Tuesday, 1st of December

Session: Climate, Start Time: 10:00 a.m.

ANALYSING TRENDS IN CLIMATE PROJECTIONS FOR MONTHLY MAXIMUM SUB-DAILY PRECIPITATION ACROSS TASMANIA

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Aims

Climate change impacts on the distribution of sub-daily precipitation will affect flooding and the future performance of stormwater assets and other infrastructure, particularly in ‘flashy’ urban catchments. The focus of research in Tasmania to date has largely been on daily precipitation data. Tasmania has many natural and regulated catchments with critical durations ranging from a few minutes, to at most a few hours (Willems et al., 2012). There is a need for greater understanding of climate change impacts on precipitation data with greater temporal and spatial resolution. The design and ongoing operations and maintenance of assets, particularly in an urban context, places special requirements on climate change impact studies and the data that informs them (Willems et al., 2012, Arnbjerg-Nielson et al., 2013).

Trend analysis has been undertaken to ascertain climate change effects at a local level on 3-hourly precipitation data extracted from six dynamically downscaled global circulation models (GCMs). Preliminary conclusions have been drawn as to the impact of changes in sub-daily precipitation resulting from climate change over the period 1961 to 2100 across the entirety of the state of Tasmania (ACE CRC, 2010).

Method

Only a limited number of GCMs and emissions scenarios could be evaluated due to time constraints. Six GCMs for the A2 SRES emissions scenario were evaluated as a part of this study. Climate models have been selected based on their skill at simulating the present climate as this is a useful indicator as to GCM performance (ACE CRC, 2010). The six GCMs selected for this study were chosen by the ACE CRC (2010) based on their ability to reproduce present-day precipitation means and variability across Australia. The six GCMs that have informed this study are CSIRO-Mk3.5, GFDL-CM2.0, GFDL-CM2.1, ECHAM5, MIROC3.2(medres), and UKMO_HadCM3.

GCMs have a spatial resolution of between 200 and 300 km along their horizontal and vertical axes. At this resolution, GCMs poorly simulate the highly heterogeneous climate conditions across Tasmania (Brown, Bennett, Parkyn & Link, 2010). It is imperative that GCMs be downscaled to improve the spatial resolution of the results and to capture localised weather patterns and topography.

Data used in this study has been quality checked to ensure that the simulated spatial and temporal patterns are as expected. Where observed precipitation data is available, the observed precipitation record has been compared with the simulated record for the period 1961-1990. The ACE CRC has thoroughly checked the 24-hour precipitation data that is comprised of the three-hourly dataset used in this study. Checks undertaken by the ACE CRC (2010) included: comparing downscaled model outputs with raw outputs from the global climate model to ensure consistency against large-scale climate variables; comparing downscaled simulated data to the observed data; checking internal consistency of climate drivers to ensure large-scale pressure patterns and ocean effects are correct; examining climate change drivers to ensure consistency with current understanding of climate change; and using climate modelling outputs as inputs to a range of biophysical and hydrological models.

Removing serial correlation from data is an important step in trend analysis to ensure that results are reliable and not unduly impacted by serial correlation contained within the data. Pre-whitening was used to remove serial correlation from the dataset. ARIMA models were fitted to the ECHAM5 sub-daily monthly maxima precipitation series to remove serial correlation and seasonal trends. This fitted ARIMA model was then applied to the remaining five GCMs to produce 36 pre-whitened datasets. LOWESS and kernel smoothing functions were applied to the pre-whitened dataset. Kernel smoothing and LOWESS smoothing techniques have been used to test for the presence of step-trends in the dataset. Agreement between the six GCMs has been analysed to allow for discussion of uncertainty between climate models.

Results

There is a general agreement at the regional scale between the six GCMs as to where decreasing and increasing trends are likely to occur in the intensity of three-hourly monthly maximum precipitation. Figure 1 demonstrates the agreement between GCMs in predicting trends in sub-daily precipitation data for kernel and LOWESS smoothed sub-daily monthly maximum precipitation.

Figure 2 below shows percent change in the intensity of sub-daily precipitation across the state. Increasing trends are observed on the west and east coast of the state, whereas declining trends are observed in the central plateau region of Tasmania. Changes in the distribution of precipitation will result in ecological, social and economic challenges for Tasmania. Where increasing trends in sub-daily monthly maximum precipitation are projected it is important to evaluate how increased flood risk and associated water quality impacts can be managed into the future.

Future analysis using other emissions scenarios will likely improve confidence in the results and allow for a greater understanding of changes to the spatial and temporal distribution of precipitation across the state. Future work should aim to link these results to average recurrence intervals. This would improve the accessibility of the results and enable them to be readily used to optimise the design and management of assets sensitive to changes in the intensity, frequency and duration of short duration precipitation events.

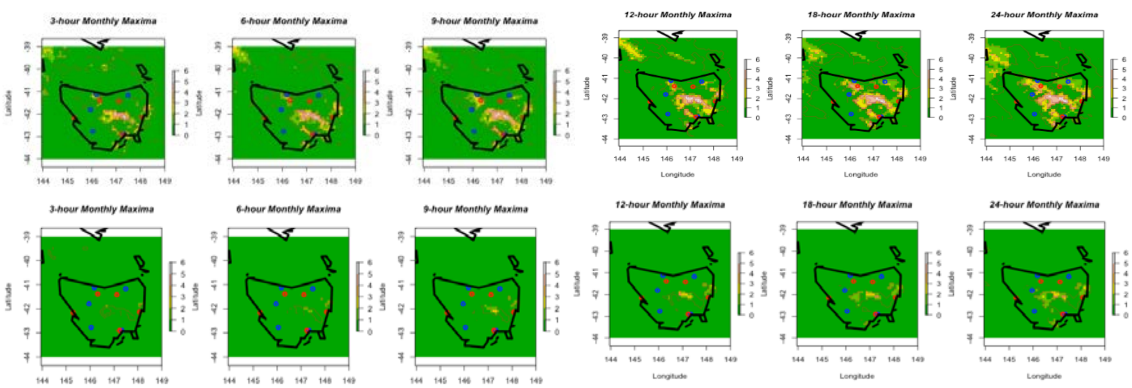
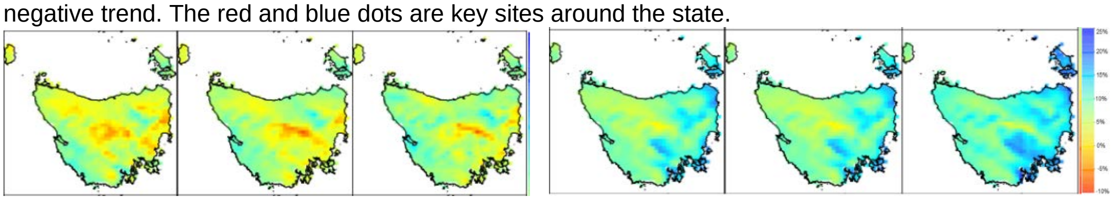


Figure 1 Agreement between GCMs as to the presence of an increasing or decreasing trend for the LOWESS (upper row) and kernel smoothed (lower row) mean sub-daily precipitation with durations ranging from 3 hours to 24 hours between the baseline period and the end of the 21st century. The colour bar ranges from zero to six, where six indicates that all six GCMs have predicted a negative step-trend and zero indicates that no GCM has predicted a negative trend. The red and blue dots are key sites around the state.



(a) (b) (c) (d) (e) (f)

Figure 2 Multi-model mean percent change in the intensity of the kernel and LOWESS smoothed 5th, 50th and 95th percentile 3-hourly monthly maximum precipitation between the baseline period (1961-1990) and the end of the 21st century (2070-2099). Mapped results are as follows: a) LOWESS Smoothed 5th Percentile b) LOWESS Smoothed Mean c) LOWESS Smoothed 95% Percentile d) Kernel Smoothed 5th Percentile e) Kernel Smoothed Mean f) Kernel Smoothed 95% percentile.

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ESTIMATING POTENTIAL EVAPOTRANSPIRATION OVER SNOW TUSSOCK GRASSLAND IN CENTRAL OTAGO

Ms Florence Isaacs[1], Dr Daniel Kingston[1], Dr Sarah Mager[1]
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Aims

The calculation of potential evapotranspiration (PET) is a fundamental part of water balance studies and hydrological modelling, but one which remains highly uncertain due to the many different, and often unreliable, means used to obtain it. Approaches vary depending on the environment, available data, and purpose of use, and the significant effect of method choice on final estimations of PET necessitates careful consideration over the most appropriate method for a given situation. Efforts to determine an accurate water balance are limited by the uncertainties in estimating PET and this is exemplified in Central Otago, New Zealand, where the significance of upland snow tussock (*Chionochloa rigida*) for enhancing water yield is proposed to sustain higher water flows to downstream catchments. The aim of this study is to determine the most accurate approach for estimating PET over upland snow tussock in Central Otago, to reduce uncertainty in hydrological modelling and water balance studies in snow tussock catchments.

Method

PET was calculated at a daily resolution using meteorological measurements made at Timber Creek, Central Otago, over a four week period. Five different PET methods were used; Penman-Monteith, Priestley-Taylor, Hargreaves, Hamon, and Turc. Estimates of PET were compared to one another, and assessed for accuracy through comparison with actual measured evapotranspiration (ET) determined using eddy correlation from flux measurements made over the same period.

Results

A comparison of the different PET estimates shows considerable variation in method performance, indicating that uncertainty in its calculation remains; and is likely to be translated to its application in hydrological modelling. Overall, the Penman-Monteith method has the closest relationship with eddy covariance measurements, and an original tendency to overestimate ET by around 30% was resolved through the application of a reduced crop coefficient (Kc) of 0.2. ET at the study site is predominantly driven by temperature, radiation and relative humidity, and the strong performance of Penman-Monteith reflects this, being the only method that accounts for all three of these variables. In contrast, the simpler temperature-based PET equations, which demonstrated weaker correlations with ET, can only account for changes in PET when driven by temperature, and thus fail to capture any of the fluctuations driven by radiation and relative humidity. However, method accuracy was shown to be strongly influenced by meteorological conditions, exemplified by days with snowfall and subzero temperatures, during which accuracy of all five methods was substantially reduced and Hargreaves and Hamon demonstrated the greatest match with ET; reinforcing the need to carefully select a PET estimate that best approximates the field conditions of the study site.

Session: Soil / Vadose Zone Hydrology, Start Time: 10:00 a.m.

HYDROPHOBICITY - A CONCERN FOR HYDROLOGICAL MODELLING?

Dr Karin Müller[1], Mrs Karen Mason[1], Dr Robert Simpson[1], Mr Carlo van den Dijssel[1], Mrs Charlotte Robertson[1], Dr Brent Clothier[1]

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Introduction and aims

Hydrophobicity or soil water repellency (SWR) is a surface condition that reduces the affinity of soil to water. It causes water infiltration rates to decrease, rain or irrigation water to pond on soil surfaces, time to the start of runoff to decrease, and runoff rates and volumes to increase. It is a transient soil property and its prediction is challenging mainly because we do not understand its ecological significance and root source. Some research showed that the degree of SWR was positively correlated with soil water content, and the concept of a site- and soil-specific critical water content was introduced (Dekker et al. 2001). But other authors have reported that SWR varied non-linearly with soil water contents (de Jonge et al. 2007). In addition, the expression of SWR is also highly variable at the micro-scale (Hallett et al. 2004) as well as at larger scales (Regalado and Ritter 2006). A lot of research has been directed at investigating potential causal relationships between SWR and other soil properties including texture, pH, bulk density, mineralogy of the clay fraction, organic carbon content and quality, and microbiological community composition (Doerr et al. 2007). In addition, the unambiguous isolation of the effects of SWR on water dynamics in soils from other hydrological parameters is extremely difficult. In particular, its effects on runoff and solute loss have been only poorly quantified. Our aims were thus to directly quantify the effects of SWR on runoff and phosphorus (P) losses at a hillslope site, and to measure how SWR changes sorptivity and infiltration dynamics over seasons.

Method

For this purpose, we conducted runoff experiments with our runoff measurement apparatus (Jeyakumar et al. 2014) on a severely water-repellent pastoral Pumice Soil in the laboratory and field (Fig. 1). Prior to all experiments, superphosphate was applied at 45 kg P/ha to the pasture to quantify the potential risk of fertilizer loss. To isolate the effect of SWR from those of other potential hydrological parameters, we sequentially simulated run-on with two liquids (i) water and (ii) aqueous ethanol (30% ethanol, v/v, as a reference fully wetting liquid), to the same intact soil slab in the laboratory, with air-drying to the initial water content between the two events. In the field, we compared results of runoff experiments conducted in parallel on adjacent fields with the same two liquids. We analyzed the runoff response to 60-min long runoff events (60 mm/h) from (i) air-dried undisturbed slabs in the laboratory (0.08 m^2, Fig. 1a), and (ii) field plots of 0.5 m^2 (Fig. 1b). We used the same principle to isolate the effect of repellency from other soil parameters on sorptivity and infiltration by measuring water and 30% ethanol infiltration into intact soil cores with our fully automated solute transport apparatus (Fig. 1c). A tension disc infiltrometer applied the liquids to the top of a core of 10-cm diameter at -50 kPa tension for the water experiments. The tension was adjusted for the experiments with ethanol taking into consideration the solution's specific density and surface tension. We determined the degree and persistence of SWR prior to the start of all experiments using the molarity of ethanol droplet (MED) and the water drop penetration time test (WDPT), respectively (King 1981).

Figure 1: Our runoff measurement apparatus (ROMA) operates with intact soil slabs of 0.08 m^2 in the laboratory (a) and at the 0.5 m^2-plot scale in the field (b). To determine sorptivity and hydraulic conductivities of repellent soils we use our fully automated solute transport apparatus (SOLO) (c).

Results

In our laboratory runoff experiments with ethanol no runoff occurred. The final drainage coefficient was around 80% (Fig. 2a). These measurements demonstrate the soil's runoff behavior under hydrophilic conditions. In the water experiments, the high persistence of SWR was reflected in a runoff coefficient of about 80% throughout the 1-h runoff experiments. Drainage started after approximately 30 min, and stayed below 10% of the water rate applied (Fig. 2b). Dissolved reactive phosphorus (DRP) concentrations in runoff samples were highest in the first sample and decreased exponentially with time (Fig. 2c). In total, 18 ±6.9% and 1.5 ±0.1% of the applied P were lost as DRP in runoff and drainage, respectively. The field experiments confirmed that SWR increased runoff and P losses (Fig. 3). About 19.3 ±5% of applied P was lost as DRP in runoff. The field runoff coefficients were generally lower than those measured in the laboratory reflecting the increased likelihood for water to re-infiltrate into the soil along the longer plots. The infiltration experiments are on-going. We conclude that SWR is an important factor in hydrological modelling and should be included in models to address appropriately this increased risk of surface water contamination by solutes exogenously applied to water-repellent soils.

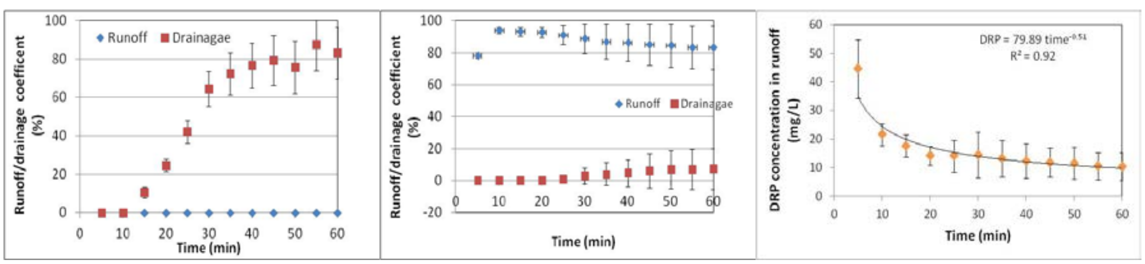

Figure 2: (a) Runoff and drainage coefficients in lab experiments with 30% ethanol. Initial average soil water repellency (SWR) characteristic of the slabs: Persistence of SWR measured by the water drop penetration time test: $WDPT_{act}$ = 6267 ± 2135 s; $WDPT_{pot}$ = 9800 ± 1470 s; Degree of SWR measured by the molarity of the ethanol droplet test MED: 102.5 ± 0.6° (b) Runoff and drainage coefficients in preceding experiments on the same slab with water. Initial conditions: Persistence of SWR: $WDPT_{act}$ = 7867 ±3137 s; $WDPT_{pot}$ = 10333 ±4382 s; Degree of SWR: 102 ±1.2° (c) Dissolved reactive phosphorus (DRP) concentrations in runoff. All results are averaged over three slabs. Bars represent standard deviations of the means.

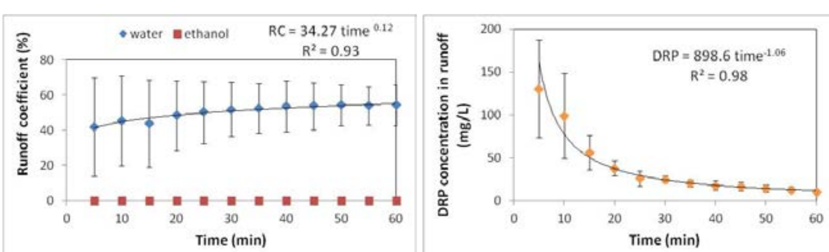

Figure 3: (a) Runoff and drainage coefficients in field experiments with 30% ethanol (initial average SWR characteristic of the plots: Persistence of SWR: $WDPT_{act}$ = 4950 ±5224 s; $WDPT_{pot}$ = 9300 ±2235 s; Degree of SWR:

102.8 ±1.6°) and water (initial average SWR characteristic of the plots: Persistence of SWR: $WDPT_{act}$ = 1117 ±723 s; $WDPT_{pot}$ = 6750 ±995 s; Degree of SWR: 102.7 ±1°. (b) Dissolved reactive phosphorus (DRP) concentrations in runoff. All results are averaged over three plots. Bars represent standard deviations of the means.

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TILE DRAINAGE: POTENTIAL RESEARCH DEMANDS AND OPPORTUNITIES

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Artificial drainage, either tile drain, mole drain or open channel drain, is a common practice to improve the aeration condition of the soil for agriculture. Before human intervention, about 20% of New Zealand soils were wet, concentrated mostly in Northland, Waikato, Canterbury and Southland. Fig 1 shows an overview of the concentration of artificial drains in Waikato, New Zealand. With around 2 million ha of poorly or imperfectly drained soils in New Zealand, artificial drainage plays a very important role in improving the agricultural productivity of New Zealand. However, the effects of artificial drainage on regional scale surface water and groundwater flows and quality are not addressed adequately in the literatures.

In this study, six specific beneficial roles of artificial drainage are distinguished: soil productivity, flood control, soil erosion, pesticide control, sustainable irrigation land use and reduction in contaminants (e.g. phosphorus, potassium, organic nitrogen and ammonium losses). On the other hand, increased nitrate leaching to surface water is considered as the main disadvantage of the tile drainage practises. Moreover, it is concluded that a combination of tile drainage with good drainage management practises such as regular monitoring of tile drainage outlet, controlled drainage and sub-irrigation may hugely reduce the volume of nitrate leached via tile drains.

Furthermore, some potential tile drainage research demands for New Zealand are suggested: understanding the hydrological effect of tile drainage on catchment and regional scales, understanding the effect of tile drainage practise on the regional groundwater system, the needs of changing tile drainage designing criteria from quantitative to qualitative criteria, opportunities of reusing the drainage water, and the role of the tile drains on the irrigation projects sustainability.

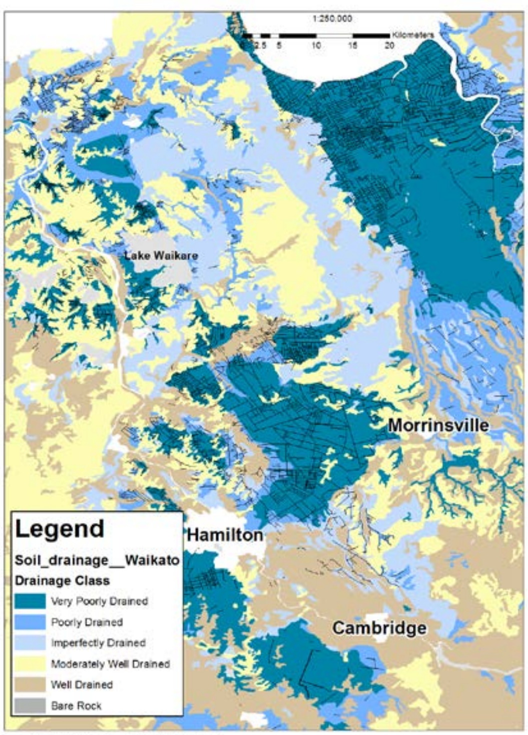

Fig1 Overview of the concentration of artificial drains in Waikato region

Session: Transport and Transformation of Contaminants, Start Time: 10:00 a.m.

THE LIFE AND TIMES OF THE BURWOOD LANDFILL, CHRISTCHURCH

Dr Hugh Thorpe[1]
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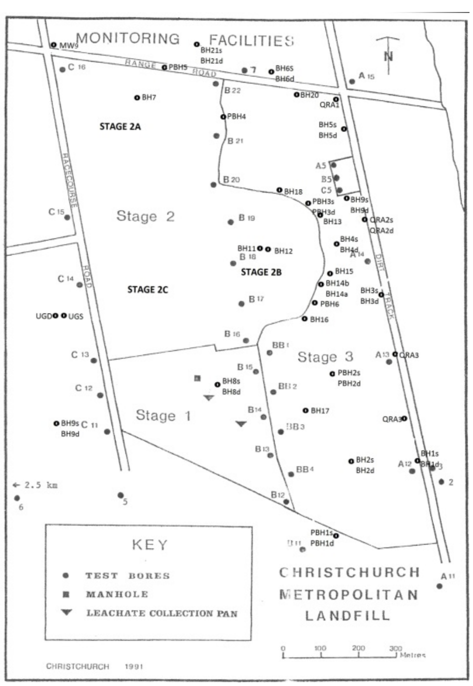
The Burwood landfill site is within 10km of central Christchurch, behind the sand dunes, only a few hundred meters from the coast at North Shore. Filling began in July 1984 and continued until July 2005. Annual fill rates were 210,000-260,000 tonnes/year of non-putrescible waste. The fill footprint is about 55ha.

The soil at the site is a medium marine sand up to 40m thick overlying the Riccarton gravel aquifer which is flowing artesian. A shallow unconfined water table exists within the sand and in fact surface water sits in the depressions. There is no lining beneath the fill and the prior available piezometric information suggested that the leachate would flow slowly towards the coast and be dispersed in the surf.

Conditions attached to the consent require groundwater monitoring to check the leachate plume and 60 monitoring bores were sunk, mostly 3-5 metres deep but with a few ranging down to 15 metres. One or two bores now have 30 years of record and monitoring continues to the present and the very large body of data is the source of information presented here.



The landfill site showing the monitoring bore array (modified from Close, 1991)

Broadly speaking the leachate plume behaved much as expected i.e. moving on an angle towards the coast but at a somewhat slower rate than calculated prior to filling beginning (Hunt and Young, 1980). The landfill footprint is so large that it is difficult to calculate the pore velocity because filling was progressive in four very large cells so defined points of origin for the leachate cannot be determined. It is however possible to discern two plumes, one originating at each end of the site and pore velocities were calculated from the times of first and peak arrival at pairs of observation bores along the line of maximum observed concentrations. Given that the filling of each cell took several years there were, in many cases, several peaks and it is probably more reliable to calculate velocities from the times of first arrivals. Velocities calculated from first arrivals are in the range 25-40 metres per year.

Many analytes travelled well enough in this environment to be used as tracers but total alkalinity seemed to generally travel slightly faster and most clearly and will be used to illustrate ground water behaviour. Numerous organics were analysed but results were generally below the limit of detection. Exceptions were vinyl chloride and bromo fluoro benzene occasionally, in a few bores at very low levels. The leachate penetrated the sand to significant depth e.g. 8-10m below ground, possibly driven by mounding of leachate beneath the filled cells.

Presumably leachate generation built up, maintained a level and then tapered off but this is not always reflected in the breakthrough curves many of which show the classic shape of growth and decay back to low levels. Others curves displayed sustained elevated values suggestive of lengthy periods of leachate generation. Double peaks could be an indication of adjacent plumes merging sideways.

Given the 30 years of rain falling on the area since filling began a significant amount of groundwater recharge must have occurred. Assuming a 600mm annual rainfall, 100mm recharge and 40% porosity an annual thickness of 250mm of sand would be saturated. Some will have flowed coastward but over 30 years this could have filled a significant thickness of aquifer with fresh water and may have depressed the leachate plume below water table. There is some suggestion that this could be true in that concentrations in a few deeper bores are higher than in adjacent shallow bores but the evidence is not conclusive.

Extrapolating from the plotted contours using the velocities calculated it would seem that the leachate plume is now at or close to the coast. This is of no great significance as the concentrations are low, the flow rate slow and the dispersion by the surf and long-shore current would be enormous.

The data used in this paper is publically available and was obtained by URS on contract to the Christchurch City Council.

References

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2014 NATIONAL SURVEY OF PESTICIDES IN GROUNDWATER

Murray Close[1], Bronwyn Humphries[1]
[1]*ESR, Christchurch, New Zealand*

Aims

In 2014 ESR co-ordinated a survey of pesticides in groundwater throughout New Zealand, which was the seventh such survey since the 4-yearly surveys commenced in 1990. The aims of the survey were to update the national overview of pesticides in NZ groundwater systems and to investigate temporal variation in pesticides between surveys.

Method

The well sampling was carried out by Regional and Unitary Authorities, generally between October and December 2014. The Waikato Regional council provided results for an additional 40 wells that had been sampled as part of their regional survey in 2012. These results have been included in this report to give a national perspective. Samples were analysed for acidic herbicides and a suite of organochlorine, organophosphorus and organonitrogen pesticides by AsureQuality. Wells were selected on the basis of the importance of each aquifer to the region, the application or storage of pesticides in the area, and the vulnerability of the aquifer to contamination, recognising that shallower, unconfined aquifers would be more at risk than deeper aquifers. If possible, where a well had been sampled for previous surveys, it was also included in this survey to give a temporal comparison. The majority of the selected wells were from unconfined aquifers.

Results

There were a total of 165 wells sampled including the 40 wells from the Waikato Regional Council. There were 28 wells (17%) with pesticides detected, with 10 of these wells having two or more pesticides detected. The maximum number of pesticides detected in one well was seven. There were one or more wells with pesticides detected in 6 of the 13 participating regions. Pesticides were not detected in sampled wells from Hawkes Bay (12 wells), Taranaki (5 wells), Horizons (23 wells), Greater Wellington (11 wells), Marlborough (17 wells), Canterbury (5 wells), and Otago (8 wells). Twenty one different pesticides were detected in this survey. Herbicides were the most frequently detected pesticide group with 4 insecticides and 2 fungicides also detected. There were 31 detections (61%) of triazine herbicides with terbuthylazine being the most frequently detected pesticide (16 detections). There were four pesticide detections exceeding 1 mg m^{-3} with only one of the sampled wells exceeding the maximum acceptable value (MAV) for drinking water. Dieldrin was detected at a concentration of 0.043 mg m^{-3} which was slightly in excess of the MAV of 0.04 mg m^{-3} (Ministry of Health 2008). The next highest detection relative to the MAV was for terbuthylazine at 17% of the MAV (Table 2) with the remainder of detections being less than 5% of the MAV.

Of the 101 wells that had been sampled on 4 or more surveys, using the sum of all pesticides detected as the comparison measure, 55% of wells had no pesticides detected for any of the surveys, 7% of wells showed an increasing trend, 8% of wells showed a decreasing trend, 20% showed a mixture of pesticides being detected and not detected with no trend, and 10% of wells had positive detections of pesticides for each survey sampled but with no trend. This indicates that the detections of pesticides is similar to previous surveys with no overall increasing or decreasing trend in totals levels of pesticides detected.

This information, combined with the similar levels of detections in the last four surveys, indicates similar levels of pesticide detections in groundwater over the last 12 years, with higher levels of detections before that time. The majority of wells sampled in each national survey have detected no pesticides and the concentrations of pesticides detected are mostly very low.

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Session: Irrigation, Start Time: 11:00 a.m.

WHAT DOES OPTIMISING THE SYSTEM CAPACITIES FOR IRRIGATION SYSTEM ACHIEVE?

Dr Channna Rajanayaka[1], Dr Greg Barkle[1], Mr Andres Jaramillo[1], Dr Edmund Brown[2]
[1]Aqualinc Research Ltd, Hamilton, New Zealand, [2]Waikato Regional Council, Hamilton, New Zealand

Introduction

Most water resources, particularly the more easily available surface waters, are highly allocated in many regions in New Zealand. Demand for water has intensified over the past decade at a phenomenal rate with the irrigated area in New Zealand estimated to have nearly doubled between 2000 and 2010 (Aqualinc, 2010). The critical period for managing water resources is in the summer months; stream flows and groundwater levels are at their lowest, and demand is highest for seasonal uses such as irrigation. Irrigation water is allocated in many regions with the emphasis on managing annual volumes, i.e. the total allowable volume allowed to be extracted over an irrigation season (m^3/year). These annual volumes are often calculated using an arbitrary “daily irrigation system capacity” of between 4 to 5 mm/day, considered to be appropriate to meet crop water demand. The system capacity is the minimum depth of water that an irrigation system must apply to be able to meet the plants water requirements without reducing yield. Due to soil water storage, the system capacity is less than the peak daily evapotranspiration requirement; however the key question is “how much less can it be”?

What is often overlooked are the ramifications for how the system capacity is used in resource allocation. The total allocable resource from run-of-stream is determined to be an instantaneous flow rate (i.e. l/s or m^3/s). This total allocable resource must not be less than the cumulative sum of the system capacities for all of the irrigators (and other users) that wish to use the resource. Therefore, the system capacities determine how many irrigators can use a resource and the area that maybe irrigated from a resource. Consequently, it is essential to optimise the system capacity to ensure that the maximum area can be effectively irrigated and thereby capture the full economic benefits from the available resource.

This presentation will demonstrate the advantages of optimising irrigation system capacities for achieving the best economic, social and environmental outcomes for a region. Additionally, it will show the effects of using ‘arbitrary’ system capacities on annual irrigation water volumes required and on drainage losses.

Method

Most resource consent applications for pastoral irrigation within the Waikato region are designed to apply a daily application depth of 4 mm/day. In Canterbury, the arbitrary system capacity is 5 mm/day or more. In this example we have modelled five different locations within the Waikato region and one location in Culverden, North Canterbury to determine what the optimum system capacities, annual volumes and drainage losses are.

A plant available water (PAW) of 100 mm for a plant water extraction depth of 600 mm has been modelled, using Aqualinc’s Irricalc soil-water balance model, for all six scenarios. A minimum irrigation return period of 7 days is used with the irrigation trigger point being a soil-water deficit of 40 mm. A Christiansen’s uniformity coefficient (UCC) of 70% has been applied in all cases. The modelled irrigation season is September to May. Daily climate data for the Waikato scenarios was obtained from NIWA’s virtual climate stations (VCS), and modelled from 1 July 1972 through to 30 June 2014. For Culverden, rainfall data from VCS P136096 and potential evapotranspiration data from Culverden recorder station, with gaps filled using Christchurch Airport data, was used. The modelled period for Culverden is from 1 July 1972 through to 30 June 2013.

In order to determine the irrigation water requirements, it is necessary to establish the criteria that the irrigation system must meet. The decision criteria used for this example are:

1. 90% of the time soil-water content should be more than 50% of PAW; and
2. 99% of the time soil-water content should be more than 25% of PAW.

The arbitrary daily system capacities of 4 and 5 mm/day were modelled for the Waikato locations and for Culverden, respectively. The system capacity for each scenario was then optimised by gradually reducing the arbitrary value until the lowest system capacity was determined that did not break either of the above two criteria.

Results

The difference between the arbitrary system capacities and the optimised values are shown in Table 1. This shows that, on average over all of the sites, a reduction of 21% in the system capacities can be achieved by optimisation.

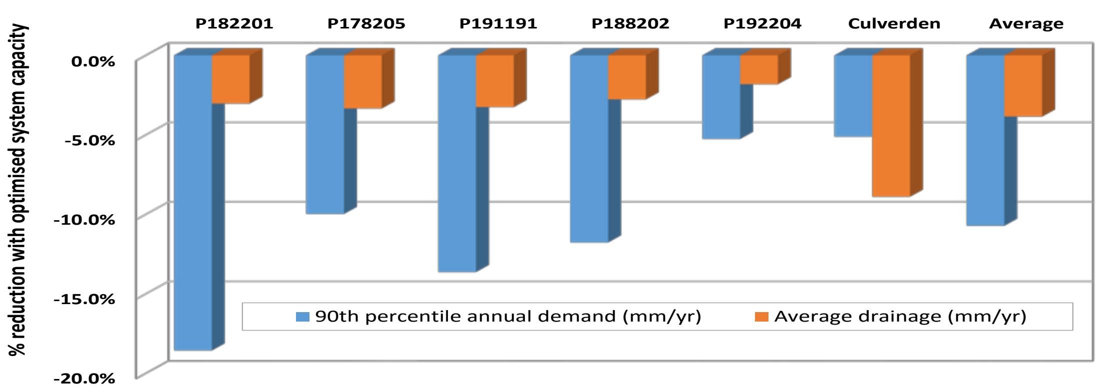
Table 1: Change in system capacities for the arbitrary and optimised approaches

System capacity	P182201	P178205	P191191	P188202	P192204	Culverden	Average
Arbitrary (mm/d)	4	4	4	4	4	5	
Optimised (mm/d)	2.8	2.9	3	3.3	3.6	4.1	
Percentage reduction	30%	28%	25%	18%	10%	18%	21%

As the system capacities are lowered, the areas irrigated can be increased for a given water resource allocation. For example, at P182201 in the Waikato region, the irrigated area can be increased by 43%. For water-scarce Culverden, 22% more area can be irrigated if the optimised system capacity approach is used.

Figure 1 shows that 90th percentile annual volume with the optimised system capacity is on average 11% lower that with the arbitrary system capacity, and drainage is reduced on average by 4% over the sites investigated. This occurs because optimised system capacities take better advantage of rainfall events and the storage capacity of the soil. This finding of a lower annual volume with optimised system capacity is valid for all irrigation takes, regardless of the water source, e.g. groundwater or surface water takes. The reduction in drainage has additional benefits such as reducing the potential for nutrient losses below the root zone, benefiting groundwater quality. Lower irrigation water use also reduces energy consumption (i.e. pumping cost). Also, the capital cost of irrigation systems are lower as pipe sizes can be smaller with the lower flow rates. Both of these gains represent a direct cost saving for the farmer.

Figure 1: Reduction in the annual irrigation volumes and drainage losses due to optimising system capacities



Conclusions

Use of optimised system capacities for irrigation water allocation from run-of-streams will allow a greater area to be irrigated from the same allocable resource. This is also important for groundwater takes that are strongly hydraulically linked to surface water. The modelled results shows that the optimised system capacities also reduce the annual water volumes and decrease drainage and potential nutrient losses below the root zone. Reduced water applied will also lower the energy use and capital cost of irrigation systems. Accordingly, optimised system capacities enhance the social, environmental and economic wellbeing of the community.

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MODELLING EFFECTS OF VARYING IRRIGATION WATER ALLOCATIONS ON FARM PRODUCTION, PROFIT AND NITROGEN LOSSES

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Purpose

This project combined hydrological, nutrient loss and financial modelling to understand how different irrigation water allocations and reliabilities of supply affect production, profit, and nutrient leaching responses for major irrigated land uses of the Waimea Plains near Nelson. Results are being applied by MPI to assess the impact of various freshwater management options, including different approaches to meet established water allocation limits, enabling water permit transfers and establishing a water augmentation dam.

Modelling and Scenario Analysis

Crop production and nutrient leaching projections were simulated using Plant and Food's SPASMO model for apples, grapes, outdoor vegetables (market gardening) and dairy land uses on four soil groups using daily climate data for the forty year period 1972 to 2011. The four soil groups range from the gravelly Ranzau stony silt loam (TAW of 110mm to 1m deep) to Waimea silt loam (TAW of 175mm) and heavier Richmond silt loam (TAW 198mm). Annual production outputs were then converted into Earnings before Interest Tax and Depreciation (EBITD) using an economic model developed by Fruition Horticulture.

Two broad water management scenarios were modelled to evaluate the effect of varying levels of irrigation water allocation on production, EBITD and nitrate-nitrogen leaching losses. The 'with dam' or 'no water rationing' scenario evaluates the effects of varied weekly irrigation allocation limits but with full reliability of supply up to those weekly limits (0, 7, 14, 21, 28, 35 mm/week and unlimited/as demanded). The 'no dam' or 'with water rationing' scenario evaluates the same crop-soil-climate combinations but with additional restrictions in irrigation of up to 100% cuts in water take modelled from Tasman District Council's proposed water allocation rules in the event the Waimea Community Dam water augmentation scheme is not built.

Results

- Averaged over 40 years of climate, and with *full reliability of irrigation* supply, farm production and average annual EBITD is barely affected when weekly water allocations are reduced from those in the Tasman District Council's Resource Management Plan. Weekly water allocations at which effects on average annual EBITD are noticed are 28mm/week for apples (Figure 1), 14mm/week for grapes, 14mm/week for dairy (as feed can be bought in when irrigation is insufficient) and 28mm/week for an outdoor vegetable market garden. However, significant losses occur in dry years. Without irrigation, apple grower EBITD would have been negative for 15 of the 40 years modelled (Figure 2).
- Averaged over 40 years of climate, and with *regular rationing of irrigation* supply under proposed 'no dam/ with rationing' rules, farm production and average annual EBITD are affected for higher weekly water allocations than in the 'full reliability/ no rationing' scenario. Weekly water allocations at which effects on EBITD are noticed are 35mm/week for apples (Figure 1), 21mm/week for grapes, 28mm/week for an outdoor vegetable market garden, and for dairy 21mm/week on heavier Richmond soils but 35mm/week on the Waimea soils
- Nitrate-nitrogen leaching is much more sensitive to soil leakiness than to whether a crop is irrigated or not (Figure 1). Therefore, there is little difference in leaching rates for the 'no rationing' vs 'with rationing' scenarios. For some irrigated crops, leaching is lower than for the dryland equivalent because of the efficiency of plant uptake of nutrients in a fully watered situation. Leaching rates from highest to lowest for the farm systems modelled are dairy, outdoor vegetables, grapes then apples.

- Crops on Ranzau gravelly soils are more sensitive than crops grown on heavier soils for all the above results. Management of irrigation water allocation and nitrate losses on Ranzau soils has therefore become a focus for Tasman District Council's Waimea Freshwater and Land Advisory Group who are currently considering the nutrient loss modelling results in formulating recommendations on catchment water quality limits.

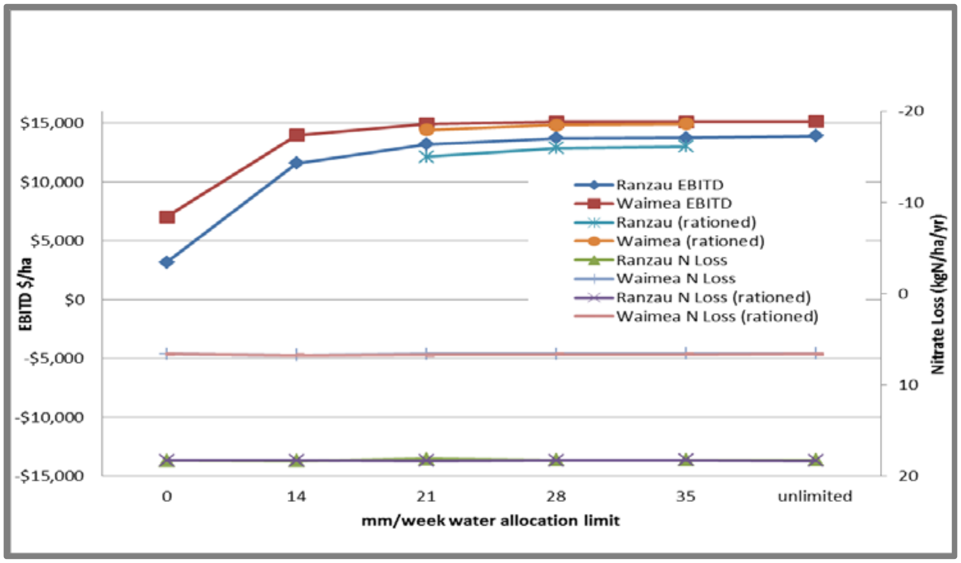

Figure 1: EBITD and nitrate loss from an apple orchard on 2 soils for varied weekly irrigation water allocations, with and without water rationing

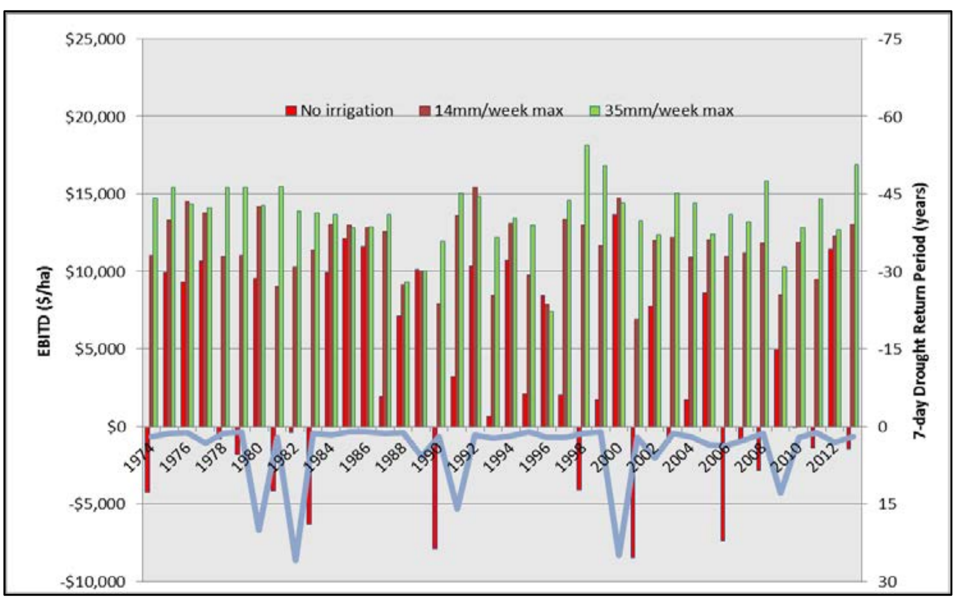

Figure 2: Annual EBITD 1974-2013 for 3 levels of irrigation water allocation for an apple orchard, plotted against return period of lowest 7-day Wairoa River flow each year

SOIL MOISTURE MODELLING AS A FLEXIBLE TOOL FOR SIMULATING THE IMPACTS OF WASTEWATER IRRIGATION SCHEMES

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[1]*PDP, Orakei, New Zealand*

Aims and Introduction

Soil Moisture Deficit (SMD) modelling has been traditionally used in farming to estimate the water required for cultivation of specific crops to improve water use efficiency. PDP have altered this modelling technique for use in wastewater irrigation applications. This revised modelling technique is simple and can be easily modified to suit project specific requirements. This modelling technique can be used to:

- Optimise the volume of wastewater irrigated to land, by allowing for wastewater storage;
- Predict the potential environmental impacts of a given wastewater irrigation depth; and
- Provide inputs to other models, such as recharge in a groundwater flow model.

Methods

Model calculations are based on a one dimensional soil moisture water balance model. Precipitation and irrigation are the inflows, with evapotranspiration, runoff, and percolation to groundwater (recharge) the outflows. The revised model is based on a “deficit irrigation regime”, which ensures that there cannot be any direct runoff of wastewater effluent, and that all irrigated effluent must pass through the soil profile. This infiltration rate should be based on field measurements, typically obtained by using a double ring infiltrometer. The deficit irrigation regime ensures that runoff of effluent cannot occur and means that irrigated water must pass through the soil profile, thus allowing vegetation and the soil itself to remove nutrients.

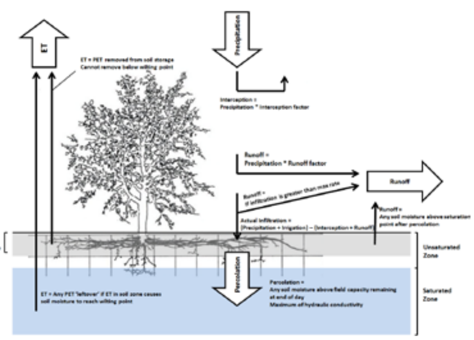

Figure 1: Conceptualisation of the soil zone used in the soil moisture model.

SMD modelling uses rainfall and evapotranspiration values at a daily time step. This data can be readily obtained from climate databases. Information regarding the soil and crop characteristics can be sourced from literature values based on observations of the soil and crop type. For more reliable results further analysis of soil characteristics can be performed. The model then calculates soil moisture and the recharge to groundwater at daily intervals.

More complex models are available which quantify similar processes, however the small amount of data required by this SMD modelling technique, and the simplicity with which it operates, means that minimal processing power is required. This simplicity means that it can be easily modified to suit specific applications or project requirements.

Applications

SMD modelling has been used successfully in predicting the impacts and improving efficiency of wastewater irrigation schemes across New Zealand. At a residential development in northern Auckland, this model was used to predict the amount of water storage required to dispose of a set amount of wastewater to a specified land area, with no leakage into the groundwater.

This technique can also be used to determine the additional recharge to groundwater caused by wastewater irrigation. An example from the Wairarapa highlights the issues and benefits of this approach and how this model can be used as a tool for infrastructure planning.

The modelling can also be utilised as an input to larger groundwater models. Using modelled recharge to groundwater is better practice than assuming recharge rates based on groundwater head calibration data alone. This approach was used to the north of Auckland, where the model was used to predict groundwater inflows both with and without a wastewater irrigation scheme, in order to represent the impact of the scheme on recharge rates.

A challenge of SMD modelling is the uncertainties which can arise from the use of non-crop plants, which vary widely in evapotranspiration rates. In particular, some of the wastewater irrigation schemes that this model was used to represent encompass native vegetation or mixed forest, making evapotranspiration rates difficult to accurately predict.

A modified version of the model was used in the Manawatu District to optimise the volume of irrigation using wastewater storage on pasture with underlying silt and clay. Wastewater storage was incorporated into the model to maximise wastewater irrigation, and the model was linked to groundwater mounding calculations to ensure an unacceptable degree of mounding did not occur.

WAIRARAPA WATER USE PROJECT – WATER DEMAND & SUPPLY

D Knappstein[1], Mr David Leong[1]
[1]*Tonkin & Taylor Ltd, Newmarket, New Zealand*

Background

The Wairarapa Water Use Project (WWUP) is investigating development of new water storage schemes in the Wairarapa Valley that will allow the community to more effectively make use of the catchment's water resources. The WWUP provides for a range of possible needs, such as supply of new areas of irrigation, increased reliability for existing irrigation and frost fighting, environmental augmentation of low summer river flows, environmental flushing flows, stock drinking water, power generation, municipal water supply, and recreational use.

A large number of dam options were identified, storing 3 to 80 million m^3 of water, and progressively narrowed to a shortlist of two sites through a complex process of concept development, desktop studies, site visits, hydrological analyses, cost estimates and multi-criteria analyses. The two schemes selected for further study, Black Creek and Tividale, are shown in Figure 1, and can irrigate about 30,000 hectares and provide water for other uses.

Three other schemes considered - Te Mara, Mangatarere and White Rock Road - have been discounted from further study by the project. Three others previously kept in reserve have also been discounted. No major flaws were identified in any of the options investigated in the prefeasibility phase of work and all are in the range of affordability. However, some schemes had large overlaps in their distribution areas and some were more favourable than others.

Aims

In this presentation, we outline the assessment of water demand and water availability, and the supply-demand modelling undertaken to establish the required capacity of the storage dams and associated refill infrastructure taking into account factors such as the irrigation service area, environmental flow regimes, level of supply reliability and alternative peak supply rates.

Method

The approach to matching storage sizes and command area extents evolved as the study progressed. During early stages of the study when a large number of scheme options were under consideration, a heuristic approach was taken to matching storage size and command area extents to provide an appropriate level of service. The latest assessment comprised supply-demand modelling over a 30 year period (1981-2012) based on historical rainfall and climatic data. Key inputs to this assessment included a theoretical daily water demand time series aggregated for each command area option and a corresponding mean daily water availability time series. The modelling considered the water balance on a daily basis, and simulated the storage volume, water harvested to fill the storage, operational discharge to scheme users, minimum residual flow released, and any spillway discharge over the modelled period. In addition, the implications of the adopted level of supply-reliability as well as a range of reduced peak supply rates for dry matter production on-farm was assessed for a pilot area. Example plots from this modelling are included as Figure 2 and 3. A future refinement will be to incorporate a drought management plan, which is expected to be adopted, into the modelling.

Results

The supply-demand modelling has provided the following:

- An improved understanding of supply reliability to scheme water users
- Quantification of the water lost over spillways and unavailable for scheme use
- Key inputs into likely electricity costs for pumping (duration of pumped flows is relevant, not just capacity)
- A tool to examine the potential savings associated with supplementing supply from storage with direct run-of-river supply
- A tool to examine the implications for storage sizes and costs of different amounts of water being available from core water allocation.

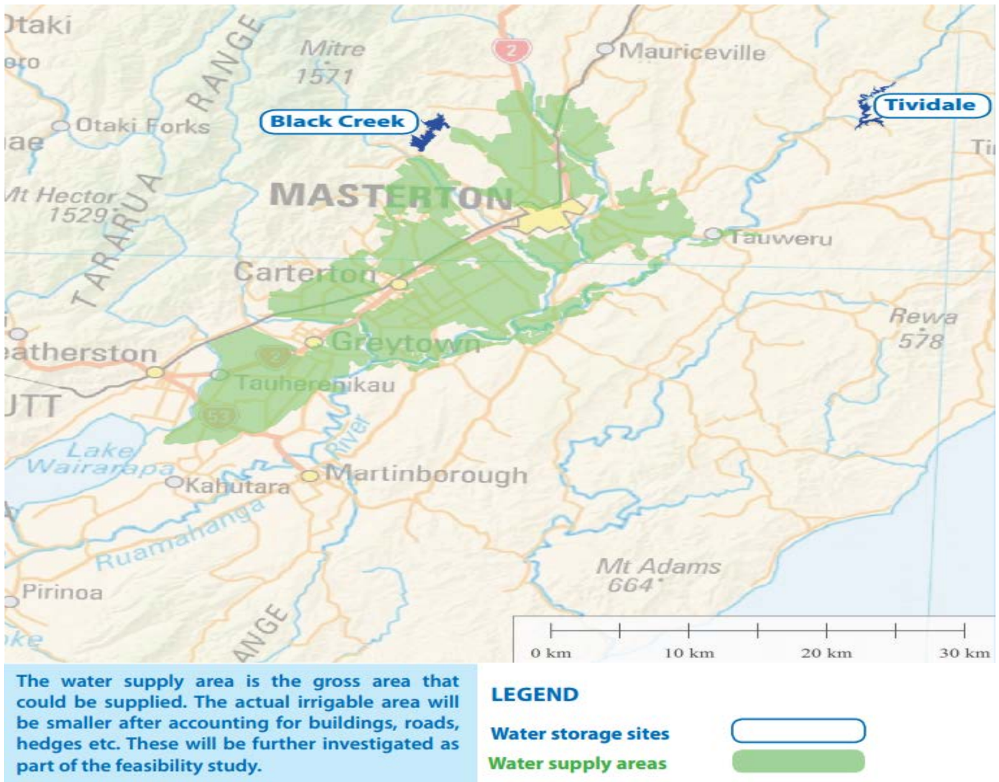

Figure 1 Schemes selected for further study, as at June 2015
(Source: Wairarapa Water Use Project, Project Update dated 10 June 2015)

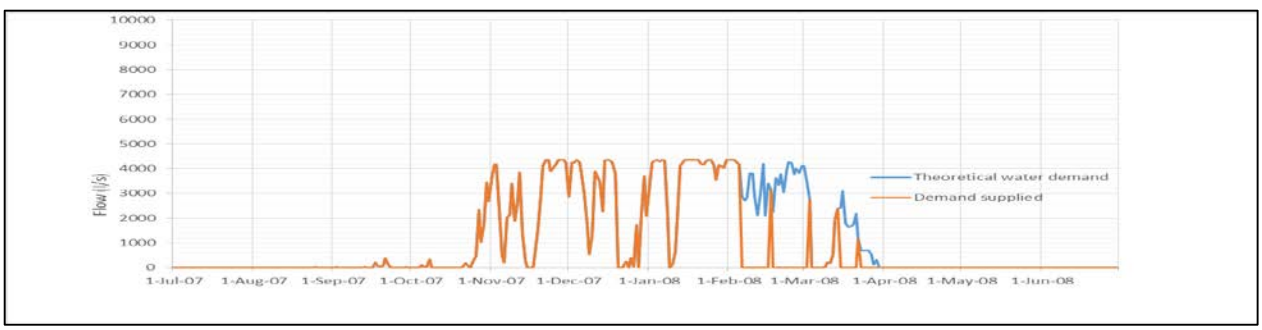

Figure 2 Example plot from supply-demand modelling for a portion of the modelled period for the Te Mara scheme - illustrating the timing and severity of shortfalls, which affects how effectively shortfalls can be managed on farm.

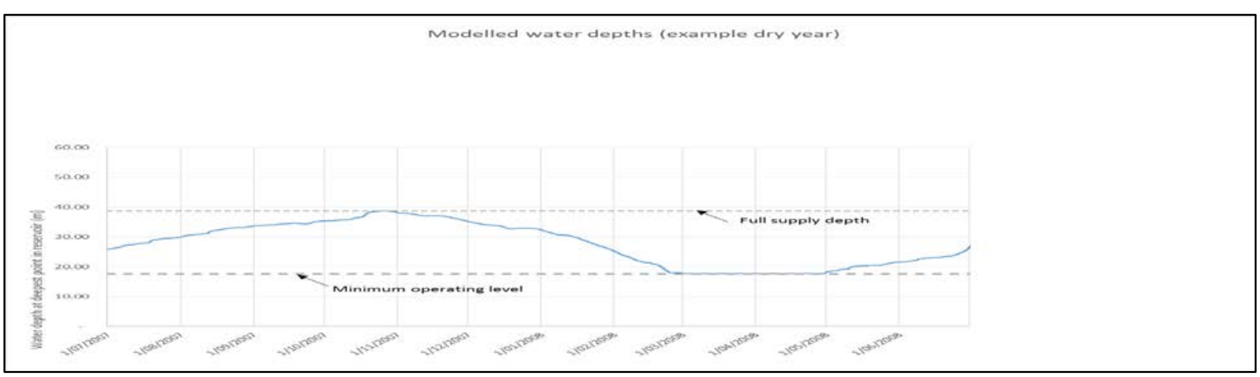

Figure 3 Example plot from supply-demand modelling for a portion of the modelled period for the Tividale scheme - illustrating the modelled water depths in a selected dry year.

Session: Transport and Transformation of Contaminants, Start Time: 11:00 a.m.

THE ASSESSMENT, REMEDIATION AND MANAGEMENT OF A TCE PLUME IN FRACTURED ROCK ON A MULTI-STAGE CBD DEVELOPMENT SITE, MELBOURNE AUSTRALIA

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[1]Tonkin + Taylor Group, , , [2]Tonkin + Taylor Australia Pty Ltd, ,

Aims

A large former brewery site in Melbourne's Central Business District is in the process of being redeveloped in multiple stages for high density residential and commercial mixed use. The range of contaminants requiring assessment, remediation and/or management on the site include petroleum hydrocarbons and chlorinated solvents, including TCE. This paper documents the significant technical, regulatory and management issues relating to the assessment and remediation of a TCE contamination plume in a fractured rock in the Melbourne CBD.

Method

The paper discusses the methodologies for characterising and remediating a TCE plume in a fractured rock setting, including development of an appropriate conceptual site model (CSM), contaminant fate and transport modelling in soils and groundwater, human health risk assessment, insitu chemical oxidation (ISCO) and ongoing management requirements. The site's geological profile beneath anthropogenic fill is fractured rock with siltstone matrix, structurally controlled by north northeast to south southwest striking bedding planes with a potential anticline closure running through the site with possible dilation fracturing and high secondary (fracture) porosity to primary porosity ratio. It was hypothesised that this fracturing profile is responsible for the observed SSW TCE plume elongation and limited plume identification or migration normal to the SSW direction.

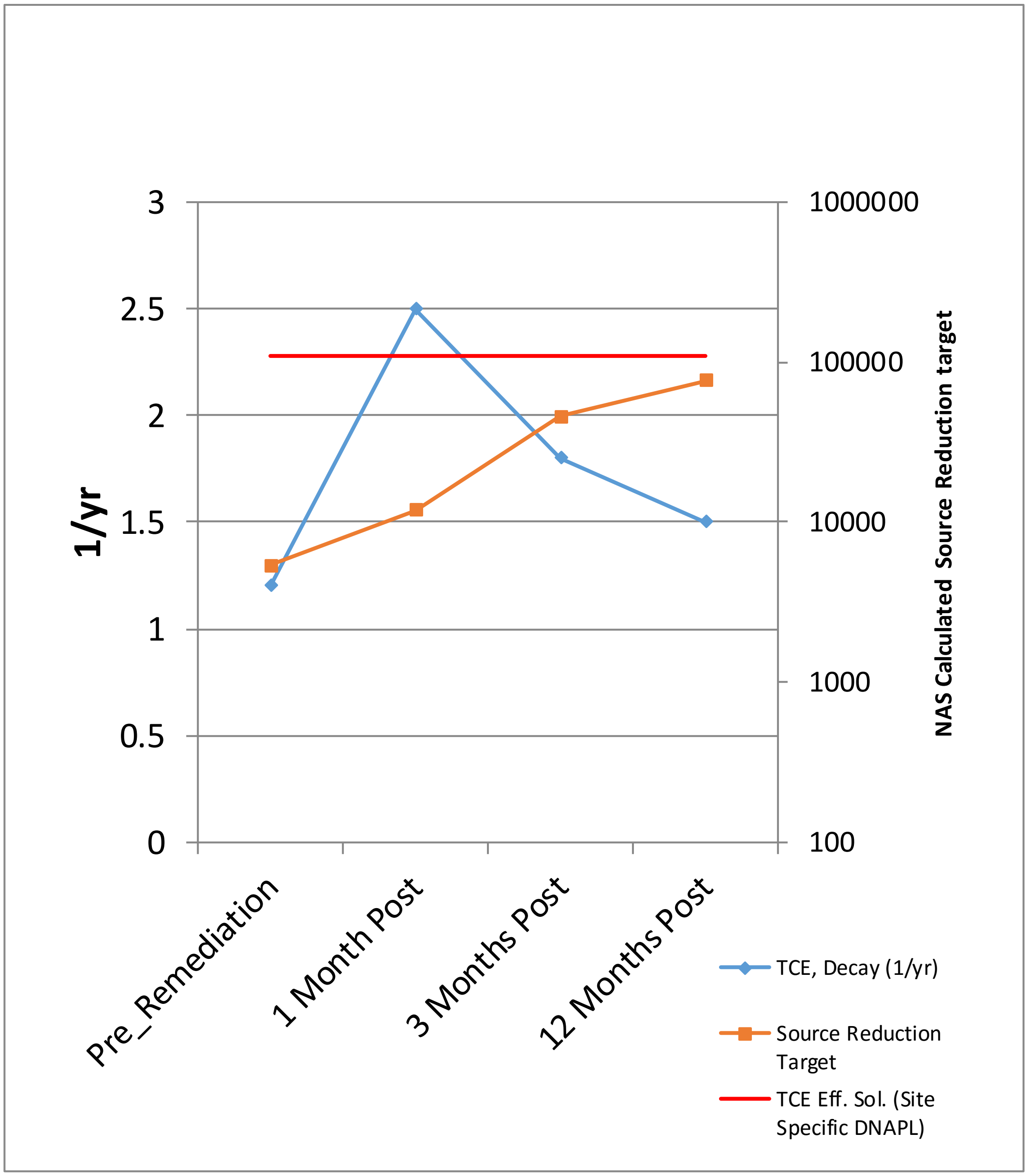
Remediation of the TCE source zone involved the injection of sodium persulfate into the source zone, via dedicated wells using an ISCO unit. For the trichloroethylene (TCE) reaction, by stoichiometric demand 3 Mol of Persulfate required for 1 Mol of TCE, where:

$$3NaS_2O_8 + C_2HCl_3 + 4H_2O \rightarrow 2CO_2 + 9H^+ + 3Cl^- + 3Na^+ + 6\,SO_4^{2-}$$

Concentration Data Assessments

Assessment of concentration data was undertaken to determine whether concentrations had changed, and establish if further injection events are going to achieve additional benefit. This was achieved by the development of a F&T Model (NAS) using pre-injection data, noting calculated degradation rate/factor, adding the post-injection concentration data profile and plotting changes to decay rate and calculated source reduction target (based on SSTL or Criteria). Effects were assessed with respect to changes to source reduction target and degradation achieved, as shown below:

Figure 1 NAS calculated source reduction targets



Results

Confirmation of the remediation goal comprised an estimate of mass removal by using a partitioning relationship to estimate the soil concentration based on measured data, pre and post remediation. The identified limitations included a realistic baseline effective solubility; no DNAPL pooling or free DNAPL has been removed and uniform DNAPL distribution (not necessarily correct).

Table 1 – Results of ISCO remediation

TCE	Pre Remediation	1 Month Post	3 Month Post	
Observed solubility	480	117	75	mg/L
Concentration of TCE Available to Groundwater	133.68	32.58	20.85	mg/kg
DNAPL Volume Estimate	3000	3000	3000	m3
DNAPL Volume Weight	6000000	6000000	6000000	kg
DNAPL Mass Estimate	802.08	195.507	125.325	kg
Mass Reduction	0%	76%	84%	

Management

Ongoing management of residual contamination is mandated and specified in a series of reports prepared by Tonkin + Taylor including Detailed Site Investigation, Remediation Action Plan, Clean-up to the Extent Practicable (CUTEP) report and Environmental Management Plan (EMP) incorporating a Groundwater Quality Management Plan (GQMP). The site is also subject to Environmental Audit. A proposed Groundwater Quality Restricted Use Zone (GQRUZ) was determined through an evaluation of groundwater fate and transport modelling, observed contaminant plume extent and the likely beneficial uses of groundwater.

ARTIFICIAL TURF FIELDS – AN EMERGING URBAN STORMWATER ISSUE?

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Aims

This study reports contaminant concentrations in stormwater runoff from a third generation artificial turf field. Third generation turf fields are different from previous generation fields because crumb rubber is used as a shock absorber. Crumb rubber is typically sourced from recycled vehicle tyres and has been identified as a potential source of metals and organic contaminants (Cheng et al, 2014; Bocca et al, 2009). A number of these potential contaminants are introduced during the tyre manufacturing process as plasticisers, vulcanisers and antioxidants (e.g. Zinc Oxides during vulcanization; Rhodes et al, 2012). The application of crumb rubber to the sports fields results in large reservoirs of potential contaminants (e.g. Zn constitutes up to 2% of tyre weight) as up to 100 tonnes can be applied to one field (Cheng et al, 2014). The wear of tyres through abrasion is a known source of urban stormwater contaminants but two recent meta-reviews (Kruger et al, 2013; Cheng et al, 2014) reported that there had been few (if any) studies of crumb rubber washoff and breakdown in the field. To address this gap in the knowledge and respond to the growing number of these types of sports fields that are being constructed in NZ and elsewhere, this study set-out to monitor heavy metal concentrations in runoff from a newly installed third generation artificial turf field.

Method

Automatic flow monitoring and water quality sampling equipment was installed in April 2013 and maintained for a two year period. The sampler was positioned to collect sample from a combination of surface runoff from the field (and surrounding concrete path), and subsurface field drainage. Flow weighted samples were taken during storm events. The water samples were collected and transported to an accredited laboratory where they were analysed for 15 heavy metals using standard analytical procedures.

Results

There were large variations in intra- and inter-event metal concentrations reflecting differences in source availability and mobility (Figure 1). Nevertheless, the magnitude of variation for some metals was large. For example, there were three orders of magnitude variation in the intra-event concentration of iron and aluminium. Copper & cadmium demonstrated source limitation with an inverse relationship between concentration and age of the artificial turf field. The majority of the metals (twelve) exceeded ANZECC guidelines for 95% species protection at least once in the first four months. Copper and zinc were present in the runoff at concentrations comparable to runoff from heavily trafficked road surfaces (carrying up to 50,000 vpd; Auckland Regional Council, 2010).

This study has shown metal concentrations in runoff from third generation artificial sports fields to be comparable to other parts of the urban fabric that are known to be major sources of pollutants (such as roads). Building these artificial turf fields into urban environments requires research into the impact of crumb rubber in receiving environments, which is especially important in small stream and low energy estuarine environments typical of many NZ cities.

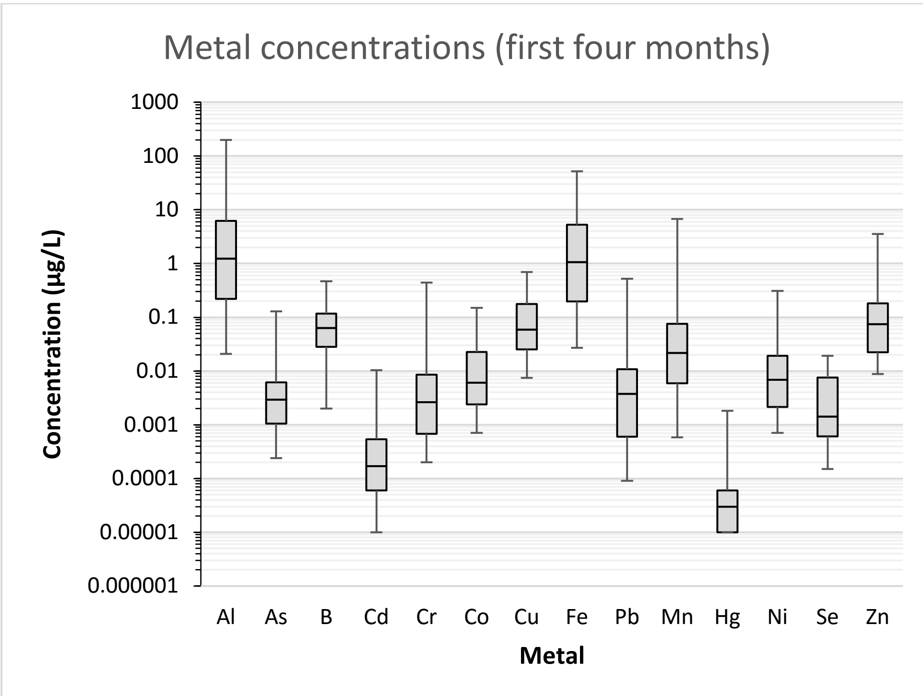

Figure 1. Metal concentrations in runoff from third generation artificial sports fields (four months of sampling)

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SOLUTE AND STABLE ISOTOPIC RATIOS OF FOG, RAIN, SURFACE AND SOIL WATERS AT TIMBER CREEK, CENTRAL OTAGO

Miss Alice Trevelyan[1], Dr Sarah Mager[1], Robert Van Hale[2], Peter Wilson[3]

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Aims

In arid and semi-arid regions, water resources are under pressure due to increasing demand for water and uncertain climatic futures. Most conventional water balances used in water resource allocation and planning purely rely on rain data when determining the sources of water input into a catchment, typically omitting precipitation inputs that are not captured in a conventional rain gauge, such as snow and fog. The amount of water potentially derived from fog is particularly important in summer when there is increased demand for surface waters for irrigation, recreation and domestic use, however defining fog and rain remains problematic. Internationally, there has been growing recognition of the potential role that fog may play in augmenting precipitation input, with research suggesting that in most fog prone catchments the volume of fog deposition can be twice that of rain. Additional input of precipitation as fog contributes to higher soil moisture content and potentially increased water yield. The emphasis on the potential role fog can contribute to stream flow is highly contested in New Zealand with debate over the significance of fog interception, particularly in native grasslands. The aim of this study is to quantify the movement of fog and rain thought the hydrological cycle and to determine if fog is a significant contributor to water yield in the Timber Creek catchment, Central Otago.

Method

Stable isotopes are a technique commonly used to distinguish between fog, rain and components of the hydrological cycle. To date only one study using stable isotopes to trace fog and rain inputs has been conducted in New Zealand, and the assertion that fog contributes to 'sub equal' portions of groundwater is widely challenged by other fog studies in New Zealand using more traditional techniques. Another tracer technique that has been used to distinguish between fog and rain inputs is the analysis of ion composition, however, this has not yet been used in New Zealand. The approach of this study is to combine water balance, direct fog collection, and geochemical tracers to quantify the potential significance of fog input into a small catchment, Timber Creek, in Central Otago. Rain water was collected in two standard rain gauges, whilst direct capture of fog was achieved through three passive harp-shaped collectors situated over collecting rain gauges. A layer of mineral oil was added to each collecting rain gauge to prevent evaporation. Soil water samples were collected through 6 suction cup lysimeters. Additionally, surface water was collected from an adjacent wetland and Timber Creek. Samples were analysed for $\delta^{18}O$ and δD using the Piccaro CRDS analyser with an analytical precision of $\delta^{18}O$ 0.09 ‰ and δD 0.9 ‰. Major anion and cation analysis was undertaken on an Ion Chromatograph (IC) and Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) at the University of Otago with an analytical precision of 0.1 mg/L for each ion.

Results

Between 5th July 2014 and 1st April 2014 there were 62 days where fog deposition occurred contributing 236 mm of precipitation to the catchment, representing an undercatch of incipient precipitation in traditional rain gauges equivalent to 17% of measured rainfall. Thus, in the Timber Creek catchment, fog is a significant source of water. Analysis of $\delta^{18}O$ and $\delta^{2}H$ shows a difference in the isotopic ratios of fog and rain in the Timber Creek catchment, with rain consistently more depleted than fog. When considering isotopic ratios across a year, there is no difference in the range of values due to seasonal fluctuations and strong differences in ^{18}O ratios between events, however, investigation into seasonal and depositional events demonstrates a difference in isotopic ratios does exist between fog and rain. River and wetland isotopic ratios remain stable year round, despite fluctuations in precpitation of up to $\delta^{18}O$ 7.5‰. River water is more depleted in stable isotopes relative to median precipation, suggesting that runoff is generated from precipitation falling at higher elevations within the catchment and it is not possible to determine from the isotopic data whether fog has any significant contribution to river flow. Preliminary analysis also suggests that there is a distinct solute character between fog and rainwater, with fog yielding higher concentrations of chloride and base cations compared to that of rain. An examination of the isotope and solute data shows strong linkages between incipient precipitation from fog and shallow soil water, suggesting that fogwater is important for sustaining plant growth, but that water does not move through the hydrological system into the river. Thus, fog is likely a small, but important contributor to incipient precipitation in Central Otago and provides key moisture for sustaining plant growth and ecosystem services, but is not a direct contributor to stream flow. Rather, fog offsets soil and plant water uptakes allowing a higher portion of rainfall to contribute to river flows, and is one element that explains the higher water yields observed from tussock grasslands.

COASTAL FRINGE GROUNDWATER: CONSIDERATIONS FOR ENVIRONMENTAL MONITORING WELL DESIGN, COASTAL DISCHARGE SAMPLING & COASTAL CHEMISTRY ASSESSMENT

Mr Aslan Perwick[1]
[1]*Pattle Delamore Partners Ltd, Auckland, New Zealand*

Aims & Introduction

- To understand the groundwater hydraulics of the coastal fringe and its implications for environmental groundwater chemistry assessment

- To create good groundwater monitoring network design (well and spring sampling) within the coastal fringe setting which targets contaminant mass flux

- Use basic geochemical modelling to determine groundwater – sea water mixing and reaction processes

Fundamental Principals

The coastal fringe (i.e. <100 m from coast) can be a difficult place to design a groundwater monitoring and sampling framework, and equally as difficult to determine groundwater chemistry results. The influence of; tidal processes, vertical groundwater flow gradients, density differences, recent climatic factors and marine water chemistry mixing and reactions, can greatly impact the groundwater quality results in coastal fringe monitoring wells and spring samples if good groundwater science is not employed.

This presentation will discuss the groundwater hydraulics within the coastal fringe for a variety of common NZ coastal settings and will describe key considerations for those who are planning contaminated groundwater investigations and/or monitoring schemes within the coastal fringe. Topics covered will include; options for placing well screens, best position(s) to collect beach face/foreshore groundwater discharge samples, timing of sampling within the tidal cycle, common reactions between groundwater and saline water – all based on targeting contaminant mass flux.

The use of basic geochemical modelling to interpret water chemistry observations and the impacts of marine water mixing using a case-study will also be presented.

Implementation Considerations

Groundwater flow paths within the coastal margin contain a significant element of vertical movement – both from the forces of freshwater-saline water density differences, and tidal forces.
The reliability of groundwater chemistry results from monitoring wells within the coastal fringe can be significantly improved, with respect to targeting contaminant mass flux, through good design based on understanding of the hydraulics at play within a particular coastal margin.

Beach face/foreshore water quality sampling can provide highly useful data on the quality of groundwater discharge and should be included in a coastal fringe groundwater assessment – but sampling location, timing and consideration of recent climatic factors is key to a meaningful assessment. The figure below (Urish and McKenna, 2004), aides in displaying where and when along a beach face/foreshore is best to collect a groundwater discharge sample in a sand dominated coastal fringe: mid-lower beach face, within 1 hour either side of low-tide. Sampling too high up the beach face will be influenced by saline water from the preceding flood tide, and should be avoided.

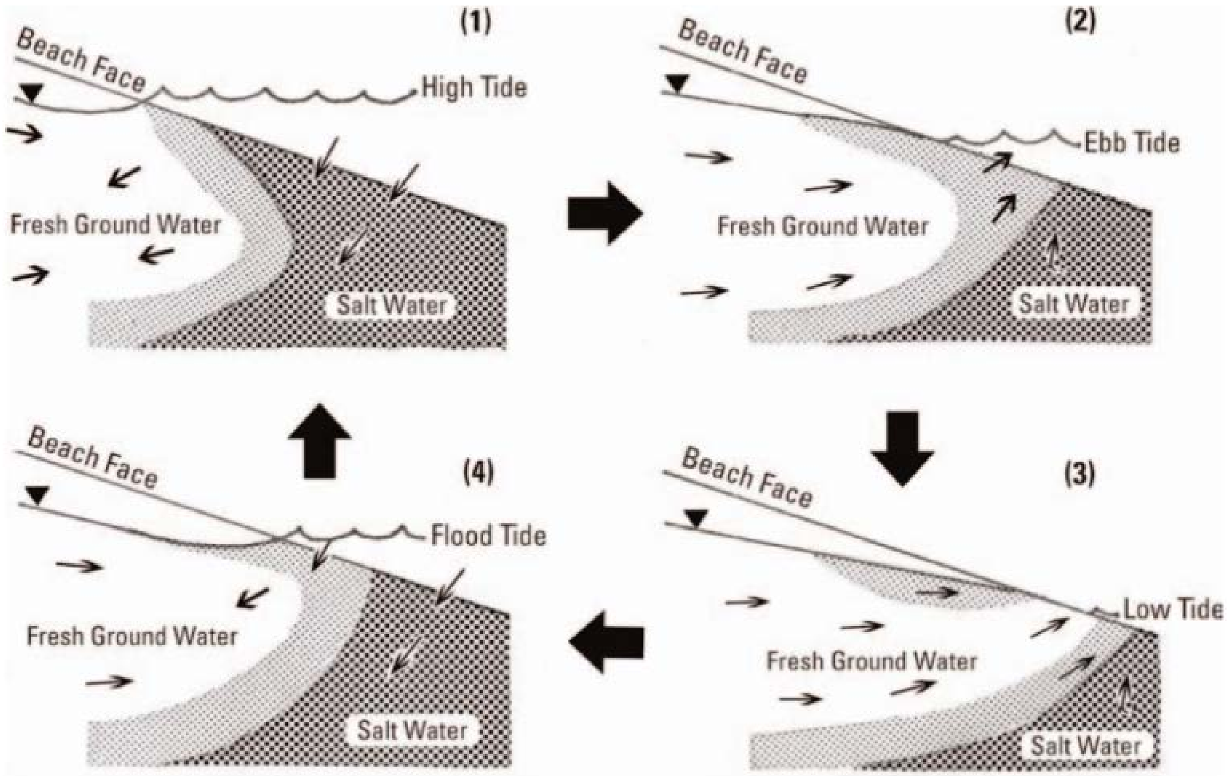


Figure Beach and groundwater discharge concepts (Urish and McKenna, 2004)

Many other elements require consideration for both well design and sample event planning, namely; rainfall, wind, swell and tidal patterns, as well as seasonal effects – which can all influence the reliability / quality of groundwater chemistry sample within the coastal fringe.

The use of basic PHREEQC reactive geochemical modelling along with understanding of coastal groundwater hydraulics has been used at an unnamed site to quantify the impacts of groundwater mixing with natural saline water within a coastal fringe zone. Precipitation of carbonate minerals and subsequent changes to groundwater contaminant chemistry is used as a prime example of the impact coastal fringe process can have on groundwater quality.

References

Urish, D. & McKenna, T., 2004. Tidal effects on ground water discharge through a sandy marine beach. *Ground Water - Oceans Issue,* 42(7), pp. 971-982.

Session: Water Quantity / Water Quality Interactions, Start Time: 11:00 a.m.

PRELIMINARY INVESTIGATION INTO THE EFFECTS OF PARTIAL CLEAR-FELLING OF PINUS RADIATA ON WATER QUALITY: A CASE FROM THE GLENDHU EXPERIMENTAL CATCHMENT

Miss Christina Bright[1], Dr Sarah Mager[1]
[1]*University of Otago, , New Zealand*

The Glendhu Experimental Catchment in Otago was established in 1979 as a paired catchment study, to determine the hydrological consequences of converting indigenous tussock grassland to plantation forestry. Situated in the upper Waipori basin, two adjacent north facing sub-catchments draining into the Waipori River have formed the basis of the study, one left in snow tussock as a control (GH1), and the other planted in *Pinus radiata* (GH2). Thirty years of work in these catchments has focussed on compared catchment water balance, sediment yields, water chemistry and soil properties during afforestation. Harvest of the planted catchment began in late 2014, offering an opportunity to investigate the initial impacts of deforestation.

Aims

The aim of this research is to assess what impact partial clear felling of *Pinus radiata* has on water quality by comparing the actively felled forest catchment (GH2) with the tussock control catchment (GH1). International studies have shown that forest clearance increases runoff, and suspended sediment, as well as potentially increasing the release of nutrients to waterways, like nitrogen and phosphorus. The current study assesses if any changes in these variables occurs during clear felling, and how those changes may indicate land disturbance and catchment erosion.

Method

The approach of this research has been to undertake a preliminary field-based study addressing five specific areas; water yield, water chemistry, land disturbance, in situ water characteristics and land management. The sampling program consists of six sampling locations, one each from the two sub-catchments (GH1 and GH2) and four from the Waipori River, above and below the confluence where streams draining GH1 and GH2 meet the Waipori River. Weekly water samples were collected from the six sites, including automatic water samplers installed at sites GH1 and GH2 collecting daily water samples. In-field instruments also included two water level loggers recording water level in the V-notch weirs built in GH1 and GH2, and a sonde recording in-situ water parameters downstream of the GH2 confluence with the Waipori River. Field methods have also included weekly measurement of in-situ water variables (temperature, specific electrical conductance, and pH) from each of the six sampling sites. Samples collected were analysed for nitrogen, phosphorus and silica using flow injection analysis. Base cations (sodium, potassium, calcium, and magnesium) and sulphur were analysed on an ICP-OES. Minor elements were also analysed on ICP-OES and included boron, aluminium, manganese, iron, zinc, barium, and strontium.

Results

Preliminary data analysis shows that there is a significantly higher export of nitrate-nitrogen from the catchment undergoing clear felling, relative to the tussock control catchment. Other identifiable differences occur in the concentrations of iron, magnesium, and sulphur. During the forest clearance phase there has been a sustained higher level of runoff from the clear-felled catchment, which is the opposite of runoff behaviour recorded during afforestation, in which water level was much lower than the control catchment. Grab samples of suspended sediment suggest that suspended sediment export is higher from the deforested catchment (GH2), when excluding the effects of organic matter. In-situ stream variables vary little between the two catchments, with pH being the only variable to show a difference.

COASTAL INFILTRATION POND – HOW MUCH WATER CAN IT SUPPLY?

Mrs Susan Rabbitte[1]

[1]*Lattey Group, Hastings, New Zealand*

The security of production for farmers brought about through irrigation of land has resulted in the consideration of groundwater supply options for increasingly marginal areas. This presentation looks at just such an area and how temporal data was collected to understand the interaction between the groundwater resource and the surrounding environment at this isolated location. The landowner has a large dune field area with potential for irrigation, but how much groundwater will the fine grained sand dunes release and how can the water be accessed at viable flow rates? A large pond was excavated to access the water, but how long will it take to refill and will it be salty or freshwater? The isolation of the study site meant there was a paucity of existing background data. There was a need to design a data collection regime to fill these knowledge gaps.

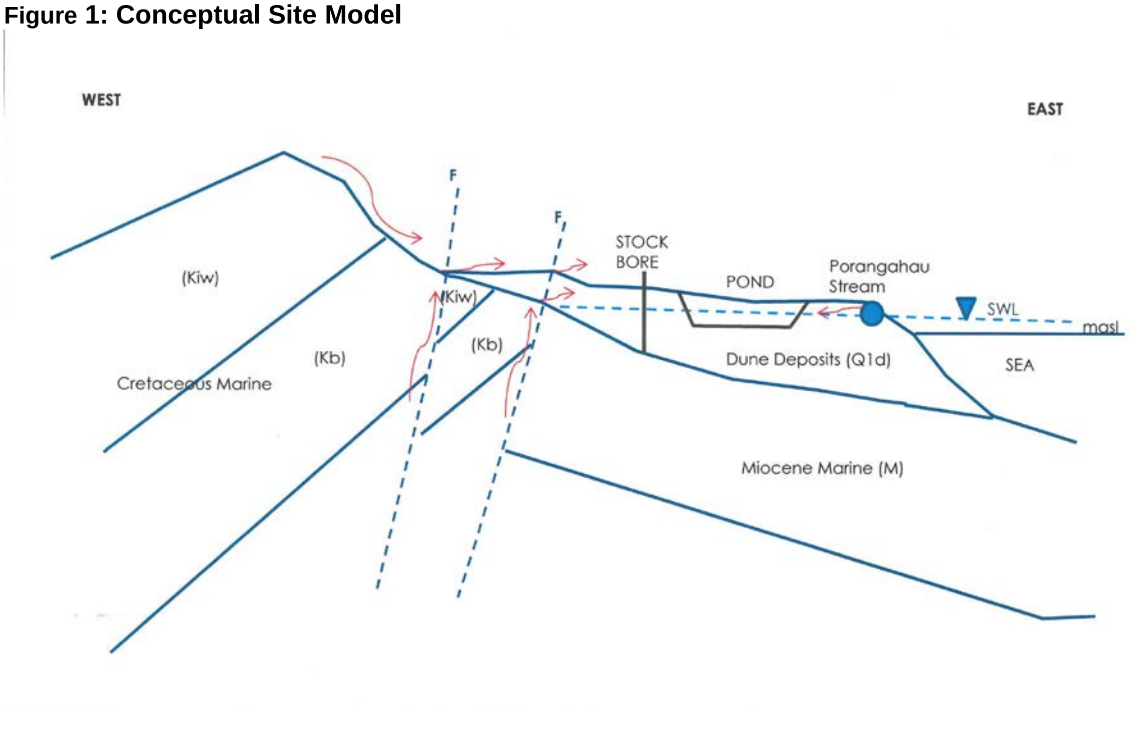
Aims

The aim of this project was to determine the irrigation requirements for the study area. Create a conceptual understanding of the groundwater resource and its interactions with surrounding springs, streams and the sea. Calculate the hydraulic conductivity of the dune field sediments, test the water quality and confirm irrigation supply volumes. Will this abstraction adversely affect any other users or the surface water resources?

Method

The project commenced with a site visit and the development of a conceptual model, Figure 1. Data collection requirements were determined to test this conceptual model. The collected data included twice daily groundwater level readings, from a water level measuring staff that was placed in the pond, in conjunction with rainfall and barometric pressure readings. The data was collected over a period of three months, January – March 2015.

Figure 1: Conceptual Site Model



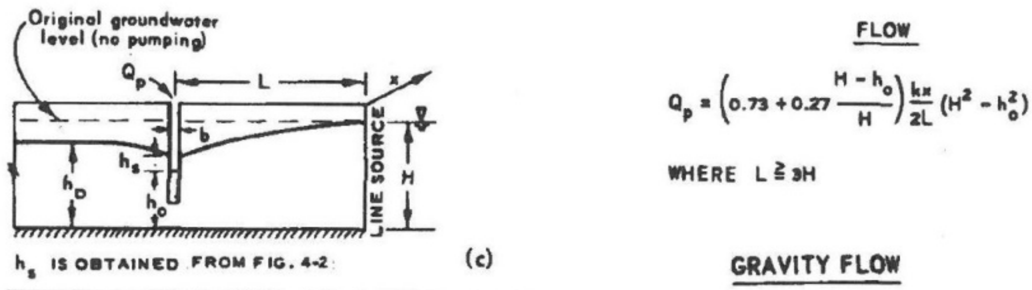
Soil samples were collected to represent the aquifer material and particle size distribution analysis was carried out. The dimensions of the ponded were measured. Two shallow piezometers were installed between the pond and the sea; samples were collected from these and an existing upstream stock well for water quality analysis. A pump test was carried out, the pond was drained and the rate of refilling was recorded.

Results

The conceptual model identified a dune field overlying Miocene marine sediments. A fault contact to the west has placed this against coastal hills of Cretaceous marine sediments. There is a surface and groundwater flow component entering the dune field from the west via rainfall run-off and fault controlled spring discharge. To the east of the pond and flowing on the beach towards the north is the Porangahau Stream. The stream separates the pond from the sea and likely discharges to the dunes.

The water quality analysis indicated no significant water quality issues within the surrounding bores. Hydraulic conductivity was determined from the grain size analysis that was a bit lower than from the pump testing but both are within the range expected for fine grained, well sorted sand. There is no apparent tidal response to the water level within the pond. A safe yield was determined using an analytical solution (ANAF, 1983), Figure 2, that was combined with pond storage and irrigation return flow for a seasonal irrigation volume. The isolation and proximity to the shoreline reduced the potential to adversely affect other users or the surrounding environment. Saline intrusion is not expected to be significant.

Figure 2: Safe Yield Analytical Solution (ANAF, 1983)



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HYDROCHEMISTRY AS AN INDEPENDENT GROUNDWATER AGE TRACER – CASE STUDY: THE LOWER HUTT GROUNDWATER ZONE

Monique Beyer[1,2], Bethanna Jackson[1], Chris Daughney[2], Uwe Morgenstern[2], Kevin Norton[1]
[1]Victoria University of Wellington , , New Zealand, [2]GNS Science, Avalon, New Zealand

Introduction and Aims

Groundwater age or residence time is the time water has resided in the subsurface since recharge. The determination of groundwater age can aid understanding and characterization of groundwater resources, because it can provide information on groundwater mixing and flow, and volumes of groundwater and recharge, etc. Groundwater age can be inferred from environmental tracers, such as SF_6 and tritium. Multiple tracers are often applied complementarily in order to increase the robustness of age interpretations. To this end, it is desirable to develop cost-effective and easily applicable age tracers/techniques to supplement the existing ones.

Hydrochemistry data are spatially and temporally widely available due to national and regional groundwater monitoring programmes. Their determination is cost-effective and relatively simple compared to the determination of existing age tracers. Hydrochemistry has been used as an age proxy and has been suggested as a potential age tracer. However, to date, the use of hydrochemistry as an independent age tracer has only been demonstrated for water recharged weeks to months ago, by relying on seasonal changes.

This study assesses whether and under what conditions hydrochemistry can be used as an independent groundwater age tracer over a wider age range (and as an age proxy and indicator for recharge sources and weathering processes) in the Lower Hutt Groundwater Zone, New Zealand. Comparison and combination of age information inferred from hydrochemistry and tritium in our study allowed for demonstration of hydrochemistry for use as an age tracer for groundwater recharged days to ~100 years ago.

Methods

The Lower Hutt Groundwater Zone (LHGWZ), located in a sedimentary basin in the Wellington Region in New Zealand, appeared to be a suitable case study to assess whether hydrochemistry can be used as an independent age tracer. Firstly, the LHGWZ was believed to have a relatively simple/homogenous aquifer structure which was thought to indicate relatively consistent, homogenous hydrochemistry-governing processes throughout the aquifer. Secondly, hydrochemistry and age tracer data were available in 15 locations across the LHGWZ. Mean residence times (MRTs) inferred with environmental tracers ranged from days to approximately 75 years. This rich dataset allowed for comparison of hydrochemistry-inferred and tracer-inferred age information and assessment of the complementary use of hydrochemistry and established age tracers for groundwater dating.

To assess whether hydrochemistry can be used as a stand-alone or complementary groundwater age tracer, the methodology illustrated in Fig. 1 was used. Firstly, hydrochemistry data were collected from sites for which hydrochemistry-age relationships were likely to exist (e.g. from sites located in one aquifer). The data were then assessed for apparent internal consistency with regard to potential drivers and controlling factors and to identify (potential) sub-datasets within the dataset (referred to as the data analysis step in Fig. 1). This is necessary because there are various processes and conditions that may affect the chemical composition of groundwater, aside from residence time and groundwater mixing. This may hinder establishment of strong hydrochemistry-age relationships and inference of age information from hydrochemistry, even if the sites were all located in one aquifer.

After identification of potential sub-datasets, hydrochemistry-age relationships and age information were inferred for each sub-dataset. For that a probabilistic approach illustrated in Fig. 1 was used. Groundwater mixing was conceptualized by simplified LPMs (lumped parameter models) from which the age distribution was determined. The following three scenarios with regard to prior age information were used:

1. To assess whether groundwater age could be determined purely using hydrochemistry and whether hydrochemistry could be used to confirm the mixing model, age information at each site was not constrained a priori; a selection of LPM types (namely the EPM, DM and PEM) were used.

A) To assess whether the often ambiguous tracer-inferred age information could be further constrained with the aid of hydrochemistry, tracer-inferred age information were used to establish hydrochemistry-age relationships.

B) To assess whether robustly pre-determined age information at one site would allow for inferring of age information at the remaining sites purely based on hydrochemistry, the age information was not constrained a priori except at one site for which tracer-derived age information was used.

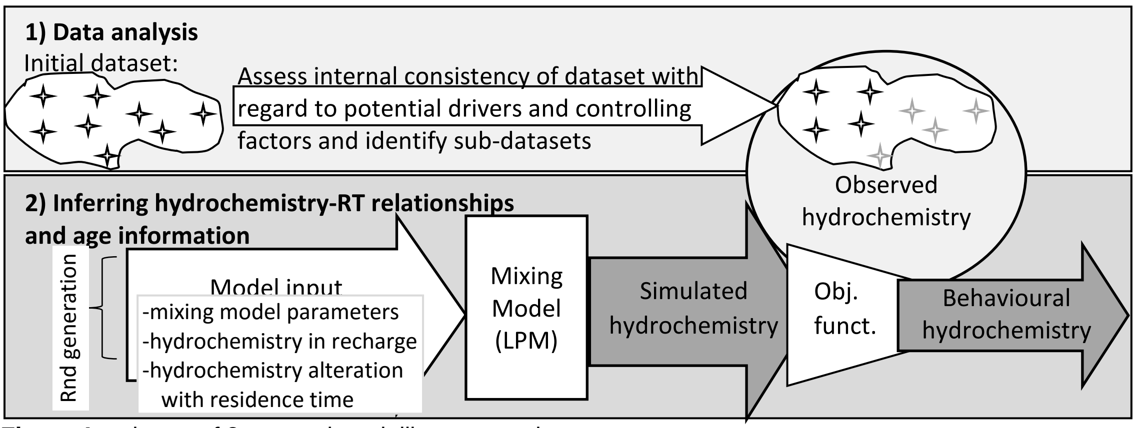

Figure 1: schema of 2-stepped modelling approach

Results

The main findings at our study site (the LHGWZ) include:

- The hydrochemistry parameters Si, Na, Ca and TDS were successfully used as complementary 'age tracers' to reduce uncertainty in age information inferred from established age tracers and to resolve ambiguous tracer-derived MRTs (at 50% of the affected sites).
- When established age tracer data was unavailable, the parameters Si, Na, Ca and TDS could act as groundwater age proxies to estimate the relative age of groundwater and to distinguish older from younger water. This finding is in line with previous studies, which have also demonstrated the use of hydrochemistry as an age proxy.
- Although it was hoped to infer more information on the age distribution purely based on hydrochemistry, this turned out difficult. No clear preference for any LPM type was found. This indicated that the LPM type (or mixing model) could not be identified purely using hydrochemistry in this study. It was speculated that it may be possible to identify the mixing model if groundwater underwent more complex mixing than observed in this study. Further study is needed to confirm this supposition.
- The use of a reference age (i.e. tracer-inferred age information at one site) aided the use of hydrochemistry as an 'independent' age tracer at the remaining sites. This finding highlights the significant potential of using hydrochemistry to supplement age information inferred from established techniques. The 'complementary' use of hydrochemistry and other groundwater dating techniques appears to be a much more cost-effective way to gain multiple age estimates than the sole use of expensive age dating techniques.

Acknowledgement Thanks to Greater Wellington Regional Council for provision of hydrochemistry data and financial support by SAC (smart aquifer characterization) project.

QUANTIFYING THE CONCENTRATION AND SOURCES OF DISSOLVED CARBON FROM FORESTED AND GRASSLAND MOUNTAIN CATCHMENTS, SOUTHERN ALPS, NEW ZEALAND

Miss Emily Diack[1], Dr Sarah Mager[1], Mr Robert Van Hale[1]
[1]*University of Otago, Dunedin, New Zealand*

Aims

Estimations of carbon flux are essential for understanding the build-up of carbon dioxide in the atmosphere and its terrestrial sinks and sources. The transfer of carbon between the atmosphere, biosphere and lithosphere is typically characterised through the global flux of riverine carbon, which has become of increasing importance in the context of carbon budgets. Carbon is constantly moving between the atmosphere, biosphere and hydrosphere with rivers acting as partial sinks for carbon as well as advecting carbon between the terrestrial and marine environments. Riverine carbon may be temporarily held within water, as dissolved carbon, or stored in riverbeds and banks as particulate carbon. Carbon naturally occurs in many forms: particulate or dissolved, and is derived from either inorganic or organic sources. The partitioning of carbon between the different forms e.g. particulate organic carbon (POC), or dissolved organic carbon (DOC) is central to understanding the geochemistry of carbon fluxes in the terrestrial sphere as well as understanding the structure and functioning of aquatic ecosystems. The aim of this paper is to assess the concentration of dissolved organic and inorganic carbon within forest and grassland mountain catchments in the Southern Alps of New Zealand and use the stable isotopic composition of dissolved inorganic carbon ($\delta^{13}C_{DIC}$) to determine the sources of dissolved carbon within the forested and grassland catchments.

Method

Water samples were collected every 3 to 6 months, under base flow conditions, from 64 catchments draining the Southern Alps of New Zealand from January 2012 until Febuary 2015. Dissolved organic carbon (DOC) samples were collected in 40 mL glass vials with silicon septa caps and analysed using a Shimadzu Total Carbon Analyser with an analytical precision of 0.2 mg C/L. Dissolved inorganic carbon (DIC) samples were collected in 60 mL LDPE bottles. Concentrations were measured using total alkalinity titrations and adjusted by pH to determine bicarbonate concentration (in mg C/L) and cross calculated using charge balance estimations of dissolved ions with an analytical precision of 5 % of total dissolved solids (in meq/L). $\delta^{13}C_{DIC}$ samples were collected in 100 mL glass vials with silicon septa caps and preserved with 10 % mercuric chloride and then analysed on a Thermo Advantage IRMS with a Gasbench sample preparation system, with a precision of 0.08‰.

Results

The median concentrations of DOC for each catchment ranges from 0.6 to 3.7 mg C/L, with the analysis of temporal variability showing no systematic increase or decrease in organic carbon between summer and winter. Thus, the amount of dissolved organic carbon in the Southern Alps rivers does not appear to respond to changes in plant uptake with seasons, or temperature. The median concentration of DIC ranges from 2.0 to 13.6 mg C/L, and similarly does not show seasonal differences. The higher values of DIC are mostly associated with highly erodible catchments, so that the inorganic carbon is likely from rock sources. Analysis of the $\delta^{13}C_{DIC}$ shows values ranging from -15 ‰ to -1 ‰, and is highly variable across the Southern Alps. Preliminary analysis suggests that the inorganic carbon is influenced by the portion of forest and grassland cover in the catchment. Forest dominated catchments produce depleted values of $\delta^{13}C_{DIC}$, whilst high grassland cover shows an enrichment in $\delta^{13}C_{DIC}$ values.

Session: Flood Management, Start Time: 1:20 p.m.

FLOOD FORECASTING REVIEW TEMUKA 2015

Mr Adam Martin[1]
[1]*Environment Canterbury, Timaru, New Zealand*

Aims

Flood Forecasting at Environment Canterbury has become a priority over the last five years, with the flood analysts wanting to make best use of available rainfall forecast data, particularly in catchments where flood warning times are short. Several flood forecasting models have been created for catchments in Canterbury using the DHI software Mike FloodWatch. The first model to be built was for the Temuka catchment. Following six floods, a review of the model's performance has been conducted, with the aim of the review being to assess the effectiveness of the Temuka flood forecasting model and recommend any additional work out of the results.

Method

There have been three flood events greater than the mean annual flood in the Temuka River since the model was built, and these, along with an additional three smaller events, have been selected for the review. The peak flow and the timing of the peak flow have been selected as the key components of the review. The aim of the analysis is to establish when the forecast data gives the best estimate of peak flow. How far in advance this 'best estimate' is to the actual peak gives us an indication of how useful the warning would have been (e.g. in terms of whether there is sufficient time for the flood controllers to act).

Results

Five events during the last five years have been selected for this review, as shown in Table 1.

Table 1. Flood events

Date	Peak Flow (m^3/s)
26th May 2010	564
31st July 2012	550
8th August 2012	390
15th June 2013	321
18th April 2014	442

*Mean annual flood ~300m^3/s

The flood peaks are plotted against the peak time, from this it can be seen which forecasts are the best both in terms of time of peak and peak flow. Table 2 is a summary of the results for the events selected.

Table 2. Flood Forecasting Results Summary

	Actual event		Flood forecast model	
Date	Time of Peak	Peak Flow (m^3/s)	Closest estimate of flow peak (m^3/s)	Time to peak warning (hr)
26th May 2010	05:30	564	511	6.5
31st July 2012	18:45	550	560	6.75
8th August 2012	10:00	390	406	5.5
15th June 2013	19:00	321	308	6.5
18th April 2014	16:00	442	336	16.5

The forecast flow results for 4 out of the 5 events are within ±10% of the actual flows. There is an outlier event in April 2014, which was affected by the forecast rainfall. The results above show that the forecast flow has been consistently good 6-7 hours before the peak. After discussion with Environment Canterbury flood controllers it has been determined that this is an acceptable warning time for this catchment.

Forecast rainfall was found to be the key factor in the accuracy of the forecasts. The forecasts are currently received on a 6 hourly basis from the MetService, this can and has led to large variations in the forecasts. It is hoped that in time these forecasts will be made more frequently, which would reduce the size of the changes in forecast and would reflect the reality of what is happening. Figure 1 shows the peak flow forecasts for the event in April 2014, and the estimate of time of peak. The red square is the actual event peak flow and timing. The forecasts are marked alphabetically from A to N. The effect of the changing forecasts can be seen to alter the prediction of peak flow as well as the time of peak.

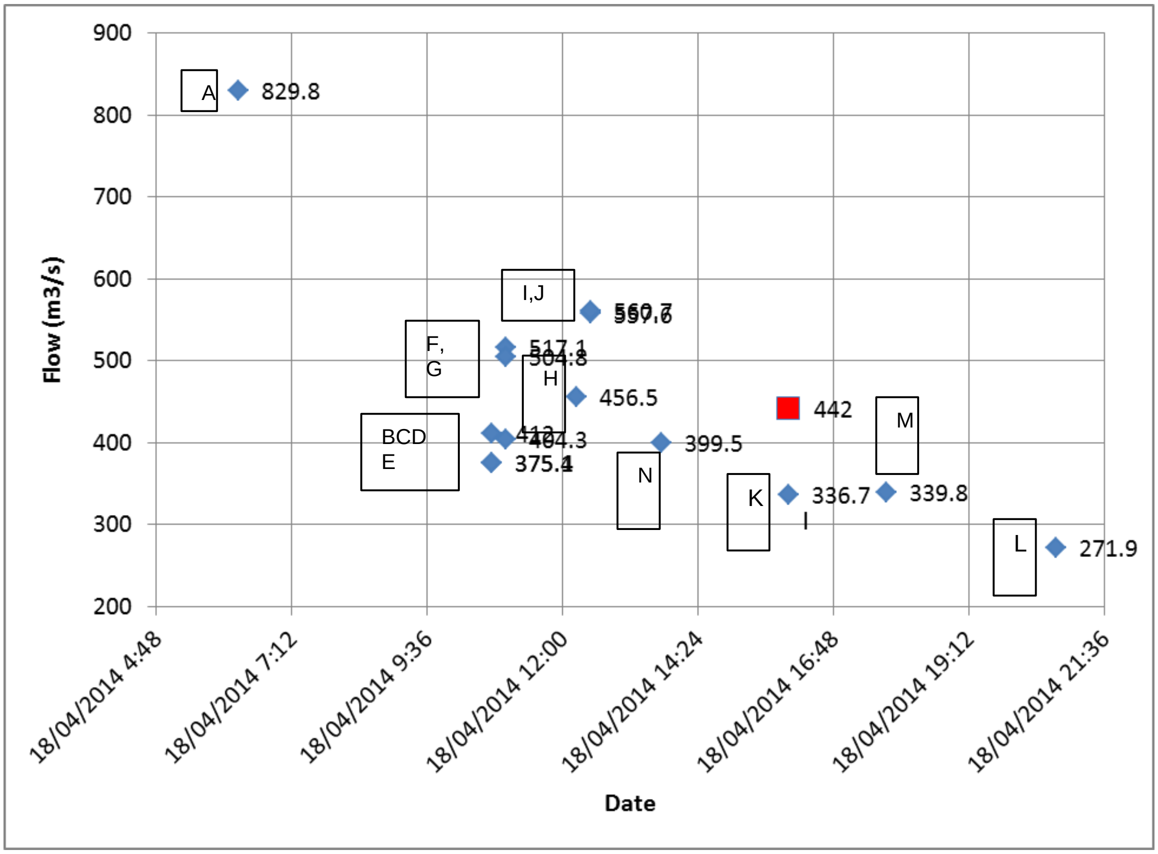

Figure 1. April 2014 Flood Forecasts

Based on the results above, the Temuka flood forecasting model is fit for purpose in providing flood peaks within ±10% of the actual peak, with approximately 6 hours lead-in time. It is expected that in time the rainfall forecasts will increase in frequency and that the model will be recalibrated using the additional data.

EVALUATING FLOOD MITIGATION OPTIONS USING GIS AUTOMATION

Mr Reuben Ferguson[1], Mr James Reddish[2]
[1]Morphum Environmental, Wellington, New Zealand, [2]Opus International Consultants, Auckland, New Zealand

Aims
Flood mitigation design can involve a large number of hydraulic simulations to compare the effects of different storm return periods and mitigation options on water levels. Identifying structures affected by flooding under each model scenario, so that mitigation performance can be evaluated, can therefore be a slow and inconsistent process. This project aimed to improve the efficiency of flood mitigation planning by automating this process within a GIS environment.

Method
A series of flood mitigation options were modelled in an intensively developed suburb in Auckland to identify the most effective way to protect residential properties from chronic flooding. An automated procedure was developed in GIS to relate predicted water levels from the hydraulic models to surveyed building floor levels so that the severity of flooding could be quantified over a range of rainfall and mitigation scenarios. The procedure assigned a flood hazard rating to each property and summarised this information in graphical and tabular forms so that the efficacy of different mitigation options could be directly compared.

Results
Automation enabled the merits of different mitigation designs to be compared more efficiently by speeding up and enforcing the consistency of data processing. This allowed the effect of different design parameters on flood impacts to be tested without a serious time penalty and consequent cost. The most appropriate mitigation option – a high-flow bypass pipeline and a stone wall flood defence – was then selected for further development. The automated approach explicitly documents the analysis workflow to clearly communicate methods and assumptions, and is widely applicable to other forms of hydrological and hydraulic analysis that have a repetitive element.

MITIGATING FLOODING AND LOW LAKE LEVELS AT WANAKA THROUGH THE USE OF PUMPED STORAGE

Mr Malcolm Taylor[1]
[1]*Waikato University, Alexandra, New Zealand*

Background/Aims

The idea of a hydro scheme at the Neck, between Lakes Hawea and Wanaka, has been raised many times in the past and as early as 1904, but has never had a detailed study. As a straight Hydro scheme there are a number of factors that work against the idea, including the remoteness of the location, transmission considerations and environmental concerns.

Recent investigations into possible pumped storage schemes in New Zealand suggested that this site be re-examined looking at the environmental effects of pumped storage rather than from a traditional Hydro Power station.

Methods

Flow and lake level data was obtained for Lakes Hawea and Wanaka, and inflow to each lake was calculated using a simple water balance. A model was constructed that simulated a pumped storage hydro station at the Neck between the two lakes and the effect on Lake Wanaka levels and outflows was examined.

Results

The results show that flooding events at Wanaka are reduced in frequency, duration and degree of flooding as measured by the lake level. Maximum levels were reduced slightly, average levels were raised by 0.3 m and low levels were raised by as much as 0.4 m. During the period of extended low lake levels in late summer and early autumn when the lake is very popular with recreational users the increase in lake level was as much as 1.1 m to bring it up to near average levels.

Conclusion

An appropriately sized pumped storage scheme at the neck between Lakes Hawea and Wanaka would have a moderating effect on the lake level at Wanaka by reducing the effects of flooding and limiting the exposed area of lake bed during dry periods.

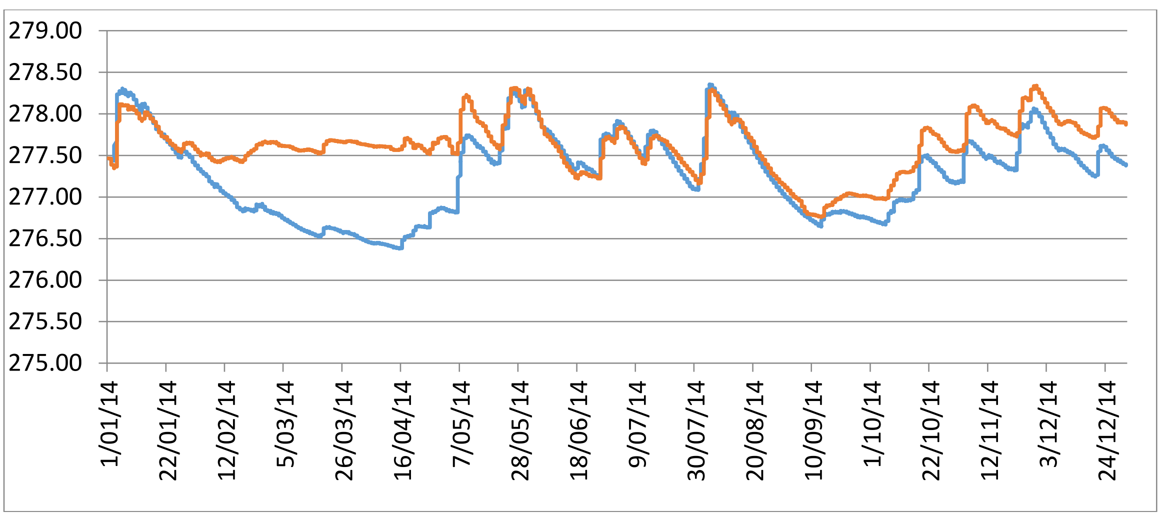

Fig 1. Actual 2014 Wanaka Lake Level (blue line) and Wanaka Lake level under pumped storage (yellow line)

FLOOD RISK MAPPING, FLOOD MANAGEMENT AND DEVELOPMENT CONTROL IN THE UK

Dr Harvey Rodda[1]
[1]*Hydro-GIS Ltd, Chalgrove, United Kingdom*

Aims

The aim of this paper is to provide a critical account of how flood risk mapping has been implemented and used in the UK since 2001 as an integral part of the planning process. The narrative will demonstrate how hydrological expertise is applied within the private development sector and how a lack of understanding of even the most basic hydrological principals from governmental agencies has led to a failed system.

Method

A programme of flood risk mapping was initiated by the UK government from 1999-2004 with the aim to provide the general public with information on the risk of flooding from rivers and the sea. The maps have been disseminated on the internet and have been widely used for emergency planning, insurance and development control purposes. The maps have been generated either from detailed site specific studies involving calibrated hydrological and hydro-dynamic models and the application of GIS; or from a generalized countrywide approach using fairly broad assumptions and an automated 2-d cell based modelling routine.

In terms of the use of the maps for development control, as a densely populated nation, there are strict controls on building in the UK and in particular the notion of building on the flood plain has often been presented in the media as one of the main reasons for increased incidents of flooding in recent years. Since 2001 the consideration of flood risk has become a statutory part of the planning process. The implementation of this through the submission of flood risk assessments as part of a planning application is discussed and in particular the failure of this approach through poor decision making by UK government agencies and local authorities is demonstrated.

Results

The failure of the approached is demonstrated by the results of four case study planning applications where plans to build on land with a demonstrated low risk of flooding have been refused, where measures proven to reduce the risk of flooding have been rejected and conversely where studies of insufficient detail in areas of known flood risk have led to planning applications being successful.

An alternative method is proposed whereby properly trained staff, with expertise in hydrology, are employed in the government agencies and they themselves are given the role of undertaking the flood risk assessments for a standard fee paid for by the developer.

FLOOD FREQUENCY ANALYSIS FOR CANTERBURY RIVERS: SUPPLEMENTING THE SYSTEMIC RECORD WITH HISTORIC AND REGIONAL FLOOD DATA

Ms Kate Steel[1], Helen Shaw[1], Adam Martin[1]
[1]*Environment Canterbury, Middleton, Christchurch, New Zealand*

Aims

Environment Canterbury is undertaking a comprehensive review of flood frequency data in the Canterbury region. The results will be used to update estimates recorded in flood response manuals maintained by Environment Canterbury.
The current estimates were calculated at different times using a range of different methods. Estimates for most sites were calculated using an annual extreme event series from the systemic record. Systemic data comes from continuous flow recorders at 42 flood warning sites on rivers across the Canterbury region. A number of sites in South Canterbury have estimates calculated using a regional method, or from an annual series supplemented with historical flood peaks.
We used data for three rivers: the Orari River; the Temuka River; and the Waimakariri River to assess the performance of available software packages and flood frequency analysis methods. Results from the pilot study were then used to develop a procedure for producing flood frequency estimates for the other rivers in the flood manuals.

Method

We looked at three different ways of obtaining flood frequency estimates: using systemic data; systemic data supplemented with historical data; and a regional flood frequency model.

HYDSTRA was used to analyse the systemic annual series. There are eight standard flood frequency analysis distributions available in HYDSTRA: the Gumbel; Generalised Extreme Value (GEV); Normal; Log Normal; Log Normal 3 parameter (LN3); Pearson Type 3 (P3); Log Pearson Type 3 (LP3); and Generalised Pareto (GPO).

We then used the Non Supervised Regional Frequency Analysis (NSRFA) package in the R statistical computing environment to perform Bayesian Markov Chain Monte Carlo analysis on a combined systemic and historical flood series. Years in the historical period with no data are represented by non-exceedance thresholds. The NSRFA package contains the same distributions available in HYDSTRA with the exception of the LP3. Additional analysis was undertaken for some rivers. If none of the standard flood frequency analysis distributions were a good fit for the data, the Two Component Extreme Value (TCEV) distribution was fitted to the data in Excel using the method of non-linear least squares.

Regional estimates were generated using a 2011 regional flood frequency analysis model created by NIWA for Environment Canterbury (Griffiths *et al*., 2011). The regional model uses the Gumbel distribution.

Results were analysed to establish which method provided the best estimate for each river. We explored why different methods might be more appropriate for particular rivers.

Results

The GEV, LN3, and LP3 distributions were a good fit for the systemic record annual series for all three rivers. The LN3 and the LP3 provide larger estimates than the GEV for the Orari River and the Temuka River, and smaller estimates than the GEV for Waimakariri River.

None of the distributions included in NSRFA were a good fit for the combined annual and historical data for the Orari and Temuka rivers. We were able to achieve a much better result by fitting the TCEV) distribution to the data (Figure 1). This is consistent with the findings of Connell and Pearson (2001) that the flood series for south eastern Canterbury rivers tend toward a TCEV distribution.

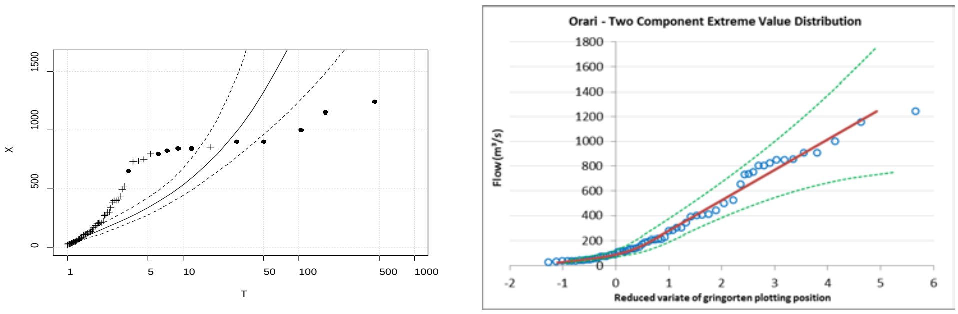

Figure 3 GEV and TCEV distributions for the combined annual and historical series for the Orari River

For the Orari and Temuka Rivers, the combined annual/historical series TCEV was the best fit overall. It produced larger flood estimates for 2.33 to 25 year return periods, and smaller estimates for 200 to 1000 year return periods than the best fit distributions for the annual series. The GEV was the best fitting distribution for the combined annual and historical series for the Waimakariri. For the Waimakariri River, inclusion of historical data resulted in larger flood estimates for all return periods.

The regional model produced much smaller estimates than the annual series or the historical series, for all return periods, and all rivers in the pilot study. Even pooled regional and at site estimates produced much smaller estimates for all return periods greater than 5 years. This may be due to the use of the Gumbel distribution which underpredicts for rivers with a tendency toward a GEV Type 2.

Conclusions

The regional method is expected to underpredict for sites with a tendency toward a GEV 2 distribution. However, for sites with a short record it can be difficult to tell which distribution is a good fit for the data, and information about flood behaviour in other rivers is needed to produce flood estimates for long return periods. Where sites have less than 30 years of record it may be helpful to use pooled estimates from the regional model to produce estimates.

Historical floods can provide useful information about the behaviour of floods larger than those observed with regularity during the period of systemic record; however they are likely to be influenced by climatic regimes. Results from the combined annual and historical flood frequency analysis for South Canterbury rivers support the hypothesis that the TCEV is the distribution of best fit for these rivers. The five largest floods in an annual series for the Orari river dating back to 1960 exhibit behaviour consistent with a two component distribution. Smart and Mckerchar (2010) found no change in the frequency of large floods since 1960 for rivers in the northern South Island. A future study could investigate whether there has been a shift in climatic regime in south coastal Canterbury since the beginning of the historical period. We recommend the inclusion of historical flood data in flood frequency analysis where reasonable flow estimates are available, and historical floods are part of the present climatic regime.

The NSRFA package allows for the use of historical flood data in regional flood frequency analysis. A future study could investigate regional flood frequency analysis for groups of similar rivers within the Canterbury region using a combined systemic and historical record. It is also possible to include historical floods in Bayesian MCMC analysis as upper and lower bounds for each flood. This would allow us to include floods that don't have precise flow estimates, and to represent the uncertainty associated with historical flood measurements in our analysis.

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Griffiths, G., McKerchar, A., Pearson, C. (2011). Review of flood frequency in the Canterbury region. Environment Canterbury report R11/50.
Smart, G., McKerchar, A. (2010). More flood disasters in New Zealand. Journal of Hydrology (NZ), 49(2), 69-7

Session: Managing to Limits: Water Quantity, Start Time: 1:20 p.m.

LEARNING BY DOING: THE TARGETED STREAM AUGMENTATION PROJECT

Dr Brett Painter[1]
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Aims

The Targeted Stream Augmentation (TSA) project is part of the Selwyn-Waihora Zone Committee's vision for Te Waihora/Lake Ellesmere and its catchment (see Figure 1), implemented through the Canterbury Water Management Strategy and Environment Canterbury's Land and Water Regional Plan. The aims of the project are to identify aquifer recharge and stream augmentation concepts that are assessed to be feasible (in a planning, technical and economic sense) and acceptable (in a cultural, ecological and community sense).

Method

The Canterbury Water Management Strategy (2009) provides clear guidance for assessing water management concepts against agreed cultural, environmental, social and economic priorities and targets. Data from all potentially relevant target areas are collated, assessed and discussed with a variety of decision-makers until agreement is reached on the generated knowledge. The specific challenges addressed by the TSA project are the "how, where and when" of aquifer recharge and stream augmentation management to assist with lowland stream ecological flow objectives without negative effects such as increased flooding risk.

The "how" relates to the source of water and method of recharge/augmentation. The "where" relates to the site of recharge or augmentation. The "when" relates to the timing and magnitude of supply. A classical approach to this situation could be to describe and solve it via a multi-objective optimisation problem. However, the wide variety of potentially relevant data from cultural, environmental, social and economic assessments (not to mention the significant weighting given to the views of potentially affected landowners) has meant that the path from data to knowledge in this instance has required a more adaptive and cyclical "learning by doing" approach.

Results

Two potentially complementary water sources have been identified. These are currently consented stock water from the Rakaia River and groundwater that passes stream depletion and well interference tests. 80-90% of consented Rakaia River stock water currently recharges the groundwater system as "unmanaged" recharge, which benefits lowland stream flows but also increases flooding risk in the lower catchment when groundwater levels are high. The upper catchment stock water network is gradually being shut down, with stockwater provided instead through groundwater consents or via the new Central Plains Water (CPW) scheme distribution. Unused stock water is able to be used for aquifer recharge due to provisions in the National Water Conservation (Rakaia River) Order. The second potential source of water is groundwater despite the catchment already being in an over-allocated state. As the groundwater system feeds the lowland streams they are managed conjunctively. This means that taking deep groundwater to augment a lowland stream has no net effect on the total catchment allocation.

An aquifer recharge and a stream augmentation method were chosen for assessment. The chosen aquifer recharge method is purpose-built soak holes. Stream augmentation is via an engineered structure that adjusts dissolved oxygen levels (and temperature if necessary) before augmenting the receiving waterway. Both methods were carefully worked through with mana whenua representatives to address mixing-of-waters questions.

The 'where' questions first required a prioritisation of lowland streams then identification and analysis of supply options with the aim of balancing cost and magnitude of supply. Cultural and ecological assessments of lowland streams between the Selwyn and Rakaia Rivers resulted in the greatest proportional minimum flow increases being confirmed for the Irwell River (minimum flow increasing from 300 to 890 l/s) and Boggy Creek (minimum flow increasing from 50 to 261 l/s).

The Irwell River is primarily fed by shallow groundwater in a paleo flood channel of the Selwyn River and originates approximately half way down the catchment. Sustained flow in the Selwyn River at this point is primarily reliant on surrounding groundwater levels. Hydrogeological investigations and local landowner discussions provided the confidence to proceed with designing a soak hole that intersects the paleo flood channel. The benefit/cost ratio assessment identified a combination of CPW distribution plus TSA-specific and current stock water distribution that could supply up to 200 l/s to a soak hole ~1 km up-gradient from the spring at the source of the Irwell River.

Boggy Creek is fed by springs and drains down-gradient from a historical swamp just to the south of the Irwell River. The majority of water quantity benefits to lowland stream springs (and potential risks such as increased flooding) from the new CPW scheme are expected to bypass Boggy Creek due to the up-gradient swamp. A benefit/cost assessment of supply options (supported by infrastructure, regional groundwater modelling and groundwater bore assessments) concluded that artesian groundwater (~60 m below ground) delivered close to Boggy Creek was the preferred option. An existing bore that could feed two intermittent tributaries in the upper reaches of Boggy Creek was then identified through the bore survey and landowner discussions.

The 'when' questions are still being explored. Groundwater modelling identified potential lag times for aquifer recharge via soak holes. An assessment of current surface and groundwater monitoring identified gaps relevant to the required knowledge from the Irwell and Boggy Creek experiments. Additional flow monitoring and groundwater monitoring bores were actioned to gather background data prior to the experiments taking place. Results from a 30-day Boggy Creek augmentation experiment in June 2015 are currently being processed and analysed but it seems to have met key objectives. These include maximising the proportion of augmented flow staying in the Boggy Creek system and diluting nutrient concentrations without flooding risk increase or other negative effects due to differing temperature or dissolved oxygen concentration. Implementation opportunities are now being explored. A 6-9 month Irwell River experiment is on track to begin in early spring 2015. Up to date details of the knowledge gained thus far in the Targeted Stream Augmentation project will be presented at the symposium.

Figure 1. Southern section of Selwyn-Waihora Zone and key features

Reference

Canterbury Mayoral Forum. (2009) *Canterbury Water Management Strategy.* [Online] Available from: http://ecan.govt.nz/publications/Plans/cw-canterbury-water-wanagement-strategy-05-11-09.pdf [Accessed 21st July 20

LAKE ROTORUA CATCHMENT BOUNDARY RELEVANT TO BAY OF PLENTY REGIONAL COUNCIL'S WATER AND LAND MANAGEMENT POLICIES

Paul White[1], K Rutherford[2], C Tschritter[1], A Lovett[1]
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Introduction

Bay of Plenty Regional Council (BOPRC) and the local community aim to restore water quality in Lake Rotorua with policies that include land-use controls within the Lake Rotorua catchment (Bay of Plenty Regional Council, 2014). These policies include land-use controls within the Lake Rotorua catchment and therefore water and land management policies within the Lake Rotorua catchment are different to policies outside the catchment. A definition of the Lake Rotorua catchment boundary, at a suitable resolution and with uncertainty limits, is crucial because it identifies the land parcels that are relevant to policies.

Method

The boundary of the Lake Rotorua catchment defined in this report was developed in two parts: a surface catchment boundary that includes most of the area in the east between Kaharoa and Mamaku township; and a groundwater boundary on the Mamaku Plateau (White, et al., 2014). These two parts combine to describe the "best-estimate Lake Rotorua groundwater catchment boundary". The surface catchment was derived from topographic contours at a 1 m interval based on the 2006/2007 LIDAR data collected by Rotorua District Council. The groundwater boundary on the Mamaku Plateau was derived using multiple data sets including: topographic contours and water budgets that used estimates of surface water flows and gridded rainfall, surface flow, groundwater recharge estimates and locations of groundwater divides. The groundwater catchments of three spring-fed streams that drain the Mamaku Plateau (Hamurana, Awahou and Waiteti) were also considered, as the catchments of these streams provide a control on the location of the best-estimate groundwater boundary across Mamaku Plateau.

The best-estimate Lake Rotorua groundwater catchment boundary was derived at a resolution of 1:2000, as this scale is suitable for policy purposes. Uncertainties in the best-estimate groundwater boundary were calculated at the 95% confidence interval. These uncertainties were identified for the surface catchment boundary with an analysis of topographic models and for the Mamaku Plateau by considering uncertainties in surface flows at Ohau Channel, Hamurana Stream, Awahou Stream and Waiteti Stream.

Results

The best-estimate Lake Rotorua groundwater boundary (including Lake Rotorua) has an area of 537.1 km^2, and produces an estimated mean flow of 16.5 m^3/s at Ohau Channel. This flow is equal to the mean observed flow at Ohau Channel. Within this area, the estimated groundwater catchments of Hamurana, Awahou and Waiteti streams produce average flows (2.6 m^3/s, 1.6 m^3/s and 1.2 m^3/s respectively) that are equal to average observed flows in these streams. The best-estimate Lake Rotorua groundwater boundary is larger than the surface catchment boundary by approximately 35 km^2. Most of this land (33.2 km^2) is within the groundwater catchment of Hamurana Springs.

The Hamurana Springs groundwater catchment was divided into three zones:

1. The Mamaku Plateau Basin appears as an area of internal drainage that provides 0.5 m^3/s of flow to Hamurana Stream, i.e., all the flow that is net of rainfall and actual evapotranspiration flows to groundwater. It was assumed that no surface flow leaves this zone as tomos are observed in the zone, ground conditions at locations of possible surface drainage were swampy, and no surface flow was observed at these locations during a field visit in winter 2014.

1) Mamaku Plateau North provides 0.8 m^3/s of flow to Hamurana Stream. This zone is relatively flat with surface topographic gradients indicating that the ground slopes to the north. Swampy conditions are common in this zone, particularly north east of the Mamaku Plateau Basin. It was assumed that no surface flow leaves this zone because little, or no, surface flow was observed in the zone during a field visit in winter 2014 and gauged surface flows in the upper Mangorewa River catchment were all close to zero.

2) Hamurana Springs groundwater catchment inside the best-estimate surface catchment, which provides 1.3 m^3/s of flow to Hamurana Stream.

The 95% confidence interval for the best-estimate surface catchment boundary in the east was an estimated 20 m. Uncertainty in the bestestimate Lake Rotorua groundwater boundary on the Mamaku Plateau was 200 m for the Hamurana Stream catchment, and -640 m to +740 m for the Awahou and Waiteti catchments. The uncertainty in the Hamuarana Stream flow is less than that of the other two streams; therefore the uncertainty in the Hamuarana Stream catchment boundary flow is less than that of these streams.

References

Bay of Plenty Regional Council, 2014. Proposed Regional Policy Statement, Clear Copy, Appeals Version 8.0c - Part 3. http://www.boprc.govt.nz/knowledge-centre/policies/the-next-regional-policy-statement/, accessed 12/8/2014.

White, P.A.; Cameron, S.G.; Kilgour, G.; Mroczek, E.; Bignall, G.; Daughney, C.; Reeves, R.R. 2004. Review of groundwater in the Lake Rotorua catchment. GNS Client report 2004/130. 231 p.

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NPSFM 2014 – SURFACE WATER ACCOUNTING SYSTEM

<u>Dr Edmund Brown</u>[1], Mr Bevan Jenkins[1], Mr Gerard Mould[2]
[1]Waikato Regional Council, Hamilton, New Zealand, [2]Enlighten Designs Ltd, Hamilton, New Zealand

Aims

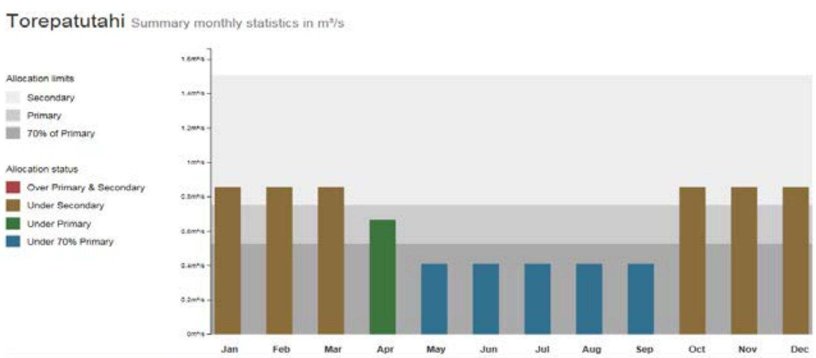
Develop a surface water accounting system for the Waikato Region to meet the requirements of the National Policy Statement on Freshwater Management 2014. The Waikato Regional Council has operated a water accounting system since 2006 (Brown and Haigh, 2006). This was only available to staff and operated on our internal GIS system. The approach presented here is to provide a similar system but making it readily available to the public and making the information more readily digestible rather than large tables of data typically associated with GIS views.

Method

Council contracted enlighten web designs to develop an online interface to present water allocation data. The product was developed over a three week period. Bevan Jenkins from Council worked in-house with Enlighten to streamline the development and testing process.

Results

A surface water take application or consent ID number is entered. The cumulative allocation is reported from the physical location of the water take, linking with all known flow statistics relating to allocation limits, down to the sea. A report is presented expressing the allocation pressure both with and without the searched water take. Seasonality of each water take is presented on a monthly time scale – Figure 1.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Limits												
Q5	5.03000	5.03000	5.03000	5.03000	5.03000	5.03000	5.03000	5.03000	5.03000	5.03000	5.03000	5.03000
Primary Allocation	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450
Secondary Allocation	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450	0.75450
APP124664_01												
Rate	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200
All Authorisations *including* APP124664_01 (Impacted)												
Impacted Rate	0.85850	0.85850	0.85850	0.66750	0.41180	0.41180	0.41180	0.41180	0.41180	0.85850	0.85850	0.85850
Impacted Rate Spare in 70%	-0.3303	-0.3303	-0.3303	-0.1393	0.11635	0.11635	0.11635	0.11635	0.11635	-0.3303	-0.3303	-0.3303
Impacted Rate Spare in Primary	-0.1040	-0.1040	-0.1040	0.08700	0.34270	0.34270	0.34270	0.34270	0.34270	-0.1040	-0.1040	-0.1040
Impacted Rate Spare in Secondary	0.65050	0.65050	0.65050	0.84150	1.09720	1.09720	1.09720	1.09720	1.09720	0.65050	0.65050	0.65050
Percentage Impacted	56.9%	56.9%	56.9%	44.2%	27.3%	27.3%	27.3%	27.3%	27.3%	56.9%	56.9%	56.9%

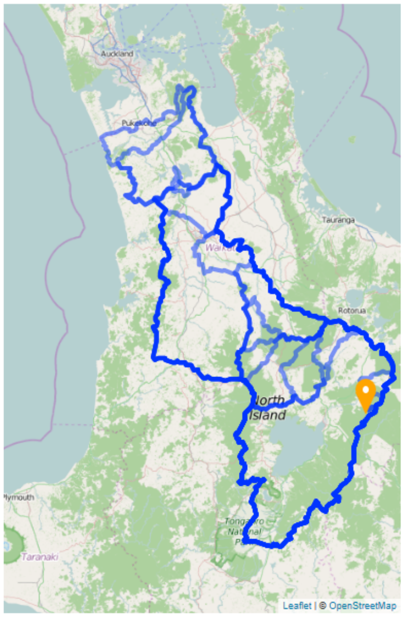
Figure 1: Monthly allocation summary for a selected catchment

The tool is update nightly linking in information relating to all surface water takes and selected groundwater takes impacting on surface water from IRIS our consent database, low flow statistics from our hydrology data base WISKI and allocation limits from the Regional Plan. An estimate of un-consented water use is provided from an in-house GIS layer (Brown 2009).

The relevant regional plan rule for processing water take applications is driven by the degree of allocation stress. This is assessed for the relevant time of year the water will be taken and the location within the catchment where the cumulative allocation pressure is greatest. The tool automatically identifies the location of greatest pressure for the consent officer. This is particularly useful in large catchments where there can be over 16 locations where flow is measured and the allocation pressure can be reported. The catchment with the highest level of allocation is highlighted with a red box, Figure 2.

Map

Toggle consents



Catchments

Description	Worst Month	Status by Month
Rautawiri	No flow data available	
Torepatutahi	Under Secondary allocation	
Waikato River at Ohakuri Dam	Under 70% of Primary allocation	
Waikato River at Atiamuri Dam	Under 70% of Primary allocation	
Waikato River at Whakamaru Dam	Under 70% of Primary allocation	
Waikato River at Maraetai Dam	Under 70% of Primary allocation	
Waikato River at Waipapa Dam	Under 70% of Primary allocation	
Waikato River at Arapuni Dam	Under 70% of Primary allocation	
Waikato River at Karapiro Dam	Under Primary allocation	
Waikato at Hamilton Traffic Bridge	Under 70% of Primary allocation	
Waikato at Ngaruawahia	Under 70% of Primary allocation	
Waikato at Huntly Power Station	No flow data available	
Waikato River 5km downstream from Huntly Power Station	Under 70% of Primary allocation	
Waikato at Rangiriri	Under 70% of Primary allocation	
Waikato at Mercer	Under Primary allocation	
Waikato River at mouth	Under Primary allocation	

Figure 2: Catchment allocation summary

The Council has not yet determined Freshwater Management Units (FMUs) for surface water management. At this time we are using existing allocation layers covering over 300 catchments across the region. This provides a much greater spatial representation that will likely be covered by yet to be determined large FMUs.

The accounting system is available at http://www.waikatoregion.govt.nz/Environment/Natural-resources/Water/Water-allocation-levels/ . Future development will provide improved reporting by each major use category. Enhancements are also being made to visualise the duration of all consents within queried catchments to aid in implementing Policy B6 of the NPS where over-allocation should be phased out

References

Brown, E.J. (2009). A model for assessing the magnitude of unconsented surface water use in the Waikato Region. *Paper presented to joint NZ Hydrological & Freshwater Sciences Societies Conference, Whangarei 2009*, New Zealand

Brown, E.J. and Haigh, A. (2006). Water Allocation Calculator*. Paper presented to* NZ *Association of Resource Management, NZ Hydrological Society and Meteorological Society of NZ joint conference 'Resource Management under Stormy Skies:* Water *Allocation at the Crossroads. 20-23 November 2004, Christchurch, New Zealand*

SURFACE WATER ALLOCATION IN THE HORIZONS REGION – CONSENTED VERSUS ACTUAL WATER USE

Mrs Stacey Binsted[1]
[1]*Horizons Regional Council, Palmerston North, New Zealand*

Introduction

Measurement of actual water use has been a key focus for Horizons Regional Council over many years and the introduction of the National Regulations for Measuring and Reporting of Water Takes has strengthened the need for this information. Horizons have been steadily increasing the numbers of takes telemetered in the region since 2004 and now collect water use data for a majority of large water abstractors (greater than 850m^3/day) across the region. This telemetered water data set has recently been processed and quality coded to give a clearer understanding of where water is actually being used in the region and where opportunities exist to redistribute water more efficiently.

It is important to understand the actual amount of water used as opposed to the amount consented for a number of reasons. If actual use is lower than consented use, this could indicate that while water is allocated on paper, in reality the water is not being used. This could also indicate the current use occurring could potentially increase as consent holders increase their use towards the maximum allowable under their consent and thus potentially exacerbate current issues and potentially drawing flows below minimum more frequently.

Method

Data for telemetered consents has recently been collated and a quality coding and quality assurance programme has been designed and implemented to process data in accordance with the NEMS Water Meter Data National Quality Coding Schema. The resulting values were then summarised on a subzone, zone and multiple subzone level to give an overall indication of actual water use in a number of areas. A large scale programme was undertaken for the 2012/13 water year resulting in a number of reports around water use and surety of supply being produced in preparation for a number of impending consent renewals in highly allocated areas.

Results

The results of this analysis indicated actual water use in a number of areas of the region are well below the amount which is actually consented. The Whanganui catchment showed maximum daily actual water use of 65% of consented, the Upper Manawatu 77%, the Mid-Lower Manawatu 58% and the Rangitikei 56% for the 2012/13 water year.

The cause of the differences between catchments has not been fully defined although some of this could be explained through there differences in terms of land use and hydrology. For example water in the upper Manawatu catchment is used predominately for pastoral irrigation with maximum use usually peaking around mid summer often coinciding with periods of low flow conditions. This analysis has shown there are a number of consent in that catchment which don't use their full allocation even during these peak times for a number of reasons including lack of infrastructure, lack of scale to make irrigation viable and changes in land use on farm, if they were to use these consents there is the potential that minimum flows could become more common which would effect all users.

The results of this analysis have highlighted some areas where water could perhaps be more efficiently allocated. This data will be use through the consenting process to justify more efficient allocation. It also highlights some of the opportunities available to users around allocation sharing and potential options for users to implement water storage schemes. The ongoing processing of this data will make dealing with consent holders who do not exercise there allocation more efficient with good quality data being available when it comes time to review or renew consents.

WATER USE: PERCEPTIONS, SEMANTICS AND SCIENCE

Dr Daniel Collins[1]
[1]*NIWA, New Zealand*

New Zealand's water cycle provides us with a range of ecosystem goods and services that underpin valued environmental, social, cultural and economic outcomes. These include the provision of drinking water, irrigation, hydropower, and taonga aquatic species along with many others. However, despite the fundamental importance of water within New Zealand, perceptions of how much water we use and how much is wasted vary, and this is not simply due to a lack of scientific data. This mismatch has implications for stakeholder decision-making, where opportunities for sustainable development may be missed or potential costs and risks go overlooked, and for community acceptance of freshwater management activities, where debate may be needlessly acrimonious.

To illustrate the issue, two examples of widespread public perceptions will be examined: (1) that only 2% of New Zealand's water is used, the rest wastefully flowing out to sea; and (2) that it takes about 1000 L of water to produce 1 L of milk. In each case, we can trace how these perceptions have likely come about, how they may be misleading, what more accurate and useful statements would be, and how to provide more accurate and useful statements.

In the case of New Zealand's water use, the 2% figure is derived from water allocation data for non-hydropower purposes, and therefore not only overlooks hydropower, which uses over 10% of New Zealand's mean annual river discharge (with multiple use removed), but also the other non-consumptive uses such as recreation, natural habitat support, tourism and others. This confusion may stem in part from ambiguity of the word "use" and in part from difficulties in communicating complex science to non-technical or less-technical audiences. A national average is also problematic because it implies that the abundant water available on the West Coast, for example, could be used in dry Canterbury or even Hawke's Bay, neither of which is practical.

In the case of water used for milk production, the "1000 L" figure may come from one of two sources: a widely distributed study of international water footprint estimates, or a popular article by the present author. A potential confusion immediately arises, however, because the latter value did not refer to irrigation alone, but instead to irrigation, rainfall and assimilative capacity combined. More useful and relevant New Zealand estimates can instead be obtained from bulk water allocation and production data, and from existing water footprinting studies in Waikato and Canterbury.

Together, these case studies show that public perceptions of water use, and of water resource issues in general, can diverge from accepted science, potentially interfering with freshwater management and use activities. This in turn highlights the value of bidirectional science communication and collaborative learning.

Session: Transport and Transfirmation of Contaminants, Start Time: 1:20 p.m.

INVESTIGATING HOW SOIL DRAINAGE CLASS AFFECTS THE REDOX STATUS OF SHALLOW GROUNDWATER

Dr Juliet Clague[1], Dr Roland Stenger[1], Mr Brian Moorhead[1]
[1]*Lincoln Agritech Ltd, Hamilton, New Zealand*

Introduction

We have recently extended our research on the assimilative capacity of groundwater systems for nitrate to the Reporoa Basin in Waikato. The particular focus of the presented study is to investigate to which extent the drainage class of the soil zone (approx. 1 m depth) affects the redox status of the underlying shallow groundwater. The Reporoa Basin offers good opportunities to address this question as soils ranging in their drainage class from well-drained to very poorly drained occur in close proximity and at locations with reasonably shallow depth to the groundwater table.

Method

Potential well locations were identified using S-map to cover the variety of soil types and drainage classes found in the area (Figure 1). Preliminary site investigations were then carried out to ascertain how accurate the S-map predictions were, and to document the aquifer material beneath the soil zone. The Childs test was used to indicate where possible reducing zones might be located (Childs, 1981). Six monitoring wells (50 mm diameter PVC) were then installed at selected locations using a novel coring method which eliminates the problem of annular gap bypass flow. An attempt was made to cover the well-drained, imperfectly drained, poorly drained and very poorly drained drainage classes found in the area; however, the supposedly very poorly drained site (GW05) turned out to be imperfectly drained. A mini bladder pump (150 mm long) located between two inflatable packers was used to sample the wells at 3 - 5 discrete intervals and characterise the groundwater chemistry. Field measurements of dissolved oxygen, pH and electrical conductivity were monitored until stable and then samples were collected. An aliquot was field-filtered (0.45 µm) and acidified (nitric acid) for the analysis of dissolved iron and manganese. A 500 mL sample was also taken and analysed for NNN (nitrate + nitrite), dissolved reactive phosphorus, total phosphorus, sulphate and silica. Future samplings will entail a comprehensive suite of analytes including carbon species, cations, anions and dissolved gases.

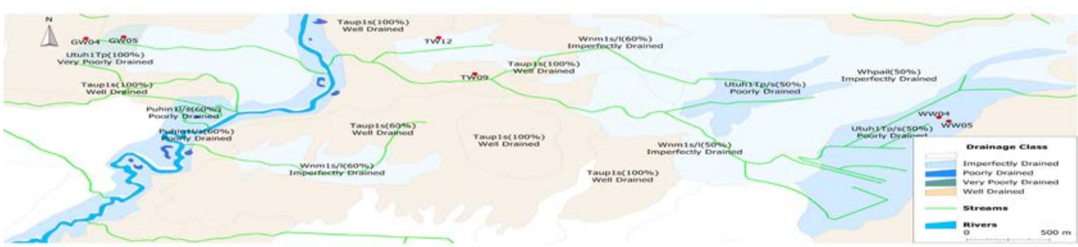


Figure 1: Location of the six wells installed in the Reporoa Basin, and the corresponding S-map soil and drainage classification.

Results

The information found in S-map provides a starting block for field investigations since such information is rarely accurate at the paddock scale. Finding appropriate profiles, with shallow groundwater required comprehensive field investigations before wells could be installed at suitable sites.

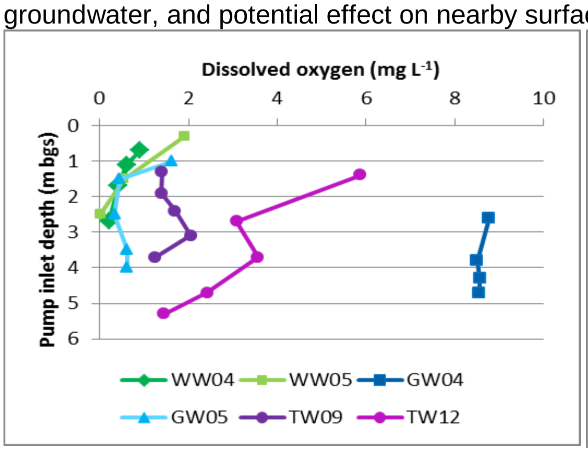
Table 1 shows the classification, Childs test response and initial groundwater redox status of the six wells installed so far. More wells will be installed to provide another profile example of both the well-drained and impeded Pumice soils found in the area.

Table 1: Soil type, drainage class, Childs test response and initial redox status of groundwater for the six wells installed in the Reporoa Basin.

Well ID	Soil	Drainage class	Childs test Response	Redox status of groundwater
GW04	Immature Orthic Pumice	Well-drained	Negative	Oxidised
GW05	Mottled Impeded Pumice	Imperfectly drained	Positive 1.0 – 1.5 m	Reduced
TW09	Mottled Orthic Pumice	Imperfectly drained	Positive 1.5 – 4.0 m	Reduced
TW12	Mottled Orthic Pumice	Imperfectly drained	Positive 2.0 – 3.0 m	Oxidised over reduced
WW04	Mellow Humic Organic	Poorly drained	Positive 2.0 – 4.5 m	Reduced
WW05	Mellow Humic Organic	Very poorly drained	Positive 1.5 – 4.0 m	Reduced

Results from the initial round of sampling indicate that denitrification is occurring in the shallow groundwater of several locations in the Reporoa area. Denitrification substantially changes the chemical composition and environmental impact of the water entering Waiotapu stream and the Waikato River by reducing nitrate to dinitrogen gas.

The well-drained, oxidised profile found in GW04, has high NNN concentrations throughout the profile (Figure 2). This well represents the impact high intensity dairying can have on the underlying groundwater, and potential effect on nearby surface water.



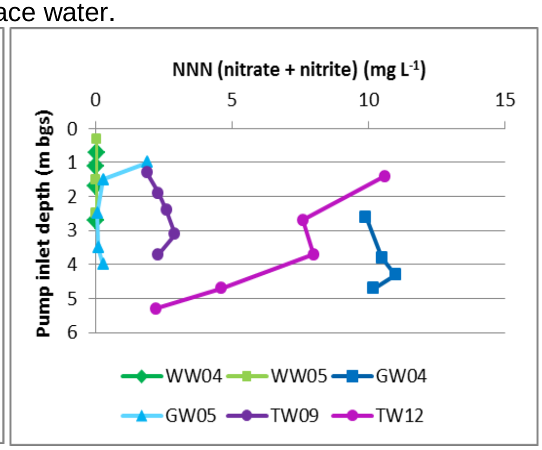


Figure 2: Profiles of the dissolved oxygen and nitrate + nitrite concentrations measured in the six wells sampled in the Reporoa Basin.

In contrast, the imperfectly drained TW12 profile shows a redox gradient with depth and concomitantly declining NNN concentrations (Figure 2). This is likely due to active denitrification, although the electron donor involved remains unknown at this stage since analysis of the predominantly sand and pumice core samples revealed low total carbon concentrations throughout (<1%).

The two poorly drained profiles (WW04 and WW05) have peat in the upper part of the profile, and very shallow groundwater (<0.4 m bgs) that is already reduced and nitrate-free (Figure 2). It is highly likely that denitrification has occurred at these sites since dissolved iron and manganese concentrations are elevated (data not shown) and the peat layer would provide a suitable electron donor for denitrification.

Future samplings will reveal how temporally stable the geochemistry of the shallow groundwater in the Reporoa Basin is, and whether the denitrification process is dynamic or constant.

This research was conducted under the ‘Groundwater Assimilative Capacity’ programme funded by MBIE.

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MODELLING HETEROGENEOUS AQUIFERS FOR ROBUST AQUIFER MANAGEMENT DECISIONS

Dr Catherine Moore[1,2], Mr David Scott[1]
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Aims

The extremely heterogeneous nature of many alluvial gravel aquifers in New Zealand presents challenges for both the interpretation of field testing (pumping and tracer tests), and for how these tests are used when simulating groundwater impacts to support decision making. Conventional analysis of aquifer tests and predictive modelling is typically done at a scale that is incapable of representing the real-world complexity and it is common to assume isotropic conditions, likely resulting in inaccurate predictions with implications for management of groundwater resources. This issue is being explored in a project which examines the options for up-scaling heterogeneous properties from fine scale models to examine how conventional approaches to analysis and modelling affect the reliability of predictions and to identify improved methods. The aim of this work is to assist in obtaining better information for management of our groundwater resources and for prediction of contaminant transport, such as pathogenic microbes, in heterogeneous aquifer systems. One aspect of this work is the characterisation of these aquifer systems at the fine scale, to support realistic upscaling analyses. A novel approach for this characterisation is presented.

Method

Markov chain based geostatistical methods characterise the juxtapostional tendencies of stratigraphic units (in our context open framework gravels, sand, sandy gravels and claybound gravels). These methods have been evaluated for their adequacy in representing the fine-scale open framework gravel features in particular which play a significant role for contaminant transport in alluvial gravel aquifers. Investigations on how to enhance this characterisation of aquifer structure include using a unique set of smoke tracing experiments (undertaken at Kyle in South Canterbury), to provide connectivity information. These smoke tracing experiments have been used to extend the application of the selected T-progs package to generate more realistic representations of the aquifer, conditioned on the observed lithology and inferred connectivity. These geostatistical characterisation improvements should lead to more accurate models of contaminant transport in heterogeneous groundwater systems.

Results

A series of logs from bore holes and a cliff outcrop provided the lithological logs used to underpin the markov chain geostatistical analysis depicted in T-progs (Figure 1a). The resulting vertical transition probability relationships are depicted in Figure 1b.

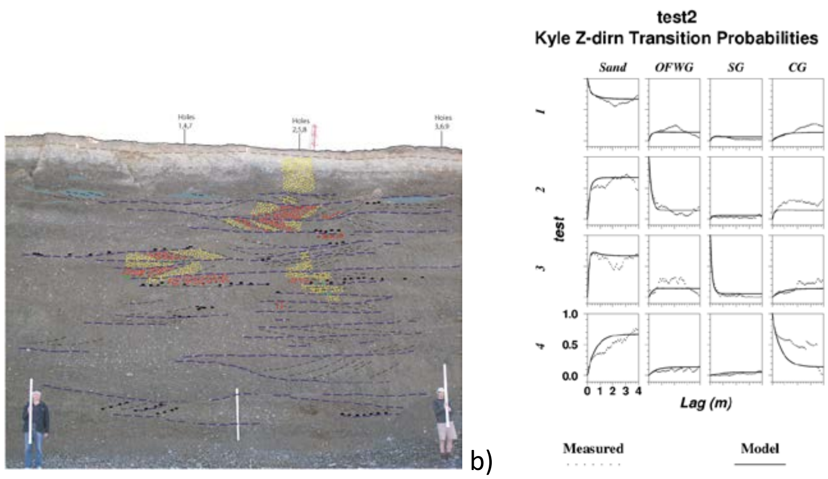

Figure 4: a) Photograph of Kyle cliff face; b) vertical transition probabilities based on bore hole and cliff lithological logs.

The lateral transitional probabilities parallel and perpendicular to the depositional direction were calculated on the basis of this vertical transition probability relationship depicted in Figure 1b. An example of the generation of multiple equally plausible aquifer property realisations on the basis of these transition probabilities is shown in Figure 2.

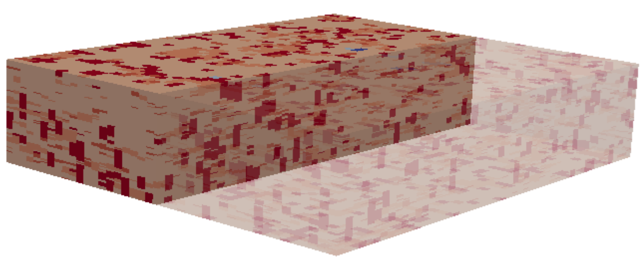

Figure 5. Hydraulic property realization generated using on the Tprogs on the basis of Kyle lysimeter bore logs.

The potential for a reduction in predictive uncertainty of contaminant transport travel times and concentration reduction resulting from conditioning fields using the use of hydraulic property fields generated on the basis of both bore logs and smoke tracer test data compared to bore logs alone is currently being explored.

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SPATIAL DISTRIBUTION OF LAG TIMES AND NITRATE ATTENUATION IN WAIKATO GROUNDWATER

Mr John Hadfield[1], Mr Murray Close[2], Mr Scott Wilson[3]
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Introduction

In the summer of 2014-15, short-term groundwater related investigations were undertaken in support of the Waiora He Rautaki Whakapaipai project (Healthy Rivers - Plan for Change). This project will establish limits and targets for nutrients (as well as sediment and *E. coli*) in waters of the Waikato and Waipa catchments. A focus on time lags and losses inherent in nitrogen transport in groundwater was part of the work undertaken and is described here. Brief reporting of radon surveys to characterise groundwater input to streams is also reported.

Lag variation

Water was sampled for age dating throughout the Healthy Rivers study area and comprised 23 groundwater samples, three springs and 21 other surface water samples. The previous year 13 surface water samples from the Upper Waikato were analysed for tritium with only two being available before that. Groundwater age estimates, by contrast, were already available from 85 groundwater wells in the study area (~160 regional-wide). The most recent groundwater samples included 10 from wells in the Waipa catchment and all were analysed for CFCs, SF_6 and tritium. Groundwater samples were also taken from either side of the redox-cline from two sites adjacent to the Waikato River south of Karapiro and one in the Hamilton Basin.

Apart from the Upper Waikato streams, the age of surface waters (expressed as mean residence time) are generally less than 15 years and average about 10 years. The base-flow dominated Upper Waikato sub-catchment streams are older with an average measured mean residence time of about 52 years (median 35 years; flow weighted mean of about 47 years). The Upper Waikato main stem water age is younger (about 12 years at Karapiro) due to the influence of Lake Taupo which provides two thirds of the flow.

The age of groundwater throughout the study area is highly variable with mean residence times often much older than surface waters (mean and median residence time estimated from the summer monitoring results are about 114 and 95 years respectively). The mean and median of the previously available groundwater age analyses was about 68 and 48 years respectively. Although the relationship between groundwater age and depth is not significant, age is generally expected to increase with depth in a recharging regime. Similarly there is no simple linear relationship between age and nitrate-N concentration in wells. Typically, however, there is a wedge shaped distribution showing groundwater older than the significant development of farming is low in nitrogen, whereas younger groundwaters range in concentration dependent on land-use influence and attenuation.

Regional scale estimates were made of the lag time for groundwater flow through the vadose zone into groundwater (Wilson and Shokri, 2015*)*. The lag time estimates were compared with available groundwater age dating information from samples taken close to the water table, and the two datasets show a similar distribution. Estimated sub-catchment travel times ranged from 9 to >50 years, although estimates in mountainous areas tended to over-predicted because of uncertainty of the water table depth.

Loss variation and redox-cline occurrence

Nitrogen attenuation in groundwater is dependent on there being conducive, anaerobic conditions and available electron donors. Experience to date with tracers in the Waikato Region, and particularly Taupo, has shown that where dissolved oxygen concentrations are sufficiently low, nitrate-nitrogen will almost invariably be attenuated. Very fast rates of nitrate-nitrogen reduction have been demonstrated in peat formation at Rukuhia.

The depth to the redoxycline was investigated using the Childs' test on core as an indicator of likely denitrifying potential. Drilling and piezometer construction was undertaken at four selected sites adjacent to the Upper Waikato hydro-lakes. At two of these sites (Little Waipa Reserve and Bulmer Landing) the redox-cline was found to be within four metres of the water table. The redox-cline was not encountered at the other two sites within 6 m and 11 m below the water table (Epworth Park and HoraHora Domain respectively). The opportunity was also taken to test core from 18 holes drilled in the Hamilton Basin for monitoring wells by Opus International Consultants Ltd for Transit New Zealand Ltd. Although the depth to anaerobic conditions below the water table was highly variable (ranging up to 50 m), it occurred almost half the time within five metres. Groundwater quality was also tested at selected sites used for Childs' test investigation. Nitrate-nitrogen concentrations were either very low or non-detect at sites indicated to be anaerobic.

Regional and community monitoring network data can be used to indicate the wider occurrence of redox conditions across the region. These may be divided into aerobic, anaerobic, mixed and indeterminate categories based on nitrate, ammonia, dissolved iron and dissolved manganese concentrations (dissolved oxygen being less reliable at many sites). Aerobic conditions are more prevalent in the regional wells (~57%) than in the community water supplies (~30%). Anaerobic conditions are represented in about 4% of regional wells and about 14% of community wells indicating some likely bias. Although the spatial distribution of redox categories is complex, the prevalence of aerobic conditions decreases with well depth.

Close (2015) used linear discriminant analysis and GIS to predict the spatial distribution of reduced groundwater zones and hence where denitrification may occur in the Waikato. Similar percentages of aerobic (56%) and anaerobic (22%) conditions were indicated in water from 435 wells (region-wide).

Radon surveys

Surveys of radon concentration were undertaken along the Pokaiwhenua and Little Waipa Streams, comprising 10 sites in each, to identify and characterise areas of groundwater inflow. Radon is a radioactive gas which can be used as a tracer of groundwater input to surface waters given it is present in aquifers but readily dissipates in air. Flow and water quality were also measured during the surveys.

The radon results show considerable variation, ranging from non-detect (<0.01) to 5.4 Bq L^{-1} in the Pokaiwhenua and from 0.2 to 28.1 Bq L^{-1} in the Little Waipa. The highest concentrations were associated with springs. The results reflect the importance of fracture flow through these Upper Waikato catchments which are dominated by ignimbrite geology. Water age dating also undertaken showed the notable spring inflows to be of similar age to the streams consistent with their base-flow domination.

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TRANSPORT AND FATE OF NITROGEN IN THE LOWER RANGITIKEI CATCHMENT

Mr Stephen Collins[1], Dr Ranvir Singh[1], Mr Aldrin Rivas[1], Dr Alan Palmer[1], Dr David Horne[1], Dr Jon Roygard[2], Ms Abby Matthews[2]

[1]Massey University, Palmerston North, New Zealand, [2]Horizons Regional Council, Palmerston North, New Zealand

Aims

A sound understanding of the transport and fate of leached nitrate-nitrogen in shallow groundwater is key to understanding the impacts of land use intensification. However these are not well understood in the Rangitikei sand country. This study was undertaken to assess the groundwater flow pattern and its interactions with the Rangitikei River; redox conditions of the groundwater; and the extent of nitrate-nitrogen attenuation in shallow groundwater in the lower Rangitikei catchment area.

Methods and Materials

The study area covers about 850 km^2 between the townships of Bulls and Sanson in the east, Tangimoana in the south and Santoft in the north (Figure 1). Groundwater flow patterns were interpreted from a groundwater-level survey conducted during October 2014 from approximately 100 existing wells installed at a range of depths in the catchment area. A piezometric map was created from the measured groundwater-level data indicating the general groundwater flow direction of shallow and deep groundwaters (wells screened at <30 m and >30 m, respectively). Groundwater interactions with the Rangitikei River were estimated qualitatively using two longitudinal surveys (6th and 20th January 2015) of river-flow gauging and water quality analyses under low-flow conditions. The river flow was measured at six locations along the lower reach of the river and grab water-quality samples were taken at the same sites for analysis of nitrate, chloride and sulphate. We also sampled and analysed 15 wells in the study area during December 2014. The collected groundwater quality parameters were used to characterise the groundwater conditions as oxic, anoxic or mixed, according to the concentration of redox parameters (McMahon & Chapelle, 2007). We further measured nitrate-nitrogen attenuation in shallow groundwater using the single-well push-pull tests (Istok, 2013). A total of nine piezometers were installed at a range of depths (3 m and 6 m) on two dairy farms (sand country and river terrace) and one cropping farm (sand country). Nitrate-nitrogen, DO and other parameters were monitored over several months.

Results and Discussion

The piezometric levels of the study area showed groundwater flow was heavily influenced by the regional topography, particularly shallow groundwater (<30 m), and so it flows mostly from elevated areas such as Marton in a south-westerly direction towards the Rangitikei River. Groundwater-river water interaction was also inferred from the groundwater contour lines where they show some refraction as they cross the Rangitikei River. This suggested groundwater discharge into the river, particularly around Bulls. River-flow gauging and water-quality analysis also suggested groundwater discharge at locations upstream and downstream of Bulls. In comparison groundwater recharge or no interaction between the river and groundwater is more likely to occur near the coast. The groundwater redox characterisation showed generally anoxic/reduced groundwater across the lower Rangitikei catchment area. Groundwater typically has a low dissolved oxygen concentration (<1 mg/L) with elevated levels of available electron donors, particularly DOC and Fe^{2+}. These groundwater characteristics provide for generally favourable conditions for nitrate reduction (Figure 1; Rivett et al., 2008), which may account for the generally low nitrate concentrations in groundwater in the area. In the installed shallow groundwater piezometers, nitrate-nitrogen levels were low except at one location (cropping), where the nitrate-nitrogen varied between 2-5 mg/L. DO was also low, generally <0.3 mg/L. The push-pull tests showed nitrate reduction at four of five piezometers, with the rate of reduction varying between 0.036 mg N L^{-1} hr^{-1} to 1.158 mg N L^{-1} hr^{-1}.

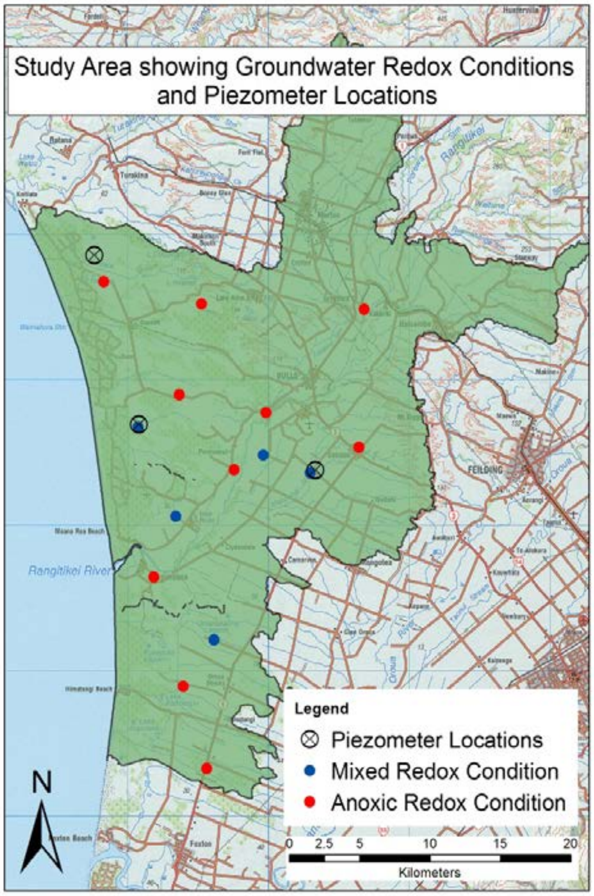

Figure 1: Lower Rangitikei catchment with groundwater redox conditions of December 2014 and locations of installed piezometers.

Conclusions

Our results suggest that groundwater is likely to be connected with the lower Rangitikei River. However, nitrate-nitrogen concentrations in the river and groundwater were generally low, especially for the river at low flows. This suggests nitrate-nitrogen may be undergoing reduction within shallow groundwater before it has a chance to seep into the river. Further evidence for appreciable levels of nitrate-nitrogen reduction in the shallow groundwater is provided by the redox characterisation of reduced groundwater and the push-pull tests. However, more spatial and temporal surveys and *in-situ* measurements of denitrification occurrence in the shallow groundwater of the study area are required.

Acknowledgements: This study is part of a collaborative project between Massey University's Institute of Agriculture and Environment (IAE) and Fertilizer and Lime Research Centre (FLRC), and Horizons Regional Council (HRC). This project is partially funded by HRC. The authors thank HRC for the financial support, in-kind support for field measurements and survey, and provision of the river flow and water quality datasets used in this study.

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CONTROLLED DRAINAGE – DOES IT WORK?

Dr Lucy McKergow[1], Dr Chris Tanner[1], Mr James Sukias[1], Dr Andrew Hughes[1], Mr Pete Pattinson[1], Mr Kerry Costley[1], Mr Gareth Van Assema[1]

[1]*NIWA, Hamilton, New Zealand*

Introduction

Where soils are prone to flooding and saturation, artificial drainage is often used to maintain profitable crop and pasture growth, reduce surface runoff and treading damage to soils, but it also contributes to the rapid conveyance of soluble nutrients into surface receiving waters (see Ballantine and Tanner 2013). Designing drainage to cope with the wettest periods of the year may result in significant periods when drainage is excessive. Increasing the residence time of water within the soil profile and in the drainage system has been shown to reduce overall drainage water yield and reduce off-site N export (e.g., Wesström and Messing 2007). The majority of overseas experience comes from cropped land and proof-of-concept trials are required for New Zealand pastoral systems.

Aims

We are evaluating the potential of controlled drainage to attenuate flow and nutrients and retain soil water at the end of the drainage season on two Waikato dairy farms.

Method

A paired catchment approach was adopted to compare drainage flows and contaminant losses with and without controlled drainage. Paired ~4 ha catchments were established at two dairy farms in the Waikato; at Tatuanui and Waharoa. At each Waharoa catchment four subsurface drains discharge into larger subsurface drains and we are monitoring the outlets of the two larger subsurface drains. A gate valve controls drainage at one site. At each Tatuanui catchment, three subsurface drains enter a surface drain and drainage is controlled on one surface drain by raising an intake pipe behind a weir. Rainfall, water levels and soil moisture are measured at the four sites. Water levels are measured in long-throated flumes and converted to flow with a theoretical rating. Pairs of time domain transmissometry sensors measure soil moisture and temperature 200 mm and 500 mm below the ground surface. Flow proportional samples are collected at all sites and analysed for nitrate-N, total N, ammonium, total phosphorus and filterable reactive phosphorus. Two s::can UV/VIS spectrolysers are deployed at the paired sites intermittently and provide high frequency (2 min) water quality data, including nitrate.

Results

These drainage system are event driven during a short four month drainage season. In 2014 drainage commenced in June and ceased at the end of October; the 2015 drainage season also commenced in June. Nitrate is the dominant form of nitrogen exported at both sites. Nitrate concentrations are higher at the Waharoa sites (median 8.3 mg/L, max 13.3 mg/L) than Tatuanui (median 2 mg/L, max 12.8 mg/L) and increase during events. Phosphorus export is dominated by FRP (medians ≤0.006 mg/L) and FRP:TP ratios are typically between 0.6 and 0.9. We have recently started controlling drainage and will report our preliminary findings.

Acknowledgements

This project is funded by MBIE through Clean Water, Productive Land (C10X1006).

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Session: Flood Management, Start Time: 3:30 p.m.

POTENTIAL CLIMATE CHANGE IMPACT ON FLOOD RISK ACROSS NEW ZEALAND

Dr Christian Zammit[1], Dr Scott Graham[1], Dr Bruce Dudley[1], Dr Abha Sood[1]
[1]NIWA, Riccarton, New Zealand

Aims

Climate change is projected to have a potentially significant but spatially variable impact on New Zealand's water cycle and flood generation mechanism. Following the IPCC5 report 9IPCC 2015), the Ministry for the Environment (MfE) has engaged NIWA to update the current 2010 flood guidance manual (MfE 2008). This guidance manual aims to provide guidance not only on potential climate change, but on potential change in different flow characteristics at daily time step for specific locations across New Zealand. However daily time step is usually not fine enough to correctly represent flood generation mechanism. This study aims to look at potential climate change impact on sub-daily flood characteristics and flood generation mechanism (ie precipitation) under IPCC5 assessment.

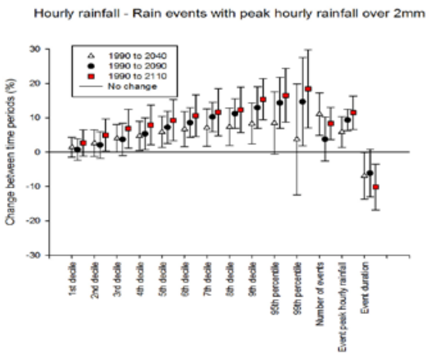
Method

Climate change fields (precipitation and temperatures) were generated using Regional Climate Models (RCM) for different Representative Concentration Pathway (RCP) at sub-daily time step over the period 1971-2120. Those climate change scenarios were generated as part of the MBIE contestable Climate Change Impact and Implication project. The RCM climate change field were used to drive hydrological simulations across New Zealand using the National hydrological model (TopNet). Analysis of the change in precipitation characteristics (ie duration, frequency and intensity) as well as flood characteristics (peak, duration, frequency) were carried out at National and regional scales.

Results

Analysis of the change of subdaily precipitation characteristics over the period 1971-2120 was carried out per decade and for precipitation event threshold of 2mm/hr. Figure 1 presents the potential change in precipitation intensity (for precipitation event over 2mm/hr) for RCM HadGEM2 and RCP4.5 across the West coast of New Zealand. Analysis indicates that sub-daily precipitation intensity is expected to change across decades.

Further analysis indicates that large variation of the precipitation characteristics are expected across the range of RCMs and RCPs resulting in potential large change in term of flood characteristics and associated flood risk.



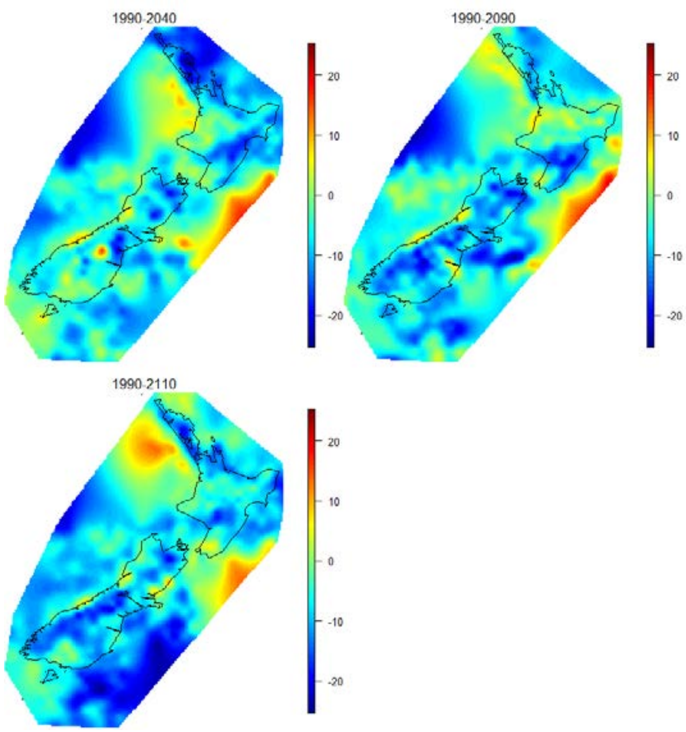


Figure 1: Hourly precipitation change for rainfall events above 2mm/hr forHADGEM2 model RCP 4.5. Results are presented in term of change of intensity to the 1990 decade reference period.)

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OLD DATA GIVES KNOWLEDGE FOR FLOOD CONTROL

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[1]NZ Nat. Inst. Water & Atmospheric Research, Christchurch, New Zealand

Aims

Catastrophic losses are escalating worldwide (Fig. 1 shows the past 45 years) and the most significant component is flooding (SwissRe, 2015). Fig. 2 shows the history of serious floods from the Yellow River, China, since year 0.
This presentation considers historic flood disasters and flood control techniques worldwide. It aims to draw conclusions relevant to the present day.

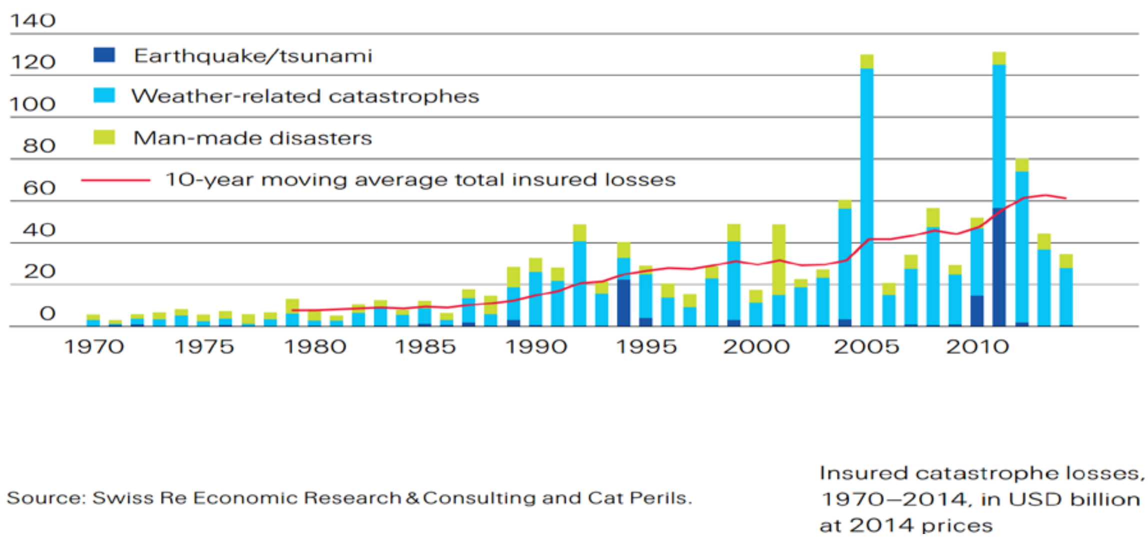

Figure 1. Insured catastrophe losses, 1970-2014, in USD billion at 2014 prices, SwissRe (2015).

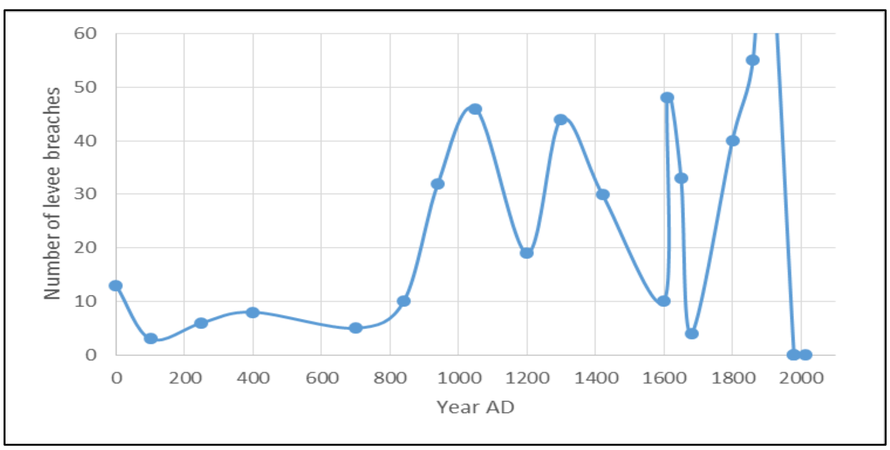

Figure 2. Major breaches of Yellow River levees over the past 2000 years, after Wang *et al* (2015).

Method

As return intervals for large flood disasters are typically longer than societal memory of flooding consequences and as morphological change in rivers takes place relatively slowly, the long-term effects of river training and control practices may not be apparent in the lifetime of the planners, designers or organisations responsible for the original schemes. Consequently, information from past disasters is often not incorporated in planning current and future flood mitigation strategies. This presentation analyses past flood history and draws conclusions relevant to the present day.

Results

Figures 1 and 2 demonstrate a trend of increasing flood disasters over the past 100 and 1000 years respectively. The history of river control on the Yellow River (Fig. 2) is described here as an example. Starting in 69 AD, following serious floods in the Yellow River, Wang Jing (30-85 AD) engineered a wide river bed to allow for sediment deposition and flood diversion. For the following 800 years the Yellow River aggraded slowly but had relatively few serious flood outbreaks. The main river then became unstable and "control" was by way of diversions. In 1289 AD the main channel diverted to a new mouth 400km to the south. From 1565-1592 Pan Jixun, the minister of construction, applied a theory that narrowing the river would enhance the velocity and carry sediment to the sea. He built primary and secondary levees to confine the Yellow River to a single thread. Annual levee maintenance was carried out from the 1660s. There were many flood breakouts and severe disasters but "the river was deliberately tied in an unfavourable course at an ever-increasing price", elevated some 10 m above the surrounding plains (Chen et al, 2012). In an 1855 flood the river returned to a northern mouth. To halt the Japanese army, in 1938, Chiang Kai-shek ordered breaching of the Yellow River levees towards the south causing hundreds of thousands of deaths and millions of homeless. The ongoing flooding disaster fuelled discontent and boosted recruitment for the Communist movement. In 1947 the river was returned to its previous channel. From 1950, Wang Huayun (Director of the Yellow River Commission) re-applied the wide river theory and the river has not breached its banks since then. However, soaring water abstraction has reduced the mean annual discharge of the lower river by 75%. In 1972 the lower river ran dry for the first time in recorded history. Rapid aggradation (100mm/year) is now occurring during normal flows and the river bed is again some 10 m above the plain. While other influences such as hinterland sediment supply, economic conditions, warfare and water abstraction are important factors, from the Yellow River's turbulent history we can conclude that, in the long term, a wide river fairway has resulted in a more stable river with fewer breaches.

Other examples of historic flooding lessons are described in the presentation.

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AN UPDATED REGIONAL FLOOD FREQUENCY METHOD FOR NEW ZEALAND

Mr Roddy Henderson[1], Dr Daniel Collins[1]
[1]*NIWA, Christchurch, New Zealand*

Estimating flood frequencies in ungauged catchments is important for the safe design of infrastructure in and around rivers, including flood protection works, bridges etc. At present, the most widely used method of estimating these values is based on McKerchar and Pearson (1989), which used 343 flow records and 6358 station-years of data. To revise the national flood frequency method we assemble a dataset of annual flood maxima drawn from 648 flow records, collectively with more than 18,000 station-years of data.

These data are used to develop a range of alternative empirical models, including log-linear regression, contouring, and Random Forests. Feeding these models is an expansive set of plausibly flood-related climatic and catchment-based explanatory variables:

- Rock types based on direct NZLRI, REC derived and the hydrogeology parameters of Hutchinson (1980);
- Soil properties similarly sourced;
- Land cover from LCDB2;
- Climate most significantly catchment mean annual rain, but also mean temperature, evapotranspiration and flow;
- Storm intensities derived from HIRDS V3 at return intervals 2 and 5 years, and an intensity for every catchment at its time of concentration;
- Catchment physiography including channel length, channel slope, area and distance to sea.
- Higher moments of the fitted rain intensity distributions in HIRDS V3

A benchmark measure of fit can be provided by application of the McKerchar and Pearson contours to the current dataset. Because of the new data available, and the longer records at sites used in both studies, this constitutes a far more extensive test than the paper by McKerchar and Macky (2001). The stated error, measured as root mean squared relative error (RMSRE), of the mean annual flood, was ±22% when 19 sites (~5.5%) with excessively large errors were removed. Bias was -0.9%. Applying a similar filter to the present dataset (exclusion of ~5.5% of sites with large errors) yields an RMSRE of ±50% and a bias of 3%.

In light of the applications for which this research has been conducted, the final method is chosen taking into account trade-offs among model error, physical plausibility, parsimony, and transparency to stakeholders and the user communities. These criteria are not correlated nor mutually exclusive and the decision among methods will be subjective to some degree. Once chosen, the selected method will be repeatable and objective and can be readily updated as more data become available.

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HOW TO TRACK A SEDIMENT SLUG: MORPHOLOGICAL MODELLING OF THE UPPER WAIPA RIVER

Dr Jo Hoyle[1], Mr Richard Measures[1], Mr Jo Bind[1], Dr Murray Hicks[1]
[1]*NIWA, Christchurch, New Zealand*

Background and Aims

In 1991 a large landslide occurred beside the Tunawaea Stream, approximately 700m upstream of its confluence with the Waipa River (the largest tributary of the Waikato River). The Tunawaea Landslide released 4 million m^3 of sediment, which initially formed a 50m high dam. In 1992, during a 2 yr return period flood, this landslide dam failed producing a flood wave equivalent to a ~100 yr return period flood at Otewa, 23 km downstream, and releasing a mass of sediment into the Waipa River. As this Tunawaea 'sediment slug' has migrated down the Waipa River, it has raised bed levels causing erosion of banks and river terraces, further contributing to the bed material in the Waipa River. Waikato Regional Council (WRC) commissioned NIWA to carry out a morphological modelling study on the Waipa River to provide guidance on how the Waipa River channel is likely to adjust in the future as this large volume of bed material moves down river. Understanding how the Waipa channel is likely to adjust in the future will help WRC to plan effective river management in response to these adjustments.

Method

To reliably predict future changes in the Waipa River using a morphodynamic model we must first be able to reproduce the adjustments that have occurred in the period following the landslide. To assess how the Waipa River has adjusted from the time prior to the landslide through to the present day we reviewed reports of the landslide dam failure and short term changes in the Tunawaea and upper Waipa (Riley et al., 1993; Parkin et al. 1993; Jennings et al., 1993), and analysed historic cross sections and aerial photographs. We then constructed a 1-dimensional morphodynamic model spanning 43 km of the Waipa River from upstream of the Tunawaea confluence to just downstream of Otorohanga Weir using NIWA's Gravel Routing And Textural Evolution (GRATE) model. We surveyed cross sections and long profiles in the Waipa River and Tunawaea Stream to provide the underlying topography for the model, and we surveyed flood heights to calibrate the model hydraulics. We collected data on bed surface and subsurface sediment size grading throughout the Waipa River and in the key tributaries to provide the bed sediment input data. Flows recorded at the Waipa at Otewa gauge were distributed between the different sub-catchments using an area weighting approach and put into the model at defined locations. The GRATE model was calibrated morphologically by comparing model results from a 1990-2015 simulation run with the observed historic adjustments. We also ran the model with no input from the Tunawaea Landslide to separate the effects of the landslide from other drivers of morphological adjustment.

Results

The results of the modelling and analysis of historical geomorphic change were assessed reach by reach to identify the main historic and future changes in the Waipa. These results show that gravel from the Tunawaea Landslide rapidly entered the Waipa River system following the landslide dam break in 1992. This gravel moved quickly through the steep, 3 km long gorge reach immediately downstream of the Tunawaea confluence, then raised bed levels significantly in the lower gradient reach as far as approximately 16 km downstream of the Tunawaea confluence. Erosion of a large area of Taupo Pumice terraces (5-6 km downstream of the Tunawaea confluence) occurred when the river bed aggraded to the point where it could erode laterally into the terrace material. This has since been controlled by engineering works. Beyond the 16 km point, the downstream spread of the slug has been dispersive rather than advective (Figure 1). In terms of future adjustment, our results predict gradual re-working of the slug gravels, both in the Tunawaea and in the upper Waipa, but little effect on bed levels (up to 0.1 m) downstream from the 16 km point (Figure 1).

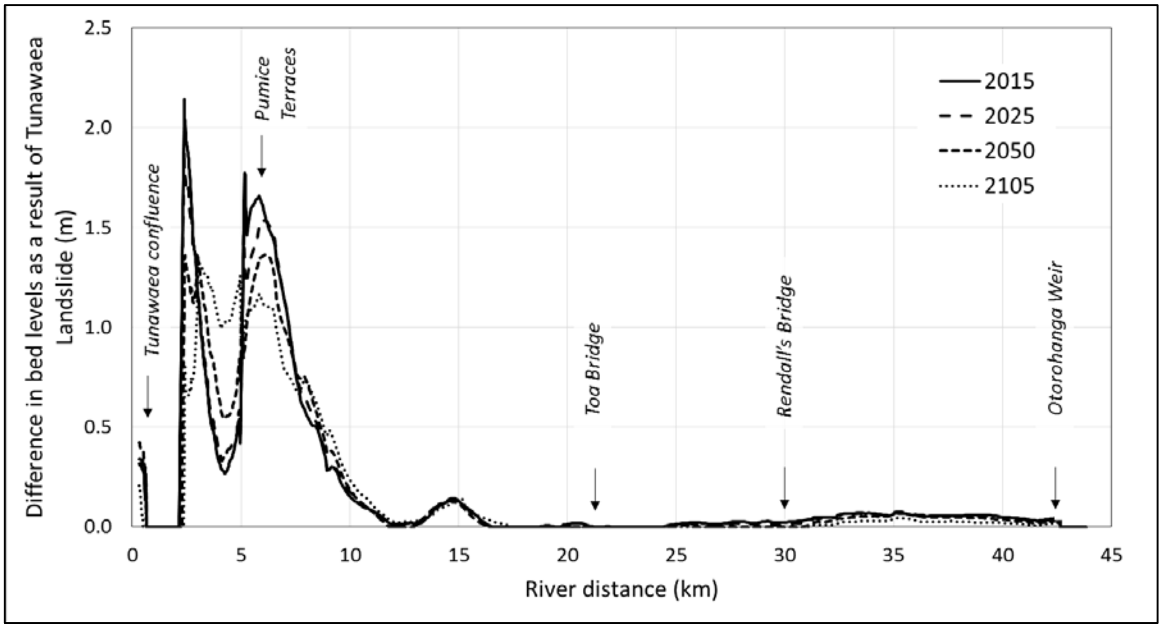

Figure 1. Current and future bed level effects of the Tunawaea Landslide.

In the lower part of the modelled reach, from Toa Bridge to Otewa, the main drivers of change in the period since the Tunawaea Landslide appear to be pre-landslide channel straightening and gravel extraction. We predict ongoing degradation in the 9 km reach between Toa Bridge and Rendall's Bridge (river distance 21 to 30 km) as a result of adjustment caused by a historic meander cut-off just downstream of the location of Rendall's Bridge. We also predict ongoing aggradation from Rendall's Bridge to 1-2 km upstream of the Otorohanga Weir as a result of the same meander cut-off. These changes are not accounted for in Figure 1 as this figure is based on the isolated effects of the Tunawaea Landslide. The model predicts stable bed levels immediately upstream of the Otorohanga Weir and ongoing degradation downstream of the Otorohanga Weir, although this is beyond the study area and model results are uncertain for this location.

Looking at the Waipa as a whole, the effects of the Tunawaea Landslide and sediment slug seem to have stabilised and future problematic bed level changes as a result of this landslide are unlikely. It should be noted, however, that similar landslide events have occurred previously in the Waipa headwaters and are likely to occur again.

References

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Session: Surface Water Hydrology, Start Time: 3:30 p.m.

DEVELOPING A STATISTICAL MODEL FOR PREDICTING 18O AND 2H RATIOS OF RIVERS IN THE SOUTH ISLAND HEADWATERS

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Aims

The aim of this paper is to characterise the spatial and temporal range in $\delta^{18}O$ and $\delta^{2}H$ isotopes of rivers draining the Southern Alps of the South Island of New Zealand.

Method

Discrete water samples have been collected every 3 to 6 months for 55 to 71 rivers draining the Southern Alps of New Zealand from January 2012 to August 2015. Grab samples were collected directly from the river and stored in 2 mL glass vials with polypropylene septa caps and measured for $\delta^{18}O$ and $\delta^{2}H$ using a Picarro CRDS analyser in the Department of Chemistry at the University of Otago. The precision for these analyses is $\delta^{18}O$ 0.1 ‰ and $\delta^{2}H$ 0.9 ‰.

Results

These water samples have been analysed for their stable isotope ratios of $\delta^{18}O$ and $\delta^{2}H$ and show marked variability across the range front that is strongly associated with variations in catchment mean elevation, distance from the coast, and latitude. Lower-elevation catchments typically have the most enriched $\delta^{18}O$ and $\delta^{2}H$ ratios, whereas the greatest depletion occurs on the east of the main divide, particularly in the interior of central Otago. West Coast catchments are enriched in $\delta^{18}O$ and $\delta^{2}H$ compared to the East Coast catchments likely due to the combined effects of close proximity to the humid air masses that form over the Tasman Sea, and orographic uplift driving isotopic fractionation over the Southern Alps. The ratios of $\delta^{18}O$ and $\delta^{2}H$ measured in these alpine rivers are consistent with mean rainfall ratios, suggesting little attenuation of the isotopic ratios as water is routed through the surface and shallow-subsurface pathways under base flow. In the headwater catchments it appears as the routing of water through the catchment has the effect of homogenising short-scale variations in isotopic ratios that occurs between discrete rain events, or during a single storm event. For the majority of catchments there is no significant difference in the isotopic ratios of $\delta^{18}O$ and $\delta^{2}H$ between seasons even in catchments that have significant snow and/or ice storage (e.g. Franz Josef, Fox, Tasman, Hooker).

A variety of morphological catchment characteristics were extracted using ArcGIS 10.1 and input into a dual direction step-wise regression to determine the key predictors of the isotopic ratios of the river water. The resultant multivariate regression (r-squared of 91% at the 99% confidence interval) determined that the mean $\delta^{18}O$ and $\delta\ ^{2}H$ ratios are predictable at the catchment scale by a) the central point of each catchments' distance from the coast b) mean catchment elevation and c) latitude or northing. The statistical output model was applied to the River Environment Classification stream orders of 5, 6, and 7 across the South Island by generating metrics of distance from coast, mean elevation and northing for catchments using the regression relationship determined from this study as the basis of a predictive model using semivariogram krigging in ArcGIS. The modelled $\delta^{18}O$ and $\delta^{2}H$ are compared to known values for rivers across the Southern Alps, and show some deviations occur (as in parts of Southland and Canterbury), and may reflect additional sources of water into these systems, such as groundwater interaction.

Conclusions

The stable isotopes from rivers draining the Southern Alps vary across the main divide; with the most enriched values occuring in low elevation catchments on the West Coast. The most depleted isotopes occur in the headwaters of Otago catchments. Isotopic ratios of 18O and 2H can be predicted using three catchment variables: distance from coast, mean elevation and latitude.

NATIONAL HYDROLOGICAL MODEL TESTING, PART II: RESULTS AND INTERPRETATION

Dr Hilary McMillan[1], Dr Doug Booker[1], Dr Celine Cattoen-Gilbert[1], Dr Christian Zammit[1]
[1]*NIWA, Christchurch, New Zealand*

Aims

Careful management of water resources is important to support the economic, environmental, recreational and cultural values of water. National-scale hydrological models support this management by providing consistent water information across all gauged and ungauged catchments. However, confidence in such models requires rigorous testing of model results (Booker and McMillan, 2015). In this presentation, we report the results of testing the New Zealand national TopNet hydrological model, for performance across multiple hydrological indices, and regional patterns in performance.

Method

A comprehensive set of test procedures for a national hydrological model has been designed by Booker and McMillan (2015). These procedures test model predictions of different aspects of the hydrograph, e.g. low flows and flood flows, and of differences in flows between catchments and between years. We apply these procedures to test the national TopNet hydrological model simulations of flow across New Zealand for 1972-2014, using data from 486 flow gauges. TopNet is a distributed, physically-based, time-stepping hydrological model, which combines water balance models for each sub-catchment with a kinematic channel routing model to route streamflow to the basin outlet. It is run at hourly time scale and ~10 km^2 spatial scale.

We quantified model performance by comparing observed and modelled hydrological indices on a daily basis, per-year basis, and across all years. We consider the performance benefits of using a statistical correction of model output. The model set-up does not include use of the flow data against which the model is compared (i.e. this is a 'model validation') because the hydrological model is uncalibrated and the statistical correction is run in 'out of bag' mode that treats each site in turn as ungauged. We compared modelled and observed flows in linear space (*Raw*) vs log space (*Transformed*); comparison in log space is used to emphasise the quality of fit during low flow periods. Model performance is quantified using a variety of different performance metrics and the reasons for any differences are discussed. Spatial and temporal patterns of model performance are explored to relate performance to either model parameterisation, model structure or model boundary conditions.

Results

Overall, the results show that the Topnet model has good skill in matching observed flows. Performance is higher in transformed (log or square root) space than in linear space: the model has higher skill during recessions and low flow periods than during flood events. Model performance against annual flow descriptors tests the ability to predict differences in the flow regimes between years. Performance for the mean annual flow and QFeb (the proportion of flow in February) is typically higher than for annual minimum and maximum flows. Mean and QFeb test the model ability to predict averaged behaviour over many days, which is less susceptible to climate or model errors than for extreme behaviour. The statistical correction of model output reduces the bias in mean flow, but otherwise has little effect. This is because the correction procedure emphasises performance in mid-range rather than extreme high or low flows.

The model is well able to simulate multi-year flow descriptor values, and differences in these values between sites. This is a less severe test than the annual flow descriptors that test differences between years, because part of the model skill derives from the strong climatic differences across New Zealand. The poorest model performance is in predicting 5-year low and high flow extremes, as the catchment is displaying unusual and extreme hydrological processes at these times, and few data are available to understand these processes.

Spatial and temporal patterns in model performance, combined with knowledge of New Zealand's hydrological landscape, can suggest reasons for model success or failure. High bias (*pbias*) in daily flow series or mean flow (Figure 1) suggests inaccuracies in the simulated catchment water balance, which could be due to rainfall measurement error or unmodelled interactions between river flows and

groundwater. This performance metric was found to be worst in Northland, lower North Island and the east coast of the South Island. For the latter two areas, groundwater interactions are likely to be the culprit due to the known importance of aquifers in these areas.
The Nash Sutcliffe (*NSE2*) performance score, which tests the model ability to simulate both absolute flow values and the patterns in flow values, shows that the model has good skill over most of the country for the annual flow descriptors (Figure 2). Areas where performance is poorer are in mountainous areas of both islands: the West Coast of South Island and the central plateau of North Island. The reasons for this could be that the raingauge network is sparser in these areas, leading to poorer quantification of rainfall extremes. In the North Island central plateau and Bay of Plenty, volcanic soils and geology have a strong damping effect on flood peaks, making it particularly difficult for the model to accurately predict maximum flows in these areas.

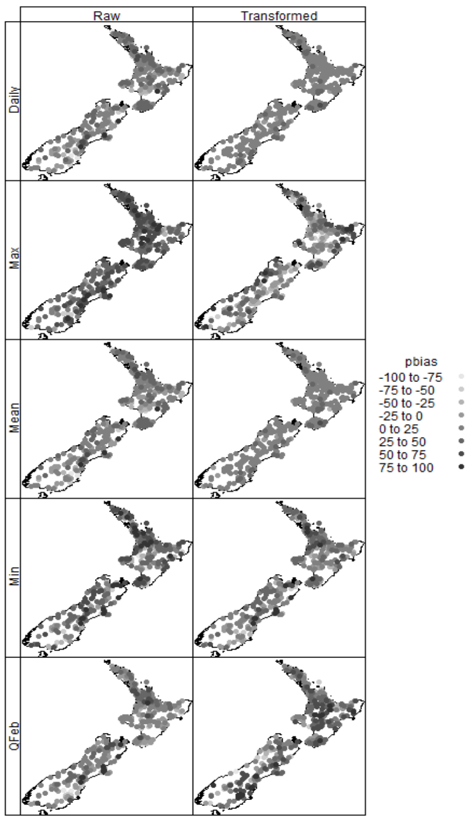

Figure 1: Bias in model performance for the daily flow series (*Daily*) *and* annual flow descriptors (*Max, Mean, Min*, *QFeb*) by location. A score of 0 indicates optimal (unbiased) performance.

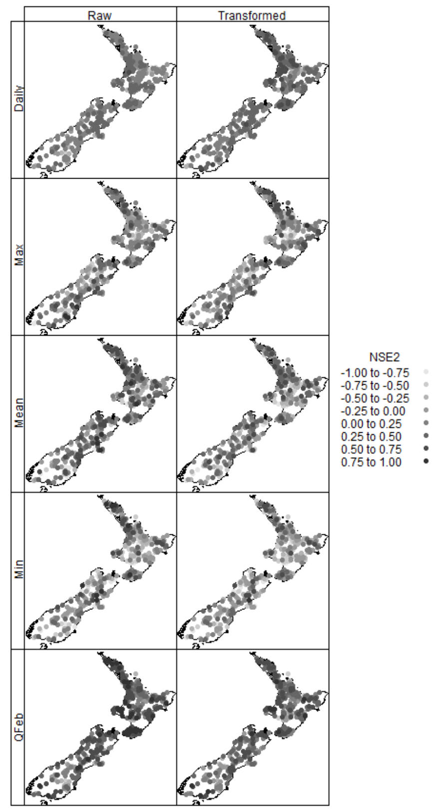

Figure 2: Nash Sutcliffe model performance scores for the daily flow series (*Daily*) *and* annual flow descriptors (*Max, Mean, Min*, *QFeb*), by location. Scores range from -1 (poor performance) to +1 (perfect performance).

Conclusions

Our results show that the national TopNet model has generally good performance across New Zealand. A statistical correction of model output reduces bias in model flow simulations, hence improving predictions of mean flow. The model has best performance in predicting average catchment behaviour, and worst performance in predicting 5-year low and high flow extremes. An analysis of regional patterns in model performance shows that the model could be improved by a better representation of groundwater processes in areas of known river-groundwater interactions.

References

Booker, DJ and McMillan, HK (2015) National hydrological model testing, Part I: Need and test procedures. New Zealand hydrological society conference, 1-4 December 2015, Hamilton.

NATIONAL HYDROLOGICAL MODEL TESTING PART 1: NEED AND TEST PROCEDURES

Dr Doug Booker[1], Dr Hilary McMillan[1]
[1]*NIWA, New Zealand*

Aims

Hydrological models that are able to simulate nationwide daily flow time-series using spatially consistent methodologies and input data are a valuable tool to support development of national polices for water management and national environmental reporting. Such models provide nationwide time-series of flood risk, drought potential, water availability for irrigation or power generation, and the effects of changes in climate on hydrology. However, when being used for these purposes, it is important that both spatial and temporal aspects of uncertainty in simulated time-series are quantified.

Previous testing of national hydrological models has concentrated on quantifying the ability to model between-site patterns in time-averaged indices (e.g., mean flow, MALF). The aim of this work is to present a comprehensive and consistent suite of test procedures that could be applied to any nationwide hydrological model which calculates daily flow time-series. The first objective of these procedures was to quantify performance when simulating patterns in: a) between-site differences in time-averaged indices; b) between-site differences in daily time-series; and c) between-year differences in annual time-series. The second objective was to identify performance across hydrological signatures represented by various parts of the hydrograph. The third objective was to identify spatial and temporal patterns in performance. The fourth objective was to provide a consistent basis for comparison of performance between different models.

Methods

We collated daily flow time-series observed at 486 sites draining reasonably natural catchments (free of major dams or diversions). These sites were distributed throughout New Zealand and represented a range of catchment sizes and hydrological conditions. Although each time-series was at least 5 years in length, not all time-series covered the same time period. Years with more than 30 days of missing data were removed from the dataset. The location of each site on the River Environment Classification national river network (Snelder and Biggs, 2002) was identified. This allowed extraction of data describing site and catchment characteristics such as topographic setting, geology and climate.

We then developed a suite of test procedures which, when applied together and over many sites, quantify model performance through time and space. The test procedures allow hypotheses which relate model performance to either model parameterisation, model structure, model boundary conditions or geographical setting to be tested. They also provide a consistent framework when comparing different modelled time-series. This is often a requirement when changes in model structure, parameterisation procedures or input data have been made. Alternatively, raw modelled values may be compared with post-processed corrected values gained after applying statistical correction procedures.

Results

A suite of test procedures was designed in which sets of observed and modelled values were compared (Table 1). These included: 1) mean daily values from the entire observed period for comparisons between days within sites; 2) mean daily values from each year of the observed period for comparisons between days within years within sites; 3) various indices calculated over the entire observed period (e.g., mean annual low flow) for comparison between sites; and 4) various indices calculated for each year of the observed period (e.g., annual low flows) for comparisons between years within sites.

For each set of observed and modelled values, we applied three performance metrics, each designed to quantify a different aspect of model performance: Nash-Sutcliffe efficiency (NSE2); percent bias (pbias); and coefficient of determination (r^2). See Moriasi et al. (2007) and references therein for full details of these performance evaluation metrics. NSE is a dimensionless metric that determines the relative magnitude of the residual variance ("noise") compared to the observed data variance ("information"). NSE is commonly used to evaluate hydrological model performance; we used a scaled version NSE2 that takes values between -1 (worst) and +1 (perfect model), with 0 representing a model that is no better than a constant prediction at the mean flow value. Percent bias evaluates the average tendency of the simulated data to be larger (negative pbias) or smaller (positive pbias) than their observed counterparts. For mean flow values, percent bias allows us to test whether the water balance of the catchment is correctly represented. Coefficient of determination evaluates the correlation between observed and modelled values. This metric allows us to test whether the model correctly models locations/years with low/high index values, even if there is systematic bias in the values. These metrics were applied to each set of observed and modelled values in their untransformed raw units, and after having applied either a log or square root transformation in order to better approximate normal distributions.

Table 1. Hydrological indices used to test model performance.

Index type	Index	Description	Calculation
Daily flow series	DAILY	Daily flow series	Model simulation of entire daily flow series
Annual flow descriptor	MEAN	Mean annual flow	Mean flow in each hydrological year
	MAX	Annual flood	Maximum daily flow in each hydrological year
	MIN	Annual low flow	Minimum daily flow in each hydrological year
	QFEB	Proportion of flow in February	Mean flow in February as a proportion of mean annual flow, in each hydrological year
Multi-year flow descriptor	QFLOOD5	5-year flood	Maximum daily flow expected during a period of 5 years, using a Gumbel extreme value approximation.
	QLOW5	5-year low flow	Minimum daily flow expected during a period of 5 years, using a normal distribution.
	QVAR	Interannual variation	Interannual variation in mean flow
	QBAR	All-time mean flow	Mean flow over entire series
	MALF	Mean annual low flow	Mean of the annual minimum flows
	MAF	Mean annual flood	Mean of the annual maximum flows

Conclusion

We developed a suite of test procedures that could be applied to any nationwide hydrological model which calculates daily flow time-series. The procedures are comprehensive because they cover a broad range of hydrological signatures across time and space. The procedures are also consistent because they have been defined in advance of their application. The suite of test procedures have been applied to the National TopNet Model. See McMillan et al (2015) for further details of this example application.

References

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McMillan, HK, Booker, DJ, Cattoen-Gilbert, C, Zammit, C (2015) National hydrological model testing, Part I: results and interpretation. Hydrological Society Conference presentation. Dec 2015.

ACHERON DIVERSION ENHANCEMENTS

Mr Lennie Palmer[1]
[1]Trustpower, Tauranga, New Zealand

The Lake Coleridge power scheme is nestled in the Canterbury high country and has been utilised for hydro-electric power generation for 100 years. Initially the Scheme had three turbines and an installed capacity of 4.5 MW, with additional turbines installed in 1917, 1922 and 1925. To augment the natural catchment inflow the Harper River and later, in 1930, the Acheron River were diverted to the lake. In 1977 the Wilberforce River was also diverted. More recently most of the generating units have been replaced or upgraded with maximum station output of 39 MW and 270 GWh pa.
The Acheron Diversion contributes around 4 GWh pa to Coleridge generation. The diversion includes and intake weir, intake screen, sediment chamber and around 5 km of diversion pipe to divert the Acheron flow into the Coleridge catchment. Flows at the intake range from a summer low of around 0.1 m^3/s and 10 percentile flow around 1 m^3/s.

Several enhancements have been completed recently on the Acheron Diversion. These include improved monitoring and instrumentation, improved sediment management, weir sluice upgrade, and weir intake screen upgrade. With about 100m fall from the diversion intake to Lake Coleridge the potential for small hydro from the diversion has also been investigated.

Aim

This presentation will cover the reasons, methodologies and outcomes of the Acheron diversion enhancements.

Method and Results

Sediment at the Acheron weir is managed by the intake weir and screens (intake size, shape and angle), weir sluicing, and intake sluicing. Sediment in the screens affects diversion capture and sediment into the diversion tunnel can close the diversion down for long periods. Due to sediment issues the sediment chamber was continually sluicing over 0.1 m^3/s. The following improvements were made:

1. Installing automated sediment basin sluicing.
- Redesign of the intake screens

Spill and waste from both intake screens and the weir sluice was observed and monitored over varying flow conditions. The weir sluice was also difficult to operate.

- Redesign and build of the intake screens (as above) and the weir sluice

A desktop scoping exercise in 2010 indicated a 3 GWh pa station would cost $4.2M and over 35 years have a positive NPV with an IRR of around 10%.

Results: Several enhancements have been undertaken recently on the Acheron Diversion. These enhancements have improved sediment management, weir sluice gate operation, and the efficiency of the intake.

Session: Transport and Transformation of Contaminants, Start Time: 3:30 p.m.

A PRELIMINARY MODEL TO ACCOUNT FOR HYDROGEOLOGIC INFLUENCES ON SPATIAL NITROGEN ATTENUATION CAPACITY AND LAND-BASED NITROGEN LOADS TO RIVERS IN THE MANAWATU RIVER CATCHMENT

B Clothier[3], Ahmed Elwan[1], R Singh[1], D Horne[1], J Roygard[2]
[1]Institute of Agriculture and Environment (IAE), Massey University, , , [2]Horizons Regional Council, , , [3]Plant and Food Research, ,

Aims

Land-based nitrogen loads to surface water bodies are influenced by hydrogeochemical conditions affecting the leached nitrogen's flow pathways and potential attenuation in the subsurface environment. Few studies available investigating the hydrogeological effects on land-based nitrogen loads stresses the need for an improved understanding of the influence of hydrogeology on nitrogen flow and attenuation in the subsurface. We defined the nitrogen attenuation factor , as the reduction 'attenuation' of nitrogen leached from the root zone, through different processes such as denitrification in the subsurface environment, to the river nitrogen load measured at the outlet of a catchment (Singh et al., 2014; Elwan et al., 2015). As different catchments often have contrasting characteristics, the is expected to vary spatially as a function of these characteristics. Thus, the estimations of the magnitude and variations of is of utmost importance. Policy makers need to take account of the magnitude and variation in the , across catchments, when formulating policies related to nutrient loss from agriculture to waterways.

The main aims of this study were (1) to quantify the magnitude and spatial variation of the throughout the Tararua Groundwater Management Zone (TGWMZ), of the Manawatu River Catchment, (2) to evaluate the relationship between the and catchment characteristics (e.g. Soil texture, rock type and land use), and (3) to use the estimated spatial nitrogen attenuation 'reduction' capacity of different rocks in a hydrogeologic based model to predict river nitrogen loads.

Methods

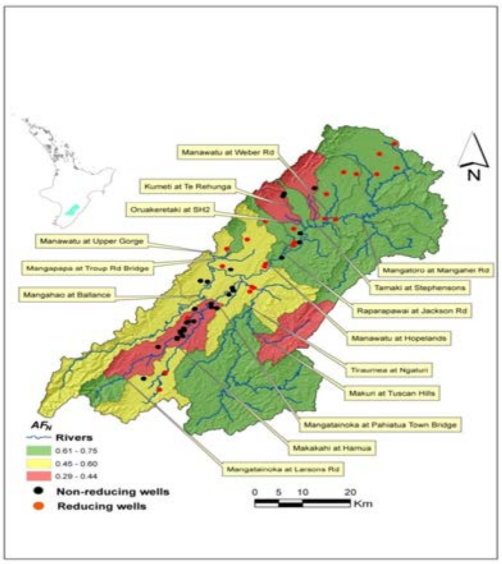
Fifteen surface water quality monitoring sites in the TGWMZ were used in ArcMap to delineate the sub-catchments upstream of these sites. The resulting shapefiles from the delineation process were used to extract physical characteristics of each sub-catchment (e.g. Soil types, rock types, and land use). The was quantified using estimates of the root zone nitrogen leaching (based on Overseer® estimates of the average nitrogen leaching from the root zone for different land uses) and the river nitrogen load (based on measured monthly soluble inorganic nitrogen concentrations and daily river flow). The potential relationship between the and catchment characteristics (e.g. Soil textures, rock types, and Base Flow Index "*BFI*") was investigated through regression analysis. Finally, a preliminary hydrogeological based model to predict river nitrogen loads using the approximate estimates of nitrogen attenuation capacities of combinations of different landuse area and underlying rock types in the study area is presented.

Results and Discussion

Our results showed that the varied from 0.29 to 0.75 across the 15 sub-catchments with an overall value of 0.58 for the whole TGWMZ. The regression analysis between the and sub-catchment characteristics showed that the has a positive relationship with some catchment characteristics (e.g. fine textured soils "clay loam", R^2 = 0.37, p <0.05) whereas it has a negative relationship with other catchment characteristics (e.g. the well-drained soils; drainage class 5 in the Fundamental Soil Layer "FSL", R^2 = -0.35, p <0.05, and the Base Flow Index "*BFI*", R^2 = -0.31, p <0.05).

Regardless of the uncertainty in the estimation of the , it showed a strong spatial correlation with the redox status of the groundwater in the TGWMZ (Figure 1A). Results showed that the sub-catchments with higher (i.e. higher capacity to attenuate nitrogen) are dominated by groundwater wells in reducing conditions. In contrast, sub-catchments with lower (i.e. lower capacity to attenuate nitrogen) are dominated by groundwater wells in oxidizing conditions.

Our preliminary hydrogeological based model accounts for only the influence of rock type. The dominant rock types were grouped into three main classes with low (<0.30), medium (0.30-0.60) and high (>0.60) nitrogen attenuation capacities. The river nitrogen loads predicted using this simple model are a strong match with the measured river nitrogen loads in the sub-catchments of TGWMZ (Figure 1B). This new approach in predicting river nitrogen loads highlights the importance of spatial attenuation capacities of different rocks in different sub-catchments. This model will be refined by assessing effects of other hydrogeological factors, such as soil texture, shallow groundwater conditions, and/or estimates of travel time, on the attenuation of the nitrogen leached from farms in the study area.



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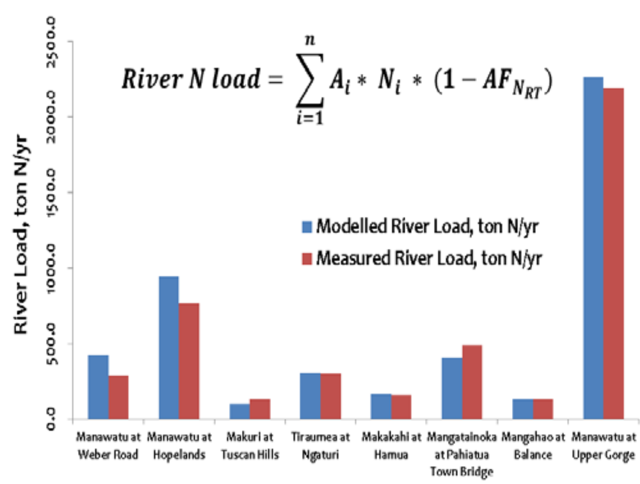

B

Figure 1: (A) Spatial variation of estimated values for all sub-catchments in the TGWMZ showing a significant match with the redox status of the groundwater (Rivas et al., 2014). Wells in the reducing conditions are mainly located in sub-catchments with the high values (high capacity to attenuate nitrogen), whereas wells in the oxidising conditions are located in sub-catchments with the low (low capacity to attenuate nitrogen) values; and (B) Modelled river *N* loads showing a good match with the measured river *N* loads for different sub-catchments in the TGWMZ. The hydrogeologic based model used to estimate River *N* load for each sub-catchment is shown where = Area of each combination of main land use and underlying rock types (L^2); = Average annual nitrogen loss rate for land use type ($M/L^2/T$); and is the attenuation capacity for each rock type.

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NPS 2014, DIGGING THROUGH THE DATABASE; TURNING EXISTING DATA INTO A "WHAT IF" TOOL.

Mr Lawrence Kees[1], M Moreau[2], C Zammit[3], C Daughney[2], C Rissmann[1], T Ellis[1]
[1]Environment Southland , [2]GNS Science, , , [3]NIWA, ,

Aims

Southland's Fluxes and Flows research project is a collaboration between Environment Southland (ES), GNS Science (GNS) and the National Institute of Water and Atmospheric Research (NIWA).The Fluxes and Flows (F&F) project is one of the three collaborative science projects set up in 2014 as part of ES's multi-facetted approach for limit setting under the National Policy Statement (NPS) (Figure 1). The other two science projects (Land Use Inputs and Ecosystem Response) also involve collaborations (ESR, Beef and Lamb) and link with the Fluxes and Flows following the source (LUI), pathway(F&F), receptor model (ER).

The aim of the ES science programme is to deliver a 3D regional, steady-state groundwater flow model, loosely-coupled to a surface water flow model, as the foundation for a series of down- scaled transient, groundwater-surface water flow and transport models (TN, TP, and sediment) to be used as a management tool to inform limit catchment setting. After one year, collaborative results were achieved and completed milestones are already helping to shape Environment Southland's policy development.

Method

The Environment Southland science programme functions through inter-organisational task assignment, shared organisational funding, and alignment with existing research programmes. Workshops are held to jointly establish work plans and schedules, and to ensure outputs are relevant between the three collaborative science projects (Figure 1) and the ES policy direction. Regular updates on progress are issued by dedicated project managers to ES policy teams and an external technical advisory group, which also conducts annual reviews of the work plans and progress against them.

Results

At the end of June 2015, two major milestones from the Fluxes and Flows projects were ready for external review: a 3D regional geological model and a comprehensive hydrochemical review of surface water and groundwater. The 3D geological model provides the foundation for the regional groundwater flow model. The work on hydrochemistry provides a detailed understanding of flow- paths and processes required to build the transport and flow models. These outputs are also intended to provide material to the ES policy team to engage with communities to raise public awareness for consultation purposes. The Land Use Input project aims to yield a base land use map for and estimates of nutrient loss for the region. The Ecosystem Response project will review existing approaches for deriving nutrient and sediment thresholds for ecosystem health and function, and will determine those thresholds for Southland surface water bodies.

The next steps include development of the loosely-coupled regional 3D groundwater-surface water flow model, to be followed by catchment-scale transient groundwater-surface water flow and contaminant transport modelling. These models will include fine-tuning the fluxes and flows model with input datasets required for the transient modelling and include a hydro-chemical assessment of the physiographic drivers of water quality.

The structure and aligned nature of the collaborations supported the delivery of the project milestones, enabled the identification of overlaps with other research projects and managed expectations in terms of outputs to both the scientific and the policy teams. Challenges associated with this large collaborative project include: additional unforeseen work, effective communication between a large inter-agency inter-disciplinary groups, and shifting planning timeframes. These challenges are met by revising communication techniques, adapting project components, and extra resourcing.
The ability to meet these challenges stems from the shared

reliance on project outputs and the team mindset generated from shared motivations for project delivery. We propose that the above process and resulting models represent hitting the "sweet spot" between simplistic and overly complex approaches to the problem to describing multiple involving many interactions. As a first-cut, it will provide a much-needed and accessible tool to guide initial decisions and highlight where more data or thinking is required.

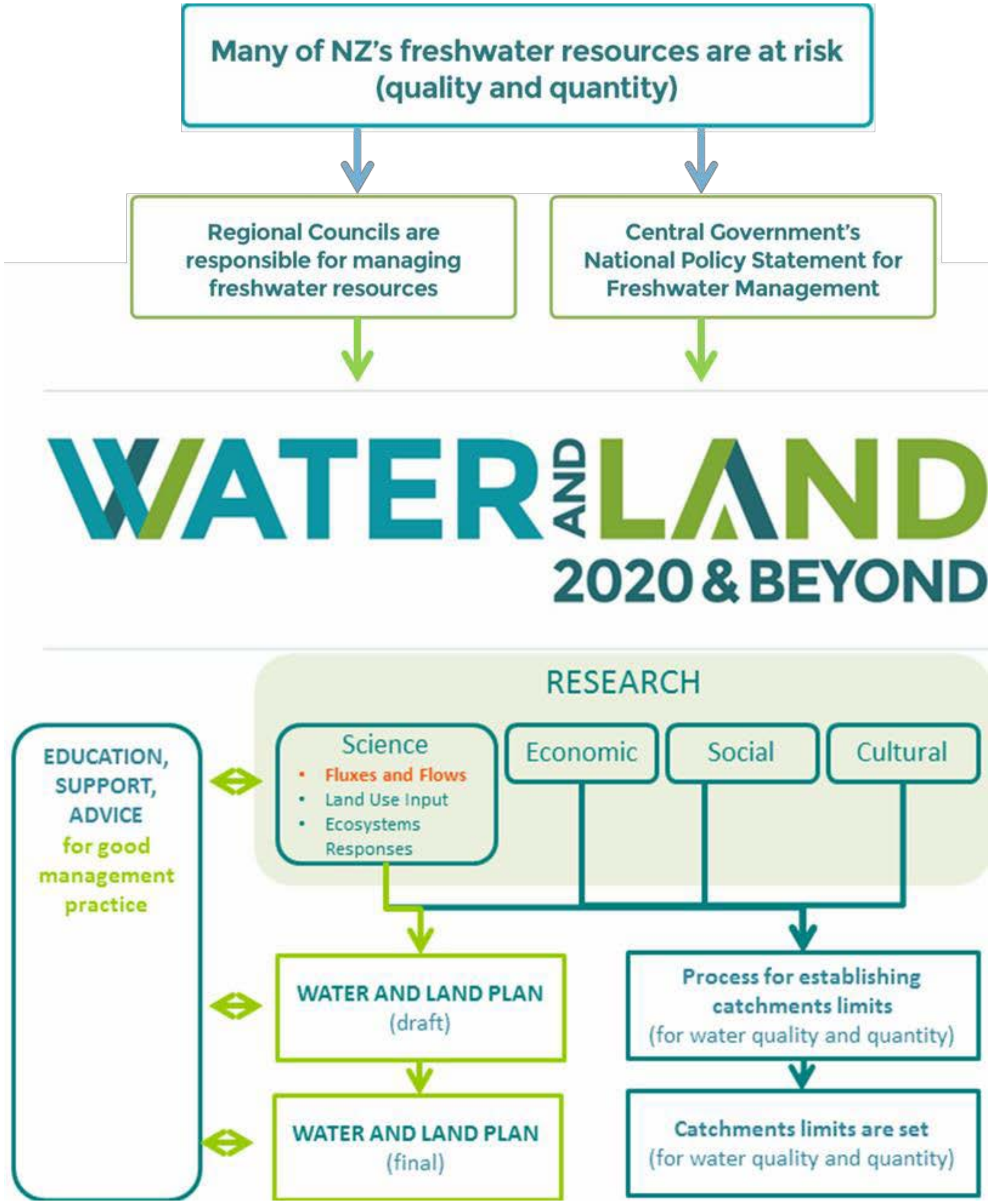

Figure 1) The Fluxes and Flows project is part of the "Water and Land 2020" research programme, which is ES's response to the NPS.

USING INDICATOR ORGANISMS TO PREDICT PATHOGEN TRANSPORT. IS IT TOO GOOD TO BE TRUE?

Dr Louise Weaver[1], P Abraham[1], L Pang[1], M Mackenzie[1], N Karki[1], J Webber[1], E McGill[1], S Lin[1], M Close[1]
[1]*ESR Ltd*

Aims

Investigating the transport of selected microbial pathogens compared with indicator organisms through sandy gravels. The aims of the research were twofold:

1. Identify the efficacy of using microbial indicator organisms to predict pathogen transport,
1) Compare the transport of microbes through open framework gravels and coated open framework gravels.

Our research project aims to improve the understanding of key transport and transformation processes of microbes in groundwater systems to determine the local scale assimilative capacity in at least two types of groundwater systems. By understanding the assimilative capacity of different groundwater systems for both indicator microbes and pathogenic microbes we aim to improve the potential risk to public health from land use and subsequent microbial transport on a local scale. Increased land use activities offer the potential for increased microbial transport into groundwater systems and subsequently drinking water.

Note this presentation is an update of that previously presented at HydroSoc 2013.

Methods

Intact core experiments investigating transport of indicator organisms (*E. coli*, F-RNA bacteriophage (MS2) and F-DNA bacteriophage (PRD1)) compared with pathogenic microorganisms (*Campylobacter jejuni*, adenovirus, norovirus and enterovirus (Echovirus 7)). Different aquifer materials have been used for the transport studies to provide a complete picture of indicator and pathogen transport in heterogeneous aquifers. Previously experiments have been completed on clean open framework gravels, coated open framework gravels and sands. These experiments were conducted in a laboratory using repacked material.

The results presented here are for sandy gravels using three intact cores collected and transported to our field site at ESR, Christchurch.

Groundwater (sourced from Christchurch tap water) was passed through the intact cores (Figure 1) with flow rates adjusted to those found in the field (Dann et al 2008, Pang 1998). An injection mix of 10 litres volume comprising microbial tracers, conservative tracer (potassium bromide, Br) and pathogenic microorganisms were injected into the column (injection duration 60 minutes). Physical conditions of the cores and flow rates are shown in Table 1.

Microbial analysis was conducted on samples over time. *E. coli* and *C. jejuni* were analysed on selective media and typical colonies counted to give a number of colonies per mL (cfu mL^{-1}). Bacteriophages were analysed using overlay assays according to APHA methods (APHA 2004) to give a number of plaques per mL (pfu mL^{-1}). Viral pathogen analysis was via molecular methods (quantitative PCR) using specific primer sets for each organism. Bromide analysis was conducted using an ion selective probe. Flow rate, dissolved oxygen (DO), pH and temperature were recorded for the duration of the experiments.

Results

All organisms tested showed large variations between cores tested (0-95%). Highlighting the variable nature of these matrices. Differences seen could be attributed to the difference in the pore volume, velocity and drainage properties In the cores. When comparing indicator organisms to pathogens there were large variatios seen here too. It was not possible as seen in previous experiements to rely on indicator organisms removal to predict pathogen removal. Compared to our previous experiments on repacked open framework gravels and sands (tested separately) large variations were seen in removal rates. These variations were within the range seen for the gravels (0-77% removal) and sands (34-99% removal).

On completion of the research the transport of indicator and pathogen removal and transport in heterogeneous aquifers will be achieved and a better understanding of the assimilative capacity of these aquifers will be possible.

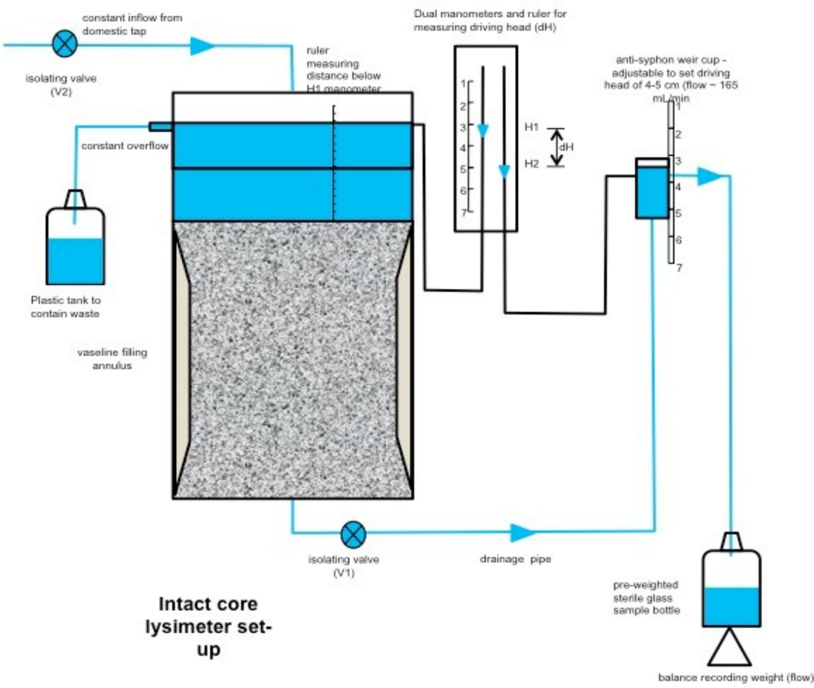

Figure 1 Intact cores set up.

Table 1 Conditions of the three intact cores

	Core 1	Core 2	Core 3

References

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VARIABILITY IN HYDROGEOCHEMICAL CONDITIONS IN SHALLOW GROUNDWATER IN THE MANAWATU RIVER CATCHMENT AND IMPLICATIONS FOR DENITRIFICATION POTENTIAL

Aldrin Rivas[1], R Singh[1], D Horne[1], J Roygard[2], A Matthews[2], M Hedley[1]
[1]Massey University , [2]Horizons Regional Council, ,

Aims

Favourable hydrogeochemical conditions in soil-water systems can attenuate nitrate (NO_3^-) leached from agricultural lands before it has impact on receiving surface waters. Denitrification has been identified as an important NO_3^- attenuation process in groundwater systems. However, the denitrification characteristics of groundwater systems vary in space and time depending on the properties of the surface and subsurface environments. The magnitude of, and variability in, attenuation capacity has implications for both the policy related to, and management of, NO_3^- losses from farm systems. Therefore it is important to investigate denitrification. However, *in-situ* measurements of denitrification are costly and time consuming. On the other hand, some water quality parameters that are commonly measured in groundwater monitoring programmes, such as redox conditions, may be used as indicators of denitrification capacity. The aims of this study were (a) to monitor hydrological and redox related water quality parameters at four selected sites in the Manawatu River catchment, (b) to determine the spatial and temporal variability in redox processes in the shallow groundwater, and (c) to identify the implications of hydrological and redox processes for denitrification at selected sites.

Method

Detailed monitoring of shallow groundwater was conducted at four study sites in the Manawatu River catchment. These sites were at: Palmerston North, Pahiatua, Woodville and Dannevirke. At each site, two to three piezometers were installed to allow sampling of shallow groundwater at depths ranging from 4.4 m to 7.7 m below ground level. Shallow groundwater samples have been collected monthly since October 2014 and analysed for a range of water quality parameters. In addition to water quality parameters measured on site (pH, dissolved oxygen, electrical conductivity, temperature, and oxidation-reduction potential or ORP), samples were taken for laboratory determinations of nitrate and ammonium-nitrogen (analysed by flow injection analysis), sulphate (by hydriodic acid reagent reduction), dissolved organic carbon (by potassium dichromate wet oxidation and titration), bicarbonate (based on alkalinity measurements and on site pH measurements), and the major cations namely, iron, manganese, calcium, magnesium, potassium, and sodium (by microwave plasma - atomic emission spectrometry). The ambient redox conditions in groundwater were determined in accordance with the biochemical succession of electron-accepting processes and sequential production of final products (McMahon and Chapelle, 2008). Redox processes were inferred by comparing concentrations of relevant parameters with threshold values as follows: dissolved oxygen (1.0 mg L^{-1}), nitrate-nitrogen (0.5 mg L^{-1}), manganese (0.05 mg L^{-1}), iron (0.1 mg L^{-1}) and sulphate (0.5 mg L^{-1}).

Results

As expected, water tables decreased (by 23 cm to 156 cm) from October 2014 to March/April 2015, the drier period of the year, at all sites. Thereafter, water tables rose and reached the highest levels at all sites in July 2015. Dissolved oxygen (DO) levels varied significantly across the sites with two sites (Palmerston North and Woodville) showing reduced conditions (DO < 0.70 mg L^{-1}) (Figure 1a). Significantly higher DO levels were observed at the Pahiatua site and in the shallower piezometers at the Dannevirke site. In general, the DO concentrations seemed to correspond with changes in groundwater level, with DO levels decreasing as groundwater levels fell (from October to March) and increasing as the groundwater levels rose in the wet months (from May to August). This indicates that conditions for denitrification are more favorable during the summer period. Other studies have made similar observations (e.g., Anderson et al., 2014). This trend appears to be reflected in the decreasing nitrate-N concentrations at the Dannevirke site (Figure 1b). However, this was not observed at the Pahiatua site where the nitrate-N concentrations were found to increase during the drier months. This may indicate low denitrification potential at this site and the observed increase in nitrate-N concentrations could be attributed to the reduced dilution during the drier months. In reduced conditions such as in Palmerston North and Woodville sites as well as in the deepest piezometer at the Dannevirke site, very low nitrate-N concentrations were found. The significant amount of iron, which could act as electron donor in the denitrification process, in these groundwaters (0.5-4.2 mg L^{-1}) is a key indicator of the denitrification potential at these locations. Initial results from measurements of redox processes support these findings with oxygen reduction identified as the dominant process at the Pahiatua site, whereas anoxic conditions and iron reduction are the dominant processes at the Palmerston North, Woodville and Dannevirke (deepest piezometer) sites.

The initial results presented here clearly indicate the variability of denitrification characteristics among sites as well as within sites (particularly at the Dannevirke site), and the temporal dynamics of hydrogeochemical properties of shallow groundwater. Given that the groundwater quality parameters used in this study are included in the monitoring programmes of regional councils, conducting such analysis with existing databases would help the assessment of spatial and temporal dynamics of denitrification characteristics in groundwater systems at a larger scale.

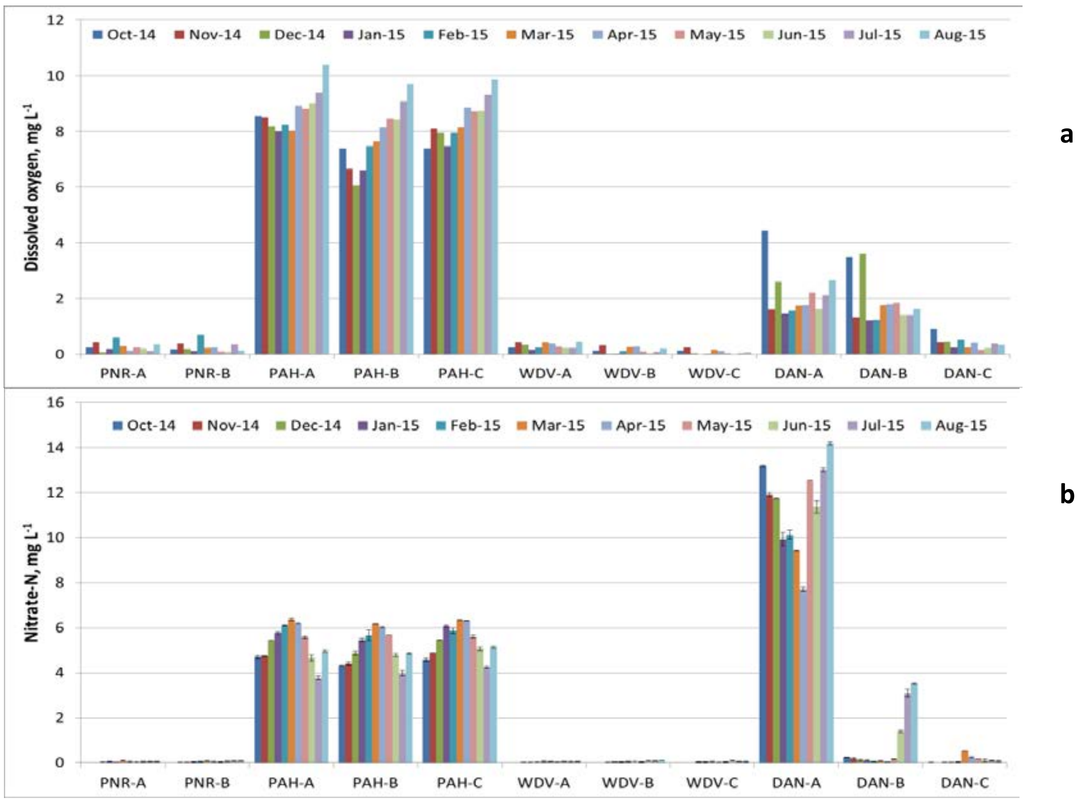

Figure 1: The variation in (a) dissolved oxygen and (b) nitrate-nitrogen concentrations at four sites in the Manawatu River catchment. Notes: PNR – Palmerston North site; PAH – Pahiatua site; WDV – Woodville site; and DAN – Dannevirke site.

Acknowledgment

This research is part of a wider collaborative research programme by Massey University's Institute of Agriculture and Environment and Horizons Regional Council to investigate the transport and fate of nitrogen as it moves from farms to waterways in the catchment.

References

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McMahon, P. & Chapelle, F. (2008) Redox processes and water quality of selected principal aquifer systems. Ground Water, 46, 259-271.

Wednesday, 2nd of December

Session: Catchment-scale Water and Contaminant Fluxes, Start Time: 9:30 a.m.

LOW SPATIAL AND INTER-ANNUAL VARIABILITY IN EVAPORATION FROM AN INTENSIVELY GRAZED TEMPERATE PASTURE SYSTEM

Jack Pronger[1], D Campbell[1], M Clearwater[1], S Rutledge[1], A WaLL[1], L Schipper[1]
[1]1School of Science and Environmental Research Institute, University of Waikato, ,

Ecosystem scale measurements of evaporation (*E*) from intensively managed pasture systems are important for informing water resource decision making, drought forecasting, and validation of Earth system models and remote sensing. Until recently, annual-scale datasets of measured *E* have not been available in New Zealand.

Aims

The primary aim of this study was to measure the magnitude and temporal and spatial variability of *E* from non-irrigated, intensively grazed, ryegrass and clover pasture. A secondary aim was to investigate the controls on *E* including the impact of regular grazing events. Finally, measured *E* was compared to modelled *E* using the FAO_{56} Penman-Monteith equation to determine whether models need to account for defoliation by grazing to accurately predict *E*.

Method

The research was undertaken on a commercial dairy farm in the Waikato region on relatively flat alluvial soils with mean annual rainfall of 1249 mm and mean annual temperature of 13.3°C. Paddock scale *E* was measured at three sites using the eddy covariance (EC) technique. The datasets from these three sites ranged in duration from 3 years to 6 months, with all three datasets overlapping for 6 months. Continuous measurements of meteorological and environmental variables, including soil moisture, were also collected.

Results

Spatial variation in *E* was less than 3% during the initial study period when up to three sites were operating simultaneously. Inter-annual variability of *E* was also less than 3% over the three consecutive years (750 – 770 mm) at one of the sites. The absence of spatial and inter-annul variation largely occurred because *E* was strongly controlled by net radiation (daytime half-hourly data $r^2 = 0.83$, $p < 0.01$) which was relatively consistent between sites and years. However, low soil moisture content during seasonal dry periods constrained *E* relative to net radiation, demonstrating that soil moisture was an important second order control. Intensive grazing events, that removed a large fraction of standing pasture biomass, were found to have little observable effect on *E*. The absence of a grazing effect suggested that leaf area was not an important control of *E*, likely because increases in soil *E* were able to compensate for decreased transpiration. Agreement between measured and FAO_{56} Penman-Monteith *E* was good on a daily ($r^2 = 0.81$) and annual (within 5%) time step so long as a water stress coefficient was applied to simulate restricted *E* during seasonal dry periods.

EVAPOTRANSPIRATION FROM IRRIGATED LANDSCAPES ACROSS NEW ZEALAND

Scott Graham[1], Maurice Duncan[1], MS Srinivasan[1]
[1]NIWA, , New Zealand

Aims

Evapotranspiration (ET) is an important component of terrestrial water balance, however, direct measurements of ET are infrequent. Precise estimates of ET are essential for a variety of applications, including irrigation scheduling and hydrologic modelling. This study employs a network of eddy covariance towers for measurement of actual ET in order to characterise the influence of climate, vegetation and agricultural management practices.

Method

Eddy covariance towers have been established in a Canterbury cropping farm, a vineyard in Hawke's Bay, and dairy pastures in Canterbury and Southland to measure turbulent exchanges of heat and water vapour. Tower-based ET is compared to models of potential ET, including the Penman method, which is currently predicted across New Zealand.

Results

Maximum observed rates of actual ET are 11.1 mm d^{-1} for the Canterbury dairy pasture, 9.7 mm d^{-1} for the ryegrass crop, 7.6 mm d^{-1} for the Southland dairy pasture and 5.0 mm d^{-1} for the vineyard. Annual totals are 940, 828, 841 and 687 mm respectively. Preliminary results indicate that ET occurs at near-potential rates in both Canterbury and Southland dairy pastures (see figure), although there is some evidence that low soil temperature limits ET at times. Ryegrass crop ET is likewise similar to potential ET during vegetated periods, however management practices, such as mowing and crop harvest, periodically reduce ET. Vineyard ET was clearly impacted by deficit irrigation techniques with ET showing a strong response to soil water content and dry season irrigation events. These results are currently being integrated into models of actual ET and soil water balance.

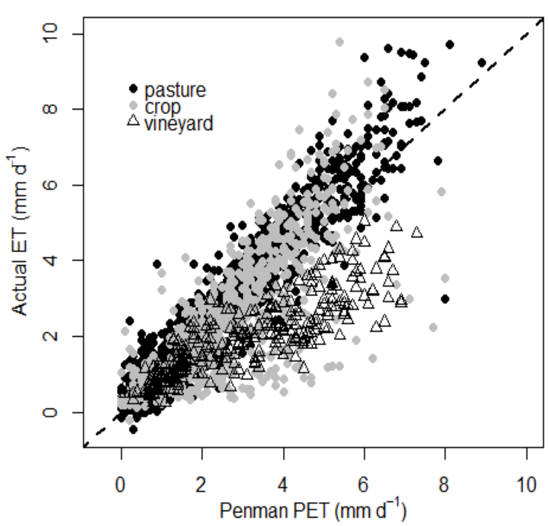

Figure: Variations of actual evapotranspiration (ET) from potential evapotranspiration (PET) as calculated by the Penman method for different irrigated cover types.

TRANSPIRATION IN PASTURE COLONISED BY WOODY SHRUB DISCARIA TOUMATOU; CANTERBURY, NEW ZEALAND

Dr Bruce Dudley[1], Dr MS Srinivasan[1], Dr Hannu Marttila[2]
[1]NIWA, Riccarton, Christchurch , New Zealand, [2]University of Oulu, Oulu, Finland

Colonization of grassland by woody shrubs is occurring in many dry areas worldwide due to altered disturbance patterns, and biological invasions. The resulting changes to plant water use can greatly alter catchment scale water cycling processes. Whole catchment studies in New Zealand have shown reductions in streamflow following replacement of grasslands with large trees. However, recent research using stable isotopes of water (δD, $\delta^{18}O$) has indicated that at least in some environments, woody species may make substantial use of soil bound water sources that would not otherwise have contributed to either groundwater or streamflow.

Aims

We aim to quantify effects of regrowth of matagouri (*Discaria toumatou*) on streamflow in a small upland pasture catchment. Further, we aim to quantify how position within the catchment influences streamflow reduction by this woody shrub.

Method

We measured transpiration in *Discaria toumatou* during summer 2014/2015 using the heat pulse velocity sapflow technique. In ongoing work, we are calculating the effects of regrowth of this woody shrub on streamflow using measurements of water stable isotopes in precipitation, soils, stem water, groundwater and streams. These effects will be compared at an array of sites from the riparian zone to near the ridgeline. Net effects of matagouri growth on the catchment water balance will be assessed by incorporating measured transpiration and light reduction by matagouri into models of evapotranspiration by pasture.

Results

We present sapflow results from summer 2014/2015 to present, and isotope results from the past year. We will present a model concept for assessing matagouri effects on the catchment water balance.

Session: General Hydrology, Start Time: 9:30 a.m.

THE EXPERIENCES OF MAORI WHO HAVE NEGOTIATED AN ALLOCATION OF WATER - IS IT RECOGNITION OF RIGHTS AND INTERESTS?

Dr Gail Tipa[1], Ms Mandy Home[2]
[1]Tipa and Associates , Outram. Dunedin, New Zealand, [2]NIWA, Christchurch, New Zealand

The Waitaki River is of paramount importance to Ngai Tahu. The statutory framework that governs the catchment includes two important documents:

- The Waitaki Allocation Plan; and
- The Environment Canterbury Land and Water Regional Plan

In 2014/2015 Environment Canterbury, in response to multiple applications to extract water, initiated a collaborative process that resulted in a plan change that set the allocation for the Lower Waitaki. Iwi were engaged in the collaborative forums and an allocation of water was set aside for mahinga kai. Local media has promoted this allocation as a “first” for New Zealand.
However, there were issues with respect to the allocation. In this presentation we want to highlight these issues and identify how hydrological advice informed a rethink of the mahinga kai allocation.

Aims
The purpose of this presentation is to:

- Summarise the experiences of Iwi representatives agreeing an allocation regime for the Lower Waitaki River;
- Identify the shortcomings with respect to the solution that was initially negotiated by the Lower Waitaki / South Canterbury Zone Committee;
- Identify the advice from hydrologists that enabled a more equitable allocative regime to be negotiated; and
- Identify what this could mean in terms of a recognition of cultural rights and interests.

Method
Environment Canterbury established a number of collaborative forums across the Canterbury. Two forums cover the Waitaki catchment (upper and lower). One forum, the Lower Waitaki / South Canterbury Zone Committee, negotiated the allocative regime that appeared in the subsequent plan change. Ngai Tahu, along with other stakeholders, then submitted on the plan change.

Results
An allocation regime is to be set via a plan change. The results clearly have implications for Ngai Tahu going forward as it needs to determine how it is to manage a significant allocation of water. Firstly, who manages it? Is it managed by the iwi authority or is the manager to be the kaitiaki runanga? Further, how does Ngai Tahu balance potentially competing tribal interests? Management needs to balance the practicality of when and how whanau are to utilise the allocation to deliver a range of outcomes alongside their obligation as kaitiaki to protect the river. Will the water be extracted? In what circumstances would the allocation be left in stream?
The process highlighted complex and interrelated issues that whanau across New Zealand need to comprehend if they are to make informed decisions about allocations, including understanding security of supply, and having an overview of the hydrology across a catchment specifically the contribution of inflows to mainstem flows. It is only by understanding these complex issues that informed decision making will be possible.

References

Evidence of F Home to Plan Change 3 Hearing which will amend the Environment Canterbury Land and Water Regional Plan

Evidence of James Winchester to Plan Change 3 Hearing which will amend the Environment Canterbury Land and Water Regional Plan

Evidence of Lynda Murchsion to Plan Change 3 Hearing which will amend the Environment Canterbury Land and Water Regional Plan

INTER COMPARISON OF EXPERIMENTAL CATCHMENT DATA AND HYDROLOGICAL MODELLING

Dr Shailesh Singh[1], Dr. Hilary McMillan[1]
[1]*National Institute of Water and Atmospheric Research, Christchurch, New Zealand, Riccarton, New Zealand*

Hydrological model account for the storage, flow of water and water balance in a watershed, which includes exchanges of water and energy within earth, atmosphere and oceans. Generally the parameter of lumped, semi or distributed hydrological model has depended on the parameter estimated at gauged location which is generally at outlet of a basin. In this approach it is hard to judge real performance of model to represent each process of hydrological cycle. This limit the utility and confidence in use of the model.

Aims

The objective of this study is, to identifying model weaknesses in reproducing actual internal catchment processes and to improve in understanding hydrological processes, through field observation. The other objective of this study is to validate physically-based semi-distributed hydrological model (TopNet) with spatially observed data from small experimental catchments to ensure that the internal dynamics and processes of the catchments are properly represented in the model.

Method

This study was carry out at Waipara experimental catchment, which is located in South Island of New Zeeland. In filed campaign, in Waterscape project of NIWA, we made distributed measurement of streamflow, soil moisture and groundwater levels across range of hillslope, aspects and distances from stream and different depths. TopNet rainfall-runoff model was setup waipara catchment. To achieve the objective of this study following steps were carried:

- The data collected were analysis for understanding the flow generation process in the catchment.
- A semi-distributed physically based (TopNet) hydrological model was set up for the catchment.
- The model was run for given time period and all the different fluxes were saved for further inter comparison with observed data.
- Detail analysis for each hydrological process was conducted to look the patter observed in the filed with flux obtained by model.

Results

Analysis of rainfall runoff ratio and average soil moisture measured at 30 cm and 60cm shows that approximately 32 % of soil moisture at 30cm trigger the runoff from the soil or around 40% of soil moisture at 60cm depth of soil. The total amount of simulated runoff from TopNet model showed reasonable agreement with observations. But regarding the specific runoff components, the model overestimated base flow and underestimated surface flow. Comparison of dynamic of soil moisture obtained from TopNet model is compared with average observed soil moisture and given in Figure 2. The results shows that soil moisture dynamic observed is well represented by the model.

Conclusion

In this study, experimental catchment Waipara data was used to validate the hydrological model TopNet. Preliminary results shows that soil moisture dynamic observed is well represented by the model. This current study is ongoing, hence, further investigation is required to prove the other internal dynamics and processes of the catchments are properly represented in the model.

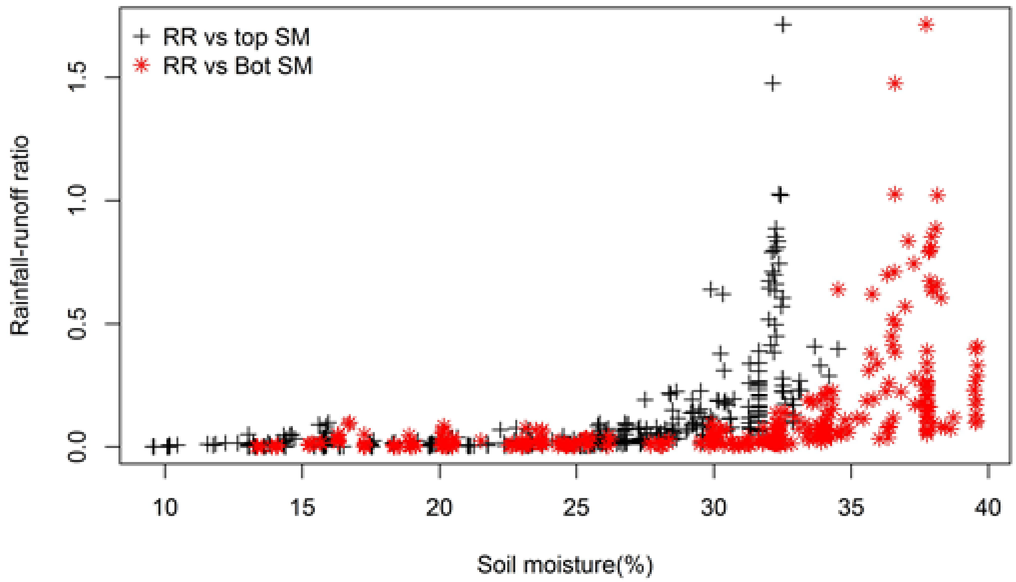

Figure 1 Rainfall Runoff Ratio VS Average Soil moisture North face

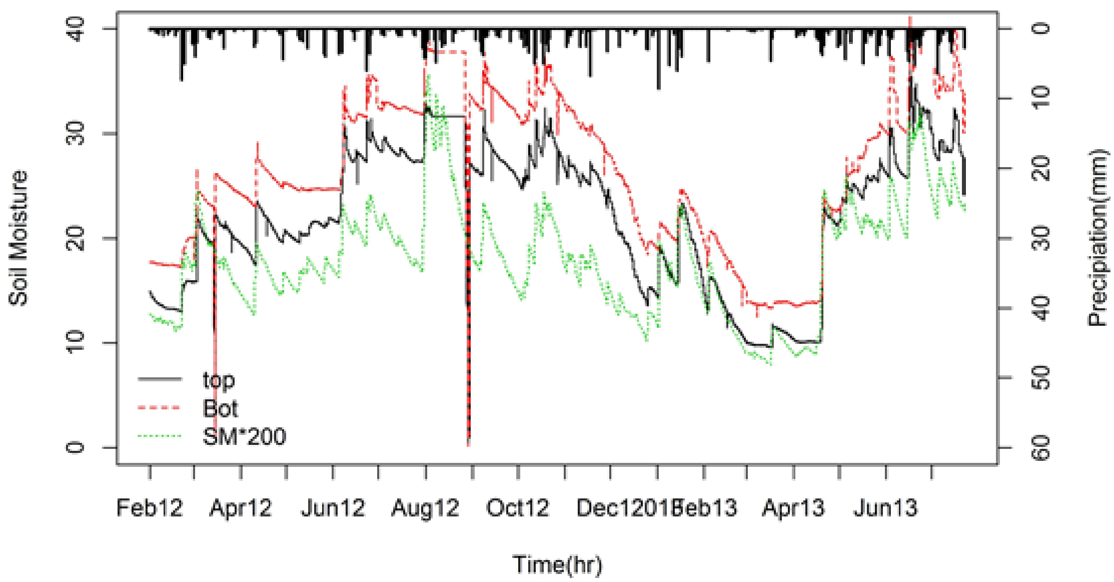

Figure 2 Average Soil moisture (red and black) at 30cm and 60cm (North face) along with soil moisture (green) dynamic from model.

UNCERTAINTY IN MODELLING GROUNDWATER FLOW PATHS BASED ON HEAD DATA ALONE: THE WAIHORA HILLSLOPE, TAUPO

Dr Simon Woodward[1], Dr Thomas Wöhling[1,2], Dr Roland Stenger[1]
[1]Lincoln Agritech Ltd, Hamilton, New Zealand, [2]WESS, University of Tübingen, Tübingen, Germany

Introduction

The Waihora research site is a small (0.6 ha) pastoral hillslope that drains into a wetland in the headwaters of the Tutaeuaua Stream on the northern shores of Lake Taupo. High-resolution piezometric head measurements have been collected at the site since 2004, supplemented by slug test estimates of saturated hydraulic conductivity at several of the wells, with the intention of describing the spatial and temporal patterns of flow paths that transfer nitrate leached from the land surface, through the vadose zone-groundwater continuum, to the wetland and stream.

Methods

A MODFLOW-NWT (Hunt et al., 2012) model of transient, 3D shallow groundwater flow was developed for the site, with three model layers representing the Taupo ignimbrite (TI), Paleosol (P) and Oruanui ignimbrite (OI) material layers, and a 2 x 2 m horizontal grid resolution. Saturated hydraulic conductivity (Ksat) patterns in each of the layers were calibrated using SVD-Assist and regularised Pilot Points in PEST, and the uncertainty of the calibrated Ksat patterns subsequently assessed using Null Space Monte Carlo analysis (Doherty, et al., 2010; Yoon et al., 2013). Finally, flow paths were calculated for each of the Monte Carlo generated Ksat realisations that fitted the data (Beven and Freer, 2001), using MODPATH version 5.

Results

Null Space Monte Carlo uncertainty analysis indicated that the available head and slug test data were not sufficiently informative to definitively determine the spatial pattern of hydraulic conductivity at the site, although modelled water table dynamics matched the measured heads with high accuracy in space and time (NSE = 0.95). Particle tracking analysis showed that the flow direction in the saturated zone was similar throughout the year as the water table rose and fell, but was not aligned with either the ground surface or subsurface material contours. Since the subsurface materials have overlapping ranges of saturated hydraulic conductivity (as assessed by lab measurements, slug tests, and model calibration), the material layers *per se* appear to have little effect on saturated water flow at the site. Flow path uncertainty analysis (Figure 1) showed that while accurate flow path direction or velocity could not be determined on the basis of the available head and slug test data alone, the origin of well water samples relative to the material layers and site contour could still be broadly deduced. Furthermore, comparison with tritium-based mean residence time (MRT) estimates at several of the wells indicated that predicted flow velocities (indicated by the length of the flow paths) were generally reasonable.

Conclusions

This study highlighted both the challenge in collection of suitably informative field data, and the power of modern calibration and uncertainty modelling techniques, to accurately define flow paths in hillslopes and other small scale systems. Despite the high uncertainty in predicted Ksat, the approach nevertheless allowed reasonable predictions to be made of potential flow paths.

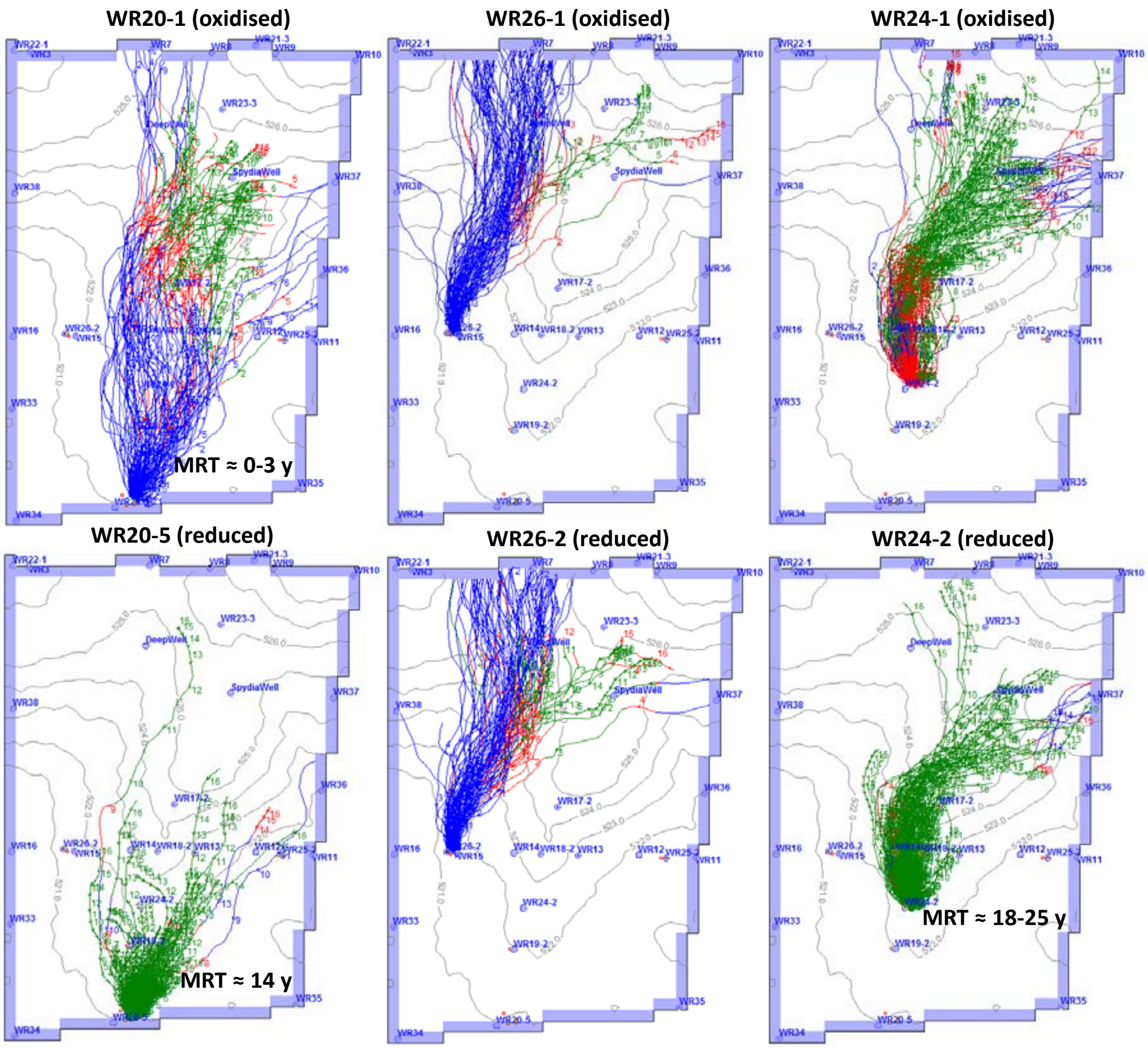

Figure 1: Uncertainty in flow paths starting on 6 July 2007 and terminating at six wells on 27 November 2008, calculated using behavioural hydraulic conductivity results. Contours show the modelled elevation of the Paleosols. Time postings are in months. MRT is tritium-estimated mean residence time in years. Trace colours correspond to material layers (blue = TI, red = P, green= OI).

Acknowledgement
This research was conducted under the ‘Groundwater Assimilative Capacity’ Programme funded by MBIE. Thanks to Aaron Wall, Juliet Clague, Brian Moorhead and Moritz Gold for their excellent technical support.

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Session: Groundwater / Surface Water Connectivity, Start Time: 9:30 a.m.

TOWARDS MODELLING WAIRAU RIVER – AQUIFER EXCHANGE FLUX DYNAMICS: DATA INTEGRATION AND UPSCALING

Dr Thomas Wöhling[1,2,3], Moritz Gosses[1], Jillian Troyer[1], Michael Ede[4], Peter Davidson[4], Scott Wilson[2]
[1]University of Tübingen, Tübingen, Germany, [2]Lincoln Agritech Ltd, Hamilton, Lincoln, New Zealand, [3]University of Technology Dresden, Dresden, Germany, [4]Marlborough District Council, Blenheim, New Zealand

Aims

The Wairau Aquifer is almost exclusively recharged by surface water from the Wairau River and serves as the major drinking water resource for Blenheim and the surrounding settlements on the Wairau Plain. Because the safe yield limit of the aquifer has been reached and a small but constantly declining trend in aquifer levels have been observed over the past decade, it has been made a high priority by the Marlborough District Council (MDC) to better understand the limits and the mechanics of the recharge mechanism. While previous research efforts have been centred at water budgets during low-flow conditions and steady-state modelling, this study aims at understanding the dynamics of river-groundwater exchange fluxes using information of Wairau river flows at three new gauging stations.

Method

Differential flow gauging, in theory, allows us to easily calculate flow losses or gains along a river section. In practice, however, the exchange-flux estimates can be highly uncertain due to unknown inputs along the section (e.g., second order streams), inaccurate stage-flow rating curves, and highly dynamic flow regimes. The uncertainty increases drastically in braided rivers like the Wairau, where flow-rating curves are changing over time (since the channel bed geometry constantly changes) and where underflow may occur in highly conductive gravel bars. We have been analysing some of these uncertainty sources, by accounting for flow lag times between rated river sections and for second-order stream contributions.
Time series of observed hydraulic heads and Spring Creek flow were integrated using MODFLOW and different conceptualizations and parameterizations of the river and aquifer properties (hydraulic conductivity and specific yield fields, river/stream conductance, anisotropy). River-exchange flux estimates that are more accurate under low-flow conditions were used for model plausibility checks. Since transient model run times exceeded our requirements for hypothesis testing and model calibration, we applied model reduction (upscaling) techniques.

Results

The consideration of flow lag-times between Wairau river gauging stations and of contributions from Northern tributaries of the Wairau explained some of the unresolved variance of the river-groundwater exchange fluxes. Our analysis shows that the fluxes are relatively constant during low-flow conditions and highly dynamic during flood events. The general dynamics of this system behaviour could also be mimicked with the transient flow model. The simulated time series of hydraulic heads and Spring Creek flow agree well with the observations. Further analysis is required to quantify the uncertainty of both parameter estimates and model predictions and to analyse the model's plausibility with regard to the observed long-term trends in aquifer levels.

HOW WELL ARE TWO- AND THREE-COMPONENT TRACER HYDROGRAPH SEPARATIONS SIMULATED BY BASEFLOW SEPARATION METHODS?

Dr Michael Stewart[1]
[1]*Aquifer Dynamics & GNS Science, Lower Hutt, New Zealand*

Aim

To test how well baseflow separation methods are able to simulate tracer hydrograph separation results.

Background

Baseflow separation has been important for over a hundred years as a way of identifying direct runoff by subtraction and relating it to the causative rainfall. The baseflow part of the total streamflow is generally regarded as sourced from groundwater discharging into streams, A wide variety of mainly graphical methods of baseflow separation have been used and continue to be used in practical applications (see the graphical example in Fig. 1). These methods are usually not based on real knowledge of baseflow variations and can be inconvenient to apply to long records. More convenient recent methods of this type are recursive digital filters that can be applied to the streamflow record to extract the baseflow hydrograph.

The introduction of tracer separation of components 40 years ago gave actual data-based separations for essentially the first time. They produced a paradigm shift in thinking about runoff generation since they showed that baseflow responds rapidly to rainfall just like quickflow, and often dominates storm hydrographs in addition to low flow periods between events.

In the spirit of proceeding from data to knowledge, this work compares two- and three-component hydrograph separations obtained from tracer studies with traditional baseflow separation methods and recursive digital filter methods, including the BRM filter (Stewart 2015) which has an algorithm constructed to simulate tracer separations. The baseflow separation method giving the best simulation can then be used to extend the temporally limited tracer separation to the whole record, to illuminate runoff processes in catchments.

Method

Comparisons are carried out with tracer studies drawn from the literature.

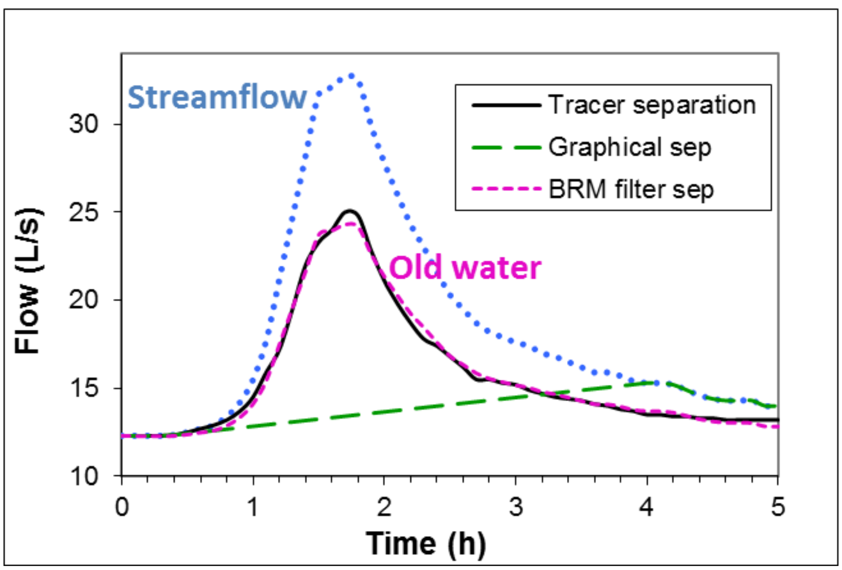

Figure 1 Two-component tracer separation of new and old water components compared with a traditional graphical separation and a fitted BRM filter separation.

Results

Eight two-component tracer studies were examined from catchments with a wide variety of climatic settings, areas, topography, soils and vegetation. Different methods fitted the tracer separations with varying quality, but the BRM was usually the best. Fig. 1 shows an example using ^{18}O to separate new and old water components from a headwater swamp in Toronto from Hill & Waddington (1993). While the graphical separation result does not bear much relation to the tracer separation, the fitted BRM separation matches it very closely.

More detailed separations are possible using two tracers with different characteristics thereby giving three-component separations – five such studies were examined. Again the different methods fitted the components to different extents, and the BRM produced the best fits. Fig. 2 gives an example from the Black Forest in Germany (Hangen et al. 2001), which used silica and ^{18}O to separate the hydrograph into three components (event rain water, soil water and groundwater). Close simulations to all three components can be achieved with the BRM filter.

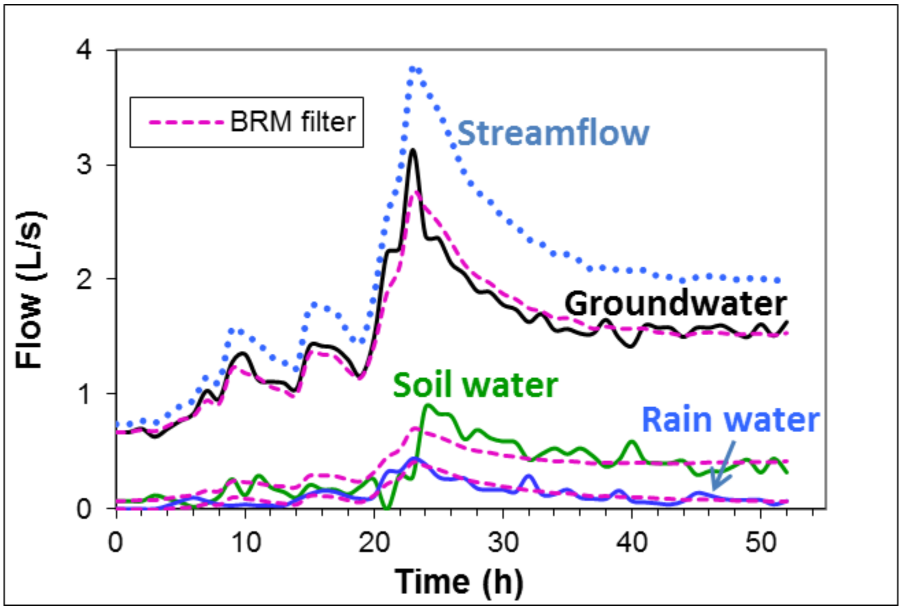

Figure 1 Three-component tracer separation into rain water, soil water and groundwater components compared with fitted BRM filter separation.

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CHANGING GROUNDWATER AGE AND SOURCE DURING DROUGHT CONDITIONS AND CONNECTIONS BETWEEN SURFACE WATER AND GROUNDWATER IN THE LOWER WAIRAU VALLEY

Dr Uwe Morgenstern[1], Peter Davidson[2]
[1]GNS Science, Avalon, Lower Hutt, New Zealand, [2]Marlborough District Council,

Aims

Groundwater is an important water source for horticulture and viticulture in the Wairau Valley during usually long dry spells in summer. Groundwaters in the shallow aquifers are closely connected to the surface waters, with unique spring-fed creeks that are re-emergences of shallow groundwater flows originating from losing river stretches upstream (Davidson and Wilson, 2011). To maintain minimum flows for healthy river environments during dry spells, groundwater usage may need to be restricted. To enable robust policy development for the Wairau Aquifer we are investigating (1) how shallow groundwaters and surface waters are connected, and (2) how the dynamics of the shallow groundwaters are changing in view of potential increases in dry spells related to climate change.

Method

The age of the water (travel time through the groundwater system), measured in surface and groundwater using tritium (Morgenstern et al., 2010), allows us to identify direct links between the surface water and groundwater. Changes in water age allow the identification of depletion of the groundwater resources, and changing sources of groundwater. We measured the age of the water during normal base flow and during the extremely low-flow conditions in the 2014/15 summer (which had the lowest well levels and flows recorded since 1982) in the northern Wairau Plains. Paired water samples from surface water flows and nearby shallow groundwater wells were used to identify the hydraulic connection, and samples from a coastal well to identify the cause for large seasonal changes of hydrochemistry.

Results

All shallow groundwaters and re-emerging surface waters close to the Wairau river are very young (including Spring Creek), indicating direct recharge with little reservoir storage to buffer against periods of high abstraction or low rates of natural recharge. Towards the southeast, with increasing distance from the Wairau river source, the water becomes older, c. 2 y around Fulton and Murphy Creeks, and 3-5 y around Doctors Creeks.

Tritium concentrations between all paired surface and groundwater samples are similar, indicating interconnected water resources. Therefore, good aquifer and land management is essential for maintaining minimum spring flows and water quality standards.

In a shallow well near the coast in the Rarangi Shallow Aquifer (RSA) north-east of Blenheim, we have detected large seasonal changes of groundwater age. During normal baseflow conditions the well contains very young (<1 y) water, which is consistent with locally recharged oxic water with high nitrate concentrations from nearby land-use activities. During extreme low baseflow conditions, the fresh young water from the last recharge season has depleted, with the well tapping only into older groundwater (>10 y) flow towards the coast, consistent with recharge from areas further from the nitrate sources and with the anoxic nature of the water. This provides the geochemical explanation for seasonal variations in nutrient concentrations in groundwater and the presence of species such as arsenic, which may affect the health of Rarangi residents which rely entirely on the RSA.

Conclusions

Isotope and age tracers have proved the connection between the Wairau Plain aquifers and the region's springs and waterways, as well as quantifying the groundwater storage. Without information about the residence time of the water in the groundwater systems, meaningful interpretation of groundwater monitoring results is difficult. Such hydrological understanding underpins all of the water management policy changes currently underway in Marlborough.

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Session: Catchment-scale Water and Contaminant Fluxes, Start Time: 11:00 a.m.

CAN ISOTOPE TOOLS RAPIDLY FILL GAPS IN KNOWLEDGE OF NITRATE SOURCES AND ATTENUATION NEEDED FOR WATER QUALITY POLICY?

Dr Troy Baisden[1], Dr Clint Rissman[2], Dr Travis Horton[3], Dr Naomi Wells[4,5], Prof Tim Clough[4]

[1]GNS Science, Lower Hutt, New Zealand, [2]Environmental Southland, Invercargill, New Zealand, [3]University of Canterbury, Christchurch, New Zealand, [4]Lincoln University, Lincoln, New Zealand, [5]UFZ, Leipzig, Germany

Aims

Management of nitrate pollution through the implementation of New Zealand's National Policy Statement for Freshwater Management (2014) creates strong demand for understanding of the sources and sinks (attenuation) of nitrate within catchments. Over the last seven years, analysis of N and O isotopes in nitrate has been developed as a tracer technique capable of constraining the sources and sinks of nitrate in New Zealand. This presentation reviews this new tool's potential to reveal sources and sinks of nitrate that may be associated with "hot spots" and "hot moments" that are difficult to resolve with other techniques.

Method

Isotopes in nitrate ($\delta^{15}N$ and $\delta^{18}O$) were measured using the Cd/azide reduction method in catchments and regions throughout New Zealand. We report specifically on studies in the Upper Manawatu, Mangatarere (Wairarapa), Hart's Creek (Canterbury) catchments. Across Southland, a broad suite of hydrochemical measurements were undertaken in "source", groundwater and surface water samples, including nitrate ($\delta^{15}N$ and $\delta^{18}O$) and dissolved inorganic carbon ($\delta^{13}C$-DIC), which are the focus of this presentation.

Results

Results from the Upper Manawatu and Mangatarere catchments show that sotopes in nitrate $\delta^{15}N$ and $\delta^{18}O$ sit on a "denitrificaton and mixing" (DAM) line with a 1:1 slope on a plot of $\delta^{15}N$ vs $\delta^{18}O$, with values generally proportional to the duration and intensity of pastoral agriculture. Additional variation in $\delta^{18}O$ relative to the DAM line appears diagnostic of seasonal sources of nitrate in each subcatchment. These $\delta^{18}O$ anomolies suggest losses of nitrate during winter and summer that can be mitigated by agricultural management.

A study in spring-fed Hart's Creek, which drains into Lake Ellesmere (Te Waihora) in Canterbury, was designed to evaluate attenuation. Results show the highest levels of attenuation in upstream sites and within 48 hours of rainfall. This suggests that soil, vadose zone and riparian zones may dominate attenuation processes.

A 150-sample preliminary dataset from across Southland, comprising "source" samples such as tile drains and springs, groundwater bores, and surface water monitoring sites, shows much lower variability in surfacewater, compared to "source" and groundwater samples. Surface waters follow the same 1:1 DAM line observed elsewhere. The position of surface water samples relative to the DAM line suggests that rapid nitrification of urea/urine may be greater in Southland than other regions. The use of $\delta^{13}C$-DIC appears promising as an additional isotope tracer, revealing the variable imprint of biological respiration, which is required to generate processes in the sequence of nitrification, oxygen consumption, and subsequent denitrification.

Overall, source signatures are commonly preserved, and denitrification signatures disappear, implying that denitrification is frequently causes 100% attenuation where and when it occurs.

Isotopic tools therefore appear promising to evaluate region and catchment-specific "hot spots" and "hot moments" of nitrate source and sink activity, such as soil, vadose zone and riparian attenutation. Approaches will be proposed to enable cost-effective and well-targeted policy development and management actions, buidling on other methodologies and filling knowledge gaps

CHALLENGES IN NATIONAL SCALE GROUNDWATER QUALITY AND QUANTITY MODELLING

Monique Beyer[1], B Jackson[1], M Trodahl[1], D Maxwell[1]
[1]*Victoria University of Wellington , , New Zealand*

Introduction

Information on groundwater quality and quantity are important to allow for protection of fresh water resources. Currently, there is no comprehensive national coverage of groundwater quality and quantity data in New Zealand. Groundwater quality i.e. chemistry data are available at ca. 100 groundwater monitoring sites across New Zealand within the National Groundwater Monitoring Programme (NGMP). Further groundwater quality monitoring is carried out by individual regional authorities through State of the Environment (SoE) reporting. These data give useful information at a point, but do not provide complete spatial coverage. To assess water quality in an aquifer, estimate groundwater quantity, and identify pressures on aquifers some regional authorities have developed small to regional scale groundwater models. National water quality modelling in New Zealand is attempted by only two frameworks, namely CLUES (Catchment Land Use for Environmental Sustainability model) [Harris et al., 2009 and references therein] and LUCI (Land Utilisation and Capability Indicator) [Jackson et al., 2013]. At this point, both GIS based frameworks have an extremely simplified representation of groundwater. This is in part due to the difficulties in representing and parameterising complex groundwater processes with the very limited available data. More detailed groundwater representations are necessary to more robustly identify and locate natural and anthropogenic pressures, such as land use practices and climate change, on water quality and quantity.

Aims

In this study, we aim to integrate more detailed groundwater quality and quantity modelling into LUCI (for New Zealand). Since surface water and groundwater interact, e.g. surface water can recharge groundwater and groundwater can discharge into surface water, a more detailed groundwater and unsaturated zone model is needed. This can help understand the dynamics and vulnerability of both groundwater and surface water and will ultimately help decision making in protecting fresh water resources. To achieve national groundwater and unsaturated zone modelling some simplifications and assumptions need to be made to reflect limitations in available data, computational limitations and the capacity of the modelling framework. Ultimately, we need to feed our model with complete spatial coverage of parameters such as hydraulic conductivity and/or residence time of the water in the saturated and unsaturated zone. However, complete spatial coverage of the required data does not exist. We present a first attempt to relate and interpolate nationally available data to parameters suitable to go into a national groundwater model and the challenges faced while doing this. Our work will also be useful in other modelling efforts that require better representation of national groundwater (and surface water) processes.

Methods

In this study, we identified nationally and regionally (publically) available data that can be related to infer parameters for a national groundwater and unsaturated zone model. We discuss choices for interpolating and extrapolating point measurements, such as groundwater quality data, and the use of mapped information, such as QMAP (the geological map of New Zealand) and S-MAP (the New Zealand soil database) that have been established through extrapolation of point measurements and expert knowledge.

Results

Examples of the identified data sources that can be used to infer parameters required for a national groundwater quality and quantity model include groundwater chemistry/quality information gained from the NGMP and SoE networks. These are expected to aid in the estimation of pristine groundwater chemistry (as demonstrated in Daughney and Reeves (2003)), may also help locate groundwater systems (simply through their location) and identify recharge areas (e.g. through recharge related changes in hydrochemistry). We present approaches to extrapolate these point measurements to achieve complete national coverage.

The Fundamental Soils Layer (FSL) and the more detailed soil map (S-MAP) contain information on e.g. permeability and nutrient retention of soil. These information is expected to help identify potential groundwater recharge areas and nutrient transport into groundwater (including nutrient degradation and adsorption in the soil), respectively. Although S-MAP contains more detailed information on soil properties than the FSL it covers less than 30% of New Zealand as of date (as illustrated in Fig. 1). We present ways to extrapolate detailed soil properties from S-MAP to areas with less detailed data.

We highlight the benefits of more recent, more detailed data sets, such as S-MAP, and assess where and what data/information are most critical to allow for national groundwater modelling to guide ongoing and future work. Such work includes the extension of S-MAP and the development of a Groundwater Portal (within the SAC project) [Klug and Kmoch, 2014] which aims to become a web-based data sharing, processing and visualisation framework for hydro(geo)logical datasets (e.g. residence time information, groundwater models, satellite inferred recharge and water table data) in New Zealand. It is important to support these efforts as these developments aid in more robust modelling of groundwater and soil water processes and ultimately better protection of fresh water resources.

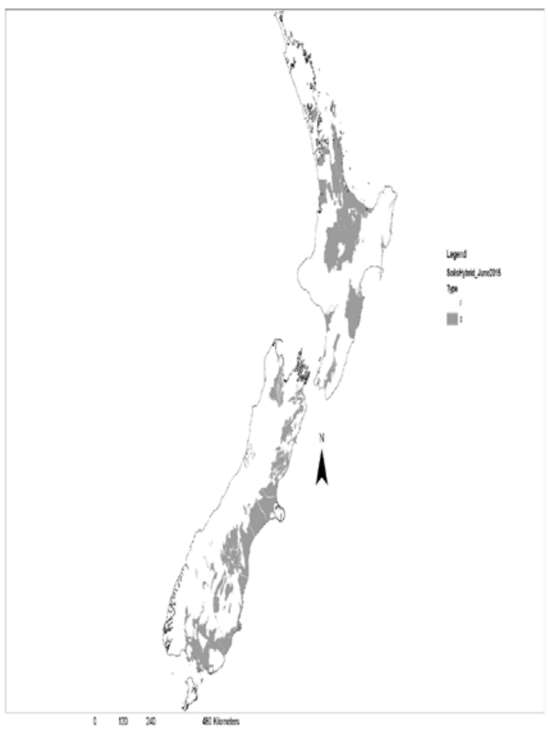

Figure 6: *coverage of S-MAP (grey areas) in New Zealand, white areas are only covered by the FSL*

References:

Jackson et al. (2013) Polyscape: a GIS mapping toolbox providing efficient and spatially explicit landscape-scale valuation of multiple ecosystem services. *Urban and Landscape Planning, 112,* 74-88.

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MODELLING THE MOVEMENT OF LEACHATE FROM A MARLBOROUGH VINEYARD DRAINING THROUGH THE SOIL TO GROUNDWATER AND RE-EMERGING AS SPRING FLOW

Peter Davidson[1], Scott Wilson[2], Rachel Rait[1], Steve Green[3]
[1]Marlborough District Council, Blenheim, New Zealand, [2]Lincoln Agritech, Lincoln , New Zealand, [3]Plant & Food Research, Palmerston North, New Zealand

Aims

Marlborough District Council as a water regulator needed to know the nitrate leaching rate of vineyard as this was the predominant irrigated crop overlying the important Wairau Aquifer used for water supply and drinking purposes for most Wairau Plain residents. MDC also wanted to know what the likely increase in nitrate concentration in groundwater and downstream aquifer fed springs would be associated with a change from vineyard to dairying or cropping.

Method

Plant & Food Research measured the leaching rate of irrigated vineyard at Giffords Road overlying the Wairau Aquifer starting in 2012. Leachate was measured using 12 drainage pipes buried several metres below the land surface in the inter-rows and under the grape plants.

Quantifying the leaching rate of nutrients from the land surface downwards to the groundwater was the first part of the travel path through the Wairau Plain. A MODFLOW model was built by Lincoln AgriTech to describe the subsequent movement of the nutrients as they were entrained by groundwater flowing horizontally eastwards towards the coast and eventually breaking the surface as part of the belt of naturally occurring Wairau Aquifer fed springs.

The flow model was calibrated based on knowledge of aquifer properties and observations of aquifer level at several MDC monitoring wells and Spring Creek flows. Once a good fit was achieved, the MT3D contaminant transport model was then used to superimpose drainage events with known nitrate-nitrogen concentrations from the leachate array, versus values in surface or groundwater within the stream tube.

Results

Average concentrations of 3 g/m^3 nitrate-nitrogen were measured in the drainage lysimeters which is relatively low when compared to similar results from dairy or cropping farmland. The median measured concentrations of nitrate-nitrogen were: 0.067 g/m^3 in Wairau River recharge water, 0.26 g/m^3 in Wairau Aquifer water downstream of the leachate array at Wratts well 3009, and 0.22 g/m^3 in in Spring Creek water at the floodgates at the end of the flow path.

The transient MODFLOW/MT3D model was run at a weekly time step and accounted for most of the variation in observed nitrate-nitrogen. The model was then used to predict the likely median nitrate-nitrogen concentrations of Spring Creek water if current vineyard was converted to irrigated pasture or arable crops. The model demonstrated the importance of the diluting effect of groundwater throughflow on land surface contaminants as well as crop type.

GROUNDWATER AND NUTRIENT DISCHARGES IN THE GREATER LAKE TARAWERA CATCHMENT

Mike Toews[1], Paul White[1], Constanze Tschritter[1], Janine Barber[2]
[1]GNS Science, , New Zealand, [2]Bay of Plenty Regional Council, , New Zealand

Introduction

A series of hydrogeological investigations was developed to assist policies that aim to reduce the discharge of nutrients (nitrogen and phosphorus) to lakes in the greater Lake Tarawera catchment, which contains eight lakes (Tarawera, Okaro, Rotomahana, Rerewhakaaitu, Okataina, Okareka, Tikitapu and Rotokakahi). These investigations have included hydrogeological characterisation with drilling, pump-testing, groundwater chemistry and groundwater age dating (e.g., Thorstad et al., 2011). Then followed development of a 3D geologic model and surface water budgets for catchments and lakes. This information allowed the construction of 3D steady-state groundwater flow models and nutrient transport models that were based on land-use scenarios.

Methods

A 3D geologic model was constructed for the region, which was translated into a finite difference MODFLOW model to simulate groundwater flow. A conceptual flow model was characterised from surface flows in streams and rivers to inform the groundwater flow model. Boundary conditions of the model include: general head boundaries for simulating lakes; drain boundaries for simulating streams; and well boundaries for specified-flux boundaries along the southeastern edge of the model near Lake Rerewhakaaitu that allows flow from the model area to the east. Five land use options were developed to consider nitrogen loading to groundwater and surface water, including: forested, low-intensity agriculture, current land use, moderate expansion of high-producing grassland, and large expansion of high-producing grassland. These scenarios were applied to a MT3DMS groundwater transport model. Budgets of groundwater flow and nutrient discharge were assessed for zones around lakes.

Results

Surface geology of the greater Lake Tarawera catchment is dominated by volcanic units, including ignimbrites and other pyroclastic deposits, as well as rhyolite lava domes and flows (Figure 1). Most of these deposits were sourced from the Okataina Volcanic Centre which is a large basin structure that includes most of the greater Lake Tarawera catchment.

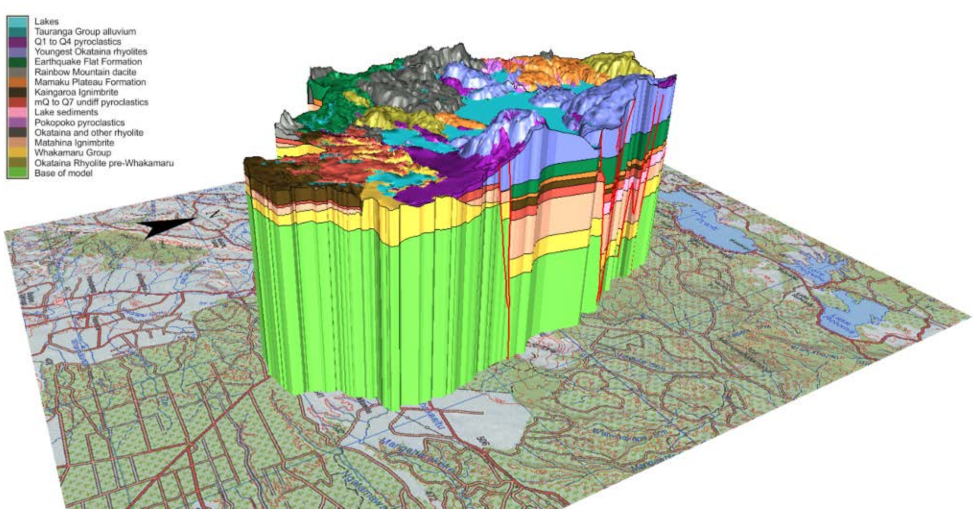

Figure 1. Geological model of the greater Lake Tarawera catchment (Tschritter and White, 2014).

The groundwater flow model shows that groundwater provides the majority of inflows to most lakes; Lake Rerewhakaaitu is an exception, as it is generally perched. Groundwater also flows between lake zones. For example, groundwater flows into the Lake Tarawera zone from all surrounding zones, i.e., Rotomahana (the largest source), Okataina, Okareka, Tikitapu and Rotokakahi. The Tarawera River is the sole surface outflow from Lake Tarawera. Two pieces of evidence indicate groundwater may flow out of Lake Tarawera down the Tarawera River valley: Tarawera River gaugings that indicate a significant increase in river flow between Lake Tarawera and below Tarawera Falls and the discovery of permeable, fractured rhyolite in a drill hole at the Lake Tarawera outlet (Thorstad et al., 2011).

Intensification of land use will result in increasing nitrogen discharge to lakes, except the perched parts of Lake Rerewhakaaitu. Most of any increase will come from the land in the west and lesser amount from the south (i.e., the Lake Rotomahana catchment). Any increase in nitrogen discharge to lakes will be mostly due to nitrogen flowing in groundwater, rather than streams. Should intensification happen, then additional work is recommended to improve understanding of groundwater catchment boundaries and aquifer properties in the western area.

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Session: General Hydrology, Start Time: 11:00 a.m.

APPLICATIONS OF BIVARIATE FREQUENCY ANALYSIS TO DROUGHT STUDIES

Professor Tae-Woong Kim[1], Jiyoung Yoo[2], Ji Soo Yu[3]

[1]Dept. of Civil and Environmental Engineering, Hanyang University, Ansan, Korea, , , [2]Dept. of Civil Engineering, Chonbuk National University, Jeonju, Korea, , , [3]Dept. of Civil and Environmental Engineering, Hanyang University, Seoul, Korea, ,

Aims

Using bivariate distribution functions the new emerging statistical schemes are recently introduced to assess drought severity and frequency. This study presents the applications of bivariate frequency analysis (BFA) with copula functions to drought frequency analysis (DAF). Bivariate drought frequency analysis (BDFA) provides comprehensive views considering drought duration and severity through constructing bivariate drought frequency curves. After reviewing the theoretical backgrounds of BDFA and copulas, this study discusses on the model performance based on the estimated quantiles and confidence intervals. Then, several applications are introduced to address the availability and usefulness of BDFA such as constructing reliable drought frequency curves, quantifying the uncertainty of estimates, and estimating the future drought risk under the climate change(Kim et al. 2006; Yoo et al. 2012; 2013; 2015a; 2015b).

Methods

Bivariate drought frequency curves are constructed based on observed rainfalls after identifying drought events. The confidential intervals of the estimated drought frequency curves also estimated based on synthetic rainfalls. The BDFA provides frequency curves incorporating the return periods and confidence intervals as shown in Fig. 1.

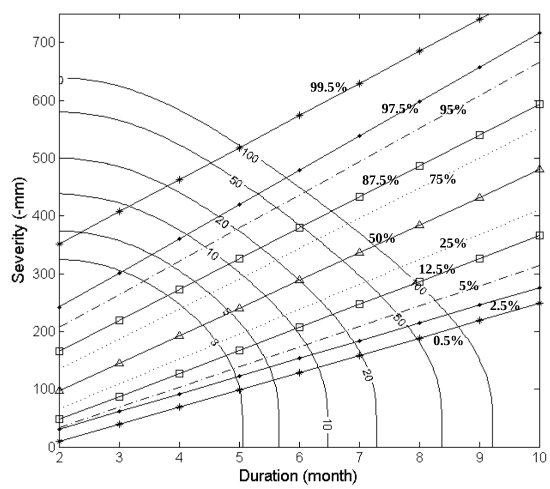

Figure 1: Bivariate drought frequency curves (Yoo et al. 2015a)

Acknowledgment

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CLIMATE CHANGE IMPACT ASSESSMENT ON WATER RESOURCES OVER THE EAST ASIA MONSOON REGION

Professor Deg-Hyo Bae[1], M.-H. Lee[1], J.-B. Kim[1]
[1]1Sejong University, Seoul, Korea,

Backgrounds of this study

Asia monsoon plays an important role on global water circulation and provides substantial precipitations and water resources to the people living within the domain. It provides many benefits, but also causes series flood and drought problems. Of course, there are various reasons for these water-related disasters, but the current climate change makes much more complicate and difficult to manage them. The objectives of this study are to evaluate the climate change impact assessments on water resources over the East Asia monsoon region and to find out the highly susceptible zones of climate change.

Methods

There are two approaches for the climate change impact assessments on water resources (Figure 1). One is the analysis of past hydro-meteorological data to detect some climate change trends. The other is the use of GCM outputs with downscaling and hydrologic models under the future greenhouse gas emission scenarios.

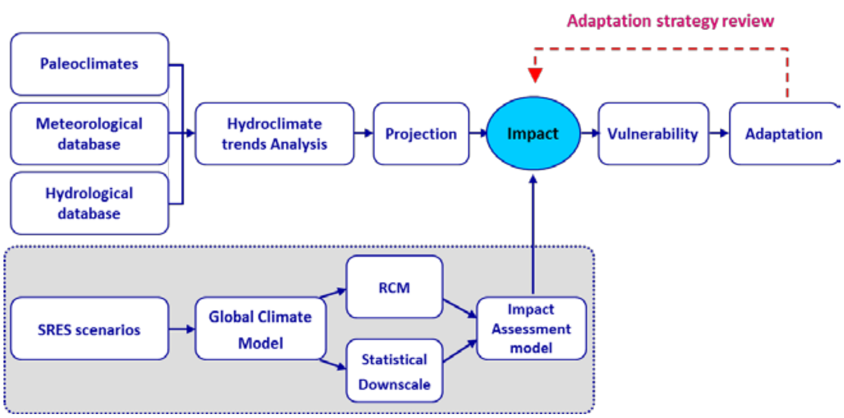

Figure 1. General process of climate change impact study on water resources

For the analysis of past historical data, Mann-Kendall statistical test was used to determine the significance of trends in precipitation and runoff data. The 0.5 degree precipitation and temperature data of APHRODITE were used for the trend analysis and the input of hydrologic model to derive the model-driven runoff data.

For the future projections over the area, GCM simulations with downscaling scheme and hydrologic model were used. The climate projections, the outputs of GCMs, were used for generating Multi Model Ensemble (MME) scenarios and for evaluating the difference for hydro-meteorological variables on the future 3 periods (called 2020s, 2050s and 2080s) relative to the past 30-year reference period. The VIC model was employed for analysis of hydrology data (Nijessen et al., 2001).

Results

Mann-Kendall test was applied to 30-years (1977-2006) of temperature, precipitation and runoff data in the study area. The test statistics were computed for each grid point and the spatial distribution of trends was obtained (Figure 2). The results show increasing (↑) and decreasing (↓) trends with 90% and 95% significance levels. They indicate that over the past 30 years, the average temperature increased approximately by 0.27℃/decade. This estimated increase is substantially high compared to global temperature increase of 0.13℃/decades (IPCC, 2007). The average annual precipitation was observed to decrease by 86.5 mm over the 30-year period. Especially significant decreasing trends of precipitation appeared over the Tibetan Plateau, Indonesia, inland India and southern Far East Russia, while increasing trends were observed over northwest China, north Pakistan, eastern Afghanistan and Korea. The average annual runoff was decreased by approximately 41.8 mm over the same time period. The spatial distribution of runoff trends was similar to that of precipitation trends.

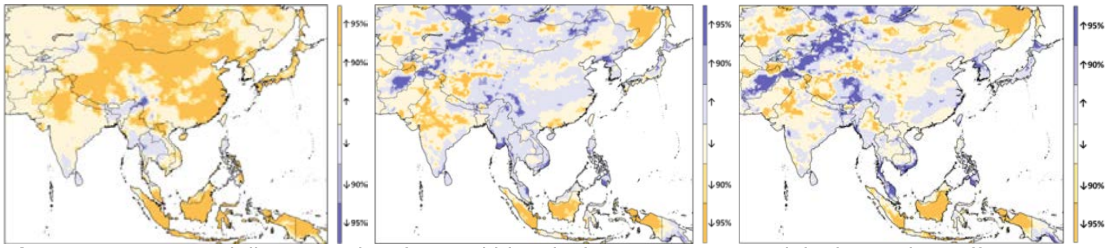

Figure 2. Mann-Kendall test results of annual historical temperature, precipitation and runoff

The changes projected in temperature, precipitation and runoff at future periods relative to the reference period are shown in Figure 3. The average temperature was expected to increase by 0.9℃, 2.1℃ and 3.7℃, while average precipitation by 1.8%, 4.6% and 10.7% in 2020s, 2050s and 2080s, respectively. The precipitation was projected to significantly increase over the southwest region of South Asia and decrease over the bordering regions of South Asia and East Asia. The 1.5%, 3.9% and 11.1% increase in annual mean runoff by future 3 periods were projected. The spatial distribution of future runoff change was similar to that of precipitation.

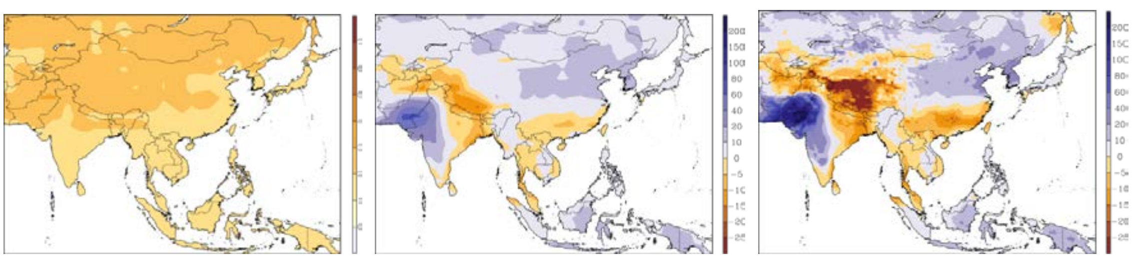

Figure 3. Relative change of temperature, precipitation and runoff by 2050s

Conclusions

The results in this study showed change with high spatial variation such as increase in precipitation and runoff over some regions and decrease over other regions of Asia. Further research needs to be carried out to identify the deriving factors of these variables. Moreover, the projected change may result in positive or negative impacts over different regions that urge the need of detailed regional impact assessment and adaptation studies over vulnerable areas to alleviate future climate change-induced disasters.

Acknowledgement

This work was jointly supported by the APN and a grant (14AWMP-B082564-01) from Advanced Water Management Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

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RELIABILITY, RESILIENCE AND VULNERABILITY OF FRESHWATER SYSTEMS

Dr Daniel Collins[1]
[1]*NIWA, New Zealand*

When designing freshwater systems to meet specified criteria or simply reporting their success - whether supplying water for irrigation, supporting conservation goals or meeting water quality targets - it is important to assess system performance. This includes how often the system will succeed, how often it will fail, and the consequences of a failure or sequence of failures. One suite of metrics used in water resource applications when time-series are available, is that of reliability, resilience, and vulnerability (RRV).

In RRV analysis, reliability describes how often a system is in an acceptable state, resilience describes how quickly a system recovers to an acceptable state after a failure, and vulnerability measures the magnitude of a failure or failures. Reliability is commonly used in New Zealand when measuring water supply systems, and resilience is considered in multi-stable aquatic ecosystems (such as Waituna Lagoon); the full suite of indicators are more typical in reservoir analysis in North America. Because of its ability to capture multiple facets of a system performance, RRV analysis has wide applicability within the scope of freshwater management and use in general, and can help inform better system design or anticipate the impacts of environmental or behavioural change.

RRV analysis requires a time-series of the system's state, such as a hydrograph or a record of *E. coli* measurements, and a definition of what separates success from failure. For reservoirs, this threshold would be the volume of water needed to satisfy all water users; for contact recreation, it would be 550 *E. coli* per 100 mL of freshwater at bathing sites. To quantify vulnerability, consequences of failure may be represented as the amount of water demanded but not available, or the number of people unable to swim due to health risks.

To provide a practical example of RRV analysis, simulated hydrographs of 10 rivers across New Zealand are used to assess the performance of river water abstractions under current and projected climatic conditions. For illustration purposes, the failure threshold (minimum flow) and abstraction limit are set as the nominal values defined in the Proposed National Environmental Standard on Ecological Flows and Water Levels. Reliability, resilience and vulnerability show variations around the country as expected. They are also liable to change this century as the climate warms and atmospheric circulation patterns shift, resulting in better or worse performances depending on the river. These changes in performance can then be used to explore high-level climate change adaptation strategies, such as how much additional water would be required to offset any negative changes, or how managing water demand affects vulnerability. Alternative expressions of resilience and vulnerability are also considered in the context of providing the most useful information to decision makers.

Session: Groundwater / Surface Water Connectivity, Start Time: 11:00 a.m.

HYDROCHEMISTRY AND WATER DATING FOR CHARACTERISATION OF THE SOUTHLAND REGIONAL GROUNDWATER-SURFACE WATER SYSTEM

Chris Daughney[1], Clint Rissmann[2], Michael Friedel[1], Roger Hodson[2], Uwe Morgenstern[1], Heather Martindale[1], Ewen Rodway[2], Magali Moreau[1], Lawrence Kees[2]
[1]GNS Science, Lower Hutt, New Zealand, [2]Environment Southland, Invercargill, New Zealand

Aims (11 pt. Arial; Bold)

The Southland region of New Zealand has an area of ca. 34,000 km^2 with complex geology and pedology. Agricultural intensification over recent decades has led to degradation of water quality in streams and aquifers, particularly in terms of nutrients, sediment and microbial pathogens. The aim of this study was to develop and apply a suite of methods that could rapidly, clearly and objectively characterize the hydrochemistry of the Southland region. Improved understanding of Southland's coupled groundwater-surface water bodies is required to meet the outcomes sought in the New Zealand's National Policy Statement for Freshwater Management (2014).

Method (11 pt. Arial; Bold)

This study employed a dataset of ca. 27,000 groundwater, river water, rain and source investigation samples that were analysed for up to 50 parameters. Interpretation of the dataset was complicated by its sheer size and by many missing or censored analytical results. A traditional self-organizing map (SOM) was used to evaluate patterns in the hydrochemical dataset and a modified SOM was used to estimate missing and censored data based minimization of topographical error and quality error vectors. Hierarchical cluster analysis (HCA) was employed to categorize the samples according to hydrochemical similarity, and then used discriminant analysis (DA) to assign incomplete sample records to the clusters based on the SOM-estimated data. Additional insight was provided by regional-scale high-precision analysis of radon and tritium concentrations in groundwater and river baseflow, which provided information on groundwater-river interaction and water age.

Results (11 pt. Arial; Bold)

The results of SOM, HCA and DA revealed 11 hydrochemical clusters that were clearly differentiated by redox state, degree of human influence, and soil and geological characteristics. These hydrochemical categories could be further subdivided to identify more spatially and temporally resolved variations in water quality. The radon concentrations in river water indicated localized areas of groundwater inflow that often corresponded to shifts in river hydrochemistry. Water dating indicated mean residence times (MRTs) of less than 10 years in baseflow for most of the sampled river reaches, but older MRT (up to 50 years) occurred in river reaches where fractured rock limestone or sandstone aquifers provide groundwater inflows. Clear relationships between hydrochemistry and water age were evident, particularly in respect of excess nutrient concentrations in young water.

The combination of the radon, water age and hydrochemical classification from SOM, HCA and DA proved to be an effective suite of methods for large-scale characterization of the Southland's hydrochemistry. This combination of methods would assist similar investigations in other parts of New Zealand and indeed elsewhere in the world.

NATION-WIDE GRIDDED BASEFLOW FROM RECHARGE AND GROUNDWATER MODELS

Mr. Rogier Westerhoff[1,2,3], Mr. Paul White[2]
[1]Deltares, Delft, The Netherlands, [2]GNS Science, Taupo, New Zealand, [3]University of Waikato, Hamilton, New Zealand

Introduction

Research in groundwater-surface water interaction (GWSWI) has gained considerable interest in New Zealand in recent years. One important topic of GWSWI is the assessment of baseflow, which is usually defined as the sum of deep subsurface flow and delayed shallow subsurface flow, or alternatively as groundwater discharging to the surface. Baseflow estimates can be derived through analyses of river hydrographs. At catchment scale, long-term baseflow can be estimated using rainfall recharge data, or vice versa. Models of rainfall recharge are often challenged, as they combine uncertain estimates of rainfall, evapotranspiration, terrain slope, and unsaturated zone parameters. Rainfall recharge is therefore easiest to estimate on a local scale, as it can be easily calibrated against observations. This process fits in the New Zealand policy framework, where regional councils manage water allocation. However, a consistent overview of rainfall recharge is difficult to obtain at catchment and national scales. This is partly due to data uncertainties, but also because data formats, density of ground observations and local models often differ per region.

Aims

The aim of this research is to estimate baseflow in New Zealand using a nation-wide rainfall recharge dataset and a simplified groundwater model.

Method

First, a nation-wide model of rainfall recharge was developed, which used estimates of hydraulic conductivity, topography, rainfall, satellite evapotranspiration, and soil data. Uncertainty of all input parameters was propagated through the model equation. Then, a water table was estimated using a loosely coupled system of rainfall recharge (incl. uncertainty) and the Equilibrium Water Table (EWT, Fan et al. 2013) method. This method calculates a seasonally varying long-term average ‘natural’ water table. The term ‘natural’ implies that not all human impacts, like water abstraction and drainage, are embedded. The EWT method has undergone improvements for application in New Zealand after recommendations of Westerhoff and White (2014). All EWT results of groundwater discharging to surface were then compiled to estimates of long-term baseflow. This coupling process further corrected the recharge data.

Results

The resulting nation-wide datasets are: (1) an estimate of the contribution of each model cell to baseflow (seasonal, resolution 200m x 200m); (2) a 1km x 1km monthly rainfall recharge estimate, including uncertainty; and (3) a seasonal 200m x 200m natural water table estimate. The rainfall recharge data validates well with known lysimeters and local model data in the Canterbury and Waikato regions. Model results in ungauged areas show that it is likely that recharge is higher than expected in some mountainous regions. This higher rainfall recharge results in high shallow baseflow (or interflow) in these areas. Nation-wide water tables point out zones where shallow water tables exist. Figure 1 shows the water table and baseflow estimates for the Hauraki Plains. Recommended further work is the application of the baseflow estimates in identification of nutrient hotspots in areas with increased nutrient loads from e.g. dairy industry. Further recommended work is catchment-by-catchment validation and regional calibration of the model results.

All work has been undertaken as part of the Smart Aquifer Characterisation, funded by MBIE. It has received co-funding from the European collaborative research programme eartH2Observe.

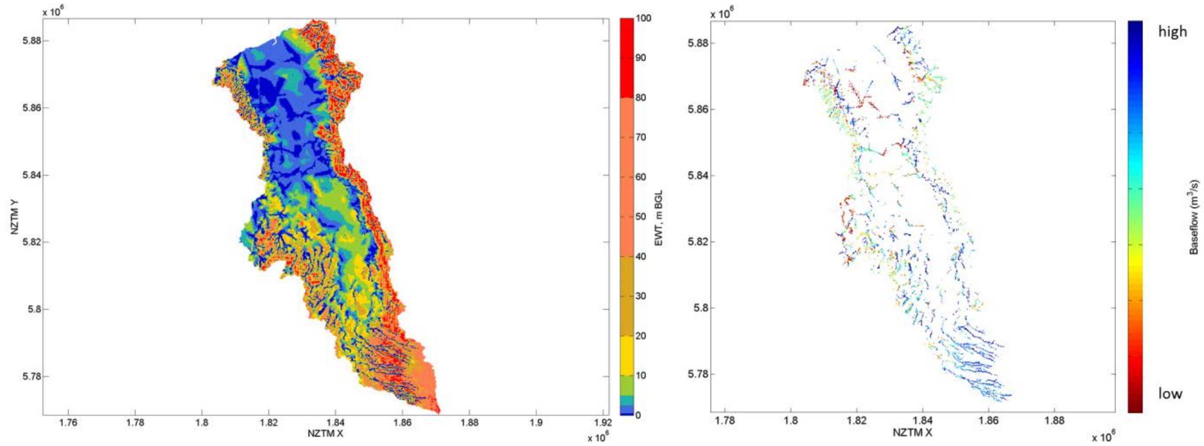

Figure 1 – Model outpus for the Hauraki Plains. ***Left:*** Equilibrium Water Table in metres below ground level (m BGL). ***Right: c***ontribution to baseflow per model pixel.

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GROUNDWATER MOVEMENT AROUND THE WAIMAKARIRI RIVER

Mr Carl Steffens[1], Neil Thomas[1]
[1]*Pattle Delamore Partners, Christchurch, New Zealand*

Aims

The Eyre River and Christchurch – West Melton Groundwater Allocation Zones (GAZ) are separated by the Waimakariri River, which is often thought to represent a hydraulic boundary to groundwater flow. Therefore, it is assumed that there is little interaction between the two zones. In general, groundwater in the Eyre River GAZ to the north has higher concentrations of some dissolved parameters, such as nitrate-nitrogen which reflects its land surface recharge source. In contrast, groundwater on the south side of the river and particularly in the Christchurch aquifers has low concentrations of nitrate-nitrogen and dissolved parameters, which reflects its dominant recharge source as seepage from the Waimakariri River.

However, various reports have put forward the hypothesis that groundwater is moving from the Eyre River GAZ, beneath the Waimakariri River, and into the Christchurch – West Melton GAZ. Those hypotheses are primarily based on groundwater quality and isotope data, with some similarities observed between groundwater on the north and south sides of the river, particularly in north-east Christchurch.

Water for public supply in Christchurch is almost exclusively sourced from untreated groundwater, so groundwater movement from the north side of the river to the south side, together with a decline in groundwater quality would be an issue of potential concern to city water managers.

The aim of this work was to review the hypotheses to determine whether cross boundary flow is likely to occur. The project was carried out for Environment Canterbury.

Method

A variety of datasets were assessed as part of this investigation including:

1. Groundwater level data (piezometric contours, groundwater level timeseries and cross section data;
- Groundwater quality data (oxygen 18 ratios, nitrate-nitrogen concentrations, chloride concentrations, cluster analysis); and
- Assessment of aquifer parameter information.

Results

Based on groundwater level and groundwater quality data from both sides of the river, the plains section of the Waimakariri River can be split into three overall sections. The most upstream reach extends from the gorge to around Courtenay Road and groundwater movement under the river within that reach is possible if the river does not provide a hydraulic barrier to such flows. That potential exists because groundwater levels are generally deeper than the river and not obviously connected to it. A hydraulic gradient from the north side to the south side of the river may also be present, although there is a lack of clearly defined data to define groundwater flow directions.

The middle reach extends from around Courtenay Road to downstream of Crossbank and groundwater movement under the river is unlikely in this section of the river. The river has a noticeable effect on groundwater levels adjacent to the river and is likely to act as a barrier to groundwater flow. Groundwater quality data indicate that the groundwater chemistry is noticeably different on the north side of the river compared to the south side, reinforcing the idea that the Waimakariri River acts as a barrier to groundwater movement, or if any movement is occurring it is making a very minor contribution.

The most downstream reach extends from downstream of Crossbank to the coast. The coastal confining layer is present in this section and groundwater at depth is apparently isolated from direct effects from the Waimakariri River. However, groundwater level data does not indicate that a hydraulic gradient from north to south is present and therefore groundwater movement from north to south is unlikely. To the contrary a deep basement trench to the north-east of Kaiapoi is likely to draw groundwater in that direction.

The various datasets reviewed are not exhaustive and the flow directions cannot be precisely defined. However, the data, and in particular the groundwater quality data, imply that if movement does occur, it is of a minor scale for the Christchurch aquifers in comparison with the much greater quantities of seepage that occur from the Waimakariri River.

RADON AS A TOOL FOR MEASURING GROUNDWATER/SURFACE WATER INTERACTION IN GRAVEL-BED RIVERS

Miss Heather Martindale[1], Dr Uwe Morgenstern[1], Dr Ranvir Singh[2], Dr Bob Stewart[2], Miss Abby Matthews[3]
[1]GNS science, Lower Hutt, New Zealand, [2]Massey University, Palmerston North, New Zealand, [3]Horizons Regional Council, Palmerston North, New Zealand

Aims

Understanding how surface waters and groundwaters interact is an integral component of managing the influence of nutrient inputs to water quality. Knowledge of the potential nutrient loads from discharging groundwater is essential for meeting the bottom line nutrient concentrations in surface waters, in accordance with the national policy statement on fresh water management. The aim of this research was to establish the potential of radon for measuring groundwater and river water interaction in the New Zealand environment. Furthermore, the study aimed to assess the potential of using radon measurements in combination with concurrent stream flow gauging and hydrochemistry data for providing more detailed information on groundwater and river water interaction processes. Test studies were carried out in the Hutt and Mangatainoka Rivers in the lower North Island.

Method

We collected 25 mL radon grab samples at 500-1000 m intervals along a 14 km stretch of the Hutt River in April 2014 and January 2015 and across the entire length, approximately 70 km, of the Mangatainoka River under low flow conditions during February 2015. The collected samples were then analysed for radon measurement at the GNS water dating laboratory using a Low Level Liquid Scintillation Counter (LCS) (Hahn & Pia, 1991). The LCS analysis method was chosen over semi-conductor, Lucas Cell field meters to enable multiple teams to collect samples at the same time. Following the results of these low-resolution surveys, radon samples were collected at high-resolution, with approximately 2-4 m intervals, along cross sections of the river where groundwater discharge was identified. Higher resolution radon sampling, at 50-200 m intervals, was also carried out along two 500-2000 m stretches in each study river where groundwater discharge was identified. Furthermore, to investigate radon concentration thresholds for distinguishing radon signals indicating groundwater recharge, hyporheic exchange and groundwater discharge, high sensitivity radon sampling was carried out using 273 mL custom made flasks in a section of bedrock outcrop in the Hutt River where the geology dictates that no groundwater discharge is occurring.

In addition to the radon sampling, extensive flow gauging surveys were undertaken in both the Hutt and Mangatainoka Rivers, with flow measured at 22 sites in the Hutt River and at 29 sites in the Mangatainoka River. Additional hydrological data including dissolved oxygen, temperature, electrical conductivity and nitrate-nitrogen concentrations were also captured in the Mangatainoka River at the sampling sites where radon samples were taken.

Results and Discussion

Groundwater discharge and recharge locations were identified in both the Hutt and Mangatainoka Rivers using radon (Fig. 1 and 2). Furthermore, high sensitivity radon analysis was able to identify where hyporheic exchange was occurring. In the Hutt River, groundwater surface water interaction is largely affected by the local geology. This is especially evident with groundwater discharge occurring predominantly on the eastern side of the river bank.

In both rivers the groundwater discharge/recharge patterns identified by radon were not matched by the concurrent flow gauging surveys, highlighting the ambiguity surrounding the use of flow gauging in gravel-bed rivers, in addition to the measurement uncertainty, for mapping river gains and losses. In both studied rivers the flow gauging data indicated areas of both groundwater recharge and discharge where the radon data showed the opposite process to be occurring. This has led to the conclusion that underflow beneath the gravels and other parafluvial exchange processes can cause the interpretation of flow gauging results to be misleading. Flow gauging with radon sampling gives a more conclusive picture of the groundwater and river water interaction processes, which is useful for managing nutrient inputs into waterways.

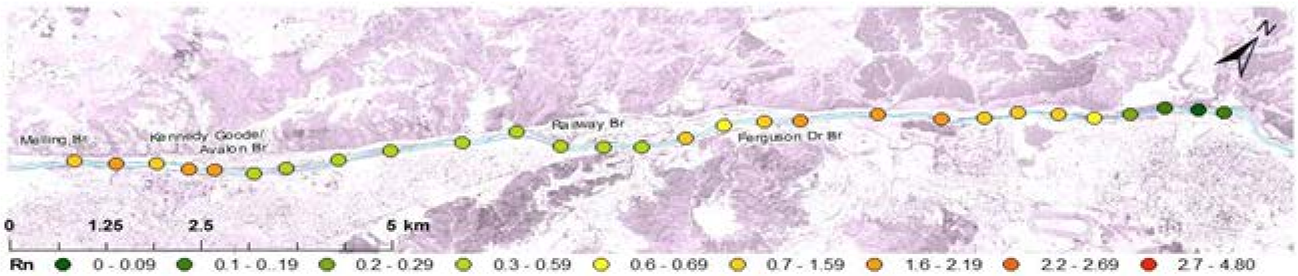

Figure 1: Measured radon concentrations in the Hutt River at low flow on 10 January 2015. The colour denotes radon concentrations in BqL^{-1}.

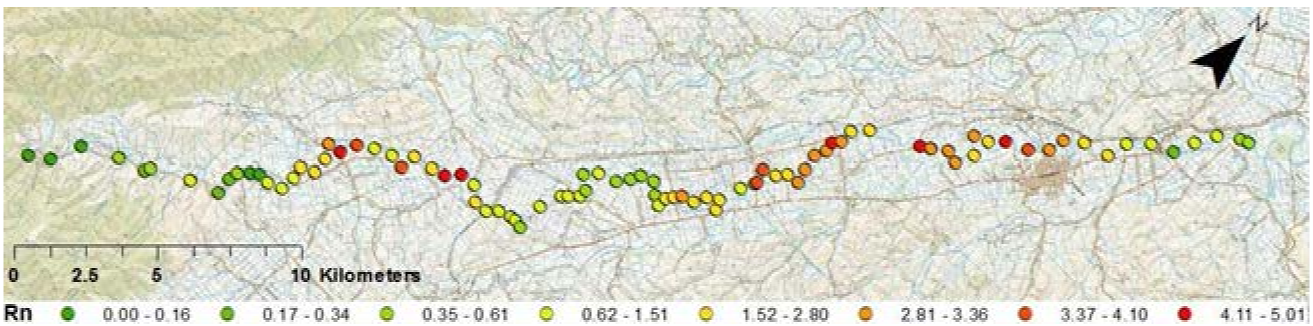

Figure 2: Measured radon concentrations in the Mangatainoka River at low flow in February 2015. The colour denotes radon concentrations in BqL^{-1}.

Reference

Hahn, P. B., & Pia, S. H. (1991). *Determination of Radon in Drinking Water by Liquid Scintillation Counting Method 913*. Las Vegas, Nevada, U.S.A.: U.S. Environmental Protection Agency.

Session: Catchment-scale Water and Contaminant Fluxes, Start Time: 1:20 p.m.

HURUNUI RIVER CATCHMENT NITRATE NITROGEN DYNAMICS EXAMINED USING CONTINUOUS CONCENTRATION MONITORING

Mr Jens Rekker[1]
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The middle reaches of the Hurunui River passes through the Culverden tectonic basin before cutting through another basement rock gorge on its way to the Pacific Ocean. The Culverden basin contains flat and rolling land for irrigated pasture and pine plantations. Current proposals for former forestry land would increase the irrigation extent, grazing intensity and conversion of plantation forestry to grazing agriculture. Ngāi Tahu Property Limited is a Māori incorporation owning the Balmoral Forest and interests in expansion of grazed agriculture. Te Rūnanga o Ngāi Tahu is the iwi authority representing the rūnanga and hapū covering the Hurunui River and Culverden basin, as well as owning Ngāi Tahu Property Limited. The authors have been working alongside both organisations to characterize the water quality trends and nutrient volumes moving through the Hurunui River system.

Aims

The objective in approaching high frequency monitoring and data acquisition in the middle Hurunui catchment was to obtain physio-chemical information relevant to periphyton dynamics and build a bridge to traditional knowledge of the wider river system.

Method

A comprehensive literature and data review was undertaken. Physio-chemical sensors and data-loggers were installed and maintained in critical nodes in the mid Hurunui river system during early 2015. A composite record was compiled across the period, including late summer, winter and early spring. Measurement and data logging by a multi-parameter sonde in the Hurunui gorge tracked electrical conductivity, pH, dissolved oxygen, turbidity and nitrate nitrogen concentration. Continuous hydrographs throughout the Hurunui catchment were collected and available from Environment Canterbury and the National Institute of Water and Atmospheric Research (NIWA), as were rainfall recording stations.

Results

Continuous monitoring downstream of the bottom of the Culverden basin has provided high resolution records at a frequency equal to continuous flow recording. This has allowed the compilation of concentration chemo-graphs for the parameters measured as well as time series mass load records when concentrations are put alongside concurrent hydrographs. The hydro-chemo-graphs indicate initial dilution by fresh and flood flows. Late summer and autumn freshes gave the appearance of flushing out nitrogen loads that had been held in various reservoirs during the proceeding summer dry period.

Estimates of calculated nitrate nitrogen mass load, both as time series and as cumulative plots indicated that freshes and floods in autumn and winter were correlated with spikes in the transport of nitrogen in the river system. The Hurunui River system comprises alpine headwaters, intermountain basins, basin & range topography and coastal ranges closer to the river mouth. Consequently, hydrologic and land use influences have a significant bearing on recorded nitrogen concentrations and mass loads, particularly when rainfall or pasture soil drainage patterns cause source shifts. These effects and other features highlighted by continuous monitoring will be examined in for the lessons that can be learned in catchment nutrient management.

DEVELOPMENT OF A REGIONAL STEADY STATE SURFACE WATER MODEL LOOSELY COUPLED TO STEADY STATE GROUNDWATER FLOW MODEL FOR SOUTHLAND

Christian Zammit[1], Dr Ude Shankar[1], Zara Rawlinson[2], Mike Toews[2], Lawrence Kees[3], Chrs Daughney[2], Magali Moreau[2], Dr Clint Riessman[3]

[1]NIWA, Riccarton, New Zealand, [2]GNS, Upper Hutt, New Zealand, [3]Environment Southland, Invercargill, New Zealand

Aims

The joint *Fluxes and Flows Programme* is a collaborative research project being undertaken by GNS Science (GNS) and the National Institute of Water and Atmospheric Research (NIWA) in association with and under contract to Environment Southland (ES). The programme aims to develop catchment-scale, three-dimensional (3D) groundwater flow and contaminant transport models loosely-coupled to surface water flow and quality models, to assist surface water, groundwater management and policy in the Southland region. The programme is phased into two components: 10 Development of an 'integrated' steady state surface water-groundwater quanity and quality across the Southland region; and 2) development of a transient coupled surface water groundwater quantity and quality model for 4 Freshwater Management Units (FMU).

The development of the surface water model is based on the development of the National hydrological model (Topnet) for the Southland region. The National hydrological model is uncalibrated, but uses information on elevation, land use, soils, geology and recession analysis to provide *a priori* parameter estimation based on the national dataset and physical catchment characteristics. Climate information is provided by the Virtual Climate Station network (VCSN), which provides daily climate information on a 0.05 degrees grid across New Zealand since 1972, associated with regional council climate information.

The NIWA component of the model construction has been phased into three components: 1) Updating on the river network based on improved digital elevation model; 2) development of a steady state surface water loosely coupled to GNS's groundwater flow and transport model and NIWA's water quality model CLUES; 3) development of transient loosely coupled surface water groundwater water quality model for each of the FMU. The paper focuses on the first two components of the work focusing on the water quantity aspect of the coupling.

Method

The first phase of the work focused on the establishment of an updated river network across the southland region (named RECv3). The updated river network was generated by merging Environment southland's Geographix Digital Elevation Model (DEM) with existing LIDDAR information available across Southland and LINZ DEM. The steps involved in the generation of the new DEM are: Liddar information was resample to make it compatible to the existing Geographix DEM, ii) merging of both DEM, iii) use of RTK control points to check potential Z error with DEM; iv) generation of the updated river network; and v) verification of the new river network with existing river network and flow directions.

The second phase focused on the generation of the new catchment attributes for use as part of the surface water and groundwater hydrological models. This involves the generation of common river nodes between the surface water and groundwater model where water fluxes will be exchanged for loose coupling purpose. This ensures that the node locations serve as: calibration points for the groundwater flow model, observation points of interest for policy development and system characterisation, and calibration points for linking to TOPNET.

Workshops have been held to conceptualise and plan the loose-coupling between the groundwater and surface water models (Figure 1). This involved defining the model's interactions, points of interaction, and the development, formatting and exchange of appropriate input and output files. Preliminary targets for calibration between the models were also tentatively set and a number of sequential runs and exchange of information between each model planned

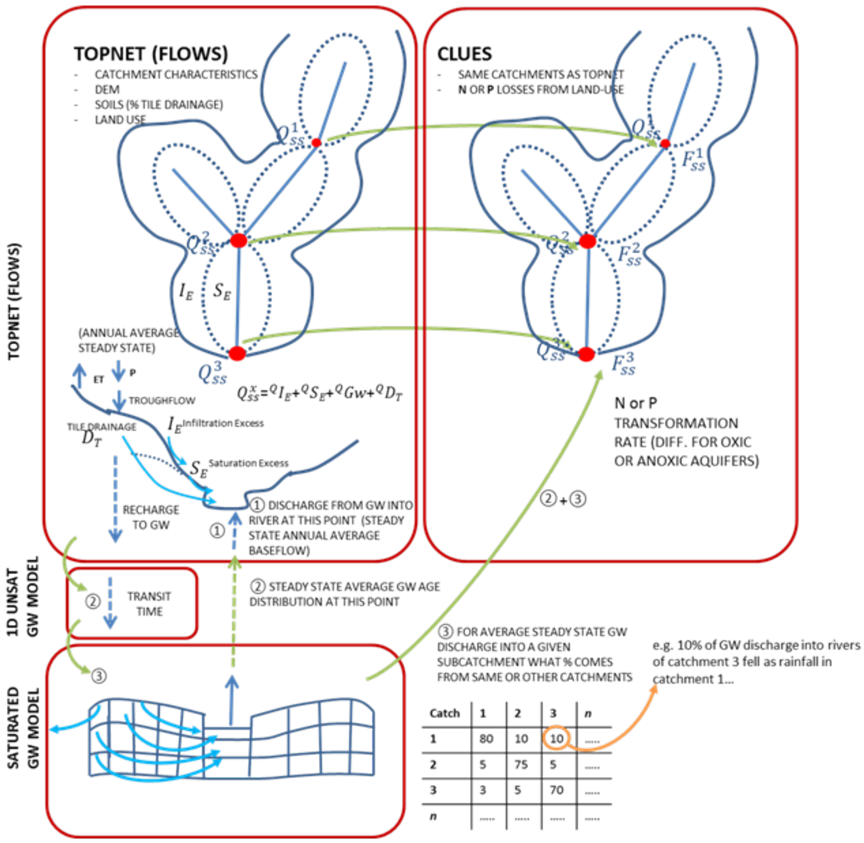

Figure 1: Schematic for coupling groundwater and surface water models.

Results

The updated DEM merged with Liddar information allows an improved definition of the river network across the region. For example the original river environmental classification river network (REC v1) contained 62,711 reaches across the Southland region. The updated model (REC v3) contains 233,077 reaches across the same area representing nearly a 4-fold increase in the number and detail of reaches. This represents nearly a third of the total number of reaches across New Zealand for REC v1.

The steady state hydrological model is currently being developed with the aim of providing streamflow inputs to the groundwater model (see Rawlinson et al 2015) as well as surface water recharge to the groundwater model.

DEVELOPMENT OF A REGIONAL STEADY-STATE GROUNDWATER FLOW MODEL LOOSELY-COUPLED TO SURFACE WATER FOR THE SOUTHLAND REGION

Ms Zara Rawlinson[1], Mr Mike Toews[1], Dr Chris Daughney[1], Dr Christian Zammit[2], Mr Lawrence Kees[3], Ms Magali Moreau[1], Dr Clint Rissmann[3]

[1]GNS Science, , New Zealand, [2]NIWA, , New Zealand, [3]Environment Southland, , New Zealand

Aims

The joint *Fluxes and Flows Programme* is a collaborative research project being undertaken by GNS Science (GNS) and the National Institute of Water and Atmospheric Research (NIWA) in association with and under contract to Environment Southland (ES). The programme aims to develop catchment-scale, three-dimensional (3D) groundwater flow and contaminant transport models loosely-coupled to surface water flow models, to assist groundwater management and policy in the Southland region. The development of the groundwater flow models is performed through co-funding and collaboration between the GNS-led MBIE-funded programme “Tracer Validation of Hydrological Systems” (TVH) and ES. The TVH research programme has a specific focus on merging hydrological tracer methods and numerical groundwater models, with emphasis on tracers for, and numerical simulation of, water age and transit time. Advancements from the first three years of the TVH programme have been applied to the development of numerical models for Southland. The GNS components of the model construction has been phased into 1) the development of a regional 3D geological model; 2) the development of a regional steady-state groundwater flow model loosely-coupled to NIWA’s surface water flow model TOPNET; 3) down-scaling of the regional models into calibrated catchment-scale flow models and; 4) performing age simulations and loose-coupling to NIWA’s surface water quality model CLUES. This paper focuses on Step 2, in particular on the methodology and collaboration behind enabling the novel work on loose-coupling of the regional-scale flow models.

Method

The second GNS work component involves the construction of a steady-state regional groundwater flow model within finite element subsurface flow software, loosely-coupled to NIWA’s TOPNET surface flow model. In order to develop a regional flow model that meets the objectives of all parties, the locations of the model nodes that define the finite element mesh have been developed through consultation with ES and NIWA. This ensures that the node locations serve as: calibration points for the groundwater flow model, observation points of interest for policy development and system characterisation, and calibration points for linking to TOPNET. Following the 2D regional groundwater flow model mesh creation (Figure 1), surfaces from the developed 3D geological model have been used to construct the 3D mesh of the flow model.

Workshops have been held to conceptualise and plan the loose-coupling between the groundwater and surface water models (Figure 2). This involved defining the model’s interactions, points of interaction, and the development, formatting and exchange of appropriate input and output files. Preliminary targets for calibration between the models were also tentatively set and a number of sequential runs and exchange of information between each model planned. As this coupling is experimental work, it was unclear what targets would be most appropriate. At a later stage, it is planned that this coupling will be further automated to allow for transient model development.

Results

The ES 3D geological model that spans the Southland region (~21,000 km^2) is presented, as well as the transformation of this regional geological model into a steady-state groundwater flow model with an extent of ~12,000 km^2, loosely-coupled to a surface water model. The relevant conceptual model developments and collaborations between the organisations are also discussed.

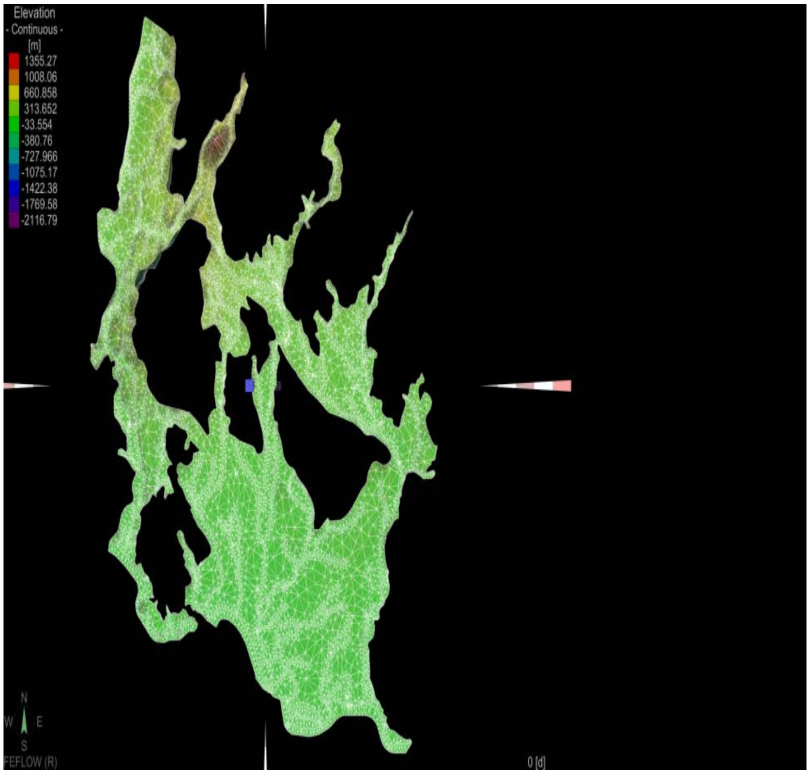

Figure 7: Preliminary 2D regional groundwater flow model mesh.

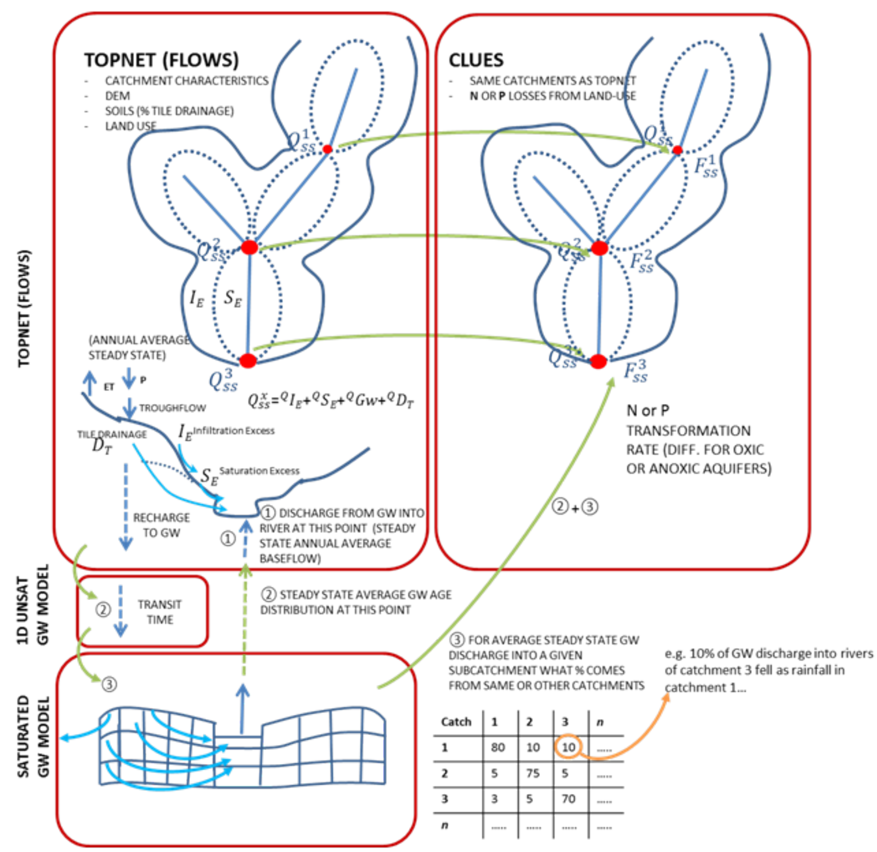

Figure 8: Schematic for coupling groundwater and surface water models.

UNCERTAINTY OF CATCHMENT NITRATE FLUX ESTIMATES CALCULATED USING THE "STREAMGEM" APPROACH WITH MONTHLY MONITORING DATA

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Introduction

The dynamic catchment model "StreamGEM" was previously used to infer water and nitrate fluxes through the subsurface of the small (15 km^2) Toenepi dairying catchment, based on long term (4 years) daily flow and monthly chemistry data collected at the catchment outlet. The approach allowed separation of stream flow into near-surface, fast- and slow-groundwater contributions, including estimation of nitrate attenuation and discharge along each flow path, as well as the uncertainty of these results (Woodward et al., 2013).

In the current project, extension of the approach to analysis of datasets from three much larger catchments was explored. Additional complicating factors in upscaling included the presence of more diverse land use, topographical, meteorological and geological zones within each catchment, as well as the potentially greater importance of time lags between precipitation events and catchment response.

Methods

The three catchments chosen for the extension of StreamGEM were: (1) Mangatangi River (195 km^2) in the Lower Waikato, which has headwaters in the Hunua Ranges, and 22% dairy and 37% drystock land downstream, (2) Puniu River (519 km^2) in the Waipa Region, which has headwaters in the northern Pureora Forest, but is mostly in 37% dairy and 46% drystock, and (3) Tahunaatara Stream (208 km^2) in the Upper Waikato, which has exotic forestry in the uplands, and 27% dairy and 18% drystock farming.

Concentration-discharge plots for the three catchments (Woodward et al., 2015) all show a moderately strong, positive relationship between flow and nitrate concentration at all sites (Figure 1). Correlation between flow and concentrations may be a prerequisite for successful application of the StreamGEM method. Also of note is the significant baseflow component evident in the Puniu, and particularly the Tahunaatara, flow records.

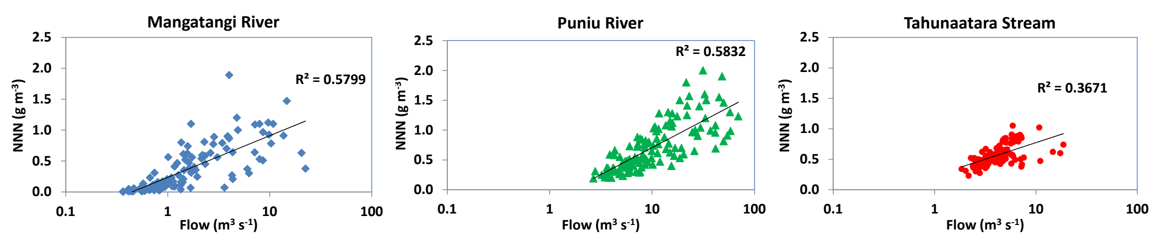

Figure 1 Positive relationship between stream nitrate concentration and instantaneous discharge for the three streams in this study.

Ten years (2003-2012) of daily stream flow and monthly nitrate data were available at each catchment measurement site, although rainfall and PET data had to be obtained from the NIWA's "Cliflo" National Climate Database, in some cases from climate stations up to 15 km away. An additional calibration parameter (R_f, "rain factor") was therefore added to the model to adjust for possible bias.

The StreamGEM model (Woodward et al., 2013) was calibrated to the flow and nitrate datasets for the three catchments using AMALGAM multi-criteria multi-method search (Vrugt and Robinson, 2007). Parameter and predictive uncertainty was then analysed using the DREAM$_{ZS}$ Markov Chain Monte Carlo algorithm (ter Braak and Vrugt, 2008). In both analyses, goodness of fit was defined using a maximum likelihood criterion, assuming a Gaussian error model (Wöhling and Vrugt, 2011). Nash Sutcliffe Model Efficiency (NSE) estimates were then calculated *a posteriori*.

Results

The StreamGEM model was successfully calibrated to the three catchment datasets with reasonable NSE values for both flow and concentration; due to the rather narrow range of flow and nitrate data in these catchments (Figure 1) the NSE values were somewhat smaller than would normally be considered acceptable. Difficulties in achieving a stable calibration to the relatively flashy Mangatangi dataset, however, suggested that the modelling of near-surface dynamics in StreamGEM needs to be refined.

Estimates of slow groundwater discharge appeared reasonable for the three catchments. It was particularly interesting to observe the model's success in reproducing expected increasing slow groundwater contributions (representing "baseflow") from Mangatangi to Puniu to Tahunaatara.

Estimates of nitrate concentrations of near-surface discharge were highly uncertain, due to the lack of stream samples during storm flow. As a result, catchment nitrate flux estimates were also highly uncertain. This highlights the need for high resolution data if stream flow and water quality are to be used for assessment of catchment nitrate fluxes.

Acknowledgement

This research was conducted under the 'Groundwater Assimilative Capacity' Programme funded by MBIE. Special thanks to Jasper Vrugt (University of California, Irvine) for sharing his AMALGAM and DREAM codes.

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REGIONAL GROUNDWATER FLOW DYNAMICS IN THE HORIZONS REGION

Dr Uwe Morgenstern[1], Rob van der Raaij[1], Heather Martindale[1], Mike Toews[1], Dr Michael Stewart[1], Abby Matthews[2], Dougal Townsend[1]
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Aims

To quantify the impact and lag time of land use and climate changes on the quantity and quality of the available groundwater resources within the framework of the National Policy Statement for Freshwater Management 2014, Horizons is increasingly focusing research on age tracers that provide new innovative approaches for understanding groundwater dynamics and hydrochemical evolution. The age tracers provide measurable information that is essential for conceptualising the regional groundwater - surface water system and inform development of meaningful groundwater flow and transport models.

Method

Areas that have wells with age, isotope and gas tracer data available cover the west coast catchment from the Wanganui Region to Manawatu, in the south the Horowhenua District, and in the west the Mangatainoka and Upper Manawatu catchments. Well depths range from shallower wells in the gravel aquifers in the Horowhenua and Tararua districts, and deeper wells in the aquifers between Palmerston North and Wanganui. Around 200 wells in the region have tracer data available, including tritium, CFCs, SF_6, ^2H, ^{18}O, Ar, N_2, CH_4 and radon. The Mangatainoka River, the Makakahi River and Waikawa Stream were investigated for areas of groundwater discharge into the rivers.

Results

Most of the groundwater samples around and north of the Manawatu River west of the ranges are extremely old (>100 years), even from relatively shallow wells, indicating that these groundwaters are relatively disconnected from fresh surface recharge. The groundwater wells in the Horowhenua tap into a considerably younger groundwater reservoir with groundwater mean residence time of 10–40 years. Groundwater along the eastern side of the Tararua and Ruahine ranges is significantly younger, typically <5 years MRT.

Extremely low vertical groundwater recharge rates are observed in the central coastal area, consistent with confined groundwater systems, or with upwelling of old groundwater close to the coast. Consistent very low vertical recharge rates along the Manawatu River west of the Manawatu Gorge indicate upwelling groundwater conditions in this area, implying groundwater discharge into the river is more likely here than loss of river water into the groundwater system. High recharge rates observed at several wells in the Horowhenua area are consistent with high nitrate concentrations in this area. Similarly, high recharge rates and therefore active water recharge is observed in the area east of the Tararua and Ruahine ranges, also accompanied by elevated nitrate. Extremely high recharge rates of >1 m/y for some wells indicate recharge from the river as the main source.

Groundwater chemistry data from dated groundwaters covering the last 100 years allow reconstruction of the baseline groundwater quality before land-use intensification 50 years ago, and the impacts of land-use activities on groundwater quality since then. The time range of the last 100 years is, however, still sparsely covered by the Horizons age tracer data set. Land-use impacts on groundwater quality are so far indicated mainly by a sharp nitrate increase over the last 50 years. Old groundwaters indicate that high magnesium, calcium, sodium, bicarbonate, and fluoride occur naturally.

Significant stretches of groundwater discharge into the rivers/streams are indicated in the middle to lower reaches of the Mangatainoka River, in the head-waters and lower reaches of the Makakahi River, and in the lower reaches of Waikawa Stream.

Conclusions

Despite the current limitations of the Horizons age, gas, and isotope tracer data set, it already has revealed details on regional groundwater processes that are pioneering on a New Zealand and international context. Additional targeted samples for the purpose of understanding groundwater processes on a regional scale will without doubt greatly improve the understanding of the regional groundwater resources.

Session: General Hydrology, Start Time: 1:20 p.m.

SNOW STORAGE ESTIMATION FOR THE OPUHA DAM CATCHMENT

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Background

Snow that accumulates in a catchment is an uncontrolled reservoir of water. Quantifying the amount of snow enables anticipation of how much snow melt will augment stream flows during the spring and summer. The Opuha Dam has been identified as having a high contribution of snow melt to its annual inflows (Kerr 2013). Knowledge of the amount of snow stored in the catchment at the end of winter would assist with water management (McCormick 2015).

Aims

The aim of the research described in this presentation was to provide an automated daily snow storage estimation system for the Opuha Dam catchment.

Method

Thirty years of daily snowfall for the catchment was estimated from rainfall and temperature observations at a low elevation site near the catchment. This follows the methods of Fitzharris and Garr (1995) but spatially distributed following McAlevey (1998) and Kerr (2005). The places within the catchment where the precipitation was likely to fall as snow was identified through consideration of how temperature and precipitation vary across the catchment. In a similar way, areas where snow melt was likely to occur were identified by estimating where the temperature was likely to be above 0 ^{o}C each day. Daily accounting of the snow fall and snow melt for each grid square enabled an estimate of the snow remaining each day. The sum of all the snow within the Opuha Dam's catchment provided the total catchment estimate. This was compared to the median value for the same day of the year for the entire thirty years to provide a relative daily snow storage estimate. Automation was achieved through implementing the routines in R and running as a scheduled task from the Aqualinc servers.

Results

The snow storage estimates are presented online as a graph with the snow quantity shown as a fraction of the median maximum (Figure 1).

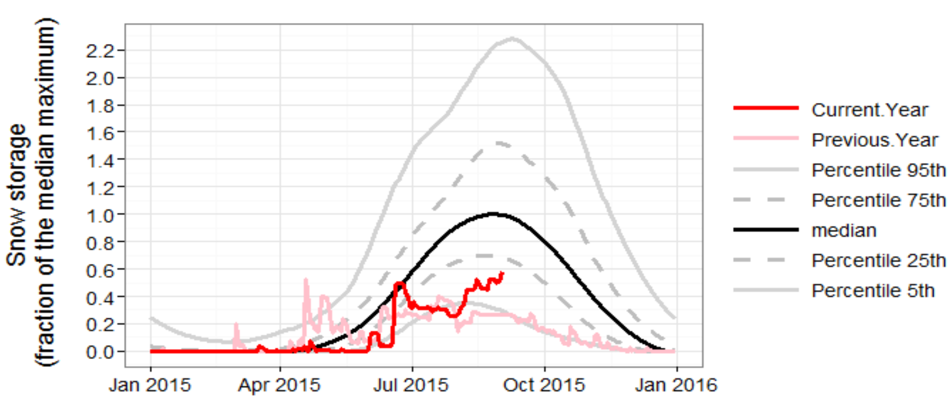

Figure 1 Opuha Dam snow storage estimate as at the beginning of September 2015. The 2014 snow estimates are in pink showing that the snow that year was in the lowest 5th percentile of the 30 years for most of winter and spring.

At the beginning of September the 2015 snow estimates were double the 2014 year, but about half of what could be expected in a median year.

Snow builds up in the catchment from April, with the maximum occurring in late August leading to complete melt by the end of December. While snow melt occurs throughout the winter, the greatest melt occurs in October. The 2014 end of September snow storage was the lowest on record. The 1986 year was the highest. The 1998 year was near the median. The automated on-line snow storage estimates are used in association with local knowledge to plan the management of the lake. In addition, the estimates provide a crucial step in developing a hydrological model for the Dam.

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HYDROLOGICAL ASSESSMENT AND WATER BALANCE FOR A SWAMP IN THE TROPICS

James Blyth[1]
[1]*Jacobs New Zealand Ltd, Auckland, New Zealand*

Aims

Willum Swamp is a standing water body located in Weipa, North Queensland, Australia. The swamp is situated in a tropical environment which has distinct wet and dry seasons. This study aimed to understand Willum Swamp's hydrological regime through the development of a water balance model and investigation of surface-groundwater interactions.

Background

Average annual rainfall at Weipa is ~1813 mm, with the majority (>90%) of this rainfall falling between the months of November and April. Annual average pan evaporation and evapotranspiration measurements are high, 2390 mm and 1984 mm respectively. Pressure transducers within Willum Swamp and in 4 surrounding monitoring bores record water levels. At the time of the assessment, water level information was available for the period of 1 December 2011 to 1 September 2013.

The geology generally consists of a topsoil layer and sub horizons made up of sandy clay or bauxite pisolites to depths of ~7 m. Discontinuous clay lenses are apparent at various depths in bore logs. Below the surface horizons lie coarse sands, which can vary in thickness from 1–6.5 m. Weipa's geology results in high hydraulic conductivity and infiltration rates: tests conducted using Single Ring and Talsma Hallam indicated rates >200 mm/hr were not uncommon. Subsequently, recharge to groundwater is a significant component of the water balance.

Previous hydrological studies at Willum Swamp had indicated the site was recharged by groundwater throughout the year. Additionally, an archaeological study by Stevenson *et al.* 2015 characterised the swamps bathymetry and through sediment cores determined that an organic, silt and clay layer with a thickness of up to 80 cm was present at the base of the swamp.

Methods

To verify if the swamp was groundwater recharged over the year, groundwater levels and rainfall data were compared to Willum Swamp's water level. This helped determine if continued baseflow into the swamp was occurring during the dry season.

Following review of water levels, a conceptual water balance was created. This was integrated into a 1D numerical model in the software GoldSim. Modelling aimed to determine the sites baseline hydrological regime and help parameterise a catchment rainfall runoff model for the wider Weipa Region. Utilising the study by Stevenson *et al.* 2015 and site LIDAR, stage storage curves of Willum Swamp were created for open water area evaporation calculations and to determine water depth. The Australian Water Balance Model (Boughton 2003) within GoldSim simulated surface runoff, baseflow recharge, baseflow and groundwater storage. A monthly seepage rate (%/d) was incorporated. AWBM parameters, seepage rate and groundwater catchment area were autocalibrated using GoldSim's optimization function, solving a regression analysis for r^2. Calibration was based on predicted versus measured Willum Swamp water levels through the short 2 year monitoring period, with manual calibrations undertaken during missing data periods.

Results

Water level data showed a rapid response in groundwater to wet season rains indicating high recharge and low runoff. During the peak of the wet season, when water levels were at their highest, the shallow aquifer recharged Willum Swamp. However as the dry season commenced (from April), receding water levels in bores dropped below the base of the swamp. These water levels and piezometric contour maps indicated the swamp became seepage and evaporation dominated throughout the dry season, draining to the shallow unconfined aquifer.

The outputs from the GoldSim water balance model were used to determine the corresponding inflows, outflow and storage change over the modelling period. This was then proportioned into average monthly parameters, such as evaporation, runoff and infiltration.

Thanks to: E Wilson, A Beaulavon and D Whiting for assistance in the project.

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MONITORING HAPUA OUTLET DYNAMICS

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[1]NIWA, Christchurch, New Zealand, [2]University of Canterbury, Christchurch, New Zealand

Background and Aims

Hapua are a locally common type of non-estuarine river mouth lagoon that forms where rivers discharge onto high wave energy, low tidal range coastlines such as in North Canterbury and the Canterbury Bight. They are separated from the sea by mixed sand and gravel barrier beaches and have highly dynamic outlet channels which can migrate rapidly alongshore, change in width and length, or close for short to sustained periods of time. Hapua are associated with important ecological, cultural and recreational values, and hapua outlet morphology has a controlling influence on lagoon water quality, flood risks to adjacent land, and diadromous fish passage. Storage and extraction of water for hydropower, irrigation and other uses affects the flow regime of many rivers with hapua type lagoons at their mouths. With increasing water use there is a need to be able to quantitatively predict the impacts of proposed flow regime changes on hapua, as well as monitor hapua condition.

An intensive data collection campaign is being conducted at the Hurunui hapua in North Canterbury. This monitoring campaign has two aims: to develop monitoring approaches which can be applied operationally at other hapua, and to collect a timeseries dataset to inform improved understanding of hapua processes and development of a predictive model.

Data collection

Timeseries data collection at the Hurunui hapua includes:

- Two telemetered time-lapse cameras to monitor the lagoon, outlet channel and beach barrier.
- Three water level recorders to monitor lagoon water level (and slope).
- Conductivity meters to record lagoon salinity.

Timeseries of Hurunui river flow and offshore waves are available from existing Environment Canterbury and NIWA monitoring stations.

As well as timeseries data, other data collection activities include:

- Surveys of lagoon and outlet channel bathymetry using RTK-GPS and echosounder mounted on a remote control boat.
- Surveys of barrier and backshore topography using structure from motion (SFM) analysis of aerial imagery collected using UAVs.
- Flow gaugings of the lagoon outlet channel.
- Sediment size data collection.

Figure 1 Time-lapse images of the North (left) and South (right) ends of the Hurunui hapua during a significant wave overtopping event in June 2015. Outlet channel visible far right.

Analysis

Automated post processing routines have been developed for the time-lapse imagery to extract timeseries of lagoon area and outlet channel position. The post processing includes image quality control, identification of wetted areas, orthorectification, and measurement of lagoon and outlet channel dimensions.

Hindcast timeseries of lagoon outflow have been developed from lagoon inflow and water level timeseries using a simple water balance model. Wave overtopping has been identified from water level and salinity records and validated using the time-lapse imagery and wave buoy data.

Conclusions

Data collection is ongoing but initial analyses are already providing insight into the frequency of different behaviours exhibited by the lagoon outlet channel and barrier and how these are influenced by changes in river flow, waves and tides. These insights are valuable to inform the development of a predictive model.

Automated post processing of time-lapse imagery coupled with lagoon water level and flow data allows indirect measurement of additional lagoon properties. This demonstrates that well sited high resolution time-lapse imagery can be a powerful tool for monitoring hapua processes. Monitoring in this way could be usefully applied at other hapua where it is likely that existing or proposed future changes in flow regime, or other changes such as mechanical opening, are likely to have an effect on the hapua.

ESTIMATING STAGE-DISCHARGE RATING SHIFTS DUE TO RIVER BED SCOUR-FILL DURING FLOODS

Dr Jérôme Le Coz[1], Dr Graeme Smart[2], Dr Benoît Camenen[1]
[1]Irstea, Hydrology-Hydraulics, Lyon-Villeurbanne, France, [2]NIWA, Hydrodynamics, Christchurch, New Zealand

Aims

When a flood wave propagates along a mobile-bed channel, bed scour and fill may be measured or indicated during the rising and falling limbs of the hydrograph, respectively (*cf. e.g.* Laronne et al. 1994, Capapé & Martín-Vide 2015). While many processes can make each local situation complex, this general trend can be explained by the bed response to the propagation of the flood wave and of the associated bedload wave. One of the practical issues related to transient scour-fill of river beds during floods is that the stage-discharge relation is changed in an unknown way, since only the stage, not the bed elevation, is usually monitored at hydrometric stations. As a consequence, large uncertainties in the flood hydrograph may arise and the flood peak discharge is potentially underestimated. In order to correct the rating curves of hydrometric stations, we need to derive simple equations based on readily identifiable parameters and time derivatives (instead of spatial derivatives) of quantities that are measured (stage h) or computed at a station.

Method

Based on the Exner equation for sediment continuity, the bedload wave celerity can be related to the bedload rate derivative with respect to bed level. The rate of change of the active bed elevation is found to be negatively proportional to the rate of change of bedload. Most common transport capacity formulas imply that the bedload wave celerity varies much less with time than the bedload rate. This allows establishing the following simple at-a-station bed response model:

$$z(t) = z(0) + \left[\frac{\partial q_b}{\partial z}\Big|_{z(t)}\right]^{-1} q_b(t) \qquad (1)$$

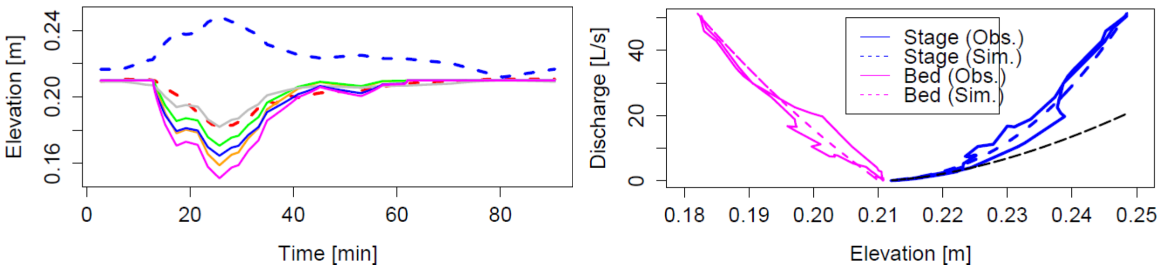
where z is the bed elevation, t is the time since initiation of sediment transport, and q_b is the volume bedload rate per unit width.

Exact solutions of Eq. 1 were derived for five bedload capacity equations: Meyer-Peter & Mueller (1948), Smart (1984), Nielsen (1992), Ribberink (1998), and Camenen & Larson (2005) formulas. Assuming that the flow is fairly uniform and the channel wide enough to approximate the hydraulic radius by the flow depth, $z(t)$ can be expressed as a function of the water level, $h(t)$, and of the critical flow depth for incipient motion $y_{cr} = (s\text{-}1)\ d\ \tau_{*,cr}\ /\ S_0$, where S_0 is the bed longitudinal slope, s is the relative sediment density and d is the grain diameter. The critical bed shear stress for incipient motion, $\tau_{*,cr}$, was computed using the formula proposed by Soulsby & Whitehouse (1997).

Results

The exact solutions for the five bedload formulas were applied to experimental data from a physical model of the Waimakariri at Gorge, in the South Island of New Zealand (Davies & Griffiths 1996). At that site, the braided river is contracted by narrow gorges, which enhances bed changes in response to flood events with intense bedload transport. In such a situation, the active width of the river (where bedload and bed changes occur) is equal to the total width of the cross-section. Results using the experiment reported by Davies & Griffiths (1996) are shown in Fig. 1. The paper provides partial information on the main parameter values, some of which remain relatively uncertain.

The results appear to be quite sensitive to the bedload equation selected and to its parameters. With the set of parameter values presented in Fig. 1a, the Camenen & Larson formula yields the best results while other formulas overestimate the scour magnitude, up to more than twice using the Nielsen formula. However, the temporal dynamics of the bed evolution is accurately predicted by all bedload formulas, and the maximum scour depth could be acceptably reproduced if parameters such as d, $\tau_{*,cr}$, etc. were calibrated within the range of realistic values. Both simulated and observed data suggest that significant scour is still present during flood recessions, with bed adjustments lasting for long times after flood peaks. The stage-discharge relation is also acceptably predicted, except for moderate hysteresis visible in the data at low flow (*cf.* Fig. 1b).



(a) (b)

Figure 1 Simulation of run 27 of experiments by Davies and Griffiths (1996). (a): observed stage and bed level (blue and red dashed lines), simulated bed level evolution using different bedload capacity equations: Camenen & Larson (gray), Ribberink (green), Smart (blue), Meyer-Peter & Mueller (orange), Nielsen (magenta); (b): stage-discharge and bed-discharge relations observed and simulated using Camenen & Larson formula; the predicted stage-discharge relation ignoring bed scour is shown in black dashed.

Application to field data from similar sites like the Rakaia river at Gorge also yielded encouraging results as regards the capability of the model to predict the timing and magnitude of scour-fill cycles induced by floods. Nevertheless, the predictive uncertainties can be expected to be as huge as those of bedload capacity equations, even when calibrated using some direct observations (gaugings, scour chains, etc.) or experiments (physical models).

The bottom shear stress, hence the bedload rate, are often found to be affected by the impact of unsteady flow conditions and changes in the turbulence intensity. This may be accounted for by correcting the friction slope, S_f, with Jones (1916) formula and use it instead of S_0 in the computations. However, this would make exact solutions of Eq. 1 much more difficult to derive. Alternatively, Davies & Griffiths (1996) proposed a model based on a comprehensive development of the 1-D hydraulics theory to account for the stage-discharge hysteresis due to transient scour-fill. The related loop effects would be interesting to be checked using field observations, though experimental evidence might be challenged by the more direct impact of cross-sectional changes.

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EARTH2OBSERVE: GLOBAL EARTH OBSERVATION FOR INTEGRATED WATER RESOURCE ASSESSMENT, NEW ZEALAND CASE STUDY.

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Introduction

Increasing demands from economic sectors such as industry, agriculture, energy, tourism and domestic use put great pressure on global water resources and this pressure may be further increased due to a changing climate. Yet, availability and quality of water resources are still difficult to estimate in different regions of the world and many countries lack basic information or observation and monitoring systems. A consistent global reanalysis dataset of water resources - an optimized global dataset that integrates available earth observations, in-situ datasets and global hydrological models comprising hydrological and meteorological water cycle components - is currently lacking. While numerous global datasets and relevant satellite observations are becoming available. The project eartH2Observe integrates available global earth observations (EO), in-situ datasets and global models and is constructing a global open source water resources re-analysis (WRR) dataset of significant length (approximately 40 yrs). Some global datasets are tested for application on a catchment scale. In New Zealand, this application focuses on evapotranspiration, rainfall recharge and water tables.

Method

As a first step, a unified forcing dataset was produced in such a way that it could be used to drive both the global land surface and the hydrological models. The resulting adjusted WFDEI forcing comprises the period between 1979 and 2012 and contains both three hourly time intervals and daily time intervals. WFDEI is based on the ECMWF ERA-Interim reanalysis with a spatial resolution of 0.5 x 0.5 degree corrected with gridded in-situ observations from the GPCP dataset. Each participating global modelling system was ran with this meteorological dataset and produced a first version of reanalysis data consisting of amongst others surface runoff, soil moisture, evaporation and river discharge. Together these datasets constitute the first Water Resources Reanalysis (Tier 1). We used a total of ten large-scale hydrological models and land-surface models with extended hydrological schemes (WaterGAP3, HTESSEL-CaMA, LISFLOOD, PCR-GLOBWB, ORCHIDEE, W3RA, SURFEX-TRIP, JULES, HBV-SIMREG and SWBM). To ensure uniform input and use of the data, the projects servers have been configured to host the forcing data and also provide an interchange platform for the project using a THREDDS data server. This server is also used to distribute the data to the rest of the world and includes an interactive portal. The first runs have been used to estimate continental runoff into the oceans using the ensemble. The resulting ensemble estimate of 51450 km^3/yr compares well with other estimates but the large spread between the models emphasizes the need for multi model simulations and further constraining of the models using remote sensing data.

At the same time, user requirements in the case study areas have been gathered and the applicability of the WRR-1 in these areas is being investigated. The case studies are conducted together with local end-users and stakeholders. Regions of interest cover multiple continents, a variety of hydrological, climatological and governance conditions and differ in degree of data richness (e.g. the Mediterranean and Baltic region, Ethiopia, Colombia, Australia, New Zealand and Bangladesh). In New Zealand, the project collaborates with the SMART Aquifer Characterisation Programme and has discussed its results to all regional councils through the Groundwater Forum. Via use of the first WRR products and feedback in the next incarnations of the WRR the case studies are very important through demonstrating the applicability of the WRR and validating the data products locally. The data is disseminated through an open data portal to ensure increased availability of global water resources information on both regional and global scale.

Results

First testing of the products in the Australian case study has shown that the forcing in this region matched the local data rather well. In addition, a significant improvement in simulated discharge was shown after using EO derived soil moisture in a data assimilation scheme in the global PCR-GLOBWB model indication that the combination of earth observations and models may provide the most accurate results. The first results of downscaling techniques applied to the global forcing to derive reference evapotranspiration show very similar results compared to local obtained estimates and a 10x10km high resolution reference potential evapotranspiration product has been made. In New Zealand, application of the data to water table estimates using a fully coupled land surface model and groundwater model are currently tested and preliminary results will be shown. Results of the discussions with regional stakeholders will also be presented at this presentation.

Session: Groundwater / Surface Water Connectivity, Start Time: 1:20 p.m.

SENSITIVITY ANALYSIS OF A ONE DIMENSIONAL HEAT TRANSPORT MODEL IN THE NGONGOTAHA STREAM, NEW ZEALAND

Mrs Maryam Moridnejad[1], C Moore[2], S Cameron[2], A Shamseldin[1], F Verhagen[3]
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To quantify springs discharge over a 1 km reach in the Ngongotaha Stream, Rotorua, New Zealand, a new approach was developed in this study in which a one dimensional transient heat transport model was fitted to fibre optic distributed temperature sensing measurements where the main calibration parameters of interest were the unknown spring discharges.

The heat transport model requires a large number of input parameters that affect the accuracy of the temperature simulation and ultimately quantification of groundwater discharge. To understand the model input-output relationship, a global sensitivity analysis (GSA) techniques including the Morris method (Morris, 1991) using PEST++ software (Welter et al., 2015) was investigated. For comparison, a linear sensitivity analysis method (Doherty, 2015), was used to quickly explore alternative model representations.

To measure stream temperature, the fibre optic cable was deployed at the streambed near the left and right banks as the groundwater fed springs discharge laterally at both banks. Thirteen springs were identified in the study reach. The left and right bank temperature profiles showed that full mixing of the spring and stream water does not occur between most of the springs due to their close spacing. Datasets of measured temperatures at the left and right bank were transformed to a new single dataset using a weighted average where the weights reflect the degree of mixing downstream of a spring.

The primary objective function for the sensitivity analysis was to minimize the sum of squared residuals between the stream temperature model predictions and the weighted average of the left and right bank temperature. Streamflow gauging upstream and downstream of the study reach showed that the stream gains ~ 500 L/s from groundwater which was used as the second objective function.

The most sensitive parameters using the method of Morris were the shadow factor, discharge of springs no.5, 4 and 1 and the view to sky coefficient. The most sensitive parameters using the composite parameter sensitivity method were the temperature of springs no.13, 12 and 3, discharge of springs no.13, solar radiation and shadow factor. The results showed that the two methods provided different parameter importance rankings. The standard deviation of elementary effects in the method of Morris identifies the extent of interaction between parameters and non-linear effect of each parameter (Saltelli et al., 2004). Two parameters with high standard deviation of the elementary effects were view to sky coefficient and shadow factor. It is believed that the method of Morris results for these two parameters are more reliable than the composite method as this method does not take into account the interaction between parameters and non-linearity.

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EXTRAPOLATION OF GAINING AND LOOSING PROPERTIES TO UNGAUGED REACHES FOR IMPLEMENTATION INTO CHES

Dr Jan Diettrich[1], Dr Jing Yang[1], Dr Doug Booker[1], Dr Murray Hicks[1]

[1]*NIWA, , New Zealand*

Aims

Freshwater is a valuable resource. It supports out-of-stream uses such as irrigation and in-stream values such as ecosystem health. Therefore it is important to be able to predict the effects of abstraction from both surface water (SW) and groundwater (GW) on river flows across New Zealand. Tools like CHES[1] set out to make such predictions, but the task is complicated by the exchange of flow between SW and GW (SW2GW). For CHES to simulate the SW flows in a catchment in an expediently way, a module needs to be developed that can efficiently simulate SW2GW interactions. A modified version of the statistical approach ELFMod (Empirical Longitudinal Flow Model)[2] is being developed and evaluated for this purpose.

Currently, ELFMod uses time-series data at gauging stations and observation bores and spot-gauging data to determine a statistical relationship between losing and gaining properties of river reaches. This relationship is then used with the time-series to simulate the flow at the spot-gauging locations. This can be done for any day for which the time-series data is available. Currently ELFMod can only determine gaining or losing of flow between pairs of spot-gauging locations, which means omitting those sub-catchments where no spot-gaugings are available. The aim of this work is to design and test a method to generalise the ELFMod parameters to ungauged sub-catchments so that SW2GW flows can be simulated for the entire catchment, allowing a more accurate SW flow to be simulated within CHES.

Method

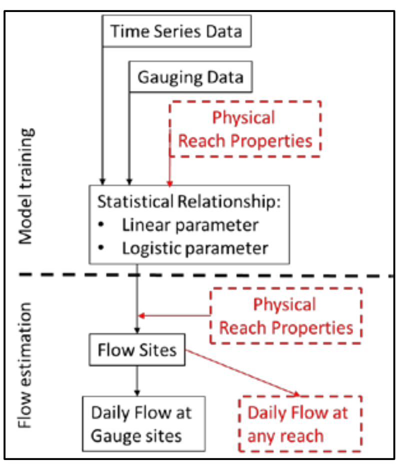

Figure 1: Flow chart of ELFMod (black) and LinReg-ELFMod (black & red).

ELFMod is based on a combination of linear and logistic statistical relationships. However, when one wants to apply ELFMod to the entire catchment of interest, one would need to know several parameters for all reaches. As these parameters cannot be measured for all reaches, we are proposing to use a linear regression model (LinReg-ELFMod) incorporating reach physical parameters that will simulate the ELFMod parameters for each reach. Figure 1 conceptualises the approach, with text in solid boxes depicting the current input, process and output of ELFMod, and text in dashed boxes depicting the additional input and resulting output for the LinReg-ELFMod approach. Physical parameters used for LinReg-ELFMod come from the following datasets: FWENZ[3], QMap[4], and FSL[5] or S-Map[6].

A pre-selection of spatial attributes from each dataset was carried out, retaining 18 independent parameters from the FWENZ database and two each from QMap and FSL. These parameters describe attributes such as slope, temperature, land use, and lithology. Overall, the physical parameters of LinReg-ELFMod allow us to simulate the linear and logistic ELFMod parameters, resulting in us knowing the losing and gaining properties for each reach in a selected catchment.

Results

The Selwyn River in Canterbury has been selected as a testing ground as it has been extensively gauged over the years and ELFMod has been applied to it[2]. In addition, this river has extended periods with long dry reaches. On the main stem of the river there are 19 spot gauging locations which have been visited between 7 and 86 times. In addition the flow recorders at Whitecliffs (top of the main stem) and Coes Ford (bottom of the main stem) were used as the time-series input. These recorders are ~60 km apart.

As a first step, 18 statistically independent FWENZ parameters were used to simulate the linear and logistic ELFMod parameters. This allows comparison of the simulated versus observed flows at each spot-gauging site using the existing ELFMod approach and the LinReg-ELFMod approach. Results for two spot-gauging locations are presented in Figure 2. The first site, Coalgate Riffle, is 7.4 km downstream of the top flow recorder at Whitecliffs, whereas the second spot-gauging site, Hawkins Riffle, is 13.3 km downstream of Whitecliffs.

a) b)

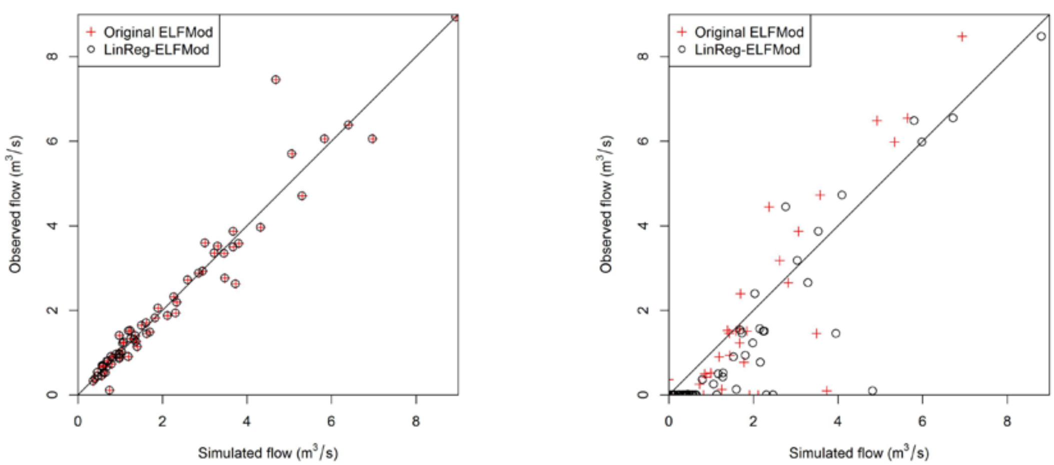

Figure 2: Observed versus simulated flows for spot-gauging locations Coalgate Riffle (a), and Hawkins Riffle (b). The crosses are the original ELFMod simulated flow values, whereas the circles are the simulated flow values using LinReg-ELFMod.

Results at Coalgate Riffle show very good estimation of ELFMod parameters using the LinReg-ELFMod approach, with both approaches being able to explain 94% of variation of the observed flows. However for some cross sections, (e.g. Hawkins Riffle) both approaches explained less than 85% of variation in the observed flow. Over all spot-gauging sites, the existing ELFMod method explained between 65% and 99% of variation in the observed flow data, with an overall mean value of 89%, while the LinReg-ELFMod approach explained between 63% and 98%, with an overall mean value of 88%. Thus the LinReg-ELFMod approach explained only about 2% less of the variation in the observed flow data than did the ELFMod approach.

Conclusion

These results indicate that the LinReg-ELFMod approach performs essentially as well as the existing ELFMod approach, but has the added advantage of being able to be applied to ungauged sub-catchments. This allows for the generation of hydrographs for gaining and losing reaches that can be used within a tool such as CHES to simulate in-stream and out-of-stream attributes.

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MODELLING SURFACE WATER – GROUNDWATER INTERACTION WITHIN NIWA'S NATIONAL HYDROLOGIC MODELLING FRAMEWORK

Dr Jing Yang[1], Dr Hilary McMillan, Dr Christian Zammit
[1]NIWA, , New Zealand

Aims

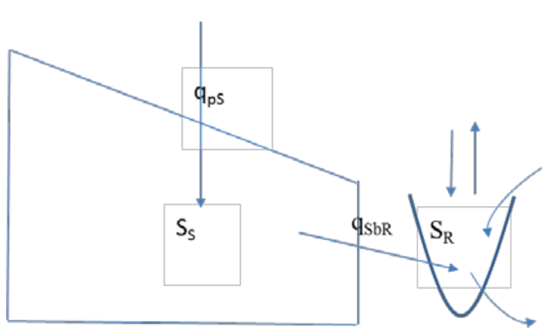
Over the past 13 years, NIWA has been developing an uncalibrated national hydrologic modelling system to simulate the hydrologic cycle across New Zealand. The model is used to support different water related decision making, ranging from flood prediction, water availability estimation, to impact assessment of landuse and climate change. NIWA's national hydrological model (TopNet) (McMillan et al., 2013), is based on TopModel concepts, has been applied successfully in most areas across New Zealand except some plains where strong interactions between surface water and groundwater are present. This is mainly due to the fact that groundwater process are too simply to represent correct hydrological processes in those areas.

One objective of the MBIE contestable Waterscape program is to enhance the capability of TopNet model in simulating groundwater flow and interactions between surface water and groundwater across all New Zealand landscape.

Method

An additional conceptual groundwater store was added to the current TopNet structure. This allows TopNet to better represent groundwater processes in areas where hydrological processes are not topographically driven. The main features of the updated model include:

- Groundwater flow: from one groundwater store to another one or two stores (fluxes q_{DuD} and q_{DdD} in Fig. 1)
- River-groundwater interaction: either losing or gaining rivers (flux q_{RlD} in Fig. 1) based on local information
- Exchange with the external: gaining from/losing to the other watershed (flux q_{XfD} in Fig. 1)



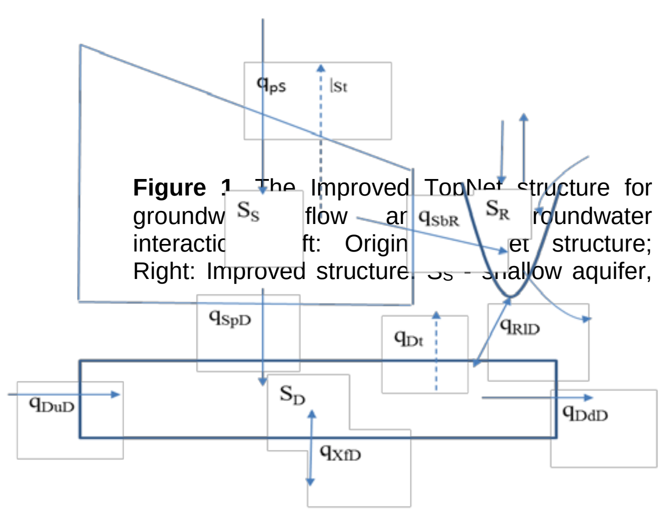


Figure 1. The Improved TopNet structure for groundwater flow and groundwater interaction. Left: Original TopNet structure; Right: Improved structure. S_S - shallow aquifer,

SR - river, and SD – deep aquifer. Arrows are fluxes)

Results

The updated model was applied to the Pareora catchment in the Canterbury region (Fig. 2). The Pareroa catchment drains an area of 539 km^2 with annual precipitation 700 mm. Previous studies (e.g. Wilson and Aitchison-Earl, 2014) show there is a strong interaction between river and groundwater in the lower Pareora catchment.

Flow stations:
- Huts, and State Highway 1 (SH1)

Concurrent gaugings:
- Holme Station Bridge, Brasells Bridge, and SH1

Losing reaches:
- Huts to Brasells Bridge

Gaining reaches:
- Brasells Bridge to SH1

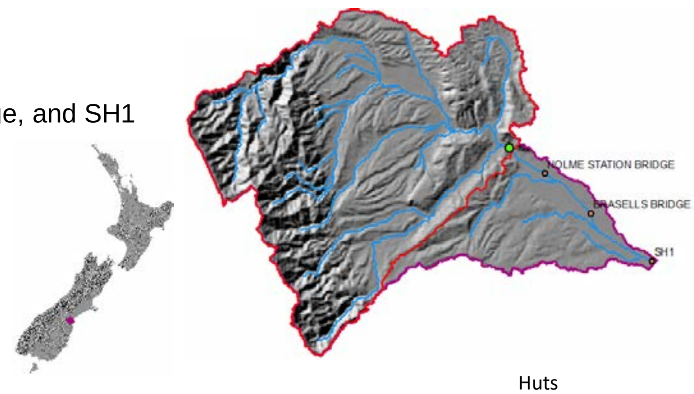


Figure 2. Location of Pareora catchment

Application and results:

- Original TopNet parameters were calibrated at Huts; Groundwater parameters were calibrated with concurrent gaugings in 2000 and 2001 (Fig. 3)
- Model was validated with spot gaugings in 2003, and flow at SH1 from 2009 to 2011
- Updated TopNet obtained a good match with observed flows
- There is a significant improvement in the low flow simulation, compared to original TopNet

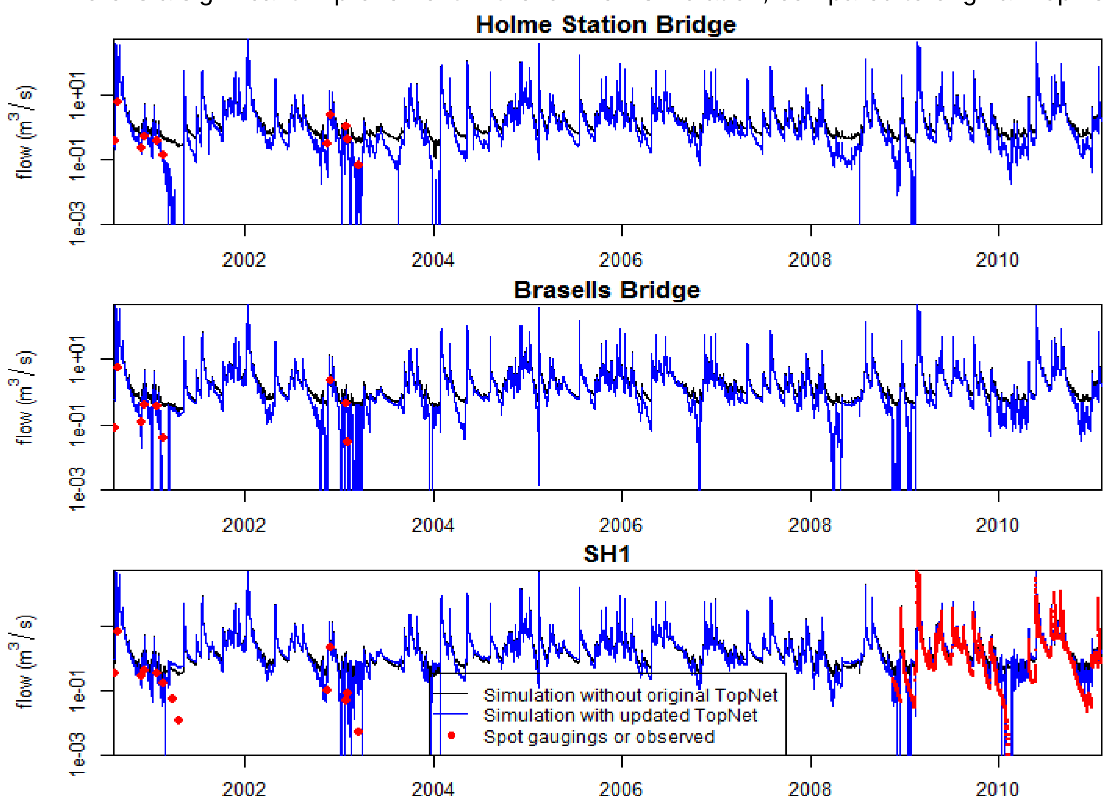


Figure 3. Flow comparison among spot gaugings (red dot), original TopNet simulation (black line), and improved TopNet simulation (blue line)

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Acknowledgement This work is Funded by New Zealand's MBIE via the **Waterscape** programme (C01X1006). We thank Philippa Aitchison-Earl from ECan for data and discussion.

UPDATE ON POVERTY BAY MANAGED AQUIFER RECHARGE PILOT TRIAL

Mrs Clare Houlbrooke[1], Mr Robert Bower[1], Mr Brett Sinclair[1], Mr Dennis Crone[2]
[1]Golder Associates (NZ) Ltd, Hamilton/Christchurch/Auckland, New Zealand, [2]Gisborne District Council, Gisborne, New Zealand

Introduction

The potential for developing a GRS (Groundwater Replenishment Scheme) in the Poverty Bay area based on Managed Aquifer Recharge (MAR) is being investigated due to existing pressure on groundwater allocation. Under the current abstraction rates, the Makauri Aquifer is experiencing a trend of declining water storage during irrigation seasons. This trend is occurring despite incomplete utilisation of water allocated under existing groundwater take consents. This allocation pressure on the main groundwater resource in the area, combined with probable tighter future limits on surface water abstraction and increasing water demand by existing users, is likely to result in issues of water supply security.

Existing private abstraction bores accessing the Makauri Aquifer represent a significant capital investment. This aquifer, when actively replenished and managed, may be able to act as an effective water distribution system linking these bores with a GRS.

Proposed Pilot Trial

The primary finding from the MAR pre-feasibility assessments (Stages 1A and 1B) was that a pilot trial is required to demonstrate the viability of a GRS focused on the Makauri Aquifer to improve the security of future water supply in the Poverty Bay area. Funding has been secured to design, plan and implement a MAR pilot trial based on the direct injection of water from the Mangapoike Dams into the Makauri Aquifer. During the initial development of the pilot trial concept, a back-up source water option for the trial was also identified. This option entails the sourcing of water from the Waipaoa River through the Waipaoa Augmentation Plant.

The position of the injection bore for the pilot trial has been selected for the following beneficial reasons:

- Proximity to two source water options:
    - Treated source water from Mangapoike Dams through the water supply pipe network.
    - A back-up treated source water supply option from Waipaoa River through the Waipaoa Augmentation Plant.
- The location of the site is to the west of the area with the greatest density of takes for water from the Makauri Aquifer as well as the greatest observed drawdown effects on the aquifer.
- There are only a few active bores with consented takes accessing the Makauri Aquifer close to the pilot trial site.
- Site access and permissions. The property located at the Waipaoa Augmentation Plant, is owned by and managed by GDC, allowing for easy access and permissions. In addition, this site also allows for on-going management of the injection bore and associated infrastructure by GDC if the pilot trial demonstrates the viability of a GRS for the Makauri Aquifer.

Proposed Pilot Trial Monitoring

The flow of water into the injection bore will be monitored at the bore head. The data generated will be analysed throughout the injection trial so that the responses in the aquifer can be analysed and assessed and differentiated from background pressure changes. This ongoing analysis will also support operational management of the pilot trial, especially during the start-up period of the trial.

Baseline groundwater level monitoring is already underway at nine targeted monitoring sites. This monitoring will be continued and intensified for the duration of the MAR pilot trial injection period and a

three month recovery period. Monitoring is also planned one additional shallow bore or standpipe piezometer together with a deep standpipe piezometer installed in a pilot bore during drilling.
Based on the results of a water quality assessment undertaken as part of the pre-feasibility study, acquisition of data in the following areas has been included in planning of the pilot trial.

1. Drill cuttings will be collected for mineralogical analysis by X-ray diffraction and thin section petrography when the injection well is drilled. The planned mineralogical analysis should identify any minerals that may react in response to changing hydrochemical conditions in the aquifer.
2. Dissolved and total iron concentrations in the aquifer water will be monitored as part of the routine sampling and analysis of water from the standpipe piezometer installed close to the injection well. The objective is to improve the current understanding of iron mobility in the local groundwater under changing hydrochemical conditions in the aquifer.
3. A down-hole camera inspection of the injection well screen will be undertaken following completion of the injection trial to confirm the effectiveness of clogging management measures incorporated in operational procedures for the trial.
4. Chlorine reaction products in the aquifer in the immediate vicinity of the injection well will be monitored to confirm the use of treated potable water does not result in the significant production of chlorinated hydrocarbons in the aquifer.

The pilot trial monitoring program is designed to generate the information required to confirm the water storage and transmission capacity of the aquifer and support the design of a GRS in the Poverty Bay.

Conclusions

The proposed Poverty Bay MAR pilot trial involves introducing water treated to a potable standard into the Makauri Aquifer through a specifically designed injection bore. Data gathered will be analysed throughout the injection trial, for both water resource and operational trial management purposes. The planned monitoring program has been designed to enable mitigation measures to be instigated during the project if any adverse effects are observed.

The proposed pilot trial has been designed to generate information for the assessment of GRS options for the region. A successful MAR trial would result in GDC, water users and other local groups in the Poverty Bay area being provided with new water management options to help address projected issues with future water supply security.

MANAGED AQUIFER RECHARGE IN THE POVERTY BAY FLATS

Mr George Hampton[1], Associate Professor William Bardsley[1], Mr Paul White[2], Mr Paul Murphy[3]
[1]University of Waikato, Hamilton, New Zealand, [2]GNS Science, Taupo, New Zealand, [3]Gisborne District Council, Gisborne, New Zealand

Groundwater in the Poverty Bay flats

In 2012 a report was commissioned by the Gisborne District Council (GDC) to examine groundwater resources in the Poverty Bay flats. This report found that groundwater elevations within the Makauri Gravel aquifer (the aquifer subject to the greatest groundwater abstractions), were declining at statistically significant rates, probably due to groundwater abstractions (White et al., 2012). As a result, the GDC is investigating whether managed aquifer recharge (MAR) can be used to help achieve the sustainable management of groundwater resources within the Poverty Bay flats. MAR is *"the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit"* (Dillon et al., 2013, p. 2). Though MAR is uncommon in New Zealand, increasing pressures on groundwater may change this. GDC is investigating two different methods of MAR, well-injection (in conjunction with Golder Associates), and infiltration basins, which is the focus of this study.

Methods and Results

Rainfall (1938-2014), river flow (1966-2014), and groundwater elevation data (1982-2014) was obtained and analysed to help characterise the groundwater system and update the work undertaken by Gordon (2001) and White et al. (2012). No statistically significant trends were present in rainfall or river flow data. Trends in groundwater level in 31 Makauri Gravel aquifer bores were analysed. Nine bores exhibited statistically significant declines in groundwater elevations ranging from -0.024 to -0.114 m/year, while two bores exhibited statistically significant increases in groundwater elevations ranging from 0.017 to 0.020 m/year.

Two sites were then identified within the Poverty Bay flats for MAR using infiltration basins using the "HIGGS Index", which was developed to evaluate a site's infiltration basin potential against other sites. While the two sites showed initial promise via a desktop study, infiltrations tests at each site indicated low rates of saturated hydraulic conductivity (6.12 cm/day at one site, less than one cm/day at the other site) due to the presence of sediments with low permeability. Hydrogeological modelling is presently being undertaken to ascertain whether an infiltration basin could be used as a tool to artificially recharge the Makauri Gravel aquifer.

Conclusion

An update of the work undertaken by White et al. (2012) found that groundwater elevations are declining at statistically significant rates within the Makauri Gravel aquifer where groundwater abstractions are greatest. Conversely, where pumping is negligible in the northern reaches of the Poverty Bay flats statistically significant increases in groundwater elevations have been observed. Therefore, it is likely that decreases in groundwater elevations, where observed, are due to groundwater abstractions, the same conclusion as White et al. (2012). If the modelling does indicate that an infiltration basin can be successfully used to artificially recharge the Makauri Gravel aquifer, given the low rates of saturated hydraulic conductivity found at the two identified sites, removal of near-surface layers of sediments of low permeability is likely to be necessary given their prevalence across the Poverty Bay flats.

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Session Theme: General Hydrology, Start Time: 3:30 p.m.

SHIFTS IN HYDROLOGICAL REGIMES AND LOW FLOW STATISTICS IN THE WAIKATO REGION OF NEW ZEALAND

Mr Bevan Jenkins[1]
[1]*Waikato Regional Council, Hamilton, New Zealand*

Aims

Investigate how the long term shifts in hydrological regimes may affect water allocation in the Waikato Region.

Method

Previous studies have looked at long term shifts in climatic variables (Salinger et al. 2001), precipitation extremes (Dravitzki & McGregor 2011) and river flow (Mckerchar & Henderson 2004). However, these previous studies have not applied their findings to the issue of water allocation and potential affect of changes in regime on allocation, or indeed allocation using a flow record that exists only during a particular phase.

Annual precipitation data were analysed for several long term raingauges in the Waikato Region to determine any shifts in hydrological regimes.

Annual average river flow data were analysed for several flow recorders across the Waikato region to determine any shifts in hydrological regimes.

Hydrological year moving seven day low flow minima's were analysed to determine whether any shifts were evident in the extreme low flow events. These are the values which are used in the application of extreme value frequency analysis methods to determine low flow statistics which are used in water allocation.

Results

Rainfall in the Waikato Region shows long term shifts (Figure 1) consistent with previous studies such as (Salinger et al. 2001).

The length of record available for analysis for river flow is shorter than that of precipitation. However, the annual river flows consistently show the same shifts as that shown in precipitation.

The most marked change in annual river flows occurred in the early 1980's with a decrease in flow compared with the preceding period. An example of this is shown in Figure 2, although it appears throughout the region. An interesting note is that the lower Waikato also shows this decrease in flow even though the addition of water from the Tongariro Power Scheme was made over this time period.

While (Mckerchar & Henderson 2004) found "The North Island data show no consistent evidence of shifts in low-flow regime.", the present studies initial results indicate that there are shifts in the low flow values used in water allocation that coincide with the precipitation, and average river flow shifts. The affect of this of allocation regimes is currently being investigated.

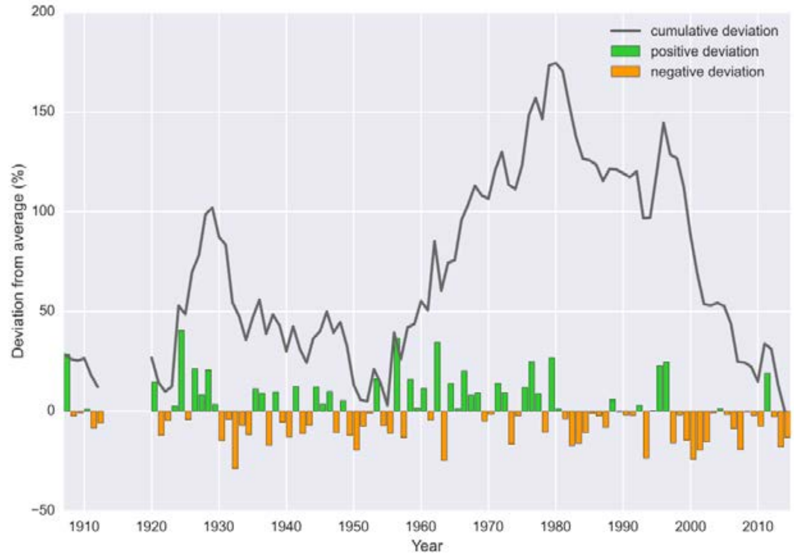

Figure 9. Cumulative deviation (trace) and annual deviations (bars) from long term annual average rainfall for Ruakura climate station for the period 1907-2014.

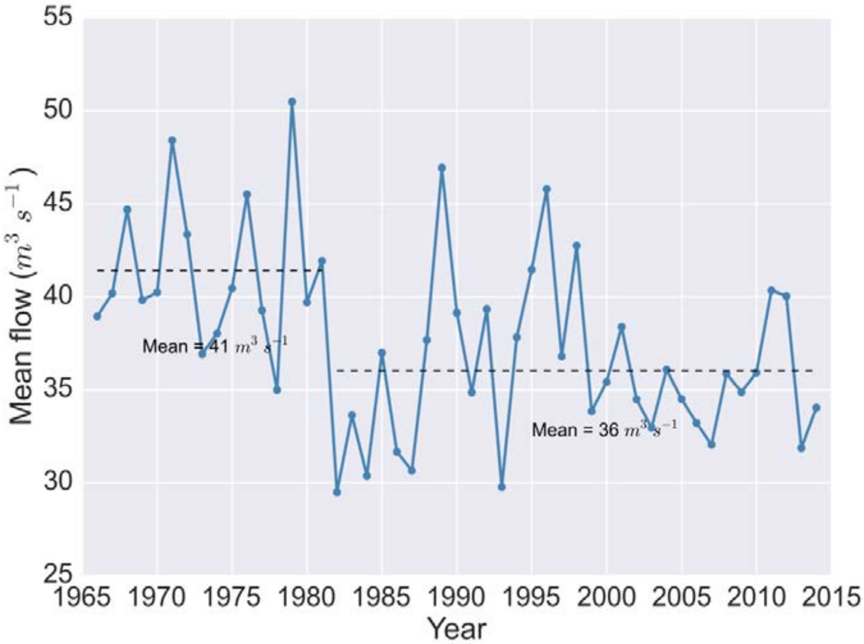

Figure 10. Annual average flow recorded for the Waihou as Te Aroha for the period 1966-2014.

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DERIVING WATER RESOURCES INDICATORS AT THE BASIN SCALE FROM GLOBAL HYDROLOGICAL AND LAND SURFACE MODELS

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Introduction

There are currently several global hydrological and land-surface models currently available. The resolution of many of these is rapidly increasing, providing simulated hydrological fluxes at a scale appropriate to managing water resources in medium-sized basins. This offers clear advantages, as these fluxes are consistently represented around the world, allowing easy comparison between different regions. The potential for improved water resources management in poorly gauged basins using these data is obvious. The Earth2Observe project, a recent research initiative funded by the European Union 7th Research Framework, aims to develop a consistent water resources re-analysis (WRR) at the global scale, based on an ensemble of such global scale models. This is developed in two phases. In the first phase, the ensemble of participating models is driven using the WATCH-ERA-Interim (WFDEI) meteorological re-analysis dataset as forcing, providing hydrological data at the global scale at 0.5 arc degree resolution, at a daily time step. These models will then be improved through improved process representation, as well as assimilating various (satellite) products to develop the second phase WRR dataset.

Method

In this paper we use this first phase WRR to explore how these data can be applied to determine indicators useful to water resources managers and basin planners. Nine of the participating models are considered, including four land surface models (LSM) and five global hydrological models (GHM). These models are run for the 32 year period from 1979 to 2012, with the common WFDEI meteorological reanalysis dataset used as forcing.

Using the results of the participating models, we explore three water resources indicators: an aridity index, based on the ratio of actual and potential evaporation; the water exploitation index, which compares water withdrawal and consumption to the renewable water resource; and an indicator that calculates the frequency of occurrence of stress in the (model) root zone, which is defined to occur when the available moisture falls below 50% of the water available in the root zone at field capacity.

Results

The resulting hydrological fluxes calculated by each of the nine models show quite significant differences, despite the use of a common meteorological forcing dataset. These differences are due to different processes representations in the models. Indicators calculated with the model outputs reflect these differences, thus showing considerable uncertainty. We show that the distribution of the value of the index depends on the hydro-climatology, with marked differences between arid, semi-arid and temperate zone areas. Figure 1, panels (a), shows the distribution of the mean value of the Aridity Index from the nine models. As expected, Northern and temperate climates show a low index, while Mediterranean and North African climates have Index values belonging to semi-arid and arid climates. The spread between the models, shown by the standard deviation in panel (b) is, however, significant in some areas; for example in parts of Eastern Europe. It is also shown that the LSM and GHM models often dominate different parts of the distribution of the indicator value. An example is shown in panel (c). The GHM's calculate lower values of the Aridity Index in the North African, Mediterranean, and Northern European climates, while the LSM's dominate the lower values in the more temperate climates. While these uncertainties are important, applying a threshold to the indices to categorise areas as arid or non-arid reveals that these uncertainties may not always be relevant. The aridity index provides a simple example. The index ranges from 0 to 1, and in this example we consider areas with an index value larger than 0.6 to be arid. This shows there is consensus between the models in most areas. That consensus is, however, lower in transition areas. The Mediterranean region is one such example, where the categorisation depends very much on the model applied (Figure 1, panel (d)). In these areas, the uncertainty in the multi-model ensemble is relevant to decision making based on the indicator. It is also in these areas where a calculating the index using a model has value, as we do not need to run a model to decide that desert areas such as in Northern Africa are arid. Similar results for the geographic distribution and uncertainty of the values are found for the other two indicators, as well as in other project case study basins in Australia & New Zealand, Bangladesh, Colombia and Ethiopia.

Our analysis shows that while both LSM's and GHM's can provide useful data for basins across the world, indices derived with the results of these models for use in water resources management planning may be quite different, depending on how hydrological processes are represented. The analysis also identifies in which climates improvements to the models, and data assimilation is particularly relevant to support the confidence with which decisions can be taken based on indicators derived from model simulation results.

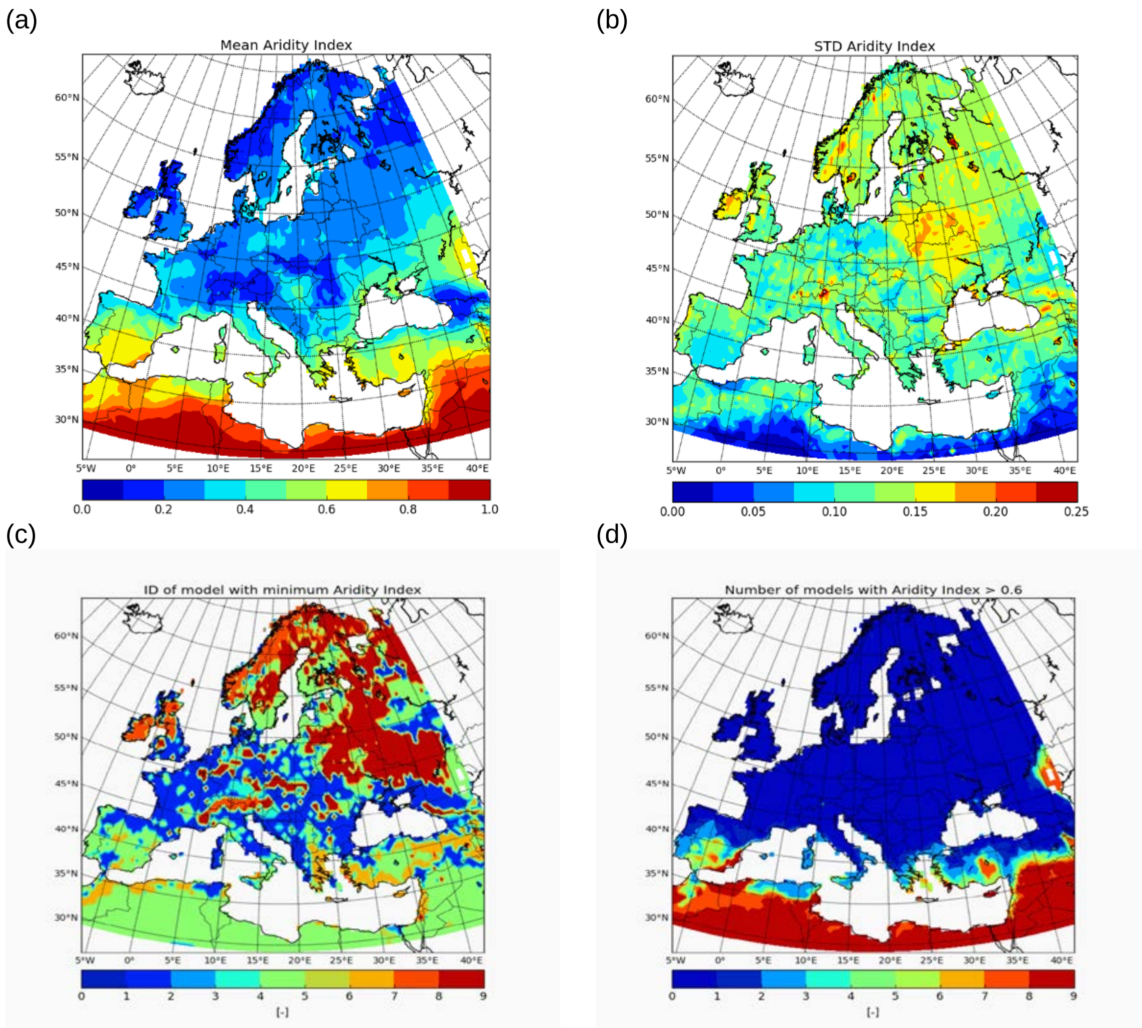

Figure 1 Distribution of the Aridity Index over Europe calculated with an ensemble of nine global scale hydrological models. Panels (a) and (b) shows the ensemble mean and standard deviation. Panel (c) shows the ID of the model that calculates the minimum Aridity Index. Models with ID's 1-4 are Land Surface Models, while those with ID's 5-9 are Global Hydrological Models. Panel (d) shows the number of models with an Aridity Index above 0.6.

ASSESSMENT OF ECONOMIC AND ENVIRONMENTAL ADVANTAGES OF A SEASONAL PUMPED STORAGE SCHEME (ONSLOW, CENTRAL OTAGO)

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Aims

A large seasonal large pumped storage scheme would provide an important component of New Zealand's electricity supply system. Potential advantages include provision of an energy buffer against extended dry periods, provision of spinning reserve, providing grid stability to enable further renewable wind power development, reducing seasonal variation and shoreline damage of scenic hydro lakes, reduced flooding frequency on the Waitaki River, provision of summer water for the Waitaki River for irrigation and recreational use. The present study seeks to quantify these advantages.

Method

A hydrological and economical simulation model was developed of the Onslow pumped storage scheme in operation. This included sub-models of the Clutha, Waitaki, Manapouri, and Waikato hydropower stations, together with wind power contributions. The model was run in hindcast mode using historical hydro flows and records of electricity demand over the period 1998-2012. The model was operated primarily with a view of seeking stabilise the existing hydro lakes at specified levels, with storage shifted to Onslow, and quantifying the various advantages arising from that operational mode.

Results

A benefit of approximately NZ$1.8 billion is estimated for the 14 years of simulating pumping and generating, with a further NZ$1.5 billion is derived by an estimated 113 MW (as a time average) of additional power being created from reduced hydro spillage, used to reduce generating from thermal power plants.

In addition, the simulations indicate provision of secure irrigation water from Waitaki River for the existing 75,000 irrigated hectares of the lower Waitaki River catchment which presently yield some NZ$550 million per annum in gross income to the local and national economy (Soal, 2012). Also, and importantly, there would be approximately 80 m^3s^{-1} of new Waitaki water for October-March and 50 m^3s^{-1} in April and September which could enable doubling the current Waitaki irrigated area.

Figure 1 shows the simulated water level of the proposed Onslow storage reservoir over the simulation period. An Onslow storage dam height of 50m would more than double the national hydro energy storage capacity.

Conclusion

The Onslow pumped storage scheme is worthy of further investigation as it appears to have economic viability, taking into account energy, agricultural, and environmental factors.

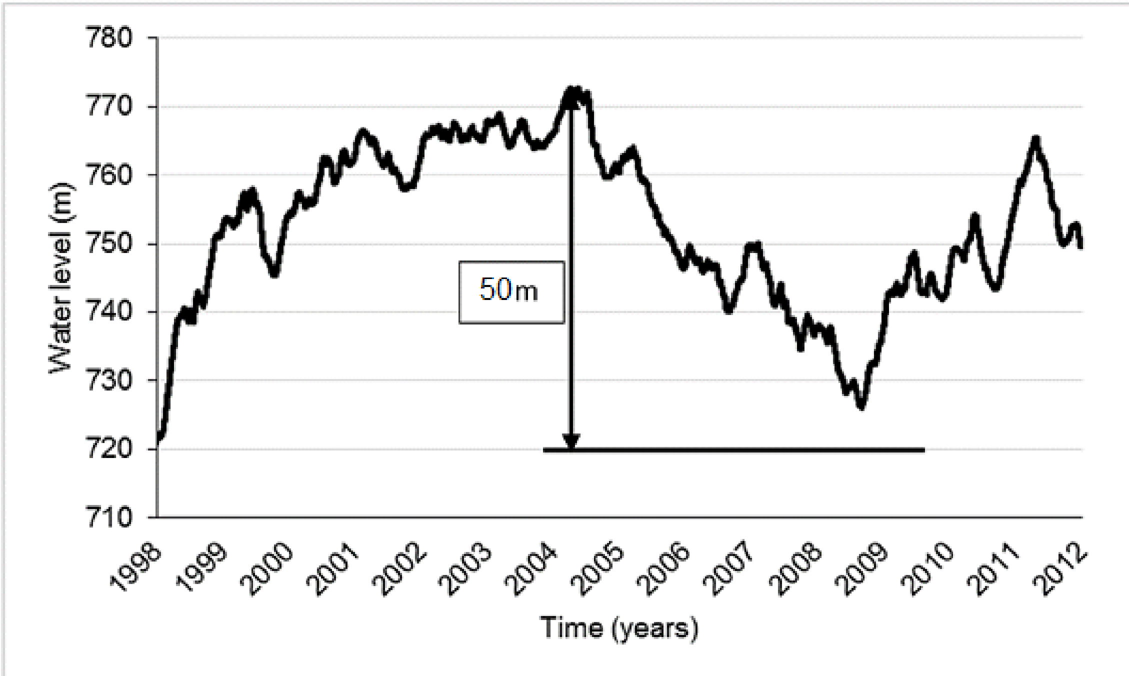

Figure 1. Simulated Onslow reservoir water level (1998-2012) using operational 80% energy efficiency, started from initial zero storage at 720 metres.

Reference

Soal, E. (2012) *Evidence of Elizabeth Soal submitted on behalf of the Waitaki Irrigators Collective Limited.* [Online] Available from: http://ecan.govt.nz/publications/Plans/rps-2011-hearing-evidence-waitaki-irrigators-elizabeth-soal.pdf.

HINDS CATCHMENT MANAGED AQUIFER RECHARGE (MAR) PILOT PROJECT

Catherine Cockburn[1], Robert Bower[1], Brett Sinclair[1]
[1]*Golder Associates (NZ) Limited, Takapuna, New Zealand*

Introduction

The Hinds/Hekeao Plains community has been heavily involved in the implementation of the Canterbury Water Management Strategy (CMWS) to develop catchment-scale solutions to water quality and quantity challenges in the catchment. The Ashburton Zone Committee (AZC) was tasked with providing recommendations to improve the management of water resources in the Hinds Plain area. These recommendations are now embodied in Variation 2, a Hinds/Hekeao Plains subchapter to Environment Canterbury's (ECan) Land and Water Regional Plan (LWRP).

One of the committee's recommendations is for a Managed Aquifer Recharge (MAR) pilot project to commence in 2015. Golder Associates (NZ) Limited has been commissioned to lead the MAR pilot trial in the Hinds catchment.

Aims

The aims of the MAR pilot trial are to demonstrate the viability of MAR in

1. Diluting nitrate concentrations in groundwater;
1. Achieving minimum flows in spring-fed streams;
2. Increasing water supply reliability for existing groundwater and surface water users;
3. Minimising the on-farm mitigations needed to reduce concentrations in groundwater.

Method

A pre-feasibility study was undertaken, with one outcome being the identification of a site for a trial infiltration basin. The trial site is located in the Valetta groundwater allocation zone where high quality water from the Rangitata River will be directed to the site for infiltration. The depth to groundwater beneath the trial site (between 10 m and 16 m bgl) is sufficient to enable the underlying aquifer to accept significant additional recharge.

Two site infiltration tests have been carried out and data analysed using SEEP/W software and Darcy flow equations. In both cases, the testing indicated a planned basin of 0.9 ha should be sufficient to infiltrate water flows to the underlying aquifer of 0.5 m3/s. Operational management of the trial will need to adapt to a number of physical factors, including rainfall patterns, flows in down-gradient coastal drains and the source water race capacity during peak irrigation season.

Results

An environmental monitoring program has been developed for the pilot trial. Monitoring will focus on identifying and tracking changes in groundwater storage and quality as well as flows in the down-gradient, spring flows and changes in overall groundwater quality. Monitoring results will be reviewed throughout the term of the pilot project. The monitoring program is intended to be flexible and subject to ongoing optimisation based on the outcomes of the data reviews. Some of the environmental monitoring systems are to be linked real-time to the pilot trial control system.

Baseline groundwater monitoring for the pilot trial was initiated in January 2015 and surface water flow monitoring followed in February. Construction of the infiltration basin is planned to start in early November 2015, with the expectation that infiltration will be underway during December.

Figure 1. Hinds Catchment MAR Pilot trial site location.

Session Theme: Groundwater / Surface Water Connectivity Start Time: 3:30 p.m.

LOW FLOW MODELLING TO DETECT RATING PERTURBATIONS

Mr Graham Macky[1], Dr Edmund Brown[2], Dr Jeff Smith[3]
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Aims

There is now increasing pressure on Councils to have accurate flow data available in real time for managing water allocation, in particular when restrictions should occur during low flow conditions. Monitoring low flow conditions in rural rivers can be difficult because of the lack of a reliable and stable stage-flow rating. Significant weed growth during such periods may cause unstable ratings and inaccurate estimates of flows. During low flow conditions in the Piako catchment of the Hauraki Plains near Hamilton, more than 50% error can occur in the rated flow within a week of the rating being corrected. This is largely due to either weed growth or sudden die off.

In the Piako catchment, calibrated hydrological models have been developed for two gauging sites, to see whether the models can determine when rating curves become invalid. The ultimate aim is to deploy such a model in real time, so that the Regional Council can identify at an early stage when the rating is changing and arrange fresh gaugings or simply adjust the rating.

Method

The prime component of these models is a lumped, conceptual rainfall-runoff model, Nedbør-Afstrømnings-Model (NAM) (Nielsen & Hansen 1973). It simulates overland flow, interflow (horizontal leakage), and base-flow components of runoff as a function of the moisture contents in four interconnected storages, but in this application only the baseflow component is of direct interest. NAM accounts first for surface storage, which loses water to evaporation, interflow and infiltration into the lower zone and groundwater storage. Evapotranspiration demands are first met at the potential rate from the surface storage, then at a reduced rate by root activity from the lower zone storage. Once maximum surface storage is reached, some of the excess water enters the streams as overland flow, and some goes to groundwater storage. Baseflow is computed from groundwater storage and a user-specified time constant.

There are up to 11 parameters in NAM that the user can adjust during model calibration, and an auto-calibration function that speeds the process. For this study, auto-calibration was used as a first step in calibration, but refinement of the calibration was completed manually to match modelled and rated river flow best during the baseflow recession which typically occurs from about November to mid-April.

To convert the NAM runoff to stream flow, groundwater flow out of the catchment should be subtracted. A desktop study (White et al. 2014) had quantified long-term groundwater flow rates from the catchments. This flow has been assumed constant except for a sinusoidal seasonal variation, with the magnitude of the seasonal variation used as a further calibration parameter.

The catchments of two long-established flow gauging sites were modelled: Piako @ Paeroa-Tahuna Rd (537 km^2) and Piako @ Kiwitahi (104 km^2). Flow-stage gauging data pairs from recent years were accessed to confirm the rated flows and conversely to identify periods when the rating might have drifted. Typically, more than 10 gaugings per year have been carried out. Rainfall and potential evapotranspiration data were obtained from virtual climate station data and averaged over the catchment.

Results

Modelled, rated and gauged flows at the Paeroa-Tahuna Road are compared in Figure 2 for 2012-13, showing baseflow recession in early 2013. The recession in the rated flow is interrupted only briefly by minor rainfall events. This period is typical of the results obtained: modelled flows are slightly higher than measured in some years and slightly lower in others, but the calibration process has replicated the trend of the recession.

This result means that this graphical comparison of modelled and measured flows should clearly indicate when rated flow data become inaccurate due to weed growth, weed die-off or bed erosion or scour. The model for the Piako @ Paeroa-Tahuna Rd is now being set up to run in real time, linked to the same real-time rainfall and flow information as the flood forecasting system for the Hauraki basin.

Some adjustment of model parameters may be desirable because the nearest rainfall data available in real time are at sites outside the catchment. Regardless, the real-time model will provide a useful early indicator that a stage-flow rating has significantly changed. With experience, it should be practicable to apply an adjusted rating prior to obtaining and analysing a new gauging. Based on past flow records and past gauging programme, this would allow a management response to decreasing flows 2-4 weeks earlier than has previously been possible. Deploying the model is therefore expected to help the Regional Council understand low-flow patterns and manage abstractions within the catchment.

References

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Figure 11 Piako River at Paeroa-Tahuna Rd, looking downstream

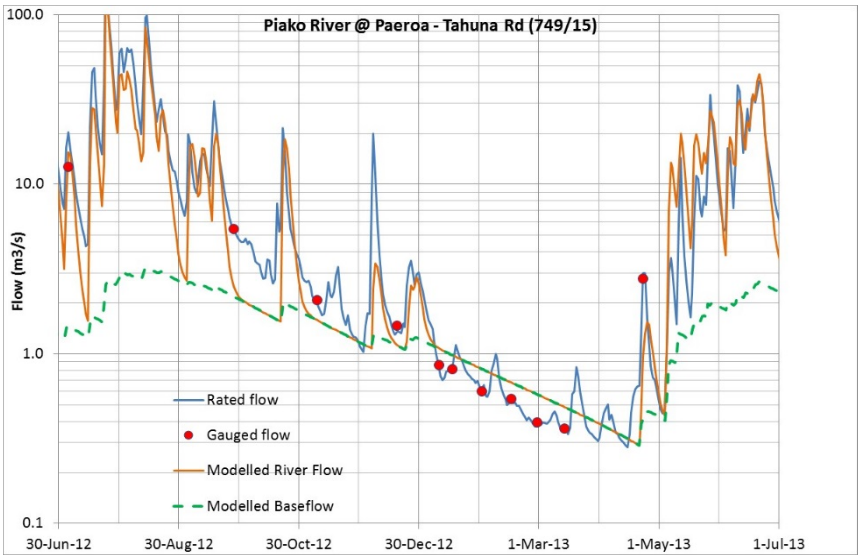

Figure 12 Piako River at Paeroa-Tahuna Rd, modelled, gauged and rated flows, July 2012 – June 2013.

GROUNDWATER RESIDENCE TIMES AND CHEMISTRY OF THE PUKEKOHE AND BOMBAY BASALT AQUIFERS

Mr Rob Van Der Raaij[1]
[1]*GNS Science, Lower Hutt, New Zealand*

Aims

A study of groundwater Mean Residence Time (MRT) and the relationship to groundwater chemistry has been carried out in the Bombay and Pukekohe volcanic aquifer systems in response to high nitrate concentrations observed in groundwater from these systems (van der Raaij 2015). Concentrations often exceed the drinking water standards for New Zealand (Ministry of Health, 2008) maximum acceptable value of 11.3 mg/L NO_3-N and also the national bottom line of 6.9 mg/L NO3-N (annual median) for nitrate toxicity in rivers (Ministry for the Environment, 2014); with implications for groundwater discharges to springs and streams.)

Method

Samples for age-tracers (tritium, CFCs, SF_6) and for major ions, minor ions and metals were collected at 10 sites in June 2014 using standard sampling protocols.

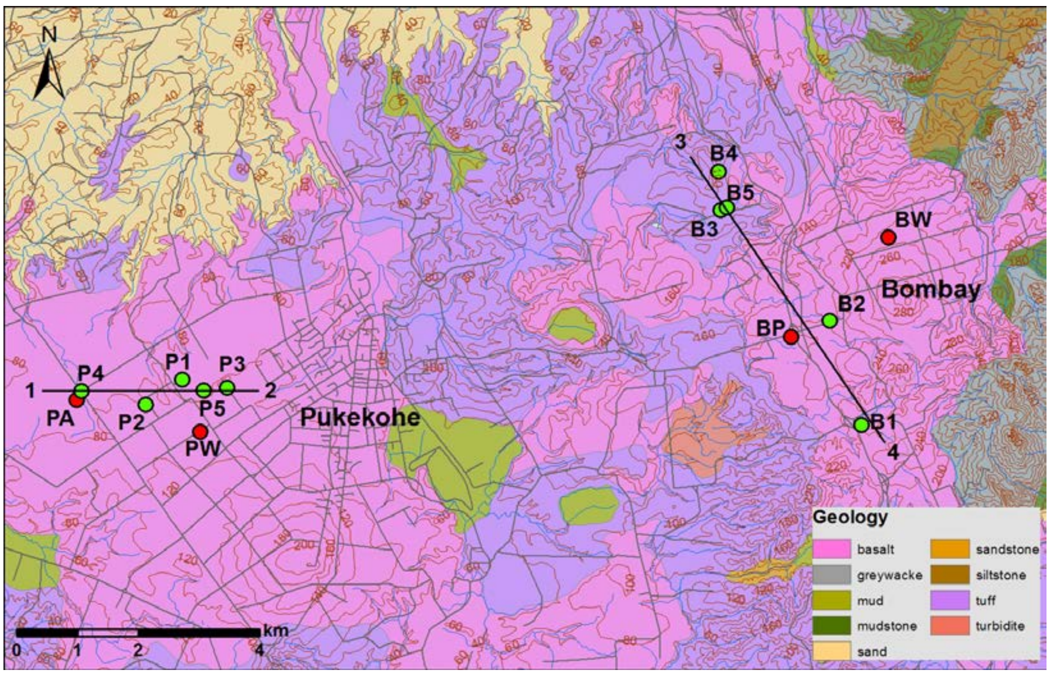

Figure 1. Map of well locations sampled for groundwater MRT and chemistry. Map background is simplified surface geology based on the QMap series (Edbrooke, 2001) with 20m contour lines

Groundwater sampled from a well or other discharge point (e.g. spring) is a mixture of water with variable residence times in the aquifer due to the convergence of different flow lines within the aquifer at the discharge point. Groundwater age-dating therefore yields a MRT of water from all converging flow lines. MRT have been calculated for all wells using the exponential-piston flow model.

Results

MRT of groundwater from the sites tested in the Bombay and Pukekohe aquifer systems ranges between 16 years and 99 years with fractions of exponential mixed flow ranging from 30% to 90%. Groundwater in Bombay aquifers shows an increase in MRT both in the direction of groundwater flow and with depth. In comparison, groundwater from Pukekohe in the upper aquifer generally has MRT younger than 50 years; meanwhile the oldest ages are seen in the lower volcanic aquifer system.

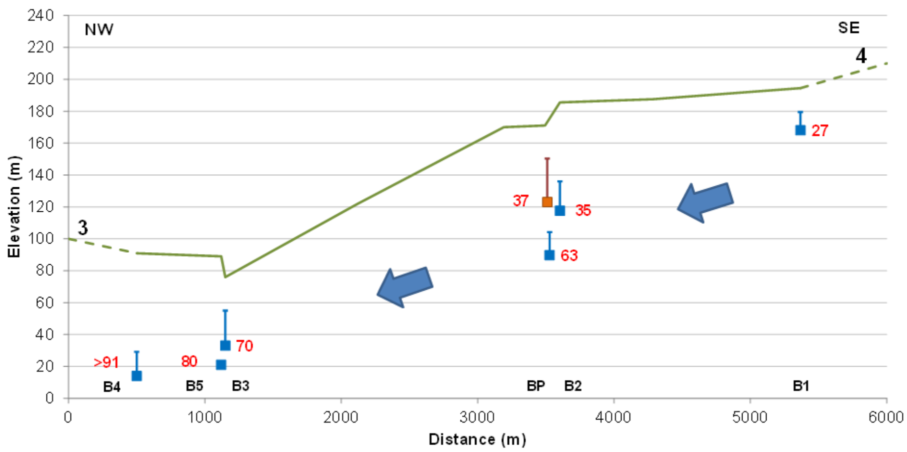

Figure 2. Transect showing groundwater MRT (in red) for the Bombay wells. The blue squares represent wells which lie approximately along the transect 3-4 plotted on Figure 1. Vertical lines indicate the length of open well from which water is drawn. The orange well is not located along the transect but is included for comparison. The green line depicts the approximate surface elevation. The arrows indicate the direction of groundwater flow as implied by piezometric contours (Murphy, 1991). Note that the vertical scale is exaggerated for figure clarity.

Groundwater in both volcanic aquifers is predominantly of type Mg-Na-Ca-HCO3-NO3-Cl or Mg-Na-Ca-NO3-HCO3-Cl. The dominance of magnesium reflects the basalt mineralogy i.e., the presence of magnesium rich olivines and pyroxenes. Nitrate is the dominant anion in younger groundwater, but is not present in older groundwater where bicarbonate concentrations are much higher.
Statistically significant positive relationships with MRT are observed for pH, bicarbonate, dissolved reactive phosphorus, potassium, and to a lesser extent, silica. Nitrate shows an inverse relationship with groundwater MRT (Figure 3). This is common for analytes associated with land-use changes and intensification. The chemistry of younger waters reflects the impacts of recent land-use, while older water retains the chemical signature of less-impacted recharge sources. Changes in chemistry observed at SOE monitoring wells Rifle Range Shallow and BP Bombay indicate that pumping induced changes to the aquifer flow regimes may be occurring. This may have consequences on the groundwater age structure of the aquifer systems.

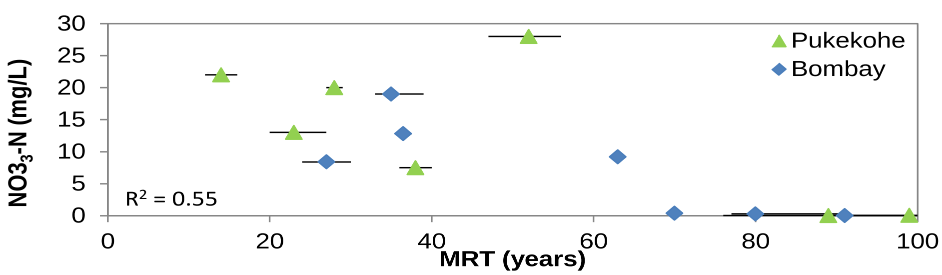

Figure 3. Plot showing the relationship between MRT and nitrate-nitrogen

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van der Raaij, R.W. 2015. Groundwater residence times and chemistry of the Pukekohe and Bombay basalt aquifers. GNS Science Report 2015/11.

PEAT LAKE WATER LEVEL SETTING AND GROUDWATER INTERACTION

Dr Ed Brown[1], Mr Bevan Jenkins[1]
[1]Waikato Regional Council, Hamilton, New Zealand

Aims

Lake Maratoto is an 18 ha peat lake largely surrounded by farmland on drained peat swamp 10 km south of Hamilton City (Figure 1). On the western edge of the lake is a small area of remaining wetland vegetation under QEII covenant. Landcare (2014) considers that the water table under the remaining wetland vegetation needs to be raised closer to the ground surface for improved vegetation health.

Our aim is to understand how much higher the lake's water levels need to be to have a beneficial impact on the water table level under the QEII protected wetland. This informatiFon will support the design of a new outlet control structure. Any decisions on lake level management need to ensure there is no flooding of the surrounding farm land.

Method

To understand the interaction between lake level and groundwater levels a MODFLOW groundwater model was developed.

Inputs to the model were:

1. Lake level from the existing monitoring started in 2002.
- Recharge calculated from rainfall and evaporation measured at nearby Hamilton airport and Ruakura climate stations.
- Geological information for the area was sourced from a study in 1985 (Green, & Lowe, 1985). The depth of lake sediments and peat was ascertained at over 150 locations using probes, auger and coring. These were taken at ~30 m intervals along 12 transects.

Calibration of the model was to:

- Discharge from the lake estimated based on the weir equation for the control structure on the Lake's one outlet.
- Groundwater levels monitored over a two year period from 29 water-table dip wells. Five of these were monitored continuously with water level loggers. The remaining dip wells were monitored manually as time permitted. All the dip wells' elevations were surveyed using RTK GPS on multiple occasions during the monitoring period and linked to the existing lake level recorder.

A trial and error process was used to calibrate the transient, weekly time step, MODFLOW model. The calibration period was between November 2013 and November 2014. Validation of the model was against independent data from November 2014 to July 2015. During the Validation period changes were made to the outlet weir to raise the lake level and provide different environmental stresses to test the model against.

The model calculates changes in groundwater level to a range of lake level scenarios. The lake level scenarios were based on the existing record (since 2002) but modified to the expected levels for different outflow control structure designs. The lake level scenarios were calculated using a simple water balance model (Golder 2013).

Results

An acceptable calibration and validation of the groundwater model was achieved to groundwater levels with a RMS error of 0.16 m. The model produced a good match with the observed seasonality for the majority of monitored locations (Figure 2). The model is now being used to understand if a modified lake level regime can provide benefit to the adjacent QE11 vegetation.

Figure 1: Location of Lake Maratoto.

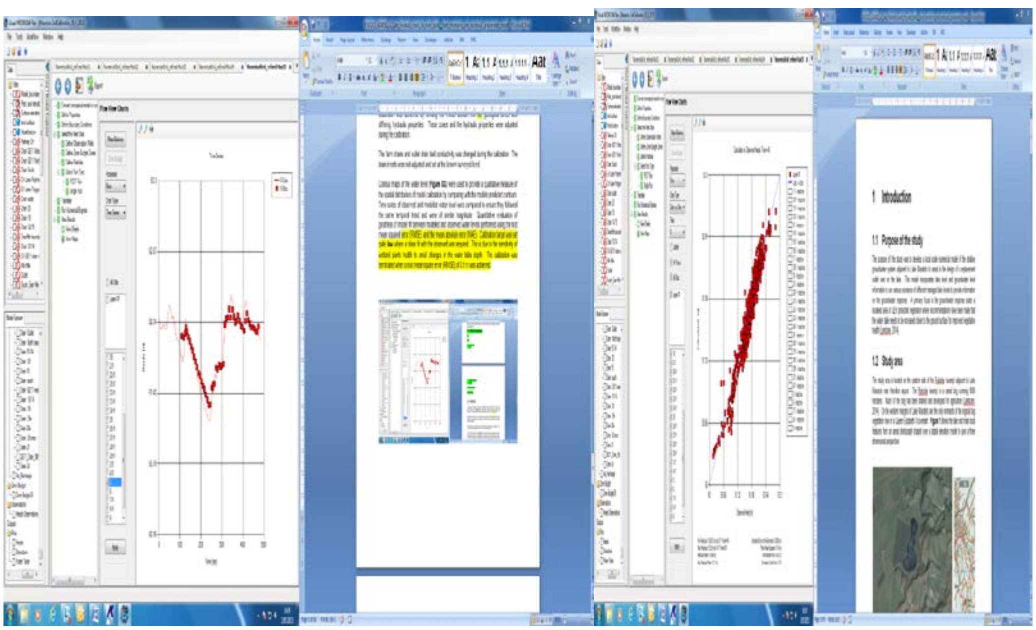

Figure 2: Time series of observed and modeled water level for one dip well (left) and observed against calculated water level for all 29 dip wells and time periods (right).

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CONCURRENT CONTINUOUS MONITORING VERSUS SPOT GAUGINGS

Mr David Leong[1], R Waldron[2]
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Background

Spot flow gauging involves the measurement of the discharge at a given location at a point in time. It is a field technique commonly used by hydrologists to fill knowledge gaps, to assist in such endeavours as:

- Understanding patterns of flow losses and gains along a river, including the effect of surface and ground water abstractions
- Assessing compliance against management plans and consent conditions
- Developing low flow estimates for ungauged locations and understanding catchment-wide low flow behavior, e.g. for water allocation
- Developing synthetic time-series records for ungauged locations via transposition from gauged catchments
- Tracking the propagation of flow events in a river system for various investigations, e.g. water quality, ecology, etc.

It is a cost-effective method and sound results for most applications can be obtained under certain conditions, predominantly stable low flow recessions. As an alternative, contemporaneous continuous monitoring is sometimes used, but remains uncommon because temporary monitoring sites involve considerably more effort to establish and maintain. However, the information able to be gathered from such sites provides an additional dimension to the understanding of streamflow behaviour, and gives superior outcomes under all circumstances compared with spot gaugings.

Aims

In this presentation, we show that for certain applications, spot gaugings alone do not provide sufficient information. Indeed, simple flow correlations developed from concurrent gaugings, if not treated with due care, can lead to misjudgment of the predicted streamflow behaviour under particular managed flow regimes. To illustrate this point, we refer to recent field investigations completed for the Waipawa and Tukituki Rivers in Central Hawkes Bay aimed at understanding and, ultimately, modelling the pattern of streamflow losses and gains in the middle reaches of these rivers, which are potentially affected by the operation of the proposed Ruataniwha Water Storage Scheme.

Method

The Hawkes Bay Regional Council has a very extensive database of historical flow gaugings for over 500 locations in the wider Tukituki catchment dating from the 1950's and earlier. The majority of gaugings have been conducted in a steady low flow setting and represent quasi-equilibrium conditions. Whilst concurrent gaugings have been very useful for developing flow correlations, mistiming issues, especially under higher flows, introduce significant uncertainty to the correlation of medium to high flows. These correlations also cannot generally be used to predict the flow losses and gains under transient conditions, such as from a managed flow release from the proposed dam, or even in a natural freshet/flood in the river.

Losses and gains are expressions of river-aquifer interaction. This is normally included in comprehensive regional groundwater models through a dynamic link at the wetted perimeter of the channel. However, where there is a low permeability zone underlying the river bed (and/or the river is perched above the regional groundwater table) the shallow aquifer adjacent to the river bed can be regarded independent of the deeper regional groundwater. In such situations the problem may be simplified to one of river interaction with dynamic bank storage.

Results

On this basis, a conceptual model has been specifically developed and calibrated using monitoring data to represent the dynamic flow exchange/conveyance processes in the Waipawa and Tukituki Rivers. Figure 1 is a diagrammatic representation of the modelled flow processes. Figure 2 shows the simulated flow response at the downstream end of the Tukituki losing reach compared with the recorded flow for that location (i.e. Tukituki upstream of Tukipo confluence).

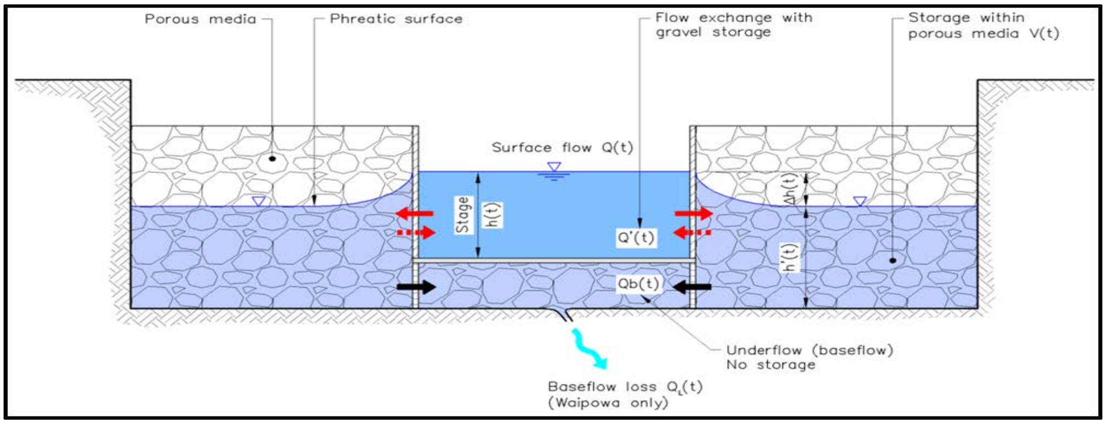

Figure 1 Conceptual model of losing reach including river flow–gravel storage interaction

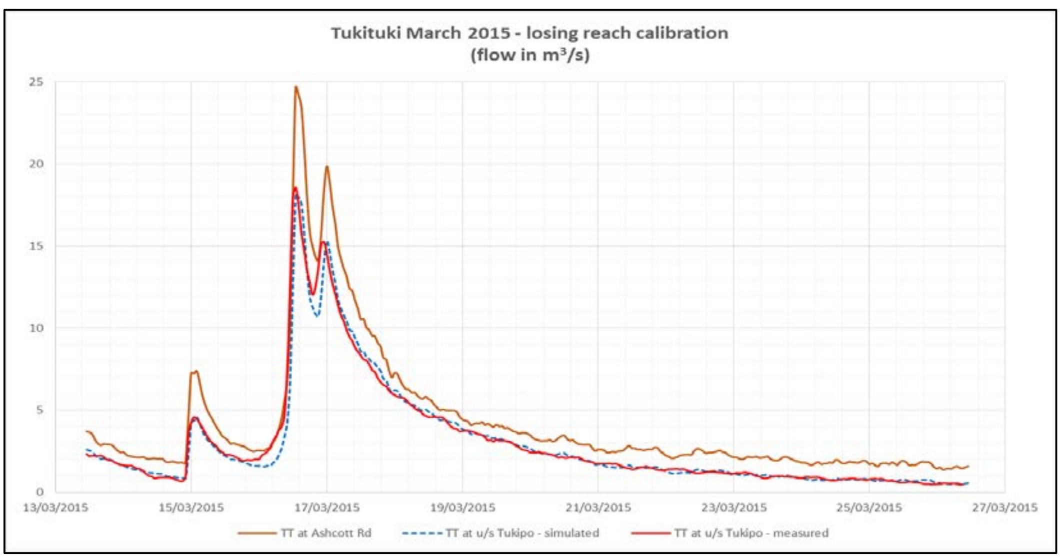

Figure 2 Calibration of the conceptual model of the Tukituki losing reach, from Tukituki at SH50 to upstream of Tukipo confluence

The findings from these investigations underline the importance of a targeted field monitoring programme involving continuous streamflow monitoring, and the value of the data collected for understanding transient flow behavior and for the development of a calibrated conceptual model that is able to simulate the dynamic flow behavior across the losing reaches of these rivers.

Session Theme: Managing to Limits: Water Quality, Start Time: 3:30 p.m.

CHARACTERISATION OF GEOGENIC ORGANIC COMPOUNDS IN WATER ASSOCIATED WITH NATURAL GAS PRODUCTION

Dr Mauricio Taulis[1], Mr William Stearman[2]
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Aims

Coal Seam Gas (CSG) is a form of natural gas (mainly methane) being extracted from the Walloon Coal Measures (WCM) in Queensland, Australia. Coal Seam Water (CSW) is normally pumped to the surface in order to depressurize coal seams and extract this natural gas. CSG operators consistently monitor both the quantity and quality of coal seam water, which is known to have a somewhat consistent geochemical signature (high bicarbonate, high sodium, moderate chloride, low calcium, low magnesium, and very low sulphate concentrations) (Van Voast, 2003). However, individual organic compounds are rarely measured in coal seam water during depressurization operations, which has made it difficult to fully identify these compounds. Previous studies in the US (Orem et al., 2014; Orem et al., 2007) have identified low concentrations of various organic compounds in coal seam water samples from various US basins, while QLD studies by Stearman et al (2014) and Tang et al (2014) have reported similar results. However, little is known about the origin of these compounds. It is widely accepted that coal contains a number of organic compounds including PAHs, heterocyclic compounds, and aromatic amines (Orem et al., 2007). Therefore, it is hypothesized that groundwater in contact with coal could potentially leach organic compounds from coal units. In 2013, a study aiming to test the hypothesis of coal acting as a natural source of organic compounds in coal seams targeted for CSG development, was carried out at Queensland University of Technology (QUT). An additional aim of this study was to test whether the coal material itself could act as a sink for organic compounds (e.g. benzene absorption) and determining whether the use of sodium hypochlorite (as a biocide) would induce Trihalomethane (THM) formation.

Method

The analysis techniques used in the present study focus on coal characterisation (to assess the nature of organic compounds contained in the coal samples) and leachate characterisation (to identify specific organic compounds and their concentrations in aqueous form). Coal samples from exploratory drilled holes were taken from coal cores, supplied by a CSG operator, from well fields in the Surat and the Bowen basins in QLD. These samples ranged from dull brown coal (e.g. lignite A) to brighter bituminous coals (e.g. low volatile bituminous). Traditional coal characterisation techniques (proximate analyses, vitrinite reflectance) in combination with solid Nuclear Magnetic Resonance (NMR) were used to characterise these coal samples. Samples were leached using an adaptation of the Toxicity Characteristic Leaching Procedure (TCLP) in order to characterise the compounds that could leach from coal during water-rock interactions. The leachates were analysed using liquid NMR (for its ability to identify organic compounds) as well as GCMS (for its ability to measure actual concentrations). In addition, Triaxial testing was used to simulate leaching under different pressure and temperature conditions; laboratory batch tests were carried out with sodium hypochlorite and benzene, to test THM formation and benzene adsorption respectively. The organic analytes of interest were polyaromatic hydrocarbons (PAH), phenolic compounds, total petroleum hydrocarbons (TPH), total recoverable hydrocarbons (THM), monocyclic aromatic hydrocarbons (MAH), and trihalomethanes (THM).

Results

TCLP test results indicate that both MAHs and PAHs occurred at very low concentrations in solutions leached from coal samples at 20°C. Likewise, the Surat coal samples leached benzene at very low concentrations, while one of the Bowen Basin samples leached benzene at a higher concentration. No detections of TPH or TRH occurred with this leaching procedure. The most commonly detected PAH in this study was naphthalene (leached in 47% of tests) followed by phenanthrene (leached in 28% of tests). Both naphthalene and phenanthrene are PAHs of low molecular weight; conversely, these particular

PAHs exhibit some of the highest water solubilities. Higher ringed PAHs were only detected in 2 Bowen Basin samples: one sample leached 4-5 ring PAHs to deionised water at 20 °C and a second sample leached ultra-trace amounts of 4-5 ring PAHs to synthetic coal seam water at 75 °C. These 4-5 ring PAH compounds included fluoranthene and pyrene, chrysene, benzo(b)fluoranthene, and benzo(a)pyrene. As the concentrations of PAHs leached from the coals were low, little trending became apparent other than the number of instances in which the (more soluble) 2-3 ring PAHs were detected over the (less soluble) 4-6 ring PAHs. Results from the Triaxial tests revealed low concentrations of benzene and xylenes in the resulting leachate product. These detections occurred in the leachate that had percolated through the reconstituted samples; no detections occurred with the recored coal samples.

Leaching of coal samples with sodium hypochlorite induced the formation of THM compounds. This suggests that the use of biocides containing sodium hypochlorite (during drilling or hydraulic fracturing operations) may be a potential source of THM formation. However, dilution effects would result in lower THM concentrations because the majority of these THM compounds would get pumped to the surface as flowback water, along with formation water that has not been in contact with the biocides. In addition, the normal procedure for managing flowback water at the surface is to contain it in specially designed containers or reservoirs, and to transport the flowback water to a wastewater treatment facility.

The benzene absorption experiment showed that sub bituminous coal from the Surat Basin has the capacity to absorb benzene from aqueous solutions. This experiment showed that 100 g of coal will absorb 8.82 µg of benzene from a stock solution having an original concentration of 68.45 µg/L of benzene. This stock solution had elevated benzene concentrations that in no way reflect actual concentrations found in either flowback or coal seam water. The sole purpose of using this concentrated solution was to test the absorption potential of coal, which turned out to be significant (99% absorption at these concentrations). However, the actual absorption of benzene by coal would be less substantial if volatilisation, which took place during this experiment, is taken into account.

The maximum magnitude of benzene detected in this study (e.g. leaching with synthetic coal seam water at T>60°C) is of similar magnitude than the maximum benzene concentration detected in samples from the Bowen Basin. On the other hand, the benzene absorption experiment showed that sub bituminous coal from the Surat Basin has the capacity to absorb benzene from aqueous solutions. This suggests that, at high concentrations, the coal material itself would act as a sink of benzene and other organic compounds. As expected, leaching with sodium hypochlorite induced the formation of THM compounds; this is not surprising as this is a common formation process (e.g. similar processes have been observed at wastewater treatment plants using chlorine as a disinfection agent). In general, more aggressive leaching methods that are not representative of in situ reservoir conditions were required to leach more elevated concentrations of organic compounds from coal. Therefore, these experiments could represent a worst case synthetic-scenario as per the leaching of organic compounds from coal. Further work is required to assess the organic compound concentrations of actual coal seam water samples in the areas from which these coal samples were collected.

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PRECIPITATION AND SOIL ZONE CONTROLS THE HYDROCHEMICAL EVOLUTION OF SOUTHLAND'S GROUND AND SURFACE WATERS

Dr Clint Rissmann[1]
[1]*Environment Southland, Invercargill, New Zealand*

Aims

The Southland region of New Zealand has an area of ca. 34,000 km^2 with complex geology and pedology. Agricultural intensification over recent decades has led to degradation of water quality in streams and aquifers, particularly in terms of nutrients, sediment and microbial pathogens (Snelder et al., 2014). Improved understanding of Southland's coupled groundwater-surface water bodies is required to meet the outcomes sought in the New Zealand's National Policy Statement for Freshwater Management (2014). Accordingly, the aim of this study was to determine the drivers of hydrochemical evolution of Southland's surface and groundwaters with a view to understanding spatial and temporal variability in water quality. This study complements the hydrochemical assessment of Southland's water (Daughney et al., 2015) by adding additional information on the drivers of hydrochemical evolution.

Method

A biogeochemical assessment of Southland precipitation, soil, soil water, surface and ground water was undertaken using a range of approaches including standard hydrochemical, soil biogeochemical and multivariate statistical methods. For this, we employed a chemical dataset comprised of ca. 28,000 ground, surface, precipitation, soil water and soil analyses. Some of the waters were analysed for up to 50 parameters including stable isotopes of boron (δ^{11}B-B), carbon (δ^{13}C-DIC), water (δ^{18}O and δ^{2}H) and nitrate (δ^{15}N and δ^{18}O). Soil chemical data for 600 individual soil profiles was obtained from TopoClimate South.

Results

The results of the chemical assessment reveal that marine aerosolic loadings and soil chemistry are the main determinants over the hydrochemical variation of ground and surface waters regionally. Sodium and Cl are overwhelmingly (90 - 100%) derived from precipitation with significant concentration occurring within the soil zone in response to evapotranspiration. Endogenous or epigenic sources of Cl are negligible and the majority of regional waters show no significant enrichment in Na above a marine aerosolic source. Ca and soil water DIC are controlled primarily by soil base saturation (BS%) that is a factor of the degree of weathering of the soil and its parent materials.

There is little evidence for the evolution of major ion signatures for Southland ground and surface waters after leaving the soil zone with the exception of areas of reactive carbonate rock and strongly reducing aquifers. Carbon isotope equilibria suggest that 60% of the alkalinity within calcite saturated aquifers hosted by marine carbonates is associated with soil zone recharge with the remainder due to water-rock interaction between soil zone carbonic acid and calcite. The other source of post-infiltration evolution occurs in response to heterotrophic oxidation of terminal electron acceptors that generate additional DIC and liberate dissolved Fe and Mn. Both carbonate and reducing aquifers are well defined and subsequent evolution of soil zone recharge is readily accounted for.

In conclusion, robust prediction of the temporal and spatial variation in the hydrochemistry of Southland is possible through combining a strong understanding of the spatial variance in marine aerosolic loadings, soil chemistry and water-rock interaction. Through this integrated understanding we are able to better predict and understand the spatial and temporal controls over water quality outcomes for both N and P species.

PREDICTING SUSPENDED SEDIMENT RATING CURVES

Dr Murray Hicks[1], Dr Dong Wang[1], Dr Sandy Elliot[2]
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Aims

Suspended sediment rating curves capture the relationship between instantaneous suspended sediment concentration (C) and water discharge (Q) in rivers. Since the suspended sediment load (equal to the product of C and Q) is typically dominated by fine-grained, easily suspendable washload, it is supply rather than capacity limited. Thus there tends to be no simple and unique function relating suspended load to local hydraulic characteristics, but rather a correlation emerges between C and Q because both sediment and water runoff from hillslopes are generated quasi-concurrently during hydrological events while supply from some riparian sediment sources (e.g. eroding banks, resuspension and abrasion associated with gravel bed mobilisation) is discharge controlled. A sediment rating curve is therefore a statistical relationship that, ideally, represents the time-averaged C for given values of Q.

Sediment ratings are typically used for determining mean annual sediment load by combining the ratings with discharge records or with flow duration curves. However, they may also be used inversely with discharge records to disaggregate mean annual sediment load into C records, or with flow duration curves to estimate exceedance percentiles for critical levels of C, such as the maximum concentration able to be tolerated by fish species or to meet targets set for water clarity (which is C dependent). Thus, in the context of the latest New Zealand Policy Statement for Freshwater Management and the likely intent to manage sediment related environmental state variables such as C and clarity in impacted waterways by setting limits on time-averaged catchment sediment loads, the ability to predict sediment ratings anywhere in New Zealand is of growing importance.

This paper describes progress on work to develop an empirical suspended sediment rating predictor for New Zealand rivers and streams based on an estimate of mean annual sediment load and catchment physical and hydrological characteristics.

Method

Two alternative empirical approaches are examined: parametric and non-parametric. The parametric approach involves representing the sediment rating by a function with parameters predicted from catchment characteristics using regression-type approaches. The function being tested is a second order polynomial of the form $\log C^* = a (\log Q^*)^2 + b (\log Q^*) + d$. C^* and Q^* are dimensionless concentrations and discharge, respectively, with $Q^* = Q/Q_m$, where Q_m is mean discharge, and $C^* = C/(k\ L/Q_m)$, where L is the mean annual sediment load and k accounts for the number of seconds in a year and unit conversions. This normalisation of C and Q is designed to take preliminary account of the effects of catchment size and overall sediment yield. The C^* and Q^* values are transformed to log units to manage the wide range of values and also homoscedasticity issues in the raw data. While sediment ratings are traditionally represented by simple, two parameter power functions of the form $C = e^a Q^b$ (or $\log C = a + b \log Q$), inspection of the sediment ratings used in the dataset commonly revealed a curved relation in log-log space, hence the use of a three parameter function.

The non-parametric approach aims to independently predict C^* values for a range of reference Q^* values, Q_r^*, thus representing the rating as a series of step-functions that interpolate between the reference Q^* values. Q_r^* values of 0.3, 1, 3, 9, and 27 were used (that is, $0.3Q/Q_m$, Q/Q_m, and so on).

The dataset compiled by Hicks et al (2011) is used to develop the predictive models. This includes suspended sediment gaugings data from some 200 sites scattered around New Zealand and comprises C-Q data pairs acquired during high flow gaugings using depth-integrating suspended sediment samplers at multiple verticals. For the parametric approach, sites were selected that contained at least eight C-Q pairs, showed reasonable data distribution and homoscedasticity across logQ space, and showed an r^2 of at least 0.6 for the parametric model fits. The a, b, and d parameters were fitted to each site's data using non-linear regression techniques within the ‘R’ environment. These parameters were then related to catchment variables using a boosted regression tree approach. For the non-parametric approach, the C_r* values associated with the five Q_r* reference values were interpolated from existing sediment rating curves developed at each site in the dataset by Hicks et al (2011), generally using Locally Weighted Scatterplot Smoothing (LOWESS) fits to the log-transformed C and Q data. The C_r* values were then related to catchment characteristics, again using the boosted regression tree approach.

Catchment characteristics included catchment area, slope, sediment yield, mean annual rainfall, mean annual runoff, mean annual flood, and a variety of other parameters extracted from the database associated with the national river network developed for the River Environment Classification (REC; Snelder and Biggs, 2002).

The boosted regression tree approach requires that predictions must be made within the model development environment, rather than by an explicit function. Thus to transfer the results nationally, the intent is to pre-calculate the sediment rating parameters and/or C_r* values and add them as fields to the REC database.

Preliminary Results

Preliminary results of the boosted regression tree analysis for the non-parametric approach showed generally good performance statistics, with r^2 (indicating proportion of variance in the dataset explained by the model) ranging from 0.88 to 0.96, the root-mean-square error (in log space) ranging from 0.30 to 0.68 (equating to factorial errors of 1.35 to 1.97 in predicted concentration), and Nash–Sutcliffe efficiency (NSE) coefficients ranging from 0.86 to 0.96 (where a NSE value of 1 indicates a perfect model prediction).

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TRACKING THE SOURCES AND PATHWAYS OF GROUNDWATER CONTAMINATION USING SYNTHETIC DNA TRACERS

Dr Liping Pang[1], Ms Beth Robson[1], Miss Lea Gillot[1], Dr Arvind Varsani[2], Dr Kata Farkas[1,2], Mr Phil Abraham[1], Ms Bronwyn Humphries[1]

[1]ESR, Christchurch, New Zealand, [2]University of Canterbury, Christchurch, New Zealand

Background

With an expansion of animal farming and urbanisation in New Zealand, groundwater resources (often used for drinking water) are increasingly exposed to pollution from animal and human faecal wastes. This has resulted in an increased need for investigating the contamination sources and their pathways in groundwater using effective tracing techniques.

Synthetic DNAs can be used as a robust investigation tool for this purpose. DNA tracers are unique, highly sensitive for detection, harmless, and inexpensive. DNA tracers can be reproduced by PCR amplification and sample analysis by qPCR is rapid. Unlimited number of DNA tracers can be designed using random sequence generator software. The use of multiple DNA tracers allows simultaneously identifying and characterising different contamination sources and pathways.

DNA tracers have been applied in field groundwater tracing studies overseas[1-3]. These applications included establishing hydraulic connection between wells and between groundwater-surface water, delineating preferential flow-paths, and identifying contamination sources. DNA tracers were traceable as far as 300 m in karst groundwater.

Method

The previous DNA tracer studies employed single-stranded DNAs, which are less stable than double-stranded DNAs in environmental conditions. In this study, linear, double-stranded 302 base-pair DNAs were used. These synthetic DNAs were developed in a Marsden project for DNA-labelling of virus surrogates (protein-coated silica particles)[4]. Our previous study demonstrated that these DNA tracers were stable and readily detectable in a number of environmental waters, treated domestic effluent, and solutions of stream sediment, beach sand and pumice sand. Compared with previous published DNA tracer studies, our DNA tracers have much lower detection limits.

To examine the usefulness of double-stranded DNA tracers for groundwater investigations, field experiments were conducted with undiluted domestic effluent collected from an oxidation pond. These included a groundwater experiment in an alluvial gravel aquifer at Burnham near Christchurch and lysimeter studies with an intact core of sandy gravel vadose zone media. The groundwater velocity passing through the sampling wells was 60-100 m/day. A non-reactive solute tracer, bromide (Br^-), was also used for validation. In the groundwater experiment, we injected 400 g Br^- but only 36 µg DNA, 8-orders of magnitude less mass than the Br^- tracer.

Results

In the Burnham experiment, DNA concentrations in the last sampling well 37 m down-gradient were still very high with a peak concentration of 3,710 copies/µL, far above the detection limit of 3 copies/µL. Compared to Br^-, the DNA tracer showed slightly earlier breakthrough due to size-exclusion as DNAs are the smallest colloids. DNA mass recovery relative to Br^- was 100% at 12 m, 46% at 21 m and 56% at 37 m. The reduction is probably due to adsorption of DNA to the aquifer media and degradation in groundwater. However the overall transport was quite similar to Br^- (Fig.1).

In the lysimeter studies, transport of DNAs was significantly less dispersive than Br^- (Fig. 2). This is a typical pattern that we have frequently observed for colloid transport in intact soil cores. DNA4 tracer peaked 3.3 times earlier than Br and its mass recovery was 74% of Br. DNA2 tracer peaked 2 times earlier than Br with mass recovery 20% of Br. The normalised peak DNA concentrations were higher than that of Br. These results suggest that DNA tracers were transported largely through preferential flow paths in the intact core, which had a higher permeability than the matrix.

Our field studies suggest that the double-stranded DNA tracers that we have developed are indeed useful for groundwater tracing purposes and characterising preferential flow-paths. We believe that, when multiple DNA tracers are used at the same time, DNA tracer technology can provide the answers to some groundwater contamination problems that the traditional tracers would be unable to resolve. This information obtained could help a development of contamination mitigation strategies.

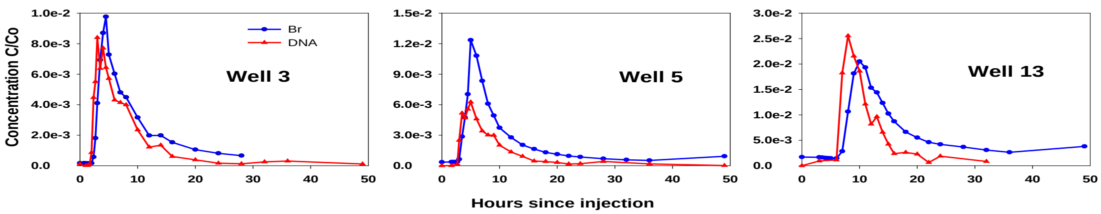

Fig. 1. Field groundwater tracing experiment in alluvial gravel aquifer at Burnham injected with domestic oxidation pond effluent. Well distance from the injection well was 12, 21 and 37 m, respectively.

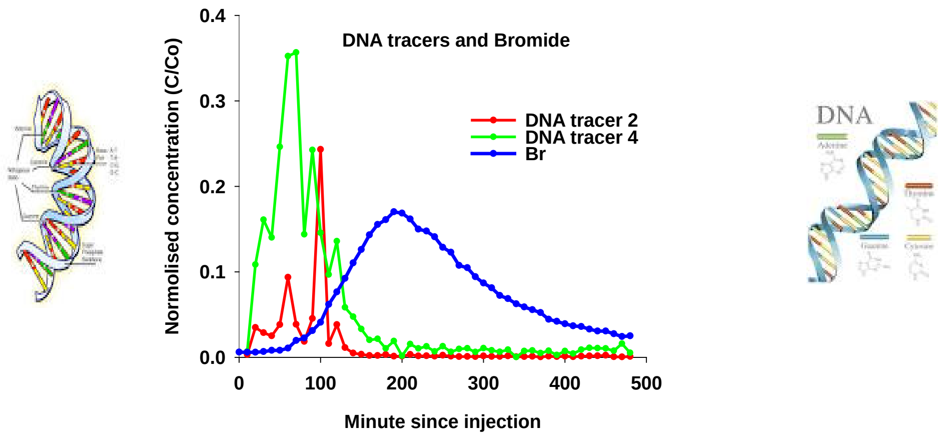

Fig. 2. Field lysimeter study injected with domestic oxidation pond effluent spiked with Br and two different DNA tracers. The intact soil core (0.5 m diameter and 0.7 m long) includes 0.3 m of silt loam and 0.4 m of sandy gravel vadose zone material.

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Thursday, 3rd of December

Session Theme: Collaborative Water Management Start Time: 9:30 a.m.

FROM DATA TO DECISION-MAKING: APPLYING THE DATA-WISDOM CONTINUUM TO COLLABORATIVE FRESHWATER MANAGEMENT

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Introduction

Alongside the National Policy Statement for Freshwater Management 2014 (NPS-FM) comes the requirement for local government to consider adopting collaborative decision-making approaches. As we discussed at the Water Symposium in 2014, this poses a challenge to freshwater scientists: the need for integration of multi-disciplinary technical work into a clearly communicated, risk-based framework that will help communities to make decisions. We outlined how this role for scientists is changing, and how integrators or 'babel fish' can help meet this challenge.

In this context, the ability of water managers and communities to make the hard decisions required for freshwater management is directly influenced by the information to hand. There is an old adage; you can't manage what you can't measure. The NPS-FM recognises the importance of this by requiring councils to have monitoring plans to measure progress towards the achievement of objectives, and to account for all water takes and all sources of contaminants. The National Objectives Framework outlines a values-based process by which water bodies are managed by selecting appropriate attribute states, where an attribute is a measurable characteristic of fresh water. There are also other drivers under the Resource Management Act (s35), regulations for measuring and reporting water takes, and under the Environmental Reporting Bill.

The data-wisdom continuum

The data-wisdom continuum offers some useful insights as to how data, information, knowledge and wisdom contribute to the freshwater management process. Figure 1 represents the relationship between data, information, knowledge and wisdom as a hierarchy; it implies both distillation and transformation at each stage, and is indicative of the scale of each.

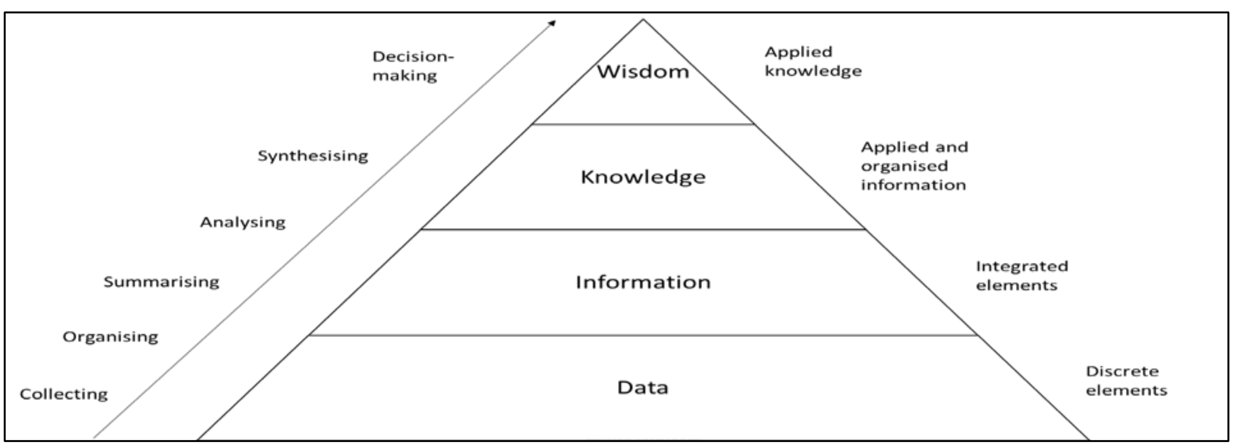

Figure 1. The Data-Information-Knowledge-Wisdom (DIKW) hierarchy (after Ackoff 1989).

Data are a series of discrete elements such as measurements of physical (e.g., channel width, depth, flow), chemical (e.g., nutrients, metals, and other contaminants), and biological (e.g., algal biomass, aquatic plants, invertebrates or fish) characteristics of water bodies. In NPS-FM terms, these characteristics are our attributes.

Information can be defined as a series of integrated elements that have been collated and organised in some way, i.e. the data have been processed so that they become useful. This organisation of data enables questions to be explored, such as: Who, What, Where and When? A database that allows queries to be made is a tool by which data (the individual elements) are organised to produce information.

Knowledge is the appropriate collection of information, with the intent to make it useful. This process is personal, using experience to add structure or interpret the patterns in information we see. Some researchers exploring the DIKW hierarchy distinguish knowledge and understanding. As an example, someone who has learned the times tables by rote can be said to have knowledge, someone who can answer a complex multiplication question to have understanding - as they know how to apply the rules of multiplication. Knowledge (and understanding) enables individuals to explore the questions: How? and Why?

Wisdom is (for most) the final step in the hierarchy, where decisions are best made. Wisdom implies that not just technical understanding will be used, but also moral and ethical judgement, to consider complex questions.

Applying the DIKW hierarchy in collaborative freshwater management

Most of the activities on the left-hand side of the pyramid, with the specific exception of 'decision making', are often carried out by scientists, making use of their scientific skills and knowledge. In collaborative processes a key challenge lies in helping collaborative groups to understand the science journey and build knowledge of their own. In our paper we will outline how the transformations through the stages of the hierarchy help translate data into useful information, and build knowledge and ultimately wisdom within collaborative decision-making groups.

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CO-INNOVATION AND WATER MANAGEMENT: LEARNINGS FROM A CASE STUDY

Dr. M.S. Srinivasan[1], Mr. Graham Elley[1], Ms. Denise Bewsell[2]
[1]NIWA, Christchurch, New Zealand, [2]AgResearch, Lincoln, New Zealand

Aims

This project is designed to explore the innovation system around water management within an irrigation scheme, and to test a co-innovation approach in using current soil conditions and forecast weather information for irrigation scheduling. In most agricultural regions of New Zealand, irrigations can be scheduled around predicted rainfall. However, in the absence of accessible, reliable weather forecast, and the ability to respond to changes in (forecast) weather conditions, irrigation and nutrient applications are seldom scheduled based on rainfall. Often irrigations and nutrient applications are scheduled before significant rainfall events, resulting in the loss of water and nutrients via drainage and runoff. Where supplies are unreliable, irrigations tend to happen even when soil moisture is high and/or rainfall is forecasted.

Method

For this project, a selection of farmers from an irrigation scheme north of Christchurch, is being provided with farm-specific observed data on current (last seven days) rainfall, soil moisture, soil temperature, drainage and evaporation, and region-specific 2-, 6- and 15-day weather forecasts. The compiled data are emailed as easy-to-read graphical plots every day. Based on these data, farmers can make informed irrigation and nutrient application decisions.

Results

Annually, the study farmers, irrigation scheme managers, researchers, and other relevant stakeholders such as the members of local catchment committee, farmers not participating in the pilot study, environmental managers from neighbouring irrigation schemes, research agencies and regulatory authorities meet for a workshop to review rainfall, irrigation and drainage data from each season and discuss the irrigation decisions made during that season. These workshops provide a forum for sharing and discussing management decisions made using data provided and reviewing and refining information provided. The key learnings from these workshops are critical in shaping the on-going study as well as identifying critical data needs, and gaps in the available knowledge among the stakeholders. The proposed talk will present examples of learnings from one of the end-of-the-year workshops.

Session Theme: Flood Management, Start Time: 9:30 a.m.

RAINFALL AND RUNOFF GUIDELINES

Mr John Pfahlert[1]
[1]*Water New Zealand*

Flooding is NZs greatest risk yet there has been no integrated policy guidance for managing flood risks at the local level since the work started by the now disbanded Water and Soil Directorate in 1988. Since that time councils have, with varying success, had to develop flood risk planning separately in the absence of any national standards.
NZRR national standards would assist in achieving universal and effective planning and management outcomes. Many of the communities exposed to flood risk are constrained in terms of knowledge and skills availability, the affordability of flood management techniques, such as flood forecasting, and access to funding for capital works.

Currently there are a number of regional guidelines and methods, as well as informal and in-house approaches to generating flood estimates by rainfall-runoff methods. Each of them can (and has) produce widely varying outputs, even when using the same input data. +/- 50% variation in runoff volume is easily possible.

Benefits of a NZRR would include savings from:

- Consent applications where analyses are undertaken using approved methods, saving the need for extensive justification of method employed and for peer review;
- The development of separate standards across all regions – one set of standards could apply nationally;
- Consistency in results across different methods would lend greater credibility to analyses, resulting in higher confidence in outputs;
- Reduction in Insurance costs as certainty and consistency allows improved infrastructure and reduces insurance premiums;
- Reduction in central government costs to assist communities in recover from floods.

The initiative of development of a NZRR has also been influenced by the Australian Rainfall and Runoff Guide (ARR), which is frequently referred to in NZ, has recently undergone an updating process with extensive research and development being undertaken. The ARR update cost over $10m. It may be possible for the NZRR to benefit from use of the ARR format and protocols but with NZ meteorological data. As the ARR document has been in wide use around NZ, even without locally specific data being available, it is likely that a NZ-specific document of a similar nature would be even more widely used.

John Pfahlert will update the Society of progress in the development of NZRR for New Zealand.

CALIBRATION OF MODELS FOR DESIGN OF FLOOD MITIGATION MEASURES AT KOPU, THAMES

Hugh MacMurray[1], Vicki Henderson[1], Elliot Egan[2]
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Aims

The aim of the work described in this presentation was to develop hydrological and hydraulic models that reproduced historical flood events at Kopu, as a basis for realistic simulation of 10 year and 100 year average recurrence interval storm events, and for design of flood mitigation measures.

Method

The calibration of the models relied on flood level information recorded by residents in the events of June 2002 and January 2004. Photos taken soon after the events showed silt lines on buildings, which were re drawn from the photos on a site visit in 2014, and levelled. Rainfall data came from the Regional Council's recording raingauge at Katinga floodgate, 10km south on the Waihou River, supplemented by daily records (with some additional information about timing of rainfall in major events), taken by a Kopu resident. In the 2002 event, the local raingauge recorded 111mm compared with 114mm at Katinga floodgate. The total rainfall at Kopu was scaled up by 15% to allow for the effect of mounting the raingauge on a high fence, and the Katinga record was used to construct a hyetograph.

The area of the catchment draining to the Kopu South floodgate is 172ha, of which about 30% is hill country, and the remainder is flat land between the Waihou River and the hills. Kopu industrial area, where the flood levels were recorded, lies on the east side of the old railway embankment which bisects the flat land. A Lidar survey of 2007 gave accurate topographical information for definition of subcatchments in the hydrological model, and was also used as the basis for a two dimensional hydraulic model of the floodplain. The details of the highway and railway embankment culverts at the time of the calibration flood events were known from as built drawings and supplementary survey, and were included as one dimensional elements in the hydraulic model.

The hydrological model was built in the HEC HMS software and represents the subcatchments as one or two planes falling to a drainage channel. Flow is routed across the planes and along the drainage channels using the kinematic wave method. The SCS curve number loss method was used, with soil characteristics taken from SMap (a Landcare Research tool).

In the June 2002 flood, the Kirikiri Stream overflowed its banks into the Kopu floodplain. This potentially compromised the calibration and the effect of a range of plausible overflow volumes on the levels in Kopu industrial area was tested in the hydraulic model.

Results

The recorded flood levels in both the 2002 and 2004 events were satisfactorily reproduced. The recorded flood levels showed a significant gradient across the Kopu industrial area, which was also reproduced by the hydraulic model. The hydraulic model showed that there is a significant difference in peak flood level between Kopu industrial area and the Kopu South floodgate, and that the area of low agricultural land south of the floodgate plays an important flood detention role for Kopu. Because the Kirikiri Stream overflow leads directly into this area of low land, it had little effect on the flood levels in Kopu industrial area, and the calibration was not sensitive to this poorly known overflow volume.

The data that was available in this case allowed a reasonably accurate estimate of storm runoff, in an area where regional flood frequency methods (such as McKerchar and Pearson 1989) show a very steep gradient of mean annual flood magnitude.

Conclusion

The simulation of the calibration floods showed that the models accurately represented the hydrological and hydraulic behaviour of the system. In a further stage of the project, the models were changed to represent present day conditions after construction of the new Kopu bridge highway. Design floods were then simulated and drainage upgrade scenarios were tested.

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Session Theme: Monitoring and Data Management Start Time: 9:30 a.m

IMPROVING THE TEMPORAL AND SPATIAL RESOLUTION OF DATA TO INCREASE KNOWLEDGE ON BEDLOAD TRANSPORT IN GRAVEL-BED RIVERS

Mr Andrew Neverman[1], A/Pro Ian Fuller[1], Prof Russell Death[1], Dr Jon Procter[1], Dr Ranvir Singh[1]
[1]*Innovative River Solutions, Massey University, Palmerston North, New Zealand*

Aims

Key to understanding the dynamic nature of gravel-bed rivers is a sound understanding of bedload transport, which is the main determinant of geomorphic change in these fluvial systems. The geomorphic condition of a river sets the template for habitat, conditioning the suitability of a channel system to support flora and fauna. However, despite decades of bedload transport studies, science still struggles to accurately and consistently measure and predict bedload transport events. This has largely been a result of our inability to measure many hydraulic and geomorphic metrics at suitable temporal and spatial resolutions relevant to the initiation of bedload transport. This paper aims to highlight some of the ways in which we can improve the spatial and temporal resolution of hydraulic and geomorphic data to better understand the thresholds conditioning bedload transport initiation. In turn these data can then be used to provide information useful to address the ecological challenge presented by the increasing growth of nuisance periphyton: understanding how substrate stability may be used to control periphyton growth may hold the key to sustainable management of our freshwater resources.

Methods

Previous research on substrate entrainment has lacked accurate quantification of substrate structure in gravel-bed rivers. This has largely been due to a lack of methodologies being available for quantifying structure at sufficient spatial resolutions. To overcome this issue Terrestrial Laser Scanning (TLS) and close-range Structure-from-Motion (SfM) photogrammetry has been used to produce sub-centimeter resolution topographic models (Figure 1). The high resolution point clouds were used to derive a range of metrics, mainly based on using the standard deviation of elevation to quantify surface roughness (Figure 2), which can be used to describe the substrate surface structure.

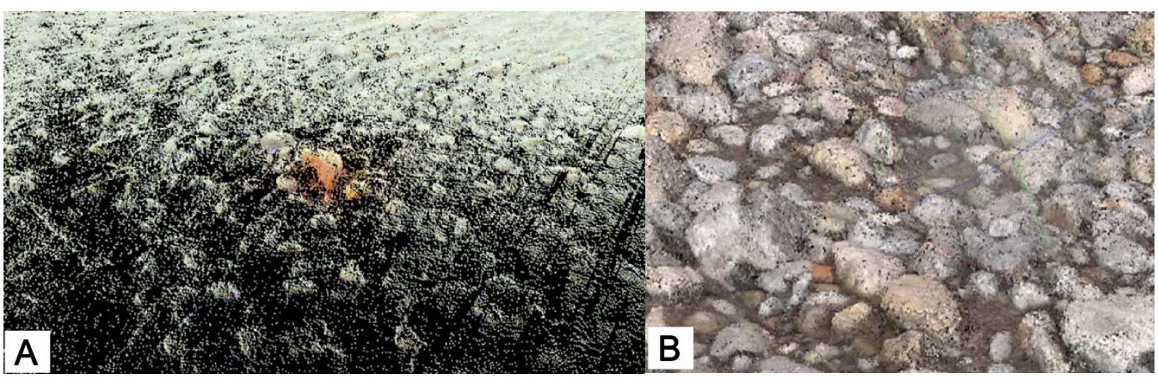

Figure 1. High spatial resolution point clouds generated using TLS (A) and SfM (B).

In order to identify thresholds for bedload transport, it is critical to be able to measure bedload transport at high spatio-temporal resolutions. To achieve this, a novel impact sensor has been developed, based on the swiss-plate geophone (see Turowski and Rickenmann, 2011; Rickenmann *et al.*, 2014), which is suitable for deployment in New Zealand's large, dynamic gravel-bed rivers. This sensor measures bedload transport by recording impacts on a steel plate generated by moving grains. The sensor is records impacts every second, allowing the exact timing of transport initiation to be identified. This can then be correlated with a range of flow metrics, particularly discharge, stage, and velocity, which can also be recorded at high temporal resolutions (Figure 3).

Results and Discussion

Following generation and cleaning of the point clouds, the point clouds were analysed with ToPCAT. This produced a range of metrics derived from the point cloud elevation data to describe the substrate surface. Using the standard deviation of elevation from point clouds has become a popular method for quantifying surface roughness. This offers a significant advantage over the traditional (Wolman, 1954) count as it removes user bias errors associated with the traditional sampling process (Daniels and McCusker, 2010). This method also allows for other metrics such as skew and kurtosis to be derived which may give insights into other aspects of substrate dynamics. The in-situ measurement of the grains accounts for grain burial, which is often not considered in traditional classification of surface roughness.

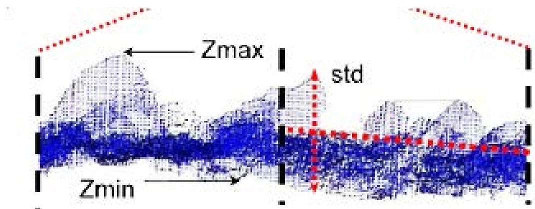

Figure 2. Deriving metrics to describe the substrate surface from point clouds. From Rychkov *et al.* (2012)

The impact sensor has shown promising results, with the sensor identifying the movement of clasts during high flows under mobile bed conditions, and recording no impacts during mean flows under static bed conditions (Figure 3). This suggests that the sensor is not detecting noise produced by the mean discharge.

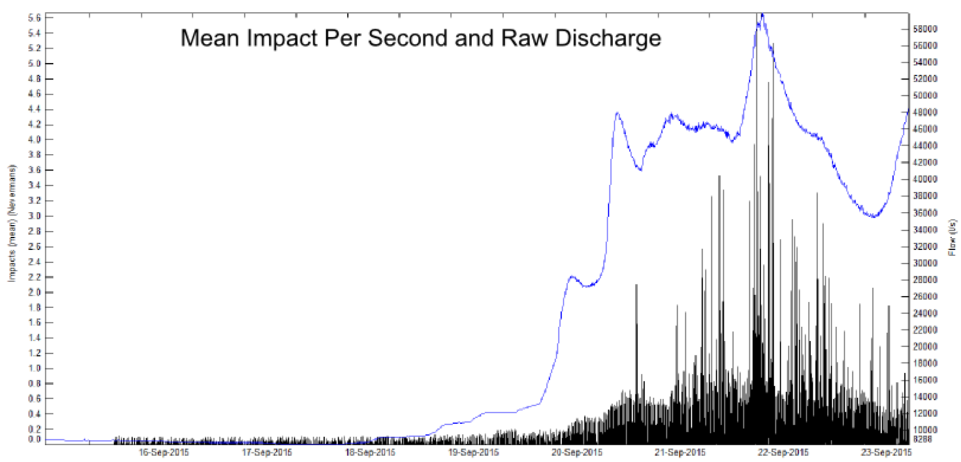

Figure 3. Graph showing the mean impacts recorded per second (black) and their relationship with discharge (blue). Impacts are measured as a 10-bit conversion of the amplitude from the geophone signal (recorded as Nevermans on the prototype sensor).

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IDENTIFYING SMALL-SCALE WETLANDS USING ORTHOPHOTOS, SATELLITE IMAGERY AND LIDAR

Dr Evelyn Uuemaa[1,2], Dr Chris Tanner[2], Dr Sandy Elliott[2], Prof. Ülo Mander[1,3]
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Aims

Wetlands play a key role in controlling flooding and non-point source pollution. In New Zealand, it has been estimated that over 90% of the former wetland area has been lost within a century and a half (Ausseil et al., 2008) and there is an ongoing trend on wetland ecosystems. This increases the need for detailed identification and assessment of wetlands which would also improve our understanding of their ecological functioning. However, the inventory and characterization of wetland habitats are most often limited to small areas or done in a coarse scale (Rapinel et al., 2015). The diversity of wetlands makes it challenging for both the field scientists and the remote sensing analysts to identify and inventory these (Tiner, 2015). Ausseil et al. (2008) performed comprehensive mapping of New Zealand palustrine wetlands, encompassing both the contemporary and historic extent of wetlands. However, the study identified wetlands with a minimum size of 0.5 ha which means that there is not much information about smaller wetlands. The aim of this study is to evaluate the combination of multispectral imagery (Landsat), orthophotos and LiDAR data to precisely map the distribution of small-scale wetland habitats.

Method

Fusion of high resolution orthophotos (0.4 m), Landsat imagery (30 m) and LiDAR based terrain indices (Topographic Wetness Index) were used to identify small-scale wetlands in the Waituna catchment in the Southland region. In addition, field observations were collected at the study site. Two radiometrically and geometrically corrected Landsat 8 images were acquired from December 2013 and August 2014 for multispectral analysis. High resolution orthophotos and topographic indices were used to increase the level of detail. Unsupervised and supervised classification was performed in ENVI 5 and spatial analysis in ArcGIS 10.3.

Results

LANDSAT images alone didn't give good results because of their coarse resolution. Wetlands often also have very complex boundaries and the fusion of multispectral imagery with high resolution orthophotos enabled to delineate wetland boundaries in more detail. In addition, LiDAR provided highly detailed information on the topography. In wetland ecosystems, the soil moisture is strongly correlated with the topography and consequently with vegetation distribution. Classification accuracy was highly improved when combining LiDAR data and multispectral images, enabling to delineate wetlands with the size of 0.1-02 ha.

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STREAM MONITORING BY COMMUNITY GROUPS – GREAT FOR EDUCATION, BUT CAN THE DATA BE USED?

Mr Aslan Wright-Stow[1], Dr Richard Storey[1], Dr Rob Davies-Colley[1]
[1]*NIWA, Silverdale Road, Silverdale, New Zealand*

Aims

Many volunteer groups across New Zealand regularly monitor local streams, and councils are increasingly involving local communities in freshwater planning. Yet data from volunteer groups are rarely used by councils or communities to inform freshwater planning or restoration, apparently because of doubts about data reliability. To test whether volunteers can produce useful stream monitoring data, we conducted a parallel monitoring study involving regional councils paired with volunteer community groups. Start your aims here (10 pt. Arial)

Method

Nine stream sites between Auckland and Nelson were each monitored monthly for water quality and six-monthly for stream invertebrates and physical habitat, over an 18-month period. Volunteers and council field staff took water measurements at the same site within 1-2 hours of each other, and invertebrate samples and habitat assessments within 1-2 days of each other. Volunteer groups used low-cost equipment based on the SHMAK kit (with extensions to include visual clarity and E. coli) while councils used established SoE protocols.

Results

There was moderate to strong concordance between volunteer and council results for most variables, while variables with weaker concordance were still capable of discriminating between “excellent”, “fair” and “poor” conditions. Our study shows that community monitoring could usefully augment regional council monitoring networks, though monitoring groups require on-going support to produce reliable data.

Session Theme: Aquifer Hydrology, Start Time: 11:00 a.m.

HYDROGEOLOGY OF THE TE WAI UNUROA O WAIRAKA SPRING

Mr Sean Berry[1], Mr Zeljko Viljevac[1]
[1]*Soil & Rock Consultants, Auckland, New Zealand*

Introduction

Multiple volcanic aquifers underlie the Auckland Isthmus, many of which represent or have represented important public and industrial water resources. Some of these aquifers feed valued surface water features nested amidst the city's urban sprawl.
So what do you do when you have a spring in your backyard?

The Te Wai Unuroa O Wairaka Spring is located in the middle of the Unitec Mt Albert campus, and despite being written about as early as 1860, little is understood about hydrogeology or the campus, the spring itself, or the evolution of the feature over the last 150 years.

The primary objective of this investigation was to provide a desktop hydrogeologic assessment of groundwater beneath the campus, particularly in relation to the Te Wai Unuroa O Wairaka Spring.

Why? For the best reasons: Tell us what we know; Tell us what we didn't know; Tell us what we still don't know.

Method

The project was divided in three phases:

1. Desktop research (what we know):
   a. Document & report search (Auckland Council, consultant reports)
   b. Bore file records (Auckland Council, NZTA / Well-Connected Alliance)
   c. Non-technical records (Public library, interviews)
2. Conceptualisation (what we didn't know):
   a. Tie it all together
   b. Conceptual groundwater/surface water model for the campus area & basalt aquifer
   c. What does it all mean
3. Gap Analysis (what we still don't know):
   a. Is anything impacting the spring?
   b. What does it mean for the campus community?
   c. How can we know more?

Results

From historic records we knew that the spring was the water source for the "Auckland Lunatic Asylum" from 1874 until c.1915 typhoid outbreak and that the recharge environment has changed significantly over the last 150 years (the development/population of Mt Albert tripled between 1903 and 1910).

We didn't know that flow from the spring has historic summer baseline flows of 8.4 l/s, and that at the height of utilisation this equalled community abstraction. We still don't know what effect upstream urbanisation has had on the physical or environmental health of the feature embedded in both indigenous culture and campus life.

Further assessment work for a more complete understanding of the Te Wai Unuroa O Wairaka Spring:

- How has upstream urbanisation impacted spring capacity?
- Impact of urbanisation on water quality?
- General effects of urbanisation and development on groundwater levels in basalt?

SUPPORTING GROUNDWATER MODEL OPTIMIZATION WITH HIGHLY PARAMETERIZED SIMULATION OF LAND SURFACE RECHARGE

Dr Fouad Alkhaier[1], Mr Hisham Zarour[1], Mr Zeb Etheridge[1]
[1]*Environment Canterbury, Christchurch, New Zealand*

Aims

PEST (Model-Independent Parameter Estimation) is a powerful tool for calibrating groundwater models and estimating the optimum spatially distributed parameters within a groundwater model domain. Recharge to the saturated zone is one of the major parameters in the process of calibration. Using reasonable starting values and upper and lower limits (hereafter referred to as initial and constraining values) is essential for the efficient performance of PEST. One method of assigning these three values is to choose roughly estimated spatially uniform values throughout the model domain and let PEST find the amplitude and spatial distribution of recharge.

However, recharge is not usually the sole parameter that PEST tries to estimate. The spatial distribution of hydraulic conductivity is also a key parameter in the calibration process. Calibrating for these two spatially variable parameters (i.e. recharge and hydraulic conductivity) simultaneously bears the risk of non-uniqueness in the solution and leaves huge uncertainty in the estimated values. Providing PEST with reasonable spatially distributed estimates of the initial and constraining values for recharge removes a significant part of uncertainty in the calibration output.

Method

We used a highly parameterized simulation of the water flow in the unsaturated zone within an integrated hydrological platform (MIKESHE) that covers the groundwater model domain (Figure 1). The inputs to this simulation were:

- Records of daily rainfall and potential evapotranspiration from NIWA's virtual climate stations in the model domain for the period 1972-2015.
- Soil map (Landcare research) with estimated possible ranges of soil hydraulic properties.
- Land cover/vegetation map (Landcare research) and the related root zone depth and leaf area index.
- Irrigation command areas with information on the related sources of water (wells information and the consents for water abstraction, Environment Canterbury).

Using these input data, MIKE SHE calculates the unsaturated water flow in the finely discretised soil profile by solving Richards equation. It calculates infiltration to the soil profile, actual evapotranspiration from soil and plants and soil moisture deficit, and it triggers irrigation when needed. The output was a set of spatially distributed recharge values with a good level of confidence.

We ran the model for three scenarios that produce the minimum, mean and maximum recharge values. These three scenarios are achieved by varying the soil hydraulic properties (mainly hydraulic conductivity) within their potential ranges. For each of the scenarios, we calculated the average recharge to the saturated zone over the simulation period (1972-2015).

Results

The three output maps of recharge then serve as initial and constraining values for recharge in PEST. All three maps presented reasonable amplitudes of recharge and took into account its spatial variability within the model domain. Soil types distribution and their related hydraulic conductivities are imbedded in these maps. The spatial distribution of rain and evapotranspiration and the applied irrigation was clear in the output maps as well.

Uncertainty in these maps remains, as there is always uncertainty in all the input data (Figure 1). However, using this method to define a space within which PEST can estimate the optimum recharge values is valuable because it leads the optimization software to find a solution that conform with the physical setup of the model domain.

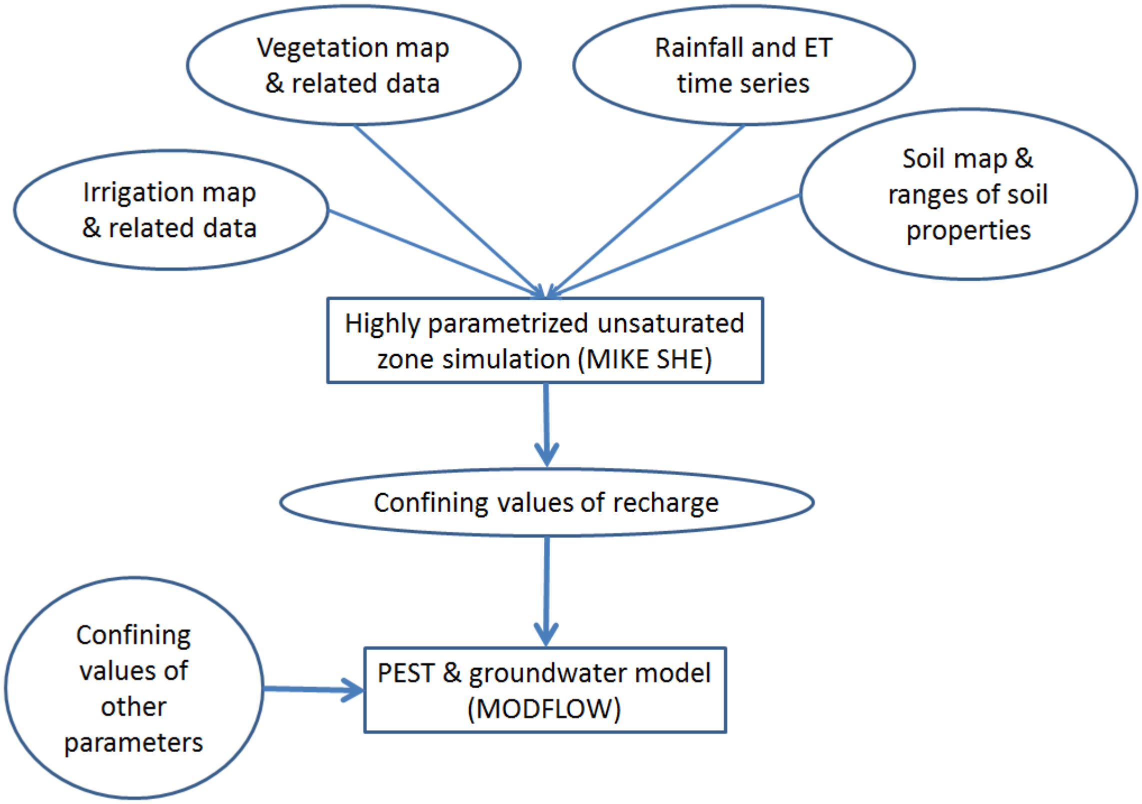

Figure 1, Method of supporting PEST with initial and constraining values produced by MIKE SHE.

INVESTIGATION OF OFFSHORE COASTAL DISCHARGE IN THE WAIMAKARIRI ZONE, CANTERBURY

Mr Zeb Etheridge[1], Dr Fouad Alkhaier[1]
[1]*Environment Canterbury, , New Zealand*

Environment Canterbury is developing a groundwater model for Waimakariri Zone to investigate the impacts of a range of nitrogen load and management scenarios on groundwater and groundwater-dependent surface water quality. One of the questions the model needs to address is the fate of nitrogen loads discharged to groundwater in the inland catchment, and in particular whether further intensification here is likely to exacerbate water quality issues in the spring-fed stream system which discharges close to the coast.

The rate of offshore flow in the coastal zone is one of the key areas of uncertainty for the model. If offshore flow rates were relatively low, nitrogen loads from the inland catchment would be more likely to discharge to the spring-fed stream system. Conversely, a high rate of offshore flow could mean that inland nitrogen discharges will be transported offshore, and the potential for adverse effects on surface water quality would be much lower. The question of offshore flow rates is also highly relevant for groundwater allocation considerations.

Dodson et. al. (2012) estimated offshore flow based on the residual of a water budget assessment. The mean recharge to groundwater in the Waimakariri zone was estimated at 17 m^3/s. Outflows were estimated at 1.6 m^3/s of abstraction and 7 m^3/s of discharge to the lowland streams and spring system. The balance of 8.2 m^3/s (approximately 50% of the total outflow budget) was assumed to discharge offshore. This estimate was slightly lower than the 10 m^3/s estimate provided in Talbot (1980). The latter was based on a numerical modelling study, although the data available to constrain the model parameters at that time were limited. A water budget analysis undertaken by PDP (1993) estimated offshore groundwater discharge at 2.9 – 3.5 m^3/s.

Brown and Weeber (1992) provide a conceptual cross section of the hydrostratigraphy of the aquifer system near Christchurch (Figure 1). The model suggests that the Riccarton Gravel aquifer extends approximately 40 km offshore, outcropping in the seabed at around 50 m depth. The underlying gravel units are considered to pinch-out offshore, with vertical leakage being the predominant means for any ocean discharge from these strata. We used Brown and Weeber's conceptual model as the starting point for this study, and interrogated a range of data (much of which has been gathered since the cross section was developed) to investigate the extent to which it holds true in the Waimakariri zone.

The geology of Pegasus bay has been a subject of particular research interest since the 2010 and 2011 Canterbury earthquakes. We used information provided by geophysical investigations of seabed geological structure to test the current conceptualisation of the coastal aquifer system. We also evaluated groundwater level data and chemistry data to test the hypothesis that offshore discharge occurs predominantly through the Riccarton Gravel.

Environment Canterbury log groundwater levels at a range of depths close to the coast. In particular there are two locations where water levels are logged at three different depths at a similar distance from the coast. We explored the use of analytical modelling tools to extract coastal zone aquifer parameters from tidal responses recorded in these coastal wells.

We used coastal aquifer parameter estimates in combination with hydraulic gradient data and our conceptual understanding of the coastal aquifer system to provide a revised estimate of coastal discharge rates.

The study shows how tidal response data can be used to parameterise coastal zone aquifers, the data requirements for such studies and level of certainty with which the groundwater level data translates into knowledge of coastal discharge rates.

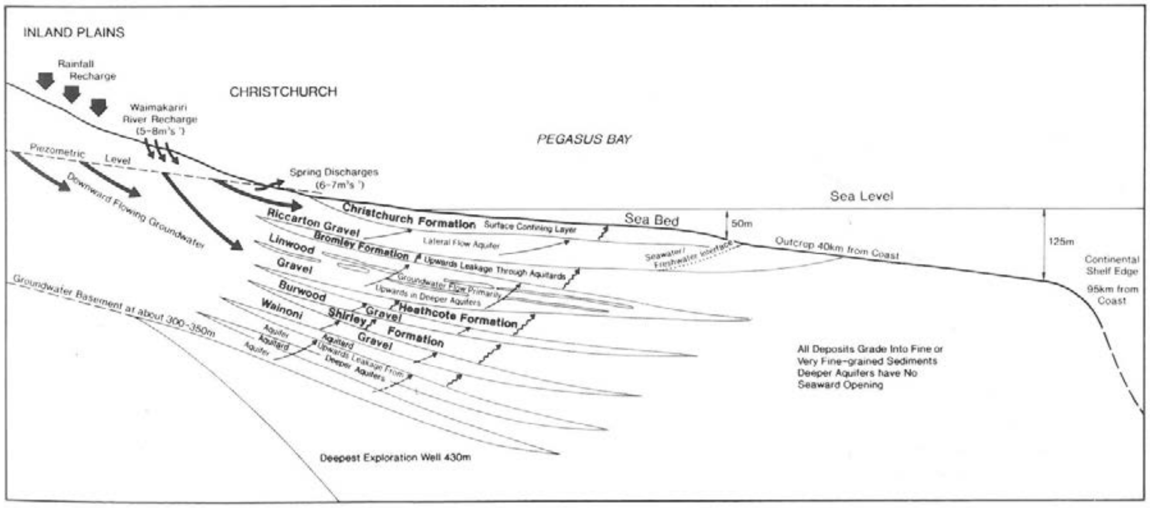

Figure 13 Cross section of Pleistocene stratigraphy beneath northern Canterbury plains near Christchurch (from Brown and Weeber, 1992)

References

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Session Theme: Collaborative Water Management, Start Time: 11:00 a.m.

KA TU TE TANIWHA – KA ORA TE TANGATA: UNDERSTANDING THE IMPACTS OF DEVELOPMENT ON FRESHWATER RESOURCES

Miss Abigail Lovett[1], Miss Gina Mohi[2], Diane Harvey[3], Diane Bradshaw[1]
[1]GNS Science, Taupo, New Zealand, [2]Ngati Rangiwewehi, Ngongotaha, New Zealand, [3]Bay of Plenty Regional Council, Whakatane, New Zealand

Background

Ngāti Rangiwewehi, GNS Science, and Bay of Plenty Regional Council (BOPRC) are researching mātauranga and scientific knowledge associated with Taniwha Springs (Pekehaua) and the Awahou Stream, Lake Rotorua. The Awahou catchment is located in Ngāti Rangiwewehi tribal rohe, and contains springs (puna) of high significance to the iwi. The main springs are currently utilised by Rotorua District Council for town water supply with a consent that expires in 2018. This Vision Mātauranga (VM) project was established in 2014 and is jointly funded by MBIE, GNS Science, Ngāti Rangiwewehi and BOPRC.

Mātauranga Māori can be defined as 'the knowledge, comprehension, or understanding of everything visible and invisible existing in the universe', and is often underpinned by whakapapa and tīkanga. In the contemporary world, the definition is usually extended to include present–day, scientific systems of knowledge that interface with the goals, aspirations and issues from an indigenous perspective. This project acknowledges the contribution of local expertise to western science and sustainable environmental management, which will be incorporated into resource management plans and land use. This model of indigenous knowledge and western science collaboration is useful for both mitigation and management of freshwater resources at a national scale.

Aims

The objective of the Ka Tu Te Taniwha – Ka Ora Te Tangata project is to understand the impacts of development in the Awahou groundwater catchment to ensure the health and wellbeing of the Ngati Rangiwewehi people. The aims of the project are to: 1) combine technical, scientific and Matauranga-a-iwi information for the Awahou groundwater catchment into an integrated data repository and knowledge resource; and 2) allow Ngati Rangiwewehi to incorporate traditional knowledge and understanding of cultural significance to inform and plan for future freshwater development in the Awahou catchment.

Method

The following four stages we designed to meet the objectives of the project:

- History of use: summarise the ownership, resource consenting and land use history of the Awahou catchment;
- Scientific repository: compile relevant scientific information (e.g. datasets, reports) for the Awahou catchment and Taniwha Springs;
- Matauranga-a-iwi: collate traditional and cultural knowledge from tangata whenua;
- Knowledge integration: combine mātauranga, scientific data and historical information to act as a tool for future decision making.

Results

A report completed in July 2015 detailed historic information including land use maps from 1840 – 2012 and a timeline of events from 1910 – 2015 (Ngati Rangiwewehi, 2015). Maps of the Awahou catchment indicate considerable conversion from indigenous forest and scrub to exotic forestry and grassland, meanwhile urban expansion is minimal and occurs mostly around the lake edge. The historic timeline details events from 1910 when the Puna o Pekehaua Reserve was formed to 2014 when the Treaty of Waitangi Deed of Settlement was signed. The Scientific Repository has been populated with datasets including: stream flow records, groundwater quality, and water age dating; and a summer low flow gauging program has been planned for the Awahou Catchment for March 2016 to increase understanding of the hydrology in the catchment. Additional plans for the project include development of a web-based portal for presentation and dissemination of scientific and mātauranga information (Kmoch *et al.*, 2015), and facilitations of an interactive learning workshop with the wider Ngati Rangiwewehi iwi.

References

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A NEW AND BETTER WAY OF DOING ENVIRONMENTAL TREND ANALYSES?

Mr Graham McBride[1], Dr Ton Snelder[2], Dr Scott Larned[3], Mr Martin Unwin[3]
[1]NIWA, Hillcrest, Hamilton, New Zealand, [2]Land and Water People, Lyttelton, New Zealand, [3]NIWA, Christchurch, New Zealand

We advocate new two-step trend assessment procedures in which we first consider whether we have enough data to confidently infer the trend direction. If we can, the second step asks “What can we say about the trend’s environmental significance?” If we can’t, extra sampling effort may be called for. These procedures have recently been used in a nation-wide water quality assessment.

Note that traditional single-step trend analyses (e.g., for a water quality variable) are applied to contentions such as “There is no change in the variable’s mean over time”. That hypothesis is assumed to be true and is only rejected if data are sufficiently convincing (e.g., if the test’s P-value < 0.05). If P is not so small all we can say is that the hypothesis is not “not rejected”; it can’t be “accepted”. If rejection occurs a “statistically significant” trend is claimed. But note therein that “trend” is not defined. We choose to define it as <u>any</u> change over time, no matter how small (everything changes over time). Consequently, the first step of our proposal abandons the traditional approach and instead addresses the question: “Have we got enough data to confidently infer the trend direction?” If the answer is “yes” we can move to the second step. The first step is objective, in that all investigators using the same data and methodology will reach the same conclusion (about the trend direction). Options for the second step will be addressed, in the context of a recently-completed nation-wide study of trends in river water quality. We also address better methods for handling censored data (such as “less than” results).

COMPARING THE OLD AND THE NEW

<table>
<tr><td colspan="2">***Fundamental notion***: There is always a trend, however “small” (everything changes over time)</td></tr>
<tr><td>***<u>Traditional way</u>***
A one-step procedure:
1. Hypothesis addressed: slope = zero</td><td>***<u>A new and better way?</u>***
A two-step procedure:
(1) Question addressed: Is slope +ve or –ve?
(2) If direction inferred, consider *environmental significance* of the trend</td></tr>
<tr><td><u>What can be inferred?</u>
Reject hypothesis?
• If “yes”, claim “*statistically significant* trend”
• If “no”, can’t claim “*statistical significance*”
– Logical error to accept hypothesis</td><td><u>What can be inferred?</u>
Can we confidently detect trend direction?
• If “yes”, then consider trend magnitude
• If “no”, “there are not enough data to tell”
– Worthwhile collecting more?</td></tr>
</table>

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18 MONTHS IN A LEAKY BOAT – LESSONS FROM CROSSING THE WAITAKI

Ms Helen Shaw[1], Mr Nic Newman[1]
[1]*Environment Canterbury, Christchurch, New Zealand*

Launching the boat – How many ECan staff does it take to cross the Waitaki?

In 2013, Environment Canterbury (ECan) commenced the development of a 'sub-regional plan' in the Waitaki catchment. The intent was to use the collaborative environment set up through the Canterbury Water Management Strategy (CWMS) to drive decision making, and ultimately to link this with the Waitaki chapter of the Canterbury Land and Water Regional Plan. This would involve the development of recommended water quality limits, through the intersection of science and community.

A multi-disciplinary team from the CWMS, Science and Planning sections of ECan joined forces. Figure 1 illustrates the many technical workstreams that provided information to the community and the planning team. Over a period of eighteen months, the teams worked with the community to develop an understanding of the current state, and the likely implications of future aspirational development. Zone Committee 'outcomes' were used as the reference point when looking at the acceptability of different biophysical, cultural, economic and social effects.

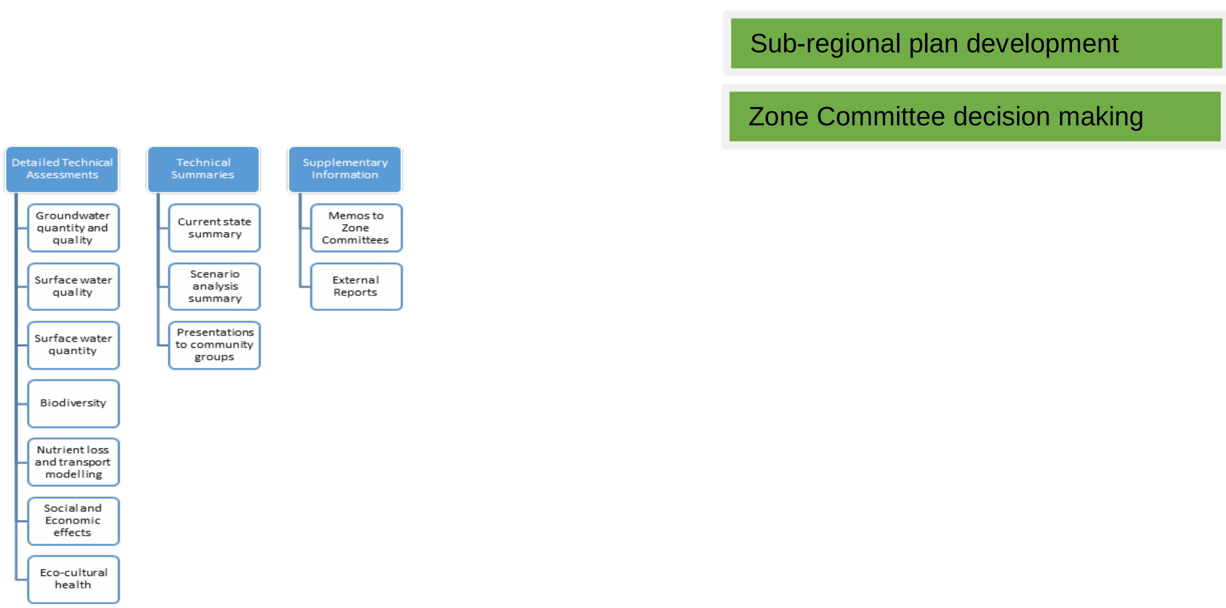

Figure 1: Technical work streams

We've sprung a leak!

There have been numerous historical issues with water management in the Waitaki catchment. Many of the residents had just come out of (or were still in) long consenting processes, and were emerging with highly complex sets of consent conditions. Coupled with this, a number of community members expressed concern that ECan had not been vigilant enough in terms of ensuring consent and RMA compliance with some existing land users. We had considerable work to do before even conversations could be had about data and outcomes – let alone shared knowledge.

Repairing the boat

Throughout the course of the project, we met with a large number of people in the community, in several different environments. These included public meetings, one-on-ones, drop-in days, and focus groups.

We had some complex information to relay; modelled data estimating nutrient losses from land use, and transport through groundwater and surface water systems; discussions on lag times; results from lake hydrodynamic modelling; the flow-on effects of water management on economic, societal and cultural values. Figure 2 illustrates one of our attempts to present complex data in a community-friendly manner.

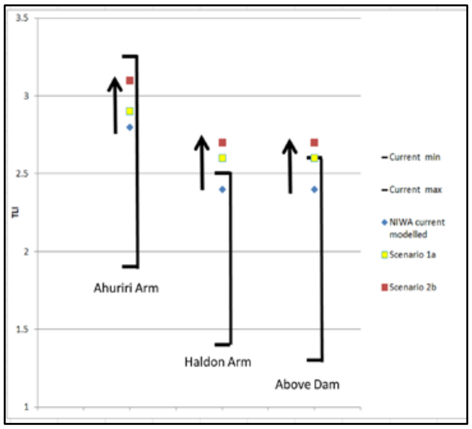

Figure 2: Predictions of TLI levels in Lake Benmore

There are a number of critical factors that the Waitaki team feel have contributed significantly to the project resulting in a community consensus on water quality limits and the development of a shared knowledge.

- Get to know the community – individual visits to locals were a breakthrough
- Get the locals to 'ground truth' the information - these people live here, they know a lot more than we do about a lot of things!
- Be honest about uncertainty and the shared implications of this
- Integrate the data into the community's reality
- Aim for shared understanding, leading to joint responsibility for the outcomes

Safely reaching the other side

From data to knowledge – how do we measure success? Figure 2 below provides our interpretation of the pathway across the 'river'. From the perspective of the ECan, team, we feel that the project has been a success because:

- The community made decisions based on the shared knowledge developed, and ended up standing behind the knowledge when challenged
- Most of the locals are still talking to us (and still asking questions!).

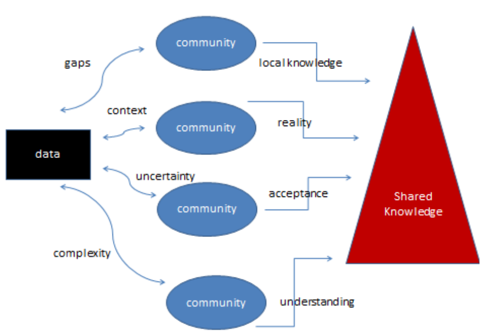

Figure 2: Knowledge is a function of data and community

Where to from here?

The project is not limited to plan development only. With the establishment of 'Zone Implementation Teams' in each of the CWMS zones, ECan staff are continuing to work in the community to implement the 'on-the-ground' recommendations made by the zone committee. These teams involve Land Management Advisors, Monitoring and Compliance Officers, and Biodiversity staff.

Session Theme: Monitoring and Data Management, Start Time: 11:00 a.m.

TOWARDS AN INTERACTIVE INTERNET-ENABLED MODFLOW MODEL FOR THE OHAU AND WAIKAWA CATCHMENT'S, HOROWHENUA

Mr Alexander Kmoch[1], Ms Ioana Gherasimescu[2], Mr Paul White[1], Mrs Abby Matthews[3], Dr Hermann Klug[2]
[1]GNS Science, Taupo, New Zealand, [2]Paris-Lodron University of Salzburg, Interfaculty Department of Geoinformatics (Z_GIS), Salzburg, Austria, [3]Horizons Regional Council, , New Zealand

Aims

Characterisation of a hydrogeological setting is a multi-faceted complex task. The unobstructed availability, access and quality of relevant data is a major challenge. Analysis and visual exploration of the datasets demand practical support by computer applications. Although a variety of software for this purpose is freely available nowadays, they require a good understanding of the technology or programming language for application in complex hydrogeological settings. Thus, integrated proprietary software products are often used to analyse and particularly provide high-quality visualisation of the system (White et al., 2010). However, these software tools are typically desktop programs with a strict licensing scheme, limited extensibility and lack of interoperability with other applications.

We present an open and free-to-use web-based (platform independent) framework to enable retrieval, exploration and visualisation of hydro-climate time series data as well as three-dimensional geological information via a web browser. The geological and water budget assessments for the Horowhenua area in southern Manawatu-Wanganui region serves as a reference to build an internet-enabled interactive groundwater model based on MODFLOW and to show how distributed data and processing services can be linked to prepare an on-demand analysis and exploration of hydrogeological data (Klug and Kmoch, 2014). A flexible toolbox design enables extensibility via open standards (Castronova et al., 2013).

Method

Typical web map viewing applications display 2D representations of geospatial groundwater data layers via OGC-compliant Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS) layers from remote servers (figure 1) and graphs for hydrological measurement data from Sensor Observation Services (SOS) (Klug and Kmoch, 2014). Typically data from SOS servers are represented and grouped by their sampling locations, i.e. sensor stations. Locations are printed on a web map and time-series data for available phenomena are then requested and graphed. To visualise the spatio-temporal distribution, level and flow of groundwater, observations and feature (rainfall, well and river flow measurements, aquifer properties, geology) data and are exposed to an OGC Web Processing Services (WPS) and thus can be integrated into web based modelling systems (Castronova et al., 2013). WPS allows distributed and chained processing in the web. Thus, computing power can be extended into the cloud, i.e. multiple instances run in parallel on different servers in the internet within a controlled and secured workspace and the ability to dynamically allocate or de-allocate computing resources. This concept has also been addressed as Service Oriented Architecture (Klug and Kmoch, 2015) to connect web-based spatial data provisioning and web processing services.

Results

The authors developed a web-based framework for access, visualisation and analysis of hydrogeological data to support the characterisation of the Ohau and Waikawa groundwater aquifers. This framework provides functionality for discovery and data access and is implemented and demonstrated within the SMART groundwater portal. As foundational principles the standardisation efforts of the Open Geospatial Consortium (OGC)[1] and World Wide Web Consortium (W3C)[2] are leveraged to make hydrogeological data and models accessible and lift the execution, analysis and visualization processes into the web and

[1] Open Geospatial Consortium, http://www.opengeospatial.org/standards
[2] World Wide Web Consortium, http://www.w3.org

to make it independent of vendor- and platform-specific data access, processing and visualization boundaries. This enhances the SMART portal towards an interactive collaboration environment.

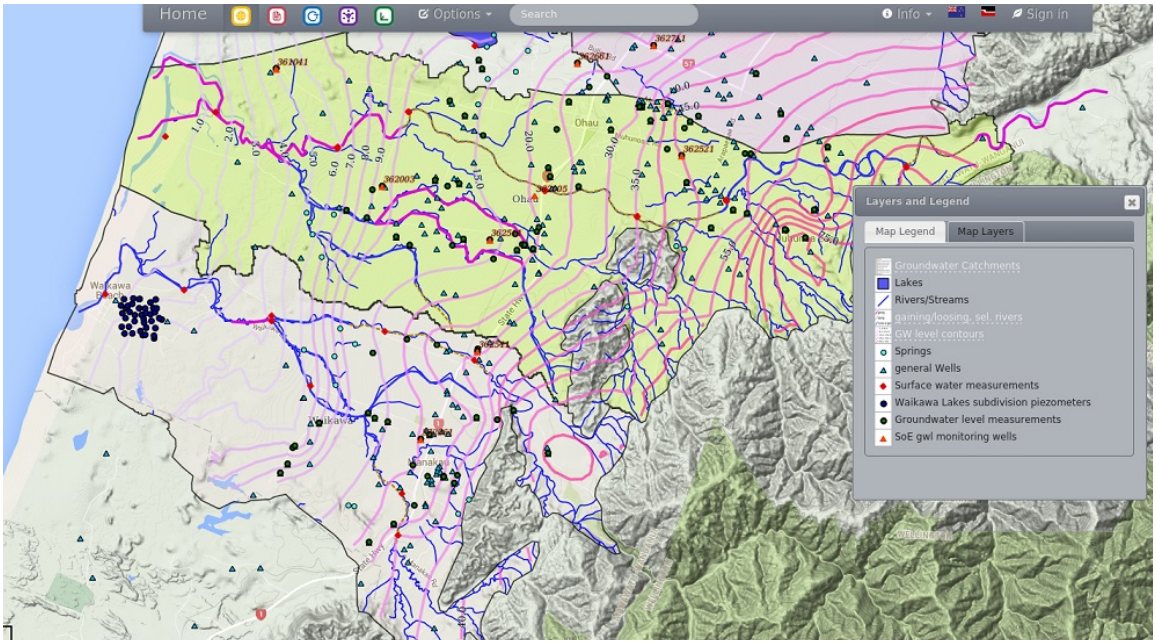

Figure 1: A web mapping view on the hydrogeological datasets for the MODFLOW model for the Ohau and Waikawa catchments, Horowhenua

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NZ GROUNDWATERS STATE AND TREND UPDATE FOR THE 2004-2013 PERIOD

Ms Magali Moreau[1], Carl Howarth[2], Chris Daughney[1]
[1]GNS Science, Wairakei, New Zealand, [2]Ministry for the Environment, , New Zealand

The Environmental Reporting Bill currently before Parliament proposes a new framework for regular, national environmental reporting on air, atmosphere and climate, land, fresh water and marine environments. This paper focuses on groundwater quality state and trends for the 2004–2013 period, which informed the 2015 Environmental Synthesis Report. It updates the assessment reported for the 1995–2008 period (Daughney and Randall 2009).

Data from the National Groundwater Monitoring Programme (NGMP) was collected for the period 2004–2013. Following quality assurance procedures, trend analysis was performed on the cleaned dataset on selected parameters (nitrate-nitrogen, ammonium-nitrogen, dissolved reactive phosphorous, dissolved iron and dissolved manganese, total dissolved solids content and electrical conductivity). State was reported using descriptive statistics and non-parametric statistical tests were used to assess statistical significance of a trend, seasonality and distributional difference. Minimum data requirements and time period selection were also investigated.

Statistically, significant trends were detected in a portion of the sites, and both increases and decreases were observed. The Ministry for the Environment and Statistics New Zealand intend to publish *Environment Aotearoa 2015* and *Environmental indicators Te taiao Aotearoa* on 21 October 2015. Detailed findings and associated data will be available from this date. Regular updates on national groundwater quality can help to identify important changes in groundwater quality in New Zealand.

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UNCERTAINTY ANALYSIS OF STAGE-DISCHARGE RATING CURVES: COMPARISON OF TWO DISTINCT APPROACHES

Dr Jérôme Le Coz[1], Dr Hilary McMillan[2], Dr Ida Westerberg[3], Dr Benjamin Renard[1]
[1]Irstea, Hydrology-Hydraulics, Lyon-Villeurbanne, France, [2]NIWA, Hydrological Processes, Christchurch, New Zealand, [3]IVL Swedish Environmental Research Institute, Stockholm, Sweden

Aims

Most of streamflow records are established using stage-discharge rating curves but uncertainty analysis methods are still lacking or not fully satisfactory. In recent years, a number of approaches have been developed by different research groups, and there is a need to better understand the differences between them. For the sake of comparison and mutual improvements, we have applied our two methods, namely BaRatin (Le Coz et al. 2014) and the Voting Point Method (VPM, McMillan & Westerberg 2015), to two New Zealand gauging stations with contrasted characteristics. Both methods produce probabilistic rating curve samples from which any statistics can be derived, so their results are directly comparable.

Methods

BaRatin is a Bayesian approach where prior knowledge on hydraulic controls is combined with the information contents of gaugings coming with their individual uncertainties. Based on common equations for hydraulic structures and open-channel flows the user sets the number and nature of controls, and prior values and uncertainties for the parameters of the rating curve model, including breakpoints. Bayes theorem is then applied to compute the posterior pdf which is sampled using a MCMC simulation technique. The resulting parameter values can be interpreted physically and checked. The total uncertainty combines a parametric component (related to parameter estimation) and a structural component (related to rating curve model inaccuracy). In its current version, BaRatin assumes that the stage-discharge relation is constant over time.

The Voting Point Method (VPM) is based on a likelihood function that accounts for random measurement errors and epistemic errors caused by incomplete knowledge of the true stage-discharge relation. Whilst the hydraulic basis is not explicit, several segments can be modelled using a piecewise combination of power functions. The VPM particularly intends to quantify the epistemic uncertainty that arises from changes in the controls over time. The Voting Point likelihood is defined in relation to the fraction of time that a particular rating curve could have been representative of the channel conditions. It is based on the weighted sum of the number of gaugings intersected by a given rating curve (within the 95% limits of uncertainty). Thus the temporal representativeness of the gauging data is reflected in the estimated uncertainty. A MCMC simulation technique is eventually used to produce rating curve samples.

Application sites

The Mahurangi at College station (North Island of New Zealand, catchment area 50 km^2) is operated by Auckland Regional Council. An artificial structure offers a stable, multi-segment stage-discharge relation with known breakpoints. The station is equipped with a V-notch nested within a wider triangular weir that rises into confining wooded banks. The VPM was applied using a three-segment model following the official rating curve. Based on a cross-section survey of the weir, main channel and forested floodplain, a five-segment model was defined prior to the BaRatin analysis. A number of gaugings are available over a wide range of stages, but the highest flows require extrapolation. One outlying gauging was discarded after indication of adverse measuring conditions by the station manager. Several high-flow gaugings are affected by large stage uncertainties due to varying flow during the streamgauging operations.

The Wairau at Barnett's Bank (South Island of New Zealand, catchment area 3430 km^2) is operated by NIWA Nelson. The station is located in a very unstable, braided river reach impacted by gravel mining activities and flood control measures such as the creation of a flood diversion channel (in 1963) and erodible embankments (since 2009) in the bifurcation downstream of the gauge (Christensen & Doscher 2010). Little data is available on the natural controls, a shingle-made riffle and the channel. The stage-discharge relation was densely gauged over the whole range of stage, with a few old gaugings suggesting that the upper end of the relation remained quite stable. However, low-flow shifts are severe and show clear temporal trends.

Results

Both methods were applied to both sites using the same uncertainties of gauged stages and flows as estimated by McMillan & Westerberg (2015). Both methods are recognised to be sensitive to the prior parameter intervals and the assumptions behind the error models. In this comparison exercise, the default options of each method were selected. Fig. 1 compares the results obtained for the Mahurangi. In spite of the different numbers of segments assumed, the shape and breakpoints of the obtained rating curves are similar. However, unlike the VPM and official rating curves, the BaRatin curves go more through the few high-flow gaugings which results in slightly lower rated high flows. Most of the high-flow gaugings show a pronounced stage variability, which was ignored in the presented analysis, and likely accounted for in the official rating. The positions of the high-flow points measured at the peak or during the rising and falling limbs of the flood are typical of a hysteresis effect. Both methods should capture this epistemic uncertainty about the high-flow rating according to their distinct principles.

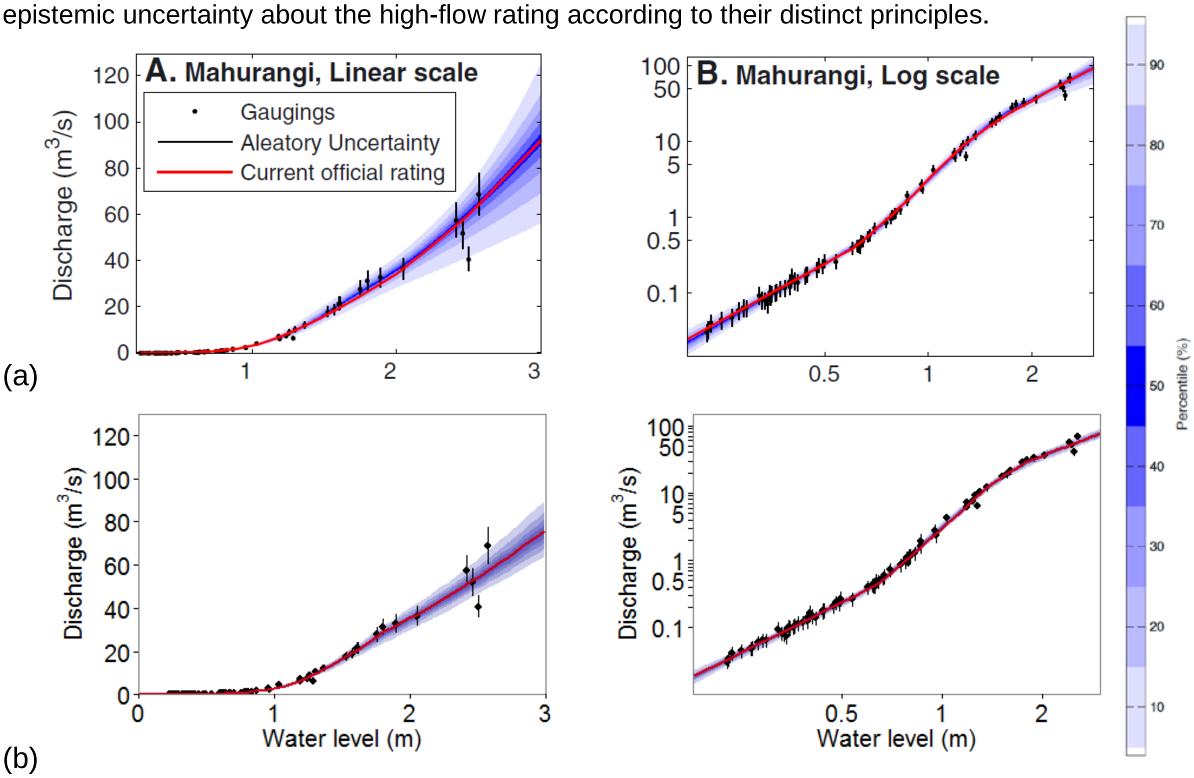

Figure 1 Results of the application of the VPM (a) and BaRatin (b) to the Mahurangi at College: gaugings with 95% uncertainty bars, computed rating curves and rating curve sample quantiles.

The VPM and BaRatin methods both claim to provide the total uncertainty of a rating curve through a large number of rating curve samples, or 'spaghetti' in BaRatin terminology. It is then straightforward to compare the uncertainty results in terms of rating curve sample quantiles (see colour bands in Fig. 1). At least the outer bounds of the uncertainty computed by BaRatin are narrower than those computed by the VPM. This is arguably expectable since additional information is provided through the priors, based on the available hydraulic knowledge. The differences induced by the two methods on basic flow statistics and signatures were also investigated. Perspectives include managing rating shifts with BaRatin (and possibly the VPM). A broader international comparison of methods for assessing rating curve uncertainties is in progress where seven methods will be compared using joint study cases.

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Session Theme: Aquifer Hydrology, Start Time: 1:40 p.m.

THE CANTERBURY PLAINS AQUIFER – A SINGLE AQUIFER

Mr Carl Hanson[1]
[1]*Environment Canterbury*

The Canterbury Plains, located on the east side of the South Island of New Zealand, overlie a thick sequence of gravelly sediments that were deposited by braided rivers flowing out of the Southern Alps. Groundwater within these sediments is widely used for domestic and community supply, irrigation, stock water and industry. The groundwater system is generally described as a set of multiple, layered aquifers separated by aquitards or aquicludes. I submit that this terminology is misleading and unhelpful, and that the groundwater system beneath the Canterbury Plains is a single aquifer.

The sediments that form the plains were deposited in a dynamic, high-energy terrestrial environment. They are strongly anisotropic and heterogeneous. The depositional environment did not allow the formation of laterally extensive layers of fine sediments that could become aquitards or aquicludes.

Broad layering does occur in the northern part of the plains along the coast, including the Christchurch area, where sea level fluctuations have resulted in layers of fine sands, silts and organic material alternating with the coarser alluvial gravels. However, the layers are irregular and discontinuous, and the fine sediments, particularly the sands, are still capable of transmitting substantial volumes of water, even if they are less permeable than the gravels.

Farther inland and to the south, it is very difficult to distinguish layers in the sediments. Bores do encounter varying yields at different depths, and in some cases these depth intervals can be correlated between bores to identify laterally extensive zones of similar yield. However, bore logs show no clear distinction between the sediments in the different zones that would indicate a strongly layered structure, and it is not clear that zones of low well yield inhibit the vertical flow of groundwater across them.

On the contrary, groundwater chemistry data show a strong component of vertical flow beneath the Canterbury Plains. Nitrate contamination from the land surface extends to substantial depths, over 100 meters below the water table in some areas. Within the layered area near the coast in the north, oxygen isotope data and major ion chemistry have shown that water from deep in the aquifer flows upward across the layers.

The evidence, therefore, does not support the presence of multiple, separate aquifers beneath the Canterbury Plains. The groundwater system is better described as a single aquifer. The aquifer is unconfined and heterogeneous, and it has an anisotropy that strongly favors sub-horizontal groundwater flow, parallel to the braided river channels that deposited the sediments. However, the anisotropy does not prevent vertical flow.

From a management perspective, the description of the groundwater system as multiple, separate aquifers is misleading. It suggests that the aquifers could be managed separately, and that a stress on one aquifer would not affect another aquifer. This is not the case. Pumping from anywhere beneath the Canterbury Plains will eventually affect the rest of the groundwater system. Short-term pumping from a single deep well may not have a measureable effect on an adjacent shallow well or stream, but cumulative effects will propagate across the aquifer in the longer term. Contaminants from the land surface migrate to great depths, and there are no aquitards or aquicludes that prevent this.

The groundwater system beneath the Canterbury Plains behaves as a single aquifer, and it should therefore be described as a single aquifer.

PREDICTING HYDRAULIC PROPERTIES THROUGH MEASURMENT OF SPECTRAL INDUCED POLARIZATION (SIP)

Dr Malcolm Ingham[1], Sheen Joseph[1], Dr Gideon Gouws[1]
[1]*Victoria University of Wellington, New Zealand*

Introduction

Theory predicts that the permeability of an aquifer material should be related to the predominant grain diameter (e.g. Revil & Glover, 1997). It can also be derived that the relaxation time associated with polarization processes taking place in the electrical double layer that forms at the boundaries of pores is similarly dependent on grain size (Revil & Florsch, 2010). This leads to the implication that measurements of relaxation time through the frequency dependence of the electrical conductivity of an unconsolidated material may be used as a proxy for measurement of permeability. Such measurements are normally referred to as spectral induced polarization (SIP). Here we present the results of laboratory measurements that demonstrate that SIP measurements may indeed be used to predict the permeability of sands typical of those found in many New Zealand coastal aquifers.

Methods

The procedure for laboratory measurements has previously been described by Joseph et al. (2015) who also demonstrated that the relaxation time associated with the polarization processes measured by SIP is independent of the pore fluid conductivity. In the present study the permeability and SIP response of samples of sands of different grain sizes has been measured, along with the permeability and electrical formation factor.

Results

Typical measurements of the SIP response are shown in Figure 1. The phase peak is a result of the frequency dependence of surface conduction that takes place in the electrical double layer as a result of charge separation induced by the applied electric field. At low frequencies the

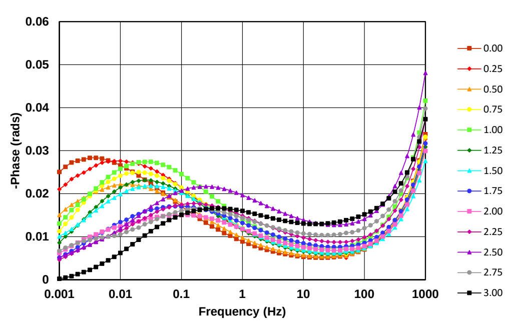

Figure 1: Example of measurements of SIP phase for sands of different grain size as indicated by the Krumbein number.

conduction process is able to readily respond to the applied field and the phase lag of the response is small. With increasing frequency there is an increasing time lag in the conductive response with a concomitant increase in phase. At sufficiently high frequency the phase decreases again as conduction can no longer respond to the rapidly changing field direction. It can be seen from Figure 1 that the characteristic low frequency peak in the phase response occurs at progressively lower frequencies as the grain size increases (Krumbein number decreases). Modelling of such curves using a Cole-Cole model (Cole & Cole, 1941) allows the relaxation time (τ_{CC}) to be determined and theoretical relationships such as

$$k = A\frac{\tau_{CC} D_i}{4m^2 F(F-1)^2} \qquad (1)$$

which predicts the permeability from τ_{CC} , the formation factor (*F*), the cementation exponent (*m*) and the ionic diffusion coefficient (D_i), to be tested. *A* is a simple multiplicative constant arising from approximations made in the theoretical developments. Figure 2 shows how measured values of permeability compare to values predicted by equation (1) with a best fitting value of *A* of 2.49.

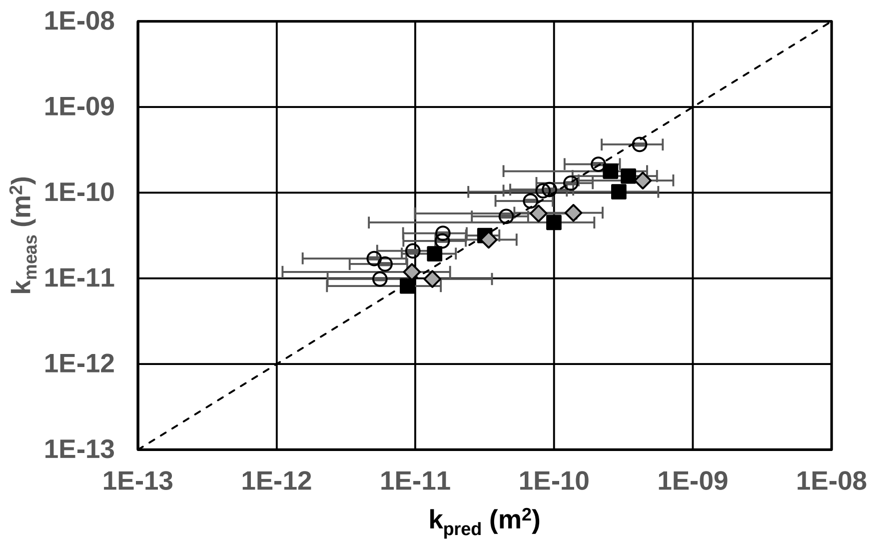

Figure 2: Comparison of measured permeability and permeability predicted by equation (1) for samples in this study, with a value of the multiplicative constant of 2.49.

Summary

Laboratory measurements conclusively demonstrate a relationship between SIP measurements and permeability for sands typical of New Zealand coastal aquifers. It is clear that field SIP measurements may be a viable geophysical proxy for hydraulic properties. If logistical challenges involved in such measurements can be overcome this will allow the measurement of permeability cheaply and over wide spatial areas.

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HYDROGEOLOGICAL EFFECTS IN CENTRAL NEW ZEALAND FROM LARGE (M>5.8)

Mr Konrad Weaver[1], Dr Simon Cox[2], C Holden[3], Associate Professor John Townend[1]
[1]School of Geography, Environment and Earth Sciences, Victoria University of Wellington, Wellington, New Zealand, [2]GNS Science, Dunedin, New Zealand, [3]GNS Science , Lower Hutt,

Aims

Earthquake-induced hydrogeological responses vary temporally and spatially, with differing polarity, magnitude and durability (Wang and Manga, 2010). We aim to constrain the importance of seismic (static and dynamic) and hydrogeological properties as factors in observed responses, as well as the degree to which permanent and transient responses have occurred in Wellington and Marlborough. Responses in groundwater level and stream flow to the following earthquakes are studied: Fiordland M7.2 (2003), Hastings M5.9 (2008), Dusky Sound M7.8 (2009), Darfield M7.1 (2010), Christchurch M6.2 (2011), Seddon M6.5 (2013), Grassmere M6.6 (2013), and Eketahuna M6.2 (2014).

Method

Importance of seismic and hydrological properties

Classification of groundwater level responses allows spatial and discrete examination of other hydrogeological and seismological variables. Responses in Wellington and Marlborough were classified (cf. Cox et al. 2012) based on the temporal change of polarity and magnitude of groundwater level hydrographs during co-seismic and post-seismic periods. Changes occurred at 55 sites, with a maximum offset of 85 cm induced by the Seddon earthquake. Perturbations are dependent in part on the intensity of shaking but also on the local geological setting.

Local shaking parameters in Central New Zealand, characterized by 235 strong-motion accelerometers of the national network have been calculated for each earthquake: Peak Ground Velocity (PGV), Peak Ground Acceleration (PGA), Arias intensity and frequency composition. Thus far, PGA ranges from 0.001g to 0.25g throughout the region.

In on-going work, Principle Component Analysis (PCA) will be used to determine which properties induce the largest variation in responses: depth, aquifer, material properties, screen length, degree of confinement, PGA, PGV, Arias intensity and frequency composition (Jolliffe, 2002).

Permanent and transient aquifer responses

Recession flow analysis uses the component of groundwater seepage to determine hydrogeological parameters in earthquake hydrology (Manga, 2001). Four variables (cf. Manga 2001) were estimated for 272 stream sites; baseflow dominance, minimum recession period of 60 days, comparable magnitude of discharge, and $R^2 \geq 0.8$. A secondary analysis relied on an average time series over several years. Hydraulic diffusivity was derived from recession constants and a simplified 1D aquifer model (Wang and Manga, 2010). By comparing before and after earthquake time-series, we found no significant alteration in hydraulic diffusivity. Such results are thought to indicate minimal permanent or long-term, large scale aquifer changes.

In hydrologically confined media, earth tides induce a poroelastic response which gives insight into crustal strain and the formation surrounding the well (Rojstaczer and Agnew, 1989). During trials and code development, distinct tidal signals were recognized in ~10% of Canterbury monitoring wells. We plan to apply the method to assess aquifer properties and earthquake effects in 107 wells in Wellington and Marlborough. Fourier transforms of the M_2 and O_1 waveforms will be derived and BK_u (B = Skempton coefficient, K_u = undrained bulk modulus) will be estimated using hydraulic coupling, volumetric strain and pressure change. Time evolving amplitude and phase will be calculated for wells with BK_u values representative of aquifer properties (~25 GPa) (Wang, 2000), using theoretical tidal dilatations and observed pressure variation. Temporal transmissivity and specific storage will be deduced from the amplitude and phase, and compared to seismic events. For wells where there are clear tidal responses, it should be possible to define any places where earthquakes induced significant change in flow, in proximity to the well.

Results

The assessment utilises 15 years of hydrological data and eight recent large (M>5.8) seismic events at near to far-field distances (30-800 km), with Modified Mercalli shaking intensities of I-VII (unnoticeable-severe) (Figure 1). It appears that observed groundwater level changes (<1 m), that were both transient (<1 hour) and persistent (weeks-months), mostly reflect stress and strain induced pressure changes imposed by these earthquakes, rather than large-scale aquifer-damage or changes to hydrogeology. Future PCA analysis will help to constrain the main factors that affect groundwater pressure fluctuations and aquifer damage.

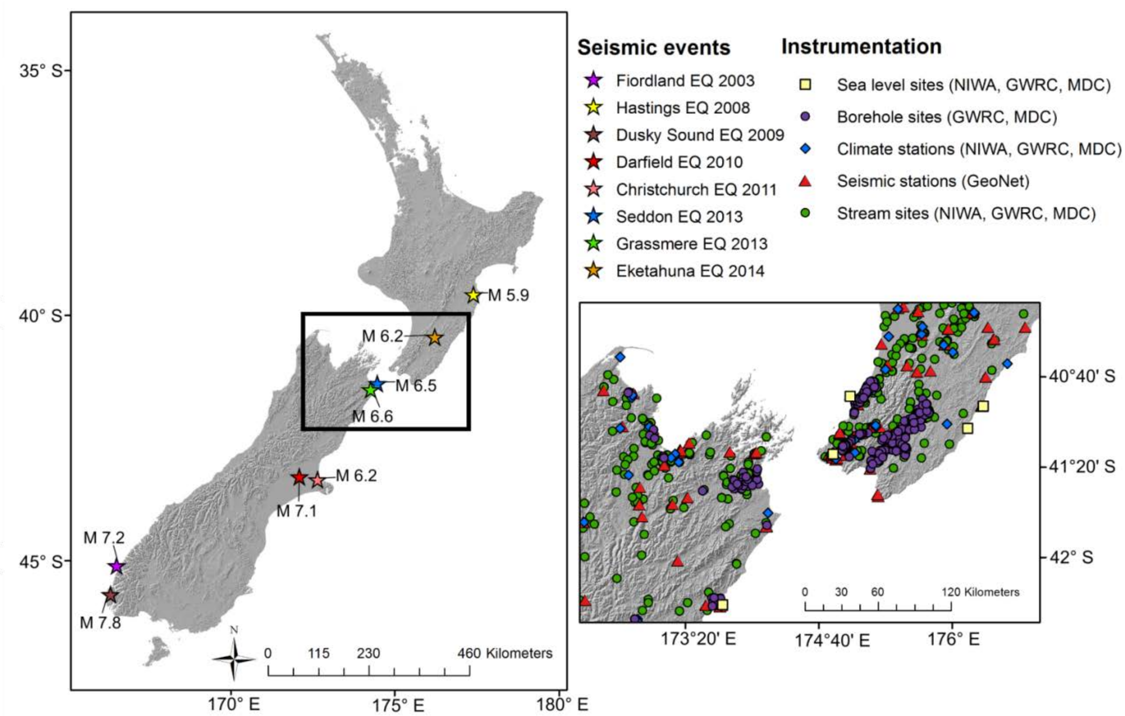

Figure 1 – (Left) Distribution of recent large magnitude earthquakes in New Zealand. **(Right)** Distribution of seismological and hydrological monitoring sites in Central New Zealand. NIWA = The National Institute of Water and Atmospheric Research. GWRC = Greater Wellington Regional Council. MDC = Marlborough District Council.

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Acknowledgements: We wish to thank Greater Wellington Regional Council (Sheree Tidswell and Doug Mzila), Marlborough District Council (Peter Davidson and Mike Ede), The National Institute of Water and Atmospheric Research (Kathy Walters) and GeoNet for the collection and provision of outstanding monitoring datasets used in this study.

LONG-TERM HYDROGEOLOGICAL EFFECTS ON THE CANTERBURY PLAINS AQUIFER SYSTEM FROM THE DARFIELD 2010 EARTHQUAKE

Dr Helen Rutter[1], Dr Simon Cox[2]
[1]Aqualinc Research Ltd, ChCh, New Zealand, [2]GNS, Dunedin, New Zealand

Aims
A number of wells across mid-Canterbury have shown a sustained rise in water levels since the Mw7.1 Darfield earthquake on 4 September 2010, some exceeding previous record high levels. This paper examines long-term (>3 year) changes that might have occurred in the aquifer system.

Method
To provide an overview of these changes, we derived mean piezometric levels from all available groundwater level data over the period three years before (pre-) versus the three years after (post-) this earthquake, then carried out statistical assessment of these data. Any wells with less than 10 months of post-earthquake data were removed from the assessment. The spatial pattern described above included all wells, at depths from a few metres to over 300 m. T tests were carried out to examine the significance of the differences in these data.

Results
When changes were examined with respect to well depth, within 10 km of the fault line, we found only 44% (12/27) of the shallow (<40 m depth) wells had a statistically significant difference in groundwater levels before versus after the earthquake, with the mean rise being 1.0 m. Deeper wells (>40 m depth) had a much greater proportion that showed significant changes (76% or 26/34), with an average rise in water level of 7.8 m. Figure 1 shows the distribution of sustained changes for > 40 m deep wells, overlain on a coloured grid of this change (using a natural neighbours interpolation in ArcGIS). The figure illustrates the north-east to south-west orientation of sustained high groundwater levels along the upper, north-western edge of the Canterbury plains, from approximately 20 km north east of the Greendale Fault to 30 km south west. The style of the response varied between wells, with the increase in mean piezometric level for the most part caused by either: (i) an increase in the rate of groundwater level recovery after the September earthquake in 2010, (ii) a lack of a recession following the event, (iii) an offset or (iv) some combination of these.
As the changes in ground elevation were between one- and two- orders of magnitude smaller that the changes in mean groundwater level, and were centred about the western end of the newly ruptured Greendale Fault, the fault offset alone cannot account for the observed spatial pattern in groundwater change.
The reasons for the increase in water level are being explored in a separate study, through examination of pre- and post-earthquake aquifer testing and comparison with static and dynamic shaking. Increases appear to be at least in part, due to a decrease in transmissivity, possibly as a result of re-sorting of sediment, with fine-grained sediment being moved into the open framework gravels (OFGs) and consequent and clogging, re-sorting of the gravel clasts within the OFGs, or truncation of these higher permeability flow paths. The analysis suggests that aquifer deformation and dynamic shaking only account for part of the response. The scale of the response may also be in part a reflection of the position in the groundwater catchment, with greater responses occurring at the head of the Canterbury plains.

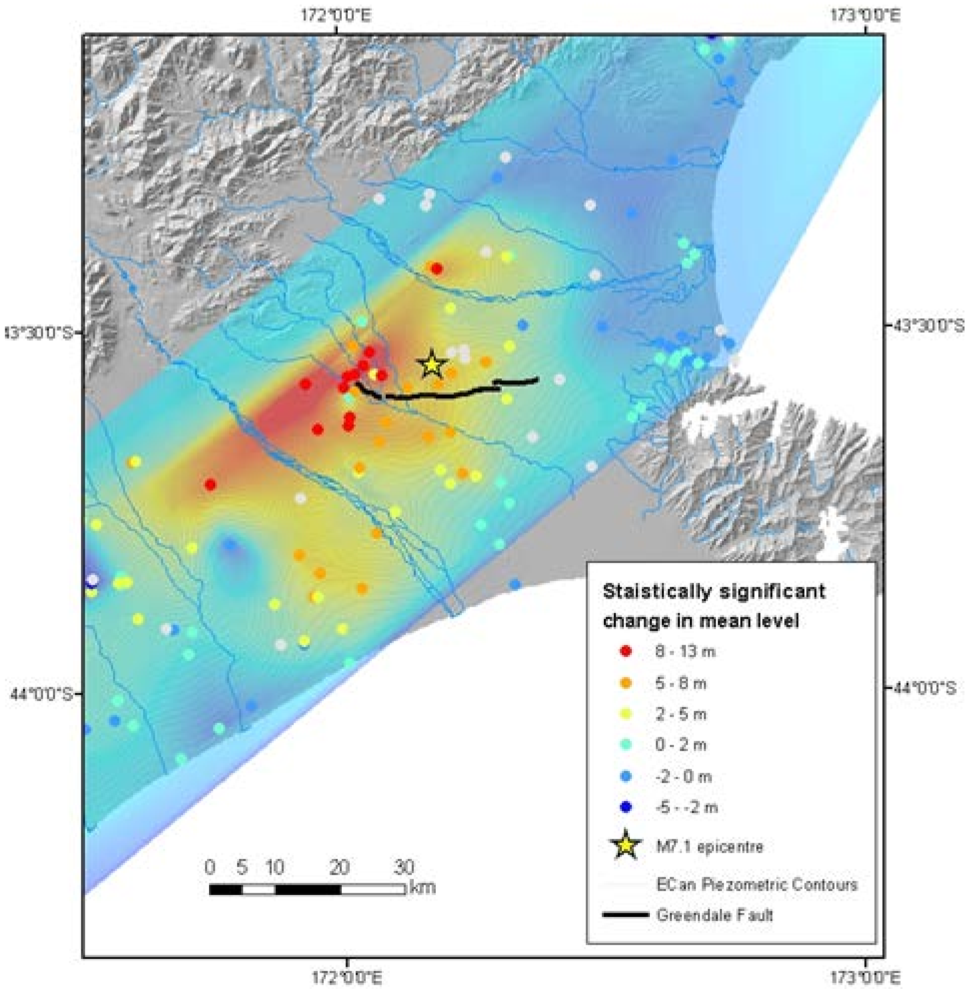

Figure 1 Distribution of sustained changes for > 40 m deep wells

STEP TESTING TO ASSESS CHANGES IN AQUIFER PROPERTIES AS A RESULT OF THE DARFIELD 2010 EARTHQUAKE

Dr Helen Rutter[1], Dr Simon Cox[3], Dr Nick Dudley Ward[2], Mr Julian Weir[1]
[1]Aqualinc Research Ltd, Christchurch, New Zealand, [2]University of Canterbury, Christchurch, New Zealand, [3]GNS Science, Dunedin, New Zealand

Aim

The Mw 7.1 Darfield (Canterbury) earthquake on 4 September 2010 generated widespread hydrological effects ranging from instantaneous changes of groundwater levels in wells, to more sustained (days to weeks) post-seismic changes in spring flow, river discharge and groundwater levels, as well as increased turbidity of water abstracted from wells. In the weeks after the earthquake, it was reported that numerous wells appeared to have declined yields. Five years on from the September earthquake, piezometric levels in deep aquifers (40 m or more depth) in an area around the Greendale Fault are still elevated, and pumping drawdown in some wells is still greater than pre-earthquake. Analytical (eigen) modelling was used to test whether the sustained high water levels were a real change after the earthquake, or whether they were due to changes in abstraction or land surface recharge. The modelling suggested there was a sustained rise in piezometric levels that couldn't be attributed to recharge and/or abstraction (see Figure 1).

Method

The only previous work that attempted to assess aquifer changes through aquifer test analysis was by Jang et al (2008). They used short time period, constant rate tests to assess changes in aquifer properties, and concluded that there were a combination of effects, including a decrease in storativity, and either an increase or decrease in transmissivity, depending on location. For our study in Canterbury, step drawdown testing was carried out in seven wells to try to determine whether the increased drawdown that had been observed in pumping wells was related to a change in aquifer properties, or effects close to the well. Other approaches, including changing the parameterisation of the Canterbury groundwater flow model (Weir, 2007), have been used in conjunction with the step drawdown testing, to assess whether the evidence as a whole suggests there are changes in aquifer properties.

Results

Clear differences in the yield-drawdown relationship occur in four wells, with potential changes in the different components of head losses from before, to after, the September 2010 earthquake. We had less confidence in other test analyses, which had high degrees of uncertainty, because of difficulties in obtaining unique results. The inability to obtain unique results appears to be the case often, when transmissivities and turbulent well losses are high, due to the difficulty in separating the components of drawdown in the pumped well.

For wells for which we have confidence in the analyses, the results suggest that sustained high groundwater levels and reduced well performance in the wells are due to both a change in aquifer properties, and a decrease in well efficiency. Testing suggests there are possibly different issues occurring at different locations, but that there is likely to be some reduction in permeability, and some increase in turbulent well losses, at most locations. This is hypothesised to be a result of a decrease in permeability of the high permeability open framework gravels, possibly due to fine-grained material being introduced into the gravel lenses during the earthquake, or due to some degree of re-packing of the clasts. Truncation of the lenses may also decrease the overall permeability of the sediments which would account for the increased piezometric levels, but wouldn't be expected to result in higher well losses.

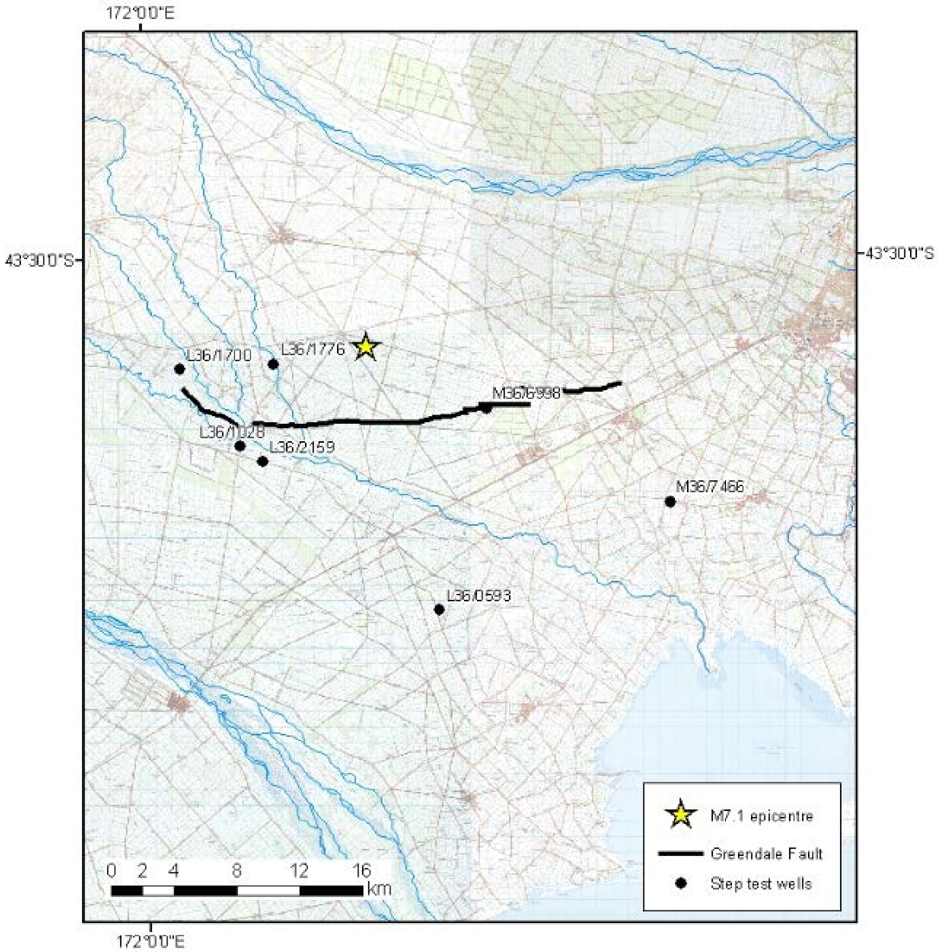

Figure 1. Locations of wells tested

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Session Theme: Collaborative Water Management, Start Time: 1:40 p.m.

WATER WHEEL DIAGRAMS - ONLINE

Dr Tim Kerr[1], Mr Julian Weir[1], Dr Caroline Fraser[1], Dr Andrew Fenemor[2], Dr Ton Snelder[3], Dr John Bright[1]
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Background

Collaborative community water planning groups have a myriad of conflicting issues to consider when formulating water management proposals. Filtering the information to a level that is comprehensible to a non-expert is a requirement for these groups to make informed decisions.

Aims

The aim of the research described in this presentation was to provide a simple accessible method of displaying catchment attributes in a coherent manner that reflects the acceptability of an attributes quantity.

Method

Through community group selection of catchment values, attributes that represent those values, and acceptability criteria of those attributes, simple quality graded bar graphs were provided for each attribute. These graphs provided a display of the attributes that are important to the community group, and on a scale that matches the community groups' measure of acceptability. By presenting the bar graph in a circle (called a Water Wheel diagram) the biasing by edge effect of traditional bar graphs was lost, and the concept of attribute opposition was more easily perceived. Through on-line presentation of the Water Wheel diagram together with descriptions of values, attributes, and attribute acceptance criteria, the community group was able to ensure transparency in formulating their water management proposals.

Results

Values, attributes and attribute acceptance criteria were selected by the Takaka Freshwater and Land Advisory Group, tasked with formulating proposals for water management in the Takaka Valley. This information was combined into an on-line Water Wheel diagram (see Figure 1 below). Estimates of attributes were prepared for a number of different water management scenarios as a way of understanding how the catchment hydrology worked and to assist with selection of water management proposals.

The Water Wheel diagram provided a snap-shot view of the state of the catchment for the status quo scenario, and an indication of what value attributes are likely to change and whether they will get better or worse under different water management scenarios.

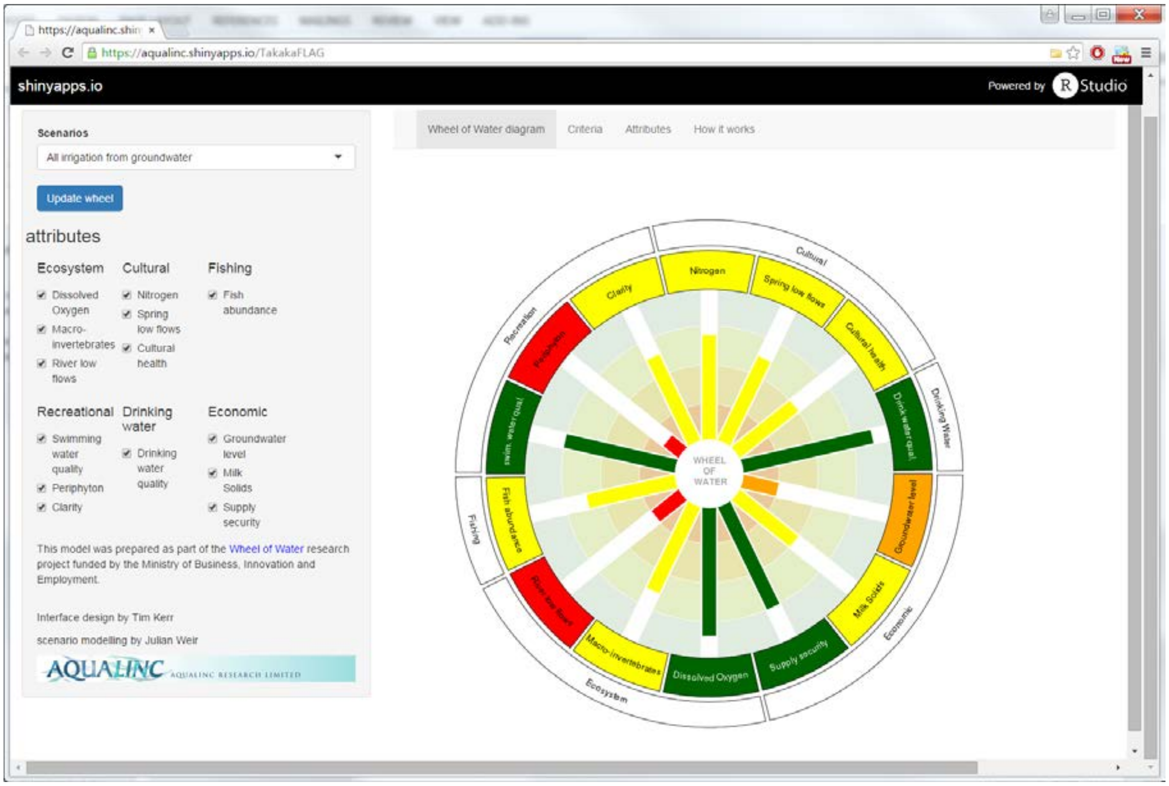

Figure Water Wheel diagram within the web page. Overall values are given in the outer rim of the wheel, value attributes are represented by each spoke of the wheel and are coloured to match the acceptance criteria as defined by the collaborative community group. Green indicates acceptable, red indicates unacceptable, yellow and orange provide intermediate acceptability levels. Individual attributes (and hence spokes) may be turned on and off for viewing simplicity. Alternative catchment scenarios may be selected enabling the related alternative Water Wheel diagram to be viewed.

NEW ZEALAND'S NATIONAL-LEVEL ENVIRONMENTAL REPORTING FRAMEWORK

James King[1], Jane Harkness[1], Carl Howarth[1], Adam Tipper[1]
[1]*Ministry for the Environment*

National-level environmental reporting plays an important role in informing the public and decision-makers of the current state and long-term trends in the environment. In New Zealand, the Environmental Reporting Bill was introduced in February 2014, and is likely to be passed into law in 2015. Once this Bill (at the time of writing) is enacted, it will provide a legal mandate for the production of regular and independent reporting using a pressure-state-impact framework. It will require the Ministry for the Environment and Statistics New Zealand to produce the reports.

In 2014 the first environmental report using the approach outlined in the Bill was produced on the air domain. A synthesis report, *Environment Aotearoa*, covering all five environmental domains (air, atmosphere and climate, land, freshwater, and marine) will be released on 21 October 2015, also following the approach outlined in the Bill. These reports have been produced under the spirit of the Bill. The freshwater domain report, due out in mid-2016, is intended to be produced under the Act.

This presentation will provide an overview of the new national-level reporting framework now in place in New Zealand. This includes the rationale for national-level reporting, roles and responsibilities of the Ministry for the Environment and Statistics New Zealand and the intent and benefits of co-production, the release cycle, and the required level of data quality for measures to be reported on. This framework is designed to move the debate on environmental issues away from data to debate around key challenges faced in maintaining and improving New Zealand’s environment.

Under the Bill, “the Secretary for the Environment and the Government Statistician are not required to include in synthesis reports information that cannot be obtained by using reasonable efforts.” For this reason we utilize information that has already been collected. Groundwater quality and quantity measures, prepared by GNS Science and discussed at this conference by Magali Moreau, is an example of this. These measures are tested against the data quality criteria of relevance, accuracy, coherence/consistency, timeliness, accessibility, and interpretability prior to being included in national-level environmental reporting.

We provide a brief summary of the measures used in *Environment Aotearoa* to inform on the state of the freshwater domain, including: river, lake, and groundwater quality; streambed sedimentation; wetland extent; and freshwater fish communities and pest species. Aquifer locations and properties, and nitrate leaching, inform on freshwater pressures, while hydro-generation and fish licenses provide some indication of the impact of freshwater on economy and recreation. Future developments will enhance both the existing state measures, and enrich the understanding of the freshwater domain across pressures and impacts.

A METHOD FOR INCORPORATING CULTURAL VALUES INTO FLOW MANAGEMENT DECISIONS

Dr Doug Booker[1], Dr Gail Tipa[2], Dr Shan Crow[1]
[1]NIWA, , New Zealand, [2]Tipa and Associates Ltd, , New Zealand

Aims

The sustainable use of freshwater resources requires managers to understand relationships between flow and instream values. While these relationships may be available for most freshwater biota, limited tools are available that quantify the relationships between flow and cultural values. The present study aimed to develop quantitative relationships between Maori cultural values supported by freshwater and flows.

Method

A score card was developed that quantified how observed flows supported four aspects of cultural health associated with freshwater resources. Participants from Moeraki, Waihao and Arowhenua Runaka with local knowledge of the waterways around Canterbury were identified. These participants then filled out score cards for each of 5 rivers on several occasions at a variety of different flows during summer. Mixed effects models were then applied to investigate: 1) if relationships were present between flow magnitude and health scores; 2) if these relationships differed between streams; and 3) if relationships between flow and cultural values were improved when differences between participants within each site were accounted for.

Results

Relationships between flow and cultural health scores differed significantly between sites and between participants within each site (Figure 1). If differences between sites and observers were not taken into account, there was a positive relationship between flow and cultural health that only explained 3% of the variation in cultural health scores (Figure 2a). If differences between sites were accounted for in the analysis, there was a positive relationship between flow and health that explained 52% of the variation in cultural health scores (Figure 2b). If differences between sites and observers were both accounted for in the analysis, there was a positive relationship between flow and cultural health that explained 60% of the variation in cultural health scores (Figure 2c).

Conclusions

There was a positive relationship between flow and cultural health scores after differences between sites and observers were accounted for. These results suggest that relationships between cultural values for freshwater ways and river flows are based on the characteristics of the site, and that values will differ between sites. Differences between participants were relatively low compared to differences between sites. The present study provides a method for quantifying relationships between cultural health and flows at different sites. Results suggest that these relationships could be developed into quantitative flow-focussed tools that could be used improve flow management decisions.

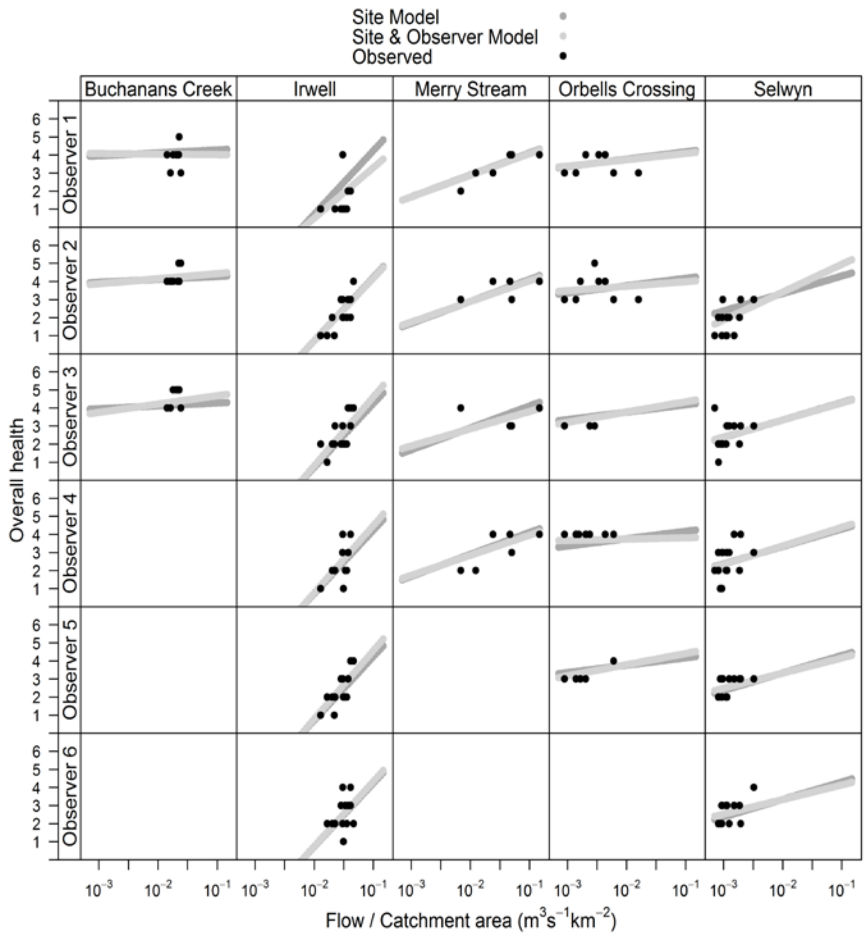

Figure 1. Observed and fitted relationships between overall health score and river flow.

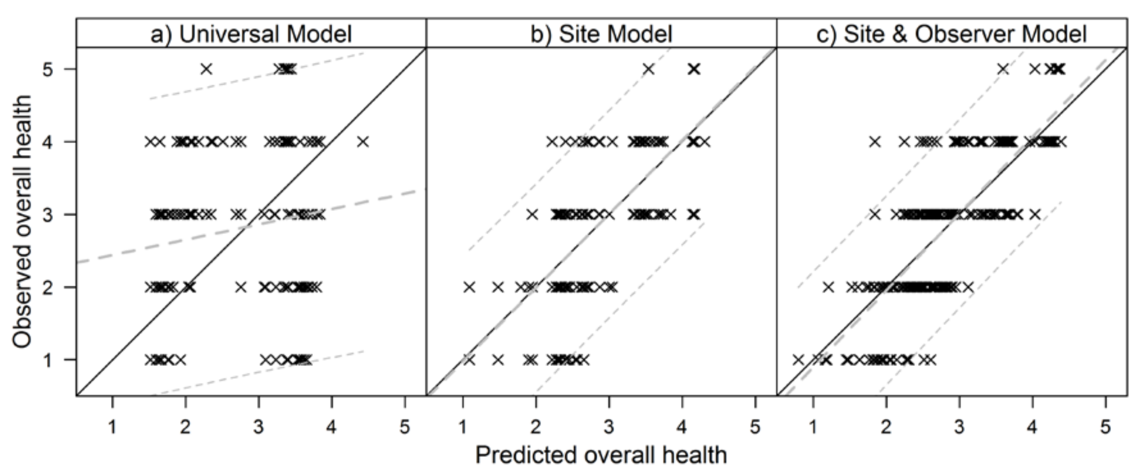

Figure 2. Performance of mixed-effects models at different levels of resolution.

ORCHESTRA CONDUCTOR OR PLAYER? CONTRIBUTING TECHNICAL INFORMATION IN COLLABORATIVE WATER PLANNING PROCESSES

Andrew Fenemor[1], Natasha Berkett[2]
[1]*Landcare Research, Nelson, New Zealand,* [2]*Cawthron Institute, Nelson, New Zealand*

Collaboration vs Consultation

Our thesis is that the nature of technical information and the way it is discussed with stakeholders is substantially different under a collaborative planning regime compared with the current planning framework (i.e. consultation under RMA Schedule 1). We argue that Schedule 1 planning processes tend to focus on biophysical knowledge structured in a predominantly reductionist paradigm and this can have the effect of marginalising community and Maori views, and of giving insufficient weight to other important considerations, such as economic or social consequences. In theory, collaborative processes allow much wider access to all forms of knowledge early on, for example alternative framings of the system and of stakeholder values, uses and management options.

Collaboration for Scientists

Under a collaborative water planning process, technical information is likely to be provided by scientists employed or contracted by the sponsoring council, which raises some interesting questions. For example, how do councils avoid the perception that they are driving the outcomes? How is technical information 'tested' in terms of its objectivity and completeness? How do stakeholders cope with uncertainty and risk, and how is this communicated? And what does being involved in a collaborative planning process mean for scientists?

Implications for Collaborative Design

Here we present findings of MBIE-funded research ('Values, Outcomes and Monitoring' and 'Wheel of Water') and from work commissioned by Environment Canterbury. We examined the use of technical information in the Canterbury zone committee processes, and interviewed scientists and stakeholders involved in other collaborative processes including Hawkes Bay, Greater Wellington and Tasman. Our findings are relevant for the handling of technical information and the design of the processes themselves. They cover these themes:

1. Design of the collaborative process including the conceptualisation of the system to be managed, and the time constraints for completing the process
1. The information needed and available for the process, including the role of stakeholder knowledge and experience
2. The operation and management of the project team

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THE INTEGRATION OF ECONOMIC, SOCIAL AND BIOPHYSICAL MODELS TO MANAGE FRESHWATER RESOURCES

Dr Suzie Greenhalgh[1], Dr Adam Daigneault[1], Ms Oshadhi Samarasinghe[1], Dr Fraser Morgan[1]
[1]*Landcare Research, Auckland, New Zealand*

Introduction

Many parts of the world are encountering water limits, whether it is water quality in parts of the United States or water availability in Australia. Many catchments in New Zealand are also facing the same types of water challenges as other parts of the world. As governments and stakeholders explore policy approaches to improving water quality and addressing reduced water availability, there is an increasing need to understand the economic implications of these choices. Increasingly this is requiring that economic modelling approaches incorporate the biophysical constraints that are facing catchments. In this presentation we will demonstrate how a catchment economic model, New Zealand Forestry and Agricultural Regional Model (NZFARM), can be used to integrate a range of environmental parameters and biophysical models as well as landowner behaviour to assess the economic and environmental impacts of resource constraints and environmental policy options. We will two applications in different New Zealand catchments to illustrate the power of these modelling approaches to inform policy choice and design.

Modelling approach

NZFARM is an agro-environmental economic land use model which has been designed to compare different scenarios. It can be used to assess how changes in technology, commodity supply or demand, resource constraints, or farm, resource, or environmental policy can affect a host of economic or environmental performance indicators that are important to decisions-makers and rural landowners. For water-related analysis this model is parameterised at the catchment scale. The model incorporates a range of land uses (such as dairy, sheep and beef, deer, arable, fruit, vegetables, scrub, exotic forest) and a range of mitigation options (such as fertiliser rates, stocking rates, etc). NZFARM has also been incorporated in the Agent-based Rural Land Use New Zealand (ARLUNZ) model which more explicitly accounts for different farmer behaviour related to succession planning, social and geographic networks and economic incentives.

Results

We will illustrate the utility of these economic models by outlining the results from 2 studies. The first is the use of NZFARM to compare between different approaches to allocate nutrients between land owners in two catchments in Canterbury. From this analysis we found that the most efficient approach changed based on catchment land characteristics, current land use and the stringency of the target. Therefore, it is unlikely that the same allocation approach will be the most efficient in all catchments. The second study uses ARLUNZ to assess the impacts of climate policy on greenhouse gas emissions and nutrient leaching. In this analysis, catchment-wide net GHG emissions (livestock emissions less forest carbon sequestration) are estimated to decline over time because of the expansion of forestry in the less productive hills region. GHG emissions do increase a small amount over time as dairy herds increase. This increase in dairy, however, results in increases in N leaching and P loss. This suggests that a policy instrument focusing on greenhouse gas emissions alone is unlikely to reduce other environmental outputs.

Session Theme: Monitoring and Data Management / General Hydrology, Start Time: 1:40 p.m.

INFRASTRUCTURE AND HYDROLOGY: IMPROVING THE RELATIONSHIP AND LEARNING FROM THE RESULTS

Mr Dennis Jamieson[1]
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Aims

Much hydrological science is undertaken to inform infrastructure practice. This paper reflects on how this process has evolved over time in New Zealand and specifically on what is occurring with water infrastructure in Canterbury. This paper focuses on how the overall impacts and opportunities from water infrastructure are becoming better informed by science rather than presenting detailed work on any particular type of water infrastructure.

Method

New Zealand (NZ) has been an active member of International Hydrological Programme (IHP) of the United Nations Scientific, Cultural and Science Organisation (UNESCO) since the 1960's. The early days of the International Hydrological Decade (IHD: 1965-75) and IHP (1975-ongoing) coincided with an expansionary phase of NZ hydrology, when substantial investments in large infrastructure such as new highways with bridges and hydro-electric power schemes were made. More recently, owing to rapid economic and government changes, NZ's role in IHP was limited. Nevertheless, IHP documentation was used to benchmark NZ hydrological activities with those of the rest of the world, and in particular introducing data telemetry.

This paper discusses how water infrastructure practices in NZ have evolved over time. Current approaches in Canterbury are reviewed with a focus on how science (social and biophysical) is being applied to achieve multi-target outcomes and how these approaches align with the current phase of the IHP (IHPVIII).

Results

Considerable water infrastructure in Canterbury was developed before the inception of integrated thinking around multi-purpose infrastructure or multiple targets in water management. The current era of water infrastructure is notable for the withdrawal of Central Government from direct responsibility for operation and as far as publicly acceptable, ownership. While this process has not been completed in terms of hydropower, all substantial irrigation water supply infrastructure in Canterbury is owned and operated by the private sector.

A feature of processes around any development has been the expectations of science. The role of science under the RMA was initially seen as being to lead thinking, resulting in approaches that have often been described as 'science led'. Parties with contrary objectives typically commission science advisors who are engaged in a duel of opinions and experience. Frustration with this situation has led to a code of conduct for expert witness (Environment Court) and attempts to reconcile conflicting opinions through Expert Witness Conferencing sessions.

The Canterbury Water Management Strategy (CWMS), developed under the auspices of the Canterbury Mayoral Forum representing all local authorities in Canterbury, is a process designed to refocus water management in Canterbury on a vision (*To enable present and future generations to gain the greatest social, economic, recreational and cultural benefits from our water resources within an environmentally sustainable framework*) based on multiple targets. Reports on progress against targets are produced at two year intervals.

The role of science information has become one of informing processes with the best information available at the time of first engagement, with the utility of science based information and any information gaps being assessed in terms of CWMS targets. This assessment process applies to existing situations and to any changes, be they infrastructure based or otherwise.

For New Zealand an important aspect of science is an understanding of how to achieve stream ecology outcomes given changed flows and nutrient status. Over time approaches to achieving outcomes have focussed on habitat availability e.g. Instream Flow Incremental Methodology (IFIM) in the 1970's), minimum flow settings and more lately flow regimes. A recurring theme is that unexpected results have been occurring as science has struggled to understand the emergence of organisms such as Didymosphenia geminata (didymo) and Phormidium and the absence of biota of waterways with excellent habitat.

The approach in Canterbury can be seen to be moving towards seeking an understanding of what is occurring to influence the state of waterways using current information and a consensus approach amongst all science personnel engaged, preferably on a collaborative science basis. While consensus amongst science personnel is ideal, but not always achievable, a primary focus is on making effective use of both existing information resources and to target additional science effort on the right questions.

The key result emerging for New Zealand is that a locally initiated concept to improve water management in Canterbury (CWMS) has re-engaged with important international guidance via the UNESCO IHP. This is an important result for science and for water infrastructure practice in NZ, particularly as central government has made a substantial effort to improve infrastructure practices across all infrastructure types via the National Infrastructure Unit (NIU) of Treasury and the National Infrastructure Advisory Board (NIAB).

As the CWMS progresses it is expected that implementation of IWRM and Ecohydrology at a regional scale (45,000km2), as opposed to a small experimental or pilot scale, will have important findings of international significance. For example engagement with other international processes (e.g. OECD water governance) indicates that there is considerable interest in the participation of Ngāi Tahu and incorporation of their cultural values in the CWMS. As this process continues it can be anticipated that NZ will provide international guidance on the incorporation of the knowledge and perspectives of indigenous people into the concept of Ecohydrology.

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METEOROLOGICAL AND HYDROLOGICAL DRIVERS OF SEDIMENT TRANSFER IN A STEEP ALLUVIAL FAN, WESTLAND, NEW ZEALAND

Mr Matt McGill-Brown[1], SJ Fitzsimons[1]
[1]*University of Otago, Gisborne District Council, Gisborne, New Zealand*

Aims

Techniques for quantifying the magnitude, frequency and patterns of sediment transfer of bedload particles has evolved from painted rock methods to modern radiofrequency approaches. This study has focussed on an underexamined area in the West Coast of New Zealand, Potters Creek, which is an ephemeral alluvial fan stream that has the conveyance, stream capacity and competency to transfer large quantities of sediment in any given flow. Using radiofrequency methods to capture sediment transfer allows for a more intricate knowledge of the fluvial-geomogpholohy interface to be quantified and understood in this environ. Analysis of the hydrological and meteorological patterns driving flashy and episodic flow conditions; capable of initiating individial particles, and the active layer of sediment will be undertaken.

Methods

RFID (radiofrequency identification) tags (23 mm) were embedded in tracer particles (between 81 – 1,236 grams), and during recovery missions a transponder was used to locate dispursed particles. RFID technology is consdiered to be a reliable and accurate method for locating dispursed tracer particles compared to other bedload tracing studies. Multiple cross sectional surveys were completed to capture volumetric sediment aggradation/degradation of the streambed at various times throughout the experiment. Time lapse photography was used to quantativley observe streamflow conditions, which was particularly useful in no-flow conditions to analyse geomorphic change, and in high-flow conditions to visualise stream geometry, wetted perimeter and bankfull conditions. D_{50} (median sediment size) analysis was completed to show the sediment size fraction change downstream, which was used to characterise the fining process and quntify sediment communition. Depth duration frequency analysis was undertaken to characterise the precipitation events that occured throughout the experiment. Rainfall data was observed at Potters Creek using a TB3 tipping bucket rain gauge, in conjunction with Franz Josef Ewes rain gauge (NIWA). A bubbler was used to measure stage, and was selected due to the ability for it to be fixed to a highly active bed layer was achieved. Discharge was calculated by regression analysis, spot flow gaugings, as well as pegging high-flow events from the time lapse photography. Vector maps were produced to show sediment transport magnitude and patterns over various spatial and temporal extents.

Results

Over the 9-month experiment, the maximum distance a tracer particle was transferred was 2,144 m. Of a small cohort of recovered particles, evidence suggests that particles abrade, on average 7 grams per 500 meters travelled. Compared to their original mass, clasts of schist composition experienced higher levels of abrasion (6.6%) compared to metamorphosed clasts (2%), as did tracer particles that were transferred from the proximal zone (10.2%) compared to mid-fan (3.7%) or distal zone (1.14%). The median sediment texture (D_{50}) decreases downstream from 99 mm in the proximal zone to 39 mm in the distal zone. Sediment has accumulated in the mid-fan zone due to a lateral injection of sediment from a tributary, increasing the D_{50}, which requires stream competency and capacity to adjust for transfer to occur. Despite a D_{50} increase in the mid-fan zone, sediment size does reduce throughout the catchment, showing evidence of rounding and fining downstream. Axial commination shows that the rate of fining from the clast of each axis is higher at the upstream sites with highest slope is, and the axis lengths are on average 2 times higher here compared to downstream reaches. Topographic cross sections show that near the previously mentioned tributary is an aggrading site, causing the alluvial fan to be characterised by sediment concavity in the mid-fan zone, these cross sections also show that aggradation and degradation zones alternate downstream. The rainfall lag on average was 100 minutes from a large rainfall interval to the peak of the hydrograph, recession to baseflow generally took another 100 minutes. Depth-duration frequency analysis of precipitation data during this experiment shows that there have been 113 events that have exceed return periods of between 2 – 50 years for durations ranging from 0.5

hours – 72 hours, with one additional event exceeding a 100-year event. Maximum discharge during this experiment was 53.54 m^3s^{-1} with 12 other events recorded to exceed 5 m^3s^{-1}, where it is likely that sediment has transferred during these events.

NATIONAL HYDROLOGIC INSTRUMENT: SHOWCASE THE NETHERLANDS

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Aims

Making rapidly and transparently automated hydrological models from national to site scale. This goal is set for the Netherlands in the year 2018. In earlier years much time has been invested in data collection, interpretation and (re)building the different models. The complete Netherlands Hydrological Instrument (NHI) is already available and has been applied in national and regional studies. Goal is to automate the process from raw data to operational models consistent at various scales. Demonstration of this principle has been proved for a regional geohydrological model.

Method

Basic principles of the NHI are open and free data sharing, coupling of different hydrological models and possibilities to work on different spatial and temporal scales.

Data is collected and provided through web portals free of cost by the national institutes for geology (TNO), water and subsurface (Deltares), soil and land use (Alterra) and climate (KNMI). The Regional Geohydrological Information System (REGIS-II) is used to show the degree of water permeability of various subsurface layers to a depth of several hundred meters. The top 30 meters of the subsurface is schematized in more detail in millions of voxels, each measuring 100 by 100 meters in the horizontal directions and 0.5 meters in the vertical direction. Data about water distribution, irrigation, water abstraction by agriculture, industry and drinking water companies is available at point or sub catchment scale. Evaporation is derived from detailed national maps of land use and soil characteristics combined with data about rainfall, evaporation and temperature.

The complete water cycle of surface water distribution and groundwater flow is modelled on national scale in five models:

1. A national surface water distribution model (SWOD);
2. A Surface Water Flow and Transport model (SWFT);
3. A model to derive water availability and demand from the hinterland (SWSC);
4. A Soil Vegetation Atmosphere Model (SVAT);
5. A Ground Water Flow Model (GW);

To achieve NHI functioning as an integrated working system, connectors have been built to calculate temporal and spatial scaling of parameters and variables between the models (Figure 1). The model enables a complete water balance to be derived for the entire country and for each region. All model input and output files can be downloaded from the national NHI data server, free of charge.

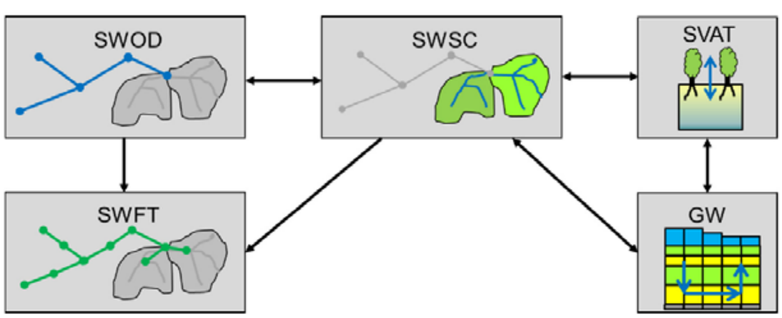

Figure 1: The relations between the five geohydrological models (De Lange et al.,2014)

It takes a lot of effort to rebuild a geohydrological model after changing basic parameters, like soil parameters or drainage levels. Royal HaskoningDHV (RHDHV) developed a method and software to transfer automatically all basic information into model input files like MODFLOW. This concept has been proved on regional scale (5000 km^2) for the province of Noord-Brabant (Verhagen et al., 2015). The model is generated from national datasets about geology and climate in addition with more local detailed information about abstractions, surface water, drainage and soil characteristics. Relatively simple the model can be adopted and run for the whole province. A detailed zoomed-in model can be generated as well.

The NHI will develop into the same direction, delivering a set of tools to derive easily model input at different scale levels. A draft set of modules and tools is already available (Minnema et al., 2013). In the NHI context Deltares, Alterra and RHDHV are cooperating to develop one platform to make all tools and data available to all users in the Netherlands. This so called Deltashell will be open source and offering full insight into model adaptions in time.

Newly generated local or regional information or knowledge will be transferred into the national database of the NHI. Thus joint invested time of research institutes and consultancies is used to elaborate the various databases which will feed the models. The time needed to (re)build hydrological models will thus be minimized.

Results

The complete water cycle of surface water and groundwater is modelled on national scale. On provincial scale the geohydrological model can be generated automatically from various basic datasets of geology, topography and surface water topography. The next years this will be scaled up to a national level.

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MODELLING BANK DYNAMICS IN GRAVEL-BED BRAIDED RIVERS

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A distinctive feature of the morphologically active braided and transitional rivers flowing in the alpine areas and planes of New Zealand is that the banks of individual braids evolve over relatively short time scales. This implies a strong feedback between in-channel processes, driven by fluvial transport, and bank processes. Bank retreat can provide significant local sources of sediment to the river over a single flood event; it can reshape the channel geometry (width and curvature) and thus interact with bar formation and progradation; and it can affect bifurcations, driving changes in the flow and sediment transport partition between the downstream channels. Modelling bank erosion is therefore essential in the prediction of river morphodynamics by two-dimensional modelling, even over relatively short time scales.

Aims

Over the last two or three decades, many approaches to modelling bank erosion have been developed. Here we first aim to analyse some existing models of bank erosion, presently embedded in two-dimensional morphodynamic models or proposed in the literature, to show their strengths and weaknesses for the purpose at hand. Then, based on this review, we aim to propose an original bank erosion algorithm.

Methods and Results

We propose a classification of the existing bank erosion models based on the algorithm used for identifying eroding banks, the approach used in the computation of bank retreat, the management of the related domain deformation, and the required grid resolution. We implement these models in a simplified, one-dimensional cross-sectional morphodynamic model to compare their different response the flow conditions.

Unfortunately, most existing models of bank erosion are only suitable for single-thread rivers, and are unfit for application to complex morphologies such as those of braided and transitional rivers. We therefore propose a new algorithm, able to automatically detect eroding banks and suitable for general (Cartesian and unstructured) meshes at various mesh resolutions. The algorithm is tested in a suite of cases, including the widening of a straight narrow channel, the erosion of the outer bank in a meandering channel over a flood, and the development of a self-sustaining braiding network.