics of the West Coast, March 26th 2019 flood. The storm registered as a Category 5 event on the West Coast, persisting for up to 72 hours with maximum IVT reaching over 1000 kg m-1 s-1, values considered to be extreme. Interesting, the return period of this storm was 5 years, relatively low considering the severity of the surface flooding.

River discharge will also be examined throughout the last 40 years across the length of the country to further understand the link between extreme atmospheric vapour fluxes and surface processes. Initial results suggest that topography may have a significant impact on the amount of precipitation that comes from individual AR events. That an AR event making landfall on the West Coast will produce more rain than an AR of the same magnitude making landfall in Auckland.

There are multiple examples of the applicability of AR detection algorithms from the USA. One such example is the management of Californian reservoirs prior to extreme events, by lowering the water levels when approaching ARs are detected. Another application is in a larger climatological perspective, addressing the annual variability of precipitation. Through understanding the link between ARs and global circulation, it is possible to discuss how extreme precipitation events may change in the future under a changing climate.

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SIMPLE INTEGRATED SURFACE WATER–GROUNDWATER CONTAMINANT TRANSPORT MODEL

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Introduction and Aims

Numerical models are often used to process environmental data, and to predict likely future environmental behaviour under a suite of proposed management options. The natural environment is complex, resulting in a natural tendency to build numerical models that are complex. However, this is time-consuming and expensive, and even the most complex numerical groundwater model cannot replicate reality. There are two reasons for this:

- Reality is far more complex than even the most complex model
- The process and hydraulic property details in the model probably misrepresent reality.

A complex model may therefore be imbued with the “wrong complexity”. A simple model is much less expensive to build than a complex model, and is likely to run faster on a computer. Hence it can be used to process environmental data in creative ways. Processing for a simple model can happen in a matter of minutes rather than hours or days that might be required for a complex model. Furthermore, a simple model does not require the same level of numerical expertise to construct and calibrate. This makes its use more “democratic” than for a complex model, for the latter is a tool that only a modelling specialist can use.

We present a simple catchment model, CLUES-GW, that provides mean-annual contaminant load and concentration estimates for surface water.

Method and Results

We developed a simple catchment model, CLUES-GW, that provides mean-annual contaminant load and concentration estimates for surface water. CLUES-GW represents an extension of the existing CLUES, the Catchment Land Use and Environmental Sustainability model (Elliott et al. 2016). CLUES-GW includes up to two groundwater reservoirs under each surface water sub-catchment. The groundwater reservoirs exchange water with the adjacent (groundwater) reservoirs. The shallow reservoir also exchanges water with the surface-water streams. The runtime of the model is approximately 4 seconds, and so the quick runtime allows extensive model calibration, uncertainty and scenario analyses.

The model was applied to two case study catchments to investigate N transport: Hauraki in Waikato region and Mid-Mataura in Southland region. In Hauraki case study, Monte Carlo parameter conditioning from 10,000 parameter realisations was used to identify the best 200 ‘posterior’ parameter sets. The posterior parameter distributions were used to examine the N loads and concentrations at key locations under the current N loading dynamics (Figure 1) and a hypothetical future scenario of 20% reduction in N loading.

The second model, Mid-Mataura was calibrated using PEST software against measured river flows, and N loads and concentrations. An approach was developed to disaggregate model outputs, of mean-annual contaminant loads and concentrations, to daily timesteps using a rating-curve relationship between measured flows and concentrations. The calibrated model output along with the relationships developed for disaggregation were used to develop daily N concentration timeseries using flow data. The daily N concentration timeseries will be used as a management tool to assist with land and water management within the catchment.

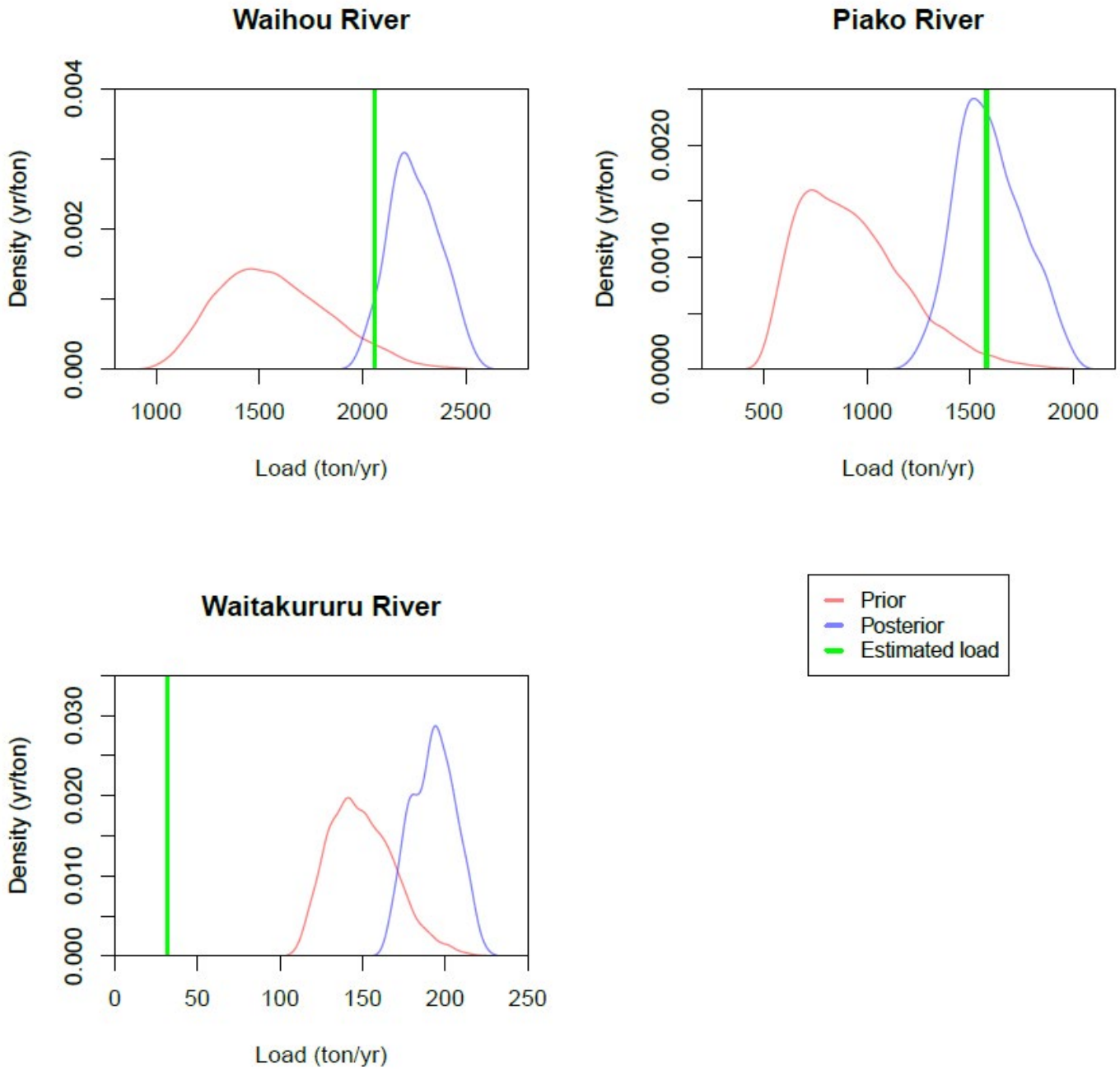

Figure 1: Prior and posterior probability distributions for load at the stream outlets to the coast in Hauraki catchment.

Acknowledgement: CLUES-GW model was developed under GNS led MBIE research programme “Smart Models for Aquifer Management” (SAM).

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MANGAWHAI GROUNDWATER QUALITY: UNRAVELLING THE SALT WATER INTRUSION AND LOW-TEMPERATURE GEOTHERMAL PUZZLE

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Aims

Mangawhai township is a popular summer holiday destination located approximately 50 km southwest of Whangarei. There is no reticulated water system with water sourced from rainwater. In summer, when rainfall is low, and the population swells, it is standard practice for residents to "buy in" water from commercial water suppliers. Numerous groundwater wells exist in the area, but few wells have groundwater quality suitable for drinking. To date, the poor groundwater quality has been linked to possible saltwater intrusion and the marine depositional environment of the Mangawhai aquifers. However, elevated water temperatures in one Mangawhai bore suggests that a low-temperature geothermal system exists in the area and that mineralised geothermal water could also be a contributor to the poor water quality.

The aim of this study is to determine the source of the high Na-Cl water in the Mangawhai area and the extent of the low temperature geothermal system using water quality indicators.

Methods

Water samples from 11 groundwater bores in the Mangawhai area were collected and analysed in August 2017. Bores were targeted to identify deep (100-250 m deep) groundwater up flows. Water samples were analysed for major cations, anions, typical geothermal tracers, and deuterium and oxygen-18 water isotopes.

The new data was combined with historic groundwater quality data from the Mangawhai area presented by Massey (1987) and Sinclair Knight Merz (2010). Data from Reyes et al. (2010) is used to compare chemical ratios from this study to those from groundwater effected by low temperature geothermal systems in the Northland and Hikurangi (Gisborne) regions.

Results

Chloride-boron-bromide relative concentration ratios (Figure 1) show that the Mangawhai groundwater samples generally plot on a seawater – mean crustal rock mixing line. Boron (B) and chloride (Cl) are conservative species that can provide an indicator of groundwater evolution. In sedimentary rocks, a progressively increasing B/Cl ratio is indicative of increased rock dissolution (Reyes et al., 2010). At the nine sites where B concentrations are greater than that of seawater, the high B and Cl water is probably derived from the deep circulating fluids that have come from the Greywacke basement rocks. $\delta^{18}O$ data (Figure 2) shows that the Mangawhai samples at most sites are enriched relative to seawater, indicating that the water samples cannot be derived from mixing with fresh seawater alone. The chemical composition of the well waters suggests a connate seawater end-member which has been transformed by diagenetic reactions. This, and the elevated residual water temperatures (27°C), likely indicates a low temperature resource at depth at Mangawhai.

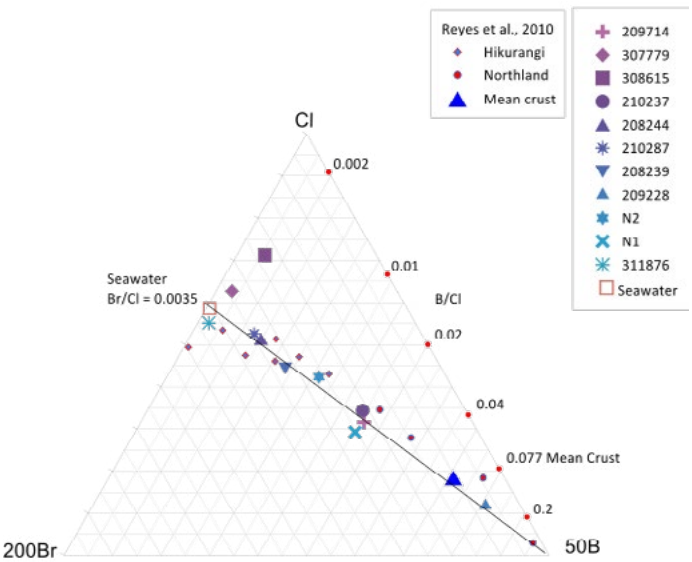

Figure 1: Relative concentrations (weight%) of B, Cl and Br for the recent Mangawhai groundwater samples. Hikurangi, Northland and mean crust data from Reyes et al. (2010).

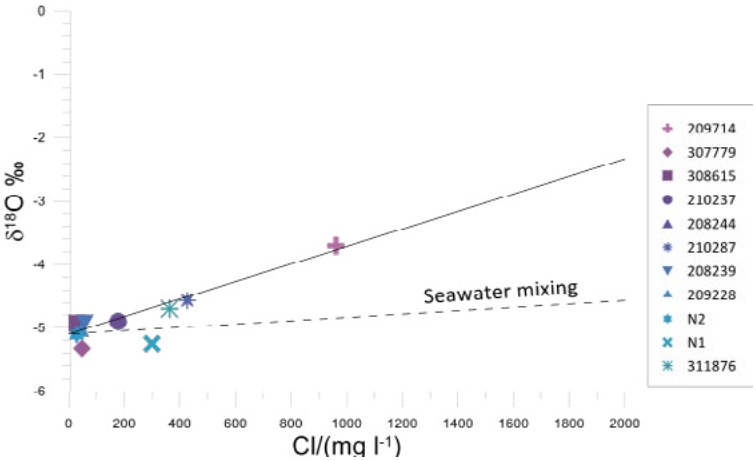

Figure 2: Cl versus $\delta^{18}O$ for the Mangawhai groundwater samples showing the Mangawhai high-Cl end-member mixing line (solid line) and the seawater mixing line.

Acknowledgements

The authors wish to acknowledge the many landowners who allowed us to sample their bores, and Northland Regional Council for supplying data and reports. This study forms part of GNS Science's "New Zealand's Geothermal Future" research programme (NGF) and was funded by the Government of New Zealand.

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SPATIAL MODELLING OF GROUNDWATER NITRATE-NITROGEN CONCENTRATIONS IN THE SOUTHLAND REGION

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[1] Environment Southland
[2] Land Water People

Aims

Nitrogen is a common contaminant of ground and surface water that is associated with human activities, particularly agricultural land use. Environment Southland (ES) is regularly required to assess groundwater nitrate-nitrogen concentrations when making resource management decisions. To date ES has relied on using spatially restricted direct measurements, simple interpolation models and risk assessments based on landscape attributes. This study investigates the use of random forest machine learning methods to model groundwater nitrate-nitrogen concentrations at different depths to provide another tool for use in resource management.

Method

We used median total oxidized nitrogen (TON) values from 527 sites and 25 potential predictors as training data for a random forest (RF) model of measured groundwater nitrate-nitrogen concentrations. This method allows the inclusion of controlling variables to guide predictions and moves away from the limitations associated with the simple geographic interpolation used by previous modelling work. We used a data filtering and predictor variable reduction process to find the most parsimonious model. The fitted model was used to predict present day groundwater nitrate-nitrogen concentration for all cells in a grid (1km^2 cells) of the Southland Region where predictor data was available. TON predictions were made for three well depths (7, 10 and 20 m b.g.l.).

Results

The reduced model (i.e., the most parsimonious model) retained only six predictors. The retained predictors included the geographic coordinates (North and East), the well depth, groundwater management zone (GWMZ), precipitation source, and landscape factors describing the transport and fate of nitrogen in groundwater (physiographic zones and variants). Model performance was low and did not improve significantly after exclusion of sites exhibiting anomalous groundwater quality and obviously erroneous TON data. The reduced model fitted using clean dataset and all the predictors had poor performance (r^2 = 33%, standard error of 0.4%) but had low bias (percent bias = -2.1%). The root-mean-square deviation was 3.3 mg L^{-1}. This study highlights some of the difficulties in modelling groundwater nitrate-nitrogen concentrations over a large area. Despite the high site scale uncertainty, the mapped predictions are a useful general description of the broad (i.e. landscape-scale) variation in groundwater nitrate-nitrogen concentrations across the Southland region (Figure 1). For example, model predictions estimate that approximately 47% and 1% of groundwater within the Southland's GWMZ's exceeds 3.5 mg/L and 11.3 mg/L (TON) respectively.

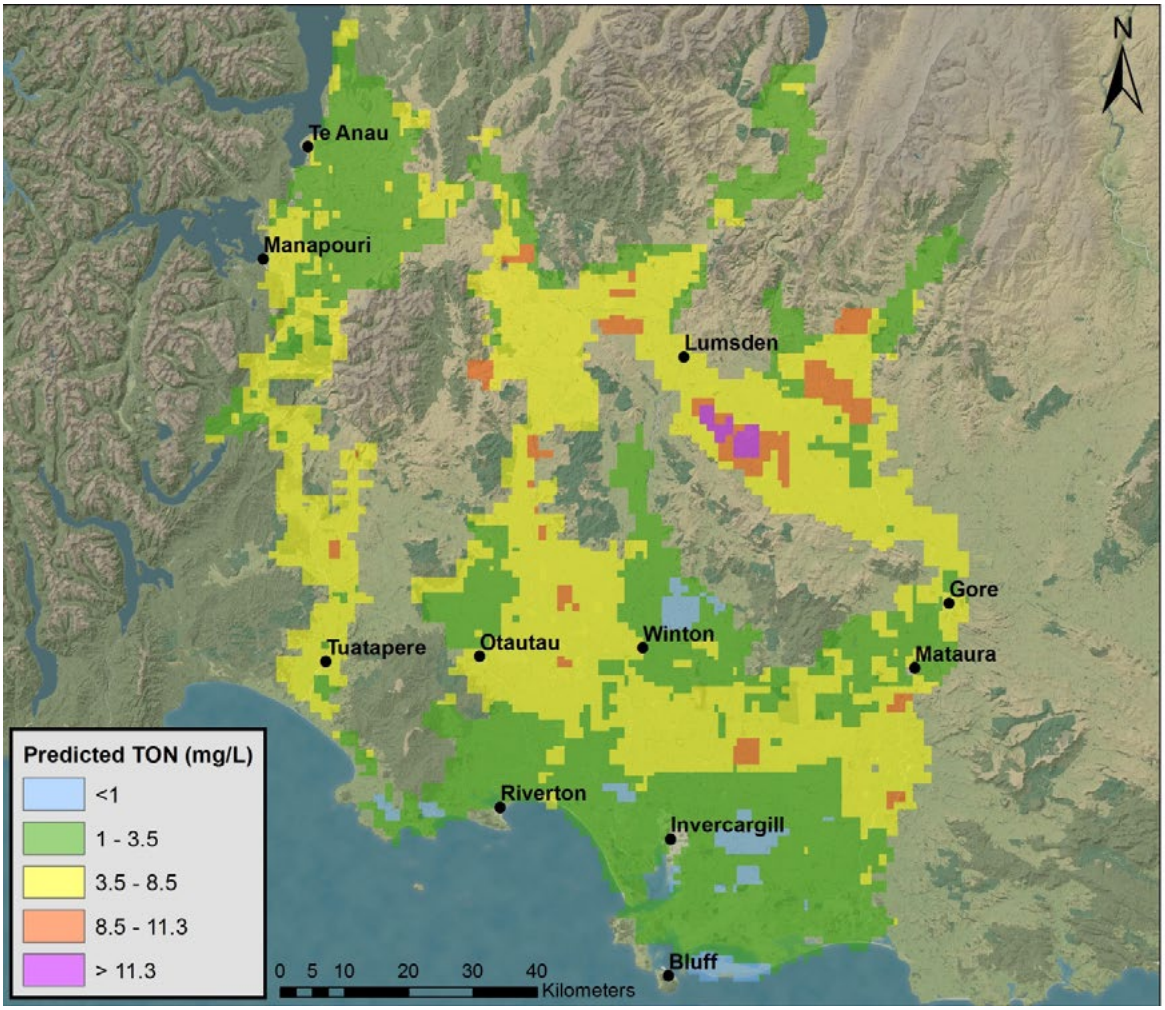

Figure 1: Model output showing predicted TON concentrations at 7 m b.g.l.

QUANTIFYING GROUNDWATER ABSTRACTION IN THE FACE OF IMPERFECT DATA

Helen Rutter,[1] Julian Weir,[1] Birendra K. C.[1]
[1] Aqualinc Research Ltd

Assessments and modelling of groundwater systems usually require quantification of groundwater abstraction (use). With increasing frequency, water takes are metered and data are becoming available. However, there is often a disconnect between the data required for an assessment and that which is available. Furthermore, data for smaller (often permitted or unconsented) takes simply do not exist.

We will outline different approaches for quantifying groundwater abstraction, including estimating actual versus consented abstraction, and estimating abstraction from unconsented takes. The first approach uses consent information and converts this to a likely actual take based on climate, crop types, and irrigated areas. The second approach estimates permitted groundwater use based on available permit information, land cover, agricultural statistics, and other data (including probable source of water).

These approaches have been used to quantify groundwater abstraction in the face of missing or imperfect data. The results have been used in varying ways, from informing policy decisions to being used as inputs to groundwater modelling.

Innovative approaches to making use of available data have enabled us to understand groundwater use in cases where abstraction data are limited or non-existent.

AN ASSESSMENT OF NITRATE TRENDS IN GROUNDWATER ACROSS CANTERBURY: RESULTS FROM A SCIENCE FAIR PROJECT

Katherine Rutter,[1] Helen Rutter[2]
[1] Rangi Ruru Girls School
[2] Aqualinc Research Ltd

Nitrate-nitrogen concentration data were obtained from Canterbury Regional Council and summarised for the purpose of a Science Fair project. Nitrate-nitrogen concentrations were summarised by decade, depth, and water management zone. Some of the patterns and anomalies are described, including potential sources of contamination, and the differences between zones are briefly examined.

The results confirm that, as would be expected, nitrate-nitrogen concentrations increase at shallow depth before migrating deeper into the aquifer. However, increases at depth are seen in all of the regions with time. The differences between the regions are marked. The influence of the Waimakariri recharge and the limitation of intensification within the Christchurch-West Melton zone have been successful in keeping nitrate-nitrogen concentrations low across much of the region (see Figure 1), though localised hotspots do occur in the south of the zone (Figure 2).

The Selwyn-Waihora zone shows mixed results in terms of the pattern of nitrate-nitrogen concentrations, both spatially and temporally. The area around Te Waihora generally shows very low nitrate-nitrogen concentrations, which has been suggested to be caused by upward flow from deeper layers and/or denitrification in the organic-rich, heavy soils around the lake. However, a region of higher nitrate-nitrogen concentrations occurs towards the southern end of the lake, which is possibly a result of effluent discharge and other land uses up-gradient, combined with a hydrogeological setting that is more susceptible to nitrate accumulation.

The Ashburton area, overall, shows the most impacted groundwater, with nitrate-nitrogen concentrations being elevated at all depths (see Figure 3). Some of the areas affected could be impacted by disposal of meat works effluent, but this does not explain the high concentrations across the whole zone, which is likely to be a result of historical and ongoing land use.

The main conclusion from this study is that nitrate-nitrogen concentrations in groundwater across Canterbury are highly variable, both spatially and temporally. Whilst the Christchurch-West Melton zone has, on the whole, relatively low nitrate-nitrogen concentrations in groundwater, the Ashburton area has a much greater nutrient contamination issue. Concentrations are also highly variable across relatively small areas, possibly reflecting factors such as local contamination sources and soil conditions.

There is evidence of groundwater being impacted, in terms of elevated nitrate-nitrogen concentrations, before dairy farming expansion in Canterbury. The influence of low and high recharge periods is also evident, with high recharge in the late 1970s likely causing high observed nitrate-nitrogen concentrations in groundwater.

This study has highlighted the high degree of variability, both temporally and spatially, in terms of nitrate-nitrogen concentrations in groundwater. It has shown differences between the different zones investigated, between the depths investigated, and has also highlighted the overall changes in nitrate-nitrogen concentrations over several decades. Using all available data, whilst having drawbacks (such as whether samples are representative), does allow a view of the patterns in nitrate-nitrogen concentrations that is not possible with a few, long time series datasets.

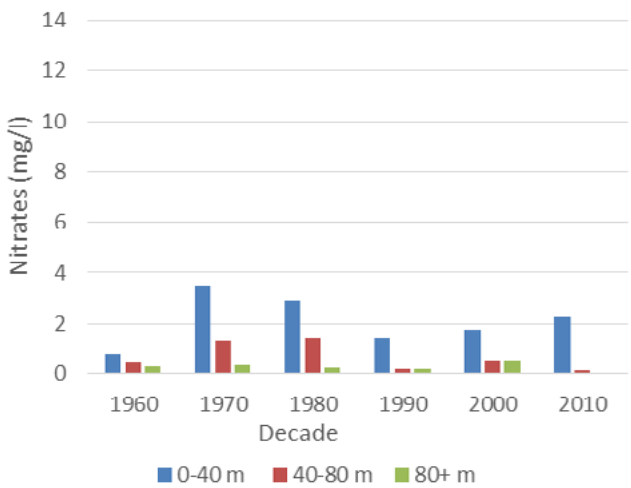

Figure 1: Average nitrate-nitrogen concentrations per decade in the Christchurch-West Melton Zone divided into well depth categories

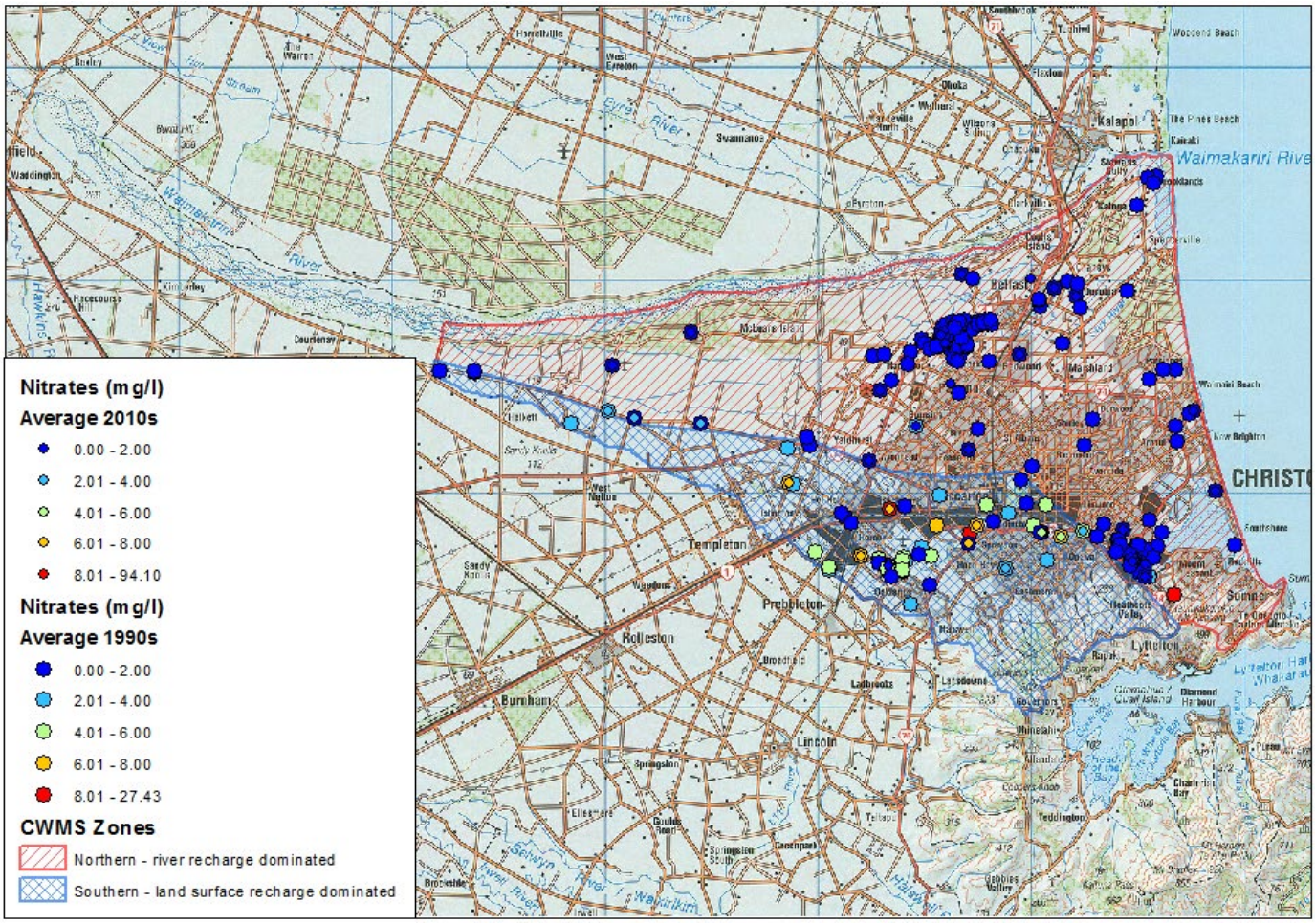

Figure 2: Spatial distribution of nitrate-nitrogen concentrations in the Christchurch-West Melton zone (1990s – 2010s)

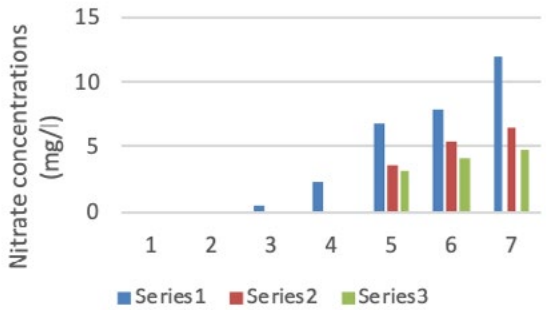

Figure 3: Average nitrate-nitrogen concentrations in the Ashburton Zone by decade

INCREASING REGULATION EFFICIENCY FOR THE REDUCTION OF NITRATE DISCHARGES FROM AGRICULTURE

Theo S. Sarris,[1] David M. Scott,[1] Murray E. Close[1]
[1] ESR (Institute of Environmental Science and Research)

Aims

Nitrate contamination of groundwater resources is a global phenomenon in both rural and urban environments. Understanding where in a catchment nitrate is removed is key for designing effective land use management strategies that protect water quality, while minimizing the impact on economic development. The objective of this study was to assess the effects of spatially targeted nitrate leaching regulation in a basin with limited knowledge regarding the representation of chemical heterogeneity. The Reporoa basin in New Zealand's North Island was selected as the case study for this work because there is a range of subsurface redox environments.

Method

Three nitrate reactivity spatial parameterizations (of increasing complexity and detail level) were incorporated in a catchment-scale flow and transport model and used to evaluate the effectiveness of four spatially targeted regulation options.

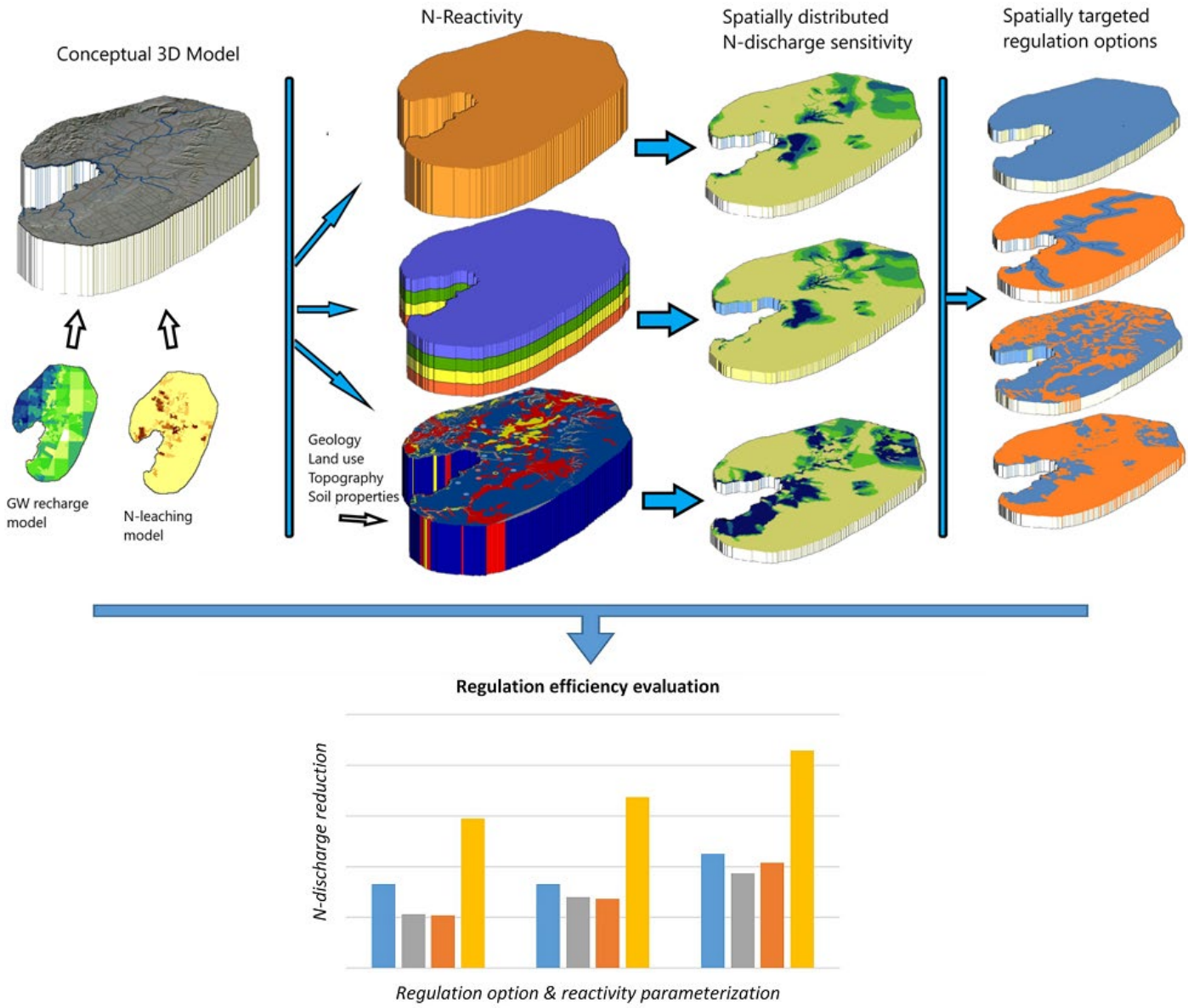

Figure 1: Steps and key elements for the assessment of spatially targeted regulation efficiency

As it is not clear where denitrification is occurring within the basin, three representations of the spatial distribution of nitrate reactivity have been considered in this study. These are a) N-reactivity is assumed uniform across the basin, both in areal and depth extent; b) N-reactivity is assumed to be depth dependent; and c) N-reactivity is assumed to be spatially variable. The denitrification process was simulated as a first-order irreversible mass reduction. The effect of regulation was simulated using the spatially distributed N-discharge sensitivity vector, which is defined as the nitrate mass discharge to surface water systems from unit N-leaching load to each model cell.

Finally the four spatially targeted regulation options considered in this study are: a riparian zone (RZ), a uniform basin-wide management zone (CMZ), a non-reducing zone (NRZ) and a discharge sensitive zone (DSZ).

Results

Implementing spatially targeted regulation is considerably more efficient than uniform regulation. Focusing regulation in areas where nitrate residence time is small such as riparian zones, or areas with low natural N-reduction results in a greater reduction of N-discharges through groundwater. In the Reporoa case study, significantly improved efficiencies can be expected when delineation of management zones considers all possible N-reduction mechanisms. This improvement is achieved by imposing regulation to the discharge sensitive areas, where management rules are applied to those areas where leaching load changes contribute the most to the N-discharge sensitivity. Such zones will always be catchment specific and account for flow paths, residence times, distribution of surface water networks as well as the subsurface zones where denitrification is occurring.

From a policy perspective, implementing a uniform regulation across a catchment could be tempting in terms of equal burden sharing and due to the uncertainties associated with mapping the target areas, but this would result in considerable lower efficiencies. In our case study, regulation in discharge sensitive zones was twice as efficient compared to the other management options.

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ESTIMATION OF ET THROUGH SIGNAL PROCESSING OF DAILY STREAMFLOW FLUCTUATIONS

Muhammad Waqas Sarwar,[1] Ali Shokri,[1] Samuel Burgess[1]
[1] University of Waikato

Introduction

In environments with a shallow water table, transpiration of plants and evaporation from the ground surface are shown to induce diurnal signals in soil moisture and water table profiles (White, 1932; Dolan, Hermann, Bayley, & Zoltek, 1984). These signals are characterized by an early morning maximum and an afternoon minimum in the soil moisture profile and groundwater table. The soil moisture depletion also tends to reduce groundwater recharge and hence discharge to the streams (Barnard et al., 2010). White (1932) was the first to estimate sub-daily evapotranspiration (ET) rates from diurnal cycles in the groundwater table. Since then, the White method has been extensively modified and revised (Fahle and Dietrich, 2014). In small headwater catchments, the fluctuations in soil moisture induce similar fluctuations in the streamflow. Streamflow monitoring is typically simpler to monitor than groundwater flow. Also, the streamflow signal manifests the riparian ET response of the whole catchment. Our research at the Toenepi Catchment (Figure 1) has demonstrated a clear difference in flow rates between day and night hours that is illustrated in Figure 2.

In this study, we assume that observed diel cycles in streamflow at the Toenepi catchment are caused by ET withdrawal during the day and lateral groundwater replenishment at night. The measurable transpiration losses start between 5 and 6 a.m., reach a maximum just before noon, and drop to zero shortly after 6 p.m. A similar trend occurs in the streamflow, but with a certain lag period.

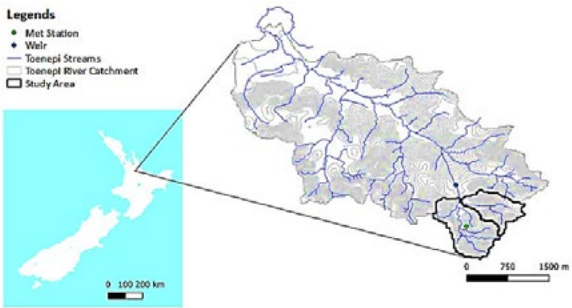

Figure 1: Toenepi River CatchmentMethod

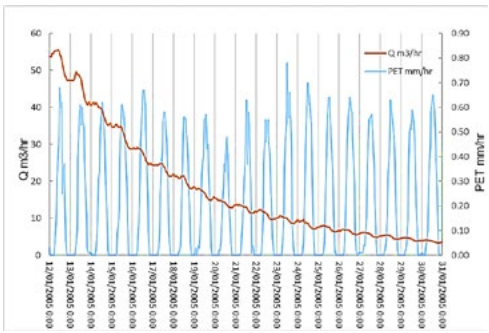

Figure 2: Diel Fluctuations in Streamflow and PET

Assuming groundwater discharge remains constant during the day and night period and neglect ET during nights, the daily flow fluctuation in the streamflow hydrograph may represent an average daily ET.

$$ET = \frac{Q_d}{A_r}$$

where Q_d is the difference between the observed fluctuating hydrograph and a hypothetical hydrograph constructed by linking each maximum daily discharge through a spline curve (Gribovszki *et al*., 2008) and A_r is the riparian zone. It is known that the riparian zone size decreases as the catchment gradually dries out (Troxell, 1936;Bond *et al*., 2002). Assuming the riparian zone shrinks exponentially in time

$$A_r = aA_w e^{-bt}$$

where A_w is the total catchment area, and "*a and b*" are constants. The "*a and b*" values are determined by fitting calculated ET from equation 1 to the reference PET values.

Results

The estimated ET are compared with the Penman-Monteith PET calculated with the meteorological data from the met station located in that catchment (Figure 3). The results are then calibrated to get optimised values for "*a and b*" parameters. A comparison between two methods shows a good correlation between the Penman-Monteith PET and calculated ET from equation 1. Also a lag time between the signal and PET is observed that the signal is varied seasonally and needs further investigation.

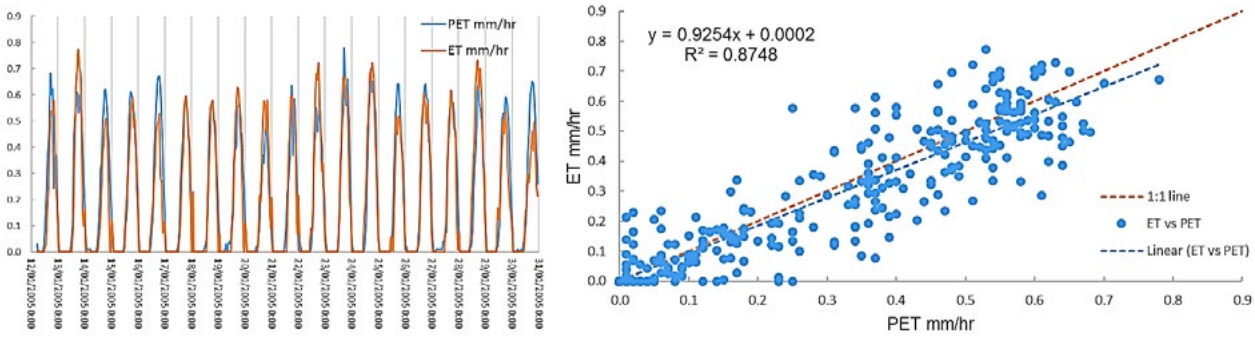

Figure 3: Comparison of Penman-Monteith ET with the modelled ETg

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THE RISK MANAGEMENT SOLUTIONS NEW ZEALAND FLOOD MODEL: DEVELOPMENT, VALIDATION, AND APPLICATION

Scudeler C,[1] Prakash M,[1] Nicotina L,[1] Comola F,[1] Satyam S,[1] Drayton M,[1]
[1] Risk Management Solutions Inc.

Aims

The geographic position of New Zealand in the South Pacific Ocean exposes the country to high flood risk since it experiences strong westerly winds, causing extreme weather conditions such as rain and storms. The vulnerability of New Zealand to floods is also clear in its history, with 86 flood events reported by the Insurance council of New Zealand (ICNZ) between 1968-2018 (1.6 events/year on average), further proving the importance of building its resilience against them (Ministry for the Environment, 2018). At Risk Management Solutions (RMS) we work on the development of models used to quantify and manage catastrophe risk and to achieve the ability to recover from the resulting damage. Here we present the methodology and preliminary results of the hazard component of the RMS New Zealand inland flood model, currently under development.

Methodology

The RMS New Zealand flood (NZFL) model calculates the damage and ensuing loss from fluvial and pluvial driven flooding. The exposure data module, the hazard module, the vulnerability module, and the financial module operate in coordination to produce the desired risk assessment under a fix set of events, representing a sensible number of scenarios of the underlying hazard.

The hazard module covers approximately 2000 river catchments and fully captures the entire range of sources of flooding by modeling rainfall continuously over a 50000-year MonteCarlo simulation. The stochastic precipitation time series and other meteorological variables are combined to form the input forcings for the rainfall-runoff model. The rainfall-runoff model is based on TOPMODEL (Beven and Kirkby, 1979; Beven, 2012) and computes for each catchment the partitioning of the incoming precipitation fluxes into either surface runoff, sub-surface catchment response, or evapotranspiration fluxes. The surface runoff then feeds into a physically-based routing model, which solves Muskingum-Cunge equation (Cunge, 1969; Georgakakos et al., 1990) to describe the evolution of the discharge in time and space within the main river network. Historical flow data (1960-2018) from 600 river gauges are used to calibrate with a multi-objective algorithm (Deb et al., 2002) the different parameters of the models, distributed at catchment level. The undefended flood extents and depths on both major and minor floodplain are finally modeled using designed hydrographs with a defined exceedance probability as input to a second order accurate 2D shallow water model (Vreugdenhil, 1994). The stochastic precipitation model and the rainfall-runoff processes are calibrated using meteorological data from the NIWA VCSN against observations collected by the New Zealand regional councils.

Results

In this contribution we show how all the available data and information are used to validate the different component of the hazard model. For the stochastic precipitation model we show that we can accurately reproduce realistic intensities and extremes with correct seasonality and spatial correlation. The rainfall-runoff and routing model calibration and validation for the period 1960-2018 are based on objective performance metrics, comparison between modeled and observed return-period flow discharges for key cities and rivers, comparison of modeled and observed runoff coefficient, and spatial correlation of the modeled discharge.

As the final step to validating the hazard model, it is shown how flood maps are produced and how the modeled flood extents and depths at different returns periods compare to similar maps obtained from local and national authorities and to published historical flood event extents.

Finally, with a general example of model operation it is shown how the RMS NZFL model would maximize the use of available information related to historical economic loss to arrive at the best estimates of risk.

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SPATIAL AND TEMPORAL PATTERN OF NATURAL HAZARDS IN NEW ZEALAND

Prakash M,[1] Satyam S,[1] Scudeler C,[1] Rafiq F,[1] Nicotina L,[1] Comola F,[1] Drayton M[1]
[1] Risk Management Solutions Inc.

Aims

Recent works have highlighted global trends in the occurrence of natural disasters and their impacts due to socio economic development and ongoing climate change (Boccard, 2018). These natural disasters can cause huge economic/insured loss and potential loss of human life. In New Zealand, the frequency of weather-related natural disasters has increased in the last four decades, in line with global trends. Historical natural disasters data can help to identify the spatial and temporal patterns of disasters. In this work, we collect and analyze global and local data of occurrence and impact of weather-related disasters in New Zealand to investigate the existence of trends, relate them to the ongoing socio-economic development and trend historical data to identify the potential cost associated with the occurrence of extreme weather events. We also investigate spatial and temporal patterns of the most frequent natural disasters in New Zealand (i.e. flood, snow, wind & tornado and storm) to identify the most vulnerable regions and the seasonality of hazard events.

Methodology

We collect data on the occurrence and impact of extreme weather events from available sources (including the NIWA historic weather events catalogue and the global EM-DAT disaster database) and create a homogeneous database of extreme weather events affecting New Zealand going as far as the beginning of the 20th century. With this database we examine the existence of historical trends in occurrence and impacts by peril, geographic region and season. Our main focus is on the occurrence of flood events either as a direct peril or when associated to other perils (e.g. storms which led to localized flooding) for which we also study trends in the associated economic and insured losses. To appropriately treat historical losses, we devise a loss trending methodology that takes into account currency variations as well as socio-economic development to quantify the potential impact today of historical events

Results

In line with global datasets we show that the number of natural hazard events in New Zealand exhibits and upward trend, especially in the last four decades. The total number of natural disasters in the last 20 years was 40% higher than the previous 2 decades. Flooding represents the main risk factor in New Zealand with ~50% of the recorded weather events being categorized as floods and shows upward trends. More significantly socio-economic development leads to an increase of exposure to floods over time with the consequence of positive trends in economic and insured flood losses to properties. Our geographic analysis shows that the Canterbury region recorded the highest number of events (70 % of them being categorized as floods and storms), followed by Auckland council. These events occurred mostly in the months of January, March and May reflecting the different mechanisms triggering natural catastrophes.

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WATER DATA: LOCAL GOVERNMENT IN AN 'AGILE' WORLD

Helen Shaw[1]
[1] Environment Canterbury

Water Data Programme – Our Vision

In the past, we trusted our data, reports and the decisions made on these. We had lots of good quality water, with a small number of requests for water abstraction. There was also less legislation and less focus on water in the environmental context. We didn't have as much data. It was easier because it was simpler.

But then one day, we realised that our systems did not account for the complexity that exists. We started collecting more and different data. New rules were put in place, and the population became more aware of water issues and climate change. When a river went dry, people started asking questions and some of our long standing assumptions were challenged.

And because of that, we were unable to do our jobs as efficiently or effectively. We were creating many 'work arounds', and we were unable to answer questions as quickly as we would like.

And so we want to provide a real time, quality assured water data infrastructure that enables appropriate, next generation water models, including forecasting, for Canterbury.

Method

Environment Canterbury's 'Water Data programme' started on 1 August, 2019, following 18 months of discovery and planning. The programme is funded mostly as a capital works programme, to build intergenerational 'data infrastructure' that will enable ECan to answer 17 'key' questions about water state, use, allocation, consent compliance and management, quickly and accurately.

We pulled together a dedicated team of people to work on the programme, including subject matter experts (planners, scientists), data warehouse and architecture specialists, business analysts, process improvement specialists, developers and data scientists. We realised that trying to sort out our data issues whilst conducting our 'business as usual' tasks was not going to result in the best outcome, or get our issues resolved quickly enough.

We opted to follow an 'Agile' project management methodology; this means creating a mindset and environment that results in a self-managing team working together to scope, plan, develop and deliver frequent outputs iteratively throughout the 2 year programme. We wanted to avoid the temptation of getting stuck down 'rabbit holes' for months on end, but to do this we need to learn to live with a certain degree of uncertainty regarding 'what's next'.

The Agile methodology has been used in software development for a number of decades, but is relatively untested in Local Government, or in data - centred projects. It comes with a host of new jargon, including 'scrum', 'sprint', 'standup', 'Epic', 'acceptance criteria' to name a few.

Our principles of working are depicted in Figure 1 below.

Figure 1: Water Data Programme Principles

A key component of the Agile approach is to use 'user stories' to help understand what it is we are building and why. An example of this is *"As a consent planner, I want fast access to the allocation limits for groundwater so that I can compare them with my consented allocation data and grant/decline consent applications appropriately".*

We want to make sure that our data is fit for our own use, but also readily available and useful to our external partners and stakeholders. Early work on the programme developed a number of 'personas' – we interviewed a number of external people to gain an insight into their perspective, and current and future needs.

Its no substitution for involving real people, but it's a starting point – throughout the programme we'll be holding workshops and co-design meetings with our internal and external stakeholders.

Results

At the time of writing, the team has been working for 4 weeks. We are navigating our way through the first question; "what is the allocation limit for xx river and yy groundwater zone?'. Its already revealing many risks, gaps and opportunities for improvement. We have found:

- Our plan limits are not digitally maintained
- The data that is digital is in multiple locations
- Some digital datasets do not mirror the Plan accurately
- There is no identified data steward or custodian for allocation limit data

Our initial work has included:

- A 'logical model' of data, reflecting business entities
- Steady state mapping of data streams
- Agreement on scales; what is a 'unit' of water?
- Identification of data sources

Building a multi-discipline self organising team takes time and effort, and we've had considerable ups and downs already, as we adjust to a completely different way of working.

AN IMPROVEMENT IN A RAINFALL-RUNOFF EQUATION

Ali Shokri[1]
[1] University of Waikato

Introduction

For many decades, the Soil Conservation Service (now the Natural Resources Conservation Service) curve number (SCS-CN) equation is known as a simple way to predict direct-runoff from a storm event (1,2). This method is the most widely used in practice and applied in a wide range of hydrologic applications, such as flood, water quality, soil moisture balance and sediment yields (3–5).

Initially, the SCS-CN equation comes from a lumped based approach that calculates total direct runoff from a storm event (6).

$$Q = \frac{(P-I_a)^2}{P+S-I_a} \quad when \quad P \geq Ia, \quad \text{otherwise} \quad Q = 0 \qquad (1)$$

In the SI units S and consequently I_a can be referred to a Curve Number (CN) parameter through:

$$S = \frac{25.4}{CN} - 0.254 \qquad (2)$$

where CN values are defined from hydrological soil group (HSG), land use, hydrological surface condition, and soil moisture condition (5).

Despite the SCS-CN method popularity(1,2), too many oversimplification assumptions raise questions about the accuracy of the equation (1,2,5). One of the misleading assumptions is that the steady-state infiltration rate is ignored in the original form of equation (6). Another ambiguity in the method is the lack of adequate explanation for rainfall intensity in the equation (7), for example, the SCS-CN method does not distinguish the differences between the effect of 4 cm rainfall in 1 hour, and 0.4 cm in 10 hours, while infiltration and runoff would be considerably different (6,8). These two limitations should be considered as a structural weakness of the SCS-CN method.

Method

Despite significant studies in improving the SCS-CN method (9), overcoming the limitations of the method remains a challenge for Water Resources Engineers In this paper, the SCS-CN equation is reorganised, and a new form of the SCS-CN equation is driven.

$$Q = \frac{(AP-I_a)^2}{(P-I_a+S)} \quad when \quad P \geq Ia, \quad \text{otherwise} \quad Q = 0 \qquad (3)$$

where *A* is a function of rainfall intesity and the steady-state infiltration rate. The new equation generalises the SCS-CN equation for a condition that the steady-state infiltration rate may not be neglected and unlike the original equation, the new equation takes the impact of rainfall intensity into consideration.

An alternative method to SCS-CN in predicting the rainfall-runoff relationship is to apply a spatially distributed hydrological model (2,10–13). In this study, a hypothetical example is designed in a way that infiltration comes into equilibrium with an ultimate infiltration. Then the hypothetical example is simulated in the *DrainFlow*, which is a couple distributed surface water and groundwater numerical model (14). Then the *DrainFlow* prediction of flow at the outlet is used as a true reference for measuring the accuracy of the modified and original SCS-CN equations.

Results

As a comparable outcome of the numerical model to the SCS-CN equation, the cumulative runoff versus cumulated rainfall graph (Q-P graph) at the outlet of the catchment is calculated and illustrated in Figure 1. An optimization model is implemented to minimize the squared error between the SCS-CN equation and the Q-P graph by changing CN in the SCS-CN equation. The best-fitted curve occurs when CN=31 and plotted in Figure 1.

As it is visible in Figure 1, the SCS-CN equation does not show an acceptable agreement with the numerical model outcomes. A mathematical explanation of the poor performance is that the SCS-CN equation possesses a 45-degree asymptote which it does not let the equation to fit the Q-P curve that has an asymptote smaller than 45 degrees.

A similar optimization runs for the modified SCS-CN equation. The best fitted-curve by the modified SCS-CN equation is plotted in Figure 1. The modified equation shows a perfect match with R^2~1 to the numerical model for A=0.85 and CN=66.

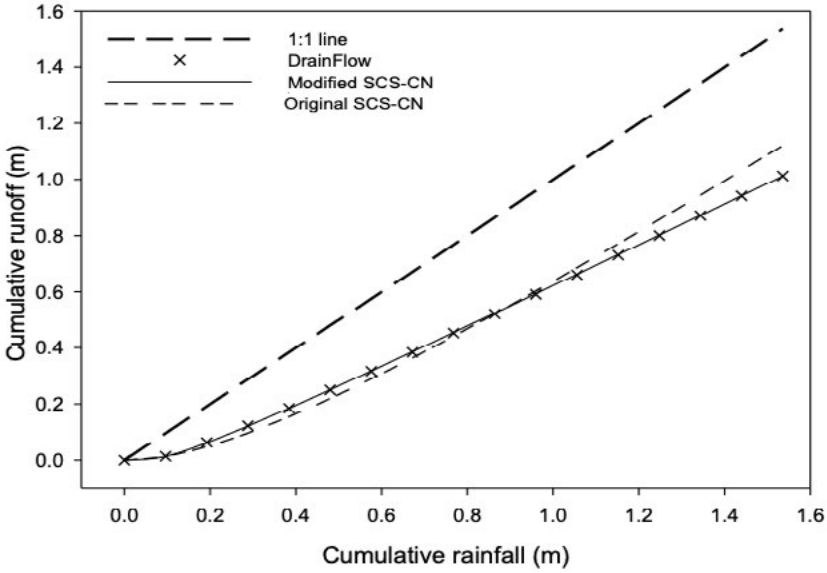

Figure 1: Cumulative overland flow versus cumulative rainfall at the outlet, calculated by the numerical model and the best-fitted curve by original and modified SCS-CN equations

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RESPONSES OF A HIGH ALTITUDE WETLAND TO LATE-HOLOCENE ENVIRONMENTAL CHANGES IN TAVEUNI, FIJI

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[3] Zayed University.

Aims

Hydrological and ecological research on wetland ecosystems, such as peatlands and lakes, can determine their responses to changing climate. However, less work has been done on tropical mountain lake and peatland ecosystems in the Pacific Islands. This paper presents the results of palaeoenvironmental investigations on Lake Tagimaucia, a high elevation volcanic crater lake, and surrounding peatlands, to reconstruct the palaeoenvironmental history of Taveuni Island in Fiji.

Method

We employed multi-proxy analyses of peat and lake sediment cores. Organic indicators (peat humification and bulk density), physical variables (grain size analysis) and bulk geochemistry (C/N, δ13C and δ15N) provided a continuous environmental change reconstruction over centennial timescales.

Results

The Tagimaucia lake and peat ecosystems are sensitive to climatic perturbations, largely driven by hydrological and temperature variabilities. Organic carbon variability, instabilities to the carbon accumulation profiles and varying organic matter decomposition are a result of changing climatic conditions in Fiji over the late Holocene. However, findings also show inconsistencies in lake chronology, stable isotopes and textural distributions, which is possibly due to sediment mixing and presence of floating algal mats in the water body.

INUNDATION WARNING SYSTEM DEMONSTRATION

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

Aims

Inundation of populated areas threatens lives, livelihoods and property. Prediction of inundation events is particularly challenging in low-lying, coastal areas where meteorological, hydrological and oceanographic influences can all interact.

The UN World Meteorological Organisation (WMO) Commission for Hydrology and WMO Commission for Oceanography and Marine Meteorology have initiated Coastal Inundation Forecasting Demonstration Projects to improve community safety and socio-economic sustainability at selected locations around the world. The projects involve technology development, transfer and training to enhance the capabilities of responsible national agencies to produce and provide integrated inundation forecasting and warning services for disaster mitigation, emergency management and coastal planning.

This talk describes the mechanics of three coastal inundation forecasting projects developed under WMO CIFDP auspices for the Dominican Republic, Indonesia and Fiji. These countries have different inundation drivers and widely differing levels of technical capability.

Method

Jakarta, Indonesia suffers from land subsidence, river flooding, local flooding and sea water inundation. The early warning solution adopted for Jakarta is a cascading forecasting process whereby global Numerical Weather Predictions (NWP) feed local NWP which drive a hydrologic model for river runoff and an oceanographic model for sea conditions. The river runoff and sea conditions feed a hydrodynamic model which produces an inundation map. The model cascade runs in real time and assimilates measurements from rain gauges and water level sensors. Maps and warnings are issued when dangerous inundation conditions are forecast.

The major threat to the Dominican Republic is hurricane-associated inundation. Modelling of hurricane strength and track followed by hydrodynamic modelling of onshore inundation is computationally demanding and could not be carried out fast enough in the Dominican Republic to be used for “live” forecasting purposes. The adopted solution for Dominican Republic was to develop a pre-populated library of inundation maps (modelled by the US/NOAA National Hurricane Center) for a comprehensive set of potential hurricane strengths and tracks. When a hurricane is predicted, the inundation map for the most closely matching hurricane track and strength is drawn from the library and warnings are issued for the locations which the precomputed map shows to be inundated. Map selection from the library is carried out by a software application which has low computational overheads and can therefore be run on portable devices.

Fiji suffers frequent inundation from both river and ocean flooding. Fiji’s location means there is high uncertainty in predictions based on global numerical weather models and there is limited historical data to calibrate and verify models. Basing inundation warnings on telemetered data overcomes some of the significant uncertainties associated with flood hazard prediction (see Smart, 2018). The new coastal inundation alert support system (CIA SS) for Fiji incorporates information from rain, river and sea level gauges with tide forecasts to indicate when inundation is imminent. Three types of alert are issued: “AWARE”, “WARN” or “CRITICAL”. The alert lead time depends on the timing of forecast rainfall or sea level conditions and the flood travel time from inland catchments to the Nadi coastal plain. In the current version of the alert lead time can vary between 3 and 12 hours. The alerts are based on trigger thresholds. For the rain gauges used in the system (covering the catchments feeding the Nadi floodplain), rainfall trigger levels were determined from historical hydrometric flood data and expert consensus. The rainfall alert triggers are not constant for a given rain gauge but vary depending on antecedent rainfall at that gauge. This allows for major differences in runoff from a wet catchment compared to a dry catchment. When a catchment rainfall alert is triggered, a floodplain warning is forecast for a future time that depends on the travel time between the rain gauge and the Nadi floodplain. As catchment runoff travels downstream it is detected by river stage recorders. The river level recorders also have trigger levels, set by studying historic flood water levels and river bank levels. When a river level trigger level is reached a corresponding alert is generated and a floodplain warning is forecast at a lead time given by the flood wave travel time from the river level gauge downstream to the Nadi floodplain. Alerts for coastal inundation from the sea also rely on trigger thresholds. The threshold levels are based on historical inundation events and the elevation heights of key infrastructure such as roads. The warning system compares measured sea level with predicted astronomical tide and any additional water level (which could have multiple causes such as wind set-up or barometric pressure) is assumed to persist over the next few hours on top of the predicted astronomical tide. This gives a total sea level forecast. These calculations are updated every few minutes. Alerts are issued if the forecasted total sea level exceeds the trigger thresholds at any time in the coming 12 hours.

Results

For Indonesia and Dominican Republic, the inundation alert demonstration phase has ended, and the projects are now fully operational. The Nadi warning system is currently in test mode. A hypothetical warning situation for the Nadi system is shown in Figure 1. The system dashboard contains a schematic diagram showing: telemetered rainfall readings from the catchments; telemetered river levels on tributaries feeding the Nadi floodplain; and telemetered and calculated coastal conditions. The dashboard indicates telemetry status (bottom left), current and forecast rainfall depths and water levels, colour-coded warnings where triggers are exceeded and floodplain or coastal warnings (in the boxes outlined in red) if warranted. Missing data is indicated by a "?" symbol. The system is robust and can operate with manually entered data should the internet fail during an inundation event.

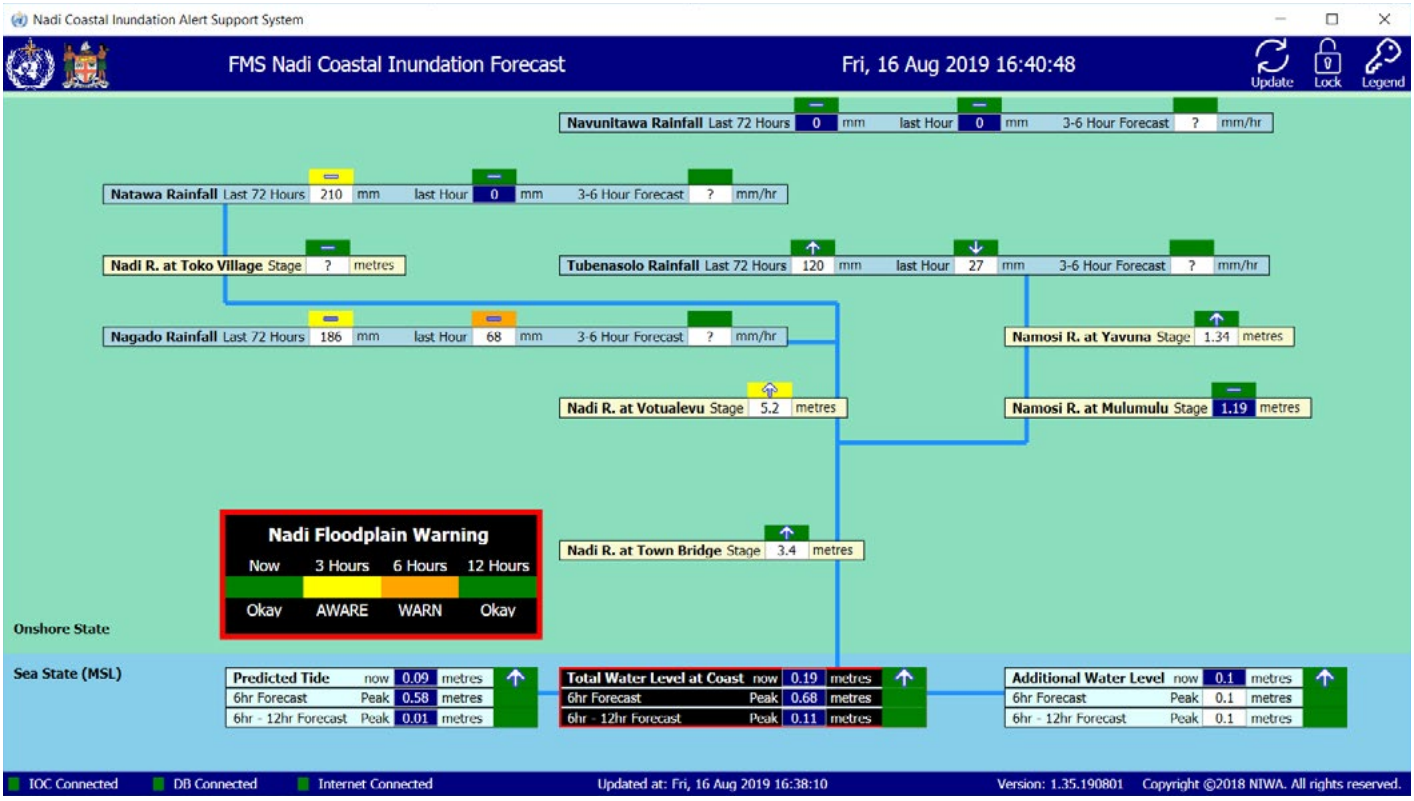

Figure 1: "Dashboard" of Nadi coastal inundation alert support system. The hypothetical figures indicate that floodplain inundation could start in 6 hours time if rainfall increases.

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QUANTIFYING LINKS BETWEEN CATCHMENT EROSION PROCESSES AND SEDIMENT-RELATED WATER QUALITY IN RIVERS

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Aims

Erosion contributes an estimated 192 million tonnes of sediment to New Zealand waters each year where it impacts water quality, ecosystem health and recreational amenity (MfE & Stats NZ, 2019). Excess fine sediment reduces optical water quality, which degrades habitat suitability for sighted predators, and once settled on the riverbed, can reduce oxygen and smother habitat (Davies-Colley et al. 2015). Accelerated erosion is also associated with significant costs in terms of production losses and storm damage to land and infrastructure (Krausse et al. 2001; Dominati et al. 2014). Despite the magnitude and cost of erosion in New Zealand, we presently lack data and models at the resolution required to quantitatively link upstream land-based erosion sources to downstream sediment-related water quality impacts.

In response, a new 5-year research programme, Smarter Targeting of Erosion Control (STEC), aims to inform design and implementation of cost-effective, targeted erosion control measures to meet national water quality targets. The STEC programme comprises four components that will 1) provide higher resolution data on erosion processes and sediment quality; 2) quantify erosion mitigation performance; 3) develop an event-scale model of erosion, sediment transport and sediment-related water quality; and 4) quantify economic benefits of erosion mitigation. Here, we focus on the first component and present an overview of our approach to link catchment erosion processes, sediment generation and sediment-related water quality.

Method

Our multi-method approach is designed to acquire new data on 1) erosion processes contributing fine sediment to rivers in New Zealand and 2) sediment properties as they reflect eroded soil properties. We require higher spatial and temporal resolution data to both improve process understanding and support development of an event-scale model. This currently involves a measurement programme to quantify a) spatial patterns in storm event-generated shallow landslides using before/after satellite imagery in combination with data on rainfall magnitude-duration from rain radar, b) earthflow movement rates and sediment delivery to streams, c) reach-scale bank erosion response to flow events, d) temporal variation in suspended sediment properties during flow events, and e) contributions from erosion sources to event-scale suspended sediment loads and floodplain sedimentary archives using sediment fingerprinting.

We are establishing a research catchment (~20 km^2) in the headwaters of the Tiraumea River (a tributary of the Manawatu) where we aim to better link erosion measurements with instream sediment response. To quantify the sources and timing of sediment delivered to the catchment outlet, we combine 5-min resolution earthflow movement rates from continuous-GNSS measurements with biannual re-survey of earthflow sediment contributions to streams (Fig. 1) using drone-based Structure-from-Motion photogrammetry (SfM) and LiDAR, alongside instream measurements of turbidity, sediment sampling, and sediment fingerprinting. We are also investigating intra-event variability in sediment source contributions to suspended sediment loads in the Oreti catchment in Southland in collaboration with NIWA's Managing Mud programme. Together, the Manawatu and Oreti catchments will provide data on erosion sources, suspended sediment loads, and sediment quality for use in calibrating and evaluating the event-scale model.

We require data on erosion source and suspended sediment properties that affect optical water quality in rivers. Data collection focuses on four catchments, namely the Manawatu, Whanganui, Oreti and Aroaro (tributary of the Wairoa River, Auckland region). Erosion source sampling is stratified by erosion process and geological parent material. Horizons Regional Council are collecting stormflow suspended sediment samples from selected sites within their hydrometric network for measurement of particle size, shape, organic matter content and light attenuation using a newly harmonised protocol for soil and sediment sample analysis.

a)

b)

Figure 1: a) Example of a monitored earthflow and b) toe erosion on the same earthflow located in the Upper Tiraumea catchment (Manawatu).

Results

This is the first year of the STEC programme and results are not yet available for most research areas. Our initial focus is on study site selection and instrumentation, data acquisition, and development of analysis procedures. We have acquired satellite imagery and rain radar data for storm events in the Horizons (2018), Waikato (2017), and Hawke's Bay (2011) regions for event-scale shallow landslide analysis. We are applying Object-Based Image Analysis (OBIA) techniques (Hölbling et al. 2016) to map shallow landslide scars and tails from this high resolution (0.5 m) satellite imagery spanning 120-700 km2. We trialled several machine learning algorithms to predict spatial patterns in landslide susceptibility (Fig. 2). This information may be used to better inform the targeting of erosion control measures and in representing shallow landslide erosion within the event-scale model.

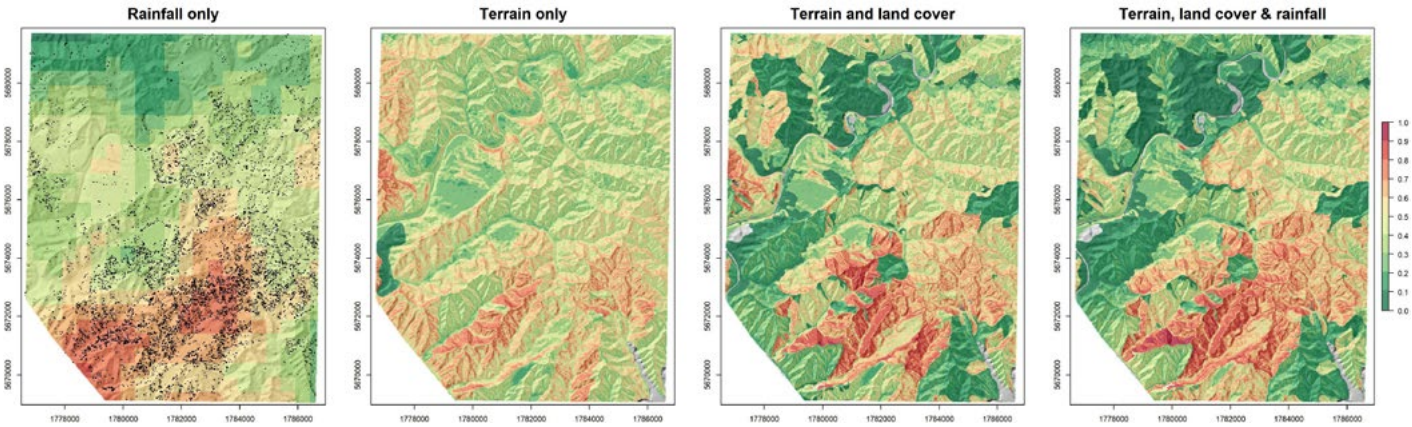

Figure 2: Example of quantitative shallow landslide susceptibility analysis based on spatial patterns in landslide probabilities derived using different inputs to a logistic regression model, where 'rainfall' comprises several magnitude-duration inputs (500 m grid) based on rain radar analysis and 'terrain' comprises slope (15 m grid), aspect, soil class and lithology for a 120 km2 area in the Whanganui catchment impacted by a March 2018 storm. Land cover is represented by LCDB 2012. The black points are OBIA-mapped landslide scars used to train and test the model.

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THE IMPORTANCE OF GROUNDWATER DATA COLLECTION AND PREDICTIVE MODELLING FOR LAND DEVELOPMENT IN AREAS OF SHALLOW GROUNDWATER

Carl Steffens, Cameron Jasper[1]
[1] Pattle Delamore Partners Ltd

Land development in areas of high groundwater requires thorough planning and investigation to ensure its viability and prevention of long term issues associated with high groundwater. Such issues can include ponded areas of groundwater on properties and in stormwater management areas, unsuccessful wastewater and stormwater discharges, and in some cases, high liquefaction risk. This is an issue in many parts of New Zealand, including Christchurch. This presentation will outline some of the recent investigations related to land development in areas of shallow groundwater around Christchurch, including the following:

- A subdivision was proposed over a shallow artesian aquifer, surrounded by spring fed streams. Land drainage was required to reduce the liquefaction risk and enable sale of the properties with an acceptable land classification risk. Excavation of the land drainage system in the confining strata was expected to result in high outflows, which required predictive modelling to ensure the level of effect on the receiving surface waterway. A detailed investigation was undertaken by PDP and the subsequent modelling was used to successfully predict the potential magnitude of outflows.
- Stormwater infiltration basins are an important method of treating runoff from developed land. Infiltration basins provide a method of maintaining rainfall recharge to the underlying aquifer and hydraulic neutrality for any stormwater runoff. In most situations, infiltration basins are located above unconfined aquifers. To determine the invert level of the basin requires an assessment of the highest groundwater level along with the amount of mounding that occurs when stormwater discharges through the basin. A number of investigations have been undertaken by PDP to determine aquifer parameters and sufficient information on long-term groundwater records to ensure that the maximum groundwater levels at the location of the infiltration basin can be predicted.
- While groundwater information is important for infiltration basins, it is also critical for stormwater management systems not requiring infiltration to ensure that high groundwater levels do not reduce the capacity in features such as detention basins and wetlands. Appropriate design, including underdrainage may need to occur in this instance. PDP have undertaken a number of investigations to assist in the design of such systems, including a large stormwater management area currently proposed in south-west Christchurch where the results were used in GIS mapping to help identify areas of inundation.

In addition to the above projects that will be discussed, this presentation will outline other aspects of development that require careful consideration in areas of high groundwater levels. These includes risks associated with wastewater discharges and the requirement to evaluate potential increased mounding from wastewater or stormwater discharges, or background groundwater levels, associated with more extreme events related to climate change. The potential for sea level rise to further increase groundwater levels near the coast is also a critical factor to consider.

AERIAL ELECTROMAGNETIC SURVEYS TO CHARACTERISE THE SUBSURFACE ENVIRONMENT OF THE WAIOTAPU STREAM & UPPER PIAKO RIVER CATCHMENTS

Wilson, S.R.,[1] Stenger, R.,[2] Clague, J.[2]
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[2] Lincoln Agritech Ltd (Hamilton)

Aims

The Critical Pathways Programme (CPP) has begun applying an innovative multi-scale measurement and modelling approach that enables to coherently link catchment, sub-catchment and transect scale hydrogeophysical information. To explore subsurface structure and identify 'critical' contaminant flow pathways at the catchment scale, aerial electromagnetic surveys were carried out in February 2019 in the Waiotapu Stream (297 km2) and upper Piako River (104 km^2) catchments. The information derived from the geophysical data will inform the first phase of catchment scale groundwater flow modelling and the selection of two contrasting sub-catchments for targeted higher-resolution ground-based geophysical surveys and associated investigations from 2020 onwards.

Method

Aerial electromagnetic (AEM) data were acquired via helicopter using the Danish SkyTEM system. This system uses time-domain EM, which provides multi-frequency data by repeated sampling of the transient magnetic field after the current has been terminated. The advantage of an aerial survey is that a large area can be captured in a short space of time, combined with large survey depth. The surveys were flown in February 2019 at ~30m elevation along east-west lines 200m apart with a sounding density of 15-20m. In total, 2020 linear km were captured in 7 flight days. The helicopter flew at a height of ~90m, with the sensor carrier frame suspended at a height of ~30m above ground level. Data was captured in dual moment mode, which resolves the upper 50m of the survey profile in detail, as well as providing data at lower resolution to 300m depth. Helicopter position and elevation was captured using high precision GPS, while laser altimeters captured the height above ground. A brief video clip on the surveys can be found here: https://www.youtube.com/watch?v=cEMIwi_B20U&feature=youtu.be

Due to intrusive nature of the low flight path of the helicopter and frame, extensive consultation with the landowners and residents took place in the form of local advertising, letter drops and community drop in sessions. The vast majority of community members who interacted with the project team were supportive of the project and interested in the results.

Initial data processing involved the manual removal of electromagnetic couplings (cultural noise generated by roads, fences, power lines etc.). This, and subsequent data inversions were carried out in conjunction with our collaborators from the Hydrogeophysics Group of Aarhus University, Denmark. Geological interpretation of the data was carried out using the GEOScene3D modelling software.

Results

The data show substantial lateral and vertical variation in electrical conductivity/resistivity. There is a varying degree of agreement with currently matched geological units, with units being more easily distinguished at greater depths (Fig. 1). This indicates that currently existing geological information may not be a good predictor for hydrological characteristics of the shallow subsurface environment. The ongoing analysis utilizing bore logs and the GEOScene3D software will provide further insight into the linkage between geological units and conductivity/resistivity. This may be particularly important for ignimbrites, as fractured and non-fractured ignimbrites can only be differentiated using geophysical methods.

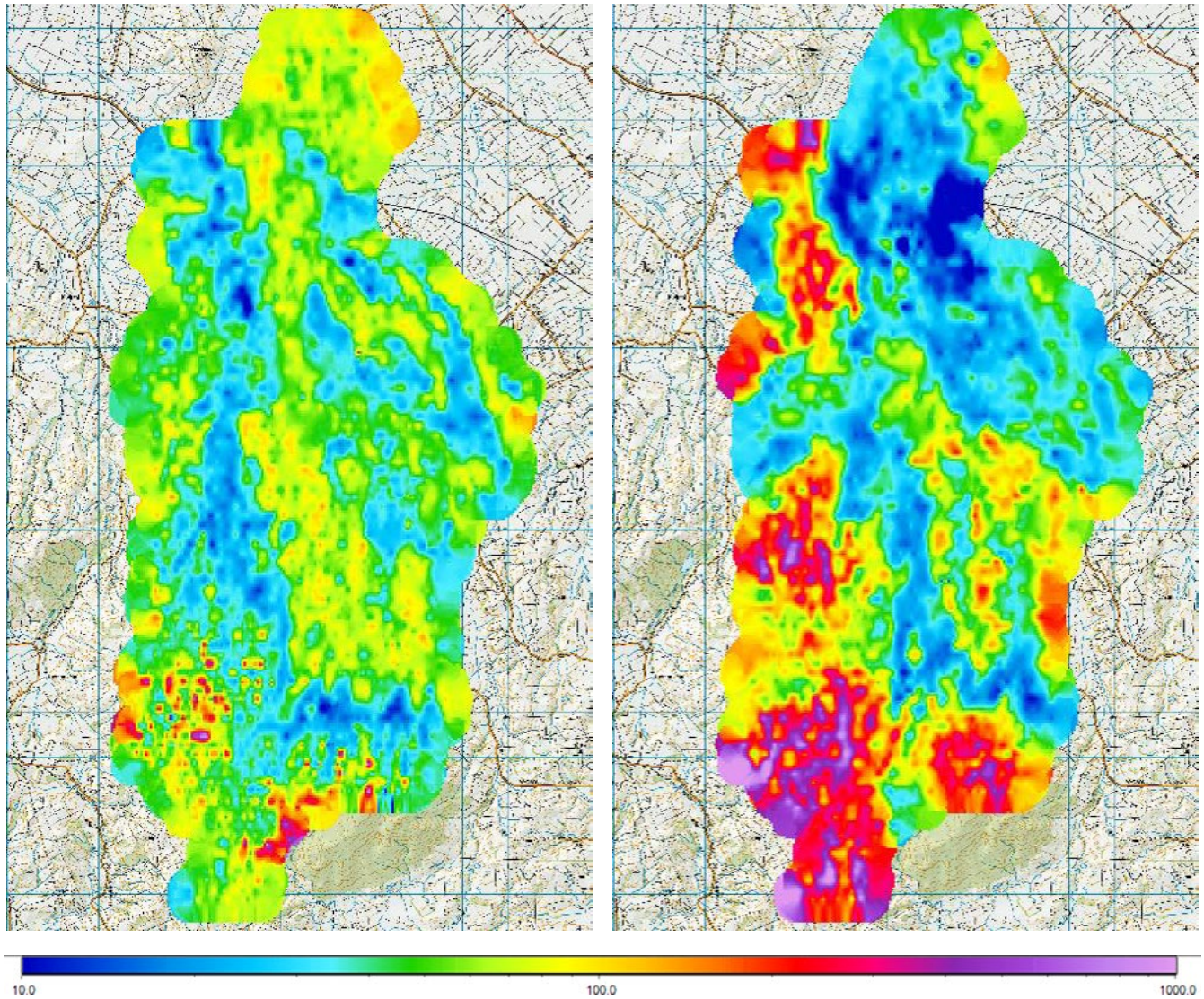

Figure 1: Resistivity map (ohm-m) for spatially-constrained inversion at 20-30m depth (left) and 90-100m depth (right) in the Piako River headwater catchment.

UPDATE ON CARBON DATING OF CHRISTCHURCH GROUNDWATER

Michael Stewart,[1] Rob van der Raaij,[2] Lisa Scott,[3] Zeb Etheridge[3]
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[2] GNS Science
[3] Environment Canterbury

Aims

This work aims to reveal the sources and flowpaths of deep Christchurch groundwater, how they have changed in response to exploitation, and how they are expected to change in the future. The goal is to improve understanding of the hydrogeological processes in the Christchurch aquifer system and allow for better management of the resource.

Method

Carbon-14, tritium, dissolved gases, stable isotopes and chemical measurements were made on samples from selected deep and shallow groundwater wells across three west-east transects in Christchurch in 2017. These results were compared with those from the previous sampling rounds each decade between 1976 and 2006 (reported in Stewart, 2012), to see how the system is responding to exploitation.

Results

The mean ages determined using carbon-14 and tritium from the 2017 sampling round are shown in the figures. Tritium ages are shown by the blue points; the maximum mean age measurable with tritium is 210 years when the tritium concentration is indistinguishable from zero (according to the lumped parameter flow model used EPM(f=0.75)). Carbon-14 ages are shown by the pink points; mean ages in the range 5 - 30,000 years can be determined with carbon-14 (using the same flow model).

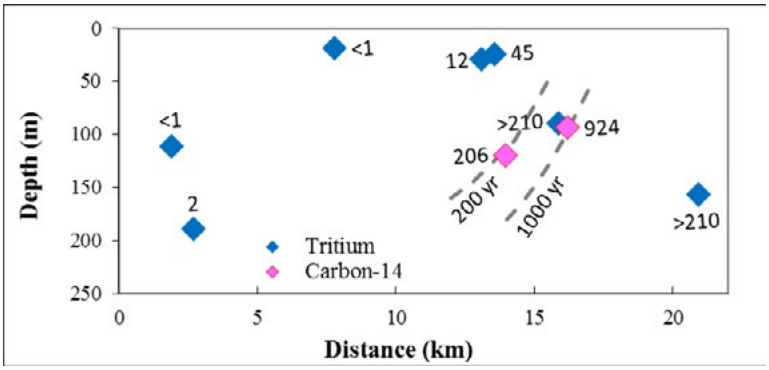

Figure 1: Mean ages along the north transect across Christchurch from west to east. Approximate age contours are shown.

Fig. 1 gives results for the northern transect across Christchurch from west to east. On the west side, two deep wells near the Waimakariri River have very young ages (<1 and 2 years respectively, but these are anomalous results). The shallow wells have young ages. Very approximate age contours are shown for 200 and 1000 year-old waters which rise towards the east as older groundwater wells up under artesian pressure in the eastern confining parts of the system. Note that the contours are gross generalisations; local effects can affect their shapes. In addition, the samples represent mixtures of water with different flowpaths which are affected by the nature of the aquifer materials.

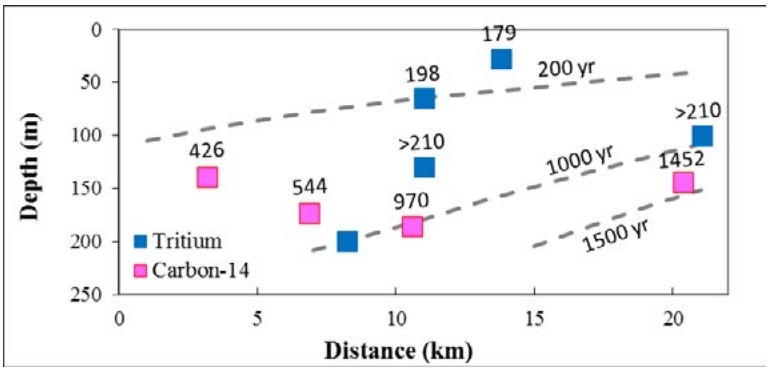

Figure 2: Mean ages along the central transect across Christchurch from west to east. Approximate age contours are shown.

Fig. 2 gives results for the central transect across Christchurch. Again the age contours rise towards the east. The contours are a little better defined.

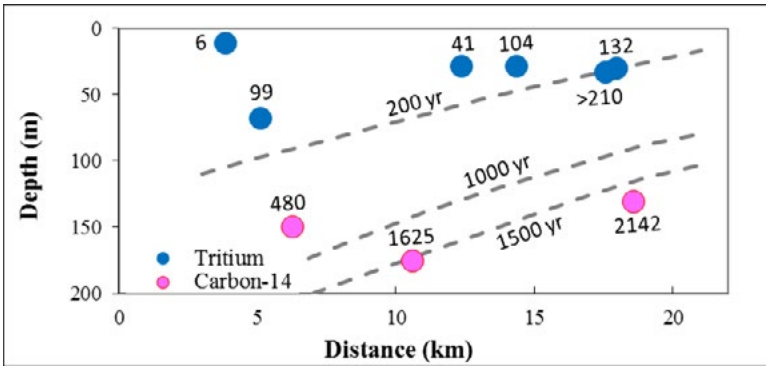

Figure 3: Mean ages along the south transect across Christchurch from west to east. Approximate age contours are shown.

Fig. 3 displays the south transect results. The shallow wells have younger ages. Land surface recharge contributes more substantially to the upper aquifer flows in this transect. At deeper levels, older water predominates and Waimakariri River recharge has a more dominating influence.

Comparison of the 2017 carbon-14 mean ages observed with previous sampling in 2006 shows that the deep Christchurch wells are continuing to draw in older groundwaters, and the west to east gradient in mean ages is being maintained or intensified. The strong gradient in age across Christchurch shows that fossil water on the coastal side is continuing to flow (and drawback from the deep blind aquifers continues). However, on the western and northern sides there is some evidence of inflow of shallow younger waters contributing to the well flows.

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DENITRIFICATION IMPRINT ON NITRATE IN OXYGENATED GROUNDWATER

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[2] Environment Canterbury

Background

Excessive nitrate concentrations in groundwater are of concern for human health and the environment. Among approaches proposed to limit nitrate concentrations is use of natural subsurface zones where potentially significant nitrate reduction occurs by microbial action within aquifers. Such denitrification has a large and relatively unknown effect on groundwater nitrate concentrations. The redox state of the groundwater is often used to assess the likelihood that denitrification has affected the groundwater (e.g. Friedel et al., 2018).

Aim

To examine the geochemistry of groundwater from the Tinwald area in association with other information to identify denitrification effects on the groundwater, as part of a larger study to understand the sources of the nitrate.

Method

33 samples were collected from wells in the area for chemical analysis of the water and isotopic analyses of the nitrate and water (Aitchison-Earl, 2019).

Results

Nitrate concentrations have been historically high in groundwater in the Tinwald area, with nitrate-N concentrations commonly greater than 11.3 mg/L (Hanson, 2002). Other ions (chloride, sulphate, etc.) are also elevated. The source of the nitrate has been identified as mainly from fertiliser with a smaller contribution from effluent (Aitchison-Earl, 2019). Groundwater recirculation with local groundwater accentuates the high nitrate concentrations seen in the area (Stewart and Aitchison-Earl, 2019).

The isotopic compositions of the nitrate samples have given interesting information. Fig. 1 shows the $\delta^{15}N$ and $\delta^{18}O$ values of the nitrate plotted against each other. Two important features are observed:

1. There is a very good linear relationship between the $\delta^{15}N$ and $\delta^{18}O$ values of the nitrate,
2. The positions of the points along the line depend on their DO concentrations.

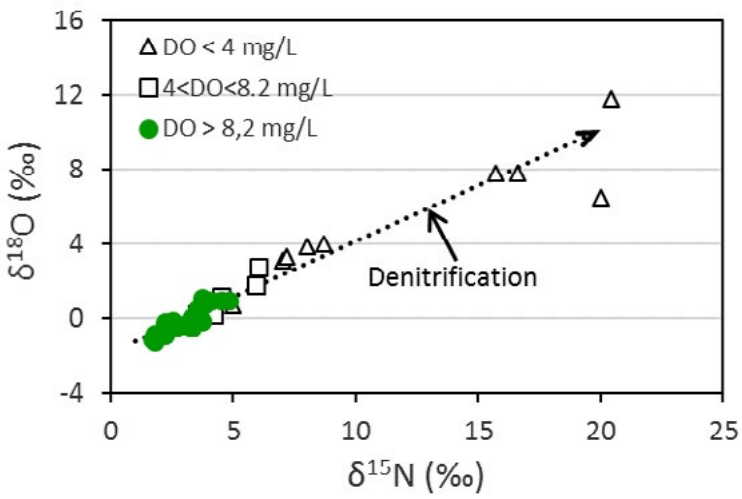

Figure 1: Plot of $\delta^{15}N$ versus $\delta^{18}O$ values of nitrate for Tinwald samples.

The first observation of the very good linear relationship between the $\delta^{15}N$ and $\delta^{18}O$ values for all points (except one) shows that many of the samples are affected by denitrification. Denitrification causes increased δ values of nitrate, along with decrease of nitrate concentration. The slope of the isotopic enrichments caused by denitrification (i.e. enrichment in $\delta^{18}O$/enrichment in $\delta^{15}N$) has been reported to be in the range 0.48 – 0.77, here the slope is 0.6. Further, the starting points of all of the samples (except one) must lie within the group of samples shown by the solid green points. Consequently, the nitrate leaching from the soil into the groundwater must have been blended by processes within the soil.

The second observation is logical, yet surprising. Denitrification is only expected to take place where DO levels are very low (e.g. < 0.5 mg/L). But here denitrification effects are observed when the DO concentrations in the groundwater are much higher. This must mean that the denitrification occurred during the past histories of the nitrates, most probably within the soil the nitrate was leached from. The lowest DO range in Fig. 1 (the open triangles with DO < 4 mg/L) shows the largest denitrification effects with $\delta^{15}N$ values up to 20‰, The intermediate DO group (the open squares with 4 < DO < 8.2 mg/L) shows intermediate denitrification effects with $\delta^{15}N$ values up to 6.0‰. The highest DO group (the solid green points with DO > 8.2 mg/L) is nearly saturated with oxygen and shows minimal denitrification effects ($\delta^{15}N$ values from 1.7 to 4.8‰).

Fig. 2 shows $\delta^{15}N$ values versus nitrate-N concentrations. The different DO ranges show different degrees of nitrate reduction due to denitrification, as expected. The grey bands show approximate ranges of possible nitrate sources (natural soil, inorganic fertiliser, effluent).

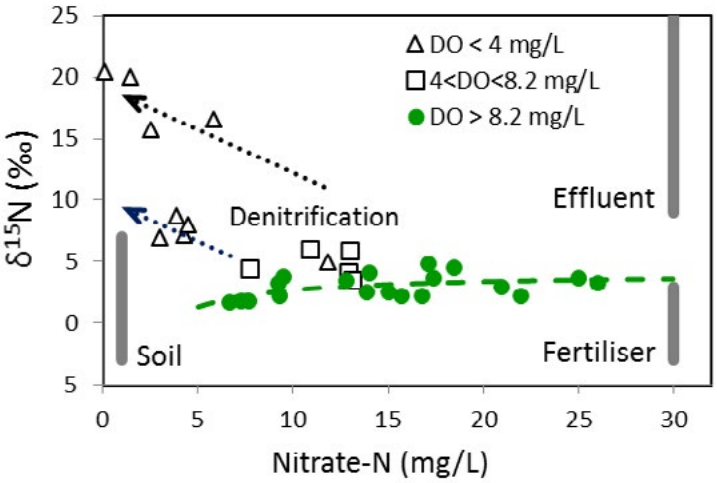

Figure 2: Plot of $\delta^{15}N$ versus nitrate-N concentration

This work has shown that nitrate in groundwater can bear the imprint of denitrification even though the DO concentration in the groundwater is much too high for denitrification to occur.

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KOPUATAI WETLAND WATER LEVEL MANAGEMENT

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[2] The University of Waikato

The Kopuatai Peat Dome (Kopuatai) is located on the Hauraki Plains of the Waikato region. This is New Zealand's largest wetland and is of high conservation value due to its unaltered state and habitat for unique species. Kopuatai is listed under the Ramsar Convention as a wetland of international importance (Cromarty & Scott 1996). The Piako River flows along the western edge of Kopuatai and the Piako River Flood Scheme was primarily built in the 1960s and 1970s and is comprised of 166 km of stopbanks, 59 floodgates, and 32 pump stations. The system is complex due to its relationship with the Kopuatai Peat Dome and emergency ponding areas surrounding the wetland (Craig 2017).

Three consecutive weather systems in April 2017 resulted in significant flooding in the lower Piako River. Flood levels from this event around Kopuatai were higher than anything previously experienced since the Piako River Scheme was constructed. Waikato Regional Council (WRC) observed overland flow from the wetland to the river during this event and are concerned that the hydrological and hydraulic regime of the wetland may have changed and exacerbated flooding of the surrounding land.

Ngati Hako, the Department of Conservation (DOC) and WRC (specifically Integrated Catchment Management) agreed to jointly consider and determine how Kopuatai water levels are managed.

Aims

The objectives of this joint project are to determine optimal water levels across the peat dome, and surrounding wetland management blocks and fringe zones, that will protect and improve native biodiversity and ecological processes, while supporting and maintaining flood management requirements.

Method

The first phase of the project involved a literature review of influences on the Kopuatai water levels including cultural aspects, ecology, hydrology, and the Piako River Scheme function and management.

The second stage involves partitioning the Kopuatai Wetland into zones with similar ecology and hydrological aspects. Using information obtained from the literature review, there will be identification of the range of water levels, including the optimum, needed to maintain and support both the flood scheme and ecological values.

Results

The final outcome of this project will be the production of a conceptual design for maintaining and protecting the wetland while ensuring the flood scheme performance where possible. This will include a conceptual design on how to maintain the optimal water level range within each of the identified wetland zones.

This talk will present on the work completed to date, including describing the role of the wetland, its hydrology, and its management in the Piako River Scheme.

References

Craig, H. 2017, *Regional flood summary: Ex-Tropical Cyclone Debbie (4-6 April), Tasman Low (11-13 April), and Ex-Tropical Cyclone Cook (13-14 April)*, Waikato Regional Council, Hamilton, NZ.

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VALIDATING THE SPHY MODEL GLACIER MODULE FOR THE RAKAIA RIVER CATCHMENT

Wilco Terink,[1]
[1] Environment Canterbury Regional Council

Snow and ice reserves are an important source of water for several regions around the globe. The upstream snow and ice reserves are exposed to the effects of climate change, making long-term water availability in some regions around the globe more challenging. Increased temperatures result in reduced glacier and snow-covered areas due to the increased melting of snow and ice as well as reduced accumulation of snow. To study these snow and glacier melting and accumulation processes, it is crucial to have model concepts available that describe these processes accurately without the need of data demanding energy-balance approaches. If we can simulate these cryosphere processes more accurately, then this will help us to understand the timing and contribution of glacier- and snow melt to the total streamflow better.

Aims

The improved SPHY (Terink et al., 2015) model glacier module (version 2.2.0, https://sphy.readthedocs.io/en/latest/index.html) has already been successfully validated for a glacier-fed river basin in Nepal. Although glaciers cover only ~3% of the Rakaia's catchment area, snow accumulation and melt play a crucial role throughout winter, and streamflow generation in spring, and therefore, validating the glacier module will be a good indicator to see whether the precipitation and temperature fields that drive the model are representative.

The aims of this presentation are therefore:

- Present the improved SPHY model glacier module
- Evaluate the glacier's mass balance as simulated by the model and assess whether the precipitation and temperature fields are representative for the upper Rakaia tributaries.

Method

Glaciers in previous SPHY model releases were not mass conserving; i.e. they were implemented as a fixed mass generating glacier melt using a degree day factor. This means that i) rainfall on the glacier was not accounted for, and needs to be corrected for as a pre-processing step, ii) snowfall, accumulation of snow, and snow melt on glacier grid cells was not taken into account, and iii) redistribution of ice from the accumulation to the ablation zone was not simulated; i.e. the dynamic retreat or advance of glaciers could not be simulated.

The improved glacier module basically comes down to overlaying your model grid with a higher resolution DEM to allow for the differentiation of multiple glacier fractions and associated elevations within one model grid cell. A more accurate representation of multiple glacier elevations within one model grid cell allows for a more accurate calculation of temperature, and thus melting rates. The more accurate temperature is calculated by lapsing the temperature from the model cell elevation to the elevation of the glacier fraction within that model grid cell. Snow and rain on the glacier are now accounted for, and melt rates adapt based on the presence of a dynamic snow pack; snow is melted before the glacier start melting. If the annual glacier's mass balance is negative (more ablation than accumulation), then the accumulated mass (snow in accumulation zone) is redistributed over the ablation cells according to the ice volume distribution of the cells in the ablation zone.

The Randolph Glacier Inventory (RGI 6.0) (Consortium & others, 2017) is a global inventory of glacier outlines, and was used to define the glaciers in the Rakaia River Catchment. Using the glacier outlines and areas from the Randolph Glacier Inventory (RGI 6.0) (Consortium & others, 2017), and a high-resolution DEM, glacier ice depth distributions were estimated using the GlabTop2-approach (Frey et al., 2014, https://glabtop2-py.readthedocs.io/en/latest/).

The model's snow parameters were already calibrated using MODIS snow cover imagery (Terink et al., HydroSoc 2018). The model is run with these optimized parameters, and the mass balance for each glacier was calculated individually before the catchment annual average glacier mass balance was calculated. To validate performance, the average annual mass balance was finally compared with values from literature because no in-situ mass balance measurements are available for the glaciers in the Rakaia River Catchment.

First Results

Since this study is ongoing, the results shown below in Figure 1 are preliminary. More details will be provided during the presentation at HydroSoc. Figure 1 shows the glacier outlines (left image) for the upper Rakaia tributaries as defined by RGI 6.0, and the ice thickness distribution for each glacier as calculated using GlabTop2 (Frey et al., 2014).

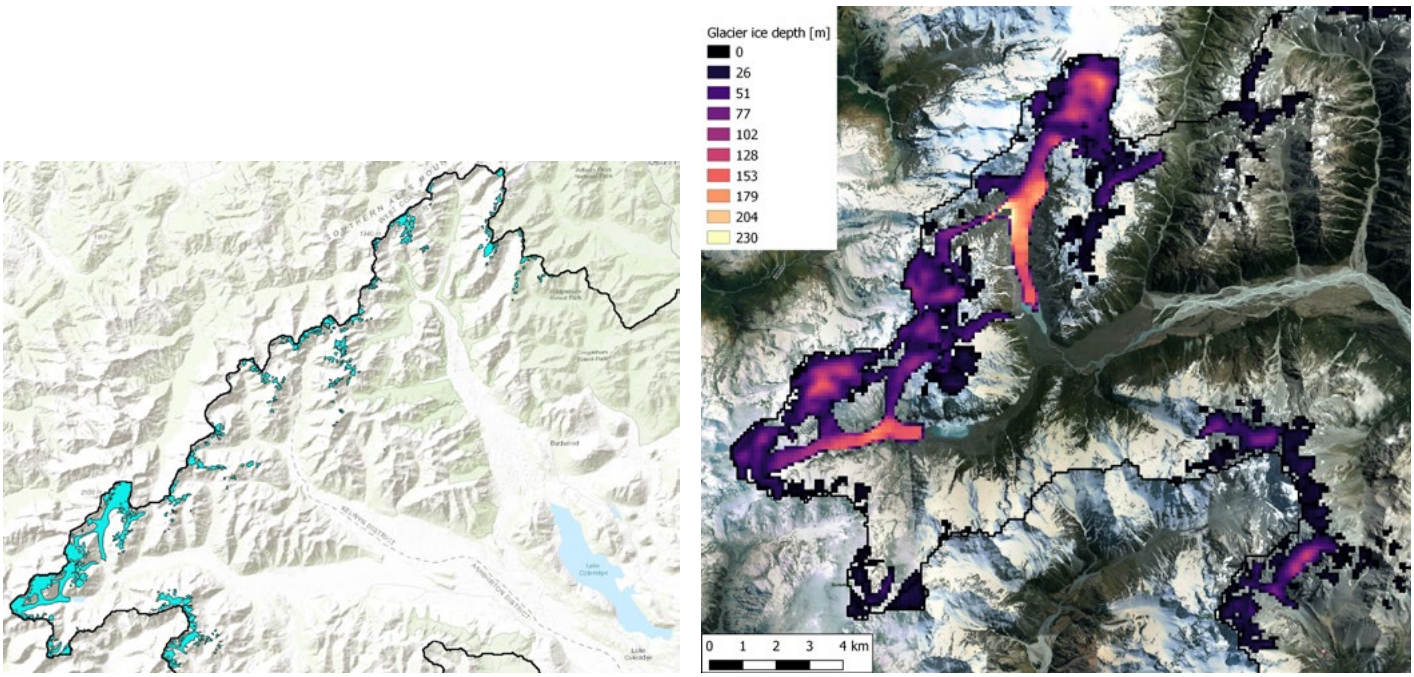

Figure 1: Left: glacier outlines in the upper tributaries of the Rakaia River Catchment according to the RGI 6.0 (Consortium & others, 2017). Right: glacier ice thickness distributions in the northwest of the Rakaia River Catchment as modelled using the GlabTop2 approach and reported by the SPHY model.

References

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MODELLING GROUNDWATER FLOW IN THE WANAKA - CARDRONA ALLUVIAL AQUIFER

Neil Thomas,[1]
[1] Pattle Delamore Partners Limited (PDP)

Aims

The National Policy Statement for Freshwater Management 2017 (amended 2017) ('NPSFM') requires the Otago Regional Council ('ORC') to set allocation limits and a minimum flow or water levels for all Freshwater Management Units in the Otago region.

To meet the requirements of the NPSFM, ORC is moving through a process of collecting technical information that will support the process of setting tailored groundwater allocation limits. In the Wanaka Basin / Cardrona Alluvial Gravel Aquifer ('Wanaka Aquifer'), groundwater is closely connected to the Cardrona River where groundwater discharge supports flows in the lowest section of the river. Aquifer discharges also support baseflows in Bullock Creek which flows through the centre of Wanaka township. Groundwater abstraction will affect baseflow in these connected surface waterways and therefore an integrated maximum groundwater allocation limit (MAL) that accounts for the effect of groundwater abstraction on surface water flows is required.

Method

ORC developed an initial computer model of the Wanaka Aquifer in 2011, which was used to investigate the potential effect of varying the groundwater allocation on flows in the Cardrona River and Bullock Creek. Computer simulations of groundwater include many parameters which are frequently poorly defined at the start of a modelling exercise. However, the model parameters can be constrained by comparing the model estimate of groundwater levels and surface water flows to observed groundwater levels and flows. Due to limited data, the initial model was not constrained to surface water flows and therefore the forecasted effects of varying the groundwater allocation on flows was uncertain.

Since 2011 further data have been collected, including surface water flows along the Cardrona River and flows in Bullock Creek, as well as additional groundwater level data. PDP were engaged by ORC in 2017 to recalibrate and update the Wanaka Basin groundwater model to include the new data. The updated model is an integrated groundwater water and surface water model that allows for the effect of surface water abstractions as well as groundwater abstractions. The model runs from July 2015 to June 2019 using weekly stress periods. Specific objectives of the recalibration included:

- Estimate the effects of groundwater abstraction on baseflows in the lower part of the Cardrona River and in Bullock Creek;
- Quantify the modelled uncertainty associated with those estimates;
- Consider the effect of additional groundwater abstraction on groundwater levels and existing groundwater users;
- Consider the effect of irrigation on groundwater levels;
- Consider potential allocation options across the Wanaka Basin

Results

The model suggests that there is a lag between the onset of abstraction and surface water depletion effects in the river such that the effect of overall abstraction on the river will eventually approach the long-term average annual abstraction rate after around 10 years of pumping. The overall effect of peak groundwater abstraction rates on river flows are likely to be smoothed and attenuated in time. That is in contrast to the effect from surface water abstractions, where the peak effect of abstraction on river flows occurs immediately. However, note that some groundwater abstractions located close to the surface waterways will have a more immediate effect. The model also indicates that, in areas progressively further east of the Cardrona River, groundwater has a progressively smaller connection to the Cardrona River).

The model has been used to investigate a series of options around allocation across the Wanaka aquifer, including different groundwater allocation limits, the effects of irrigation on groundwater levels and surface water flows as well as consideration of different flow restrictions on surface water takes.

USING VULNERABILITY ASSESSMENTS TO DESIGN A "BIG RIVER" FLOW STUDY IN A CATCHMENT INVOLVING MULTIPLE HAPU

Tipa, G.,[1] Home, M[2]
[1] Tipa and Associates Ltd
[2] Te Runanga o Arowhenua

Aims of the research

The aim of the research was to determine a method to help Maori structure a "big river" study in the Waitaki catchment. When faced with a large catchment and limited capacity, it is not physically possible for Maori to assess every river within a catchment. The study needed to ensure that the sub-catchments of greatest cultural significance and need (from a cultural and scientific perspective) were the rivers that were to be investigated. Our objective was to combine the results from cultural assessments for 50 sites in the Waitaki with a vulnerability assessment methodology. If successful this would identify those sub-catchments that could be categorized as highly vulnerable. They would then become the focus of further investigations, including flow studies.

Methods

Secondary data sources were utilized. The Cultural Health Index has been applied at more than 50 sites in the catchment. A report card for the cultural health of the catchment, reporting against 45 indicators, was available. We accessed a range of Cultural Impact Assessments, specific to the Waitaki, that had been prepared by Ngai Tahu since 2003. A series of climate change reports, prepared by NIWA for Te Runanga o Ngai Tahu in 2016, were also available. Finally, Environment Canterbury had prepared a range of technical reports as part of the limit setting processes in the Waitaki. Therefore, we had a rich database of qualitative and quantitative data that included historic paintings, survey maps and photographs, along with contemporary photographs. We reviewed vulnerability assessment methods that have been applied in other resource management contexts.

Results

We compiled a matrix to visualise the results of the cultural assessments undertaken at sites spread from Aoraki to Korotuaheka (a Maori reserve) at the river mouth. Whanau aspirations for each site were separately recorded. Expert opinion and analysis of CIAs, whanau evidence, climate change reports, and technical reports helped assess the likelihood of these aspirations being realized. This information then enabled us to calculate the risk for each site. We used a whanau expert panel to rate the consequence, as only Manawhenua can assess cultural impacts. Whanau are already active in the Waitaki and are implementing a range of strategies and policies that could be described loosely as adaptation strategies. Therefore, we also used our whanau expert panel to rate adaptive capacity. Once we had estimated risk, consequence and adaptive capacity we had the components necessary to determine the vulnerability of the respective sub-catchments. The overall result was a list of 10 sites assessed as highly vulnerable that will be subject to in-depth studies over the next 2 years. In other words, instead of thinking about 50 sites and risking "spreading the effort too thinly", whanau used a robust method to narrow their focus to 10 streams. The discipline of a vulnerability assessment also identified a number of areas of significance to Maori, where limited data prevented an assessment of their vulnerability.

USING FUZZY COGNITIVE MAPS TO VISUALIZE AND UTILIZE MATAURANGA MAORI AND SCIENCE IN FRESHWATER MANAGEMENT

Tipa, G.,[1] Nelson, K.[1]
[1]Tipa and Associates Ltd

Aims of the research

The overarching aim of the research was to develop a better understanding of the range of methods available to Manawhenua and resource managers to aid utilization of Matauranga Maori in water management. We examined the value of using fuzzy cognitive maps to structure and analyse data collected by iwi, hapu and whanau concerning the health of river catchments, and their perceptions of the factors that adversely impact stream health, and consequently their cultural beliefs, values and practices that are dependent upon healthy river systems. The focus for this work was the Opihi catchment, which afforded Manawhenua an opportunity to inform the limit setting process of the Orari Temuka Opihi Pareora Zone Committee.

Methods

Data were collected via interviews, hui, and hikoi to sites of significance. Field assessments were undertaken and the Cultural Health Index was applied at 12 sites, and the cultural flow preference methodology was also applied at several sites. This mixed methods approach provided a rich database of qualitative and quantitative data complemented by a visual record of contemporary and historic riverscapes.

Results

We examined how fuzzy cognitive maps (FCMs) can be used to inform the decisions of Maori with respect to management of valued catchments. Our presentation will identify how different knowledges informed construction of FCMs for 14 sub-catchments in the Opihi, and one for the catchment as a while. When analyzed, the FCM highlighted differences between whanau expectations and perceptions, and those of non-Maori, in other words the differences between matauranga Maori and scientific assessments of the same waters were explicit. In our case study, centered on the Opihi catchment, we created a weighted, directed FCM, which was a semi-quantitative representation of individual and group knowledge. FCMs are increasingly are being used globally to promote collective decision-making or to better understand knowledge held within communities. Our Opihi FCMs combined knowledges, preferences and values with semi-quantitative estimations of perceived relationships between concepts/variables. By understanding relationships between variables, the FCM helped identify components of a “solutions package” that are needed to protect the wahi taonga and wahi tapu of significance to Manawhenua. We can illustrate how cognitive mapping and its extension fuzzy cognitive mapping, can assist Maori to more effectively structure and apply matauranga Maori to aid identification of their management needs for inclusion in regional planning processes, participation processes to set minimum stream flows and nutrient limits. Crucially, our FCM helped Manawhenua participate in the regional council run scenario planning processes and provided guidance on the non-negotiables for inclusion in solutions package for the sub-catchments of the Opihi.

A SURFACE WATER NETWORK METHOD FOR GENERALISING STREAMS AND RAPID GROUNDWATER MODEL DEVELOPMENT

Michael W. Toews,[1] Brioch Hemmings[1]
[1] GNS Science

Aims

The construction of numerical models of complex hydrogeological systems is often time-consuming and burdensome. It is also the stage of a modelling project where subjective structural decisions are hard-wired, often never to be reassessed in the ongoing study. As part of the groundwater modelling component of Te Whakaheke o Te Wai (TWoTW), the team are developing methods to speed up the construction of the structural components of the case-study numerical models. Streams are a key component to most hydrogeological systems in New Zealand, as they route and exchange water and nutrients to and from aquifers. Model simulated outputs of these systems require adequate simulation of surface water processes and groundwater–surface water interactions. For example, predictions of in-stream concentration of a contaminant that is pertinent to a desired ecological metric, may, in part, be controlled by the contribution to surface water flow from relativity dilute groundwater sources as well as the transport of the contaminant through the surface water network.

In the context of groundwater models using MODFLOW, the Stream-Flow Routing (SFR) package is often used to provide the numerical representation of surface water processes (Niswonger and Prudic, 2005). Additionally, MT3D-USGS (Bedekar et al., 2016) can be used to simulate nutrient transport between aquifers and streams using the Streamflow Transport (SFT) package. The MODFLOW SFR package construction requires definition of the spatial and sequential distribution of stream reaches and segments. This includes approximating stream elevations, widths and flow inputs as well as a hierarchical description of routing direction. The temptation for the modelling practitioner is to provide a description the surface water network that most closely reflects the infinite complexity of the real world system, especially as this is usually the only component of the modelled system that is visible to model users and stakeholders. Development of such surface networks can be laborious, and the product is often at a level of detail that is miss-aligned with complexity and detail of the groundwater components of the model that it needs to integrate with. As well as being time-consuming to construct, this level of complexity and detail can result in long model run-times and poor model numerical stability that precludes the use of the model as a tool for informing robust decision-support through incorporation of stochastic uncertainty analysis techniques. The aim is to develop a programmatic method that can rapidly build a surface water network from an input collection of line geometries. High-level processing assigns each segment characteristic attributes for the network, and other methods are available to simplify and reduce the complexity of the surface water network. Once a network is built, it can be translated to existing MODFLOW and MT3D-USGS models as SFR and SFT packages, respectively.

Method

We have developed in Python a prototype object-oriented method for building a surface water network. By design, the minimum input to create a surface water network is a collection of 2D line geometries representing streams, each with a unique identifier. High-level evaluation of the segment and catchment geometries assign properties to each segment, including: Strahler stream order, downstream flow sequence, upstream catchment area and estimated stream width.

Once an initial surface water network is built, methods are available to simplify the network into derivative surface water networks. An aggregate method is used to merge groups of connected segments and catchment polygons, for example from a dense 1st order network to a more coarse 3rd order network. The result is a surface water network with a reduced number of segments and complexity. A remove method is used to trim parts of the network upstream and or downstream from a list of segment IDs. The density of segments can also be reduced with this method using other criteria, for example remove reaches with an upstream area less than 5 km2 to create a simpler network without minor tributaries.

Translation of a surface water network to MODFLOW and MT3D-USGS is provided using FloPy (Bakker et al., 2016). The SFR-builder constructs a discretised numerical representation of the segment geometries, based on an overlay of each segment line geometry on an exiting MODFLOW model grid. The SFR-builder has other methods to adjust stream elevations to ensure model streams always flow in the down-elevation direction and are below the defined (discretised) model top. While this can lead to departures from real-world surveyed stream elevations it is necessary to ensure model stability and that there is potential for surface water and groundwater exchange across the modelled network – accounting for the fact the model surface is itself and abstraction from the realworld topography.

Surface water flow estimates and observational data can be incorporated into the defined network FLOW and RUNOFF parameters, and contributions from stream segments that are not explicitly represented in the model can be aggregated and incorporated in the model network. The SFRbuilder includes several methods to minimise numerical instability associated with surface water process simulations (e.g. circular routing between collocated modelled segments – i.e. in the same model cell) and automates modification of the model (and approximated) definition of the surface water network to help mitigate instability.

Results

The methods developed exist as a prototype, currently in a private GitHub code repository with continuous integration testing. Surface water networks have successfully been built and verified for catchments between 3 and 500,000 segment line geometries. Their applications are being tested and applied in a real world case-study MODFLOW model for the Heretaunga Plains, Hawke's Bay, NZ, as part of the TWoTW project as well as in other modelling studies that the modelling team at GNS are working on.

It is hoped that this surface water network and SFR-builder will save time in groundwater model construction, provide more reproducible surface water network definitions for the modelling studies in TWoTW, and provide scope for more rapid model up-scaling and downscaling as well as opportunity to more easily investigate the sensitivity of model predictions to model structural definitions.

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UPDATE ON THE DEVELOPMENT OF THE NEW GROUNDWATER RESEARCH PROGRAMME AT GNS SCIENCE

Tschritter, C.,[1] Westerhoff, R.,[1]
[1] GNS Science

Over the last two years, GNS Science has restructured its MBIE Strategic Science Investment Funding. As a result, funding in groundwater research was increased from $0.9M to $2.4M, and therefore the GNS Science Groundwater SSIF research programme was entirely re-designed.

The primary aims of the new Groundwater SSIF programme are: to develop advanced hydrogeological maps, methods and models (in 2D, 3D and 4D, applicable from local to national and seamless between scales) that will improve the sustainable management of groundwater resources, with the aim of enhancing economic, social, cultural and environmental outcomes for the nation. Collaboration with national and regional authorities, research institutions, industry organisations, and other CRI's is integrated throughout the programme.

As part of the design process, a stakeholder survey was sent out to 156 stakeholders, comprising national and regional government representatives, including both managers and scientists. The stakeholder survey included the high-level project structure of the proposed programme. Feedback was received from 50 stakeholders. This feedback contributed to the design of workstreams and detailed project plans.

This presentation will provide an overview of the high-level design, the stakeholder survey results and the workstreams of the new Groundwater SSIF programme at GNS Science.

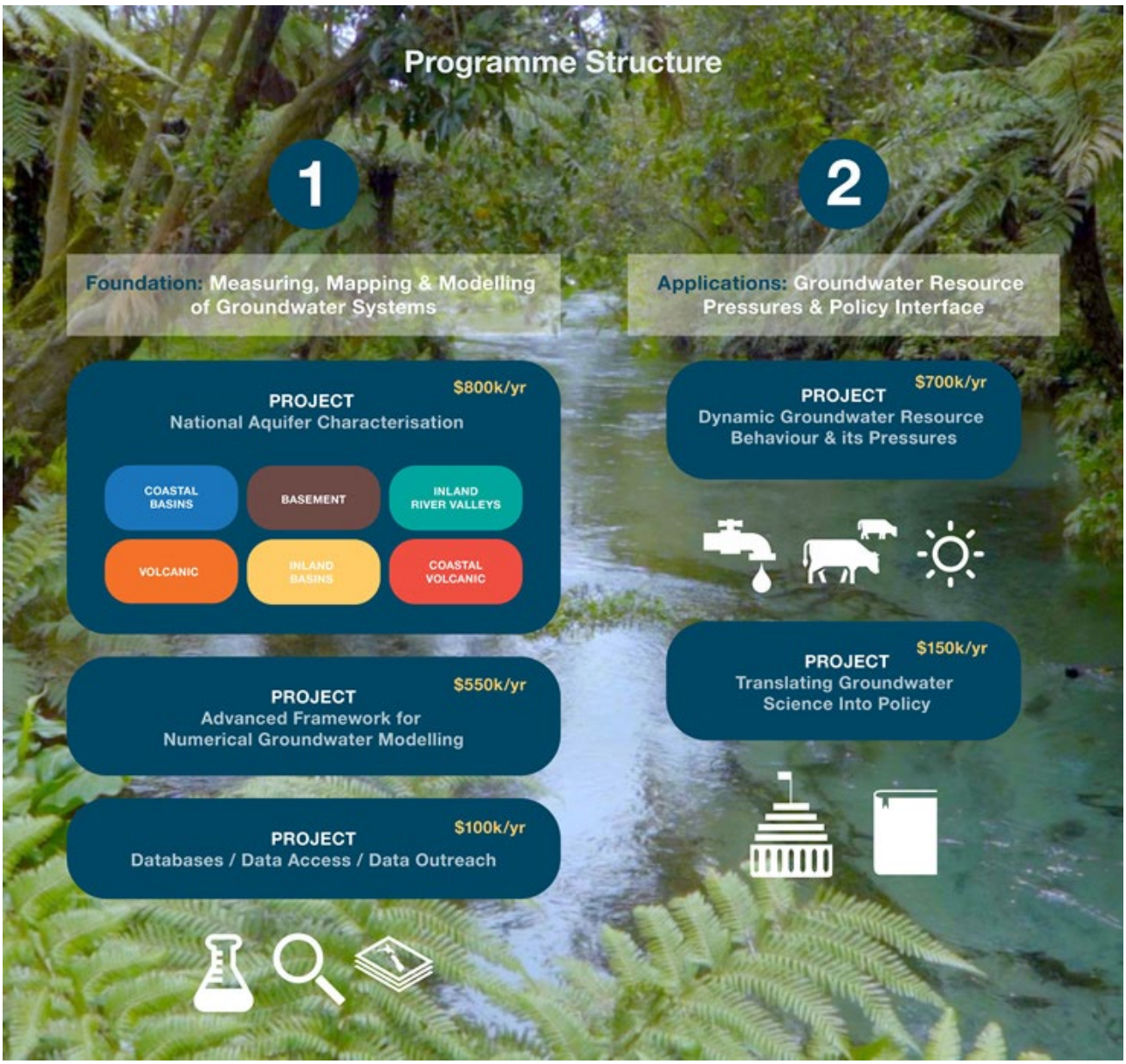

Figure 1: High level programme structure and projects of the new Groundwater SSIF programme

STORM EVENT SEDIMENT SOURCE TRACING FOR TEMPORAL AND SPATIAL ANAYSIS

Vale SS,[1] Fuller IC,[2] Procter JN,[2] Basher LR,[1] Dymond JR,[1]
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Aims

In this study sediment fingerprinting is applied to a storm event that took place between 27th – 30th November 2013 in the Manawatu river catchment, New Zealand. The aim was to understand the temporal dynamics in sediment sources during a flood event by evaluating SSC-Q hysteresis patterns in relation to sediment fingerprinting derived source proportions for the storm event and modelled spatial origin.

Method

Discharge and SSC data were obtained for the Manawatu river and five of its main subcatchments for the duration of a storm event. The data was used to derive SSC-Q hysteresis metrics, storm event metrics and subcatchment discharge and sediment load contribution to the Manawatu monitoring site. Sediment fingerprinting is used to determine sediment source contribution based on geochemical properties. Sources were sampled using composite sampling for geomorphological terrains representing a combination of geological and erosion process: Mudstone (MS), Hill Subsurface (HSS), Hill Surface (HS), Mountain Range (MR), Channel Bank (CB), Unconsolidated (US), Gravel Terrace (GT) and Limestone (LS). Suspended sediment samples were taken hourly from the monitoring site during a 53-hour storm event. The <63 µm fraction was analyzed for geochemical properties using XRF and LA-ICP-MS. Tracer selection procedures were employed to derive the best selection of tracers including bracket test for tracer conservativeness followed by Kruskal-Wallis and Stepwise-Discrimination Function Analysis (DFA) to select the tracers which maximize discrimination between source groups. The selected tracers were incorporated into a multivariate mixing model to estimate the relative proportions of sediment source contributions during the storm event. A spatial model of intra-storm sediment loads for each sub-catchment was developed to visualize and understand sediment origin during the storm event.

Results

Sediment source classification was achieved used 16 selected tracers: CaO, Lu, Cs, Sr, Tm, Na_2O, P_2O_5, Fe_2O_3, Pb, U, Hf, MnO, Zn, MgO, Nb and Y. Source contribution varied throughout storm event with mudstone varying between ≈ 20 – 60 %, both Hill Subsurface and Hill Surface sources ranging from 0 – 24 % and Mountain Range sediment ranging from ≈ 24 – 46 % (Figure 1).

High variability was observed between hourly source apportionment, either reflecting the highly variable nature of sediment transport dynamics or uncertainty inherent in sediment fingerprinting models (Figure 2). Smoothed data indicated some source trends occurring between phases of the storm event in combination with changing

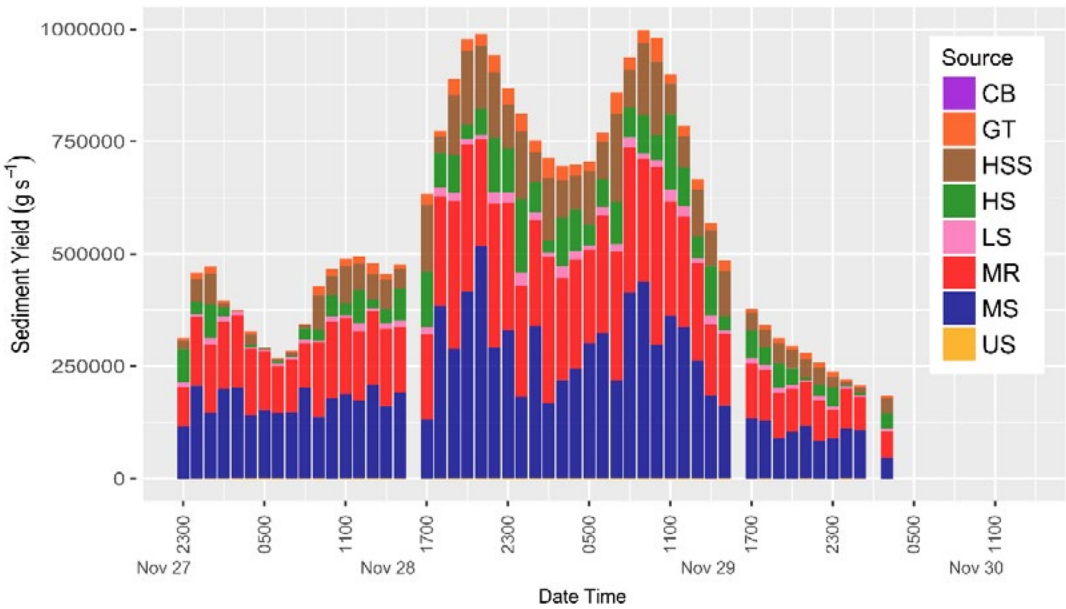

Figure 1: Hourly source contributions during the storm event; percentage, sediment load.

sub-catchment sediment load contribution. Hill Subsurface and Hill Surface sources ranged from ≈10 – 14 % for most of the storm duration, dropping to ≈ 2.5 % between 2:00–8:00 hrs on 28th Nov 2013, corresponding to the first sediment load minima associated with the Pohangina subcatchment contribution (Figure 2; Figure 3). A clockwise hysteresis indicated that in the initial phase, sediment source proportions are originating from nearby sources but given sources of sediment estimated from sediment fingerprinting, it is likely this sediment is stored channel sediment reflecting the original sediment source. This would explain the exhaustion of Hill Surface and Subsurface sediment and evidence of a gap between exhaustion of the Hill Surface and Subsurface source material stored in channel and the arrival of new sediment from these sources providing insights to sediment transport dynamics. The spatial model of the source loads provided an effective means to visualize the origin of the sediment and a better spatial interpretation of sediment fingerprinting, which is typically limited by a poor spatial resolution.

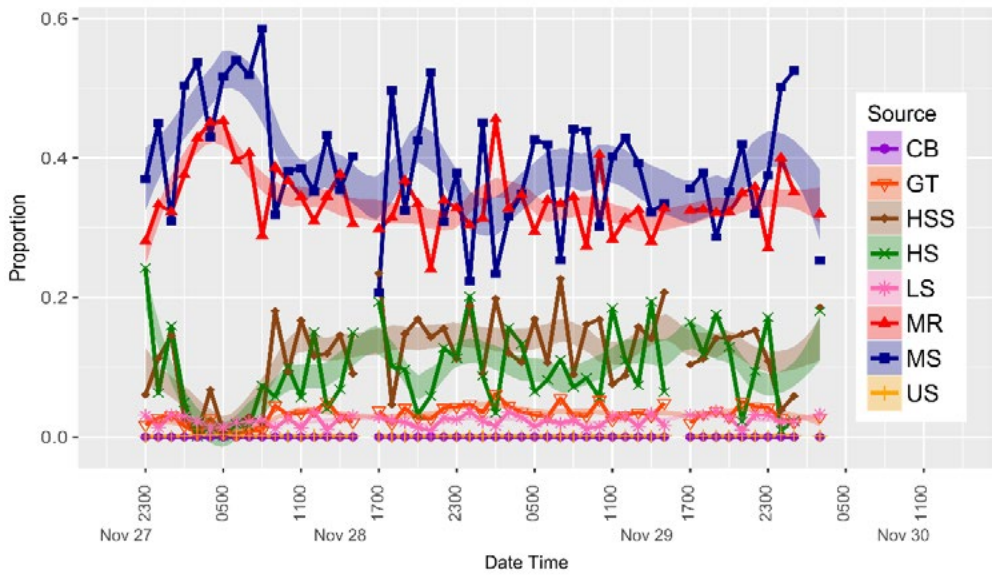

Figure 2: Mean proportions of each sediment source throughout the storm event along with smoothed values shown by the shaded line

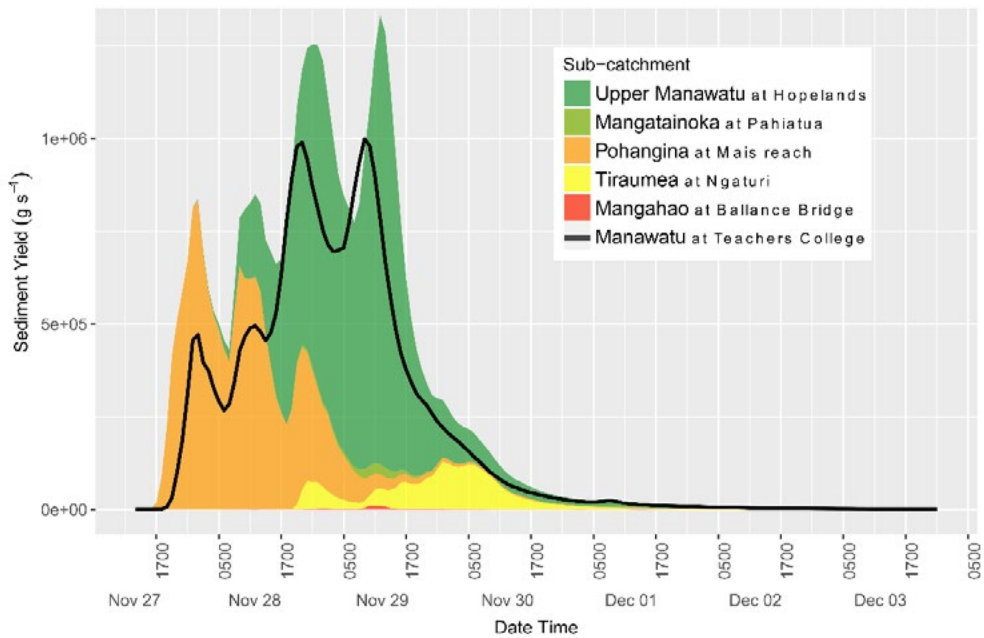

Figure 3: Manawatu at Teachers college sediment yield superimposed over adjusted cumulative sediment yield.

CREATING A GROUNDWATER ISOSCAPE FOR NEW ZEALAND

Rob van der Raaij,[1] Vanessa Trompetter,[1]
[1] GNS Science

Aims

Isoscapes are spatial models of variation in the isotopic composition of various substances in the environment. This project aims to create an isoscape for New Zealand groundwater, utilising measured stable isotope data to develop a predictive model for hydrogen and oxygen isotopic spatial patterns in groundwater.

Groundwater acts as an integrator of the isotopic signal of long-term precipitation inputs, and can provide benefits for studies involving catchment hydrology, groundwater hydrology, groundwater / surface water interaction, and other studies that may require knowledge of the average isotopic composition of water such as agricultural authentication and biosecurity.

Method

Stable isotope data ($\delta^{18}O$ and $\delta^{2}H$) has been collated for more than 3000 New Zealand groundwater samples over hundreds of sites. This data is being mapped and modelled to create a national-scale groundwater isoscape (Figure 1). Modelling techniques such as general linear models (GLM) and classification and regression trees (CART), alongside geostatistical interpolation, have been explored using correlations with variables commonly associated with variations in stable isotope values, such as elevation, latitude, distance from the coast, air temperature and precipitation.

Results

The modelling is ongoing. This talk will present the results to date, with a discussion of problems encountered due to the large variability in New Zealand's terrain and climate and to other issues.

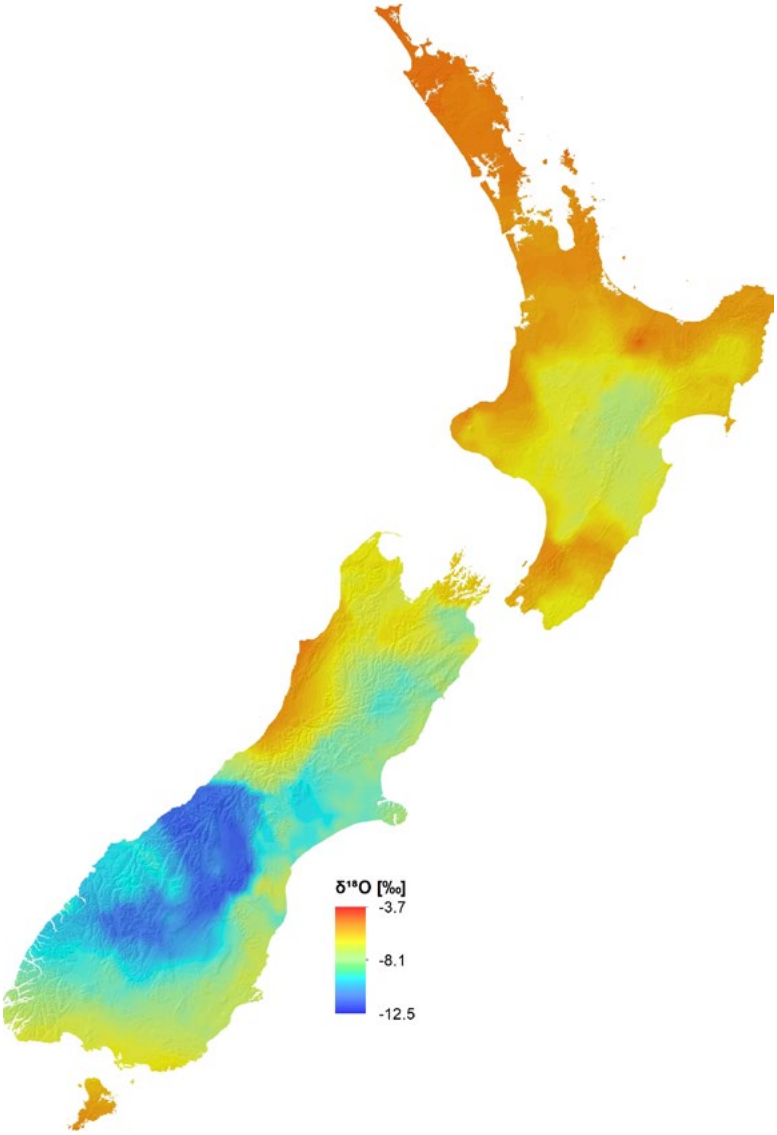

Figure 1: Map of spatial variability in δ18O of New Zealand groundwater created using empirical Bayesian kriging (ArcGIS 10.5.1).

IMPACT OF THE KAIKŌURA EARTHQUAKE ON RIVER AND GROUNDWATER INTERACTIONS

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[1] WSP Opus

Aims

The Ward community relies on the Flaxbourne and Waima/Ure Rivers for a diverse range of agricultural practices and land uses; including irrigation, stock water, and domestic potable water supply. Dramatic changes to the landscape and waterways have occurred since the Kaikōura Earthquake, including potential changes to the flow regimes of the rivers and the connection between surface water and groundwater.

This project aimed to characterise the low flow regime, the nature of the low flow recession, and the gaining and losing reaches of these rivers to identify how the flow dynamics of each river has changed as a result of the Kaikōura Earthquake.

Method

A series of low flow gaugings along the main stem of each river was undertaken. Since water resources are generally most stressed during summer and periods of prolonged low flow, gauging was undertaken at monthly intervals from December 2018 to April 2019.

Concurrent gaugings commenced at the boundary of the hill country, where all flow is confined within bedrock channels, and extended downstream to the limit of tidal influence. Gauging locations were broadly upstream and downstream of major tributaries, and where other known controls influence flow. Locations were also based on existing data held by Marlborough District Council (MDC) (Figure 1).

Figure 1: Low-flow gauging locations on the Waima/Ure and Flaxbourne Rivers.

Results

Comparison of the flows at Blue Mountain and the SH1 Bridge shows a significant loss of surface flow over this reach. In general, there is a reduction in flow in the Waima/Ure River downstream of Blue Mountain i.e. flows are higher at Blue Mountain than at The Narrows, the Ure Road Bridge, the SH1 Bridge, and upstream of the coast (Figure 2). This is a function of the area and depth of gravels overlying the bedrock and valley configuration. Consequently, there is a strong hydraulic connection between the river and adjacent aquifers.

However, there also appears to have been a shift in this relationship since the earthquake. A greater proportion of the flow at Blue Mountain is now 'lost' upstream of the SH1 Bridge (Figure 3). This shift does not appear to exist, at least to the same level, between the Blue Mountain and the Ure Road Bridge, where a slight increase in additional flow is apparent i.e. there is less loss of flow to the groundwater. The change in the proportion of surface flow 'lost' to the underlying gravel is largely the result of changes to the connectivity between surface water and groundwater between the Ure Road Bridge and SH1 and a potential increase in groundwater storage as a result of tectonic uplift.

The low-flow gauging results for the Flaxbourne catchment show a reduction in surface flow downstream of Dog Hill to SH1 of between 14% and 31%. Flows then increase from SH1 to the coast; which cannot be attributed solely to the inflow from Needles Creek.

This change in river behavior is consistent with the differential uplift that resulted from the Kaikōura Earthquake. Uplift at the coast reduced the channel gradient and provided a greater volume of porous gravel above sea level. This has facilitated both greater storage and greater underflow i.e. flow through the gravel.

The longer-term effects of this are difficult to predict. However, over time, equilibrium conditions with the 'new sea level' are likely to develop. The Waima/Ure River will degrade through the uplifted gravel to attain a grade and long-profile similar to that before the Kaikōura Earthquake. Once this has occurred, it is likely that the surface water and groundwater dynamics, and their interaction, will return to something similar to that before the earthquake. The speed of downcutting will be controlled by the frequency, magnitude and duration of flood events. Since floods are essentially random in time, any future changes in the lower Waima/Ure catchment are difficult to predict at this time.

The apparent shift in the previously developed relationship between flows at Blue Mountain and at SH1 has significant water resource implications. There appears to be significantly less surface flow at SH1 relative to Blue Mountain since the Kaikōura Earthquake. The reduction in surface flow in the lower Waima/Ure catchment has implications for the management and maintenance of surface flows, instream services and ecological values, and the connectivity between surface water and groundwater. There are also potential consequences for both surface water and groundwater abstraction.

The characteristics of the past summer were atypical and therefore the above results should be regarded as tentative. Further gaugings are planned for the coming summer.

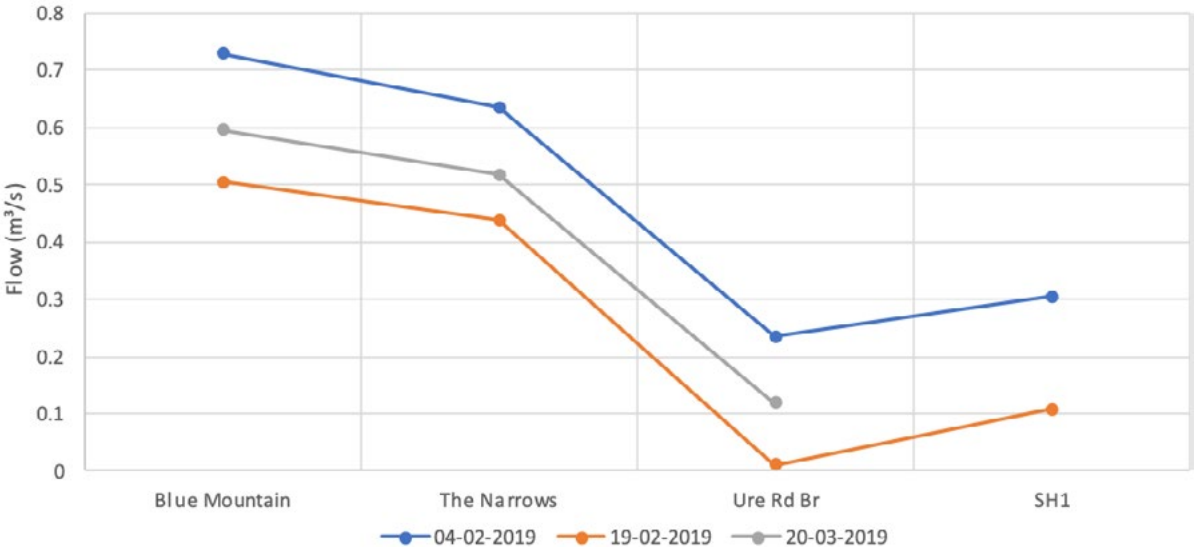

Figure 2: Gauging results for established gauging locations on the Waima/Ure River.

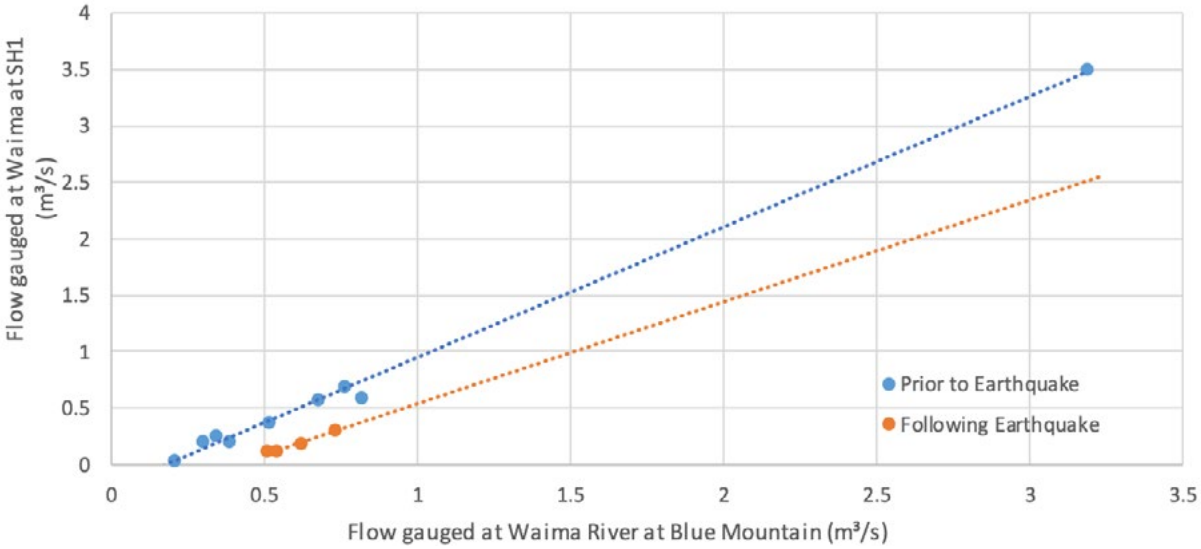

Figure 3: Correlation of flows recorded in the Waima/Ure River at Blue Mountain and SH1.

ARE CHANGES AFOOT BELOW? ASSESSING GROUNDWATER ECOSYSTEM RESPONSE IN A CLIMATE OF CHANGE

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Introduction

When considering the challenges facing civilisation one of the most important is water, both quality and quantity. We are already seeing indications that all is not well below ground. A little understood but vital component of understanding the risk to future sustainable water supplies is the role groundwater ecosystems play in protection of groundwater supplies. Groundwater is important to maintaining ecosystem serves and plays an integral part of the water cycle and regulation of climate. On the flipside we need to understand that **it is these groundwater ecosystems that provide the services critical to maintaining groundwater systems.** Overseas studies have highlighted that multiple risks occur to our groundwater in the face of climate change. These include, long term decline in groundwater levels, increasing frequency and severity of groundwater drought and floods, increasing mobilisation of pollutants, and saline intrusion in coastal aquifers. Changes in land-use activities also impact groundwater systems from over allocation, increasing urbanisation leading to reduced aquifer recharge and potential decrease in infiltration.

Aims

Our research is focused on changing the gap in our knowledge and assisting the challenges facing civilisation by providing information on the diversity of micro to macro-fauna present in NZ aquifers and begin to understand the functions and resilience of these vital ecosystems. What are the key stressors to the system and when does the system tip out of balance?

Methods

In order to study the diversity and function in groundwater we have established methods for sampling across the taxa (micro to macro-fauna), a key component to obtaining robust data. We have undertaken studies at field locations across regions in NZ and are now combining this with laboratory studies to understand the stressors on the system and how resilient they are to stress.

Results

The results are demonstrating that there is a wide diversity of fauna present in NZ aquifers. We can see significant differences in the attached communities compared with transient groundwater communities. Fig 1 shows the Shannon and Simpson diversity index between biofilm (attached) and groundwater communities at microbial taxa level (16s, bacterial and archaeal data). Within the microbial taxa there are differences seen between the lithology and water chemistry present. There are indications that the impact of land use can also be seen (Fig 2). For example, the presence of firmicutes (mostly aligned to Clostridia) seen in certain sites could indicate high interaction between the surface and groundwater as all the sites are relatively shallow (Fig 2). Previous research has suggested Clostridia used as an indicator of faecal contamination as they reside in mammalian guts, but also soils (Gomilla et al., 2008). Other research where contamination or surface to groundwater interaction occurs have seen similar results (Ben Maamar et al., 2015).

For eukaryotic (protozoa, mites, Stygofauna) organisms we have demonstrated that molecular tools can be a useful approach to gaining a picture of diversity in groundwater, where traditional taxonomic approaches are lengthy and inefficient. The biggest challenge facing us for these taxa is developing a large dataset to compare molecular sequence data. More combined effort across research organisations is needed to achieve this.

We will present an overview of the findings over the past three years at our field sites and provide suggestions to the development of a tool to monitor changes that may be occurring in groundwater systems. The vital role groundwater ecosystems play in the water cycle: above, below and beyond, will be demonstrated.

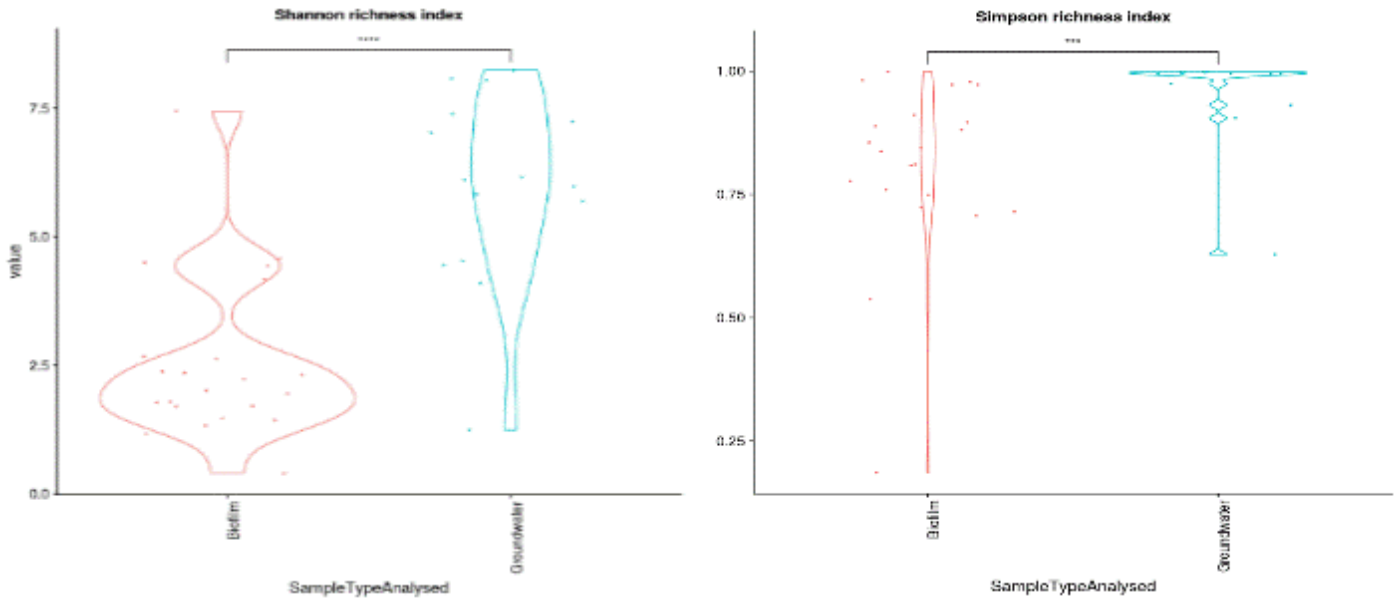

Figure 1: Shannon and Simpson alpha diversity between biofilm (attached) and groundwater (transient) microbial communities across all sites.

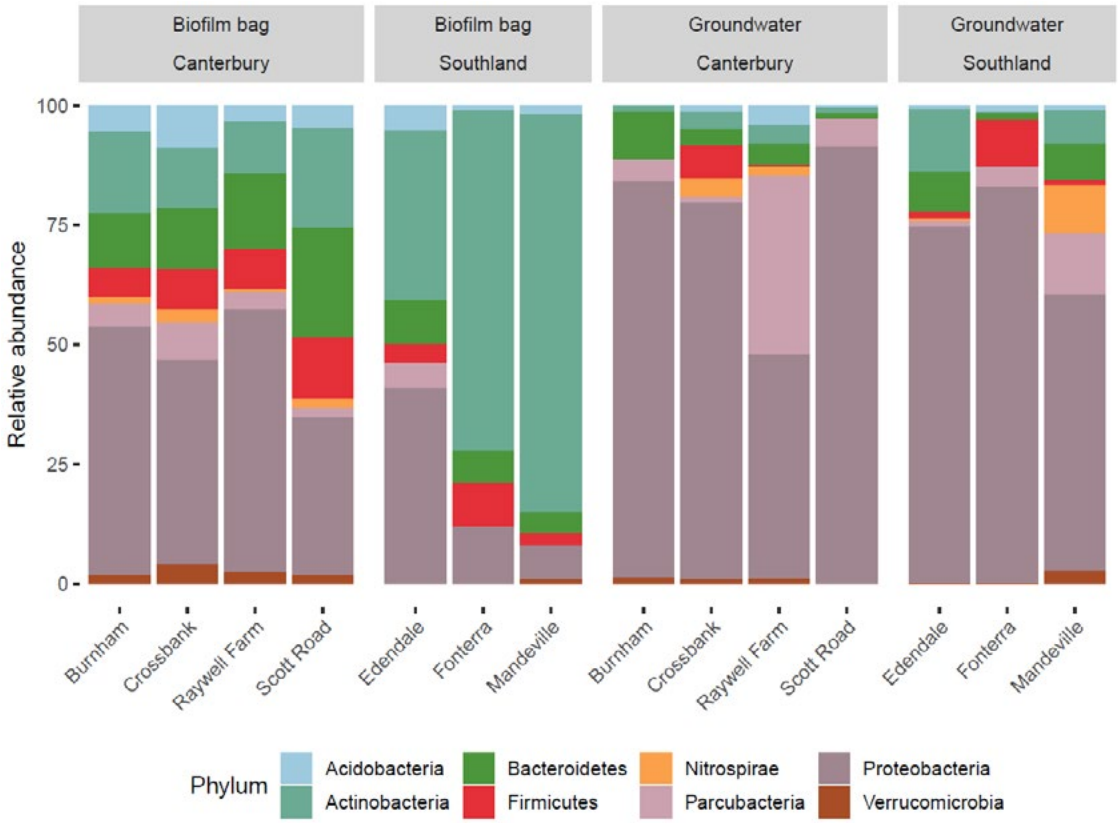

Figure 2: Example results of the biofilm and groundwater diversity seen in one season (summer) at sites across regions.

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NATIONWIDE ESTIMATES OF RENEWABLE AND NON-RENEWABLE GROUNDWATER VOLUMES IN NEW ZEALAND

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Aims

Estimates of groundwater volume are important for sustainable water management. For example, regional councils undertake groundwater volume assessments that relate to local policy and allocation. At the same time, central government also undertakes national-level estimates, which are important to inform high-level national initiatives and funding (e.g., associated with environmental and economic trade-offs). These different stakeholders require data at different spatial scales, which has led to a lack of consistency between groundwater volume estimates across these scales. Until recently, this gap could not be bridged due to data limitations. However, the availability of a high-resolution digital geological map of New Zealand (the 1:250,000 QMAP (Heron 2014)) and nationwide recharge data (Westerhoff et al., 2018a) has paved the way for a step-change in the improvement of water volume estimation.

The objective of this study is to develop the first nationally-consistent and high-resolution (250m x 250m) estimates of renewable and non-renewable groundwater volumes in New Zealand.

Method

Several input datasets were used to estimate total groundwater volume. These datasets include: the QMAP; look-up tables of effective porosity and hydraulic conductivity per rock type (e.g., Tschritter et al., 2017); calculation of the decrease of hydraulic conductivity and porosity over depth (Beven and Kirkby, 1979; Ramm and Bjorlykke, 1994); a nationwide model that estimates the water table depth (Westerhoff et al. 2018b), improved with observed water levels; and nationwide rainfall recharge.

Porosity was integrated between the water table and the hydrogeological basement, i.e., the depth where hydraulic conductivity reaches a threshold value (e.g., < 0.1 m/day). Use of this threshold means that any water occurring in, e.g., crystalline rocks, meta-sediments, carbonate and fine-grained sedimentary rocks are not taken into account. The estimated volume is considered to correspond to water that is stored in coarse and poorly sorted Quaternary and Tertiary sediments, i.e., where groundwater is most commonly abstracted from. The volume estimate obtained was not adjusted for the presence of confining layers.

For each region of New Zealand, recharge was compared to total groundwater volume to distinguish between renewable and non-renewable volumes.

Results

We present estimates of groundwater volumes across New Zealand, which are in the same order of magnitude as previous research suggests (e.g., ~1700 km^3 by Toebes (1972) or ~700 km^3 by Moreau and Bekele (2014)), with the additional improvements that our method is the first that estimates spatial variation on a national 250 m raster (Figure 1). Our high spatial resolution facilitates easy estimation of water volumes at different scales, e.g., nationally, per region, per catchment or per aquifer, including uncertainty estimates.

Only a small fraction (a few percent) of the total groundwater volume in New Zealand is renewable, and this fraction varies per region. Our method can aid in better distinction between renewable and non-renewable water resources at different scales, either per catchment, per region, or nationally (e.g., the New Zealand's Physical Stock Account for Water by Ministry for the Environment and StatsNZ). Future improvements are suggested towards incorporation of water stored in fractured rock aquifers, a better distinction between volumes in unconfined and confined aquifers, and incorporation of spatially-explicit water usage data.

Acknowledgements

This work was developed as part of The New Zealand Groundwater Atlas Project, funded by the Ministry for the Environment.

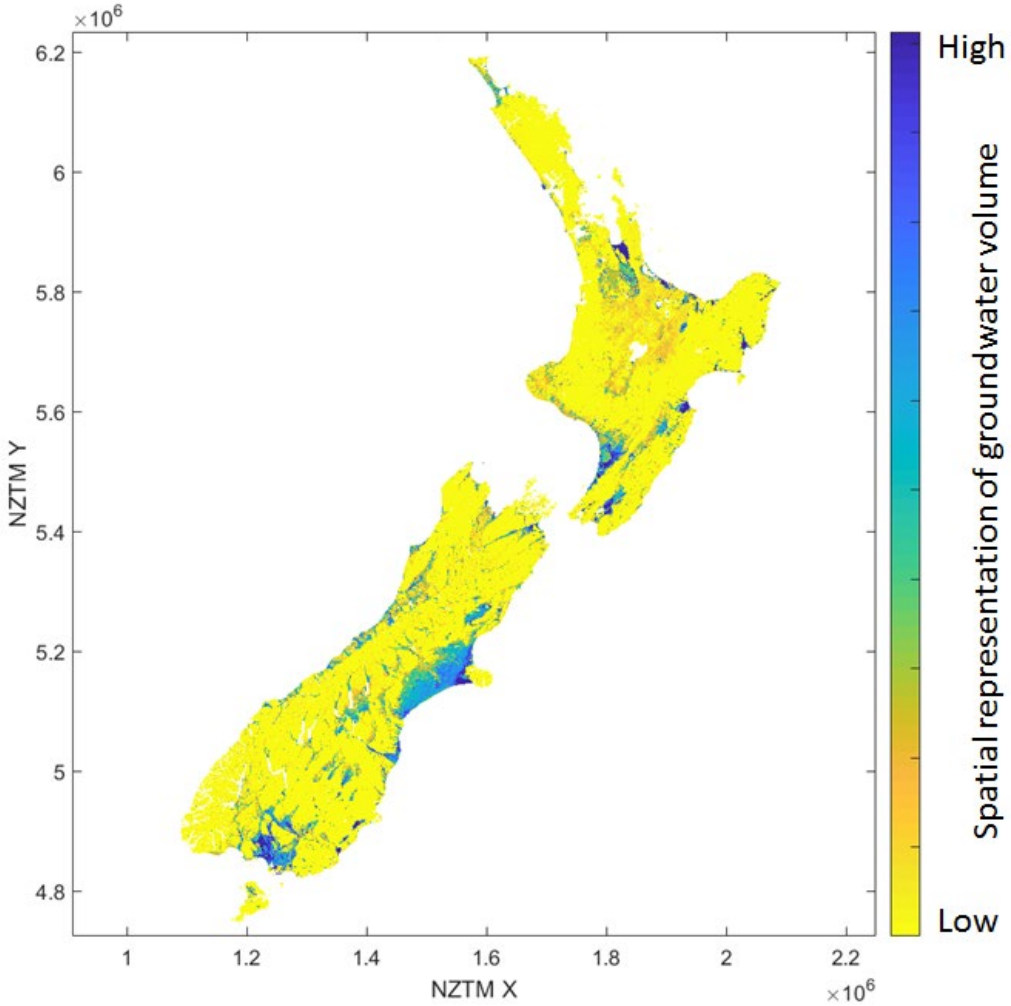

Figure 1: Spatial distribution of groundwater volume in New Zealand.

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UPDATE ON GROUNDWATER MAPPING, MONITORING AND MODELLING ACTIVITIES IN THE NEW ZEALAND WATER MODEL

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[1] GNS Science, New Zealand
[2] NIWA, New Zealand

Aims

The New Zealand Water Model Hydrology Project (NZWaM-Hydro) aims to develop hydrological understanding across the New Zealand landscape with a combination of data on surface water, soil, subsurface (geology), and groundwater. In March 2016 the NHP was submitted by NIWA as an MBIE contestable research programme ('Surface water-groundwater model for national applications') with core partners Landcare Research and GNS Science. 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 surface water to groundwater in a New Zealand Water Model. This presenation serves as an update of the groundwater acttivitites in the project up to date.

Method

The technical groundwater activities in the NZWaM project have mainly consisted of 1) geospatial information provision of hydraulic properties; 2) building of a groundwater module able to interact with the surface water module; 3) development of a water age module, with groundwater and surface water age combined.

Results

For the geospatial information taks, we present results of hydraulic properties developed for the project. Those consist of national-scale layers of hydraulic conductivity, effective porosity. We identify datasets developed in other projects that will further improve the national-scale layers.

For the groundwater module, we present:

- tests that have been run through development of a dynamic gaining and losing reaches scheme, based on groundwater discharge to surface from the groundwater model;
- case study results in three regions of implementation of a nationwide groundwater model used for regional-scale studies;
- testing of the modelling chain with an advanced (MODFLOW) model for .a combined surface water / groundwater prediction and improved uncertainty estimates;
- discussion of the difference between groundwater catchments and surface water catchments.

For the water age module, we present the results of isotope field sampling, carried out by regional councils, analysed by both GNS Science and NIWA, and made available through a regularly updated open-access spreadsheet. Stable isotope data will be used to improve catchment-scale isoscape layers for stable isotopes; the tritium and stable isotope data gathered might improve water age estimates from groundwater entering the stream as baseflow.

Acknowledgements

This work was developed as part of The New Zealand Water Model (NZWaM-Hydro) Project, funded by MBIE through NIWA SSIF funding.

COASTAL AQUIFER SYSTEMS: FACIES AND GROUNDWATER FLOW

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[1] GNS Science, New Zealand
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Aims

New Zealand's aquifer systems have been classified by general type and mapped (White, P.A. 2001 and Moreau et al., 2019, respectively). Coastal aquifer systems are important to New Zealand because they are the source of groundwater for many cities and towns (e.g., Napier, Hastings, Blenheim, and Christchurch). Commonly, spring-fed streams are popular amenities for these communities that are widely used for recreation and are navigable in part.

This paper describes generic hydrogeological facies of New Zealand's coastal aquifers.A type-example of the Lower Wairau Plain, Blenheim is used to represent numerous elements of these facies, including: gravel aquifers and palaeoestuarine sediments (aquicluides), White et al. (2016, 2017).

The paper also addresses the benefits of a facies approach to the understanding of the Wairau Plain groundwater system. Lastly, the relevance of this work to New Zealand coastal systems is discussed.

Method

Hydrological facies, of Holocene and Pleistocene age, were identified in the Lower Wairau Plain coastal aquifer system. The 3D distributuion of each facies was then defined with top, and bottom, 2D surfaces. Then, features of each facies were identified from 3D models of lithology, static groundwater pressure and groundwater budgets (White et al., 2016). Lithological features include sediment size (i.e., gravels, sands and fine sediments) and the distribution of contiguous sedimentary deposits. Static groundwater pressure, 3D pressure and water budgets indicated 3D groundwater flow directions.

Results

Hydrogeological facies include aquifers, aquitards and aquicludes (Table 1). Mapped in 3D, the geomorphic units provided evidence for the development of aquifers and aquicludes in the Lower Wairau Plain. For example, the gravel riser, now buried, is formed of gravel, sand and shell. This facies was probably deposited in a coastal environment, much like that of today's coast. The riser generally marks the eastern boundary of relatively thick Holocene gravels deposited by the Wairau River; this boundary is characterised by relatively high-upwards vertical pressure gradients and groundwater outflow into spring-fed streams and swamps as indicated by water budgets.

Table 1: Hydrogeological facies of the coastal Wairau Plain groundwater system.

Facies name	Age	Depositional environment	Hydrogeological class
Rararangi Gravel	Holocene	Coastal	Aquifer
Palaeoestuary	Holocene	Estuary	Aquiclude
Gravel Riser	Holocene	Coastal	Aquifer
Buried valleys	Holocene	Intertidal	Aquitard
Holocene gravels	Holocene	Terrestrial	Aquifer
Pleistocene gravels	Pleistocene	Terrestrial	Aquitard

A facies-based classification is relevant to the understanding of New Zealand coastal systems. For example, numerous coastal systems (e.g., Hauraki Plains, Heretaunga Plains, Waimea Plains-Nelson and Christchurch) include sedimentary units that were formed in most of the depositional environments found in the Wairau Plain (i.e., Table 1). Therefore, these systems may exhibit similar hydrogeological properties to the Wairau Plain, e.g., all groundwater recharge may flow to spring-fed streams and swamps.

In contrast, some systems contain few of these facies. For example, Pleistocene terrestrial gravel is the sole facies in the coastal Ashburton-Rakaia groundwater system indicating the potential for off-shore groundwater discharge.

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A NATIONAL GROUNDWATER REDOX STATUS MAP FOR NEW ZEALAND

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Aims

The aim of our research was to produce a model of groundwater redox prediction for the whole of New Zealand. One of the requirements for this was to overcome sample selection bias observed in our previous regional-scale studies. The predominance of groundwater samples from oxic environments created a dataset for model training which was highly imbalanced, and hampered model performance (Close et al. 2018).

Method

The approach we have taken is to develop a multivariate statistical model to relate observed redox class (the response variable) to the physical variables associated with the sample locations (predictors). The trained model is then used to predict redox status in areas without observation data. All modelling was carried out using the statistical package R version 3.5.3.

Groundwater chemistry samples from regional council databases were assigned an oxic, reduced, or mixed redox status using an approach modified from that used in McMahon and Chapelle (2008). The predictor variables were sourced from nine spatial datasets of physical and hydrological characteristics with national coverage (minus mountainous areas). The predictor variables were collated using ArcGIS Pro software and intersected with the redox observations from about 7,500 wells. Sample selection bias was corrected by applying the 'synthetic minority oversampling' (SMOTE) method (Chawla, et al. 2002) to generate a balanced redox classification dataset (Blagus & Lusa 2013) for model training.

Principal components analysis was used to generate a correlation matrix between the predictive variables. This enabled correlated predictors (e.g. soil order and drainage) to be identified and selectively removed. A random forest model was trained on the balanced groundwater redox observation dataset. Model performance was independently tested using repeated random ten-fold cross validation with ten repetitions (100 model runs in total). Performance metrics were the model accuracy, and Cohen's kappa (comparison between predicted accuracy and the agreement expected due to chance).

Some evidence of predictive variable bias was evident in the feature selection process, as demonstrated by a null-case test. This predictor bias was overcome by the application of Conditional Inference Random Forest model, or cForest (Strobl et al. 2007), which was used for our final predictions.

Results

The cForest model produced a holdout accuracy of 0.81 and a kappa value of 0.71 for the 100 cross validation model runs. The model enables groundwater redox predictions to be made at a specified depth (Figure 1). The feature-importance metric indicates the most influential predictors to be (in order): soil drainage, sample well depth, flow Fre3, elevation, sub rock, geological age, MALF, and land use.

Predictive modelling required that the national dataset data be split into four sub-regions for it to be computationally feasible in R and GIS. The predictions were parallelised and took a total of two days processing time for each depth using a 2.1 GHz Xeon Gold 6152 CPU processor with 44 cores. Spatially joining the prediction results to the source polygons took an additional four to five hours for each sub-region.

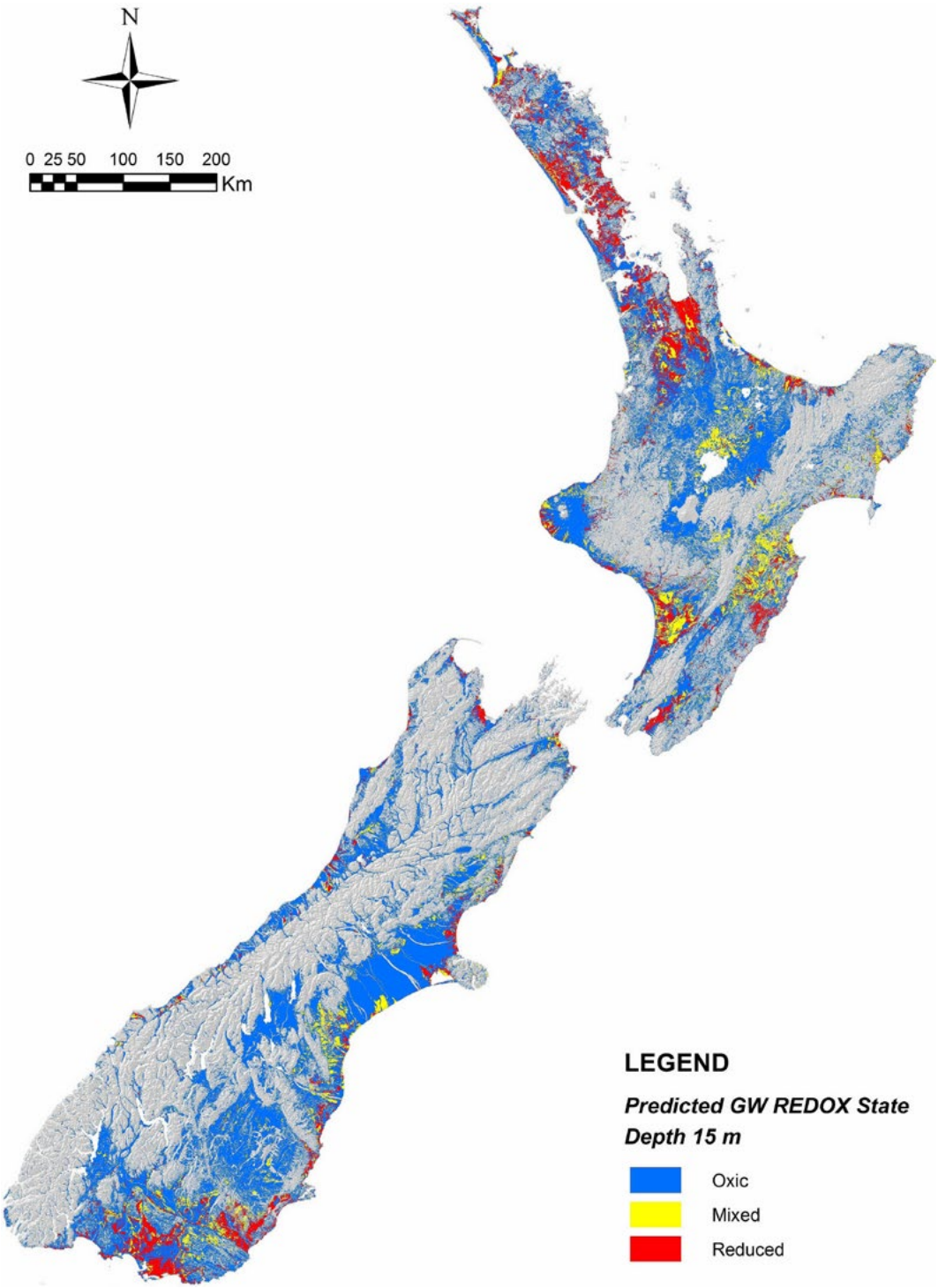

Figure 1: Groundwater redox status predictions for 15m depth

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PREDICTING WAIRAU PLAIN GROUNDWATER STORAGE – PROGRESS ON THE OPERATIONAL AQUIFERWATCH TOOL(BOX)

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Aims

The Upper Wairau Plain Aquifer serves as the major resource for drinking water and irrigation in the Blenheim region. Natural recession of groundwater levels and storage occurs annually during the summer months in the upper part of the highly conductive gravel aquifer. Due to a number of particularly dry summers, aquifer storage has reached critical levels several times in the past. If this trend continues into the future, it might require water take restrictions to be imposed by the Marlborough District Council (MDC) who manages the groundwater resource.

The aim of this work is to develop methods and tools that give the MDC at any given time an early warning whether or not these critical levels are likely to be reached and when it is likely to occur. This contribution reports on the progress to develop a corresponding operational framework to forecast Wairau Plains Aquifer groundwater levels and storage. The tool will create more lead time for the MDC in decision making and adaptive management of the Wairau Plain groundwater resources.

Method

A numerical groundwater flow model of the Wairau Plain was previously set up to understand the main drivers of aquifer storage (Wöhling et al. 2018). Since that model posed practical restrictions to be of use for operational management purposes, we tested several data-driven surrogate models with easily attainable inputs that could be derived directly by an automated database query of the MDC monitoring network. In addition, a Wairau River flow master-recession curve has been derived from historic (observed) time series data.

A more recent development is the use of Eigenmodels to predict Wairau Aquifer groundwater heads. Eigenmodels have been applied several times for this purpose in New Zealand. Here, a tailor-made version of the model is used and coupled with Markov chain Monte Carlo (MCMC) sampling for model calibration and parameter uncertainty analysis.

Several Eigenmodels are embedded in a modular prediction framework that allows for a flexible description of critical model inputs depending on different states of knowledge and on different purposes of the analysis. This includes not only the different alternative modelling techniques to predict groundwater heads, but also modular functions to describe groundwater exchange flows, and different predictors of Wairau River flow – the main driver for aquifer recharge. For the latter we have tested recession curves but also an ensemble-based predictive hydrological model for the entire Wairau catchment.

Results

Surrogate models and Eigenmodels in particular perform very well in hind-casting historic groundwater levels at selected locations of the Wairau Plain Aquifer. The models are efficient and fast, which is a prerequisite for the operational management support tool. The way how aquifer recharge is described as a function of river discharge proved to be very sensitive to the accuracy of the results. Further investigations are under way to better understand the detailed processes of this relationship which are a matter of ongoing research in braided rivers.

The corresponding driver and key input to the framework is the Wairau River flow. Flow recession events (when it is not raining in the catchment) are well captured by the master-recession curve, but a truly predictive operational tool requires a rainfall-runoff model to predict river flows also when it rains. Initial results with the hydrological model ensemble are promising once the Virtual Climate station Network (VCSN) rainfall input is corrected for its bias (significant underestimation) in high-elevation areas of the upper Wairau catchment.

The components of the predictive framework were tested and applied to historic data. Periods with critical groundwater levels were successfully detected. Work on integrating the different components in the modular framework is well under way. Future plans also include the propagation of input uncertainty through the framework, in addition to the treatment of parametric and predictive uncertainty which is implemented already.

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APPLICATIONS OF THE INTEGRATED SURFACE-GROUNDWATER MODEL TOPNET-GW

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Aims

The National Policy Statement for Freshwater Management (NPS-FM; Ministry for the Environment, 2017) provides direction on how local authorities should carry out their responsibilities for managing freshwater, acknowledging *Te Mana o te Wai (integrated and holistic well-being of a freshwater body)* as an integral part of freshwater management. Implementation of *Te Mana o te Wai* requires an integrated and holistic understanding of the pertinent natural system and processes when simulating surface and groundwater bodies. Application of Te Mana o te Wai concepts to water management is supported through the development of an integrated surface-groundwater model TopNet-Groundwater (Topnet-GW; Yang *et al*., 2017), as part of the New Zealand Water Model (NZWaM-Hydro) framework. This paper presents the application of this model to three contrasting catchments: Mataura in Southland, Rangitikei in Horizons, and Taruheru in Gisborne. Implications for a-priori parameterisation (pre-calibration) of such models, enabling regional scale and national scale applications, are presented.

Method

Over the past two years a large modelling effort has been carried out in the reformulation and a-priori parameterisation of the integrated surface water and groundwater model TopNet-GW through collaborations with regional and district councils, GNS, and University of Bristol, UK. The a-priori parameterisation uses national datasets that combine the expert knowledge (e.g., surface water and groundwater flow processes) of scientists from national research institutes and regional authorities (Yang *et al*., 2019). These datasets include: groundwater-surface water interactions (i.e., loss and gain of streamflow to, and from groundwater); riverbed characteristics such as conductance, and water budgets.

Assessment of the performance of TopNet-GW applied to the three case studies, is carried out through comparison with the NZWaM-surface water module (TopNet) using NZWaM Benchmarking performance metrics (adapted from McMillan and Booker, 2017).

Results

Based on the parameterisation method and datasets developed at NIWA, TopNet-GW is now applied in the Mataura, Rangitikei and Taruheru catchments.

Results from the three catchments will be compared with those simulated with TopNet using the benchmarking method. The advantages and disadvantages of the compared approaches will be also be discussed.

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IMPLEMENTATION OF CATCHMENT SCALE SURFACE WATER TAKE AS PART OF THE NEW ZEALAND WATER MODEL

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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 (NPS-FM) requires Regional Councils, in collaboration with iwi and communities, to set limits on water use, and establish allocations to stay within these limits.

Effective and efficient limit-setting and allocation require tools that can accurately i) 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; and ii) enable conceptualization of impact of human activities on water resources. The latter is usually achieved using hydrological models that are used to make predictions and develop scenarios of the future by combining scarce measurement data, information about processes like runoff, and detailed maps of streams, aquifers, soils and other catchment properties.

The New Zealand Water Model – Hydrology (NZWaM-Hydrology, referred to hereafter as NZWaM) 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. As a result, NZWaM 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 on recent progress made within the development of the surface water module as part of the NZWaM project.

Method

The NZWaM-Hydrology aims to develop a catchment-scale combined surface water and groundwater model that can be applied and parametrized at the national scale. To enable application at national and regional scale, the national TopNet model is used as the default surface water hydrological model.

In addition to the coupling of the NZWaM surface water module with different sources of soil hydrological information (e.g. from FSL and Smap), a water take module at a catchment scale was conceptualized and developed to simulate impacts of human activities on water resources. The water take module aims to represent the impact of:

- Consented water takes (paper consents), removed from a river and applied to the landscape as precipitation during day of take at their maximum rates or at a fraction of the maximum rate
- Water takes associated with agricultural needs, based on crop parameters and climate drivers
- Water takes based on water metering data, or simulated time series of water use scenarios

Results

Results will be presented from the implementation and application of the surface water take module to one of the case study catchments (Oreti and Mid Mataura in Southland, Rangitikei in Horizons and Taruheru in Gisborne). Implications for the future development of the surface water module will be discussed.

UPDATE ON THE NEW ZEALAND WATER MODEL-HYDROLOGY PROJECT

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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 third 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).

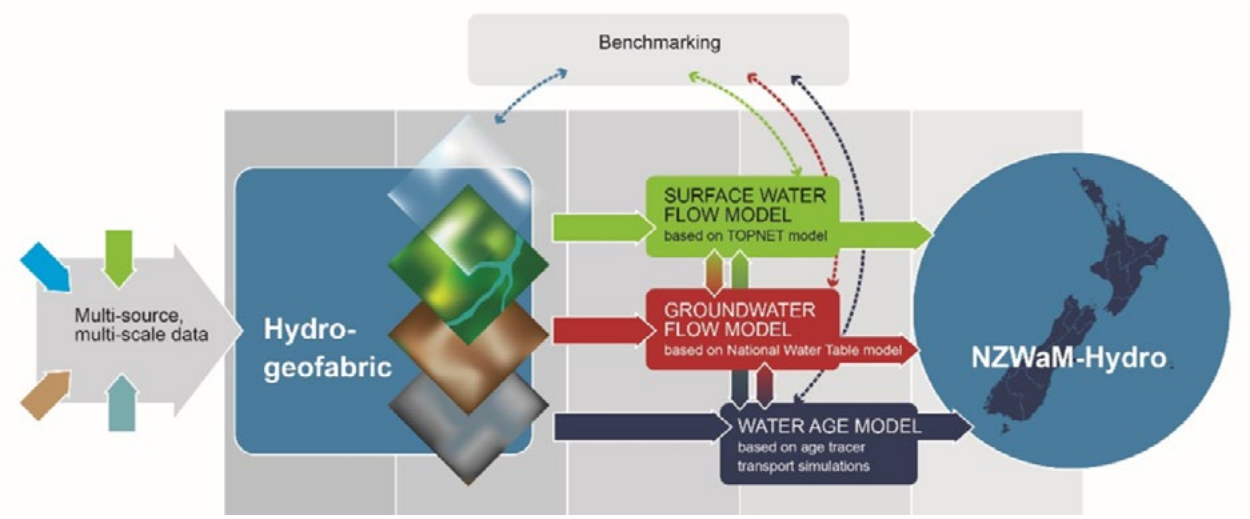

Figure 1: Conceptual organisation of the NZWaM-Hydrology project.

Results

- A large component of the NZWaM-Hydrology work over the period 2017-2019 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.

EFFECTIVE REPRESENTATION OF THE GEOLOGY IN GROUNDWATER MODELS OF STRATIFIED HETEROGENEOUS AQUIFER SYSTEMS – AN EXAMPLE FROM THE LOWER MANAWATU CATCHMENT

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Introduction

Groundwater modelling has become an essential tool in hydrogeological investigations and assessments. Models simplify reality. This notion is in line with the principle of parsimony, widely known as the Occam's razor – entities must not be multiplied beyond necessity. In a lecture in 1933, Albert Einstein clarified that *"… the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience."* (Dyson, 2011).

Geology has a huge bearing on hydrogeology. Stratigraphy and structure determine the configuration of hydrogeological units and lithology determines their hydraulic properties (Zarour, 2018). Realistic groundwater modelling entails effective representation of the geology of the modelled system. Data and/or other resource limitations can result in oversimplified representation of the geology in groundwater models, degrading their overall effectiveness. Where data and resources are not lacking, 'detail-modellers' commonly strongly insist on including all geological minutiae in their models, envisioning that more complex (highly parametrised) models are somehow superior (Voss, 2011). Models that have simple geology can be made complex by including extensively detailed spatial variations in model parameter values to achieve a best possible fit between model estimates and observed data. Voss (2011) notes that there is no evidence to added value of highly parameterised models.

Aims

The objective of this presentation is to demonstrate the techniques used to represent stratification and hydraulic property heterogeneity in the Lower Manawatu Catchment (LMC) groundwater model. The LMC groundwater model is simple and realistic. The techniques used to develop it are readily transferable to other regions in New Zealand and globally.

Method

The hydrogeological system in the LMC consists of an extensive Plio-Pleistocene sequence of alternating cold and warm climate deposits. Data available for geological modelling include publicly available digital elevation data (DEM) (Columbus et al., 2011), geological map (QMAP) data (Heron, 2014), seismic data (Melhuish et al., 1996), and descriptions of drill cuttings from driller's logs (bore logs) from Horizons Regional Council groundwater database.

Study of the geological history and available bore log data enabled development of a system for classification of driller's drill cutting descriptions into a QMAP-like units. Development of the geological framework for the groundwater model entailed synthesis of geological map data and interpreted bore logs to produce a 3D geological model. Significant differences between bore depths and lack of bore log data in inland elevated areas did not enable straightforward interpolation between bore logs. To overcome this problem, virtual bores of constant depth were placed along strategic transects across the catchment. Geological maps, field observations of outcrops, bore log data, and reported seismic survey interpreted data were used to mark contacts on the virtual bores. This enabled the construction of stratigraphical cross sections along the above-mentioned transects (Figure 1). Constrained computerised geospatial interpolation of real and virtual bore log data, outcrop data and cross sections enabled the construction of a 12-layer 3D lithostratigraphical model for the catchment.

The geological model layers were assigned 'representative' materials. Hydraulic property ranges were defined for each material. In order to represent heterogeneity in each model layer, pilot points were used to allow varying hydraulic property values within the range identified for the material assigned to the layer. Automated parameter estimation code PEST by Doherty (2015) was used to calibrate the model against observed groundwater head and flux targets. Excessive model parametrisation was avoided through the use of a minimal number of pilot points placed strategically according to well defined requirements.

Results

A simple, realistic and useful groundwater model was developed for the LMC. It incorporates an effective representation of the geology, which should help to make it acceptable to the public, environmental and resource management authorities, practitioners and researchers. The developed groundwater model provides a good balance for the need for effective representation of the traits of the modelled system and the need for simplicity. The techniques used to develop the geological model and represent hydraulic heterogeneity within hydrolithostratigraphical units can be used in other places in New Zealand and around the world. The 3D geological model can be used in other applications like structural geology research, natural hazard management and resource exploitation (e.g. quarrying).

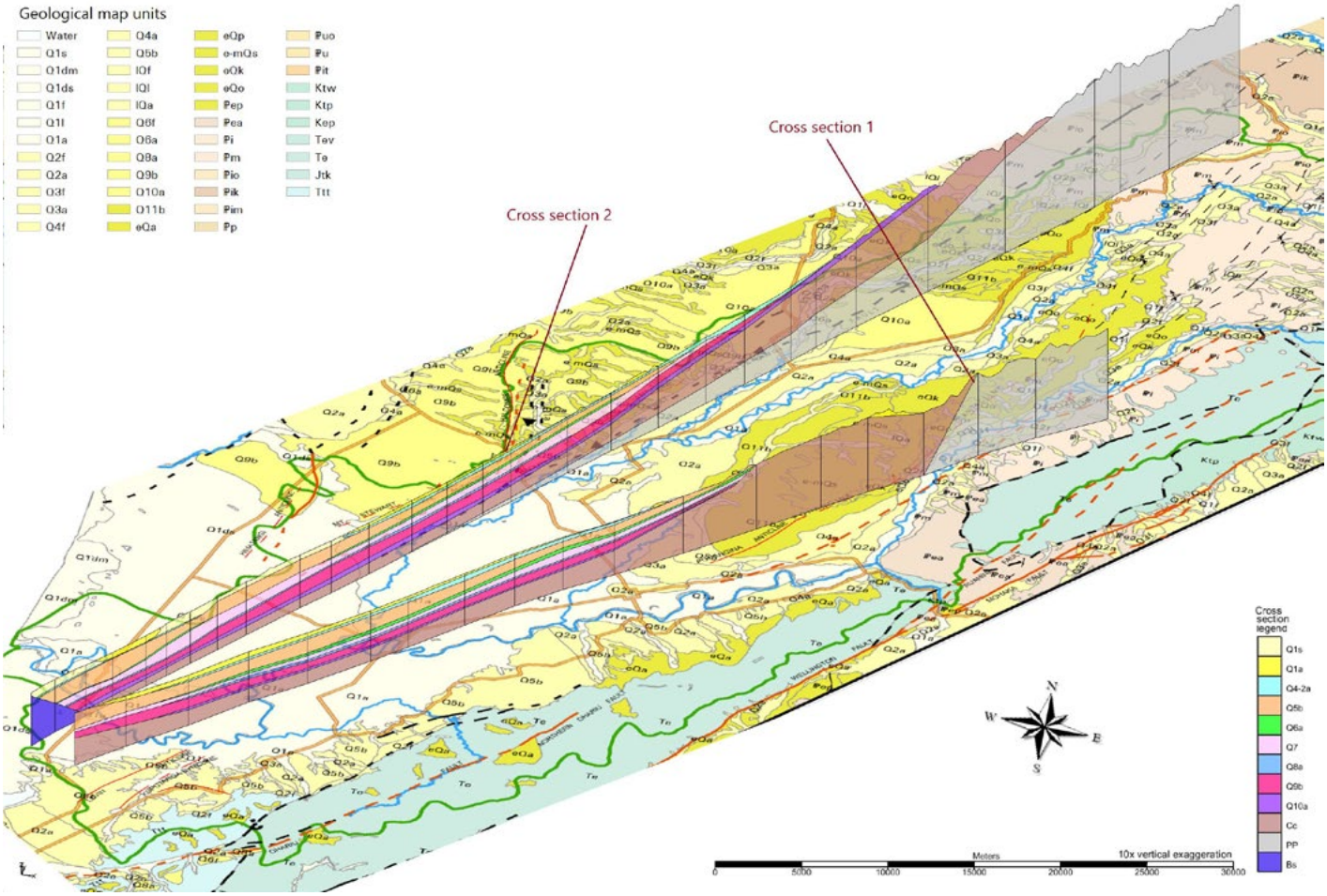

Figure 1: Stratigraphical cross-sections between imaginary wells to help with 3D stratigraphical modelling.

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