

IN THE MATTER OF the Resource Management Act 1991

AND

IN THE MATTER OF resource consent applications by Southdown Holdings Limited, Five Rivers Limited and Killermont Station Limited to take and use water in the Upper Waitaki Catchment.

1. STATEMENT OF EVIDENCE OF JOHN CHARLES BRIGHT

1.1 My full name is John Charles Bright. I am a Water Resources Engineer with 30 years experience. My relevant qualifications are B.Sc. (Physics, 1975), B.E. (Hons) (Agricultural, 1978), and Ph.D. (Agricultural Engineering, 1986). I am a member of the American Society of Civil Engineers and the New Zealand Hydrological Society. I am currently employed as the Managing Director of Aqualinc Research Ltd. A summary of my relevant expertise and experience is set out in my CV in **Appendix A**.

1.2 I confirm that I have read the Environment Court's Practice Note dated 31 March 2005 and that I have complied with it when preparing my written evidence and agree to comply with it when giving this oral evidence. This evidence is within my area of expertise outlined above.

2. SCOPE OF EVIDENCE

2.1 I have been asked to present evidence in relation to four farms in the Mackenzie Basin that are seeking consent to irrigate land. Specifically, my evidence covers the following matters for Glen Eyrie Downs, Ohau Downs, WHL Killermont and Killermont Station.

- (a) Development of Farm Environmental Management Plans (FEMPs) for each farm.
- (b) Describes the local groundwater environment that is potentially affected by each farm.
- (c) Identifies what the site specific nutrient discharge allowances are for each property.

- (d) Describes the on-farm nutrient leaching and groundwater quality monitoring proposed for each farm to ensure effects on groundwater are no more than minor.

2.2 In preparing this evidence, I have reviewed the following documents:

- MWRL Water Quality Study reports (GHD, August 2009a,b)
- Waitaki Catchment Groundwater Information (SKM, 2005)
- Seven day mean annual low flow mapping of the tributaries of the Waitaki River (Gabites and Horrel, 2005).
- Farm Environmental Management Plans for each of the four farms (GHD, 2009c,d,e; Aqualinc, 2009b)
- The evidence of Ian McIndoe, Dr Melissa Robson, John Kyle, Dr Greg Ryder, and Bob Engelbrecht.

3. DEVELOPMENT OF FARM ENVIRONMENTAL MANAGEMENT PLANS

3.1 FEMPs are one of four components of the comprehensive and robust approach proposed by the applicants to managing the effects of the proposed irrigation development on water quality. The four components are:

- Specify farm-specific Nutrient Discharge Allowances (NDA) such that full compliance with NDAs avoids significant adverse cumulative effects.
- Develop and implement a FEMP, based on an assessment of the risks of local adverse effects, for each farm. The FEMP includes monitoring, auditing, and corrective action requirements that ensure adverse effects are no more than minor.
- Monitor compliance with the NDA and with the FEMP
- Apply specified corrective action if monitoring and auditing shows corrective action thresholds or triggers have been reached.

3.2 NDAs for each property were developed as part of the Water Quality Study undertaken by GHD and were described in evidence by Dr Bright and Dr Robson on 21 September 2009. The proposed NDAs for Glen Eyrie Downs, Ohau Downs, WHL Killermont and Killermont Station are specified later in this evidence.

- 3.3 Development of the FEMPs is an iterative process during which the design of the farm system, its management, and the monitoring, auditing and corrective action requirements are progressively refined to avoid or mitigate potential adverse effects, and to meet farm feasibility requirements.
- 3.4 In May 2009 Aqualinc was engaged to develop FEMPs for the four properties concerned, with assistance from GHD staff. This included designing and undertaking on-farm field work required to obtain the data needed to develop the FEMPs. The majority of this work was undertaken by Dr Robson (GHD) and Dr Greg Barkle (Aqualinc), under my supervision.
- 3.5 The initial focus of the FEMP development process was to identify potentially sensitive receiving environments and to gain the detailed understanding of the proposed farm development required to use OVERSEER™ to estimate average annual nutrient leaching losses for each farm. This was achieved through a combination of site visits and discussions with farm owners, on-site mapping of water courses, and a review of ecological information provided by Dr Ryder, Dr Goldsmith and Dr Bartlett following their site visits.
- 3.6 Information on water courses and potentially sensitive areas was overlaid on maps of the preliminary irrigation system layout to identify areas potentially at risk of adverse effect. The design of the irrigation system was progressively modified to create un-irrigated, fenced off, riparian margins along almost all water ways.
- 3.7 Soil samples were taken, soil depth measured and the presence or absence of soil compaction layers tested using a soil penetrometer, at multiple sites along soil transects. Transects were selected to obtain data representative of the main mapped soil types on each property. This data was used in the set up of OVERSEER™, and to provide a benchmark against which future measurements can be compared to determine the rate of soil development. Soil data from the surveys conducted on Ohau Downs, Glen Eyrie Downs and WHL Killermont are presented in the relevant FEMPs.
- 3.8 OVERSEER™ was set up for each property, based on the proposed farm system, and used to estimate average annual losses of nitrate and phosphorous. The estimated losses were compared to each property's NDA.
- 3.9 In order to meet the NDA on properties for which dairy farming is proposed, it was necessary to re-design the farm system around a predominantly pasture cut-and-carry operation to minimise nitrate leaching due to urine patches. To achieve this three of the farms (Ohau Downs, Glen Eyrie Downs and WHL Killermont) propose to house the dairy herd in cubicle stables for a substantial proportion of the year. The fourth property (Killermont Station) proposes to supply

feed to adjacent dairy farms on a cut-and-carry basis, from "Pebble Block". The other areas of proposed irrigation on Killermont Station will be used to provide a more reliable supply of feed to their existing sheep and beef operations. The resulting farm systems are described in evidence by Mr McIndoe, Dr Robson and Mr Engelbrecht.

- 3.10 The key to reducing the nutrient losses to below the NDA is to minimise urine patches in the field, and the opportunity for phosphorous run-off into water ways, by collecting a substantial proportion of the dung and urine on hard-stand areas, separating the solids from the liquid, storing the solid and liquid effluent until it can be applied to land at a rate that matches plant uptake of nutrients, and applying the effluent to land very uniformly.
- 3.11 As part of our investigation of effluent management options for the proposed dairy farms I visited three cubicle barn dairy operations in South Canterbury. The proposed effluent management systems are substantially based on these successful South Canterbury systems. The principal differences between those proposed by the applicants and those in use in South Canterbury are the use of centre-pivot irrigators to apply the liquid effluent and the much larger storage capacity.
- 3.12 Centre-pivot irrigators are proposed for applying the liquid effluent because they can achieve high application uniformity, their application depth is adjustable over a very wide range to match the soils capacity to store liquid at the time of irrigation, and they will be in operation for normal irrigation purposes during the pasture growing season. It is proposed that liquid effluent be injected into the irrigation water supply at the time of normal irrigation.
- 3.13 Separation of liquid from solid effluent minimises the risk of sprinkle nozzle blockage and provides opportunity for any surplus effluent from the farm to be sold off the property as soil conditioner / organic fertiliser. The ability to sell effluent off the property provides an additional practical mitigation option, should monitoring indicate a developing risk of exceeding the NDA.
- 3.14 Sufficient capacity will be provided to store effluent for seven months so that effluent applications can be matched to nitrogen uptake by pasture. Applying nitrogen to pasture at a rate that matches plant uptake of N minimises the availability of nitrate for leaching and thus the risk of nitrate leaching to groundwater.
- 3.15 Having designed the proposed farm systems to meet their respective NDAs, a Farm Environmental Risk Assessment was carried out by Dr Robson to identify potential adverse effects local to the farm and not avoided or mitigated through complying with the specified NDA, and to develop options for avoiding or mitigating these potential local effects.

- 3.16 Assessment of the environmental risks associated with the proposed farm operations was based on mapped information, site visits, discussions with the farmers concerned, and ecological information to be presented in evidence by Dr Ryder, Dr Goldsmith and Dr Bartlett. More detailed information on the Farm Environmental Risk Assessment and the development of the FEMPs is presented in evidence by Dr Robson.
- 3.17 The proposed farm systems and their FEMPs have been reviewed by Mr Engelbrecht, a farm management consultant with more than 40 years experience. The review findings are presented in evidence by Mr Engelbrecht. In summary Mr Engelbrecht concludes that for almost all of the mitigation, monitoring and auditing options proposed in the individual property FEMPs there is a financial advantage in implementing them. Usually these are in the form of on-farm cost savings, without any loss of productivity. All of the mitigation options are, in Mr Engelbrecht's opinion, practical.

4. OHAU DOWNS

The local groundwater environment

The groundwater sub-catchment context of the farm

- 4.1 The location of Ohau Downs is shown in Appendix B, Figure 1. The proposed irrigated areas on this property lie within the Ohau and Wairepo groundwater sub-catchments, and within the Wairepo surface water sub-catchment, as defined by GHD (2009a) and shown in Appendix B, Figure 2. The bulk of the irrigated area lies within the Wairepo groundwater sub-catchment. The nature of the proposed irrigation development is described in evidence by Mr McIndoe and the proposed farm management practices are described, in an environmental management context, in evidence by Dr Robson.
- 4.2 Understanding of the nature of groundwater flow and interactions with surface water ways in the sub-catchment is derived from observations of surface water features, flow paths and measured flow rates, and groundwater flow modelling undertaken by GHD (2009b). This is a conventional approach to building an understanding of interactions between surface water and groundwater bodies.
- 4.3 The direction of groundwater flow across the majority of the property is understood to be in an east-south-east direction, in general alignment with the direction of flow of Wairepo stream, based on the results of the steady-state groundwater flow modelling undertaken for each sub-catchment by GHD. Beyond the property the groundwater flow is understood to turn to the north east and flow towards the Wairepo Arm of Lake Ruataniwha. Groundwater under the

part of the property that is within the Ohau groundwater sub-catchment flows in an east-north-east direction towards Lake Ruataniwha.

- 4.4 Wairepo Creek loses water to the groundwater system between the Upper Ford flow gauging site to the Lower Ford flow gauging site at a rate of about 12 litres/second/kilometre (Figure 24 in GHD, 2009b, included in Appendix B as Figure 3). Between the Lower Ford and Ohau Road Bridge all of the stream flow is diverted south into the Wairepo water race that runs south into the Willowburn basin. Wairepo Creek, downstream of Ohau Road Bridge, gains water from highland areas via Temple Creek, Barclays Creek, Spring Creek, Exhibition Gully and Sunset Gully.
- 4.5 The Wairepo surface water sub-catchment is estimated by GHD (2009b) to receive approximately 42 Mm³ of water per year from the highlands. GHD partition this volume into 20 Mm³ of groundwater flow and 22 Mm³ of surface-water flow. The groundwater sub-catchment also receives about 22 Mm³ of recharge from rainfall and existing irrigation of 1300 hectares. The total outflow is estimated to be 44 Mm³ of groundwater discharge and 13 Mm³ of surface-water flow to the Wairepo Arm of Lake Ruataniwha. The balance is diverted into the Willow Burn sub-catchment as stock water race flow.
- 4.6 All drainage from rainfall falling on the Ohau Downs property is understood to go to groundwater, there being no flow gaining reaches in the Wairepo Creek in the vicinity of Ohau Downs and no significant surface water features on that part of the property overlying the Ohau groundwater sub-catchment. This means nutrients leached below the rootzone do not pose a risk to stream health within and in the vicinity of the Ohau Downs property. Because nutrients in drainage water will be transported to groundwater, not surface water, the proposed NRRP rule that nutrient concentrations between the points where a river enters and exits a property not be raised by more than 0.01 mg per litre for N and 0.001 mg per litre for P will be met. During times of short duration high intensity rainfall events there may be some lateral subsurface drainage flow to surface water. If such events result in exceedance of the values specified in the rule, in my opinion the effects will be no more than minor because of their infrequency and short duration.

The water quality management Node Points between Ohau Downs and Lake Benmore.

- 4.7 The Water Quality Study demonstrates that drainage water from the property contributes to nutrient concentrations that are proposed to be monitored at the following Node Points: Wairepo Groundwater (at Wairepo Arm, Lake Ruataniwha), Wairepo Surface water (at Wairepo Arm, Lake Ruataniwha), and Ohau Groundwater (at Lake Ruataniwha).

Current groundwater quality

- 4.8 There is currently no data on the quality of groundwater underlying Ohau Downs. Observed mean nitrate-nitrogen concentrations in groundwater, at well H38/0036 located near the Wairepo Arm of Lake Ruataniwha, is 0.4 mg/litre, with a range of 0.01 to 0.72 mg/litre. However there is an increasing trend in concentration. It is probably that the increasing trend is due to recent irrigation development and that the concentration will increase to 1.13 mg/litre that GHD (2009b) has estimated to be the steady state concentration, given the current level of development. The observed mean nitrate-nitrogen concentration in Wairepo Creek near its outlet is 0.051 mg/litre, with a range of 0.002 to 0.16 mg/litre.

Effects of the proposed development on drainage inputs to the groundwater system

- 4.9 Irrigation of 2000 hectares, applying up to 600 mm/year, is expected to generate 270mm of drainage per annum on average. The mass of nitrate-nitrogen estimated by OVERSEER to be leached from the farm on an average annual basis is 44,762 kg. The total mass leached under an alternative farm system of intensive beef, sheep and dairy support is estimated to be 49,804 kg of nitrate-nitrogen.
- 4.10 Assuming that all of the nitrate-nitrogen that is leached from the farm comes from the irrigated area only, which is a very conservative assumption, the average annual nitrate-nitrogen concentration in the drainage water would be approximately 8.3 mg/litre. This means that water from even the most shallow of water supply bores would be less than the 11.3 mg/litre nitrate-nitrogen drinking water limit.

The site specific nutrient discharge allowances for this property

- 4.11 The site specific nutrient discharge allowances for this property are listed in the FEMP for Ohau Downs (GHD, 2009c) as follows:

Node Point	Total N Discharge from this farm (kg/year)	Total P Discharge from this farm (kg/year)
Wairepo groundwater	57,594	4,493
Ohau groundwater	55,594	5,893
Wairepo Creek surface water (ANZECC)	86,954	3,893
Northern Arm of Lake Benmore	69,454	3,793

- 4.12 The most constraining of these thresholds are Ohau groundwater (55,594 kg/year) for nitrogen and the Northern Arm of Lake Benmore (3,793 kg/year) for phosphorous. These figures are the proposed nutrient discharge allowances for Ohau Downs, as defined through the Water Quality Study (GHD, 2009a) and presented in the first joint statement of evidence by Dr Bright and Dr Robson on 21 September 2009.

Expected nutrient discharges from this property, and their expected effects

- 4.13 An assessment of the average annual nitrate leaching loss from the farm, when it is fully developed, has been made using OVERSEER™. OVERSEER™ input parameters were selected to represent the farm's climate and soils, and the proposed pasture management, animal management, irrigation management, effluent management, and farm production, as described in the Ohau Down's FEMP (GHD, 2009c). The assessment was undertaken by Dr Robson, who is qualified to use OVERSEER™ for this purpose.
- 4.14 The predicted average annual nitrogen leaching losses from the whole farm area after mitigation is 44,762kg of N, and 1,331 kg of P. For the alternative farm system the leaching losses are estimated to be 49,804 kg of N and 1,565 kg of P.
- 4.15 These quantities are comfortably within this farm's proposed nutrient discharge allowance. As described in the WQS (GHD, 2009a), nutrient discharges that do not exceed the specified nutrient discharge allowance for each specific farm are not expected to cause more than minor adverse effects on downstream receiving waters, such as nuisance periphyton growth, or a change in the trophic level index of Lake Ruataniwha or Lake Benmore.
- 4.16 As discussed in 4.6 above, nutrients leached below the rootzone on this property do not pose a risk to stream health within and in the vicinity of the Ohau Downs property because surface water ways flowing through the property lose water to groundwater.

5. GLEN EYRIE DOWNS

The local groundwater environment

The groundwater sub-catchment context of the farm

- 5.1 The location of Glen Eyrie Downs is shown in Appendix B, Figure 4. The proposed irrigation areas on this property straddle a groundwater flow divide that separates the Wairepo and Quail

Burn groundwater sub-catchments. Approximately 60% of the proposed irrigated area lies within the Wairepo sub-catchment and the balance in the Quail Burn.

- 5.2 The proposed irrigation development is described in detail in evidence by Mr McIndoe. Dr Robson describes in her evidence the farm management practices proposed for Glen Eyrie Downs to meet constraints on the cumulative effects of land-use on water bodies and to avoid, remedy or mitigate potential local adverse effects.
- 5.3 Understanding of the nature of groundwater flow, and of interactions between surface water and groundwater, in both sub-catchments is derived from observations of surface water features, flow paths and measured stream flow rates.
- 5.4 Drainage from the area of Glen Eyrie Downs that is to the north of the DOC reserve is expected to flow as groundwater through the Wairepo Basin in general alignment with the direction of flow in Wairepo Stream. It discharges into the Wairepo Arm of Lake Ruataniwha.
- 5.5 As described in Section 4, drainage beneath the root zone in the northern part of Glen Eyrie downs is expected to contribute to groundwater flow in the sub-catchment, and not to stream flow on the property or close to the property.
- 5.6 Drainage from the area of Glen Eyrie Downs that lies to the south of the DOC reserve flows south through the Quail Burn sub-catchment to the Ahuriri River basin and ultimately into the Ahuriri Arm of Lake Benmore.
- 5.7 Groundwater and surface water flows from the Quail Burn basin are funnelled through a pass in the Cloud Hills Range and discharge into the Ahuriri sub-catchment. Flow gauging data shows that the Quail Burn loses about 400 l/s to groundwater in its upper reaches (upstream of Glen Eyrie Downs), but gains about 400 l/s in its mid and lower reaches. Drainage water from the area that is proposed to be irrigated and which lies within the Quail Burn sub-catchment is expected to contribute to the surface water flow gain.
- 5.8 The Quail Burn sub-catchment is estimated to receive a total of 20.6 Mm³ of water flow per year from the Diadem Ranges. The division of this volume between regional groundwater and surface water flows was estimated to be 5.3 Mm³ per year and 15.3 Mm³ per year respectively (GHD 2009b). Recharge from drainage within the basin is estimated to be 15.7 Mm³ per year, under existing conditions. Groundwater discharge from the Quail Burn into the Ahuriri sub-catchment is estimated to be 17.7 m³ per year, with 18.7 Mm³ per year being discharged in the Ahuriri River as surface water. The transfer of water from groundwater to surface water within the Quail Burn is therefore 3.4 Mm³ per year.

- 5.9 Water and nutrients draining below the rootzone are therefore expected to contribute to flow and nutrient load in the Quail Burn.
- 5.10 The effects on surface water quality of developing all of the proposed irrigated land in the Quail Burn were assessed in the Water Quality Study (GHD, 2009a), by modelling, to be no more than minor providing the nutrient discharge from each property was less than the NDA specified for each property. As shown in 5.20 below, the proposed development of Glen Eyrie Downs, factoring in the benefits of the proposed mitigation, complies with the NDA specified for it by the WQS.
- 5.11 The observed mean nitrate-nitrogen concentration in the Quail Burn at Hen Burn Road is 0.014 mg/litre, with a range of 0.002 to 0.032. This is the mean of all samples listed in Appendix AA of the WQS Summary Report (GHD,2009a). The nitrate-nitrogen concentration for the Quail Burn at mean flow predicted by the GHD modelling is 0.014 mg/litre. This is a very good match between measured and modelled values. However it must be tempered by the fact that the flow rate at the time the samples were taken is not reported, apart from the three samples obtained by GHD, so the robustness of the comparison is unknown. Almost all of the samples were taken in the period October to April over the last five years. As such they probably sample a reasonably wide range of flows and are broadly representative. The one sample that is identifiable as having been taken at about the mean flow had a nitrate-nitrogen concentration of 0.002 mg/litre. The GHD model is more likely to be overestimating nitrate-nitrogen concentration, and therefore be conservative in its assessment of land-use impacts, than to be underestimating nitrate-nitrogen concentration.
- 5.12 On balance, it is my opinion that the GHD model of surface and groundwater flows in the Quail Burn gives representative results and consequently that full development of the proposed irrigation will result in adverse effects that are no more than minor, providing all applicant properties comply with their NDA.

The water quality management Node Points between Glen Eyrie Downs and Lake Benmore.

- 5.13 Drainage water from the property is expected to contribute to nutrient concentrations that are proposed to be monitored at the following Node Points: Quail Burn groundwater, Quail Burn surface water (both at the sub-catchment outlet to the Ahuriri River Basin), Ahuriri surface water node, Wairepo groundwater (at Wairepo Arm, Lake Ruataniwha), and the Ahuriri Arm of Lake Benmore.

Current groundwater quality

- 5.14 While there is no groundwater quality data for the Quail Burn, measured nitrate-nitrogen concentrations in the neighbouring Hen Burn catchment are 0.55 mg/litre. There is currently no irrigation development in the Quail Burn and very little irrigation development in the Hen Burn.
- 5.15 GHD's (2009b) modelled nitrate-nitrogen concentration in drainage water on a basin-wide basis, is 1.39 mg/litre.
- 5.16 These data indicate that the GHD model may be providing conservative overestimates of the effects of land-use activity on nitrate-nitrogen concentrations in the Quail Burn.

Effects of the proposed development on drainage inputs to the groundwater system

- 5.17 The proposed irrigation of 2068 hectares, applying up to 600 mm/year, is expected to generate 325mm of drainage per year on average. The mass of nitrate-nitrogen estimated using OVERSEER™ to be leached from the farm on an average annual basis is 30,781 kg/year. The average annual nitrate-nitrogen concentration in the drainage water is estimated to be approximately 4.6 mg/litre, assuming the proposed development occurs and that all of the nitrogen from the farm is actually leached from the irrigated area only. This is significantly less than the drinking water standard of 11.3 mg/litre of nitrate-nitrogen which means shallow bores could be safely used for drinking water supply.

The site specific nutrient discharge allowances for this property

- 5.18 The site specific nutrient discharge allowances for this property are listed in the FEMP for Glen Eyrie Downs (GHD, 2009d) as follows:

Node Point	Total N Discharge from this farm (kg/year)	Total P Discharge from this farm (kg/year)
Wairepo groundwater	38,139	2,344
Wairepo Creek surface water (ANZECC)	66,968	1,724
Quail Burn surface water (periphyton)	65,727	3,172
Quail Burn groundwater	64,900	3,792
Quail Burn surface water(ANZECC)	69,656	2,758
Ahuriri River at Ahuriri Arm of L Benmore (periphyton)	67,175	1,931

Ahuriri River at Ahuriri Arm of L Benmore (ANZECC)	72,054	3,792
Ahuriri Arm of Lake Benmore	50,030	1,621

- 5.19 The most constraining of these thresholds are the Wairepo groundwater threshold for nitrogen (38,139 kg/year) and the Ahuriri Arm of Lake Benmore for phosphorous (1,621 kg/year). These figures are the proposed nutrient discharge allowances for Glen Eyrie Downs, as defined through the GHD Water Quality Study (GHD, 2009a) and presented in the Glen Eyrie Downs Farm Environmental Management Plan (GHD, 2009d).

Expected nutrient discharges from this property, and their expected effects

- 5.20 An OVERSEER™ assessment of the nutrient losses from Glen Eyrie Downs, when it is fully developed and managed in accordance with its Farm Environmental Management Plan, gives average annual nutrient losses of 31,155 kg of Nitrogen per year, and 1,603 kg of phosphorous per year.
- 5.21 Both loss rates are below Glen Eyrie Down's nutrient discharge allowance. The proposed development of this farm is not therefore expected to generate more than minor adverse effects on downstream water bodies.

6. WHL KILLERMONT

The local groundwater environment

The groundwater sub-catchment context of the farm

- 6.1 The location of WHL Killermont is shown in Appendix B, Figure 5. The proposed irrigated area lies within the Ahuriri River sub-catchment and the Omarama Stream sub-catchment, as defined by GHD (2009a) and shown in Appendix B, Figure 2. A description of the proposed irrigation development is provided in evidence by Mr McIndoe. The farm management practices proposed for this farm are described in evidenced by Dr Robson.
- 6.2 Well H39/0003 is located in approximately the middle of the proposed irrigated area. The water table there is 3 metres below ground level. Beneath the 600mm depth of topsoil and clay the stratigraphy has been described as greywacke gravels, becoming coarser with depth.

- 6.3 Given the depth to the water table and the free draining materials, it is highly likely that all water draining below the rootzone drains straight to groundwater with no lateral movement to the Ahuriri River or the Omarama Stream, between which the farm is located.
- 6.4 Concurrent measurements of Ahuriri River flow indicate that the river loses significant flow to groundwater between Clay Cliffs and SH8 Bridge. White et.al. (2004) estimated that downstream of Clay Cliffs the river loses $1.5 \text{ m}^3/\text{sec}$ of flow to groundwater. At the upper end of this losing reach the river is understood to be perched significantly above groundwater (GHD, 2009b). In the vicinity of SH8 Bridge surface flow features indicated that groundwater begins to emerge at the surface, giving rise to a number of small streams. Current understanding is, therefore, that the Ahuriri River, in the vicinity of Clay Cliffs is perched above groundwater and the degree of perching reduces steadily as one moves downstream so that by SH8 the river and groundwater are closely coupled and the river begins to gain flow from groundwater. Losses from the Ahuriri to groundwater are considered to be at their highest (over the reach in question) near Clay Cliffs and progressively reduce as one moves downstream, past WHL Killermont, and onto SH8 Bridge.
- 6.5 Flow gauging data for Omarama Stream indicate that the stream gains flow over the reach from Swamp Outlet to Wardells Bridge. Probably sources of flow include drainage from Tara Hills surface irrigation as well as from the highland areas. Modelled piezometric contours (GHD, 2009b, Fig 18) indicate that groundwater flow is in a north-easterly direction across Killermont from the Omarama Swamp.
- 6.6 All water draining below the rootzone on Killermont is therefore expected to flow to regional groundwater in the Ahuriri River basin and to not contribute directly to Ahuriri River or to Omarama Stream flow locally. Omarama Stream flow between the points where the surface water ways 'enter' and 'exit' the property. The proposed development is therefore very unlikely to result in an increase in nutrient concentration of 0.01 mg per litre of N or 0.001 mg per litre of P
- 6.7 The Ahuriri River basin receives surface water and groundwater flows from the Quail Burn, Hen Burn, Willow Burn and Omarama Stream, as well as from the Ahuriri catchment above the South Diadem recorder site. The volume of drainage water from rainfall and irrigation in the Ahuriri River Basin, at 6.9 Mm^3 per year, is approximately 0.6% of the total groundwater and surface water flow through the basin.

The water quality management Node Points between Killermont and Lake Benmore.

- 6.8 Drainage water from Killermont is expected to contribute to nutrient concentrations that are proposed to be monitored at the following Node Points: Ahuriri groundwater, Ahuriri surface water (both at the sub-catchment outlet in the vicinity of SH8 Bridge), and the Ahuriri Arm of Lake Benmore.

Current groundwater quality

- 6.9 The nitrate-nitrogen concentration in groundwater in the Ahuriri River Basin is approximately 0.1 mg/litre, based on monitoring of well H39/0002 located close to Omarama, upstream from the Ahuriri River basin node point. This indicates that there is very little impact on groundwater quality from existing agricultural activity and available assimilative capacity with respect to the groundwater quality threshold.

Effects of the proposed development on drainage inputs to the groundwater system

- 6.10 Irrigation of 1100 hectares, applying up to 600 mm/year, is expected to generate 208mm of drainage per annum on average, based on modelled drainage under irrigated agriculture (Aqualinc, 2009a). The mass of nitrate-nitrogen estimated by OVERSEER to be leached from the farm on an average annual basis is 17,857 kg.
- 6.11 Assuming that all of the nitrate-nitrogen that is leached from the farm comes from the irrigated area only, which is a conservative assumption, the average annual nitrate-nitrogen concentration in the drainage water would be approximately 7.7 mg/litre. This is significantly less than the 11.3 mg/litre nitrate-nitrogen drinking water limit, meaning that shallow bores could be used as a source of potable water.

The site specific nutrient discharge allowances for this property

- 6.12 The site specific nutrient discharge allowances for Killermont are listed in its FEMP (GHD, 2009e) as follows:

Node Point	Total N Discharge from this farm (kg/year)	Total P Discharge from this farm (kg/year)
Ahuriri groundwater	46,486	1,669
Ahuriri River at Ahuriri Arm of L Benmore (periphyton)	47,640	620

Ahuriri River at Ahuriri Arm of L Benmore (ANZECC)	46,486	1669
Ahuriri Arm of Lake Benmore	35,262	515

Expected nutrient discharges from this property, and their expected effects

- 6.13 An assessment of the average annual nitrate leaching loss from Killermont, when it is fully developed, has been made using OVERSEER™. OVERSEER™ input parameters were selected to represent the farm's climate and soils, and the proposed pasture management, animal management, irrigation management, effluent management, and farm production, as described in the Killermont FEMP (GHD, 2009e). The assessment was undertaken by Dr Robson, who is qualified to use OVERSEER™ for this purpose.
- 6.14 The predicted average annual nitrogen leaching losses from the whole farm area is 17,857kg of N, and 442 kg of P.
- 6.15 The quantity of nitrogen leached is substantially below the specific nutrient discharge allowance for Killermont, and within this farm's proposed nutrient discharge allowance for phosphorous. As described in the WQS (GHD, 2009a), nutrient discharges that do not exceed the specified nutrient discharge allowance for each specific farm are not expected to cause more than minor adverse effects on downstream receiving waters.

7. KILLERMONT STATION

The local groundwater environment

The groundwater sub-catchment context of the farm

- 7.1 The location of Killermont Station is shown in Appendix B, Figure 6. There are four proposed irrigated areas: Frosty Gully Scheme (28ha), Manuka Creek Scheme (75ha), Woolshed Block (300ha) and Pebbly Block (216ha). Frosty Gully and Manuka Creek schemes lie entirely within the Omarama Stream sub-catchment, Woolshed Block is divided equally between the Omarama Stream sub-catchment and the Ahuriri River sub-catchment, and Pebbly Block lies entirely within the Ahuriri River sub-catchment, as defined by GHD (2009a) and shown in Appendix B, Figure 2. A description of the proposed irrigation development is provided in evidence by Mr McIndoe. The farm management practices proposed for this farm are described in evidenced by Dr Robson.

- 7.2 Static groundwater level has been measured to be approximately 38 metres below ground at well H39/0045, which is located on Killermont Station, just to the north of the proposed Woolshed Block.

Current groundwater quality

- 7.3 The nitrate-nitrogen concentration in groundwater in the Ahuriri River Basin is approximately 0.1 mg/litre, based on monitoring of well H39/0002 located close to Omarama, upstream from the Ahuriri River basin node point. This indicates that there is very little impact on groundwater quality from existing agricultural activity and available assimilative capacity with respect to the groundwater quality threshold.

Effects of the proposed development on drainage inputs to the groundwater system

- 7.4 Irrigation of 619 hectares, applying up to 600 mm/year, is expected to generate 208mm of drainage per annum on average, based on modelled drainage under irrigated agriculture (Aqualinc, 2009a). The mass of nitrate-nitrogen estimated by OVERSEER to be leached from the farm on an average annual basis is 9,254 kg. If no irrigation occurs on Pebbly Block and the farm system is changed accordingly, the average annual nitrate-nitrogen leaching loss reduces to 8,860 kg.
- 7.5 Making the conservative assumption that all of the nitrate-nitrogen that is leached from the farm comes from the irrigated area only, the average annual nitrate-nitrogen concentration in the drainage water would be approximately 7.2 mg/litre. This is significantly less than the 11.3 mg/litre nitrate-nitrogen drinking water limit, meaning that shallow bores could be used as a source of potable water.

The water quality management Node Points between Killermont Station and Lake Benmore.

- 7.6 Drainage water from Killermont Station will contribute to nutrient concentrations that are proposed to be monitored at the following Node Points: Ahuriri groundwater, Ahuriri surface water (both at the sub-catchment outlet in the vicinity of SH8 Bridge), and the Ahuriri Arm of Lake Benmore.

The site specific nutrient discharge allowances for this property

- 7.7 The most stringent WQS thresholds for Killermont Station are those of the Ahuriri Arm of Lake Benmore. Killermont Station's Nutrient Discharge Allowances are listed in its FEMP (Aqualinc,

2009b) as 9,440 kg N per year (including a 1500 kg re-allocation from WHL Killermont) and 179 kg P per year.

Expected nutrient discharges from this property, and their expected effects

- 7.8 An assessment of the average annual nitrate leaching loss from Killermont Station, when it is fully developed, has been made using OVERSEER™. OVERSEER™ input parameters were selected to represent the farm's climate and soils, and the proposed pasture management, animal management, irrigation management, effluent management, and farm production, as described in the Killermont Station FEMP (Aqualinc, 2009b). The assessment was undertaken for Aqualinc by Dr Robson, who is qualified to use OVERSEER™ for this purpose.
- 7.9 The predicted average annual nitrogen leaching losses from the whole farm area is 9,254 kg of N, and 172 kg of P.
- 7.10 The discharge of nutrients to groundwater are estimated to not cause more than minor adverse effects on downstream receiving waters under the proposed development and associated FEMP because they do not exceed the nutrient discharge allowance specified for Killermont Station. It should be noted that 1500 kg of WHL Killermont's NDA for nitrogen has been granted to Killermont Station.
- 7.11 The Ahuriri River, adjacent to Killermont Station, is perched about 40 metres above groundwater level, as measured in well H39/0045 (GHD, 2009b). This, together with the generally free draining soils in the areas to be developed for irrigation, means that drainage below the root zone will recharge groundwater and will not move laterally to the Ahuriri River where it may have had a local or on-site adverse affect on surface water quality. Simultaneous flow gauging of the Ahuriri River has shown that the river recharges groundwater through the section of river that lies between Clay Cliffs, on the true left bank, and Pebbly Block on the true right bank (White, et.al., 2004). I consider it very unlikely that drainage water from Pebbly Block would contribute nutrients to the Ahuriri River at or in the vicinity of Pebbly Block and, therefore, any adverse effects of irrigation on Pebbly Block are unlikely to be more than minor.
- 7.12 The modelled direction of groundwater flow (north-east) is consistent with the spatial pattern of water inputs and the emergence of groundwater into the Ahiriri River flow near Omarama. The direction of flow indicates that drainage water from the area to be irrigated will not contribute to Omarama Stream flow, and therefore will not have a more than minor adverse affect on its water quality.

- 7.13 The proposed development is therefore very unlikely to result in an increase in nutrient concentration of 0.01 mg per litre of N or 0.001 mg per litre of P in surface water ways.

8. MONITORING COMPLIANCE WITH FEMPS

- 8.1 Farm Environmental Management Plans have been prepared for Ohau Downs, Glen Eyrie Downs, WHL Killermont and Killermont Station that include nutrient thresholds specific to each farm to ensure that discharges of nitrogen and phosphorus to waterways from the proposed farm operations do not result in potentially significant adverse effects on local streams and receiving water bodies. On-farm nutrient management and mitigation approaches have been designed to achieve these thresholds, and to address local issues and the ecological imperatives highlighted through the work of Dr Bartlett, Dr Ryder, Dr Goldsmith and, recently, Mr Mikaere.
- 8.2 Compliance with these thresholds will be essential to ensure that cumulative effects on surface water bodies of the Upper Waitaki Basin are protected and environmental effects are no more than minor. The Farm Environmental Management Plans set out the monitoring and reporting required to demonstrate compliance with the thresholds.
- 8.3 The FEMPs detail comprehensive monitoring and auditing requirements to demonstrate, on an annual basis, compliance with the NDAs specified by the WQS as well as compliance with actions that mitigate the on-site or local effects of the proposed developments.
- 8.4 One of the most important points of obligation, and therefore monitoring points, is nutrient leached below the rootzone. Its importance lies in the fact that monitoring at this point provides feedback on the effects of the activity at the end of the first year of operation. In practice it provides feedback on compliance, without any time lag.
- 8.5 It is practical and robust to do this using a combination of strategically placed lysimeters in combination with the use of OVERSEER™.
- 8.6 It is recommended that sets of three drainage lysimeters be installed on the first blocks to be developed for irrigation, and be operated continuously for the duration of the consents. The sets of lysimeters should be strategically located on WHL Killermont in an area that has a plant available water capacity of 45mm, on Ohau Downs in an area that has a plant available water capacity of 65mm, and on Glen Eyrie Downs in an area that has a plant available water capacity of 120mm. The proposed sites (see Appendix B, Figure 7) will provide leaching measurements across a range of soils and climate settings.

- 8.7 Early installation of these lysimeters provides opportunity to measure actual nutrient losses under the first developed areas and to use this data to fine tune OVERSEER™. They should be installed prior to the commencement of irrigation so that leaching can be monitored for the whole of the first year of irrigation system operation.
- 8.8 The lysimeters could be to the design developed by the late John Milne and myself for use on the Lincoln University Dairy Farm. The 60 lysimeters built and installed to this design have been operating successfully for several years.
- 8.9 For each lysimeter it is recommended that the following monitoring take place:
- Continuous measurement of drainage, rainfall and irrigation.
 - Drainage-volume-based sampling of the drainage water and analysis for nitrogen, phosphorous and carbon species.
 - Recording of the date and dry-weight of pasture removed from lysimeters on the date on which the rest of the paddock is harvested by cut and carry, or is grazed.
 - Recording of dates and amounts of all fertilizer and effluent applied to land. Effluent to be sampled and its composition analysed.
- 8.10 At the end of each year of operation, the total annual measured N leached will be compared with the OVERSEER™ estimates of the average annual N leached.
- 8.11 If the actual N leached is greater than the farms NDA then the following corrective action is recommended:
- 8.12 A new NDA is calculated by multiplying the current NDA by the ratio of the OVERSEER™ estimated N leached to the actual N leached.
- 8.13 The farm management is then revised so that it results in an OVERSEER™ estimate of N leached that is less than the new NDA.
- 8.14 It is my opinion that it is unlikely that the average measured annual nitrate losses will exceed the OVERSEER™ estimated annual nitrate losses. I base this on the following observation.
- 8.15 The nitrate leaching losses estimated for the three proposed farm systems which are primarily cut-and-carry operations, and Killermont Station's Pebbly Block, are between ½ and 1/3 of the nitrate losses for a conventional grazed dairy farm.

- 8.16 In a review of nitrogen leaching losses from different forms and rates of farm effluent applications, Cameron and Di (2004) report that farm dairy effluent applied as 4 split applications of 50 kg N / ha per year using flood irrigation resulted in an annual loss of nitrogen of 6 kg N /ha. In contrast annual loss of nitrogen from grazed pasture was determined to be 33 kg N / ha. The N leached due to the cut and carry operation was about 1/5 of the N leached under grazed pasture.
- 8.17 I conclude from the Cameron and Di review that the benefits of a cut and carry operation, in terms of the reduction in N leached, are very likely to be underestimated by OVERSEER™. The estimated N leaching losses from the (primarily) pasture cut-and-carry areas of the four farms that are the subject of this evidence are therefore likely to be conservative over estimates.

9. CONCLUSIONS

- 9.1 It is unlikely that the proposed developments on any of the four farms will cause significant adverse local effects because the nitrate concentration in drainage water is low, relative to the drinking water standard, and very little drainage water is expected to enter local surface waterways.
- 9.2 The WQS (GHD, 2009a) set farm-specific nutrient discharge allowances which, when complied with, are unlikely to cause adverse cumulative effects on water quality that are more than minor.
- 9.3 The farm management systems proposed for Ohau Downs, Glen Eyrie Downs and WHL Killermont, and Killermont Station, along with the management actions specified in each property's Farm Environmental Management Plan, result in nutrient discharges that are lower than the specified nutrient discharge allowances.
- 9.4 All four farms meet the relevant proposed WQS thresholds for avoiding significant adverse effects on Upper Waitaki water bodies.

10. REFERENCES

Aqualinc (2009a) Irrigation and Drainage Modelling of the Upper Waitaki Basin. Report C08054/1 prepared for GHD Ltd.

Aqualinc (2009b) Farm Environmental Management Plan. Report for Killermont Station Limited. Killermont Station. August 2009.

Cameron, K.C. and Di, H.J. (2004) Nitrogen leaching losses from different forms and rates of farm effluent applied to a Templeton soil in Canterbury, New Zealand. NZ Journal of Agricultural Research. Vol 47: 429-437

Gabites, S. and Horrell, G. Seven day mean annual low flow mapping of the tributaries of the Waitaki River. ECan Report R05/16. 2005

GHD (2009a) Cumulative Water Quality Effects of Nutrients from Agricultural Intensification in the Upper Waitaki Catchment: Summary Report. Prepared for Mackenzie Water Research Ltd. August 2009-09-02

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GHD (2009c) Farm Environmental Management Plan. Report for Five Rivers Limited. Ohau Downs Station. August 2009

GHD (2009d) Farm Environmental Management Plan. Report for Williamson Holdings Limited. Glen Eyrie Downs Station. August 2009.

GHD (2009e) Farm Environmental Management Plan. Report for Williamson Holdings Limited. Killermont. August 2009.

SKM (2005) Waitaki Catchment Groundwater Information. Report prepared for Ministry for the Environment.

White, P., Reeves, R., Barrell, D. and Smith, M. (2004) Groundwater in the Upper Waitaki Catchment. A report prepared for Glassons Potts Fowler.

John Charles Bright

Appendix A: Curriculum Vitae

Full name:

Dr John Charles Bright

Present position:

Aqualinc Managing Director

Research Programme Manager: Groundwater Quality Protection & Groundwater Allocation

Present employer:

Aqualinc Research Ltd.

Present work address:

Level 3, 11 Deans Avenue, Riccarton, Christchurch

Hapu/Iwi: *(if applicable)*

Academic qualifications: *(including year awarded)*

BSc (Physics) University of Canterbury 1976

BE (Honours) University of Canterbury 1979

PhD (Engineering) University of Canterbury 1986

Years as a practising researcher: 9 FTE (18 @ 0.5 FTE researcher)

Track Record

Research Title	Principal outcome	Principal end user and contact
Groundwater Quality Protection: <i>Programme Leader</i> (LVLX0302) (LVL805) 1998-2009	Increased scientific defensibility of Policy and Consent decisions in regard to managing land-use effects on groundwater quality. Increased research capacity – 6 successful Ph.D. research projects from this programme.	Regional Councils Dr Ken Taylor (Environment Canterbury)
Groundwater Allocation: <i>Programme Leader</i> (LVLX0303)	Increased capability for quantifying the relationship between in-stream and intrinsic values for water and water depths and flows. New water allocation framework for New Zealand developed for consultation with stakeholders. New water allocation framework is currently the subject of a feasibility study by Marlborough District Council.	New Zealand Business Council for Sustainable Development. Peter Neilson. Marlborough District Council. Pere Hawes.
Irrigation Demand	More rigorous technical / policy	Irrigation New Zealand. Dr

Management: <i>Principal Investigator</i> 2008-09	analysis underpinning Regional Plans. New approach to irrigation water demand management.	Terry Heiler.
Sustainable Irrigated Agriculture Project. <i>Lead Investigator</i> 2000-07	Understanding that irrigation system design is the key factor limiting irrigation efficiency. Definition of key performance indicators for irrigation, Irrigation Design Code of Practice	MAF and Irrigation New Zealand. Grant McFadden and Dr Terry Heiler.
Strategic Water Management <i>Lead investigator</i> 2000-09	A clear understanding about the long term water supply reliability issues facing New Zealand, and options for addressing them.	Regional Councils (Southland, Canterbury, Tasman, & parts of Marlborough, Wellington, Hawkes Bay & Auckland)
Canterbury Groundwater Model <i>Programme leader</i> 2000-09	Increased understanding of Canterbury's groundwater system. Information from application of this model has been used by: <ul style="list-style-type: none"> • ECan (Lynton Dairy consent) • Applicants for groundwater take consents – Rakaia Selwyn, Selwyn Waimakariri, Valetta groundwater zones • DairyNZ to increase understanding of effects of dynamic allocation of groundwater. • Central Plains Water Ltd. • Barrhill Chertsey Irrigation Co. 	Resource consent applicants. DairyNZ (Dr Mike Scarsbrook) URS (Ltd) (consultants) (Mr Walter Lewthwaite)

Honours/distinctions/membership of societies, institutions, committees:

Member, MfE & FRST Water Research Strategy development committee, 2009.

Member, Advisory Board, Canterbury and Lincoln Universities Joint Water Management Centre, 2009

Chairperson, Natural Resources Engineering Advisory Board,

Canterbury University, 2007-2008

Board Member, NZ Irrigation Association, 2001-2004

Member, PGSF Review Committee, 1997

The Arch Campbell Award (NZ Water & Wastes Association), 1997

Lincoln University Foundation Award, 1991

State Services Commission Study Award, 1981-85

RDK Agricultural Engineering Award, 1978

Member, American Society of Civil Engineers

Member, NZ Hydrological Society

Professional positions held: (*years, position, institution, activity*)

2004 – 2008, Managing Director, Aqualinc,

Business management (50%), Research Programme leadership (50%)

1996 – 2003, Research Manager, LVL,

Business management (50%), Research, Programme leader (50%)

1993 – 1995, Senior Research Engineer, LVL,

Research (100%)

1987 – 1992, Senior Engineer, LVL, Software engineering

1985 – 1986, Engineer, MWD, Water Resources Engineering

1981 – 1985, Engineer, MWD, Postgraduate Research

1979 – 1981, Assistant Engineer, MWD, Irrigation Engineering

Present research/professional speciality:

Integrated water resource management, groundwater quantity and quality management, water demand management, computational hydraulics, irrigation and drainage engineering.

Number of refereed publications: 18

Number of patents: 0

Number of significant publications not included in the above: 70

List of major achievements pertinent to this research proposal:

1. Major publications (in the last five years).

- Bright, JC. (2008): A New Approach to Water Allocation Management in New Zealand. Water Down Under 2008 - 4th International Conference on Water Resources and Environment Research, Adelaide, April 2008. pp 1606-1617.
- Close, ME; Bright, JC; Fuli Wang; Liping Pang; and Mannering, M (2008). Key features of artificial aquifers for modelling contaminant transport. Accepted for publication in Ground Water. DOI 10.1111/J.1745-6584.2008.00474.X
- Painter BDM and Bright JC (2006): Adaptive Management of Water Resources: A New Zealand Case Study, *Proceedings of "2006 AWRA Summer Speciality Conference: Adaptive Management of Water Resources"*. American Water Resources Association.
- Painter, B.D.M., and Bright, J.C. (2006) Participatory & adaptive management of groundwater allocation: a Selwyn catchment case study, Proceedings of "NZWWA Water Conference 2006 - Enough for Everyone?" Oct 11-13, 2006, Christchurch, New Zealand, CD Rom NZWWA06finalpaper00075.pdf.
- Brown, Peter., Cochrane, Thomas., Krom, Thomas., Painter, David., and Bright, John. (2006) Optimal on-farm multicrop irrigation scheduling with limited water supply. *Computers in agriculture and natural resources: Proceedings of the 4th World Congress, July 2006*.
- Yoon, H; Close, ME; Huang, J; Brooks, MC; Wood, AL; Bright, JC; Goltz, MN. (2006) Validation of mass flux measurement methods in an artificial aquifer. *Remediation of chlorinated and recalcitrant compounds. The 5th International Battelle conference, Monterey, California, May 22-25, 2006*.
- Good J. and Bright JC (2005): An Object-Oriented Software Framework for the Farm-Scale Simulation of Nitrate Leaching from Agricultural Land Uses – IRAP FarmSim. *In Zerger, A. and*

Argent, R.M. (eds) *MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand*, December 2005, pp. 170-176. ISBN: 0-9758400-2-9

- Kim, SJ; Huang, J; Close, ME; Bright, JC; and Goltz, MN. (2005) Use of an Innovative Mass Flux Measurement Method to Evaluate Groundwater Source Remediation Technology Performance. *CSR-1 conference, Chicago*. October 23-27, 2005
- Close, ME; Bright, JC; Stanton, G; and Flintoft, MJ. (2004) Sampling the vadose zone in stony alluvial gravels using suction cups. *Journal of Hydrology (New Zealand)* 43(2): 77-94.
- Wang, F., and Bright, J. (2004) Scale effect and calibration of contaminant transport models, *Ground Water* 42(5): 760-766.
- Wang, F; Bright, J; Hadfield, J (2004): A three-dimensional N-dynamics model and its application to simulating nitrate transport in an alluvial aquifer. *Journal of Hydrology (NZ)* 42(2):145-162.
- Lowry, T; Bright, J; White, P; Close, M; Robb, C; Cameron, S (2003): Groundwater resource management in New Zealand, information gaps analysis: A case study. *International Journal of Water Resources Development* 19(4): 579 – 592.

2. Major achievements in commercial, social and environmental areas (including evidence of relationship management, business, commercial and project management expertise, if relevant).

- Development of a new water allocation framework for New Zealand under a commission from the New Zealand Business Council for Sustainable Development. The allocation framework includes water quality management / assimilative capacity accounting. The feasibility of its application throughout Marlborough District is currently under investigation.
- Development of FarmSim, a tool for predicting the farm scale effects of different types and intensities of land-use on nitrate leaching to groundwater. This has involved a substantial collaborative effort from 6 research providers in the IRAP partnership.
- Development and testing of a method for quantifying the potential effects of climate change on irrigation demand and groundwater recharge, river flow, and water supply reliability.
- Development of the strategic water study methodology that compares potential long-term water demand from all sectors with the supply characteristics of surface and groundwater resources to identify surpluses and shortfalls, and to determine how to reliably meet long-term water demand. This methodology has been applied in Wairarapa, Marlborough, Tasman, Canterbury, Southland, Hawkes Bay and Auckland. The detail of its application continues to evolve, in response to regional differences, and improve, as we learn from each project.
- Expert witness in five Resource Consent application hearings regarding large-scale development of surface and groundwater resources, and in hearings for the proposed Natural Resources Regional Plan for Canterbury.
- Capability development: I have secured research funding that has enabled four of my staff to gain their PhD's over the last 12 years, and funded two other PhD programmes at Lincoln University.

3. Demonstration of relationships with end-users.

- Co-author of groundwater allocation management guidelines developed with MAF/MfE support for regional council use.
- Assisting several community groups (Rakaia-Selwyn Water User Cluster Groups) and sector groups (Fonterra, DairyNZ, Irrigation NZ) prepare submissions on proposed regional plans, or variations to plans, in Canterbury and Waikato regions.
- Invited speaker at several national conferences on water management over the past two years and at a hui organised by Ngai Tahu in 2008 as part of their deliberations over water management policy.
 - ❖ National Integrated Environmental Management Forum, Wellington, 2008.
 - ❖ Briefing of Cabinet Ministers on Canterbury Water Management, Christchurch, 2008.
 - ❖ Climate Change Workshop, Blenheim, 2008.
 - ❖ NZ Institute of Agricultural and Horticultural Sciences, Christchurch, 2007

- ❖ Horticulture NZ Conference, Auckland, 2006.
- Averaged approximately one presentation per month over the past two years, to community groups and water sector stakeholders on groundwater, water allocation and strategic water management issues.

Appendix B: Maps and Figures.