

CHALLENGES IN CUMULATIVE IMPACT ASSESSMENT: CASE STUDIES FROM CANTERBURY, NEW ZEALAND

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ABSTRACT

As sustainability limits are being reached there is a need to undertake cumulative impact assessments as well as assessments of a project's environmental effects. In Canterbury sustainability limits were being reached in relation to water availability for further irrigation development and in relation to water quality decline due to diffuse pollution from land use intensification associated with irrigation. This paper identifies some of the challenges in cumulative impact assessment from the experience of its application to water management in Canterbury. The modelling of cumulative effects on Lake Benmore water quality due to land use intensification in the Mackenzie Basin indicated the problems of modelling uncertainties in setting catchment load limits. The setting of limits on extraction from the Rakaia-Selwyn groundwater zone indicated the need to review all existing consents for groundwater extraction to add constraints to manage cumulative extraction effects. Setting nitrogen limits on land use in the catchment of Wainono Lagoon highlighted the need to consider the equity in allocation of limits not only among existing users but also between existing users and new users. In the Hurunui catchment, the implementation of nitrogen limits on land use led to the establishment of farmer collectives to manage the cumulative effects together with farm environmental plans to manage individual farmer contributions. The development of a water quality management strategy for the Hinds Plains identified that a catchment approach using managed aquifer recharge was more cost-effective than on-farm advanced mitigation measures. These examples highlight the challenges and progressive approaches beyond project level EIA that are needed to manage cumulative effects.

Keywords: cumulative effects, water management, complex models, equitable allocation, institutional arrangements, mitigation cost-effectiveness.

1 INTRODUCTION

This paper describes five cumulative impact assessment case studies from water management in the Canterbury region of New Zealand. The case studies highlight some of the additional challenges associated with cumulative impact assessment compared to project impact assessment. The first case study of water quality in Lake Benmore looks at the challenge of complex modelling needed for cumulative effects analysis and increased data requirements for model calibration and validation. The second case study of cumulative effects management of groundwater depletion in the Rakaia-Selwyn Groundwater Zone illustrates the more comprehensive conditions on individual bores that are required to address groundwater basin management in addition to interference effects on adjacent bores. For the third case study of nutrient enrichment of Wainono Lagoon, the issue of equity in allocation of nitrate load limits among existing users and creating headroom for new users is a challenge of cumulative effects management that is beyond project level assessment. In the fourth case study of operational management of nutrients in the Hurunui catchment, the institutional arrangements for cumulative effects management is described. Farmer collectives have been established to develop environmental management systems to achieve water quality outcomes and to align individual farm environmental plans for nutrient management. The fifth case study of the Hinds Plains looks at the cost effectiveness of project level mitigation and catchment level intervention to reduce the nitrate concentrations in groundwater from land use intensification.



2 CUMULATIVE EFFECTS ANALYSIS OF LAKE BENMORE

Irrigation expansion in the Mackenzie Basin, primarily for converting dryland sheep farms to irrigated dairy farms, was leading to increased nutrients in rivers and lakes in the catchment of Lake Benmore. Concerns about eutrophication in Lake Benmore led to the assessment of the cumulative effects of land use intensification. Lake Benmore is an artificial lake in the Southern Alps and forms part of the Waitaki hydroelectric development. It has two arms (Fig. 1). One is the northern Haldon Arm with a large inflow from the Ohau C Canal (about 250 m³/s annual average flow) fed mainly by glacial catchments (Lake Tekapo, Lake Pukaki and Lake Ohau) that are relatively unaffected by land use intensification. The other is the western Ahuriri Arm with a smaller inflow from the Ahuriri River (about 28 m³/s annual average inflow). The Ahuriri Arm is more sensitive to increased nutrients and is susceptible to algal blooms.

An initial modelling study in 2008–2009 (Norton et al. [1]) used computer models that simulate coupled hydrodynamic, water quality and biochemical cycles in aquatic ecosystems that provided three dimensional predictions of nutrients, temperature, dissolved oxygen and phytoplankton as an input to lake management decision making. The key management issues were the trophic status of the lake (using the Trophic Level Index (TLI) as a performance measure) and nitrogen loading from catchment land use (this is the main contaminant from conversions to dairy farms). Modelling was being used as a predictive tool to relate the cumulative effects of land use intensification (in terms of nutrient loading) to water quality objectives for Lake Benmore (in terms of TLI criteria). A second round of modelling in 2011–2013 for different catchment scenarios using updated lake inflow data raised questions about the adequacy of model validation. Also measured in-lake nutrient concentrations were higher than predicted concentrations based on available river flow and nutrient concentrations: this pointed to possible insufficiencies in the input data for nutrient loading (Spigel et al. [2]).

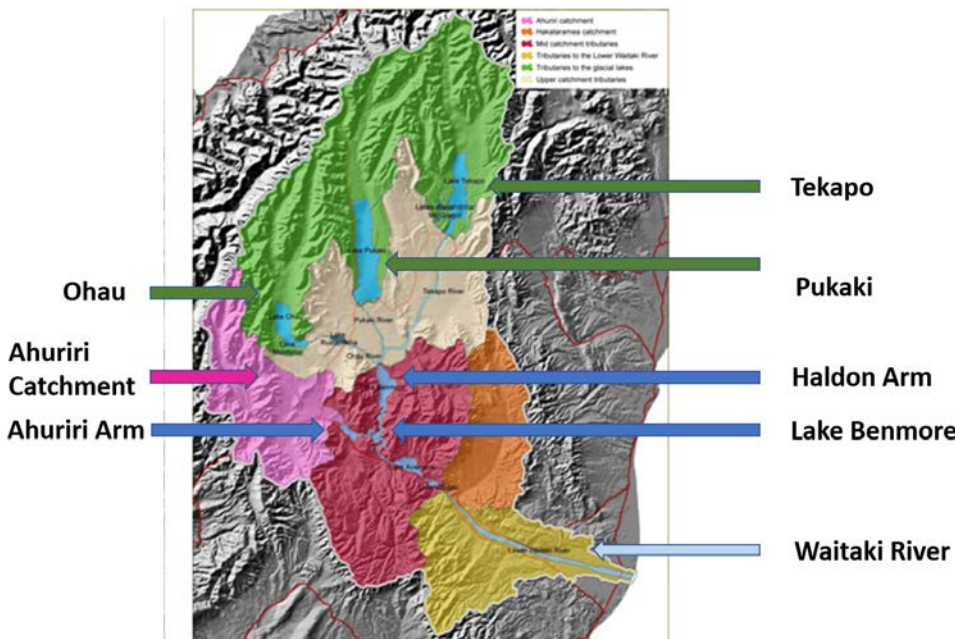


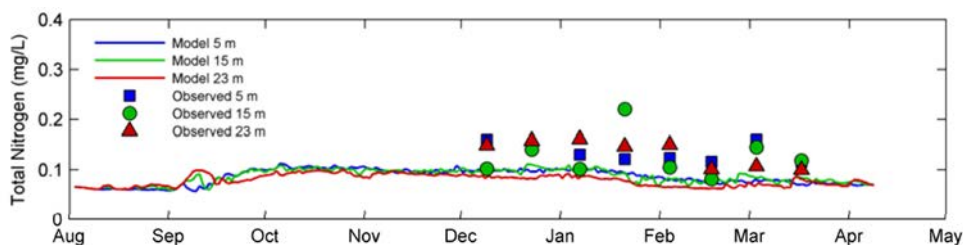
Figure 1: Lake Benmore in the Wataki catchment. (Source: Environment Canterbury.)

For the more sensitive Ahuriri Arm, the initial assessment in 2008–2009 indicated a current catchment load for total nitrogen of 173 tN/y. The initial modelling predicted that the total nitrogen load for the lake to remain in the oligotrophic range (TLI = 2.9) was 256 tN/y. This implies that there is potential for further intensification in the Ahuriri Catchment. However, the updated modelling in 2012–2013 found that the Ahuriri Catchment load had been underestimated: the revised figure for total nitrogen was 253 tN/y. It was also found that the model was underpredicting nutrient concentrations. This implies that there is no capacity for further intensification in the Ahuriri Catchment if the lake water quality criteria are to be met. (Refer to Table 1 and Figs 2(a) and (b).)

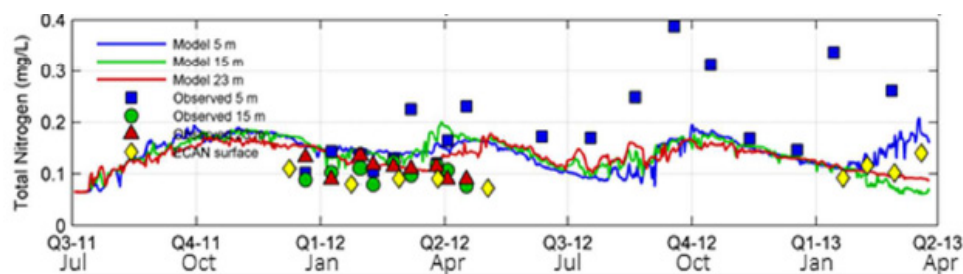
Table 1: Comparison of modelled and observed total nitrogen concentrations for the Ahuriri Arm of Lake Benmore. (Source: *Spigel et al. [2].*)

| | Total Nitrogen ($\mu\text{g/L}$) | Trophic Level Index Total Nitrogen component |
|--------------------|------------------------------------|---|
| 2008–2009 observed | 132 | 2.77 |
| 2008–2009 modelled | 89 | 2.26 |
| | | |
| 2011–2012 observed | 119 | 2.63 |
| 2012–2013 observed | 248 | 3.60 |
| 2011–2013 modelled | 133 | 2.78 |

Note: Averages over depths for observed results and corresponding model predictions.



(a)



(b)

Figure 2: Simulated (lines) and observed (dots) values for total Nitrogen at three depths in the Ahuriri Arm. (a) Results from August 2008 to April 2009; (b) Results from July 2011 to April 2013. (Source: *Spigel et al. [2].*)



Calibration relied on expert judgement by visual comparison of modelled and observed values. As noted by Robson and Hamilton [3], it is not yet feasible to apply statistical fitting or optimisation algorithms to coupled three dimensional hydrodynamic and biogeochemical models at reasonable resolutions; in practice, complex simulation models are most commonly calibrated by trial and error.

A key message from this example is the need for comprehensive and robust data for catchment loads and lake dynamics to facilitate calibration and validation of complex models for cumulative effects analysis.

3 REVISED CONDITIONS FOR RAKAIA-SELWYN GROUNDWATER ZONE

The Canterbury Plains is major unconfined aquifer holding 70% of New Zealand's available groundwater. It is recharged by rainfall and seepage from rivers that cross the plains. One of the groundwater zones is between the Rakaia and Selwyn Rivers (Fig. 3). The groundwater system is the source of flow to lowland streams that feed Te Waihora/Lake Ellesmere. There is a high natural variability in lowland streamflow related to variations in recharge to groundwater. Groundwater extraction in the Rakaia-Selwyn Groundwater Zone enables irrigation, primarily for conversion to dairy farms, and is lowering the groundwater table. A major issue is the cumulative effect of groundwater extraction on the reduction in flow in the groundwater-fed lowland streams which was further exacerbated in years of low rainfall (Jenkins [4]).

To distinguish between the effects of abstraction and climate variability in relation to the reduction in groundwater levels a time series finite-difference modelling tool (Eigenmodel) was developed (Bidwell [5]). The tool uses monthly measured or estimated land surface recharge values (1972–2006), estimates of groundwater use (for the period 1990–2006), and the monthly groundwater monitoring record. Values of land surface recharge and estimated use are calculated for each month for an entire groundwater allocation area and converted to millimetres/month.

A typical plot of a monitoring record that has been modelled using the Eigenmodel method is presented in Fig. 4. The modelling process is an iterative one, where the model is trained or calibrated, using the recharge and monitoring record over a limited period of time, such as 1972–1990. The model then predicts the likely groundwater level over the remainder of the record, 1990 onwards. The reason why the model is trained only over the early period is that during that time, little abstraction was occurring. The model is, therefore, measuring aquifer parameters associated with a purely climatic response. Fig. 4 shows that for the period after 1990, there is a progressive difference between the actual and modelled groundwater levels; this difference is due to groundwater abstraction. The reduction in groundwater level is due to both climate variation and groundwater abstraction with a marked drawdown each summer due to abstraction.

In order to manage the cumulative effects of groundwater abstraction, groundwater zones were identified and zone allocation limits set with the primary aim of maintaining flows in groundwater-fed streams. The policy was established to restrict takes from groundwater when the “effective allocation of groundwater” exceeded the “groundwater zone allocation limit”. Groundwater zone allocation limits were based on 50% of the land surface recharge and the effective allocation of groundwater was based on the consented volumes and the type of use (e.g. for irrigation users with daily rate of extraction limits, effective allocation was assumed to be 60% of their consented rate over a 150-day irrigation season) (Scott [6]).

The policy also meant changing the conditions on all groundwater extraction consents when a groundwater zone was fully allocated. Conditions on groundwater extraction had



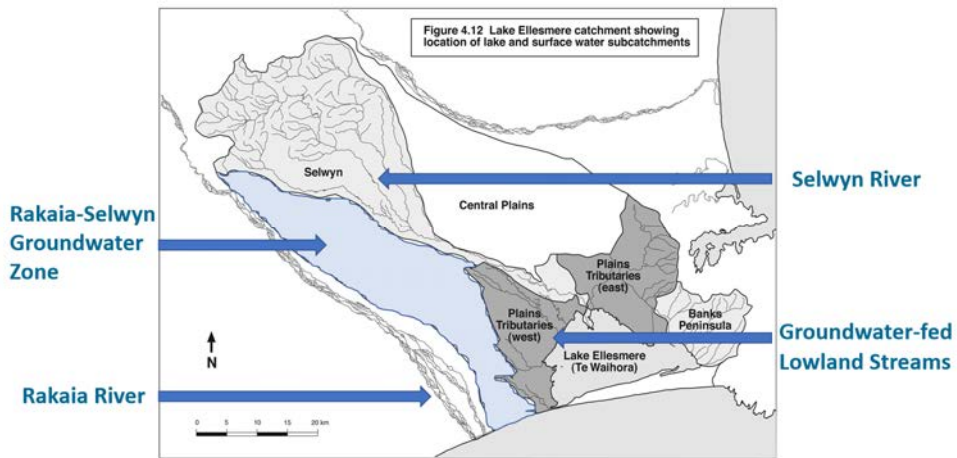


Figure 3: Rakaia-Selwyn groundwater zone. (Source: Environment Canterbury.)

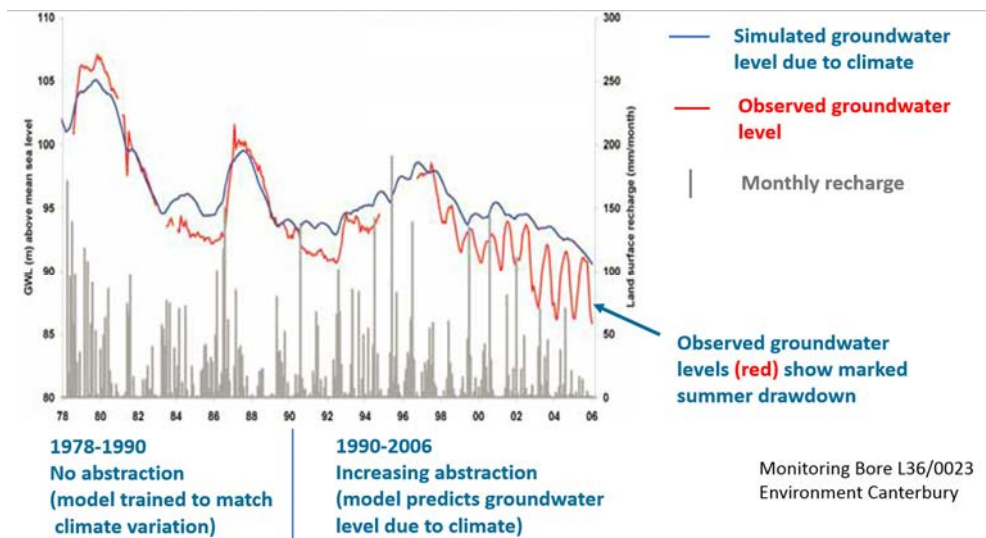


Figure 4: Actual and modelled groundwater levels in Rakaia-Selwyn groundwater zone. (Source: Bidwell [5].)

originally been based on the effect on the yield of neighbouring bores. The objective was that there would be no significant adverse effect, in conjunction with other bores, on neighbouring bores. Interference effects were to be no more than 20% of the available drawdown and 80% of drawdown was to be available at a groundwater level exceeded 80% of the time during the period of proposed use (Environment Canterbury [7]). This led to constraints on bore location and daily rates of abstraction.

To manage cumulative effects of abstractions on flows in groundwater-fed lowland streams additional constraints are needed to deal the total volume extracted and annual

variations in groundwater levels from climate variability and abstractions. Not only were further takes restricted but also additional conditions were imposed on existing users through a review of consents in the Rakaia-Selwyn Groundwater Zone. Additional conditions to address cumulative effects were:

- An annual extraction limit to manage total extraction from the zone (in addition to the daily limits to manage interference effects on neighbouring bores);
- The ability to reduce annual allocations based on water available in the groundwater zone;
- Metering of groundwater wells;
- Restrictions on takes from wells with hydraulic connection to lowland streams in times of low flows in that stream (Environment Canterbury [8]).

4 WAINONO LAGOON NUTRIENT ENRICHMENT

Wainono Lagoon is a coastal lake in South Canterbury. There is an artificial opening to the sea which has allowed greater drainage of the wetlands surrounding the lagoon. The drainage has facilitated clearing for agriculture. Nutrient enrichment from surface runoff and groundwater seepage has led to the lake becoming hypertrophic with high levels of nutrients, turbidity, and planktonic algae. The conceptual diagram of how water and nutrients, predominantly nitrate, travel through the tributary catchments of Wainono Lagoon is shown in Fig. 5.

Water quality in the Wainono Lagoon has a Trophic Level Index (TLI) of 6.5 and exceeds the goal of achieving a TLI of 6 (Canterbury Water [10]). To achieve this there was a need to reduce the nitrogen loading in the catchment of the lagoon. A draft nitrogen load limit and allocation framework had been developed to meet a TLI of 6 for the lagoon, involving a 15% reduction in nitrogen load to maintain current water quality and a 30% reduction to achieve a TLI of 6 for Wainono Lagoon (Norton [11]). The proposed allocation framework was on the basis of “grandparenting” – allocation directly related to historical discharges.

However, a group of farmers expressed dissatisfaction with the nitrogen allocation framework in relation to the equitability of the framework for low emitters compared to high emitters because high emitters receive a greater allocation. The concern was not about the need to set catchment load limits to achieve environmental outcomes but the method of allocation (Norton et al. [12]). The Nitrogen Allocation Reference Group (NARG) was formed comprising a variety of farming interests, rūnanga (local Māori) representatives and general community interests.

Grandparenting of current discharges was rejected. NARG proposed a requirement for all land users to achieve a minimum of Good Management Practice with respect to nutrient discharges so that poor performers were not rewarded with high nitrogen allocations. The main area of negotiation was the need to create headroom from improved management by high emitters to enable flexibility for nitrogen load increases by low emitters. “Maximum caps” were to be placed on high emitters according to soil type (35 kg/ha/y for light soils, 25 kg/ha/y for medium soils and 20 kg/ha/y for poorly drained soils) and that they be given a time period to adjust. “Flexibility caps” were set for low emitters. Initially these would be set at 10 kg/ha/y (excluding steep hill country farmers who would be assigned 5 kg/ha/y) (Norton et al. [13]).

The agreement by the NARG was accepted by the Zone Committee, the regional council and the two district councils (Waimate and Waitaki) related to the South Canterbury Zone. The agreement was incorporated in the proposed plan change to the Land and Water Regional Plan (Environment Canterbury [14]).



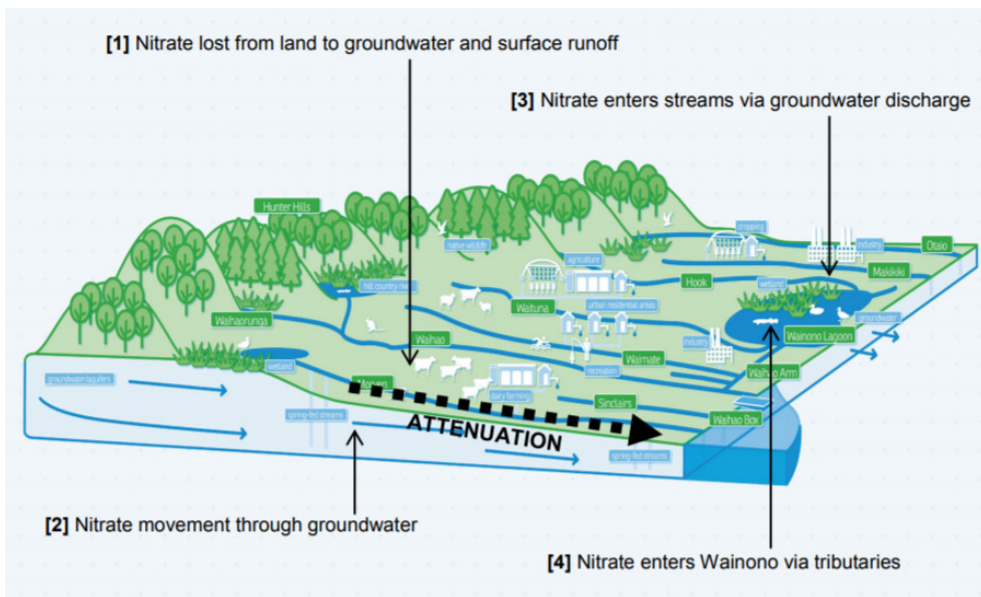


Figure 5: Conceptual diagram of water and nitrate flow in tributary catchments of Wainono Lagoon. (Nitrate is lost from land to groundwater (1), travels with groundwater (2) and is discharged to spring-fed streams and the lower reaches of hill-fed rivers (3) which are tributaries of Wainono Lagoon (4). Nitrate is attenuated along the way due to a variety of processes including denitrification in anoxic groundwater and soil, uptake by riparian vegetation, and uptake by periphyton and macrophytes in streams and rivers.) (Source: Norton and Robson [9].)

However, since the preparation of the proposed plan change there has been a revision of Overseer (the model used to estimate nitrogen loss rates for farms), adjustments to the leaching rates from the Look-Up Tables (the basis for estimating nitrogen leaching rates from farms with different soil types), concerns about the assumptions about denitrification in poorly drained soils, and revisions to soil mapping in the Wainono Lagoon catchment. The changes are likely to affect the calculations of catchment loads and maximum caps and thereby the flexibility caps. Interested submitters on the plan change were asked to caucus on the implications of these changes (Whiting et al. [15]). While there is agreement that the changes need to be addressed, the discussions reignited the debate about the appropriate nitrogen allocation methodology and the fairness of the allocations (Environment Canterbury [16]).

5 FARMER COLLECTIVES IN THE HURUNUI CATCHMENT

Water quality concerns from land use intensification in the Hurunui catchment have led to the introduction of nutrient limits to address cumulative effects (Environment Canterbury [17]). In relation to operational management the focus has been on water quality in rivers and lakes. The main operational elements are having farmers adopt good management practice, setting nutrient contaminant limits with respect to rivers and lakes, linking these river and lake limits to catchment nutrient loads, and, allocating the catchment loads among existing

users while trying to create headroom for new users. The primary governance element is the establishment of farmer collectives based on irrigation districts, tributary catchments (or stream allocation zones), or farm enterprises. Collectives need an approved Environmental Management System (EMS) that defines water quality outcomes for the collective consistent with regional plan requirements. The EMS also requires an inventory of nutrient loss rates, identification of the nutrient risks and how those risks will be managed including a statement of best nutrient management practices.

The EMS also defines the contractual arrangements with members including a Farm Environmental Plan (FEP) consistent with the EMS, and, how the FEPs will be audited and compliance achieved. The FEP has to address irrigation management, soils management, nutrient management, effluent management as well as wetland and riparian management. The compliance approach is based on audited self-management. This includes an audit process of assessing performance against management actions and outcomes at the individual property level. The EMS sets out the record keeping requirements, how audit results will be fed back to members and shared with the wider community and how issues of poor performance are to be managed.

The institutional arrangements were designed following Ostrom's principles of "self-managed communities" (Ostrom [18]), in particular, defining boundaries for collective management consistent with the resource issue being managed, ensuring congruence between the management rules and local conditions, establishing collective choice arrangement for the operational rules, monitoring of actions and outcomes, and, allowing users to devise their management arrangements. This differs markedly from the traditional approach under the Resource Management Act of the regulator (the regional council) setting consent conditions for individual farmers and monitoring compliance with these conditions.

6 COST-EFFECTIVENESS OF CATCHMENT APPROACHES

The Hinds catchment has a high nitrate loading from land use intensification that is causing elevated nitrate levels. The current load for the Hinds catchment is calculated to be 4500 tN/y. It is estimated that land use change associated with increased intensive dairying activities could further increase the catchment load to 5600 tN/y. This would lead to a nitrate concentration in shallow groundwater of about 14 mgN/L. This is well over the chronic toxicity levels for most aquatic species and exceeds the New Zealand Drinking Water Standard of 11.3 mgN/L (Canterbury Water [19]). The national bottom line for ecosystem health for rivers for nitrate is 6.9 mgN/L (annual median) (New Zealand Government [20]) and this was set by the Ashburton Zone Committee as the water quality objective for shallow groundwater which is the source for groundwater-fed streams in the Hinds catchment.

To achieve this nitrate concentration target, options for on-farm mitigation of nitrate leaching and for dilution through managed aquifer recharge were investigated. Four levels of on-farm mitigation were analysed: (1) GMP – good management practices, (2) AM1 – Advanced Mitigation level 1 (e.g. soil moisture monitoring to manage irrigation), (3) AM2 – Advanced Mitigation level 2 (e.g. covered feed pads), and (4) AM3 – Advanced Mitigation level 3 (e.g. reducing stocking rates and fertilizer application rates). Eleven different farm systems were analysed for different soil and rainfall conditions (Everest [21]). Three levels of managed aquifer recharge were analysed: 0 m³/s, 2.5 m³/s and 5 m³/s. Different levels of irrigation expansion were compared to the current baseline (48,000 ha irrigated): an increase of 15,000 ha and an increase of 30,000 ha (Scott [22]).

To achieve the combination of economic and environmental objectives for the Zone, the Ashburton Zone Committee's favoured option was for 30,000 ha of irrigation expansion, for the dairy and dairy support farming systems (i.e. the major contributors to nitrate discharges)



to implement at least AM1, and for 5 m³/s of managed aquifer recharge (Canterbury Water [23]). The water quality modelling indicated that the water quality target could be achieved with AM3 without the need for aquifer recharge. However, the Zone Committee did not consider AM3 as a viable option based on the economic modelling. Net Profit After Tax (NPAT) was the key indicator: NPAT incorporates both operational profitability and capital investment in mitigation measures. While operational profitability can be maintained with advanced mitigation measures, increased farm infrastructure means that NPAT reduces as mitigation levels increase (Everest [24]).

Drawing upon the data from economic and water quality modelling, Fig. 6 shows an example of the loss in net profit after tax (in \$/ha) for one farm system (dairy farm system 2: 3.4 cows/ha with a mixture of irrigation types) associated with different levels of mitigation. The results are plotted against the modelled nitrate levels in shallow groundwater without managed aquifer recharge and with 30,000 ha of irrigation expansion.

As shown in Fig. 6, AM3 mitigations achieve a modelled nitrate level in shallow groundwater of 5.2 mgN/L. This is below the 6.9 mgN/L water quality target set by the Ashburton Zone Committee consistent with the national bottom line for nitrate toxicity in streams. However, for Dairy Farm System 2, AM3 mitigation comes at an estimated loss in NPAT of \$776/ha (compared to a current net profit estimate of \$835/ha, i.e. a 93% reduction). The Ashburton Zone Committee considered that the threshold of affordability for most dairy farmers was AM1 mitigation. As shown in the figure AM1 mitigation would result in an estimated loss in NPAT of \$116/ha, or 14% of the current practice NPAT of \$835/ha.

However, this only achieves a modelled nitrate level in shallow groundwater of 9.5 mgN/L. Fig. 6 shows the further reduction in nitrate levels achieved by incorporating 5m³/s of managed aquifer recharge – modelled to be 6.5 mgN/L. The capital cost of managed aquifer recharge has been estimated to be \$1.2 m (Environment Canterbury [25]). For an irrigated area of 75,000 ha, this represents an average cost of \$16/ha. In economic terms MAR is a cost-effective way of achieving the water quality target.

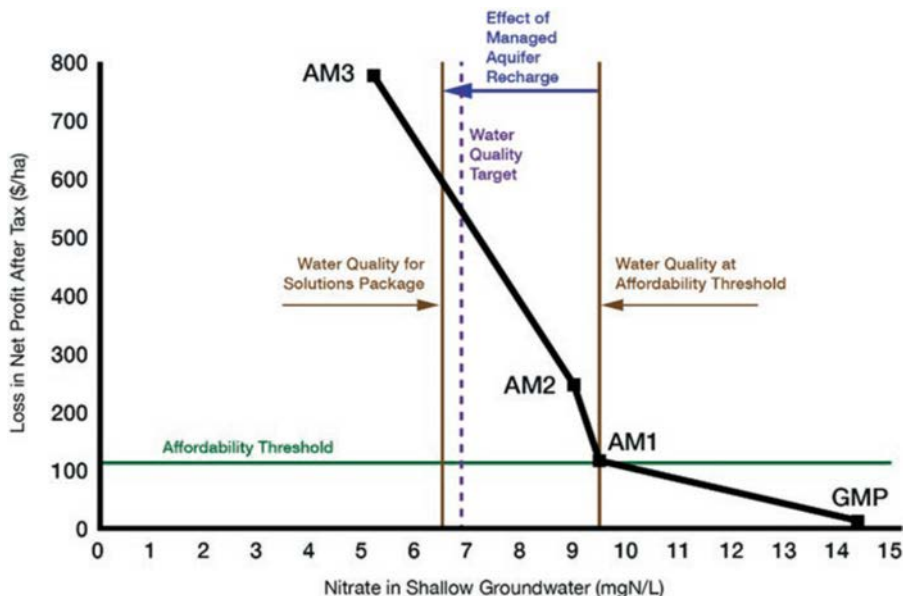


Figure 6: Cost of mitigation measures to achieve nitrate reduction. (Source: Jenkins [4].)

7 SUMMARY OF CHALLENGES IN CUMULATIVE IMPACT ASSESSMENT

The examples of cumulative impact assessment provided in this paper highlight challenges beyond those associated with project impact assessment. The Lake Benmore example demonstrated the challenge that arises from the reliance on complex models to predict cumulative effects. This requires all contaminant sources to be known and accurate modelling of lake dynamics if model outputs are to be relied on for managing cumulative effects. Comprehensive and robust data are needed for model calibration and validation. The Rakaia-Selwyn Groundwater Zone example illustrated the need for additional conditions to manage cumulative effects compared to managing project impacts. In addition to managing interference effects of groundwater withdrawal on neighbouring wells, there were conditions for cumulative effects including: annual extraction limits, the ability to reduce allocations either from reduced rainfall recharge or increased extraction, metering of extraction, and restrictions on extraction where there were hydraulic connections to streamflow. In the case of Wainono Lagoon, the introduction of allocation limits for nitrates generated by agricultural land use led to questions about equity in allocation. This was both for allocation among existing users and for allocation between existing users and new applicants. In the Hurunui Catchment, not only were catchment nutrient load limits and load allocations to individual farms set, but also the institutional arrangements for achieving compliance with the limits were modified for cumulative effects management. Farmer collectives were established with an Environmental Management System for the collective achievement of water quality outcomes, and with Farm Environment Plans for individual farmers to set out how they will achieve their contribution to nutrient management. Using the concept of audited self-management, individual farmers monitored outcomes, and their actions and monitoring were independently audited. This contrasts with typical project compliance through the regulator setting conditions and monitoring compliance with those conditions. In the case of Hinds Plains, it was shown that catchment level interventions can be cost effective compared to individual farm mitigation measures. One of the challenges of cumulative effects management is exploring regional scale interventions as well as project scale mitigation which is the focus of project level EIA.

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