Poster Abstracts

In order of presenter's last name

TRACKING CONSENTED IRRIGATED AREA THROUGH TIME

Philippa Aitchison-Earl,[1]
[1] Environment Canterbury

Introduction

To model groundwater recharge and associated nutrient losses from soil to groundwater, we need to know which areas of land have been irrigated and when they were irrigated. Greater recharge occurs under irrigated conditions because the soil profile is wetter so rainfall is more likely to drain to groundwater. Estimates of irrigated area through time can help us match modelled predictions to measured groundwater levels, stream flow and nutrient levels.

For most currently active consents, our consents database includes a shape file of irrigated area, however this is not available for expired consents. Environment Canterbury has estimated irrigated area through time for past projects using purpose-built, project-specific databases for sub-areas of Canterbury. These databases are not updated once they are developed.

Aim

Our aim is to create a Canterbury-wide, GIS-based dataset of consented irrigated area through time, linked to Environment Canterbury's consents database. Consented irrigated area provides an estimate of the maximum area of irrigation. This may later be refined to estimates of actual irrigated area using methods such as remote sensing or demand models.

Method

We queried our consents database to identify irrigation water use consents with no associated shapefile. We reviewed consent files both in digital and paper form for maps of irrigated area or legal land descriptions. This information was used to create new shapefiles to upload to the consents database.

Results

A trial project over the 2018/2019 summer documented a methodology to create a shape file dataset linked to the consents database. Data sets were created for the Pareora Catchment and for the Kaikoura Water Management Zone.

The Ashburton Water Management Zone is now being assessed to further test the methodology and to identify process improvements, including potential algorithms for scripting. We plan to continue the program over the 2019/20 summer and into future summers. We have identified 22,262 irrigation consents (active and expired) to take groundwater or surface water for irrigation. Of these, only 3,065, or 13%, have existing shape files of irrigated area. We will focus our efforts on priority areas such as those with planned groundwater models.

DETECTING CHANGING TEMPORAL INFLITRATION PATTERNS AFTER FOREST CLEAR FELLING: PROPOSAL FOR A GEOLOGICAL WEIGHING LYSIMETER EXPERIMENT

Earl Bardsley,[1] Dave Campbell,[1] Adrian Pittari[1]
[1] University of Waikato

In a recent overview publication, Blöschl et al. (2019) identified 24 unsolved problems in hydrology. The fourth in the list was *what are the impacts of land cover change and soil disturbances on water and energy fluxes at the land surface, and on the resulting groundwater recharge?* We are locally in a good geographical and research position to go some way toward answering this question. At the University of Waikato we established the concept of replicated geological weighing lysimeters as a means to accurately monitor area-integrated surface water mass changes in real time (Fig. 1). In essence, we used the pore water pressure of deep aquifers as a means to "weigh" mass changes on the land surface above.

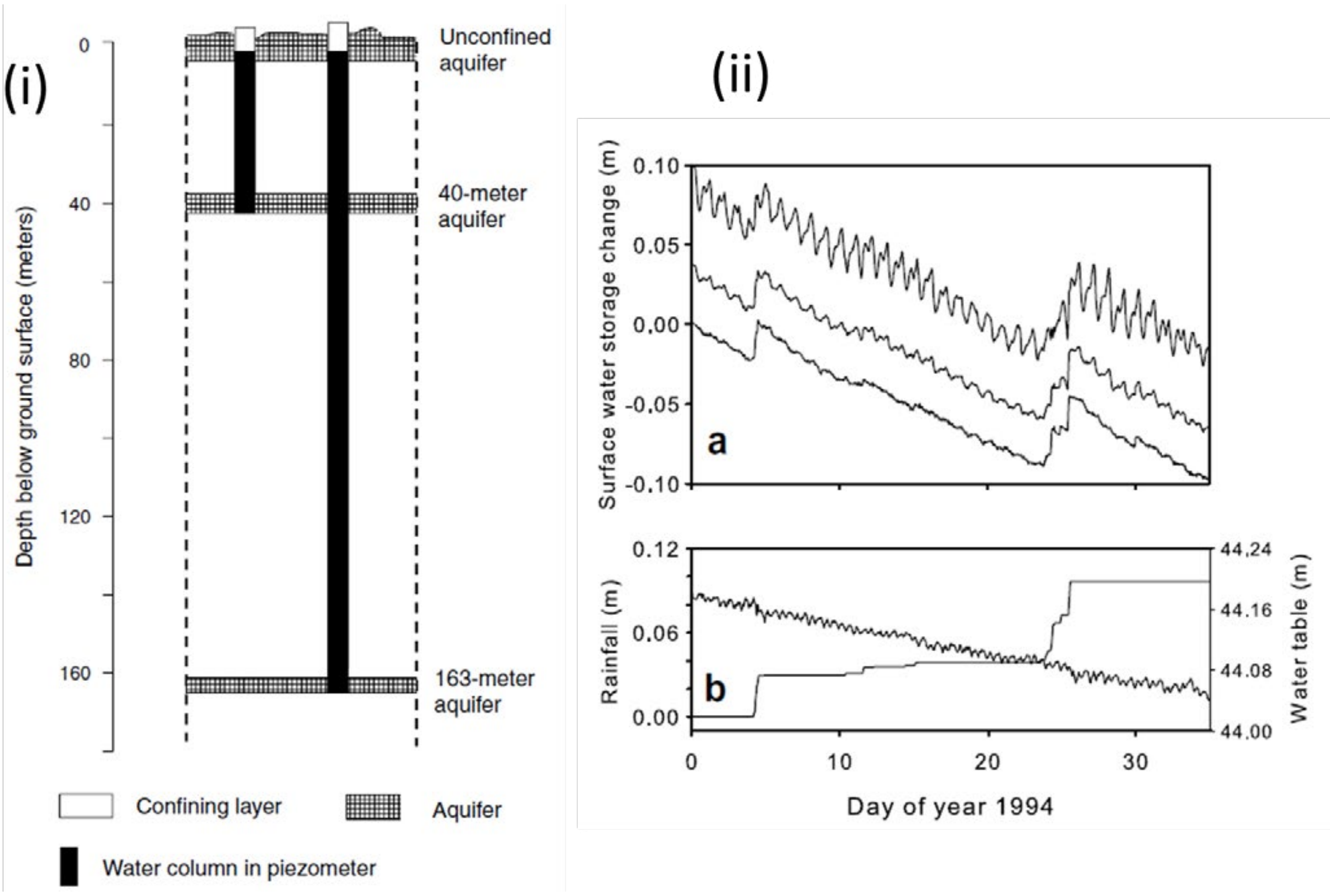

Figure 1: Results from a replicated geological weighing lysimeter (gwl) experiment in the Waikato. (i): A two-aquifer gwl field experimental setup near Matamata. (ii): (a) Upper to lower plots are respectively surface water storage change estimated from the 163-metre aquifer, from the 40-metre aquifer, and from combining both aquifer estimates. Cyclic fluctuations are Earth tides. (b) cumulative rainfall and water table. Note real-time detection of rain events in the deep aquifers but not in the water table. From Bardsley and Campbell (2007).

The aim would be to locate a gwl beneath a plantation forest to be clear felled in about a year, noting the before-after changes in gwl-detected infiltration. The best site is likely to be on the Kaingaroa plateau, which is underlain by a sequence of semi-horizontal ignimbrites serving as the replicated monitoring aquifers. This would be a world-first study and would initially reflect the forested situation where the water mass from an individual rain events will not remain at site very long because of foliage interception loss. A dramatic mass reduction from clear felling would be followed by greater rainfall infiltration, seen as rain mass increments being maintained as in Fig.1.

Bardsley, W.E., Campbell, D.I. 2007. An expression for land surface water storage monitoring using a two-formation geological weighing lysimeter. *Journal of Hydrology 335*, 240-246.

Blöschl et al., 2019. Twenty-three unsolved problems in hydrology (UPH) – a community perspective. *Hydrological Sciences Journal 64*, 1141-1158

GAINING COMMUNITY BUY-IN AHEAD OF SKYTEM FLIGHTS

Juliet Clague,[1] Roland Stenger,[1] Scott Wilson,[1]
[1] Lincoln Agritech Ltd

Introduction

An integral part of Lincoln Agritech's MBIE-funded Critical Pathways Programme is the survey of two contrasting catchments using the helicopter-borne time-domain electromagnetic system (SkyTEM), originally developed by Aarhus University in Denmark. The surveys were carried out by SkyTEM Australia during February 2019 using a helicopter flying in parallel lines 200m apart and at a height of approx. 90m. A carrier frame containing the instruments was suspended under the helicopter and was flown at approx. 35m above the ground surface (Figure 1). Although the helicopter was flying relatively fast (80-100 km/hr), the low altitude and persistent noise had the potential to make the survey intrusive in the catchments. We were particularly concerned with minimising stock disturbances by the low-flying helicopter and with allaying fears that these flights might form part of Waikato Regional Council's compliance monitoring. Therefore, Lincoln Agritech carried out a community information and engagement campaign in each of the catchments to promote the necessity of the work and gain the good will of the local community.

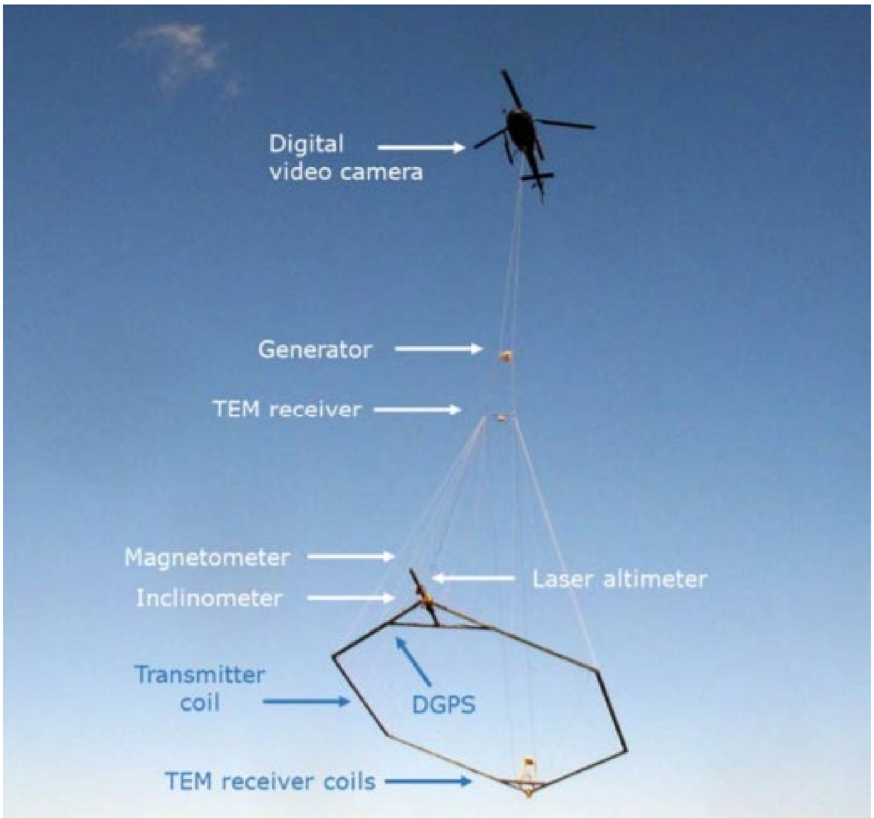

Figure 1: The helicopter and instrumentation used in the SkyTEM surveys

Method

As civil aviation rules allow for the operation of a helicopter with a slug load flying below 500 feet, the SkyTEM publicity campaign was to communicate our research intent and gain goodwill in the community, rather than seeking consent. For this purpose we utilised a wide range of networks including community facebook groups, our contacts within the local iwi (Ngāti Hauā, Ngāti Tahu – Ngāti Whaoā), DairyNZ consulting officers, Beef+Lamb NZ, Federated Farmers and local newsletters. We also put notices in newspapers and organised a rural delivery letterbox drop to all households in each catchment. This advance notice advertised a community drop-in session where we were available at a local hall to discuss the research objectives and any concerns the community might have.

Results

We had some interested landowners and farmers make contact in each catchment, willing to support the research and provide local information, which we found very useful. A youtube clip of the flights has been made freely available and can be viewed at: https://www.youtube.com/watch?v=cEMIwi_B20U&feature=youtu.be.

Once the data has been interpreted and refined, we will keep the community up to date with our progress through another community drop in session. Then, the next stage of the project will involve more in-depth surveys of two sub-catchments within each catchment, so we will be utilising the contacts made during this community liaison campaign to gain local information and access to land.

A NOVEL NONPARAMETRIC APPROACH TO ESTIMATING JOINT EXCEEDANCE PROBABILITY FOR CORRELATED HYDROLOGICAL HAZARDS

Ngoc Hieu Dao,[1] Earl Bardsley[1]
[1] University of Waikato

Bardsley and Vetrova (2017) gave a NZ Hydrological Society conference presentation on a nonparametric approach to estimating joint exceedance probabilities, described more formally by Bardsley et al. (2019). A sense of the method for the bivariate case is given in Fig. 1. All possible lines between data points are envisaged as being occupied by 1-dimensional probability distributions. So, for example, in Fig. 1 the probability of the two variables concerned both exceeding 12 units together is obtained by integration of all the distributions along those portions of the lines in the upper right sector defined by the dashed lines.

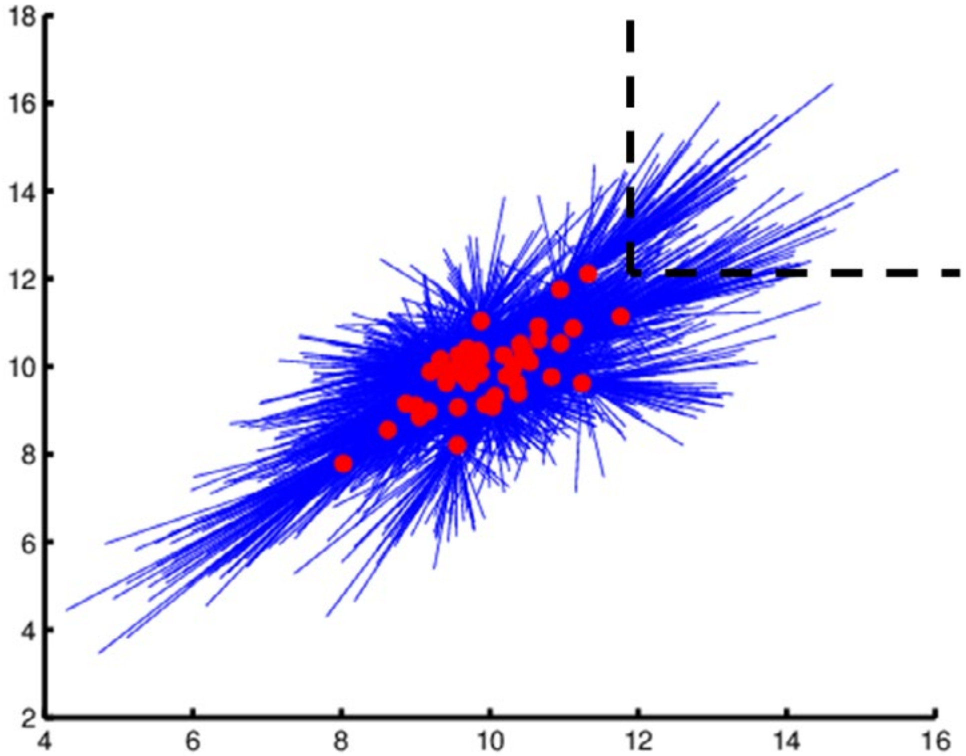

Figure 1: Graphical representation of the nonparametric estimation for joint bivariate exceedance beyond 12,12 for two correlated variables.

Reporting on part of a PhD study on this topic, the poster will show how the method fares against some copula models in the literature which have been applied to multivariate hydrological data. Specifically, results will be presented for when the nonparametric method is applied to data simulated from the copula models. When standard estimation methods are applied to the data the copula models fare better because the data is simulated exactly from that model. However, in the real world the true distribution behind the data is never known, and the nonparametric approach gets progressively better against parametric methods as the data simulation shifts progressively away from the original copula.

Bardsley, W.E., Vetrova, V. 2017. Lines in N-space: an approach for multivariate hydrological extremes. Presentation to the 2017 New Zealand Hydrological Society Conference, Napier.

Bardsley, W.E, Vetrova, V., Dao, N.H. 2019. Line mesh distributions: an alternative approach for multivariateenvironmental extremes. *Stochastic Environmental Research and Risk Assessment 33*, 633-643.

RNA STABLE ISOTOPE PROBING – A USEFUL TOOL FOR IDENTIFYING ACTIVE MICROBIAL COMMUNITIES UNDERTAKING AEROBIC METHANE-DRIVEN DENITRIFICATION.

Emmanuel Egbadon,[1] Kathryn Wigley,[1] Louise Weaver,[2] Lee Burbery,[2] Kim Baronian,[2] Peter Gostomski,[2]
[1] University of Canterbury, New Zealand
[2] Institute of Environmental Science and Research, New Zealand

Aims

Aerobic methane-driven denitrification is a process that could be utilised to remove nitrate from contaminated aquifers (Modin et al., 2007). However, neither the process nor the microorganisms involved are fully understood. Identifying active biofilm community members that are oxidising methane is one of the first steps required to understand the process of methane-driven denitrification. RNA stable isotope probing is a novel method that enables active members in a microbial community to be identified and linked to a function in a microbial community (Manefield et al., 2002). The objective of this study was to use RNA stable isotope probing to identify the active members within an aerobic methane consuming community.

Method

A microbial biofilm was established in a packed bed reactor under continuous supply of 2% (v/v) methane as the sole carbon source and nitrate as the nitrogen source. The reactor was inoculated with microbial culture from sandy gravel sediment from Lowcliffe, South Canterbury.

RNA stable isotope probing was performed in a series of batch experiments to identify active community members. Briefly, biofilm from the reactor was inoculated into serum bottles containing either 10% ^{13}C-labelled CH_4 or 10% ^{12}C-unlabelled CH_4. After incubating for 96 hours, total RNA was extracted from the biofilm, separated by isopycnic density-gradient centrifugation in a CsTFA density gradient and fractionated according to RNA buoyant density. Isotope ratio mass spectroscopy was also carried out to confirm incorporation of $^{13}CH_4$ into RNA.

Results

Amplicon 16S rRNA gene sequencing (Illumina MiSeq) of the biofilm revealed a community dominated by *Methylocystis* spp. (40%) (Figure 1). All other genera had a relative abundance < 15%. RNA stable isotope probing revealed that the % of total RNA in the heavier fractions (> 1.77 g/ml) from the ^{13}C experiments was greater than from the ^{12}C (unlabelled) controls (39% vs. 13%). qPCR targeting the *pmo*A gene (diagnostic for methanotrophic bacteria), similarly showed that the relative abundance of pmoA in the heavier fractions was greater in ^{13}C-labelled RNA compared with unlabelled RNA (73% vs. 9%). Finally, isotope ratio mass spectrometry of extracted RNA confirmed assimilation of ^{13}C; increasing from 1% in unlabelled RNA to 11% in 13C experiments. Collectively, these preliminary results indicate that RNA stable isotope probing was able to resolve members that were actively participating in methane oxidation from the rest of the (non-active) community.

Future work will focus on using high throughput sequencing of the labelled and unlabelled fractions to determine exactly which bacteria are being labelled and if any cross feeding is occurring. Cross feeding of heterotrophs is one hypothesis for methane-driven denitrification.

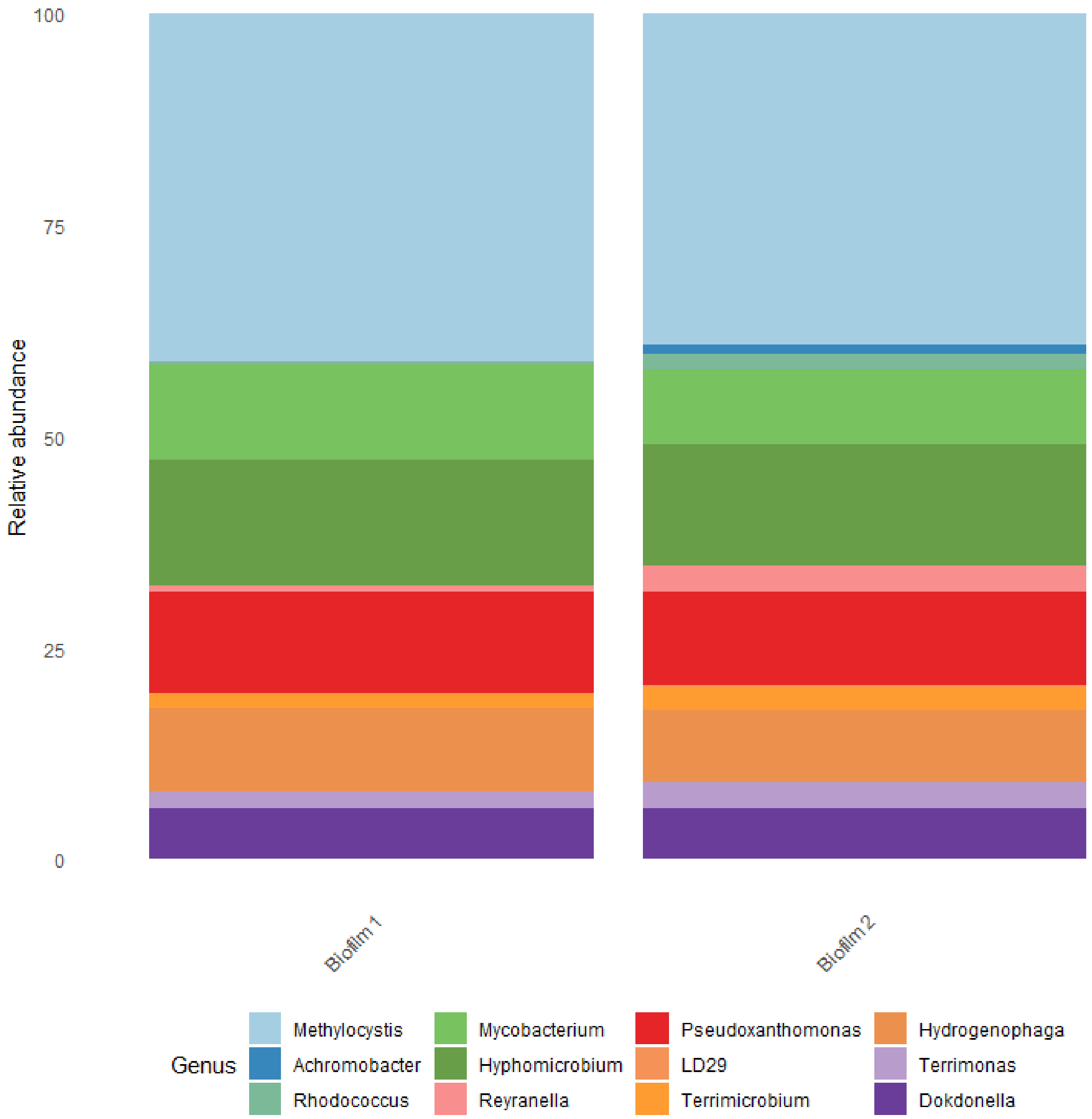

Figure 1: Relative abundance of genera in biofilm from the packed bead reactor (Rep 1 & 2) based on 16s rRNA gene sequencing (Illumina MiSeq). Unassigned Genera have been removed.

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MODIN, O., FUKUSHI, K. & YAMAMOTO, K. 2007. Denitrification with methane as external carbon source. *Water Research*, 41, 2726-2738.

DEVELOPMENT OF AN AGENT-BASED MODEL FOR MONITORING RAINFALL BETWEEN TWO TELECOMMUNICATION ANTENNAE

Saeid Esmaeil Nia,[1] Ali Shokri,[1]
[1] Waikato University

Rainfall affects the electromagnetic waves passing through the atmosphere. The attenuation of waves confronting hydrometeors and its application is implemented in rain radars for decades. In the recent year, by developing cell phones infrastructures, a new method adopted from rain radar studies to calculate the rainfall intensity by using the attenuation of the waves between two cell phone towers. The new method uses a correlation between rainfall intensity and the attenuation of waves:

$$R=aA^b \qquad (1)$$

where R is the rainfall intensity, A is the attenuation of the waves and "*a and b*" are constant parameters that depend on the drop size distribution.

Since the number, size and position of raindrops are varied temporally and spatially, the attenuation of the waves changes continuously. Therefore, equation 1 may estimate a range of rainfall intensity for the same rainfall rate. So, a robust model is required to improve the estimation. Considering the number of raindrops can be more than a billion between two towers, a deterministic approach to predict the attenuation of waves is almost impossible. In this study, instead, an agent-based model is implemented to investigate the attenuation of waves between two mobile towers.

Aims

The main purpose of the study is detecting and magnifying the inaccuracies of common methods that use wave attenuation to measure rainfall intensity. The specific inaccuracy is produced as a result of using constant *(a)* and *(b)* in the equation 1 across different raindrop distribution. Besides, based on the hypothesis of the study, it is expected that the attenuation for the same rainfall intensity vary within particular bounds relying on DSD. Analyses would suggest a more accurate relationship to produce rainfall intensity from wave attenuation.

Method

Agent-based models are a powerful tool to simulate the behaviour of autonomous individuals as agents and their interactions in a system. In this model raindrops are taken as the "Agents", the attenuation of waves in different positions as the "Rules", and the space between two towers as the "Environment". The goal of the model is to calculate the total power at the receiver antenna.

Maxwell equation is solved by a finite element model to calculate the effect of a raindrop on the microwave power behind each raindrop (Figure 1). Also, the space between the transmitter and the receiver is split into the size of the agents. At each time step, the space between the two towers is randomly filled with the agents. A schematic diagram of the agent-based model is shown in Figure 2.

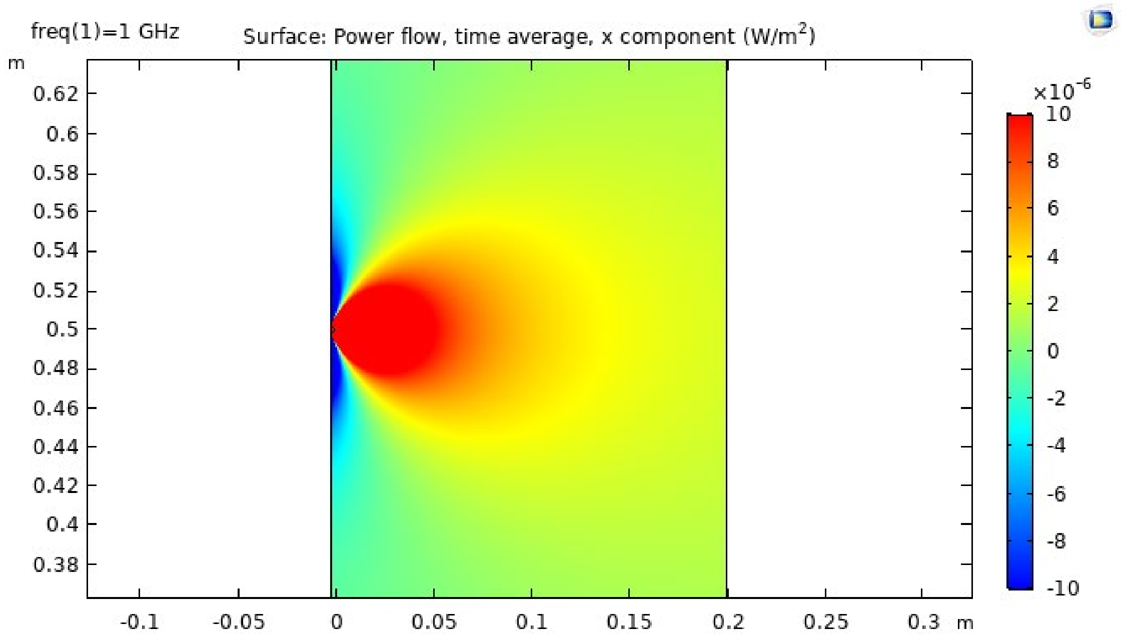


Figure 1: The effect of a raindrop on the microwave power behind each raindrop

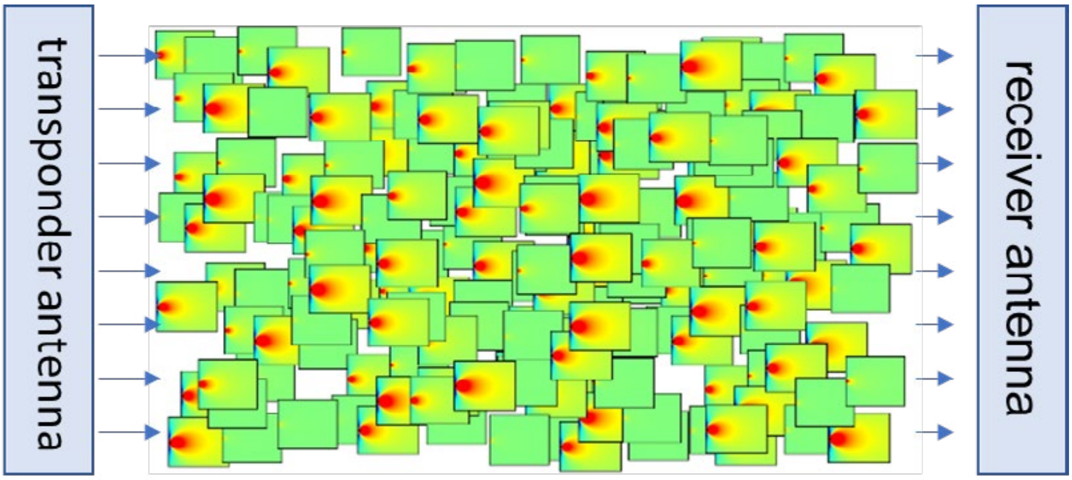
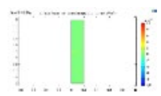
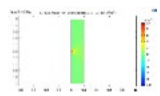
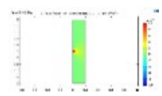
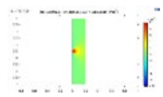
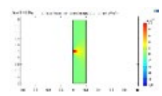
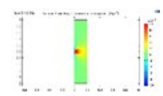
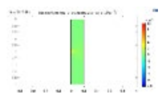
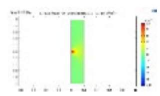
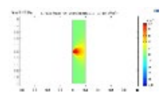
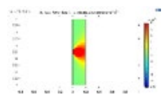
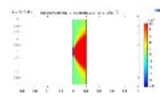
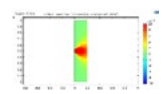
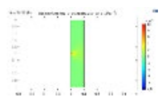
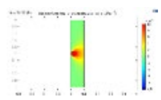
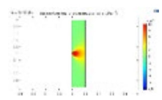
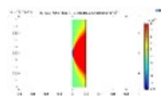
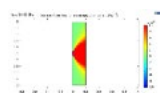
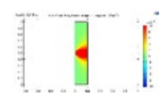


Figure 2: A schematic diagram of the agent-based model

Results

The power of wave is modelled for different raindrop sizes. Table 1 shows the graphs of wave power simulated for 6 drop diameter in three frequencies. Considering a Lognormal distribution for raindrops, particular DSD for the rainfall intensity gives the number of raindrops of each size that are precipitating. In the model, small matrixes of raindrops pasted to the matrix of simulation space (Figure 2). While the primary runs of model shows the variation of attenuation, the information and data from commercial communication links in cell phone infrastructures is going to be applied.

Table 1: Simulated rain drops in the space of 100*20 cm passing the wave frequencies of 1, 5, and 10 GHz

Drop Diameter (mm)	1	2	3	4	5	6
frequency = 1 GHz						
frequency =5 GHz						
frequency =10 GHz						

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THE CONTROLS ON SPATIAL AND TEMPORAL VARIATION OF WATER TABLE DEPTH AND SOIL MOISTURE CONTENT IN DRAINED AGRICULTURAL PEATLANDS

Glover-Clark. G.L.,[1] Campbell, D.I.[1]
[1] University of Waikato

The Waikato Region contains approximately half of New Zealand's peatlands, over 75,000 ha of which have been drained for pastoral agricultural use (Pronger et al., 2014). Drainage triggers irreversible changes to peat physical and hydrological characteristics, as well as significant carbon dioxide (CO_2) emissions and ongoing land subsidence (Berglund & Berglund, 2011).

Maintaining high water tables throughout the year has been frequently suggested as a mitigation method to reduce surface subsidence and CO_2 emissions in drained peatlands, whilst ensuring sufficient soil moisture conditions for plant productivity (eg., Renger et al., 2002; Wessolek et al., 2002). In practice, high water tables are not easily attainable, especially in periods of dry weather. Further complicating this, is the limited spatial influence that drains have on water table depth, often rendering them ineffective (McLay, Allbrook & Thompson, 1992).

An understanding of the factors controlling hydrological variation through time and space will aid in decision making of best management practices for these soils.

Aims

The aim of this research is to determine the controls on the spatial and temporal variation of water table depth and soil moisture content on two Waikato dairy farms with similar management practices but contrasting drainage designs. The relationship between water table depth and soil moisture content, and roles of the surface water balance, peat physical properties and drainage design will be investigated as potential controls. This study also aims to describe changes in peat surface elevation, and the influence of hydrological variation on pasture production and CO2 emissions.

Method

Detailed hydrological transects were established at the two research sites to observe how water table depth and peat surface elevation vary over time and space, through a combination of manual and automatic measurements. Repeated laser scan surveys were carried out for further measurements of surface elevation. Soil cores, regularly sampled from along both transects, and measurements from soil moisture probes were used in analyses of soil moisture content and its relationship with water table depth. Eddy covariance measurements of evaporation and CO_2 fluxes were used to assess the energy and carbon balances, as well as pasture production.

Results

The two sites received 62% of normal rainfall between January and June 2019. During this period, preliminary results indicate drainage design is not the dominant control on hydrological variation when drains are not actively transporting water. Maximum water table depths at the two sites of 1.1 and 1.4 m, reached in late May, coincided with maximum peat shrinkage values of 60 and 50 mm, respectively. Investigation of the relationships between soil moisture content and water table depth found a capillary rise of 0.6 m at both sites, indicating potential subsurface moisture redistribution. Over the extended dry period, the two sites had net CO_2 losses of 11 and 27 tonnes CO_2 ha^{-1}, large variations which are likely driven by differences in soil properties and hydrology.

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FRAMEWORK FOR MAPPING ON-FARM WATER POLLUTION USING SATELLITE AND UAV REMOTE SENSING

Griffiths, J.A.,[1] Schimel, A.,[1] Goeller, B.,[1] Steinmetz, T.,[1] Singh, S.,[1] Smart, G.[1]
[1] NIWA, Christchurch, NZ.

Surface water quality in New Zealand is degraded due to intensification of farming over the past 30 years. Decreasing water quality results in loss of biodiversity and natural heritage, risks to human health due to toxic algal blooms; and socio-economic losses. Water quality may be partially restored through a more effective management of livestock manure, waste effluents and fertilizers. As both surface and groundwater provide the main transport medium for such pollutants, it is critical that on-farm pollution sources, pathways and sinks can be accurately identified and mapped (across a range of spatial and temporal scales) to allow targeted mitigation. This project sought to develop a robust scientific framework to better identify the spatial and temporal dynamics of on-farm water and pollutant movement, through the integration of available satellite and UAV remotely sensed data.

To represent a range of farm activities that may generate soil or water pollution, the developed system utilised satellite imagery to identify areas of high nutrient and runoff within farm boundaries (as these areas are potential source, pathway and sink areas for water pollutants). Once these areas have been identified, UAVs will be used with appropriate sensors to map local-scale key water pollutant variables. Better knowledge of the spatial and temporal variability of pollution transport via runoff or subsurface pathways will inform better pollution management and mitigation. The specific objective of this work was to develop a proof-of-concept image processing pathway for farm-scale identification and monitoring of agricultural pollution (Nitrate) hot-spots.

The work programme of the project included the following steps:

1. Obtain satellite imagery (Sentinel-2) and field analytics for chosen field site.
2. Derivation of biophysical and bio-chemical parameters from crop canopy and reflectance data (green LAI, chlorophyll content).
3. Use of above parameters in canopy reflectance model to derive agronomic indicators
4. Derivation of spatial map of Nitrate excess based on above indicators and hydrology models to identify Nitrogen hotspots and how/if they vary over time.
5. Assessment of implications of model predictions and comparison with field data.
6. Identification of areas of uncertainty (e.g Nitrogen inputs) and outline approach to reduce or quantity such uncertainty in the future.

In addition to development of the data processing chain and methodology, outputs of the project included the development of a market viability assessment of market opportunity and scope, including business case and plan for execution for bringing the resulting methodology to market.

COMBINING ENVIRONMENTAL TRITIUM AND MODELLING OF HYDROLOGIC SYSTEMS ON LARGE SCALE FOR DECISION MAKING AND CLIMATE CHANGE AND LAND-USE ASSESSMENT

Gusyev M.,[1] Denda M.,[1] Kikumori Y.,[1] Morgenstern U.,[2] Akata N.,[3] Hirabayashi K.,[4] Toyota M.,[4] Tsujimura M.,[5] Yamanaka T.,[5] Sakakibara K.,[4] Stewart M. K.[2]
[1] ICHARM, Japan
[2] GNS Science, New Zealand
[3] NIFS, Japan
[4] Shinshu University, Japan
[5] University of Tsukuba, Japan

Aims

The aim of this study is to understand surface-groundwater interactions for improving river ecosystem management in the Chikuma River basin, Japan, by combining measured tritium (3H) concentrations and hydrological modelling. Environmental tritium is a useful tracer tool for estimating water transit times and improving the performance of hydrological models. Its applications in Japan and other Asian countries have been limited so far (Gusyev et al., 2016a; 2019). The block-wise TOPMODEL (BTOP), which has been applied globally and locally for climate change and land-use impact assessment in many river basins (Magome et al., 2015; Gusyev et al., 2015, 2016b,c; Zhang et al., 2018), can utilize estimated mean transit times (MTTs) for calibration of lumped groundwater dynamics.

Method

The Chikuma River basin with an area of about 2,500 km2 is a sub-catchment of the Shinano River and is located in the central part of Japan between 300 and 2,470 m above mean sea level (m.a.s.l). In 2018, we collected monthly precipitation from May to October at four locations between 400 and 1,350 m.a.s.l. and sampled selected well, spring, and river locations between January and September for tritium analysis. Collected precipitation samples were analyzed with medium accuracy in Japan and ultra-low level analysis was conducted at GNS Science Tritium Laboratory in New Zealand. These tritium concentrations were utilized to estimate mean transit times (MTTs) at sampled locations with exponential-piston (EPM) lumped parameter model. In addition, the global BTOP model, which is using modified topographic index (Gusyev et al., 2017) and has been setup in river basins with 600-arcsecond grid size in catchments above 5,000 km2 (Magome et al., 2015; Gusyev et al., 2015; Gusyev et al., 2016b), is used to demonstrate the influence of MTTs on simulated daily river discharge from 1950 at selected gauging stations in the Chikuma River basin.

Results

Measured tritium in monthly precipitation indicated temporal variability due to the origin of air masses in spring and summer of 2018 and spatial variability of tritium concentration at two similar altitudes was also observed in the Chikuma River basin. The tritium concentration of river water samples is between 1.7 TU and 2.8 TU with higher concentrations measured at baseflow indicating groundwater recharge occurring during spring season. This result was similar to shallow wells and springs except one deep well that had much smaller tritium concentrations of 0.624 (±0.024) TU. Using these tritium concentrations we estimated MTTs in river water between 9 and 31 years with EPM models and these MTTs were utilized in the BTOP model of the Chikuma River basin suggesting the influence of groundwater dynamics on baseflow independent of calibrated model parameters as demonstrated for the past and future climates. In future studies, we plan to continue water sample collection for tritium analysis in the Chikuma River basin and implement direct tritium and nutrient simulation in the BTOP model in a fully distributed manner.

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WELL HEAD PROTECTION: ESSENTIALS FOR SECURE WATER

Hector, R,[1] Weir, J,[1] Rutter, H[1]
[1] Aqualinc Research Ltd

There has been a heavy regulatory focus on secure drinking water supply bores in light of the Havelock North water supply contamination event of 2016, and in particular those bores owned and operated by city and district councils. The New Zealand Drinking Water Standards specify the criteria that must be met in order to demonstrate that a bore is secure. These standards include reference to environmental drilling standards for drilling soil and rock (NZS4411) which outline bore construction requirements. The standards are relatively thorough with regards to bore construction expectations. However, to ensure a secure supply of water the process is not as simple as picking a location on a map and drilling until a suitably productive water-bearing formation is encountered.

Rather, consideration of the following key aspects is essential for a bore to be compliant with the standards:

1. Surrounding land use;
- Regional hydrology and hydrogeology;
- Likely contamination sources and distances to contamination sources;
- Potential pathways for contamination to enter the bore;
- Exclusion of animals from the vicinity of the bore head;
- Subsurface hydrogeology;
- Drilling fluids used during bore construction;
- Materials used in construction (i.e. casing and screen material, gravel pack, and grout seals);
- Grouting to a standard that prevents ingress of water from the surface, or from any sources other than the screened aquifer;
- Development of bores to ensure residual drilling fluids are removed prior to bore commissioning;
- Likely contributions of water from local surface water bodies; and
- Preventative treatment of water post-abstraction.

These aspects should all be considered as part of the design process before drilling commences.

A large number of bore head assessments have been completed throughout New Zealand to determine compliance with the Drinking Water Standards. From this, a number of lessons have been learned, as follows:

- It is essential that well heads are completed to above ground level, not in sumps below ground level. If wells are finished below ground level, contingencies must be put in place to ensure sumps do not fill with water if the sump pump fails.
- Regular maintenance of well heads should be completed, especially any well head feed-through glands (.e.g. for cables).
- Cement bond logs should be considered to determine the effectiveness, or otherwise, of surface grouting.
- It is essential to contract drillers who are familiar with the requirements for drinking water bores, are experienced in the installation of drinking water supply bores, complete thorough daily drill reports (including registers of materials used), and who are members of the well drillers federation.

An example of a well-constructed, compliant well head is shown in Figure 1.

Figure 1: A secure and compliant well head.

Important issues can often be broader than the well head itself. Therefore, careful planning of both bore construction, and reviews of the likely hydraulic and hydrogeological settings are essential for avoiding a large number of potential issues.

Should there be any degree of uncertainty regarding the security of the source of water to a bore, then finding an alternative location should be considered as the potential adverse consequences for human health can be substantial.

TOWARD MODERATING LAKE TAUPO OPERATIONAL WATER LEVEL VARIATION

Yasaman Karaminik,[1] Earl Bardsley[1]
[1] University of Waikato

Given ability to control Lake Taupo outflows, there is no evident environmental advantage to have high lake levels for any extended period of time if this can be avoided. In particular, high water levels coupled with strong winds may lead to wave erosion along the upper portions of lake beaches. Also, high water levels pose an increased risk of flooding along lake shorelines and in the Waikato River, in the event of high river inflows to the lake from major storm events.

Lake water level control ability is restricted to a degree by inflow hydrology because high lake inflows always lead to lake level rises. However, some indication of the level of possible control over lake level extremes can be seen in Fig.1, illustrating model output differences between seeking to maximize income from the Waikato power stations, and a multi-use compromise between income generation and having lake water levels more often in the mid-range.

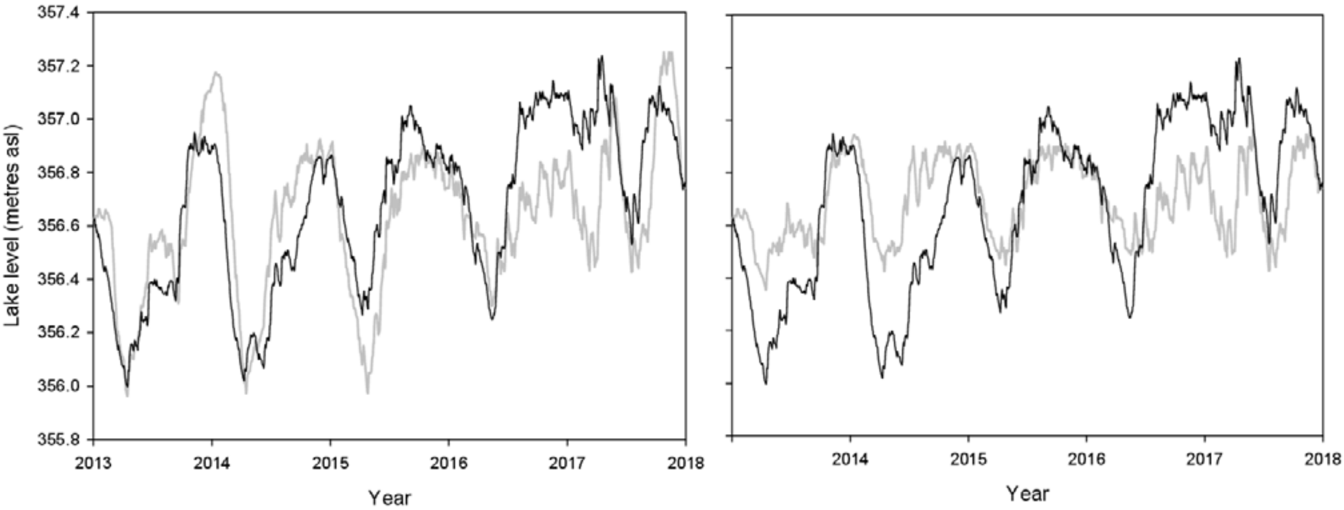

Figure 1: Lake Taupo water levels 2013-18 (solid line) and simulated water levels (grey lines) from models with weighting toward electricity income generation (left) and lake mid-range levels (right). From Bardsley (2019).

My PhD project, started in October 2019, will be a simulation study developing two multi-use optimization scenarios of Lake Taupo water level operation. Both approaches will forecast lake inflows for various lead times and both will evaluate different lake water release schemes as applied to the past record of lake inflows. The first scenario will incorporate lake level optimization with some weighting toward having lake levels within a mid-level range. This would result in a change to the present water level duration curve. The second scenario will maintain the present curve, but seek to reduce the number of cases where lake water levels remain high (or low) for a time.

Bardsley, W.E. 2019. Multi-objective optimisation for Lake Taupo water level management? Journal of Hydrology (NZ) in press.

DEWATERING ASSESSMENTS USING ANALYTIC ELEMENT MODELS

Kevin Ledwith,[1] Jeremy Bennett,[1] Britt Albers,[1] Tara Forstner[1]
[1] Tonkin & Taylor Ltd

Infrastructure projects that extend below the water table present challenges for engineers and construction contractors. If groundwater is not adequately controlled then excavations may flood or become unstable, which can result in delays and increased costs. Dewatering assessments typically involve prediction of groundwater inflow rates and drawdowns in the vicinity of a proposed excavation. The objective of predictive groundwater modelling is to inform decisions for groundwater control, to allow excavations to be constructed in suitably dry, stable and safe conditions, and to assess the effect of drawdown induced settlement outside excavations.

Analytic Aquifer Simulator (AnAqSim) is groundwater modelling software developed by Fitts Geosolutions that is based on the Analytic Element method (AEM). AEM is more flexible than simplified analytical solutions (e.g. Theis drawdown), and model development and runtime is generally faster than popular groundwater numeric modelling packages such as Modflow. Tonkin & Taylor Ltd (T+T) has recently adopted AnAqSim to estimate drawdown and groundwater inflows for temporary construction dewatering assessments.

Analytical solutions are useful for high-level dewatering assessments, but often rely on assumptions that are typically not valid, as well as limitations including the inability to model: multiple layers, variable aquifer parameters, and irregular geometries. Simplified analytical solutions are also inherently unsuitable to solve time-dependent (transient) models, and often neglect the resistance to vertical flow, which is particularly important under an excavation.

Steady state models can be quick and straight-forward to develop, however they will under-estimate early time groundwater inflows and will over estimate early time drawdowns. Thus, if an excavation is only open and dewatered at the scale of days or weeks, early-time groundwater inflows will be greater than those predicted using a steady-state model solution. Similarly for drawdown estimates, if an excavation is only open and dewatered at the scale of days or weeks, early-time groundwater drawdowns will be less than those predicted using a steady state model.

AnAqSim has full transient capabilities, a full suite of line boundary types, permits multiple aquifer layers, anisotropic hydraulic conductivity, and confined and unconfined domains. The AEM allows each hydrologic feature or “element” to be represented by precise analytic equations, with each set of elements superimposed to form complex solutions. AnAqSim has the capability to export high-resolution three-dimensional pathlines, head surfaces, section view transient head profiles, plan view drawdown zone of influence plots, and groundwater level hydrographs from specified observation points.

One key advantage of AnAqSim compared with popular finite element modelling packages, such as SEEP/W, is the ability to model groundwater flow in three dimensions. Using SEEP/W, two-dimensional cross sections are developed first and model analysis is fixed to a selected line of section. Whereas AnAqSim assigns spatial extents in plan view, with aquifer properties applied through a series of input tables, which allows the model to be solved and analysed in three dimensions. This key difference is useful for modelling irregularly shaped excavations and for assessing drawdown at multiple neighboring points of interest, such as existing buildings and/ or other infrastructure surrounding an excavation.

Furthermore, T+T has recently developed a bespoke tool, using python and R programming, which allows unattended transient AnAqSim models to run in batch mode. Once a base case model has been developed, the tool allows multiple models to be automatically generated, solved, and post-processed with remarkable accuracy and efficiency. This functionality allows the user to quickly interrogate a significant number of model scenarios, which is particularly useful for assessing uncertainty of sensitive hydraulic parameters such as hydraulic conductivity, porosity, specific yield, and seasonal groundwater levels.

The case study presented is an example AnAqSim model and sensitivity analysis workflow. The example results show a comparison between early-time and late-time transient time steps, and a comparison between a range of input values for hydraulic conductivity and specific yield.

HAY BALES, WARATAHS AND WIRE - A #8 APPROACH TO FARM SCALE INTEGRATED WATER AND RESOURCE MANAGEMENT

Legg, J,[1] Hoggard, J,[2] Edkins, R,[1] Farrow, D[1]
[1] Aqualinc Research Ltd
[2] Kaikōura Plains Recovery Project

Following the 7.8 Mw Kaikōura earthquakes of 2016, several pastoral areas were subsequently unproductive due to changes in local hydrological conditions.

To address these issues, the Ministry of Primary Industries' (MPI) funded the Kaikōura Plains Recovery Project (KPRP) – a three year initiative designed to investigate and understand the impacts of the earthquake to both the ground, local hydrological conditions – which may mean future changes in land use in certain areas. As part of this remit, the KPRP engaged Aqualinc Research Limited (Aqualinc) to develop cost-effective, innovative, and practical solutions to return the land to productive use at two sites.

This paper presents a case study of one of the sites. At Ensors' Farm (west of Kaikōura), drainage solutions were developed, and advice provided regarding forward management options. A 420 m open drainage trench was developed, to drain surface water into Ewles Creek to the south. A key issue (identified previously) was the risk of sediment from the excavation activities into the receiving water body. Subsequently, solutions needed to be developed that were effective, as well as practical from the farmer's point of view. Various solutions were implemented such as, hay bales, geotextile fabric and multiple sediment traps during trench construction. This integrated approach reduced turbidity levels during excavation from 2300 to 36 Nephelometric Turbidity Units (NTU), representing a 98.4% reduction in material that would have ordinarily entered Ewles Creek.

Notably, oxidation of anoxic and alkaline groundwater in the walls of the trench, resulted in precipitation of ferric hydroxide – known locally as 'Ochre'. This 'sludge' presented both engineering and environmental concerns as it had the potential to not only clog up and block pipes – thus reducing their efficiency; but also have immediate and knock on effects such as covering plants with a fine sludge (thus reducing their ability to respire via photosynthesis), as well as increasing the Total Suspended Solids (TSS) fraction in the water column which will affect invertebrates and fish as well as provide a medium for algae to develop

Options to limit this reaction and the consequent precipitate are being currently being considered and yet to be implemented. Further investigations as to the potential extent of this reaction is recommended to ascertain its potential impacts, and this may limit the ability to drain certain parts of the Plains.

Whilst the project is ongoing and therefore some of the issues are yet to be resolved, this paper seeks to identify both the technical and non-technical learnings from the project such as the need for collaborative and adaptive management strategies, clearly defined goals and objectives, effective stakeholder engagement, the use of different knowledge cultures and the need for transparent cost: benefit analysis.

Keywords

Sediment Control, anoxic groundwater oxidation, drainage, Integrated Water Management, stakeholder engagement, knowledge cultures, Number 8 wire, Mātauranga Māori

QUANTIFYING HUMAN IMPACTS ON DROUGHT IN NEW ZEALAND

Lynds.J,[1] Kingston.D [1]
[1] University of Otago

Aims

Drought is a natural hazard, but is becoming increasingly aggravated by human actions (Shukla & Wood, 2008). Meteorological indices are used to monitor drought, but these do not include human influence on drought occurrence or magnitude (Van Loon *et al*. 2016). As such, the focus for this research comes from the disconnect that exists between drought and human activities. The research will involve using meteorological indices and hydrological data to investigate the difference between values in order to quantify human use of water from a case study river. Understanding human influence on drought is an increasingly important topic, with a warming climate and higher water consumption placing extra stress on already stretched resources. A river within the South Island of New Zealand will be selected to be investigated as a gap in research has been identified. The potential significance of this study is that it will find a way to quantify human water use, and the impact on drought conditions that this has in New Zealand. As such, the aim of this research is to quantify the extent of human water use, and the impact of this on droughts magnitude and occurrence. This will be achieved through comparison of meteorological and hydrological drought indices for a study catchment.

Method

A river will be chosen based on having a singular human use of water (irrigation), and having a historic and complete data set. Meteorological drought indices (SPI, SPEI, SRI) will be calculated using meteorological data. Data will be obtained from both Environment Canterbury, and NIWA in order to undertake research in this area. Rainfall, radiation, temperature, humidity, wind data will be acquired from the National Institute of Water and Atmospheric Research (NIWA) Climate and Flow Database (CliFlo), from a location close to the river flow gauge that is used. Potential Evapotranspiration (PET) will be calculated to represent the amount of evapotranspiration that occurs in an environment with an unlimited water supply (Lu. et al 2005). Standardised Precipitation will be calculated using the Standardised Precipitation Index (SPI), along with the Standardised Precipitation Evapotranspiration Index (SPEI). These climatological drought indices are used to compare drought severity, duration and extent across different temporal and spatial scales (Stagge et al 2015). Accumulation periods of 1, 3, 6 and 12 months will be used. These timescales have been deemed sufficient in allowing for meteorological and hydrological drought analysis to be performed (Gumus et al 2016). A comparison of SPI and SPEI calculations will occur, along with drought analysis. This will investigate the length, and magnitude of droughts to deduce a human impact on the river.

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POSSIBILITY OF PUMPED HYDRO STORAGE USING LAKES HAWEA AND WANAKA IN CENTRAL OTAGO

Mohammed Kadhim Majeed,[1]
[1] Manukau Institute of Technology

Earlier papers relating to a large multi-purpose pumped storage plant based around an expanded Lake Onslow have been described by Majeed (2019), Bardsley (2005) and Bear (2005). However, the narrow "Neck" between Lakes Hawea and Wanaka in Central Otago has long been considered as a potential pumped storage location and could also operate in a multi-use manner, and is thus described in this paper for the sake of completeness. Smaller pumped storage schemes of this type may become more common as a variety of new designs become available, in addition to changing economic factors, the availability of low-cost off-peak energy, more intermittent energy integration into the national electricity grid, and the increasing importance of a number of environmental factors.

The Neck was considered as a hydro-electric resource in the 1904 "Hay Report". However, it was regarded as too remote and there were environmental concerns that had to be given serious consideration at the time.

The horizontal distance between the two lakes at the Neck is just 2 km. Coupled with the approximately 64.5 metres difference in lake water levels, this gives pumped storage potential in conjunction with some net power generation of about 30 MW. Lake Hawea would serve as the upper reservoir and is presently controlled as Contact Energy's main hydro storage. On the other hand, Lake Wanaka experiences natural water level variation and is under protection by Act of Parliament against any deliberate modification of lake levels. The current conservation order would, therefore, need to be modified for Wanaka to allow pumped storage using the two lakes.

A possible coupled hydro and pumped storage scheme between Lake Wanaka and Lake Hawea is discussed in this study. The optimum pumping/release rates of water between the lakes were examined based on the concept of the minimum risk of flooding in Wanaka town, while ensuring the maintenance of a mid-range level in Lake Hawea and achieving the lowest energy losses at the Clyde and Roxburgh stations. The simulation model was run in different scenarios with target levels in Lake Hawea of between 340 and 342 masl and pumping rates between 70 and 250 m^3s^{-1}. The output results showed an optimum pumping rate of about 170 m^3s^{-1}, releasing 211 m^3s^{-1} and giving 120MW of installed capacity.

This hypothetical scheme would increase the benefit of the Lake Hawea storage. The main advantages of the scheme are that it would create a new power scheme to reduce power spill losses at the Roxburgh and Clyde stations and provide a spinning reserve service. With the option of large installed capacity, it is also possible to buffer against short-term wind power fluctuations. It would also make irrigation costs within the Hawea irrigation scheme negligible, reduce lake level fluctuations in both Lakes Wanaka and Hawea, and reduce the possibility of both flooding and low lake levels in Lake Wanaka.

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EVALUATING NATIONAL-SCALE RIVER FLOW FORECASTS FOR NZ

C. Cattoën,[1] J Conway,[2] A. Mari,[3] K. Montgomery,[1] N. Fedaeff,[4] U. Shankar,[1]
D. Lagrava Sandoval,[1] T. Carey-Smith[3]
[1] NIWA, Christchurch
[2] NIWA, Lauder
[3] NIWA, Wellington
[4] NIWA, Auckland

Aims

In New Zealand, flooding is the most frequent natural disaster while hydro-electricity is the main source of renewable energy (NZ, 2015). A national river flow forecasting system has potential benefits not only for disaster risk reduction through early awareness of potential floods, but also for hydropower operation, recreation, irrigation planning and regulatory/monitoring activities. The New Zealand Water Model flow forecasting system has been developed to produce and communicate qualitative 48h river flow forecasts at the national scale for all catchments (both gauged and ungauged). Here we present a preliminary evaluation of performance of categorical river flow forecasts produced since the start of the operational system in October 2018.

Method

Model framework

The New Zealand Water Model (NZWaM) is NIWA's framework for national river modelling; it encompasses model data (geofabric), hydrological models (quantity or quality), and applications (e.g. river flow forecasting, climate change scenarios). Operational river flow forecasts are produced by coupling NZWaM's hydrology model, NZWaM-Hydro, to output from NIWA's high-resolution (1.5km) convection-permitting numerical weather prediction model, NZCSM. Initial conditions for the flow forecasts are provided by NZWaM-Hydro model simulations driven by gridded observed climate data (Virtual Climate Station Network; VCSN (Tait et al., 2006)). Ensemble flow forecasts are produced every 6 hours, providing hourly hydrographs for more than 60,000 river reaches (Strahler order 3 and above) for up to 48 hours lead time.

Model forecasts are processed into flow categories (e.g. well below normal, below normal) using flow duration curve exceedance thresholds derived from a 40-year model climatological simulation. Categorical flow forecast information is visualised for national through video produced using the Presentation Cartography software, and the videos and categorical forecasts are currently being tested by a group of stakeholders.

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

In order to use a consistent approach in gauged and ungauged catchments, the national NZWaM-Hydro is uncalibrated to observed historic flows. To provide unbiased forecasts, we developed categorical flow categories (well below normal, below normal, normal, above normal, well above normal and extremely high) using flow duration curve exceedance thresholds (90%, 66%-90%, 33%-66%, 33%-10%,10%-1%, top1%) developed for each river reach. The model climatological flow duration curves were produced from 40 years of hydrological model simulations with the identical model set-up to the forecast system using VCSN (Tait, et al., 2006) as climate input. To ensure the forecasted flows are consistent with the model climatology, the precipitation input from the NZCSM forecasts are bias corrected against the VCSN using a quantile matching procedure that accounts for a variable correction at different rain rates (Cattoën et al., 2016).

Evaluation framework

The production of operational flow forecasts at a national scale started in October 2018. Two methodologies have been used to evaluate forecasts. In the first, categorical flow forecasts were compared to the initial-condition simulations produced by NZWaM-Hydro driven by VCSN climate data. This allows us to assess the skill of forecasts at any and all river reaches. Forecast errors here are dominated by the errors in forecast precipitation. The second methodology compares flow forecasts observed 'natural' river flows where flow data is available to NIWA in near-real time. This provides a more in-depth evaluation at a limited number of sites. Forecast errors are due to errors in both the forecast precipitation (and other climate input) as well as the hydrological model representation of real hydrological processes and uncertainty in initial hydrological conditions.

To assess flow forecast performance we focused on three aspects: ensemble forecast reliability, bias and error. Ensemble forecast metrics including the ranked probability skill score were applied to assess the confidence with which the model can forecast categorical flow conditions at different lead times (12, 24 and 48 hours). At sites with observed data, the quality of the ensemble spread was evaluated using rank-histograms. As well, at these sites, forecast categories were evaluated against observed categories. As a first step to evaluating the system performance in flood conditions, binary threshold exceedance scores such as probability of detection, false alarm rate, hit rate and critical success rate were evaluated for the 'extremely high" category.

Results

The NZ water forecasting system is a first attempt at producing and communicating national flow forecasts driven by a convective scale weather model. Validation of the forecasts is a work-in-progress and we anticipate initial results will be available in November 2019. As the operational archive grows and quality-assured observed flow data becomes available, evaluation of forecast performance will be undertaken at a larger suite of gauged stations. In parallel, engaging with potential users and stakeholders to acquire critical feedback and refine the system's usefulness will continue to guide future development directions.

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QUANTIFYING ACTUAL DENITRIFICATION IN GROUNDWATER SYSTEMS

Rogers KM,[1] van der Raaij R,[2] Morgenstern U,[2]

[1] National Isotope Centre, GNS Science (email : k.rogers@gns.cri.nz)

[2] GNS Science

Aims

Nitrate is a significant issue in New Zealand's groundwater systems and waterways. It promotes growth of algae in waterways and degrades aquatic habitat and affects the water's recreational value. Elevated nitrate levels are toxic to animals and humans. Understanding the distribution and reduction rate of nitrates is critical for managing nitrogen loads in New Zealand's aquifers. GNS Science has developed a method to measure the reduction of nitrates by co-analysis of argon, neon and excess nitrogen gas which occur from either natural atmospheric input or denitrification of nitrates.

Method

Argon and neon are derived from the atmosphere, so their presence is used to quantify (or not) excess nitrogen gas which arises from reduction of nitrates during denitrification. Groundwater samples with dissolved gasses are collected in 1 litre flasks for analysis. The dissolved gases are extracted and measured, with the ratios of $Ar:N_2$ and $Ne:N_2$ indicating their origin (Figure 1); either higher $Ar:N_2$ and $Ne:N_2$ for atmospheric input or lower $Ar:N_2$ and $Ne:N_2$ ratios for excess N_2 from denitrification.

Traditional analysis of groundwater nitrates using isotopes is no longer possible once denitrification takes place as the nitrate content is often below the reliable detection limit. Dissolved gasses reveal the origin of the excess N_2 gas, providing information on denitrification pathways and quantifying denitrification efficiency. When combined with other age tracers such as SF_6, they can provide evidence for denitrification rates over time.

Results

Measurement of 'excess N_2' is the most promising method for directly measuring denitrification that has occurred in an aquifer. Current efforts to locate and characterise denitrification zones can also be confirmed by quantifying the extent of denitrification by measuring excess N_2 gas changes (Figure 2). Our initial studies show excess N_2 gas method is useful to detect denitrification and quantifies the amount that has occurred (Figure 3), even in sites with mixed redox states. This suggests the method will be useful to improve knowledge around denitrification zones and quantify levels for ongoing regulatory monitoring. To consolidate this research, we are now seeking partners to undertake small scale projects and apply the method to further studies.

Figures

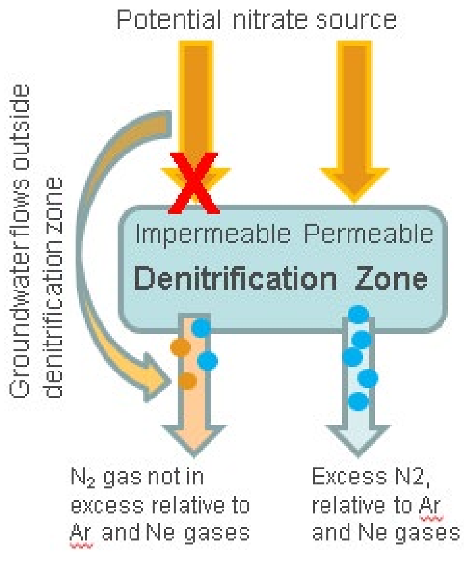

Figure 1: Determining efficiency of denitrification zones.

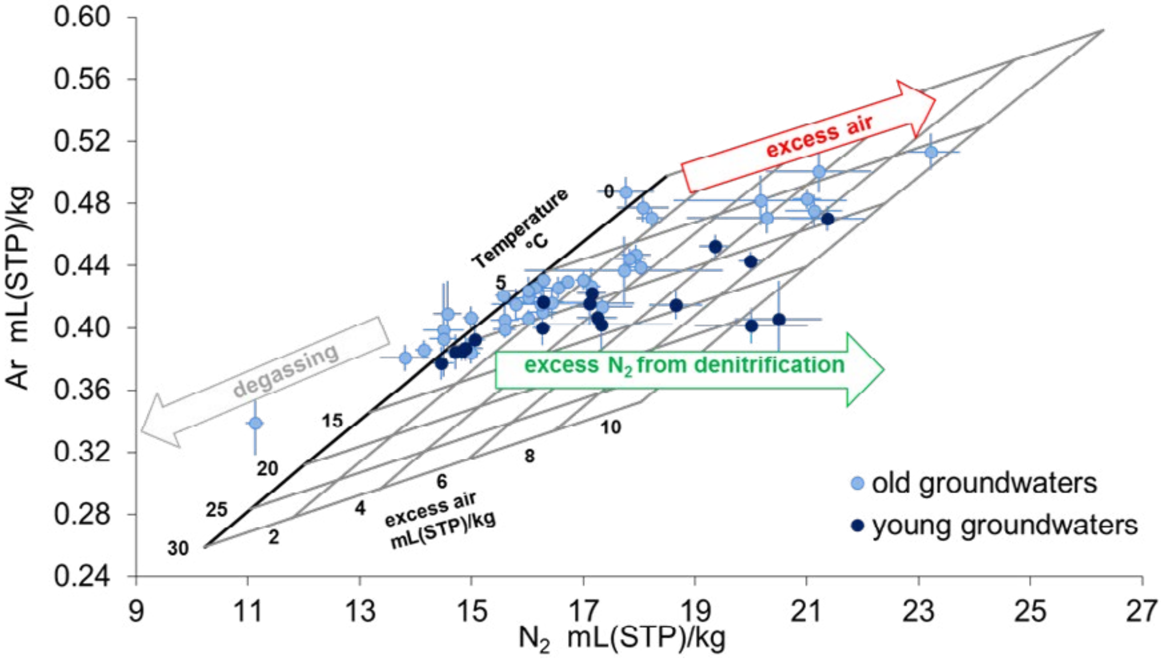

Figure 2: Excess nitrogen gas from denitrification

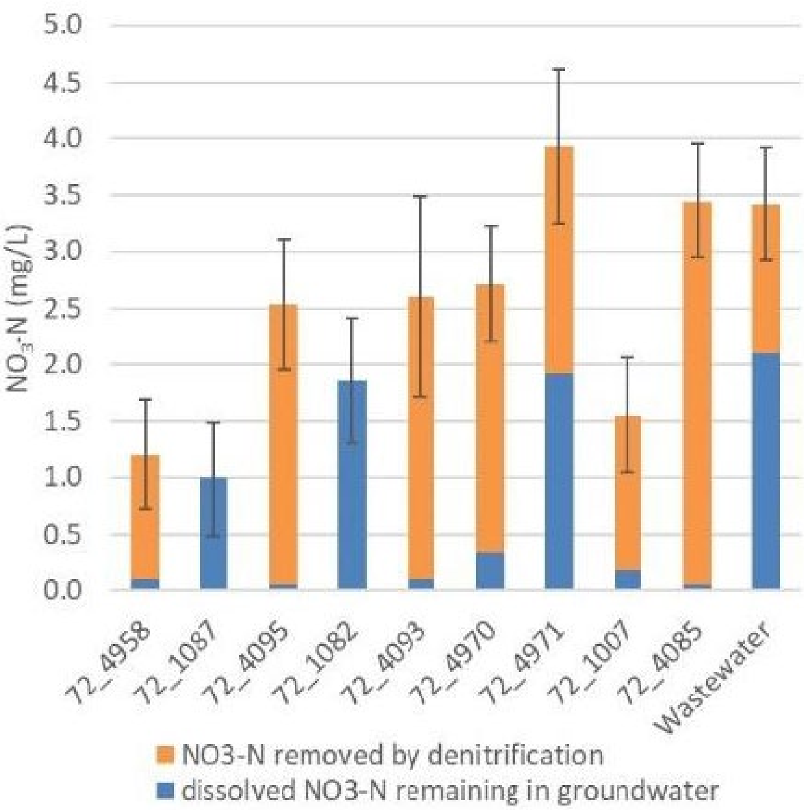

Figure 3: Proportion of concentration of nitrate in the groundwater system which has been denitrified and that which remains in the groundwater.

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FARM NUTRIENT LOSSES TO GROUNDWATER IN THE WEST MATUKITUKI VALLEY, LAKE WANAKA CATCHMENT

Mourot, F.,[1] Fraser, J.,[2]
[1] GNS Science
[2] Otago Regional Council

Aims

In the nitrogen-sensitive catchments of Otago, such as the high-country lake catchments of Wanaka, Hawea and Wakatipu, the Otago Regional Plan: Water (RPW; Otago Regional Council, 2012, 2018) introduced nitrogen limits and a permitted activity threshold of 15 kg N/ha/year , which will come into effect from April 2020.

In relation to this plan change, a research case study was developed in the West Matukituki Valley to better characterise the nitrogen and phosphorus fluxes to groundwater from low intensity farm land and the potential impacts on the nearby hydraulically connected river.

Method

A monitoring programme was set up on a low-intensity farm land, located in Lake Wanaka catchment at Raspberry Flat, which included soil drainage monitoring sites under contrasting land uses (sheep-cattle grazed pasture, cattle-grazed winter forage crop), to measure nutrient losses from these sites through the soils and enable comparison with values estimated by the nutrient management tool OVERSEER.

Nutrient fluxes were measured[2] for crops (126 kg N/ha/year and 1.6 kg P/ha/year) and pasture (14 kg N/ha/year and 0.9 kg P/ha/year) between July 2015 and June 2016 (Smith et al., 2016).

The monitoring programme also observed the water quality of the local aquifer and the connected Matukituki River at Raspberry Flat to investigate the relationship between the nutrients leaving the root zone and their effects on the local pristine freshwater bodies.

In 2018, GNS Science was commissioned by ORC to analyse the water quality monitoring data, and where possible, to link the soil drainage quality results to water analyses in groundwater and in the Matukituki River. The hydrodynamics of local water bodies, was also characterised, as being a prerequisite to interpret the water quality results.

Results

The predominant nutrient species in groundwater were nitrate for nitrogen (median concentrations: 0.06 - 1.2 mg/L) and dissolved reactive phosphorus for phosphorus (median concentrations: 0.002 - 0.005 mg/L).

The effect of land use on Raspberry Flat was noticeable but attenuated (Figure 1), leading to median nitrate concentrations below the maximum natural background threshold value for New Zealand (2.5 mg/L; Morgenstern and Daughney, 2012). Considering the inputs through the soils (nitrate concentrations in soil drainage), these low nitrate median concentrations in groundwater were attributed to attenuation processes. Dilution effects from river and creek recharge were inferred to be the main sources of attenuation, but denitrification processes might also have occurred in the vadose zone.

Despite, these low nitrate median groundwater concentrations, a noticeable difference was observed for the Matukituki River nitrate concentrations measured upstream and downstream of Raspberry Flat (0.04 and 0.068 mg/L, respectively). There was also a clear correlation of the nitrate concentration pulses observed in the aquifer, and at the downstream Matukituki River site, due to groundwater discharge upstream of this river site.

Due to the relatively brief study data set, statistical calculations to verify compliance with the RPW were not possible. However, calculations carried out for the West Matukituki State of the Environment surface water site (located downstream, near the river’s discharge into Lake Wanaka) indicate that the RPW limit for nitrate nitrite nitrogen was narrowly met over the 2013–2018 period.

[1] threshold calculated below the root zone
[2] at an approximative depth of 0.5m below ground level

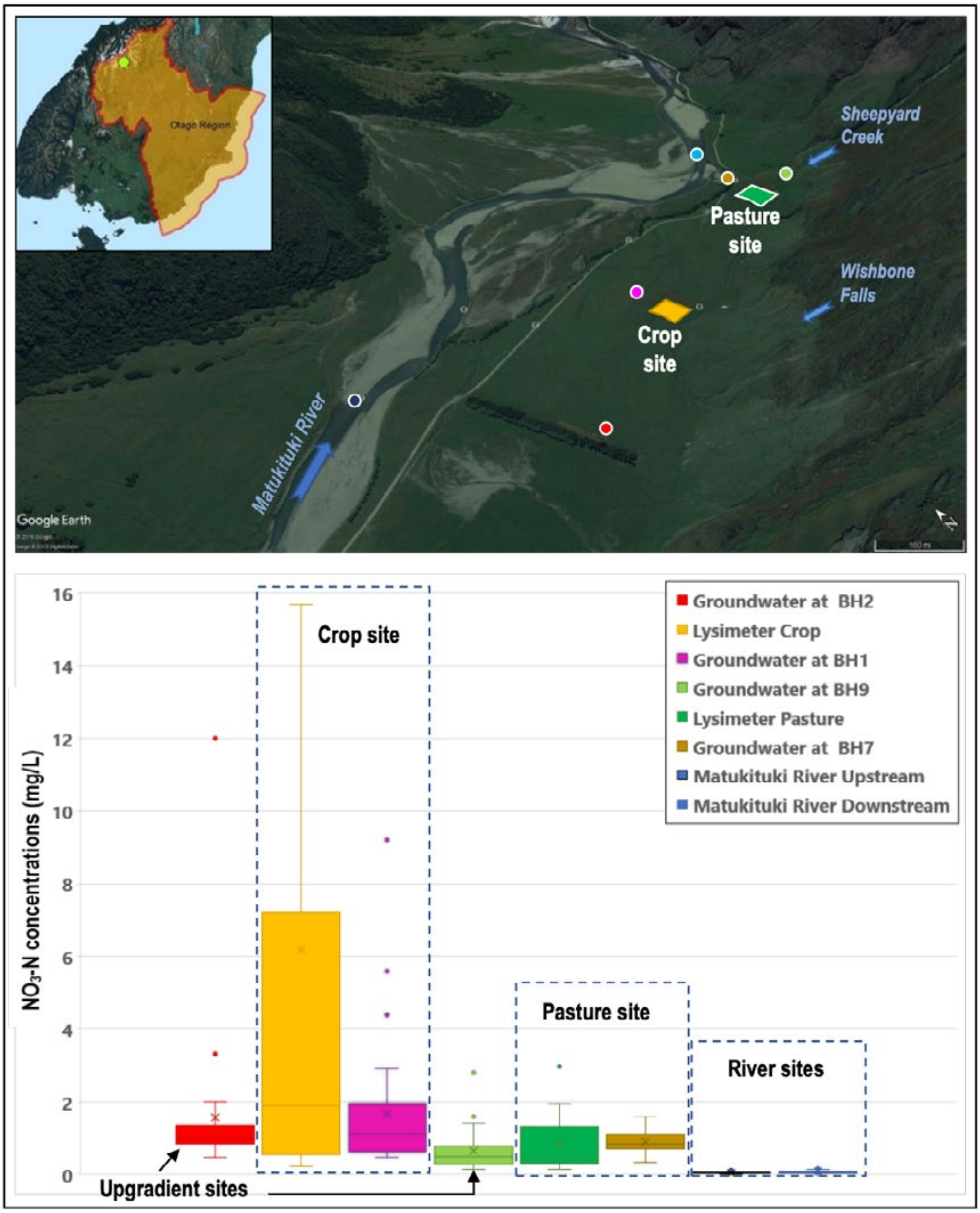

Figure 1: Nitrate nitrogen concentrations measured in soil, groundwater and surface water -Raspberry Flat, West Matukituki (Dec 2014 -Dec. 2016).

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A CATCHMENT-SCALE MODELLING FRAMEWORK TO TEST THE FEASIBILTY OF LAND MANAGEMENT SCENARIOS FOR ACHIEVING PROPOSED SEDIMENT ATTRIBUTE BOTTOM LINES

Neverman, A.J,[1] Basher, L.,[1] Spiekermann, R.,[1] Dymond, J.R.,[1] Fragaszy, S.,[2]
[1] Manaaki Whenua – Landcare Research
[2] Ministry for the Environment

Aims

New Zealand has naturally high rates of erosion and sediment load by global standards, with an estimated 192 million tonnes of soil eroded annually (Ministry for the Environment & Stats NZ, 2019). In addition, land use can cause elevated sediment loads. Excess sediment is a key contaminant in New Zealand freshwater systems (Davies-Colley et al., 2015). Sediment attribute classes and bottom lines (minimal allowable standard) have been proposed for inclusion in the National Policy Statement for Freshwater Management (Franklin et al., 2019) to manage sediment impacts on freshwater ecosystems. Hicks et al. (2019a) modelled the reduction in suspended sediment load required to meet the proposed bottom lines using a revised Suspended Sediment Yield Estimator (SSYE, Hicks et al., 2019b) to produce catchment load reduction targets proportional to current modelled load.

Regional councils need to understand what changes may be required in land use practices to achieve the sediment load reductions required to meet catchment bottom lines. This requires a model that can estimate changes in catchment sediment loads under different land use scenarios while incorporating the effect of mitigations that have been recently implemented but are still maturing. With 44 percent of sediment estimated to come from pasture (Ministry for the Environment & Stats NZ, 2019), erosion and sediment control (ESC) mitigations on land currently in pasture will be a significant component of achieving the sediment attribute bottom lines. This paper presents a modelling framework which enables scenario testing of different ESC mitigations on erodible pasture to estimate the reduction in suspended sediment loads achieved by each scenario. The outputs can be used to identify feasible mitigation scenarios and provide inputs to economic modelling scenarios (see Neverman et al., 2019). A case study is presented using three scenarios: implementation of Whole Farm Plans (WFPs), Afforestation (Aff), or Riparian Exclusion (RE).

Method

A framework was developed (Fig. 1) that utilises nationally available datasets to estimate present and future sediment loads considering 1) the location and extent of existing ESC mitigations and 2) current and future reduction achieved by mitigations as they mature and reach full effectiveness over time. This framework facilitates assessment of the impact of future land management scenarios on pastural land. The sediment reductions achieved by different scenarios could then be compared to the sediment load reductions required to achieve the proposed bottom lines.

The New Zealand empirical erosion model (NZeem®, Dymond et al., 2010) was used to estimate present day suspended sediment loads (baseline) using inputs for present land cover and the spatial extent and maturity of existing ESC mitigations (WFPs, Aff, and RE). This analysis was undertaken in 585 catchments identified by Hicks et al. (2019a) as requiring load reductions to meet the proposed bottom lines. The baseline load calculated with NZeem was multiplied by the proportional load reduction required to achieve bottom line from Hicks et al. (2019a) to calculate an NZeem-based absolute load reduction target for each catchment. The predicted reduction in sediment from baseline anticipated to result from the maturation of existing WFPs was then calculated. In catchments where maturing of existing WFPs did not achieve the load reduction required to meet bottom line, further mitigation was applied through three scenarios: WFPs or Aff on highly erodible pasture (defined as the intersection between LUC 6e, 7e, 8e and grassland from LCDB), or RE on major streams (Dairy Accord, Semadeni-Davies & Elliott, 2016). Using estimates from SedNetNZ (Dymond et al., 2016), the suspended sediment load was partitioned into that derived from hillslope (82%) and bank erosion (18%) processes. Under the WFP and Aff scenarios, the hillslope load derived from highly erodible pasture was reduced by 70% and 90%, respectively (see Dymond et al., 2016). Under the RE scenario, the bank erosion load was reduced by 80% in major streams (see Dymond et al., 2016). The catchment load under each scenario was calculated and subtracted from the baseline load to calculate the load reduction achieved and compared to the load reduction target to see whether and where bottom lines are met under each scenario.

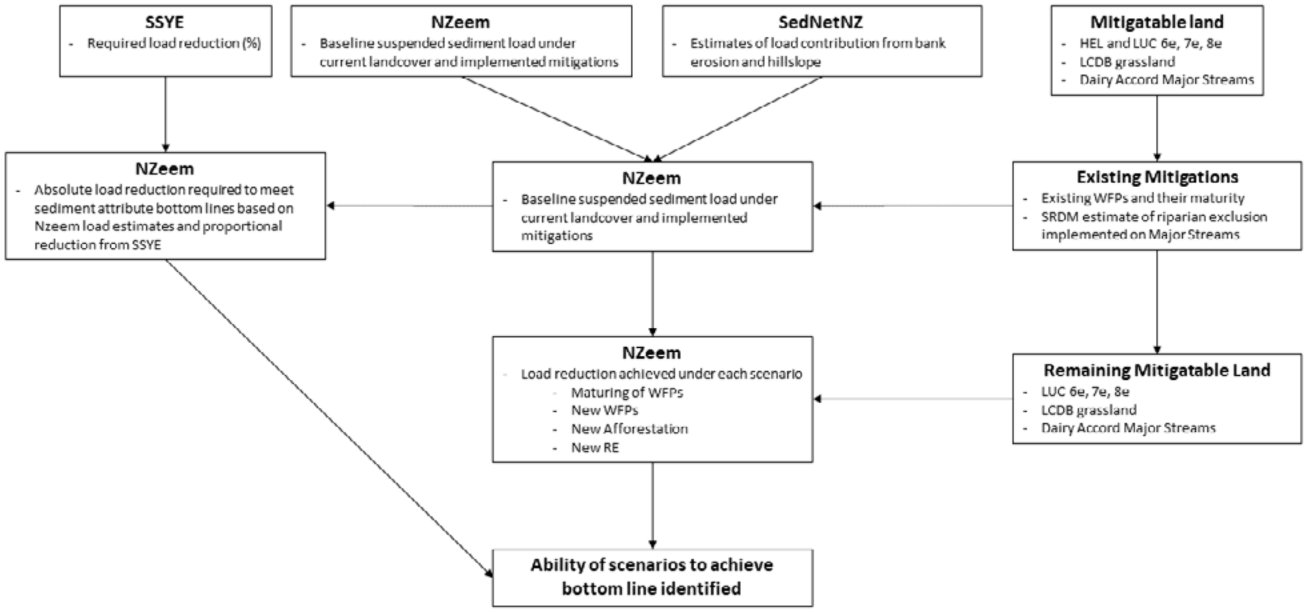

Figure 1: The workflow between modules of the modelling framework.

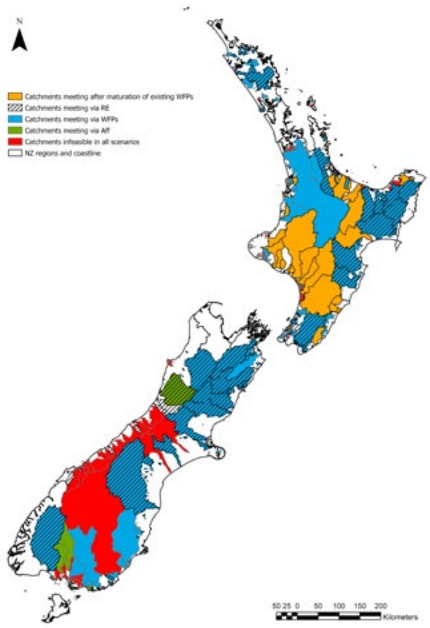

Figure 2: Map showing the erosion mitigation required to achieve proposed sediment attribute bottom lines. From Neverman et al. (2019).

Results

The model found that sediment attribute bottom lines could be achieved in 53 of the 585 catchments through existing WFPs reaching maturity (Fig. 2). In the remaining 532 catchments, sediment attribute bottom lines could be met in 331 catchments (10.8 million hectares) with implementation of WFPs only, with no requirement for land use change. A further 14 catchments (900,000 hectares) could meet target through Aff. 28 catchments (200,000 hectares) that did not achieve the bottom line through either WFPs or Aff, could achieve the target through RE. These were typically smaller catchments with little to no land suitable for WFPs or Aff. In total, sediment attribute bottom lines were found to be achievable in 70% of catchments analysed (11.8 million hectares).

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A FRAMEWORK TO ASSESS THE RELIABILITY OF A MULTI-PURPOSE RESERVOIR UNDER UNCERTAINTY IN LAND USE

Anh Nguyen,[1] Thomas A. Cochrane,[1] Markus Pahlow[1]
[1] Department of Civil and Natural Resources Engineering, University of Canterbury

Aims

Available fresh water resources are becoming scarce due to higher demands by industrial, recreational, municipal, and agricultural sectors. Reservoirs are one of the most efficient types of structures used to manage water resources for multiple purposes. Nevertheless, demands from individual sectors result in a variety of constraints that need to be addressed. Furthermore, socio-economic development in reservoirs' catchments result in potential changes in forest, agriculture and urbanisation cover which can significantly affected inflows into reservoirs. There have been a number of studies quantifying the impact of land use changes on stream flow, but few of them have considered that impact on a reservoir's water supply. Thus, the main aim of this study is to develop a framework using a reliability-based optimisation model in conjunction with the Soil and Water Assessments Tool Plus (SWATPlus) model (Arnold et al., 2012) to assess the reliability of a multi-purpose reservoir's water supply under uncertainty in land use.

Method

The framework combines a reliability-based optimisation model with the SWATPlus model. The reliability of a reservoir's water supply is defined as the probability that a reservoir operates in the set of satisfactory constraints. A Genetic optimization model was developed with the objective of minimizing the gap between water demands and water releases and satisfying water use and policy constraints.

A calibrated SWATPlus model was used to simulate reservoir inflows under various possible catchment land use scenarios. The inflows generated by the SWATPlus model were input for the optimisation model to obtain the reliability of reservoir's water supply.

Within a reservoir's operational timeframe under each land use scenario, inflows and water demands vary randomly. To account for this, a probabilistic approach is used. Inflows and demands are generated using a Monte-Carlo routine. Each inflow and a water demand combination results in a reliability of water supply. The different combinations lead to a possible range of water supply reliability of a reservoir (Figure 1).

To test the framework, the Nuicoc reservoir in the north of Vietnam was used as a case study. The reservoir has a capacity of 175 million cubic meters and supplies water for irrigation, urban use, river downstream and recreation. Initial simulations were conducted for 11 years with the baseline land use and three projected land use scenarios (S1, S2 and S3). The main driver for land use changes in the case study is urbanisation. Therefore, in comparison with the baseline land use, the Scenario S1 and S2 had a higher urban area. Scenario S3 considered replacement of forests with orchards (Table 1).

Table 1: Percentage of land uses in Baseline and Scenarios

Land use	Baseline	Land use scenarios					
		S1	Change	S2	Change	S3	Change
ORCHARD	14.12	16.38	2.26	9.63	-4.49	29.60	15.48
FOREST	52.99	52.87	-0.12	52.87	-0.12	39.65	-13.34
PADDY	14.83	8.93	-5.91	7.79	-7.05	11.90	-2.93
RURAL AREA	9.34	7.02	-2.31	5.62	-3.72	8.43	-0.91
URBAN AREA	1.18	7.24	6.06	16.54	15.36	2.86	1.68
OTHER	7.54	7.56	0.02	7.56	0.02	7.56	0.02

Results

Modelling results showed that under the same climate the growth in urban area resulted in an increase of the water supply reliability (Figure 2). Urban areas in the scenario S1 increased from roughly 1 % to about 7 %, and generated higher inflow resulting in an increase from 87% to 91% in mean reliability of water supply. Scenario S2, which had the largest urban area (17%), produced the highest inflow and a mean water supply reliability of 96%. In Scenario 3, the considerable decline in forest area from 52% to 40% created increased inflows into the reservoir. This resulted in 90% chance that the reliability could range from 98% to 100%.

In summary, this study confirms that land use changes have considerable impacts on stream flow as well as the reliability of reservoir water supply. However, the study did not considered the risk of floods caused by increased discharges or other risk factors. Furthermore, although lower forest area seems to result in higher reliability of water supply, this will result in larger amounts of sediment transferring from the catchment into the reservoir and negatively affect its volume capacity. Trade-offs needs to be considered in detail.

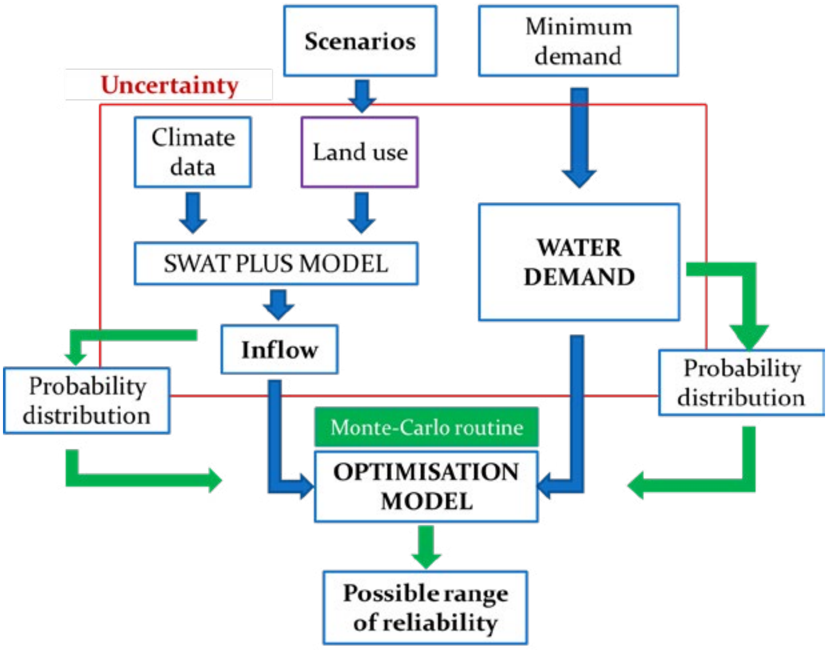

Figure 1: Framework to quantify impacts of land use changes on the reliability of a reservoir's water supply

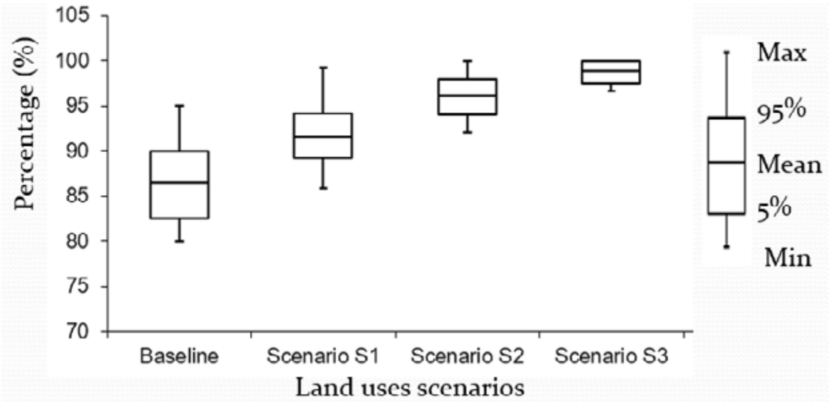

Figure 2: Range of the reliability of reservoir's water supply under land uses scenarios

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DOES METEOROLOGICAL DROUGHT HAVE IMMEDIATE EFFECT ON LOW FLOW IN NORTHLAND RIVERS?

Hoa X. Pham[1]
[1] Northland Regional Council

Northland region has been experiencing dramatic reduction in stream water level, and in particular low flow drought conditions. The most direct connection is likely to be between deficit rainfall and stream flow during both brief and prolonged drying periods.

Northland meteorological drought tool well defines the degree of dryness (rainfall deficit) and the length of the dry periods. However, the gap remains in quantifying the impact of dryness on stream flow.

Aims

This study aims to investigate the best practice to identify drought events with reference to a particular flow site.

Method

Literatures demonstrate that droughts cannot be simply characterized by a lack of precipitation via meteorological drought, especially when dealing with complexity of hydrological processes (Loon, 2015; McKee, Doesken, & Kleist, 1993; Wilhite & Glantz, 1985) (Figure 2). Hydrological drought is most often associated with low flow periods in rivers and low levels in lakes, reservoirs and groundwater resulting in lack of available water in the hydrological system (Nalbantis & Tsakiris, 2009). Literatures also reveal quantitative links in the arrival time and/or period between meteorological and hydrological droughts which can be detectable through drought indices (Tokarczyk, 2013; Ye Zhu, Wen Wang, Vijay P. Singh, & Liu, 2016).

In this study, Standardised Precipitation Index (SPI) and Standardised Discharge Index (SDI) as indicators of meteorological and hydrological droughts (WMO, 2012), respectively were selected. Pearson test with different time delays were employed to examine the relationships between the two drought types, and linear regression equations were established where appropriate.

Results

Conventionally, the main parameter to separate drought low flow is threshold discharge, which was adopted at 1 in 5 year 7-day low flow (Q_5) and presented in Table 2. The number of days

stream flows are under Q_5 threshold differs from sites to sites, depending on catchment natural and artificial processes. Flows at selected gauges may or may not be representative for the catchments due to water abstraction, diversion ant etc. In this traditional approach the mutual relationship between rainfall deficit and low flow is not explicitly explained.

Alternatively, the use of SPI and SDI indices is successfully to quantify the duration and severity of meteorological and hydrological droughts. Table 3 shows the relationships between SPI and SDI which vary with different lag times. The significant correlations are found between SDI-1 and SPI-1 and gradually decrease for SPI-3, 6, 9 and 12. This suggests that meteorological drought has immediate effect on the hydrological drought. These relationships are clearly demonstrated in in Figure 4. A specific example is also represented in Table 4 and Figure 3 for Mangakahia catchment for current dryness.

In conclusion, the combined SPI and SDI is an effective practice for hydrological drought detection with reference to a flow gauge. This is proved for the investigated flow gauges.

Table 2: Summary on conventional drought low flows

Flow recorder sites	Start year	CA (km^2)	Q_5 (l/s)	Number of drought low flow days	Drought flow days (post-2009) ((%)
Maungaparerua at Tyrees	1967	11.1	23.2	313	35
Hatea at Whareroa	1986	38.5	87	108	0
Mangakahia at Gorge	1964	246	1210	301	8
Ngunguru at Dugmores	1969	12.5	61	401	16
Opouteke at Suspension	1984	105	497	105	5
Waihoihoi at Marrys	1984	25.1	61	185	5
Whakapara at Cableway	1959	162	602	416	24
Awanui at School Cut	1958	222	472	301	37

Note: data used in this table is up to June 2019

Table 3: Correlation coefficients between SDI and SPI for different lag times

Flow recorder sites	Rain gauges	SDI(1)				
		SPI(1)	SPI(3)	SPI(6)	SPI(9)	SPI(12)
Maungaparerua at Tyrees	Kaeo at Bramley	0.82	0.75	0.60	0.43	0.40
Hatea at Whangararoa	Hatea at Glenbervie	0.80	0.71	0.63	0.48	0.40
Mangakahia at Gorge	Mangakahia at Twin Bridge	0.82	0.61	0.49	0.41	0.36
Ngunguru at Dugmores	Ngunguru at Dugmores	0.73	0.72	0.66	0.53	0.23
Opouteke at Syspension	Opouteke at Brookvale	0.81	0.63	0.49	0.38	0.36
Waihoihoi at Marrys	Waihoihoi at Brynderwyn	0.78	0.65	0.46	0.41	0.35
Whakapara at Cableway	Whakapara at Puhipuhi	0.80	0.69	0.58	0.47	0.38
Awanui at School Cut	Kaitaiai EWS	0.54	0.36	0.39	0.28	0.28

Note: Pearson test was performed at 95% of confidence

Table 4: Linear regression equation developed for Mangakahia at Gorge

Mangakahia at Gorge	SDI (1) = -0.1 + 0.703 * SPI(1) + 0.247 * SPI(3) + 0.0416	$R^2 = 0.71$

Note: This equation may change with consideration of more different variables and longer data time series

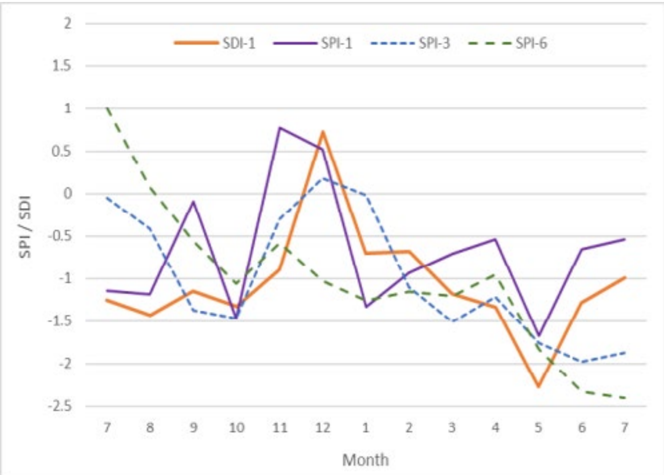

Figure 3: Relationships between SDI-1 and SPI-1-3-6 at Mangakahia during July 2018 – July 2019 period

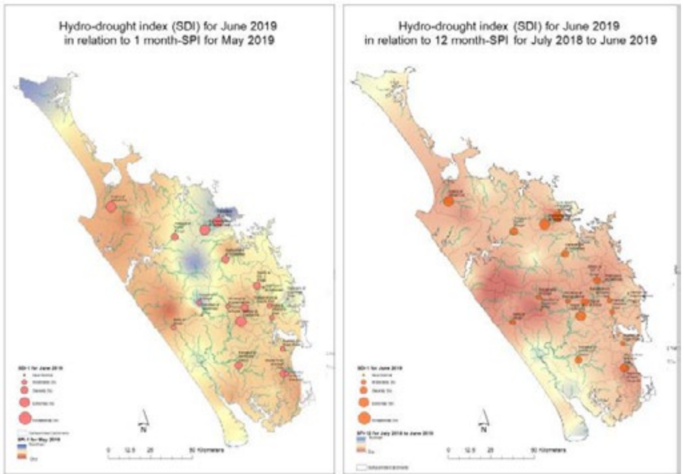

Figure 4: Spatial relationships between SDI-1 and SPI-1 (a, left) and SPI-12 (b, right)

Recommendations

For robust assessment of the impacts of meteorological drought on hydrological drought for Northland, the followings are recommended for further studies (1) to include a wider range of catchment in terms of catchments characteristics and activities; (2) to compute catchment rainfall instead of using only single-point data at rain gauges; (3) to verify the SPI-SDI relationships using more historic drought events; and (4) to integrate with evapotranspiration, soil moisture, groundwater and remote sensing-based indices.

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A GENERAL BEERKAN ESTIMATION OF SOIL TRANSFER PARAMETERS METHOD PREDICTING HYDRAULIC PARAMETERS OF ANY UNIMODAL WATER RETENTION AND HYDRAULIC CONDUCTIVITY CURVES: APPLICATION TO THE KOSUGI SOIL HYDRAULIC MODEL WITHOUT USING PARTICLE SIZE DISTRIBUTION DATA

Pollacco J.A.P.,[1] Fernández-Gálvez J.,[1,2] Carrick S.[1]
[1] Manaaki Whenua – Landcare Research
[2] Dept. of Regional Geographic Analysis and Physical Geography, Univ. of Granada, Spain

Aims

Soil hydraulic characterization is crucial to describe the retention and transport of water in soil, but current methodologies limit its spatial applicability. This paper presents a cost-effective general Beerkan Estimation of Soil Transfer parameters (BEST) methodology using single ring infiltration experiments to derive soil hydraulic parameters for any unimodal water retention and hydraulic conductivity functions. The proposed method relies on the BEST approach. The novelty lies in the use of Kosugi hydraulic parameters without need for textural information. In addition, the method uses a quasi-exact formulation that is valid for all times, which avoids the use of approximate expansions and related inaccuracy. The new BEST methods were tested against numerically generated data for several contrasting synthetic soils, and the results show that these methods provide consistent hydraulic functions close to the target functions. The new BEST method is accurate and can use any water retention and hydraulic conductivity functions. (Fernández-Gálvez et al., 2019)

Results

This paper develops two novel methods, $BEST_{QEI}$ and $BEST_{SA}$, which generalize the existing BEST methods to make predictions of any unimodal $\theta(h)$ and $K(\theta)$. In fact, these methods predict the WRHCFs on the basis of KG formulae, but it is demonstrated that these functions may depict any of the formulations for WRHCFs (including the VG type). KG functions were chosen because they are based on physical principles (log-normal distribution for pore size distributions). In the absence of PSD, the developed $BEST_{QEI}$ and $BEST_{SA}$ allow estimates of the full set of hydraulic parameters from the cumulative infiltration but require a link between the KG parameters (i.e., relationship between σ and h_{kg} as). This simplifies the procedures and avoids sources of errors due to the hypotheses behind the use of the pedotransfer functions of the previous BEST methods.

The developed new BEST methods are valid for all times and always manage to provide estimates, without any failure. This alleviates troubles and dysfunctions often encountered with the previous BEST methods. In addition, the objective functions of $BEST_{QEI}$ or $BEST_{SA}$ are improved, because they consider both transient and steady states and optimize their related contributions to the global objective function. Another novelty is the constraint implemented in these objective functions by defining the shape parameter, σ, as a function of the scale parameter for hydraulic pressure head, h_{kg}, as explained above.

The proposed $BEST_{QEI}$ and $BEST_{SA}$ methods were validated using numerically generated cumulative infiltrations with the HYDRUS-3D model for several synthetic soils. Following is a summary of the results.

Unconstraining the feasible parameter space:

- The predictions made with $BEST_{SA}$ are comparable to those made with $BEST_{QEI}$, but this needs further testing with real experimental data.
- Similar results were obtained by deriving the hydraulic parameters of KG and VG. These results suggest that $BEST_{QEI}$ and $BEST_{SA}$ methods are general, since they equally well represent any type of WRHCFs.
- The computed infiltration by using $BEST_{QEI}$ and $BEST_{SA}$ and observed hydraulic parameters accurately matches generated cumulative infiltration data with HYDRUS-3D for soils with a low gradient of hydraulic conductivity close to saturation. It is hypothesized that soils exhibiting specific hydraulic properties with high gradients could be inadequate for the use of the BEST model. The $BEST_{QEI}$ and $BEST_{SA}$ should be further tested with real experimental data to settle this hypothesis.
- The inversion of infiltration by using $BEST_{QEI}$ and $BEST_{SA}$ is accurate, but $t_{\mathrm{trans\_stead}}$ computed by $BEST_{QEI}$ is considered more realistic than that computed by $BEST_{SA}$.
- $BEST_{SA}$ and $BEST_{QEI}$ make accurate predictions of S and K_S, with S being predicted slightly more accurately than K_S.

Constraining the feasible parameter space:

- To constrain the feasible parameter space or make predictions without PSD, it is necessary to establish a relationship between the shape and scale hydraulic parameters.
- Although the predictions of WRHCFs are reasonable accurate for most soils, σ and h_{kg} exhibit "sets of truly linked parameters", and therefore their predictions are not unique. It is foreseen that more physical σ and h_{kg} values would be obtained with further constraints between K_S and the hydraulic parameters of the KG model.

Reference

Fernández-Gálvez, J., Pollacco, J.A.P., Lassabatere, L., Angulo-Jaramillo, R., Carrick, S., 2019. A general Beerkan Estimation of Soil Transfer parameters method predicting hydraulic parameters of any unimodal water retention and hydraulic conductivity curves: Application to the Kosugi soil hydraulic model without using particle size distribution data. Adv. Water Resour. 129, 118–130. https://doi.org/10.1016/j.advwatres.2019.05.005

IMPACT OF CLIMATE CHANGE ON CROP WATER DEMAND AND GROWTH

Girard, R.,[1,2] Zammit, Z.,[1] Rajanayaka, C.[1]
[1] National Institute of Water and Atmospheric Research (NIWA), Christchurch
[2] Montpellier Supagro, Montpellier, France

Introduction and Aims

Agricultural production is directly impacted by climate variables such as temperature and precipitation and CO2 level in the atmosphere. These variables control crop growth and health; thus, they directly affect crop yield (Miloševic, 2015). These variables are also impacted by climate change. In New Zealand, climate change projections envisage a temperature increase between 0.7° to 3° Celsius at different parts of the country in the next 100 years, associated with more frequent periods of drought for some areas (Mullan *et al*., 2018). This temperature rise is a consequence of the increase of the concentration of CO_2 in the atmosphere (IPCC, 2018). Although a certain amount of CO_2 occurs naturally in the atmosphere, there are several human activities (e.g. burning fossil fuels and transportation) that increase levels of CO_2. This increase also directly impacts the plant growth through its effect on the photosynthesis (Bazzaz and Sombroek, 1996) increasing the challenges faced by the farming community to develop and implement strategies to deal with climate variability and extremes.

The aim of the research project was to understand the potential impact of climate change including CO_2 level on crop development and change in crop water use, using numerical modelling. This presentation will illustrate the model results of links between climate change and crop water use.

Method

The effect of climate change on crop water use was assessed between reference period (1985-2005) and two future periods: mid-century (2035-2055) and late-century (2080-2100) using a hydrological model. Due to the exploratory nature of the study, we used only one Global Climate Model (GCM) HadGEM2 (UK) and one Representative Concentration Pathway (RCP) 8.5 (corresponding to the largest expected change in temperature and precipitation). A case study site in Hawkes Bay (latitude: -39.1, longitude: 176.7) was used for this research (Figure 1), as the east coast of the North Island of New Zealand is predicted to become drier and is currently associated with higher productive agricultural land. We also limit this investigation to unirrigated pasture land use.

Software tool Hydrus-1D, which simulates water flow through the soil matrix, evaporation and water uptake from a single root distribution was used. The choice of the model was driven by the fact that we could implement process change using a step by step approach.

Figure 1: Study location.

Results

The results show that under RCP8.5 and using only climate information, PET increases by more than 1 mm/day on average over summer over 2080-2100 period compared to 1985-2005. The increased PET is primarily driven by predicted increases in solar radiation, temperature and wind speed. However, actual evapotranspiration is significantly lower due to limited availability of soil-water for crop uptake as average daily rainfall is predicted to reduce by approximately 0.4 mm/day over the next century at the study location.

Following literature review, the impact of CO_2 on plant water demand was simulated through a reduction of PET with increased CO_2 (Kruit et al., 2008). Model results suggest that the predicted CO_2 rise in the atmosphere due to climate change will have a complex impact on crop water use. The elevated CO_2 level reduces stomatal conductance and in turn slows down the crop transpiration resulting in reduced water use. Due to lower water uptake by crops, the model simulation for this specific location shows that availability of soil-water storage can be extended up to 5 days by mid-Century (Figure 2), and up to 15 days by end-century. However, the combined effect of increased CO_2 level and increased Leaf Area Index (LAI) (through photosynthesis stimulation) has not been investigated yet.

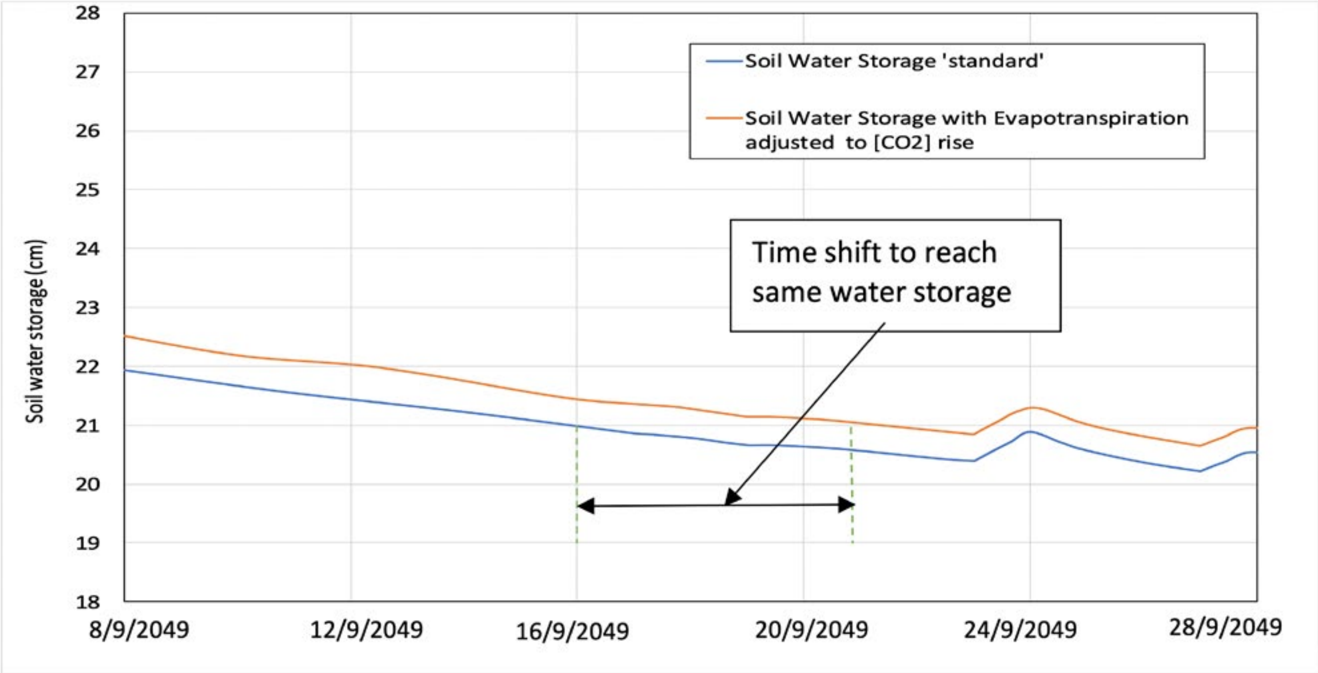

Figure 2: Estimated change in crop water use due to increased CO_2 concentration in atmosphere.

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CAN WE DETECT OFFSHORE FRESH GROUNDWATER IN CHRISTCHURCH?

Carlos Rosado*,[1 2]
[1] University of Canterbury
[2] Environment Canterbury

Groundwater is a highly valued resource for Christchurch because it is the main source of drinking water supply for the city. This groundwater also supplies flow to surface waterways that are highly cherished for their cultural, recreational and social values. The aquifer system that provides this high-quality water extends offshore, but it is not well understood how much (if any) groundwater flows out as submarine groundwater discharge. And if it does flow out, can it be detected?

In this poster, I will give an overview of the coastal hydrogeology of Christchurch and explore the ideas and methods that we have used to attempt to detect offshore fresh groundwater.

Aims

The broad purpose of this investigation is to understand the implications of groundwater vulnerability and resilience in the coastal part of the Christchurch aquifer system. Vulnerability to contamination arising from seawater intrusion and resilience in relation to groundwater extraction in the coastal zone. This investigation aims to provide information about the sustainability of the aquifer system and the risks to drinking water supplies in the coastal part of Christchurch arising from groundwater extraction and seawater intrusion.

Methods

We designed and started to trial an offshore survey to attempt to measure near-bottom electrical conductivity variations along the seabed that would suggest the presence of freshwater rising from the seafloor. The offshore survey consists of 20 km long transect lines in right angles to the Christchurch coastline. The measurements are logged by a boat-towed probe.

Results

Preliminary results from the offshore survey include transect-time conductivity plots and CTD (conductivity, temperature, depth) profiles obtained along the 20 km long transect lines.

Key words: Coastal hydrogeology, offshore groundwater, seawater intrusion

* This research project is conducted as part of a PhD programme at the University of Canterbury. The project is supported and partly funded by Environment Canterbury.

DEVELOPING A TRIAGE TOOL FOR ASSESSING DISCHARGES IN COMMUNITY DRINKING-WATER SUPPLY PROTECTION ZONES

Scott, L.,[1] Trewartha, M.[1]
[1] Environment Canterbury

Aims

We were asked to develop some simple, conservative, risk-based guidelines to help Environment Canterbury consent planners prioritise resource consent applications that fall within community drinking-water supply protection zones. The guidelines are intended to help non-technical users triage consent applications and identify those that pose the highest risk for community drinking-water wells.

There are currently over 500 protection zones around community drinking-water sources in Canterbury. Under the operative Canterbury Land and Water Regional Plan (CLWRP), most activities that involve discharging contaminants to land within protection zones require a resource consent. Since 2017, farmers in Canterbury have also needed a land use consent if they exceed certain intensity thresholds. If the farming occurs over a protection zone, the potential effects on the drinking-water supply need to be considered. Therefore, our risk assessment guidelines needed to include both point source discharges and diffuse discharges from farming.

Method

The focus of the triage tool is on assessing the risk of faecal pathogen contamination where the primary transport path to drinking-water is through groundwater. We use a qualitative risk assessment matrix (Figure 1) with two key factors: potential hazard posed by the discharge and likelihood of pathogens reaching the drinking-water supply. In its current form, the tool does not consider the public health consequences relating to either the number of people supplied or the infectiousness of the pathogens if the supply should become contaminated.

		HAZARD			
		Minor	Moderate	Major	Severe
LIKELIHOOD	Almost certain	Moderate	High	Extreme	Extreme
	Likely	Low	Moderate	High	Extreme
	Possible	Low	Moderate	Moderate	High
	Unlikely	Low	Low	Low	Moderate

Figure 1: Risk matrix

Results

The hazard is determined by the nature, size, volume/loading, application method, timing and other practices relating to the source and any mitigation or treatment put in place to limit the release of pathogens. We have begun developing a system (Figure 2) for rating the potential hazard from diverse sources of faecal contamination, based on expected pathogen loading, which we hope to expand with more quantitative data in the next phase of the project

For each activity, we relied on expert judgement or available data (e.g. from consent monitoring data or literature) to estimate the relative ranges of faecal contamination hazard posed by the discharge/source. Users of the triage tool look up the default highest hazard rating for an activity and are guided to seek extra information which could support lowering the hazard for the specific application.

Discharge/ source	Potential Pathogen Hazard				Questions to be answered to assign hazard	Also releases nitrate X = minor XX = moderate XXX = major
	Minor	Modeate	Major	Severe		
Onsite domestic wastewater	X	X	X		Size ? Treatment? Application method?	XX
Animal processing wastewater		X	X	X	Composition? Volume? Treatment?	XXX
Flood irrigation of any animal effluent or animal processing wastewater				X	Any reason why poor practice is acceptable?	XXX
Stockyards		X	X	X	Area? Type/number? Management? Stormwater discharge?	XX
Winter grazing		X	X	X	Area? Type/number of animals? Management?	XXX
Dry animal waste/manure storage and spreading	X	X			Composition? Volume/areaa? Management? Irrigated?	XX
Cemetery		X			Size? Management?	XXX
Arable farming	X	X			Livestock present?	XXX

Figure 2: Extract from the hazard factor table

The likelihood classes in the risk matrix (Figure 1) are based on how likely any faecal pathogens from the land use or discharge are to survive and contaminate the water supply. We developed a simple flowchart to guide the user in assessing contamination pathways, which includes the wellhead security and surface water connection (direct access to well); passage through the unsaturated zone and groundwater; and any treatment of the water supply.

The flowchart relies on simple conservative thresholds which we developed based on local data:

1. Any faecal discharge is assumed likely to contain high enough concentrations of pathogens to break through the soil in Canterbury, either via matrix flow or by preferential (macropore) flow.

- Depth to groundwater is the largest control on pathogen transport. Using *E. coli* data from regional groundwater monitoring we established that *E. coli* counts above <1 are common for depths <20 m and uncommon for depths >80 m or wells with artesian levels >5 m above surface. These thresholds are used in the flowchart.
- Pathogen removal rates in groundwater are typically one or more orders of magnitude lower than in the unsaturated zone, but it may be enough to remove bacteria over long distances if the depth to groundwater is >20 m. We used the E. coli removal estimates for pit latrines (the poorest performing on-site wastewater system) to derive a safe distance threshold of 300 m (Scott, 2012).

We assumed that water treatment would decrease the likelihood of contamination but is also not failproof. Because chlorination is effective against multiple organisms and leaves a residual in the water, we assigned likelihood ratings two classes lower for chlorinated supplies. For other treatment (UV or ozone) we reduced the likelihood rating by one class.

The triage tool has been trialled by consent planners assigning ratings for the hazard factor and likelihood factor in the risk matrix to decide whether an activity represents a low, medium, high or extreme risk of causing faecal pathogen contamination of a community supply well. Applications have ranged from stormwater and onsite wastewater systems to farming activities with grazing animals. Based on the level of risk, the planner and consent applicant are guided to seek appropriate technical advice. This can include additional information to be requested, more detailed assessment of the potential effects by the applicant or additional mitigation for all high-risk applications. Lower risk applications do not need as much rigour and can be processed with less technical input and, typically, with standard consent conditions.

Reference

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DEVELOPMENT AND ASSESSMENT OF A SEDIMENT MANAGEMENT ROUTINE FOR SOIL AND WATER ASSESSMENT TOOL (SWAT)

Shrestha, J.P.,[1] Pahlow, M.,[1] Cochrane, T.A.[1]
[1] University of Canterbury

Aims

Dam operators face several challenges, with sediment deposition being one of the most crucial challenges. Sedimentation causes the reduction of significant storage volume, loss of hydropower generation and downstream impacts. Sediment management techniques such as flushing or sluicing can be used to successfully manage reservoir sedimentation. In this study, we developed a Reservoir Sediment Management routine (ResSMan), integrated into the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), a physically based hydrological model. The ResSMan routine has capabilities to predict the accumulation of trapped sediment, its impacts on the storage-capacity of a reservoir, and losses in hydropower generation under user-specified operation policies. Furthermore, it allows to compute the restoration of storage volume due to the removal of sediment by flushing (removal of sediment from a reservoir by passing water and sediment through flush gates located at the low level of a dam) and sluicing (bypassing sediment before suspended sediment solids have settled down in reservoirs).

Method

A case study application of the ResSMan routine was carried out for the Nam Kong 3 reservoir with a catchment area of 646 Km2 within the Sekong River basin in Lao PDR. The simulation of flushing was carried out for every year at the specified date from 2020 to 2025. The process of flushing in the ResSMan routine comprises three phases: drawdown of water surface level, removal of sediment by flushing through gates at the base of the dam, and refilling the reservoir (Figure 1). The routine assumes that sediment deposits uniformly within the reservoir cross section and that deposited sediment can be removed only when the flushing channel attains its long term capacity ratio (LTCR). LTCR is the ratio of the storage capacity of a reservoir that can be sustained due to flushing in the long term to the original capacity of a reservoir.

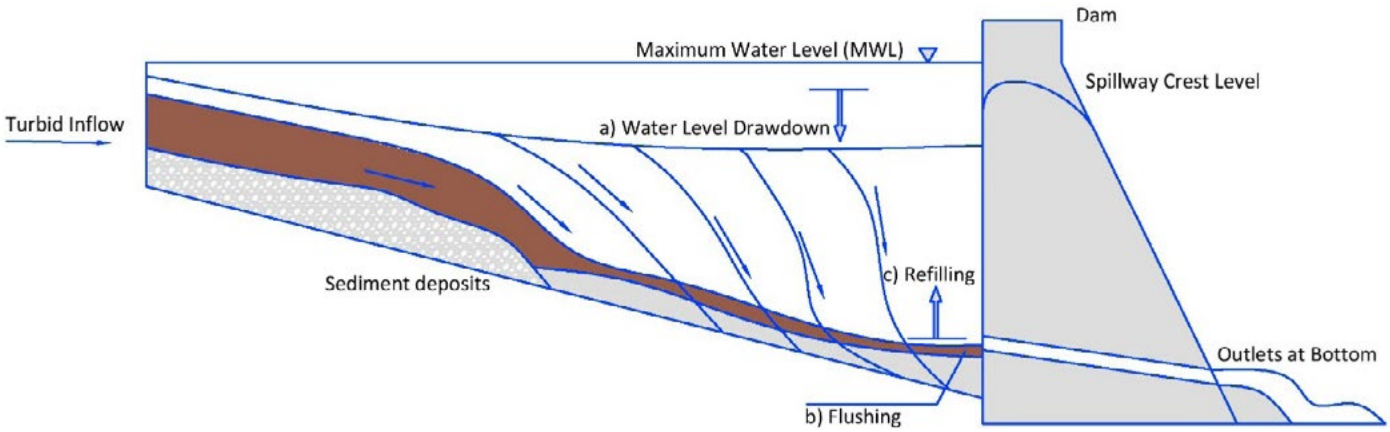

Figure 1: Flushing process to remove reservoir sediment deposits (a) water level drawdown, (b) flushing, (c) refilling reservoir.

The SedSim model, (Wild & Loucks, 2012) a one-dimensional deterministic daily time step simulation model to simulate flow, sediment, hydropower production and various reservoir sediment management techniques (Wild et al., 2015), was used to evaluate of the performance of the newly developed routine.

Results

The performance of the ResSMan routine was assessed by comparing results to the SedSim model for the Nam Kong 3 reservoir case study. The ResSMan routine and SedSim model showed a close correlation for sediment outflow (in log scale) from the reservoir (Figure 2) and for accumulated sediment from 2020 to 2025 at the Nam Kong 3 reservoir (Figure 3).

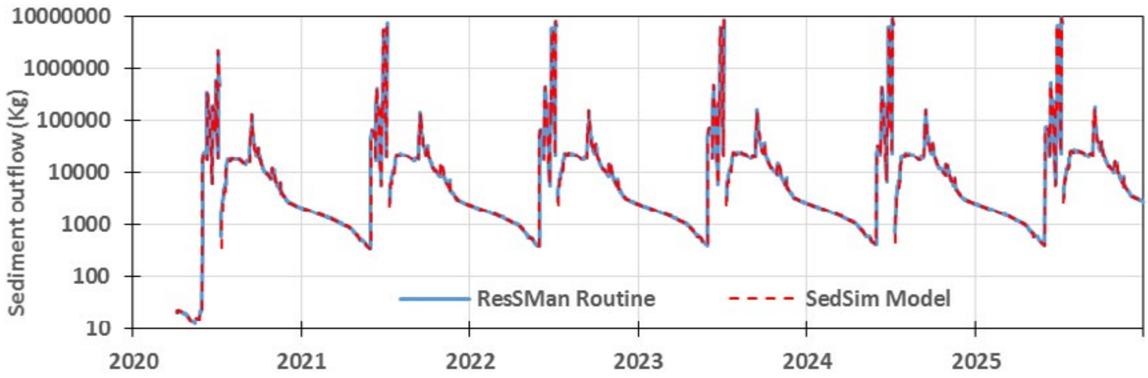

Figure 2: Sediment Outflow from the reservoir simulated with the ResSMan routine and SedSim Model.

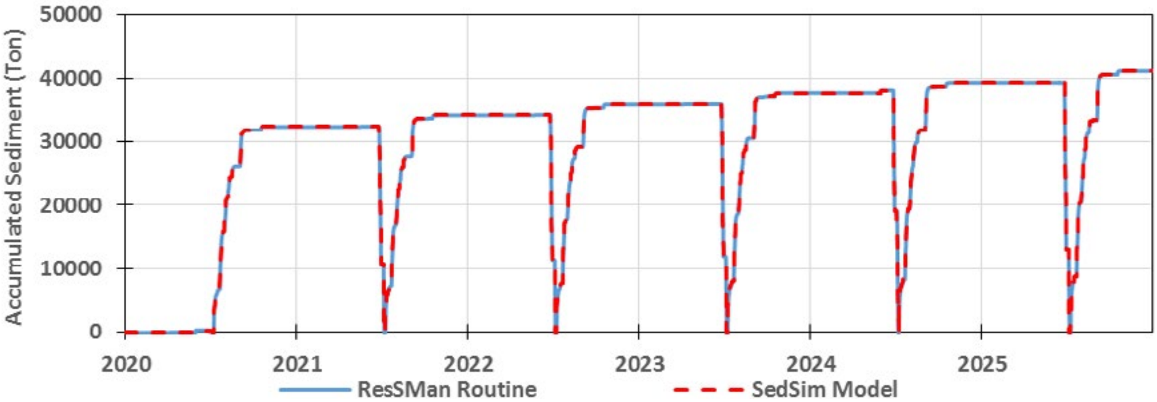

Figure 3: Accumulated sediment simulated with the ResSMan routine and SedSim Model.

More specifically, the ResSMan routine shows a good correlation with SedSim when flushing is simulated with Root Mean Square Error (RMSE) value of 403.8 kg and R^2 value of 0.99. The ResSMan routine can currently be applied to only a single reservoir, but full integration with SWAT will allow for simulation of multiple reservoirs. Full integration with SWAT will allow for the understanding of the impacts of climate change and landuse change on reservoir sediment management.

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WETLAND UPGRADE MONITORING PROGRAMME IN CHRISTCHURCH

Silveira, F.C.,[1] Cochrane, T.A.,[1] Bello-Mendoza, R.,[1] Charters, F.[1]
[1] Hydrological and Ecological Engineering Research Group, Department of Civil and Natural Resources Engineering, University of Canterbury

Aims

Hayton's Stream, a tributary of the Heathcote River in Christchurch, has a long history of poor water quality; elevated heavy metals and nutrients have been recorded in both baseflow and stormflow conditions (O'Sullivan & Charters 2014; Silveira 2017). Recent sediment analysis of Hayton's Stream (ENGEO 2018) found toxic concentrations of heavy metals, in particular cadmium (Cd), lead (Pb) and zinc (Zn), thought to be the results of both industrial point source pollution and diffuse stormwater pollution.

Construction works are underway to increase the performance of the Wigram Retention Basin (WRB), an engineered detention pond located in the lower reach of the stream, by creating three additional wetland cells. The increased retention time would improve treatment performance as well as adding to flood resilience in this area (Figure 1). However, due to the elevated concentrations of heavy metals in the existing pond's sediment and continuing contributions from stormwater, the performance efficiency of the new treatment system is uncertain. The main objective of this project is to assess the changes in water quality achieved by the upgrade, by monitoring the existing and new ponds water quality during pre and post-construction phases.

Method

A two-phase monitoring approach is being used to assess the efficiency of the existing pond (pre-upgrade; Phase 1) and the combined pond and wetland system (post-upgrade; Phase 2). Phase 2 includes monitoring of the individual pond and wetland cell components. Water samples have been collected at the inlet and outlet of each pond or cell using an automatic sampler, under baseflow (BF) and stormflow (SF) conditions. Samples were collected analysed for nutrients (nitrogen and phosphorus) and heavy metals in both total and dissolved forms.

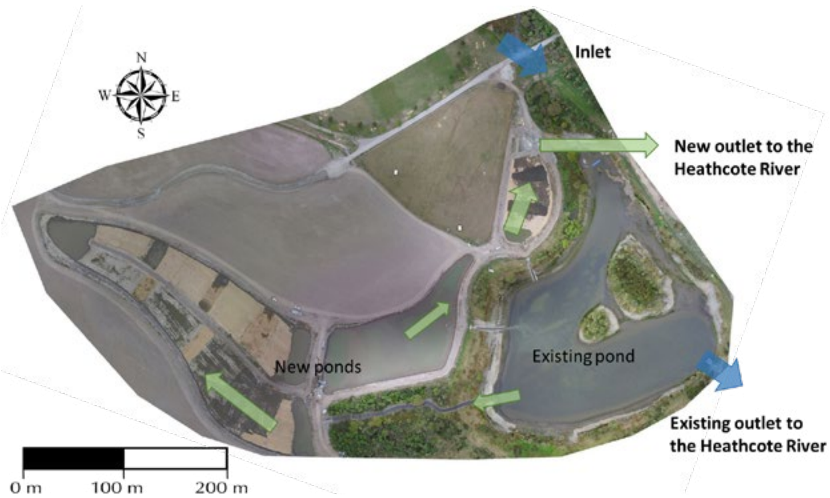

Figure 1: Aerial image of Wigram Retention Basin with old existing pond (bottom right side) and the outlet to Heathcote River (blue arrow) and new constructed ponds (bottom left and middle) and new outlet to the Heathcote River. Green arrows show the future water path once construction is completed.

Results and Discussion

During Phase 1 sampling of the existing pond, four stormflow (sf) and four baseflow (bf) sampling campaigns were done (Table 1). Under BF conditions, pollutant concentrations did not change significantly however, under SF conditions large changes in pollutant concentration were observed.

Table 1: Sampling dates, number of samples collected and rainfall characteristics.

Flow conditions	Stormflow								Baseflow							
Date	9/4/2018		9/7/2018		23/8/2018		8/11/2018		27/2/2018		17/4/2018		25/6/2018		27/8/2018	
Inlet or outlet	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Samples collected	19	48	20	24	24	24	21	23	24	24	0	24	19	17	23	23
Interval (hour)	1	1	1	1	1	1	6	6	1	1	n/a	1	1	1	1	1
Total Rainfall (mm)	21.4	49.4	5.9		2.2		28.5		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Duration (hour)	24	48	4		13		22		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

The median concentration of total nitrogen (TN) was similar across inlet and outlet samples under BF conditions while under SF conditions the median concentration and standard deviation were greater at the inlet compared to the outlet. In both cases, the concentration of TN was below the 1.5 mg/L Land and Water Regional Plan (LWRP) Schedule 5 limit (Canterbury Regional Council 2015) at the outlet (Figure 2). The variation in TN concentrations was less at the outlet compared to the inlet, highlighting the ability of the WRB's buffer capacity.

Phosphorus concentrations, however, were recorded in exceedance of the 0.016 mg/L Australia New Zealand Environment and Conservation Council (ANZECC) guideline value in all scenarios, with median concentration up to 15 fold the ANZECC guidelines (Figure 2). Phosphorus concentrations were marginally lower at the outlet compared to the inlet under SF but showed an increase under BF conditions, which could refer to phosphate accumulated in the WRB.

The heavy metals Zinc (Zn) and aluminium (Al) were well above ANZECC guidelines for a 90% level of protection of aquatic species (ANZECC 2000) in all flow conditions at the inlet and outlet of the WRB. Zn was mainly in its dissolved form and Al was mainly in its particulate form. The heavy metals Zn and Al were above ANZECC guidelines for a 90% level of protection of aquatic species (ANZECC 2000) in all flow conditions at the inlet and outlet of the WRB. Zn was mainly in its dissolved form and Al was mainly in its particulate form. Dissolved Zinc (DZn) concentrations decreased considerably under both flow conditions at the outlet but were still above 15 ug/L ANZECC guideline (Figure 3). Total Aluminium (TAl), however, did not show a decrease in concentrations in both flow conditions; under BF conditions concentrations were two-fold higher at the outlet compared to the inlet. In addition, concentrations were well above 80 ug/L ANZECC guideline under BF conditions, with median concentrations ranging from five-fold the guideline at the inlet to eleven-fold at the outlet.

Construction of the new wetland cells is due for completion in August 2019 and Phase 2 sampling will commence then to compare water quality parameters between pre and post-construct of the ponds. This monitoring programme would generate data on pollutant removal to help the future of wetland design.

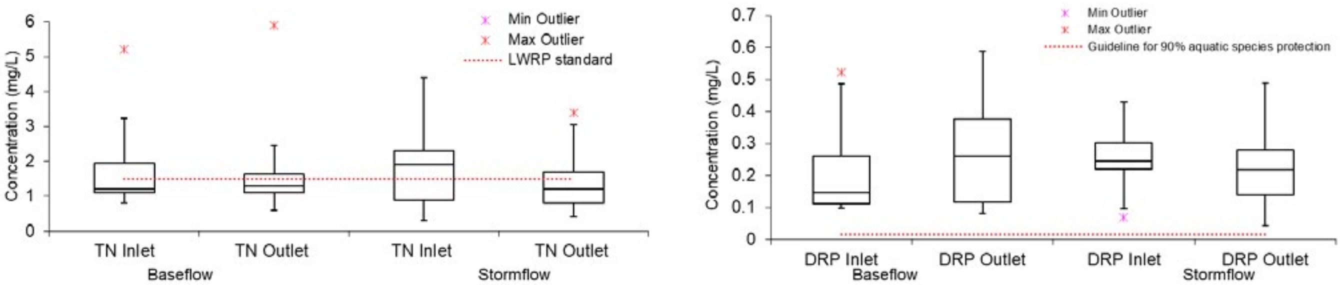

Figure 2: Left graph shows concentrations of TN at WRB under BF and SF conditions at the inlet and outlet of WRB compared with LWRP standard and left graph shows concentration of DRP under BF and SF compared with ANZECC guideline.

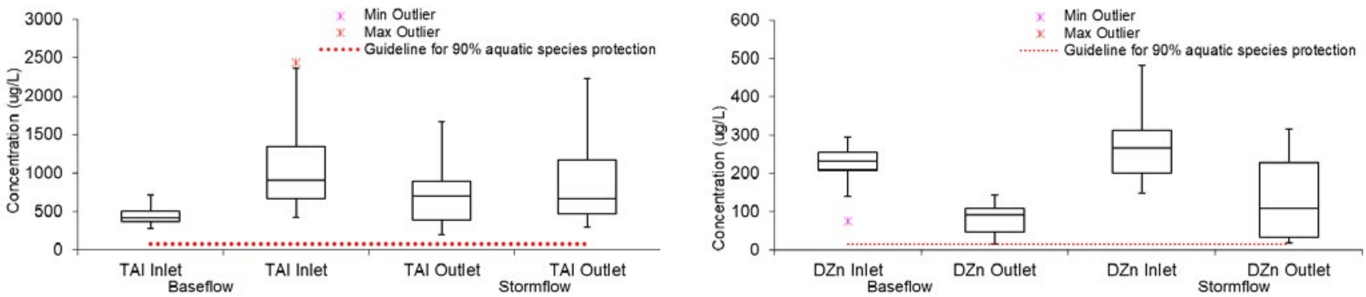

Figure 3: Left graph shows concentrations of Total Aluminium at WRB under BF and SF conditions at the inlet and outlet of WRB compared with ANZECC guideline and left graph shows concentration of Dissolved Zn under BF and SF compared with ANZECC guideline.

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TRACER SELECTION AND SOURCE DISCRIMINATION FOR GEOCHEMICAL SEDIMENT FINGERPRINTING

Smith HG,[1] Vale S,[1] Swales A,[2] Woodward B,[2] Olsen G[2]
[1] Manaaki Whenua – Landcare Research
[2] NIWA

Aims

Sediment fingerprinting is a technique for quantitatively determining the proportional contributions of sediment from catchment sources delivered to downstream locations. It involves selecting tracers that discriminate sediment sources and un-mixing contributions from those sources. Tracers may include geochemical, fallout radionuclide, magnetic, and compound specific stable isotope (CSSI) properties of soils and sediments. While the basis for discriminating sediment sources is well understood for some tracers such as fallout radionuclides (Wallbrink & Murray, 1993), there has been less investigation of source discrimination using soil geochemical properties (Smith & Blake, 2014) beyond differences that depend on contrasts in geological parent material (Vale et al. 2016). Here, we examine the ability of geochemical tracers to discriminate sources according to erosion process and land cover in a catchment characterised by a single dominant parent material using two tracer selection procedures.

Method

The Aroaro stream is a 22 km^2 sub-catchment of the Wairoa River in the Auckland region. The catchment is underlain primarily by greywacke with a narrow alluvial fill along the valley floor. It was selected for our study because a March 2017 storm caused extensive shallow landslides (typically up to 1 m deep). These landslides enabled widespread collection of subsoil samples at locations throughout the catchment. We sampled pasture (12 sites), harvested pine (12), kanuka scrub (7) and native forest (4) locations. Composite soil samples were collected at 0-2 and 40-50cm depth increments to represent surface and shallow landslide (subsoil) erosion sources at each sampling location, except for scrub where only surface samples were collected. Soil depth profiles (0-2, 10-20, 40-50, 90-100cm) were also sampled from landslide scarps at a subset of sites. Composite channel bank and stream bed sediment samples were collected at 10 and 11 locations along the main channel network, respectively. All composite source samples comprise at least 10 discrete samples mixed in the field. Samples were dried, disaggregated, sieved to <63µm, and underwent geochemical (x-ray fluorescence and laser ablation-inductively coupled plasma-mass spectrometry), fallout radionuclide (gamma spectrometry), and laser particle size analysis. In total, this provided 44 potential tracers for use in discriminating and un-mixing sediment sources.

We applied two tracer selection procedures. The first (termed 'KW-D') involved the widely used combination of the Kruskal-Wallis H test and Discriminant Function Analysis to select a minimum number of tracers that maximise discrimination between sources (Collins & Walling, 2002). The second (termed 'NC') applied an alternative approach outlined by Smith et al. (2018) to identify and remove tracers that exhibit evidence of non-conservative behaviour between sources and sediment related to downstream changes in tracer concentrations unrelated to source mixing. This method does not select tracers based on levels of source discrimination. We applied both procedures to select tracers to discriminate sources according to a) erosion process (3 sources) and b) erosion process and land cover (8 sources). A Bayesian mixing model framework, MixSIAR v3.1.7 (Stock et al. 2018), was used to quantitatively un-mix source contributions to the combined stream bed sediment sample set.

Results

The two selection procedures produced contrasting tracer sets. The KW-D method selected 8 ($^{210}Pb_{ex}$, Ga, Gd, Na_2O, Pb, Sc, U, Zr) and 12 tracers (Al_2O_3, CaO, Cs, Eu, Fe_2O_3, Ga, Na_2O, Pr, Rb, SO_3, TiO_2, Zr) for the 3 and 8 source combinations, respectively. The NC method selected 10 tracers ($^{210}Pb_{ex}$, Al_2O_3, Ce, Cu, Ga, Rb, SiO_2, Th, TiO_2, Yb) for both source combinations. Only one tracer was common to all three tracer sets (Ga).

Dimension reduction procedures such as principal components analysis (PCA) provide a means of visualising source group discrimination based on the selected tracers (Figure 1). Both the KW-D and NC methods provide clear discrimination of sources based on erosion process (surface, landslide-subsoil, channel bank). Discrimination of erosion process and land cover (8 sources) is less clear with land cover groups clustering into surface and subsoil, reflecting the dominant control of depth on soil geochemistry. CSSI tracers may improve land cover source discrimination and will be included in subsequent analysis. In all cases, channel bank (alluvium) is a distinct source.

Despite the different combinations of tracers and sources, un-mixing consistently showed that channel banks were the dominant source of fine-grained sediment stored on the stream bed. The predicted range in mean proportional contributions from channel banks and 95% credible intervals were 74-83% and 66-92%, respectively, across the four tracer-source combinations. Evidence of bank erosion was widespread. By contrast, sediment from landslides generated by the March 2017 storm appears to have largely flushed through the main channel network by the time of sampling in November 2018 or remains stored on lower slopes or in headwater channels.

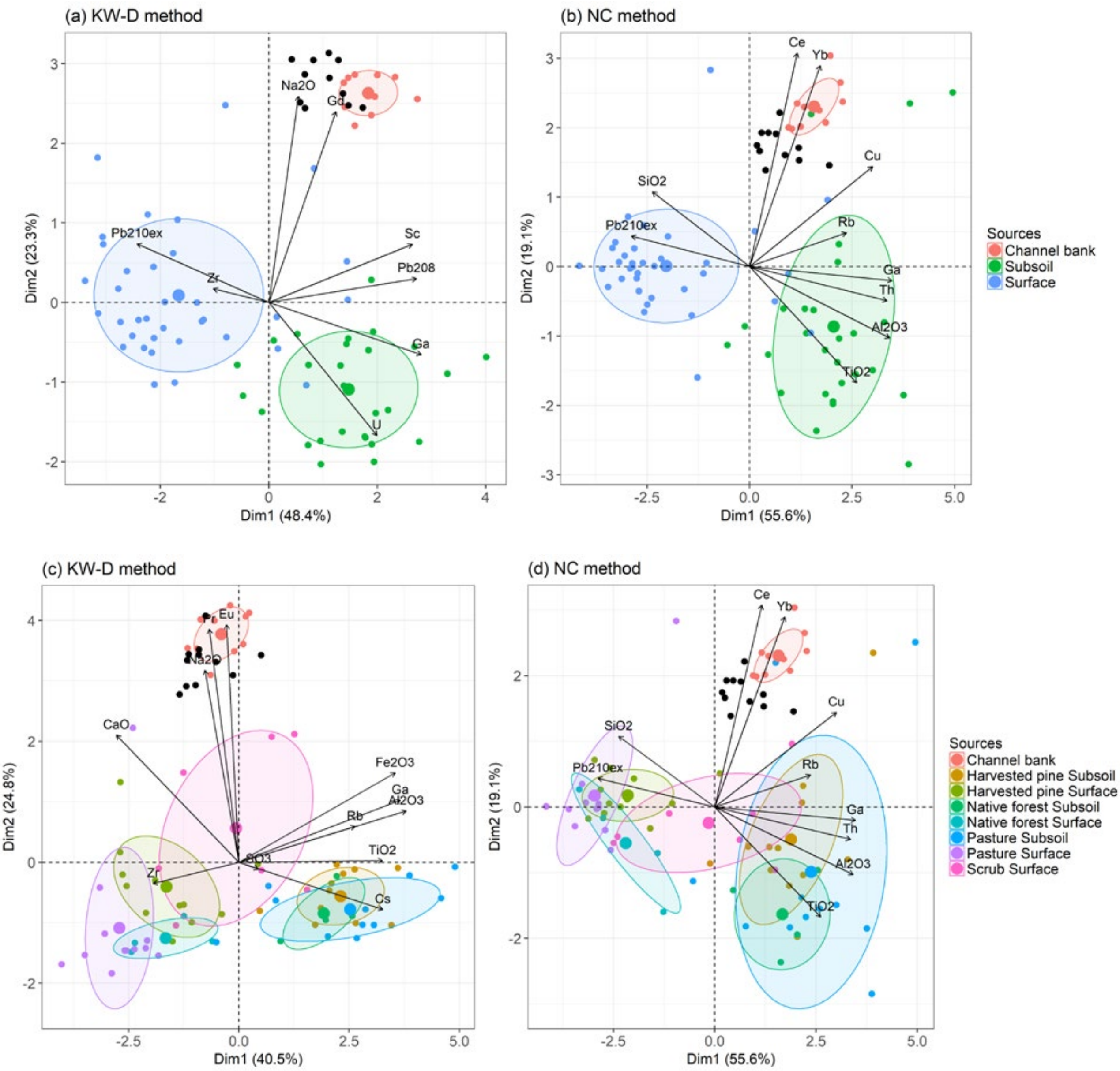

Figure 1: Plots of the first two principal components for tracers selected by the KW-D and NC methods for 3 and 8 source combinations using geochemical and fallout radionuclide data. Stream bed sediment samples are shown as black circles. Ellipses represent 50% of group variability.

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PREDICTING SPATIAL PATTERNS IN BANK EROSION FOR CATCHMENT SEDIMENT BUDGETS IN NEW ZEALAND

Smith HG,[1] Spiekermann R,[1] Dymond J,[1] Basher L,[1]
[1] Manaaki Whenua – Landcare Research

Aims

Riverbank erosion is often an important component of catchment sediment budgets but remains one of the least understood erosion processes in New Zealand (Basher, 2013). In catchments where anthropogenic impacts have accelerated bank erosion, the resulting increased supply of sediment can degrade water quality, aquatic habitats and infrastructure (Owens et al. 2005). We require information on sediment load contributions from bank erosion alongside other erosion processes to develop catchment sediment budgets to assist with catchment planning and the targeting of erosion mitigation. This necessitates approaches that can predict spatial patterns in bank erosion at catchment, regional or national scales.

Numerical models that require high levels of parameterisation and are computationally demanding are less suited to these larger scale applications. Hence, a balance between model complexity, spatial scale and available data is needed. In response, catchment sediment budget models such as SedNet (Prosser et al. 2001) and SedNetNZ (Dymond et al. 2016) adopt a conceptual, steady-state design to predict spatial patterns in mean annual erosion and sediment yields over large areas. Here, we aim to develop a new bank migration model for catchment, regional or national scale applications that 1) better represents spatial variability in factors influencing migration rates and 2) improves predictive performance compared to the existing representation of bank erosion in the SedNetNZ model.

Method

Bank migration rate in the SedNetNZ model is based on an empirical relationship with mean annual flood (Dymond et al. 2016). Our new model represents bank migration as a function of reach-scale stream power, channel sinuosity, soil texture-based erodibility, valley confinement, riparian woody vegetation, and channel protection works (Smith et al. 2019). The stream power of the mean annual flood (MAF) is computed for each REC2 reach in a catchment based on the relationship between MAF and mean annual discharge estimated by a water balance model (Woods et al. 2006), which is available for all REC2 stream links from the CLUES water quality model (Elliot et al. 2016). We include representation of the effects of channel sinuosity (Crosato, 2009), bank erodibility based on estimated silt + clay content (Julian & Torres, 2006), and valley confinement on bank erosion. The sinuosity and bank erodibility terms require calibration. National-scale data on woody vegetation cover derived from Landsat TM mapping (Dymond & Shepherd, 2004) is used to estimate the proportional extent of riparian woody vegetation for each reach.

We calibrate and test the new bank erosion model in the Manawatu catchment (5870 km^2) using mean annual reach-scale bank migration rates derived from mapping of channel planform change (n = 30 reaches) using repeat high-resolution aerial photography (2011-2016). Annual maximum flows during this period were not statistically different from the longer-term MAF used in the model for major tributaries in the Manawatu catchment. The bank migration rate data was ranked and alternating records assigned to calibration and evaluation sets (n = 15 each) to ensure statistical consistency between the datasets (Wu et al. 2013). We also applied a cross-validation approach involving 1) leave-one-out (LOO) cross-validation where the model was calibrated using n – 1 data and evaluated on the remaining point and 2) repeated random splitting of the dataset into two equal sized groups for calibration and evaluation.

Results

The new bank migration model significantly improves predictive performance compared to the previous SedNetNZ model (Smith et al. 2019). Mean observed and predicted migration rates were not significantly different (p = 0.854) for the new model (1.5 vs. 1.6 m y^{-1}), whereas these values (1.5 vs. 0.4 m y^{-1}) were significantly different (p < 0.001) using the previous representation of bank migration in SedNetNZ. Mean absolute errors (MAE) for the new model were 0.60 and 0.69 m y^{-1}, respectively, for the calibration and evaluation datasets formed by ranking and splitting, compared to 1.2 and 1.1 m y^{-1} for the previous model. Comparable predictive performance was also observed for the new model using LOO (MAE = 0.69 m y^{-1}) and 2-fold cross validation repeated 200 times (MAE = 0.76 m y^{-1}).

Analysis of measured bank migration rates with individual variables at reach-scale showed that percent silt + clay derived from soil maps exhibited the strongest linear correlation (Pearson's r = –0.59). This is consistent with higher silt-clay content increasing bank cohesiveness and reducing bank erodibility. Other variables were non-significant. The lack of correlation demonstrates how interactions between reach-scale factors contribute to high levels of variance in observed bank erosion rates. For example, the presence of riparian woody vegetation does not necessarily produce low bank migration rates but depends on other factors such as bank silt-clay content.

The model results show that improved prediction can be achieved by combining spatial representation of multiple factors over large catchment areas, despite low correlation between individual variables and bank migration rates.

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A REVIEW OF EUROPEAN FIELD LYSIMETER RESEARCH: LEARNINGS FROM AUSTRIAN LYSIMETER WORKSHOPS

Srinivasan, MS,[1] Lovett, A,[2]
[1] National Institute of Water and Atmospheric Research Ltd, Christchurch
[2] Earth & Environmental Science Ltd, Lincoln

Field lysimeters are used worldwide to study water and nutrient transport processes such as evaporation, plant water use, drainage and leaching. These lysimeters are based on the general concept of intercepting (vertically), collecting, and measuring freely-draining water. Based on attendance at the 2017 and 2019 European Lysimeter Research Group workshop held in Gumpenstein, Austria, we reviewed the similarities and differences in construction, research focus and data use between European and New Zealand lysimeter networks, and opportunities to enhance NZ field lysimeter research. The review is limited to field-based lysimeters only.

Site set up

- The European network is largely made up of weighing lysimeters that are fully managed and controlled for inputs (e.g. nutrient, pesticide and irrigation application, and surface vegetation). The sites are not actively animal-grazed. Many sites are operating for several years to decades. The NZ lysimeters are located in real-operational farms, with minimal control on management practices (e.g. grazing, nutrient and irrigation scheduling, vegetation). Since NZ lysimeters are not excluded from animal traffic, instead of using weighing lysimeters, the outflow is routed through tipping-bucket gauges to get a measure of drainage.
- Because of their large size the European lysimeters are generally artificially packed. The NZ network is made up of lysimeters that were extracted as undisturbed soil columns.
- European lysimeters vary from 20 cm to 2-3 m in diameter, and from 1 to > 2 m in depth. The NZ lysimeters are uniformly sized at 50 cm in diameter and 70 cm in depth (and 100 cm for the single cropping lysimeter). The NZ lysimeters are located in pastoral farms, where rootzone is limited to 40-50 cm and a 70-cm deep lysimeter is considered sufficient. However, the European researchers indicated that the NZ lysimeters may need to be a deeper than 70 cm (at least 1 m) to avoid ponding at the bottom. This ponding could cause a capillary fringe, increasing plant water use and transpiration. This could result in an underestimation of drainage volume and an error in drainage timing. At some NZ sites, cotton wicks are added to the bottom of lysimeters to avoid ponding and encourage free drainage.
- The number of lysimeters per site in European lysimeter facilities vary with their research focus and funding, while this number per NZ site is predominantly three with some sites having two.

Knowledge sharing and capability development

- The European lysimeter group is well organised and gather together every two years for a two-day scientific workshop at Gumpenstein, Austria, and a field visit to nearby lysimeter sites. These workshops are attended by 60-70 researchers. At the workshop, researchers share data and results from their sites, seeking input and collaboration from others. In contrast, the NZ lysimeter network has no real organisation or regular gathering, and thus, offers fewer opportunities for sharing knowledge and experience, and encouraging collaboration.

Data use

- The primary users of data from European lysimeter network are researchers for describing soil hydrological and hydraulic processes and for developing and parameterising transport models. At the Austrian lysimeter workshop, there was no evidence for data use by regional governments to draw policies or allocate resources, though the Gumpenstein lysimeter facility is funded by the local government, or by farmers to manage their farming practices such as water and nutrient scheduling. In contrast, data use in NZ is more applied, including use by farmers to describe irrigation water use efficiency and by the regional councils to estimate groundwater recharge and verify groundwater recharge models.

Research focus and experimentation

- The European lysimeter group is more focussed on nutrient and pesticide transport research and less on groundwater recharge. In NZ, very little leachate collections have been undertaken at field lysimeter sites to describe nutrient transport, aside from one joint regional council-CRI site in Canterbury (Methven) and a private site in Waikato. In NZ, nutrient transport research is conducted under controlled conditions in custom-built lysimeter facilities, where intact soil cores are transported from various field sites. The biggest challenge to NZ field lysimeters is its inability to characterise unaccounted nutrient input from grazing animals.
- Because of their controlled nature, European research largely focuses on issues such as oasis effect (micro-climate variations induced by the height of vegetation in and around lysimeters), drought effects (quantifying the impact of drought on evaporation and plant productivity), impact of irrigation using waste water on leachate, pesticide leaching and climate change (e.g. impact of soil temperature increase on productivity and soil carbon).
- The Gumpenstein lysimeter facility at Austria hosts researchers from the region. This has two benefits:1. provides visibility and funding to operate the site; and 2. provides researchers immediate access to a fully-equipped site. None of the NZ field lysimeters is shared among researchers to enable a wider use, funding support, and opportunities to collaborate.
- The climate change research done using field lysimeters at Gumpenstien is unique attempt to collect field-based evidence. While the field based lysimeter network in NZ does not offer to do such controlled experiments, the lab-based lysimeters may offer an opportunity to initiate such a research in NZ, allowing us to develop an observation-based evidence on climate change impact.

QUANTIFYING SOURCES OF OVERBANK SEDIMENT DEPOSITS IN THE LOWER OROUA RIVER USING SEDIMENT FINGERPRINTING

Vale SS,[1] Smith HG,[1]
[1] Manaaki Whenua - Landcare Research

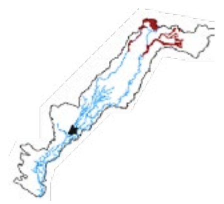
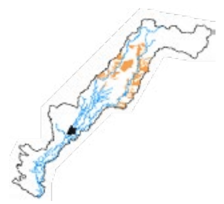
Aims

In this study a sediment fingerprinting investigation was undertaken in the Oroua River catchment to 1) evaluate particle size and mineralogy of the sediment sources; 2) geochemically characterize the dominant sediment sources based for two size fractions and 3) quantitatively determine relative source contributions to overbank deposits in the lower Oroua catchment.

Method

The Oroua river drains a ≈ 900 km2 catchment originating in mountainous terrain before flowing through steep hill country followed by alluvial floodplains to join the Manawatu River. Sediment fingerprinting is used to determine sediment source contributions based on geochemical properties. Source sampling aimed to characterize geomorphologically based spatial source units which possess distinct geochemical signatures and can be related to sediment erosion processes (Table 1). This comprised 6 sediment sources with a minimum 8-sample replication for each source. The sediment sink samples were collected from grab samples form overbank sediment deposits in the lower Oroua River, and within-channel sediment deposits within the mid-Oroua River.

Table 1: Sediment source characteristics from the Oroua River catchment

Mountain Range (MR)	Mudstone (MS)	Hill Subsurface (HSS)	Hill Surface (SS)	Unconsolidated (US)	Channel Bank (CB)
					
84 km^2	44 km^2	179 km^2	735 km^2	74 km^2	450 km^2

Sediment samples was separated into <63 μm and 125–300 μm size fractions to represent both fine and coarse sediment sources. Bulk geochemistry and radionuclide activity concentrations were determined using XRF, LA-ICP-MS and gamma spectroscopy. Tracer selection employed two approaches: 1) the widely applied method after Collins and Walling (2002) using Kruskal Wallis (KW) and Discriminant Functional Analysis (DFA) to select the most suitable tracers for tracer selection; 2) an approach following Smith et al. (2018) whereby tracers are removed based on evidence of 'non-conservative' behavior through particle size relationships. A multivariate frequentist mixing model was applied to determine relative sediment source proportions for each size fraction and these were compared to synthetic mixtures to test model performance. A spatial model for specific sediment yield was also determined based on the sediment source proportions and spatial source areas.

Results

Tracer selection for model 1 produced 14 elements (K_2O, Cr, Er, Ce, MgO, Na_2O, ^{210}Pb, Cs, V, BaO, Ho, Fe_2O_3, SiO_2, and P_2O_5) while Model 2 produced 12 elements; K_2O, MgO, Y, Pr, P_2O_5, Fe_2O_3, Dy, La, V, Zr, ^{226}Ra, and SrO. Both methods of tracer selection showed good agreement between major sediment source estimates. Using method 2, the dominant sediment contributing to Overbank deposition in the lower Oroua River was from Hill Subsurface (31–37%) and Unconsolidated sediment sources (26–27%), followed by Mudstone (9–10 %), Mountain Range (9–15%), Hill Surface (7–8%) and Channel Bank sediment (18%) (Figure 1). This was broken down into two particle size fraction which showed varying source contributions. The < 63-μm-size fraction shows Unconsolidated sediment sources (36–41%) and Hill Subsurface (27–34%) are the dominant sources, followed by Mudstone (11–12%), Hill Surface (8–11%), Mountain Range (3–4%) and Channel Bank (12%). The 125–300-μm-size fraction shows Hill Subsurface (37–42%) and Mountain Range (17–32%) as the dominant sediment sources to Overbank deposits, followed by Unconsolidated (10–12%), Mudstone (10–12%), Hill Surface (2–8%) and Channel Bank (27%).

Testing two different tracers sets showed tracer selection used for un-mixing sources influences the accuracy of source apportionment when compared with known synthetic mixture combinations. The < 63-μm fraction deviation was generally < 5% from the synthetic mixture for each source except Channel Bank which deviated from 5 to 13%. Removing Channel Bank as a source improved the synthetic mixture testing performance for the < 63-μm-size fraction. The deviations for the 125–300-μm-size fraction were generally 5–7% difference, while removal of the Channel Bank did not improve the accuracy. Channel Bank sediment sources present a challenge for statistical differentiation from other major sediment sources due to this source representing a mixture of upstream sources.

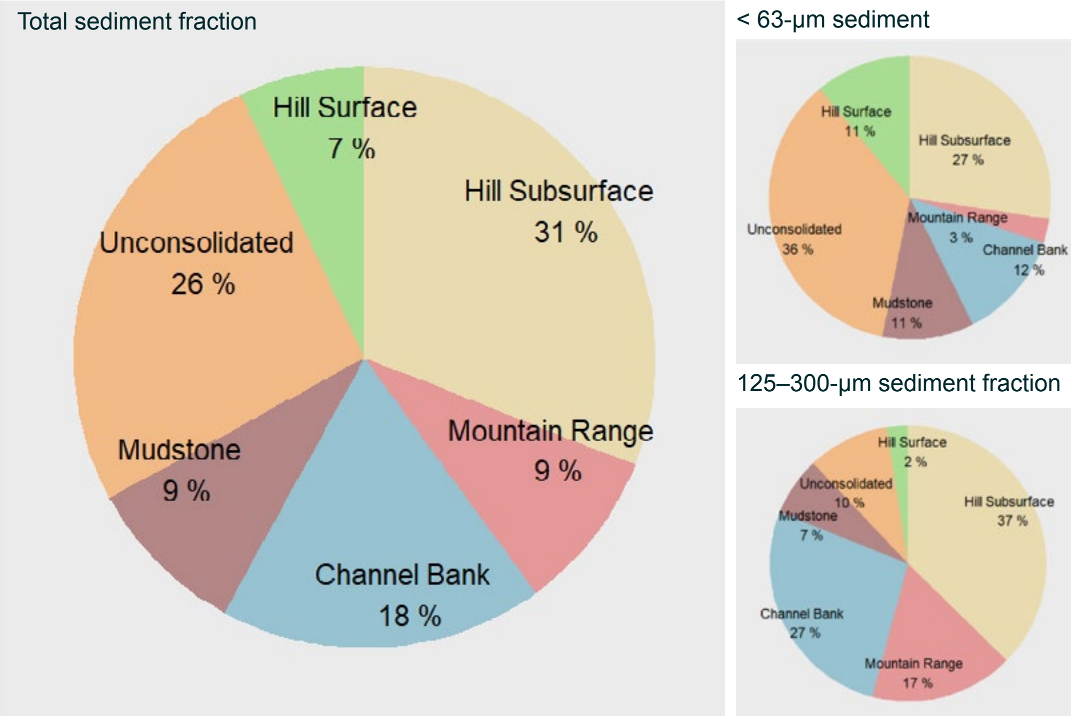


Figure 1: Pie graph of relative sediment source contributions for total sediment size fraction (left); < 63-µm sediment fraction (top right); and 125–300-µm sediment fraction (bottom right)

The highest specific sediment yield source originates from Unconsolidated (1928–2151 t km–2 yr^{-1}) followed by Mudstone (1131–1257 t km–2 yr^{-1}), Hill Subsurface (953–1138 t km–2 yr–1), and Mountain Range (589–981 t km^{-2} yr^{-1}). Hill Surface (52–60 t km–2 yr^{-1}) displays a low specific yield due to the large potential area and Channel Bank is responsible for up to 220 t km^{-1} y^{-1} by length (Figure 2). This emphasizes that the Unconsolidated sources of sediment provide the greatest specific sediment yield; steep hill terrain also provides a significant total load but over a larger spatial area.

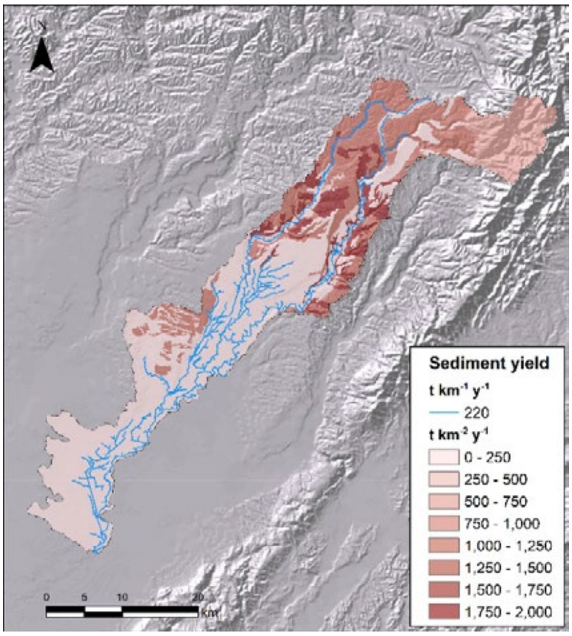


Figure 2: Total specific sediment yield derived from sediment fingerprinting proportions distributed across spatial extent of source material

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REMARKABLE RECORD OF RAINFALL RECHARGE AT KAHAROA, 2005 TO 2019

White, P.A.,[1] Green, M.[2]
[1] GNS Science, New Zealand
[2] Bay of Plenty Regional Council, New Zealand

Aims

The Kaharoa rainfall recharge site was built in 2005 to measure rainfall recharge to groundwater in the Mamaku Plateau, which is a key water resource for the Bay of Plenty region and for the Lake Rotorua catchment.

Rainfall recharge is the most important inflow to groundwater in the area; early hydrological research suggested that rainfall recharge on Mamaku Plateau was approximately 50% of rainfall (White et al. 2007). However, this figure was the subject of much debate and so the Kaharoa site was built to monitor rainfall recharge in the long term.

The Kaharoa rainfall recharge site consists of a ground-level rainfall recorder and two lysimeters (L1 and L2), White et al. (2007). Early measurements of rainfall recharge, i.e., the period August 2005 to July 2006, found that rainfall recharge at L1 and L2 was 49% and 17% of rainfall, respectively. Soon after, L2 was repaired after testing showed this lysimeter was leaking at the base of the soil column.

The Kaharoa record is remarkable because measured recharge is very large: rainfall recarge in L1 and L2 totalled 16.6 m and 12.4 m, respectively, between 2005 and August 2019. This paper reviews data from the Kaharoa rainfall recharge site to assess hydrological features relevant to the groundwater resource including: long-term rainfall recharge rates; the seasonality of rainfall recharge and the relation between rainfall intensity and rainfall recharge. In addition, the paper summarises other hydrogeological applications of the Kaharoa installation including measurements of nitrogen discharge from soil with rainfall recharge.

Results

Annual averages in the 13 full years of recording were: rainfall (2071 mm/year), L1 (1228 mm/year) and L2 (927 mm/year), i.e., rainfall recharge, as a percentage of rainfall, averaged 58% and 43% in L1 and L2, respectively. These results support early hydrological research that indicated rainfall recharge was approximately 50% of rainfall in the area. Rainfall recharge occurs throughout the year and is largest in the winter months (Table 1). Interestingly, rainfall recharge in summer is commonly associated with the occurrence of summer storms, as observed by White et al. (2007).

Table 1: Rainfall and rainfall recharge at the Kaharoa site in the period of record (1/07/2005 to 17/08/2019) for 'standard' 30.4-day months.

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
	mm/month											
Rainfall	158	146	155	243	188	201	182	198	167	140	88	167
L1	70	49	70	131	116	146	134	188	97	55	21	88
L2	49	40	55	94	94	112	97	116	91	46	18	61

Reference

White, P.A, Zemansky, G., Hong, T., Kilgour, G., Wall, M., 2007. Lake Rotorua groundwater and Lake Rotorua nutrients – phase 3 science programme technical report. GNS Client report 2007/220 to Environment Bay of Plenty. 402p.

BIAS CORRECTION FOR SIMULATED SOIL MOISTURE USING MOS: LINEAR REGRESSION VS. CDF MATCHING

Yang Yang,[1] Trevor Carey-Smith[1]
[1] NIWA, Wellington, NZ

Aims

Soil moisture is vital for vegetation growth, controls the portion of rainfall amount that goes into groundwater or runoff, greatly affects river flow, and impacts water resource management. Soil moisture is also important meteorologically as it affects latent heat fluxes and sensible heat fluxes to the atmosphere, thus, affecting local winds, convection and precipitation (Yang et al., 2011, and others).

The most reliable way to acquire soil moisture data is via direct soil moisture observations, but sites with direct routine observations are quite sparse and there are relatively few long-term records especially compared to meteorological records. Using surface meteorological observations to drive a land surface model (LSM) is a common way to obtain (infer) soil moisture "data". However, even a well-tuned LSM can produce large errors due to poor soil texture descriptions in the model. In addition, an LSM is usually one dimensional (i.e. considering soil water flow along the vertical only) and possible lateral water flow in the soil is not considered. This may lead to quite large errors in simulated soil moisture in areas (often hilly or mountainous) where the lateral soil water flow is present (Yang et.al. 2014).

In our previous studies (Yang et al. 2018), we introduced two MOS approaches, the linear regression MOS and the rescaling MOS, to bias-correct the simulated soil moisture. Both MOS methods can significantly correct the errors/ biases in an LSM model's soil moisture simulations. The best results were from the linear regression MOS (MOS-SN) that considered the seasonal variations of soil moisture by establishing different linear regression models for different seasons within a year. In this study, we introduced another MOS method, cumulative distribution function (CDF) matching (MOS-cdf). This method has been used to adjust the satellite-derived soil moisture with respect to the simulated soil moisture by a land surface model so that the satellite-derived soil moisture can be used in land surface data assimilation to improve simulated soil moisture (Reichle and Koster 2004). We also compare the performance of the two MOS approaches, CDF-MOS vs. MOS-SN

Method

In this study, The Joint UK Land Environment Simulator (JULES 3.1) is configured to run with 4 default soil layers whose depths are: 0.0 – 0.1 m; 0.1 – 0.35 m; 0.35 – 1.0 m and 1.0 – 3.0 m. These are also the fixed soil layer depths used in the UK Global Unified Model (UM), and the regional models configured from the UK UM.

Soil moisture observations (0 – 40 cm soil layer) at 10 New Zealand sites were used in this study. The forcing data used to drive the model were from observations except for the longwave radiation, which was from archives of regional numerical weather model simulations over New Zealand. JULES simulations have been conducted at these stations for three years from 1 January 2013 to 31 December 2015. The first year was used for model spinup. For more information about how to setup and run JULES at these stations over New Zealand, one may refer to Yang et al. (2014).

The linear regression MOS-SN, combining four 3-month linear regression models that were created for different seasons and corrected the simulated soil moisture for the corresponding time periods. The CDF matching method (MOS-cdf) is to match the cumulative distribution of the simulated soil moisture by JULES to the in-situ soil moisture observations. i.e., $cdf_o(x') = cdf_m(x)$, where x is the simulated soil moisture and x´ is the soil moisture observations. Data during 1 January 2014 to 31 December 2014 were used to establish the MOS models, which were applied to 1 January 2015 to 31 December 2015 to correct the biases/errors in simulated soil moisture. Calculation of bias (simulation – observations) and mean absolute difference (MAD), etc. were conducted for 1 January to 31 December 2015 at 10 sites with soil moisture observations.

Results

As was found by Yang et al. (2014), Jules performed poorly at Lauder, Balclutha, Ranfurly, and Middlemarch, due to possible lateral soil water flow present at the 4 sites (Fig. 1). Using MOS, the simulated soil moisture at these sites was significantly improved. The biases in simulated soil moisture at these sites due to possible lateral soil flow present but not considered in the model were significantly corrected. In terms of mean absolute difference (MAD) and biases (Fig. 2), MOS-SN and MOS-cdf are very close with the former slightly better than the later.

The corrected soil moisture by MOS-cdf are always within the observation ranges. However, for MOS-SN, occasionally the corrected soil moisture is higher (lower) than the observation maximum (minimum). MOS-cdf is better than MOS-SN in this regard. Thus, in the application, it is recommended to use both methods.

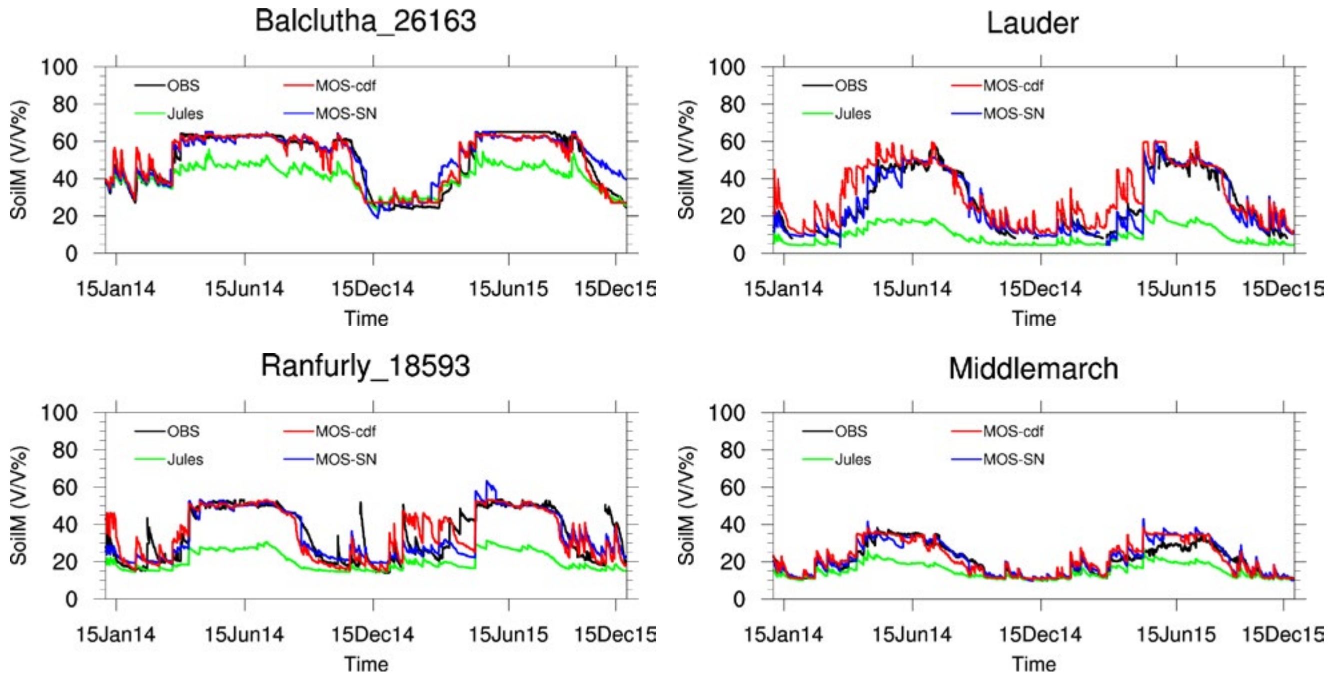

Figure 1: Observed (OBS) and simulated (Jules) soil moisture volumetric content using hourly driving data, and the MOS corrected soil moisture using MOS-cdf and MOS-SN.

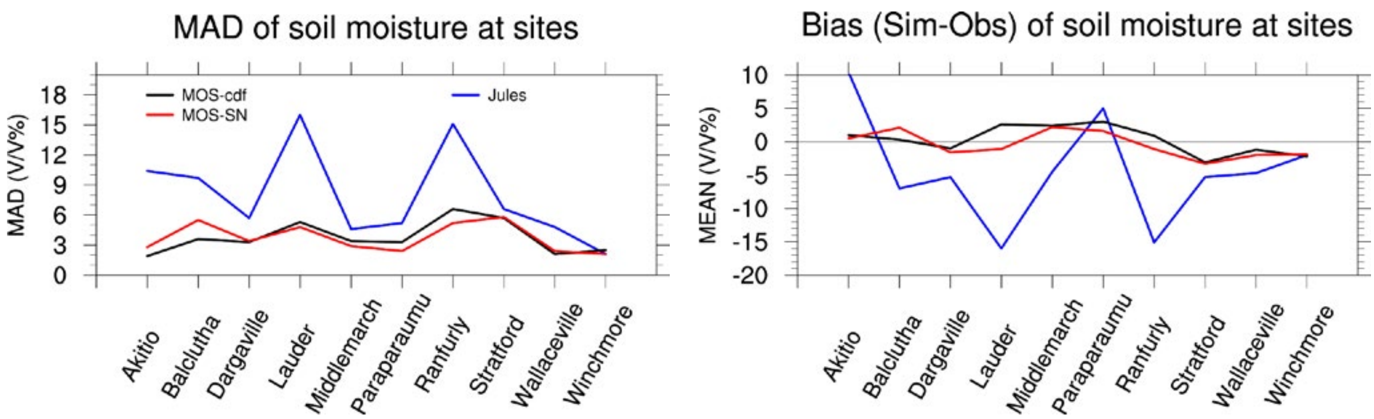

Figure 2: Mean absolute difference (MAD) between observed and simulated soil moisture and the biases (simulation – observations) during 1 January 2015 to 31 December 2015 for Jules simulations (Jules), and the MOS corrected soil moisture using MOS-SN and MOS-cdf.

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HYDROCHEMISTY OF GROUNDWATER IN DUNEDIN, NEW ZEALAND

Yeo, S,[1] Cox, S.C,[2] Mager, S[1]
[1] University of Otago
[2] GNS Science

Aims

The aim for this study is to understand the hydrochemistry of the shallow coastal aquifer in the low-lying areas of Dunedin, New Zealand. Through the analysis of water samples extracted from the different bores distributed across the aquifer, a hydrochemical signature can be used to derive the original sources of the water and inform the dynamics of the subsurface water transport in the aquifer. Understanding the sources of water in the aquifer is needed to develop an informed strategy to combat the issue of surface flooding in South Dunedin, which is linked to the storativity of the underlying aquifer. Additionally, analysis will be undertaken of the South Dunedin aquifer and harbourside margin of Dunedin to determine its vulnerability to the effects of coastal intrusion and saturation from permeating surface water.

Method

Water samples have been collected from 22 bores bi-monthly since March 2019. The samples have been analysed for *E. coli* concentration, stable isotopes (^{18}O and ^{2}H), total alkalinity, major cations & anions, and minor chemistry, including indicator trace heavy metal species, including total dissolved iron, strontium, aluminium, and manganese. During sample collection, in situ measurements for water depth from the surface (DTW), specific electrical conductance ($\mu S\ cm^{-1}$), pH, and temperature (ºC) were recorded at each bore during sampling. Additional samples were collected from possible source waters, including: municipal supply drinking water, raw effluent from the Tahuna waste water plant, sea water from St Clair beach, harbour water from Anderson's Bay, storm water outfall, rain water, spring water from Speights brewery, surface water from the Water of Leith, and percolated water within the historic Caversham rail tunnel.

Results

The preliminary results of this study indicate a pronounced saline intrusion into the South Dunedin aquifer, and a freshwater composition to the harbourside aquifer in central Dunedin, which lies in a band of industrial land use on reclaimed land. The pattern of saline intrusion is variable with distance from the coast or harbour, meaning there are other factors that likely drive the occurrence of saline intrusion into the aquifer.

The effect of heavy rainfall events causes a rapid increase in groundwater level and has the potential to exacerbate the effects of infiltration excess overland flow during extreme events. This effect is due to the relatively low water storage capacity of the aquifer due to its typically high water table that occurs year round. However, little is known about the main sources of water that drive the response in water table – is the water saline and is it connected to marine processes and coastal intrusion, or are there pulses of freshwater that displace the sea water within the aquifer during high rain events? To explore this further, we observed the profile of salinity down 6 bores prior to a rain event, and then 96 hours later following two days of significant rainfall (40 mm).

There were notable differences in the conductivity of bore water before and after a rainfall event. The most evident differences are an expected dilution post rainfall (Fig 1b). Freshwater lenses were typical at the uppermost portion of the water level. However, lenses of freshwater occurred at the top or bottom of the bore, or in some instances, both (Fig 1a). The responses shown in this figure give an indication of areas within the aquifer that are more affected by rain events, and suggest that in some locations lenses of freshwater occurred below the saline water, despite lower fluid densities. It is suggested that these fresh water incursions into the bores are short-lived as the fluid densities will gradually cause the saline waters to displace freshwater at the bottom of the bores. However, further work is needed to determine the range of freshwater displacement within the groundwater that follows rain events.

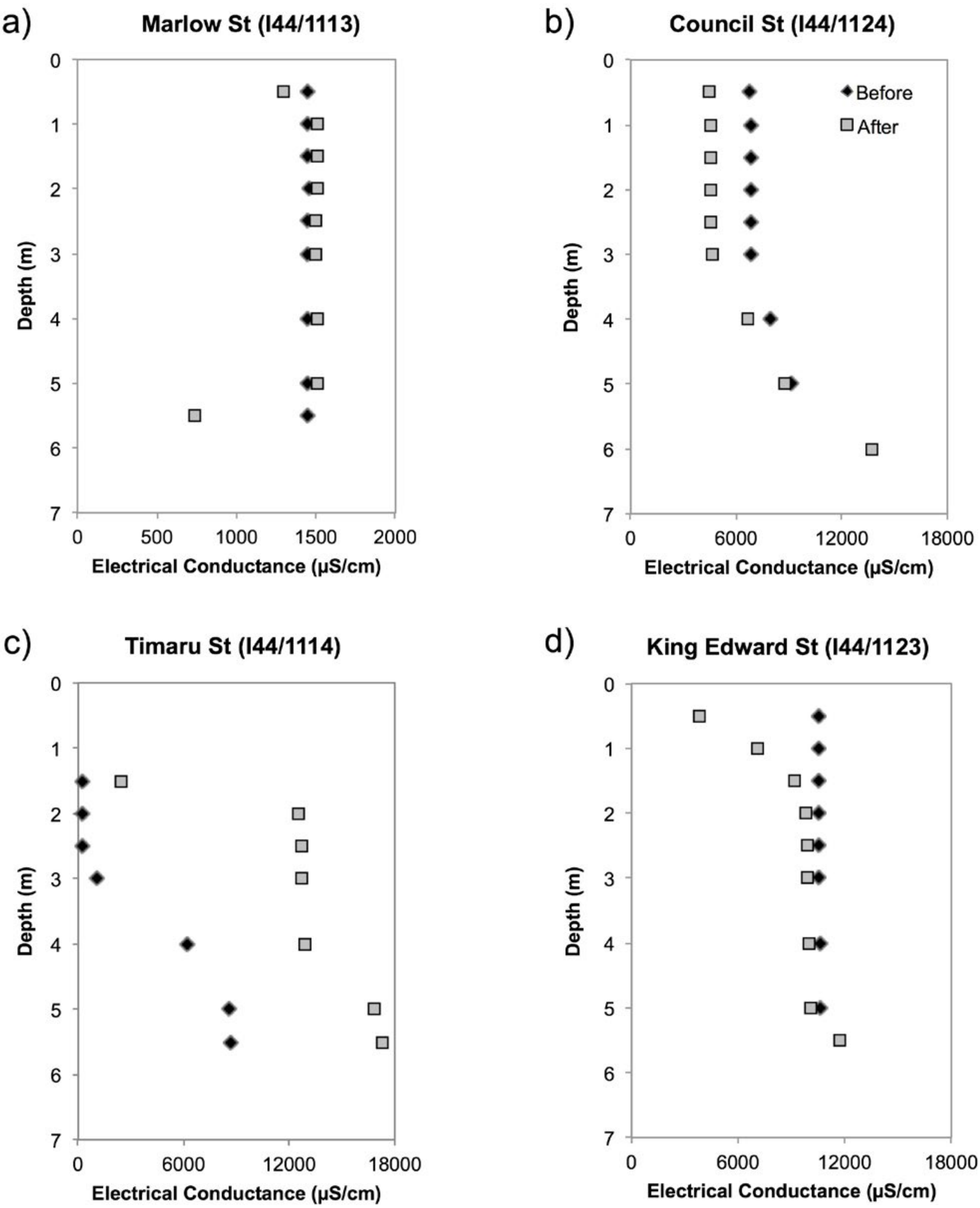

Figure 1: Specific electrical conductance of bore water from four sites in Dunedin before and after a rainfall event.

SNOW WATER EQUIVALENT AT NIWA'S SNOW AND ICE NETWORK SITES - CHALLENGES FOR SNOW MODELS

Christian Zammit,[1] Ambre Bonnamour,[1,2] Lucas Loumy,[1,2] Jono Conway,[3]
[1] NIWA Christchurch
[2] École Polytechnique Universitaire de Montpellier
[3] NIWA Lauder

Aims

Understanding and modelling snow cover dynamics in the Southern Alps of New Zealand is an important step towards quantifying the effects of the snowpack on stream hydrology and how these may change in a future climate. Along with potential effects on steam ecology, changes in the timing and magnitude of snow storage and melt may have economic and social implications in catchments with hydro-electric generation and abstraction for irrigation and other uses.

Method

NIWA's Snow and Ice Network (SIN) was designed to fill gaps in the climate network at high-altitude areas and provide the information needed to improve our understanding of snowpack dynamics in the Southern Alps. This work presents collated timeseries of snow water equivalent (SWE) at six SIN sites over the period 2007-2018 and discusses the challenges associated with modelling SWE at these sites. The sites cover a diverse range of alpine environments from Fiordland to Nelson Lakes and from 1140 m to 2000 m above sea level (Figure 1). Along with standard meteorological variables, at each site, a snow pillow provides continuous measurements of the SWE stored in the snowpack.

At each site, SWE is simulated using two different snowpack models. The first is a conceptual temperature-index model developed by Clark et al. (2009) that parameterises the rate of snowmelt as a function of season, days since the last snowfall and occurrence of rainfall. The second is an enhanced temperature index (ETI) model developed by Pellicciotti (2005) and recently adapted for New Zealand conditions by the Deep South 'Icey' project. Snowmelt in the ETI model depends on both air temperature and incoming solar radiation, as well as a time-varying surface albedo that controls the amount of solar radiation absorbed by the snowpack. The models were driven with combinations of climate data from the site and gridded climate data (Virtual Climate Station Network; VCSN (Tait et al., 2006)).

Figure 1: Snow and Ice Network site at Mt Larkins, 24th June 2016.

Results

Both models show variable performance for the period of snow accumulation at each site, which largely reflects uncertainties in the precipitation and temperature data used as input, as well as the unresolved processes such as preferential deposition and redistribution of snow by wind. Simulations using climate input from the historical period of regional climate model runs were also compared to average timeseries of SWE at each site

Timeseries of snow water equivalent from NIWA's SIN network provide a unique and valuable opportunity to understand and quantify snowpack dynamics in the Southern Alps. Future efforts to model the snowpack will be aided by improvements in the precipitation and radiation data available at the sites along with efforts to simulate more of the physical processes that control snow accumulation and melt in these environments.

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