Community owned micro-hydropower in developing countries: Success, challenges, and added benefits

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Isolated communities in developing countries struggle to meet their energy demands partly due to the difficulty in connecting to national electricity grids. Basic energy demands are often met with the use of expensive and polluting fossil fuels. An alternative way of meeting energy demands can be through the use of micro-hydropower (MHP) systems, if the right conditions exist. To evaluate the feasibility of an MHP scheme at a particular location, economic, physical, environmental, social and political factors need to be considered. Evaluating some of these factors often requires engineering skills and complex calculations, which prevents isolated communities from assessing the feasibility of a potential MHP scheme. Research is needed to understand how the various factors contribute to the success or failure of MHP schemes in developing communities. Numerous communities from Nepal, Bolivia, Cambodia and the Philippines have been visited to acquire the necessary field experience. New Zealand's existing MHP schemes have also been studied to provide perspective on the socio-economic linkages to further understand the hindrances affecting undeveloped countries. The research done has identified the key intervenient factors of MHP success and is developing a pre-feasibility analysis tool that considers and correlates affecting factors. A multi-criteria decision-making algorithm has been chosen to analyse the qualitative and quantitative multidisciplinary variables affecting MHP schemes. This research will create a tool to facilitate remote villages with limited economic and educational possibilities to perform pre-feasibility assessments for MHP generation. This study will help advance the knowledge of MHP management and design.

Solute mixing in hierarchical sedimentary deposits

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Solute mixing and spreading are important processes in understanding many contamination problems. These processes are determined by the spatial distribution of hydraulic conductivity. Many approaches to characterising hydraulic conductivity fields reduce complex sedimentary architectures to relatively simple geometries. The assumptions implicit in these methods are often violated and therefore sedimentary architecture may not be realistically represented in hydrogeological modelling efforts.

Hierarchical sedimentary deposits are typically unconsolidated sediments composed of assemblages of facies at multiple scales and are formed by cyclical depositional processes (e.g. glacial advance and retreat). Such deposits often form important aquifer systems, from which groundwater is extracted. The properties that make these aquifer systems productive, such as high hydraulic conductivity, also make them vulnerable to over-extraction, as well as contamination from diffuse and point sources.

In this PhD project, realistic spatially distributed hydraulic conductivity fields will be generated using various sediment generation tools, constrained by quantitative and qualitative information. Groundwater flow and solute transport modelling will be performed using the hydraulic conductivity fields, and the model outputs will be assessed using relevant metrics. A framework for including geological information in hydrogeological modelling studies will be developed, including a workflow suitable for practice. This poster presentation will include preliminary results and a project outlook.

Field-saturated hydraulic conductivity testing: Groundwater testing in geotechnical boreholes

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The need for groundwater impact and dewatering assessments may not be identified until late in the overall investigation phase. The collection of meaningful groundwater information within a geotechnical investigation is achievable, provided the correct methods are used in the field, suitable numerical solutions are applied to the data, and the reliability of the results is appropriately reported.

Various field methods are available; the practicality of each must be individually assessed for any given project. Where the need for groundwater data may not yet be fully realised or understood by stakeholders, wanting to proactively undertake onsite testing early on in an investigation may require ways of fitting the groundwater agenda in to the geotechnical programme. Factors such as limits on field-time, borehole drilling methods and stratigraphy can all impose constraints on the validity of groundwater testing data.

Aims

This assessment has aimed to:

1. Identify potential limitations and issues with onsite testing methods
2. Assess reliability of field-testing techniques, and provide meaningful discussion of reliance on results
3. Find ways in which protocols can be revised to provide a higher degree of confidence.

Regional high resolution mapping of irrigated areas

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Accurate maps of irrigated area and type are important for both water quality and quantity management. We present a method for mapping in detail both the irrigated area and irrigation type. We have applied the method in Canterbury, where about 500,000ha is irrigated. We discuss data accuracy, including a comparison with the Normalized Difference Vegetation Index and consents databases. We discuss potential applications of this dataset, including catchment nutrient accounting, irrigation efficiency mapping, and water infrastructure planning. The method also provides a means for tracking changes over time in greater detail than is possible with Statistics New Zealand five-yearly estimates.

Soil moisture infiltration rates and groundwater residence time in Central Otago tussock grasslands

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Tussock grasslands of Central Otago have high water yields as a result of their low evapotranspiration rates and ability to intercept precipitation from fog. This study builds on current research into water yields and tussock grasslands, using a soil moisture budget approach combined with direct measurements of soil moisture to determine if the incidence of fog contributes meaningful amounts of water to soil moisture. Time domain reflectometry probes were installed in a tussock grassland catchment site to complement an existing two-year record of precipitation, runoff and meteorological observations. These data were used to develop a soil moisture model for the study site, and the model output compared to in field observations of soil moisture. The objective of the study is to validate a soil moisture model suitable for grassland high country in Otago, as well as quantify the seasonal trends and the response of soil moisture to precipitation in a variety of forms (rain, fog and snow) and across differently scaled events. These observations will aid in developing a better hydrological model that accounts for the distinctively high water yields that occur under tussock grasslands and contribute to the development of a framework for valuing and preserving the hydrological function of high country tussock in water allocation in the region.

Validation of TAPM's meteorological data generator on Australia's east coast

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As predictive modelling become increasingly prominent in engineering, it also becomes important to ensure that the data being utilised for these models are accurately portraying the reality.

The Air Pollution Model (TAPM) is software developed by the CSIRO as a prognostic modelling system which has been utilised for meteorological generation. The purpose of this study is to determine the effectiveness and accuracy in which TAPM is able to generate meteorological data for three different sites on the east coast of Australia.

Historical data collected from the Bureau of Meteorology (BOM) monitoring stations at northern (Weipa), central (Archerfield) and southern (Newcastle) sites on the east coast of Australia have been compared using statistical methods to the data generated in TAPM.

Two key indicators have been looked at when comparing generated to observed data: consistency and accuracy. Consistency was tested using correlation to compare how well the annual pattern is being followed. Accuracy was tested with forecasting skill comparing the values at each point.

The results indicate that TAPM is able to generate data for temperature and evaporation with high accuracy (skill_V; 1.27 to 1.09 and skill_R; less than 1) and consistency (correlations 0.80–0.93). The least accurate was rain (skill_V; 0.03 and skill_R; greater than 1) (correlations; 0.14).

From this study, it was found that the general annual weather patterns were being followed; however, there were often large discrepancies in value.

Hydrological modifications in the Mekong floodplains from development and climate change

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The Mekong floodplains play an important role in poverty and hunger alleviation in Vietnam and Cambodia. Their high agricultural productivity is partially due to the natural hydrological regime of the Mekong River; however, regional demand for electricity is leading to the development of over 120 upstream hydropower dams, which may alter the hydrology of the floodplains forever. Within the floodplains, an extensive system of delta-based flood protection is being constructed to increase agricultural production, but which can have negative effects on other parts of the delta. Rising sea levels due to climate change and the observed land subsidence will exasperate the problem of flooding in unprotected regions. The main aim of this study was thus to investigate the effect of potential changes in floodplains' hydrological regimes by modelling development and climate change scenarios. Full development of hydropower dams will increase dry season water levels by 23%, but wet season water levels will only change by slightly over 1% in the upper floodplain. Flood protection systems will significantly change water storage capacity and water allocation in the floodplains, causing significant regional changes in flood patterns. Sea level rise will result in the inundation of a vast region of the Vietnamese coast, while land subsidence could cause localised changes in flooding patterns, but to a lesser impact than water infrastructure development. Region-wide transboundary water resource use policies are needed to address future changes in the balance between agricultural productivity, energy generation, and the natural environment.

Uncertainty in climate change impacts on Southern Alps catchments: The role of hydrological model complexity

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Climate change scenario modelling for New Zealand indicates a series of hydrological changes can be expected. Hydrological modelling is a critical tool to assess the likely impacts of future climate change on river runoff. The most comprehensive (i.e. distributed) hydrological models are generally complex and require large amounts of input data, computer power and time. The use of semi-distributed models to perform essentially the same function can yield a relatively efficient method of scenario hydrological modelling. Thus, this research tests whether a relatively simple model can be effectively used for scenario modelling in the context of the Southern Alps of New Zealand, specifically the Shotover River. This research will provide useful insight into appropriate hydrological modelling methodology in the Southern Alps, as well as the likely implications climate change may have on future availability of New Zealand's freshwater resources.

The power of radioactive isotopes in hydrology

Johannes Kaiser[1]
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This presentation gives an overview of the production, sample analysing (including sample preparation) and application of tritium, radon and radiocarbon in the water dating laboratory at GNS Science.
These radioactive isotopes have half-lives of 12.3 years, 3.8 days, and 5,730 years, respectively.
Applications are groundwater dating, drinking water security and groundwater–river water interaction in New Zealand rivers.

How much carbon is transported in pristine river systems?

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Mountainous rivers are important conveyors of organic carbon to the marine environment. Estimates of carbon flux vary greatly between different river systems, and relatively few studies have investigated the carbon flux of New Zealand rivers. This study investigates the sources and transfer of carbon within a pristine alpine catchment in New Zealand, based on data collected in the Haast River. The study reports on the different portions of carbon being transferred through the Haast River, derived from observations collected at different times of year (e.g. seasons) as well as a consideration for downstream changes in carbon. Chemical and isotopic tracers were used to determine where carbon is derived within the landscape to quantify the flux of atmospheric carbon that is drawn down via rock weathering, and what influence weathering and thin alpine soils have on sources of inorganic carbon. Water samples were collected and analysed for particulate and dissolved organic carbon, as well as inorganic carbon, in conjunction with major and minor solute chemistry. Preliminary data analysis suggests that under baseflow conditions particulate organic content is not a significant contributor to overall suspended material concentrations, accounting for <2% of suspended load (0.5mg C/L). By comparison, dissolved organic and dissolved inorganic carbon occur in significantly higher concentrations (1.2–1.9mg C/L and 3.5–5.5mg C/L) in the Haast River and under baseflow conditions are the dominant forms of carbon flux.

Water scarcity and drought in the Lindis catchment, Central Otago

Jessie Loft[1], **Daniel Kingston[1]**, Sarah Mager[1]
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Water-scarce situations (i.e. where demand is greater than supply) are a critical issue in water resource management. Water scarcity can be exacerbated by drier than usual conditions, but separation of the effects of water scarcity versus drought can be difficult. This study investigates the relative importance of water scarcity and drought for the availability of water in the Lindis River, Central Otago. The Lindis River frequently runs dry in the summer, becoming disconnected from the larger Clutha River. To determine the extent that extreme low flows are driven by abstractions versus the naturally low rainfall conditions that occur in summer, a two-step hydrological modelling procedure was employed. First, a model was developed for the upper Lindis River, where flows are not altered from allocated abstraction. This model is then applied to the lower Lindis flow records, to reconstruct what "natural" flow would likely be in the lower catchment. Comparison of the modelled "natural" river flow record with the observed (impacted) river flow record suggests that summer river flow in the Lindis is substantially lower than it would be in the absence of human abstraction. Results indicate that the Lindis River would never disconnect from the Clutha during January–March, and would only have rare disconnection events in December and April, in comparison to their frequent actual occurrence. As such, the results of this study provide a useful tool for reconstructing river flows to account for the effects of human abstraction and provide vital information for ongoing management of this catchment.

Engaging with Groundwater Resources of New Zealand: An interactive poster presentation

Abigail Lovett[1], Uwe Morgenstern[1]
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The Groundwater Resources of New Zealand (GWR) Programme is GNS Science's core funded hydrogeology research programme (2011–2021). The programme is funded by the Ministry for Business, Innovation and Employment and includes collaborations with regional and national authorities, and other research and industry organisations. The primary aim of the GWR Programme is to inform ways to improve the sustainable management of, and economic returns from, groundwater resources in New Zealand. The current programme is structured through six hydrogeological research projects: hydrogeology, water fluxes, bio-geochemical tracers, National Groundwater Monitoring Programme, resource pressures, and stakeholder engagement. One of the objectives of the programme is to increase collaboration and relevance of research by engaging and working with end-users. The aim of this interactive poster presentation is to increase stakeholder awareness of the GWR programme research topics and aims, present recent science outputs, and to promote engagement and collaboration with stakeholders.

Quantifying groundwater discharge using radon-222

Heather Martindale[1], Uwe Morgenstern[1], Rob Van der Raaij
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Radon-222 is a hydrological tool useful for identifying the locations of where groundwater is discharging into rivers or streams. However, radon has not yet been used to quantify groundwater discharge into rivers in the New Zealand environment. To quantify groundwater discharge using a box model approach, the rate at which radon degasses from the river needs to be calculated. In this study radon samples are collected in areas of nil groundwater discharge. Over a relatively small stretch of river this will provide the degassing rate of radon. These results are then compared to modelled values with the purpose of providing a range of expected radon degassing rates under different flow and geological conditions. From this, groundwater discharge can then be quantified with an associated uncertainty.

Construction of an impact plate geophone to record sediment movement in New Zealand gravel-bed rivers

Andrew Neverman[1], Ian Fuller[1], Prof Russell Death[1], Jon Procter[1], Ranvir Singh[1]
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Gravel-bed rivers are a significant feature in the New Zealand landscape and a focal point for many issues surrounding water, infrastructure and the environment. Bedload transport is a key process in gravel-bed rivers as a driver of erosion which has implications for infrastructure development in and around rivers. Bedload transport is also significant for many other instream processes, in particular as a control on habitat structure and aquatic community composition. Understanding bedload transport should therefore be a high priority for effective management of New Zealand rivers, both for maintaining ecological health and reducing impact on infrastructure.

Despite decades of research, the accurate predication of bedload transport still eludes scientists. The inability to record bedload transport in natural channels at suitable spatio-temporal resolutions has been a significant limiting factor in this pursuit. Geophone-based impact plates are seeing increasing use in bedload transport studies and as monitoring tools. However, many of the impact sensors in the literature either require permanent support structures for installation, or are installed in paving slabs in relatively low-energy systems, limiting their application in New Zealand rivers. This paper demonstrates the development of a novel installation method for impact plate geophones in New Zealand's relatively high-energy, dynamic gravel-bed rivers which anchors the impact plate without permanent support structures.

Application of ANNs for regional flood estimation: A case study for New South Wales, Australia

Prof Ataur Rahman[1], Sasan Kordrostami[1]
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Flood estimation in ungauged catchments is often needed in hydrology. Regional flood frequency estimation (RFFE) methods can be used for this purpose. The RFFE models in Australia are mainly based on linear models, such as Index Flood Method, Quantile Regression Technique, Parameter Regression Technique and Probabilistic Rational Method. The application of non-linear RFFE techniques such as Artificial Neural Networks (ANNs) is quite limited in Australia. In this paper, an ANNs-based RFFE model is presented for New South Wales (NSW) State in Australia. It uses data from 88 gauged catchments in NSW which are smaller than 1,000km^2. A total of eight predictor variables are considered and five different model forms are tested. It has been found that an ANNs-based RFFE model can provide more accurate flood quantiles than the Australian Rainfall and Runoff (ARR) RFFE Model. The relative error values for the ANN models are in the range of 35% to 55%, which are generally smaller than the ARR RFFE Model. It has also been found that use of a greater number of predictors does not necessarily enhance the prediction accuracy of an RFFE model.

Physiographic controls over Southland's groundwater and surface water chemistry: Methods

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The Physiographic Project is a component of Environment Southland's Water and Land 2020 and Beyond programme, and their response to the National Policy Statement for Freshwater Management. The physiographic work is a novel approach, which characterises the landscape based on water source, recharge mechanism, combined soil and geological reduction potential, geomorphic and substrate (soil, rock and biological sediments) composition to provide a better understanding of the relationships between key characteristics of these spatial frameworks and both hydrochemical and water quality variation. Simplification of the hydrochemical framework to account for only water quality outcomes results in nine Physiographic Units that respond differently to land use pressures in terms of water quality outcomes.

This talk details the methodology applied to develop physiographic units for Southland. Specifically: (i) the underlying theory of by which spatial gradients in hydrochemical signatures were understood – our "bottom up" data-driven approach, followed by (ii) a "top down" approach to spatially map areas with similar inherent properties (driver assemblages) that influence regional water quality (2) . Development of a "top down" mapping process involved development of objective mapping rules for classification of key driver assemblages (recharge mechanism and combined redox) that respond distinctly to land use pressures. Specifically, nine unique water quality driver assemblages produced nine distinct physiographic units. The mapped units are intended to help facilitate and inform land use management for the protection of human and ecological health of regional waterbodies.

Evaluation of the predictive reliability of flow and transport models of heterogeneous alluvial aquifers

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Alluvial deposits are known to be highly heterogeneous, yet standard methods for interpreting and predicting alluvial aquifer behaviour are often based on methods that assume relatively homogeneous and isotropic conditions. Furthermore, while this heterogeneity can impact aquifer responses, predictive model simulations of aquifer impacts are typically undertaken using a model discretisation that is much coarser than many of the heterogeneous aquifer structures. We have generated a "virtual" braided aquifer model and used it to simulate the response to pumping and tracer tests. These test results have then been interpreted using model-calibration based methods to infer alternative descriptions of the hydraulic conductivity distribution of the "virtual" aquifer. These model calibrations have been undertaken using a coarser model grid than that of the "virtual" aquifer. The utility of these alternative "upscaled" hydraulic conductivity descriptions has been evaluated by considering how well they are able to predict the "virtual" aquifer's response to pumping or tracer injection at other locations. Comparisons of predictive performance of these calibration-based upscaled fields are made with alternative upscaled fields based on a numerical permeameter method. This comparison demonstrates that predictive reliability is influenced by many factors, including the way in which the model-calibration problem has been formulated, the nature of the test under evaluation, and the type and location of a particular prediction.

Dynamics of nitrogen compounds in Haytons urban drainage stream, Christchurch

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Concentrations of nitrogen compounds in Haytons Stream, an urban waterway in Christchurch, New Zealand, have been reported to be above local guidelines. High levels of ammonia and/or related nitrogen compounds can be toxic to aquatic organisms and can have a significant effect on the stream's ecological health. Numerous environmental and physical factors such as organic matter content, hydrology/hydraulics, temperature, sediment characteristics and interactions with other contaminants can cause transformation or dilution of nitrogen compounds along the stream. The aim of this project was thus to assess the sources, types, and transformation of nitrogen compounds in Haytons Stream through water quality monitoring at various locations along the stream, over time and in stormflow and baseflow conditions. Initial results have confirmed previous reports. Levels of oxidised nitrogen were found to exceed the local guidelines in 90% of samples while ammoniacal nitrogen in some of the samples was up to 8 times higher than local guidelines. Results also show that the predominant nitrogen form changes with flow conditions. During baseflow, nitrogen is mostly in its inorganic form at the upper and middle parts of Haytons and in organic form at the lower part. During stormflow, the majority of the nitrogen is in its organic form. Nevertheless, the total nitrogen at each site is of about the same magnitude in both conditions. Analysis suggests that point discharges, sediments in the stream bed and street runoff water are contributing to the nitrogen load in Haytons Stream. Results of this study have implications for stormwater management.

Effect of observational uncertainty on hydrological modelling

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Hydrological models 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. These models use metrological data to generate flow. There are several sources of error in meteorological data; namely, through measurement at point level, on interpolation etc. When erroneous input is pass to model, one cannot expect error-free output from our prediction. Every prediction is associated with a certain uncertainty. Quantification of these uncertainties is of prime importance in real-world forecasting. In this study, an attempt has been made to study uncertainty associated with hydrological modelling, using data depth function. To see the effect of uncertainty in rainfall on flow generation through the model, the input to this model was altered by adding error, and a different realisation was made. A Monte Carlo simulation was done to generate a huge number of hydrological model parameter sets from uniform distribution. The model was run using these parameters for each realisation of the rainfall. The parameters which are good for different realisation are more likely to be good parameters sets. For each parameter set, data depth was calculated and a likelihood was assigned to each parameter set based on the depth values. Based on this, frequency distribution of the likelihood was analysed. This methodology was demonstrated using the TopNet model on Waipara catchments located in the South Island of New Zealand. It has been found that the likelihood assigned is reasonable in quantifying uncertainty in the model prediction.

Building a stable isotope map of New Zealand groundwaters

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Stable isotopes are valuable tracers for groundwater, allowing for recharge source determination.
The two main sources of recharge into groundwater are seepage from rivers or infiltration from rainfall. Variations in δO18 and δ2H can be used to study transport times of water through a catchment, into a stream or through a soil to an underlying aquifer.
During the analysis of tritium, stable isotopes are measured on the distilled water sample, before and after enrichment, as part of the tritium calibration procedure. The Water Dating Lab at GNS Science has quantified the isotope shifts during the distillation process to allow for correction of the altered isotope data for hundreds of New Zealand groundwater samples.
This corrected stable isotope data can be mapped, enabling us to refine the current precipitation model and provide a spatiotemporal distribution of isotopes for identification of regional flow processes and a source of estimated isotopic values at unmonitored sites. This stable isotope data from groundwaters will be added to the database for rain to obtain a higher spatial resolution of stable isotope signature in New Zealand catchments.

Groundwater residence times and chemistry of the Pukekohe and Bombay basalt aquifers

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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. 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. 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. 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.

The effect of windbreaks on spray irrigation evaporation

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Conversion to modern sprinkler irrigation methods, namely centre pivot and lateral spray irrigation technology, has led to the removal of many windbreaks in Canterbury. Although originally installed largely to reduce the soil losses during high winds in summer, well-established shelterbelts also reduce water evaporation by reducing wind speeds across the pasture. The loss of spray irrigation water to evaporation is a waste of water and energy, but before such losses can be effectively reduced, we need to better understand the relationship between farm and climate conditions. We have determined a relationship between windbreak height and permeability, and sprinkler irrigation efficiency by measuring spray evaporation from an experimental “irrigator” fitted with Nelson Rotator R3000 and Spinner S3000 nozzles, under various climatic conditions, as well as wind speed reduction across pastures with multiple windbreaks of variable height and permeability. This showed that the increased wind speed due to windbreak removal could lead to significantly increased evapotranspiration and spray evaporation losses of up to 64% in the dry northwesterly Canterbury winds. However, irrigation water could be made to go further using irrigation systems that can operate in conjunction with lower but still effective windbreaks. With climate change projections indicating that the Canterbury region will become windier and hotter in the future, the role of effective windbreaks in reducing water losses will become increasingly important.