Landcare Research
Manaaki Whenua
POLICY BRIEF

Sharing the Pie:

The dilemma of allocating nutrient leaching between sources

Technical Documentation

Adam Daigneault, Suzie Greenhalgh, Oshadhi Samarasinghe

BACKGROUND

The following technical documentation provides more details of the model used for the analysis in the *Equitably Slicing the Pie: Water Policy and Allocation* policy brief and the results of the analysis.

This analysis and documentation has been prepared for a journal article.

CONTENTS

METHODOLOGY

To investigate the efficiency and equity implications of a number of approaches to allocate non-point source nutrient discharges we empirically assess the impacts of six different allocation approaches and a cap and trade scheme in two catchments (the Hinds and Selwyn catchments) in New Zealand's South Island. The assessment takes an economic land use modelling approach to assess the economic and environmental impacts of reducing nitrate (N) loads from the agriculture and forestry sectors. The spatially explicit agro-environmental economic model used estimates changes in land use, agricultural output, farm management, and environmental impacts at the sub-catchment level.

Allocation approach

Various approaches for allocating nutrient discharges to meet water quality limits in New Zealand have been proposed by regional authorities, industry bodies and researchers. Four approaches based on existing land use, two based on land characteristics, and one that represents the least cost approach are compared in this assessment. The least cost option demonstrates the most efficient outcome for the catchment and can be interpreted as a catchment having a single landowner who is making the optimal economic decisions for the whole catchment.

The key elements of each of the allocation approaches we compare are listed in Table 1. In all cases, existing land uses can continue as long as they operate within their allocation discharge allowance and any change in land use must remain within the property's existing discharge allowance.

Table 1. Non-point source allocation approaches

Allocation	Description
Grandparent	Landowners given a nutrient discharge allowance (NDA) based on their land use and nitrate leaching rates during a benchmarking or baseline period. The grandparented allocation may be reduced in proportion to the nutrient load target, e.g. a 10% reduction reduces the amount of NDAs a landowner receives by 10%, if necessary.
Catchment average	All landowners in the catchment are given the same NDA regardless of land use and this is the average of total N discharge from land-based sources. The allocation of the resource is determined by dividing the target catchment load by the total productive area in the catchment.
Land cover average	Landowners managing a specific land cover (e.g. pasture, forest, arable, etc.) are given the same NDA. The allocation of the resource is determined by first dividing the target catchment load by current land cover area (e.g. if pasture is 60% of the area, it receives 60% of the target load), and then dividing each land cover target load by the total area of that land cover in the catchment.
Sector average	Landowners within the same sector (e.g. dairy or sheep and beef) are given the same NDA. The allocation of the resource is determined by first dividing the target catchment load by current land use area (e.g. if dairy is 30% of the area, then the sector receives 30% of the target load), and then dividing each sector target load by the total sector area in the catchment.
Natural Capital	NDAs are allocated based the physical quality of the land, soil and environment. Generally, more NDAs are allocated to more versatile classes of land.[1] The allocation is independent of existing land use or land cover. For this assessment, land use capability (LUC)[2] is used as a proxy for natural capital. The allocation is independent of existing land use.
Nutrient Vulnerability	NDAs allocated based on the nutrient leaching capacity of the soil. More NDAs would be allocated to land with lower 'vulnerability'[3] or greater capacity for filtering nitrates. The allocation is independent of existing land use.
Least Cost	Landowners are allocated an initial amount of NDAs based on any of the 6 allocation approaches. Landowners are then allowed to buy and sell NDAs, and will choose to do so until their marginal cost of reducing N is equal to the marginal benefit of emitting it.

---

[1] See appendix for more details on how allocation is distributed for natural capital.

[2] LUC is a system derived from two components: the land resource inventory, which assesses the physical factors of land considered to be critical for long-term land use and management; and the land use classification, which categorises land into 8 categories according to its long-term capability to sustain one or more productive uses (Lynn et al. 2009).

[3] See appendix for more details on how allocation is distributed for nutrient vulnerability

Economic land use model

The allocation approaches are tested using an agro-environmental model. The model is a comparative static, partial equilibrium, non-linear, mathematical programming model of the New Zealand forest and agriculture sector (Daigneault et al. 2012; Greenhalgh et al. 2012). It is designed for detailed modelling of catchment-scale land uses to enable the consistent comparison of policy scenarios against a baseline by assessing relative changes in economic and environmental outputs. It can be used to assess how changes in technology, commodity supply or demand, resource constraints, or farm, resource, or environmental policy can affect a host of economic or environmental performance indicators that are important to decisions-makers and rural landowners.

In addition to estimating economic output from the agriculture and forest sectors, the economic land use model also tracks a series of environmental factors including N leaching, phosphorous (P) loss, and GHG emissions. Simulating endogenous land management is an integral part of the model, which can differentiate between 'business as usual' (BAU) farm practices and less-typical options that can change levels of agricultural output, nutrient leaching, and GHG emissions, among other things. Key land management options include changing fertiliser regimes and stocking rates, adding an irrigation system or implementing mitigation technologies such as the installation of a dairy feed pad or the application of variable rate irrigation. Including a range of management options provides the ability to assess what level of regulation might be needed to bring new technologies into general practice to achieve environmental goals. Landowner responses to N leaching and P loss restrictions in the model are parameterised using estimates from farm biophysical and budgeting models such as OVERSEER,[4] and FARMAX.[5] The biophysical models rely on detailed soil, climate and management information to estimate environmental impacts.

The model's objective function maximizes the net revenue[6] of agricultural production across the entire catchment area, subject to land use and land management options, agricultural production costs and output prices, and environmental factors such as soil type, water available for irrigation, and any regulated environmental outputs (e.g. nutrient leaching limits) imposed on the catchment. Catchments are be disaggregated into sub-regions (i.e. zones) based on different criteria, e.g. land use capability, irrigation schemes, etc., such that all land in the same zone will yield similar levels of productivity for a given enterprise and land management option.

To avoid the overspecialisation and corner solution problems associated with mathematical programming models, the model uses positive mathematical programming (PMP) to calibrate the model to the observed catchment baseline land use. We extend the general PMP formulation by nesting sets of nonlinear transformation functions under the PMP formulation.

The objective function, total catchment net revenue (π), is specified as:

$$Max\ \pi = \sum_{r,s,l,e,m} \left\{ \begin{array}{c} PA_{r,s,l,e,m} + Y_{r,s,l,e,m} - \\ X_{r,s,l,e,m}\left[\omega^{live}_{r,s,l,e,m} + \omega^{vc}_{r,s,l,e,m} + \omega^{fc}_{r,s,l,e,m} + \tau\gamma^{env}_{r,s,l,e,m}\right] \\ -\omega^{land}_{r,s,l} Z_{r,s,l} \end{array} \right\} \qquad (1)$$

where *P* is the product output price, *A* is the product output, *Y* is other gross income earned by landowners (e.g. grazing leases), *X* is the farm-based activity, ω^{live}, ω^{vc}, ω^{fc} are the respective

---

[4] www.overseer.org.nz

[5] www.farmax.co.nz

[6] Net revenue (farm profit) is measured as annual earnings before interest and taxes, or the net revenue earned from output sales less fixed and variable farm expenses. It also includes the additional capital costs of implementing new land management practices.

livestock, variable, and fixed input costs, τ is an environmental tax (if applicable), γ^{env} is an environmental output coefficient, ω^{land} is a land use conversion cost, and *Z* is the area of land use change from the initial (baseline) allocation. Summing the revenue and costs of production across all zones (*r*), soil types (*s*), land uses (*l*), enterprises (*e*), and management options (*m*) yields the total net revenue for the catchment.

The level of net revenue that can be obtained is limited not only by the output prices and costs of production but also by a number of production, land, technology, and environmental constraints.

The production in the catchment is constrained by the product balance equation and a processing coefficient (α^{proc}) that specifies what can be produced by a given activity in a particular part of the catchment:

$$A_{r,s,l,e,m} \le \alpha^{proc}_{r,s,l,e,m} X_{r,s,l,e,m} \tag{2}$$

Landowners are allocated a certain amount of irrigation (γ^{water}) for their farming activities, provided that there is sufficient water (*W*) available in the catchment:

$$\sum\nolimits_{s,l,e,m} \gamma^{water}_{r,s,l,e,m} X_{r,s,l,e,m} \le W_r \tag{3}$$

Land use in the catchment is constrained by the amount of land available (*L*) on a particular soil type in a given zone:

$$\sum\nolimits_{e,m} X_{r,s,l,e,m} \le L_{r,s,l} \tag{4}$$

and landowners are constrained by their initial land use allocation (L^{init}) and the area of land that they can feasibly change:

$$L_{r,s,l} \le L^{init}_{r,s,l} + Z_{r,s,l} \tag{5}$$

The level of land use change in a given zone is constrained to be the difference in the area of the initial land-based activity (X^{init}) and the new activity:

$$Z_{r,s,l} \le \sum\nolimits_{e,m} \left(X^{init}_{r,s,l,e,m} - X_{r,s,l,e,m} \right) \tag{6}$$

and we assume that it is feasible for all managed land uses to change, with the exception of native forestland and tussock grassland under conservation land protection:

$$L_{r,s,native} = L^{init}_{r,s,native} \tag{7}$$

In addition to estimating economic output from the agriculture and forest sectors, the model also tracks a series of environmental factors including N leaching, P loss and GHG emissions. Where farm-based nutrient leaching or GHG emissions (γ^{env}) are regulated by placing a cap on a given environmental output from land-based activities (*E*), landowners could also face an environmental constraint:

$$\sum\nolimits_{s,l,e,m} \gamma^{env}_{r,s,l,e,m} X_{r,s,l,e,m} \le E_r \tag{8}$$

Finally, the variables in the model are constrained to be greater or equal to zero such that landowners cannot feasibly use negative inputs such as land and fertiliser to produce negative levels of goods:

$$Y, X, L \ge 0 \tag{9}$$

The 'optimal' distribution of soil type $s_{1 \ldots i}$, land use $l_{1 \ldots j}$, enterprise $e_{1 \ldots k}$, land management $m_{1 \ldots l}$, and agricultural output $a_{1 \ldots m}$ are simultaneously determined in a nested framework that is calibrated based on the shares of initial enterprise areas for each of the zones. Detailed land use maps of the catchment are used to derive the initial (baseline) enterprise areas and a mix of farm surveys and expert opinion is used to generate the share of specific management systems.

The main endogenous variable is the physical area for each of the feasible farm-based activities in a catchment ($\mathrm{X}_{\mathrm{r,s,l,e,m}}$). In the model, landowners have a degree of flexibility to adjust the share of the land use, enterprise, and land management components of their farm-based activities to meet an objective (e.g. achieve a nutrient reduction target at least cost). Commodity prices, environmental constraints (e.g. nutrient cap), water available for irrigation, and technological change are the important exogenous variables, and, unless specified, these exogenous variables are assumed to be constant across policy scenarios.

The allocation of farm activity area is specified through CET functions. The CET function specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of available options. This approach is well suited for models that impose resource and policy constraints as it allows the representation of a 'smooth' transition from across production activities while avoiding unrealistic discontinuities and corner solutions in the simulation solutions (de Frahan et al. 2007).

At the highest levels of the CET nest, land use is distributed over the zone based on the fixed area of various soil types. Land cover is then allocated between several enterprises such as arable crops (e.g. process crops or small seeds), livestock (e.g. dairy or S&B), or forestry plantations that will yield the maximum net return. A set of land management options (e.g. good management practice bundle, reduced fertiliser regime, etc.) are then applied to an enterprise which then determines the level of agricultural outputs produced in the final nest.

The CET functions are calibrated using the share of total baseline area for each element of the nest and a CET elasticity parameter, σ_i, where $\mathrm{i} \in \{\mathrm{s}, \mathrm{l}, \mathrm{e}, \mathrm{m}, \mathrm{a}\}$ for the respective soil type, land cover, enterprise, land management, and agricultural output. These CET elasticity parameters can theoretically range from 0 to infinity, where 0 indicates that the input is fixed, while infinity indicates that the inputs are perfect substitutes (i.e. no implicit cost from switching from one land use or enterprise activity to another).

The CET function is nonlinear, where the marginal rate of transformation between land used in one enterprise activity under a particular management system and land used for another enterprise system under a specific management system is declining. The parameters for these equations are derived from the area of each farm level activity in the baseline ($\mathrm{X}_{\mathrm{r,s,l,e,m}}$), the net return to each activity ($\pi_{\mathrm{r,s,l,e,m}}$), and an elasticity of transformation (σ_{e}). Net returns for each activity are obtained from shadow prices on calibration constraints that are placed on the objective function (equation 1).

The enterprise-level CET function is mathematically represented as:

$$RAC_{r,s,e} = \alpha_{r,s,e} * \left[\sum\nolimits_{r,s,l,e,m}\left(\delta_{r,s,e} * X_{r,s,l,e,m}\right)^{-\rho_e}\right]^{-\left(\frac{1}{\rho_e}\right)} \qquad (10)$$

where $\mathrm{RAC}_{\mathrm{r,s,e}}$ is the area of enterprise *e* under management system m, and $\delta_{\mathrm{r,s,e}}$ is the CET allocation parameter for enterprise area *e* on land use l and soil type *s* in region *r*, specified as:

$$\delta_{r,s,e} = \frac{\pi_{r,s,l,e,m} * {X_{r,s,l,e,m}}^{1+\rho_{r,s,e}}}{\sum_{r,s,l,e,m}\left(\pi_{r,s,l,e,m} * X_{r,s,l,e,m}\right)^{1+\rho_{r,s,e}}} \qquad (11)$$

$\pi_{r,s,l,e,m}$ equals the net return per hectare for each enterprise that is derived from the shadow value of constraints placed on the allocation of enterprise activities in each region, where ρ_e is the CET substitution parameter estimated based on the CET elasticity parameter σ_e:

$$\rho_e = \frac{1-\sigma_e}{\sigma_e} \tag{12}$$

and $\alpha_{r,s,e}$ is the enterprise CET scale parameter based on the share of one unit of that enterprise activity *e* on soil type *s* in region r:

$$\alpha_{r,s,e} = \frac{RAC_{r,s,e}}{\left[\sum_{r,s,l,e,m}\left(\delta_{r,s,e} * X_{r,s,l,e,m}\right)^{-\rho e}\right]^{-\left(\frac{1}{\rho e}\right)}} \tag{13}$$

The mathematical formulation for the land use and management-level CET functions are similar to the enterprise-level CET function.

The CET elasticity parameters ascend with each level of the nest between land cover, enterprise, and land management, as landowners have more flexibility to change their mix of management and enterprise activities than to alter their share of land use or to move land uses across soil types. For this analysis the CET elasticities are specified as follows land cover ($\sigma_L = -2$), enterprise ($\sigma_E = -3$), and land management ($\sigma_M = -20$). A large CET elasticity was used in the land-management nest to simulate that most landowners are likely over the long term to employ new management technologies on their existing enterprise to meet environmental constraints rather than change land use. These parameters are based on the econometric estimates of New Zealand land use change by Dake (2011) and Kerr and Olssen (2012). The CET elasticity parameter for soil (σ_S) is set to be 0, as the amount of a particular soil type in a zone is fixed. In addition, the parameter for agricultural production (σ_P) is also assumed to be 0, implying that a given activity produces a fixed set of outputs.

The economic land use model is programmed in the modelling General Algebraic Modelling System (GAMS) software package. The baseline calibration and scenario analysis are derived using the non-linear programming (NLP) version of the CONOPT solver (GAMS 2011).

DATA AND PARAMETERISATION

Catchment Characteristics

The two comparison catchments, Hinds and Selwyn, in the South Canterbury region of New Zealand have geographical proximity, but differ in their land use and land management mix, climate, soils and topography (

Table 2). The diversity between catchments provide the necessary conditions to assess the efficiency and equity of allocation approaches and how they may vary between catchments because of existing land use and management mix and land characteristics.

Table 2. Characteristics of the Hinds and Selwyn catchments

Characteristic	Hinds	Selwyn
Location	South Island; directly drains to the sea	South Island; drains into Lake Elsmere
Area of catchment (ha)	135 400 ha of land under productive uses	232 200 ha of land under productive uses
Land use mix (%)	47% dairy, 16% dairy support, 14% sheep & beef, 20% arable, 2% plantation forestry, 0.2% horticulture, and 0.1% other productive uses	56% sheep & beef, 20% dairy, 14% arable, 6% plantation forestry, and 4% other productive uses.
Area (ha) irrigated (percent of catchment irrigated)	~ 85 000 ha (63%)	~100,000ha (43%)
Soil mix	Mostly very light and light soils.	Mix of Light, Medium and Poorly drained soils.
Ave growing season rainfall (mm)	450	400
Ave growing season Max temperature (^{o}C)	18.8	19.2
Ave Growing season Min temperature (^{o}C)	7.3	8
Slope[a]	~200m	~340m
N leaching (kgN/ha)[b]	32.8	18.4

a: based on weighted average digital elevation model across the catchment
b: average across all land uses in the catchment

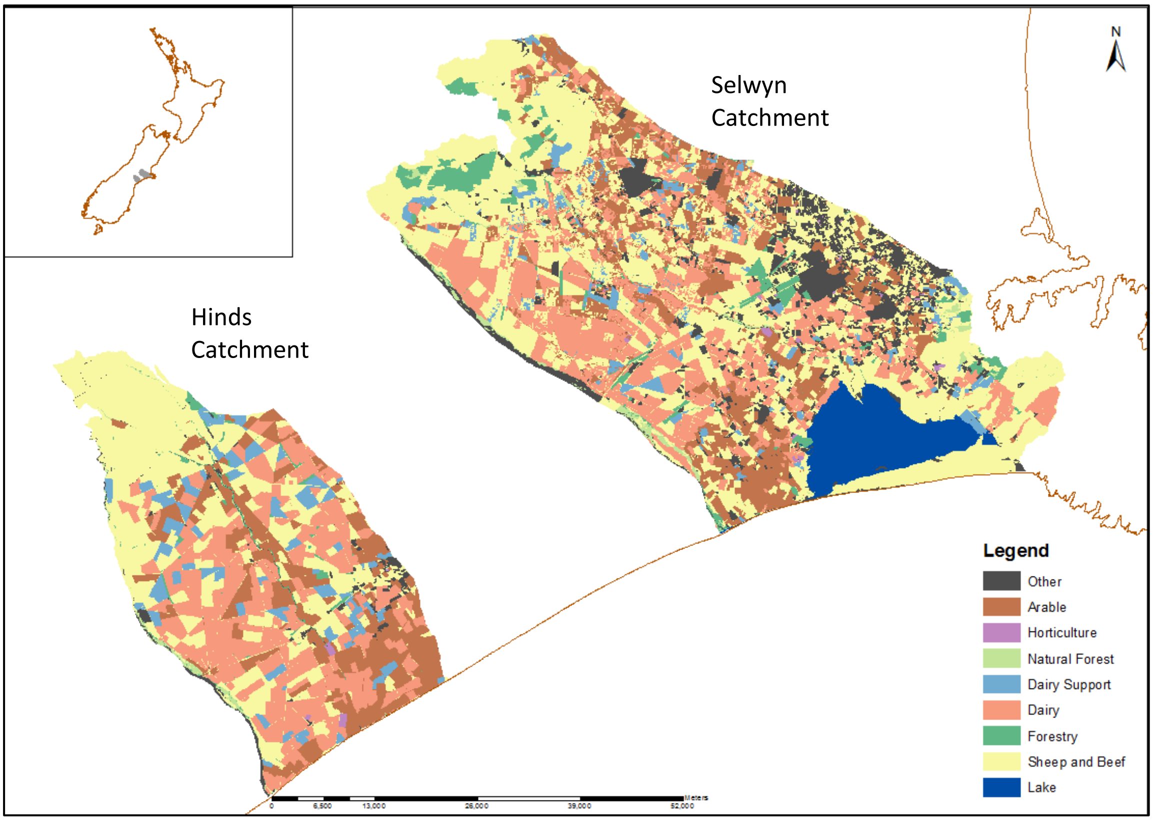

Figure 2. Hinds and Selwyn catchment land use.

Farm management practices

A range of farm management practices are modelled to account for the heterogeneity in landowner behaviour and nutrient loading targets in each catchment. The mitigation options are organised as current, good, and advanced mitigation (AM) management practices (Table 3). Each management practice has a different effect on net farm revenue, and nutrient losses in the two catchments, as estimated by Everest (2013). A summary of the range of these figures for each modelled land use is listed in Table 4. The distribution of current land management practices were estimated using survey data on landowner behaviour in the Canterbury region (Brown 2013).

Table 3. Modelled Farm management practices

Management Practices	**Description**
Baseline (Base) Practice	Current practices by a typical farm in the catchment
Good Management Practice (GMP)	Practices undertaken by the top 25% of farmers in the catchment. These practices typically reflect farmer compliance with supplier and local government regulations.
Advanced Mitigation 1 (AM1)	Practices that modify farm systems to employ some simple nutrient loss reduction strategies. These changes are expected to have minimal effect on net farm revenue but will require some management changes and capital purchases to upgrade existing infrastructure. Also includes all practices in GMP, if applicable.
Advanced Mitigation 2 (AM2)	Practices that significantly modify farm systems to reduce nutrient losses, primarily through capital investment. These changes are not expected to impact production, but additional capital costs could reduce net farm revenue. Also includes all practices in GMP and AM1, if applicable.
Advanced Mitigation 3 (AM3)	Practices requiring major farm systems change to reduce nutrient losses. These include reducing physical inputs and stocking rates beyond economically optimal levels. These changes are expected to reduce net farm revenue. Also includes all practices in GMP, AM1, and AM2, if applicable.

Table 4. Range of baseline net farm revenue and nutrient losses by land use

Land Use (systems)	**Net Farm Revenue ($/ha)**			**Nitrate Leaching (kgN/ha)**		
	Mean	*Min*	*Max*	*Mean*	*Min*	*Max*
Dairy (2)[a]	$3,875	$3,686	$4,289	48.6	6.9	79.2
Dairy Support (2)	$1,159	$1,140	$1,983	47.9	1.6	86.5
Sheep & Beef (3)	$457	$326	$495	13.5	6.8	32.0
Arable (4)	$973	$561	$1,983	18.2	4.0	54.9
Horticulture (1)	$8,583	$4,805	$10,791	8.1	0.7	14.0
Forestry (1)	$650	$650	$650	0.8	0.5	1.1
Native Bush (1)	$0	$0	$0	0.9	0.0	0.0
Other (3)	$312	$0	$1,285	2.2	6.9	19.6

a: Parentheses refer to the number of enterprise system options for each land use.

In total, there are 17 different land uses and 8 soil types, with 5 different management practices in each catchment. For the arable and pastoral land uses, for instance, each landowner potentially has 55 discrete combinations of land use and land management options to choose between producing 440 different levels of nutrient losses across the different soil types.

Nitrate leaching allocation

The baseline NDA under the different allocation approaches is listed in Table 5. This represents the allowable baseline N leaching rates on a per hectare basis that landowners (on average) would receive each year.[7] The figures in Table 5 indicate that the Hinds catchment has a much larger per hectare allocation than Selwyn because of the number of high-leaching enterprises in the catchment, as determined by baseline land use and distribution of soil types.

Table 5 also shows there is a lot of land use variability across the different allocation approaches. For example, the average dairy farmer is allocated a higher leaching rate for the grandparent and sector average approaches relative to the other allocation approaches. On the contrary, forestry and horticulture land uses receive relatively less under these allocation approaches as they are typically lower leaching operations. However, for the natural capital and nutrient vulnerability approaches forestry and horticulture could be initially allocated a higher N leaching rate than they currently leach allowing them to further intensify or sell their excess allocation to other landowners, if permitted.

There is also likely to be a range of preferences for allocation approaches even within a given land use/sector. Table 5 only presents average N leaching rates for each land use, which can be misleading for the grandparent, natural capital, and nutrient vulnerability approaches. This is because individual landowner N leaching rates for these allocation approaches vary based on current practices, land use capability class, and nutrient filtering capability. In both the catchments, for instance, N leaching from dairy farms within the catchment ranges from 7 to 76 kgN/ha, and thus a farmer implementing good management practice on poorly drained soils on LUC class IV land (i.e. lower N leaching rate) is likely to prefer a different allocation than does a dairy farmer implementing baseline practices on very light soils on LUC Class I land (i.e. higher N leaching rate).

Table 5. Annual nitrate leaching rates (kgN/ha/yr) by land use

Land Use	Baseline	Grandparent[a]	Natural Capital[b]	Catchment Average	Land Cover Average	Sector Average	Nutrient Vulnerability[c]
			Hinds Catchment				
Dairy	56.2	56.2	32.5	32.8	36.6	56.2	32.8
Dairy Support	55.6	55.6	33.4	32.8	36.6	55.6	32.4
Sheep & Beef	14.6	14.6	30.9	32.8	36.6	14.6	32.7
Arable	22.4	22.4	36.7	32.8	21.5	22.4	34.5
Horticulture	8.8	8.8	40.6	32.8	21.5	8.8	37.4
Forestry	0.8	0.8	33.8	32.8	0.8	0.8	31.6
Other	0.8	0.8	29.9	32.8	21.5	0.8	33.0
Total	**32.8**	**32.8**	**32.8**	**32.8**	**32.8**	**32.8**	**32.8**
			Selwyn Catchment				
Dairy	41.0	41.0	18.9	18.4	20.9	41.0	19.4
Dairy Support	40.3	40.3	18.6	18.4	20.9	40.3	18.7
Sheep & Beef	12.4	12.4	17.8	18.4	20.9	12.4	18.8
Arable	14.1	14.1	21.5	18.4	12.8	14.1	18.0
Horticulture	7.4	7.4	20.0	18.4	12.8	7.4	18.5
Forestry	0.8	0.8	15.2	18.4	0.8	0.8	19.3
Other	3.5	3.5	14.7	18.4	12.8	3.5	20.6
Total	**18.4**	**18.4**	**18.4**	**18.4**	**18.4**	**18.4**	**18.4**

a: allocation will also vary by soil type for each enterprise
b: allocation will also vary by land use classification
c: allocation will vary by nutrient leaching vulnerability classification

---

[7] There is within land use variation for the grandparent, nutrient vulnerability, and natural capital approaches, as these allocation approaches vary based on soil N leaching rates, N leaching vulnerability, and land use classification.

RESULTS

Baseline calibration

The baseline calibration for the Hinds catchment estimates that net catchment income from current land-based operations is about NZ$246 million. Total N leached from diffuse sources is estimated to be about 4,440 tN/yr, or an average of about 32.8 kgN/ha across all productive land in the catchment. A majority of both the profits (68%) and N leaching (47%) in the catchment are from the 43,600 ha of dairy farming.

In the Selwyn catchment, total net catchment income from the current land-based operations is estimated at about $295 million NZD. Total N leached from diffuse sources is estimated to be about 4,270 tN/yr, equating to an average of about 18.4 kgN/ha across all productive land in the catchment. As with Hinds, the primary source of profit (61%) and N leaching (43%) in the catchment is from the 46,000 ha of dairy. The baseline outputs by land use for the two catchments are listed in Table 6.

Table 6. Summary of key baseline estimates for Hinds and Selwyn catchments

Land Use	Net Farm Revenue (million $)	N Leaching (tons)	Area ('000 ha)
	Hinds Catchment		
Dairy	167.2	2,491	43.6
Dairy Support	12.6	609	11.0
Sheep & Beef	39.4	618	49.8
Arable	21.9	720	27.7
Horticulture	3.6	3	0.3
Forestry	1.3	2	2.0
Other	0.1	1	0.9
Hinds Total	**246.1**	**4,443**	**135.4**
	Selwyn Catchment		
Dairy	179.7	1,900	46.4
Dairy Support	8.3	287	7.1
Sheep & Beef	58.0	1,576	126.9
Arable	32.6	472	33.5
Horticulture	6.1	5	0.7
Forestry	8.6	10	13.2
Other	1.4	15	4.3
Selwyn Total	**294.6**	**4,266**	**232.2**

Policy scenario estimates

The estimated impact of N reduction policy scenarios to catchment net revenue by enterprise, allocation approach, and N reduction target is shown in Figure 3. It is apparent that the impacts can vary widely and are not consistent across the two catchments, even for the same reduction target or allocation approach. For example, the relative and directional impact to arable profits change significantly depending on the allocation approach, and these farmers generally stand to lose more under the sector and land cover averaging approach because they have higher leaching rates relative to other sectors in the catchment (with exception of dairy, which has more mitigation options), and thus must mitigate a relatively higher amount of N. There are some noticeable consistencies across the different scenarios too. Dairy stands to lose the largest net revenue in nearly all cases, with the exception of the least cost approach. This is expected because dairy is by far the highest earning land use in both catchments. Dairy also has relatively low mitigation costs. Forest and horticulture revenues and area are generally estimated to expand a lot more in Selwyn relative to Hinds because that catchment already has some infrastructure (e.g. harvest, transport and processing equipment) for those sectors and hence more easily support their expansion.

Table 7. Summary of Hinds and Selwyn catchment estimates

Scenario/Allocation approach	**Net Revenue (million $)**	**N Leaching (tons)**	**Net Revenue (million $)**	**N Leaching (tons)**
	Hinds		*Selwyn Catchment*	
Baseline	$246.1	4,443	$294.6	4,266
10% Reduction Target				
Least cost	–1%	–10%	0%	–10%
Grandparent	–2%	–10%	–2%	–10%
Natural capital	–7%	–27%	–11%	–38%
Catchment average	–9%	–35%	–10%	–36%
Land cover average	–9%	–34%	–9%	–35%
Sector average	–5%	–21%	–1%	–10%
Nutrient vulnerability	–10%	–36%	–9%	–34%
25% Reduction Target				
Least cost	–4%	–25%	–3%	–25%
Grandparent	–4%	–25%	–7%	–25%
Natural capital	–9%	–32%	–13%	–42%
Catchment average	–12%	–41%	–13%	–42%
Land cover average	–12%	-40%	–11%	–39%
Sector average	–9%	–31%	–4%	–25%
Nutrient vulnerability	–13%	–43%	–12%	–39%
50% Reduction Target				
Least cost	–14%	–50%	–14%	–50%
Grandparent	-19%	–50%	–24%	–50%
Natural capital	–17%	–50%	–15%	–55%
Catchment average	–21%	–56%	–20%	–54%
Land cover average	–21%	-56%	–19%	–52%
Sector average	–21%	–50%	-15%	–50%
Nutrient vulnerability	–24%	–59%	–23%	–57%

For the 10% N reduction target, overall net revenue reductions of meeting the policy ranges between 1% and 10% in Hinds while it is between 0% and 11% in Selwyn (Table 7). However, the distribution of net revenue reductions among enterprises differs between the two catchments. For example, reductions for dairy are higher in Selwyn for all allocation approaches except grandparenting (where on average they receive the highest allocation) and the least cost option. S&B experience revenue gains across almost all the allocation approaches in Hinds while the net revenue impacts are more mixed in Selwyn (Figure 3). Net revenue gains for forestry are more pronounced across all allocation approaches in Selwyn compared to Hinds, primarily due to infrastructure differences.

The 25% N reduction target estimates that catchment wide net revenue reductions range between 4% and 13% in Hinds and between 3% and 13% in Selwyn (Table 7). As with the 10% reduction target, there are observable differences in the distribution of net revenue impacts across both land uses and catchments (Fig. 3). The least cost option, grandparenting, and sector averaging allocation approaches are often least disruptive approaches for both catchments. That is, the distribution of changes in net revenue for most land uses is less than the other approaches.

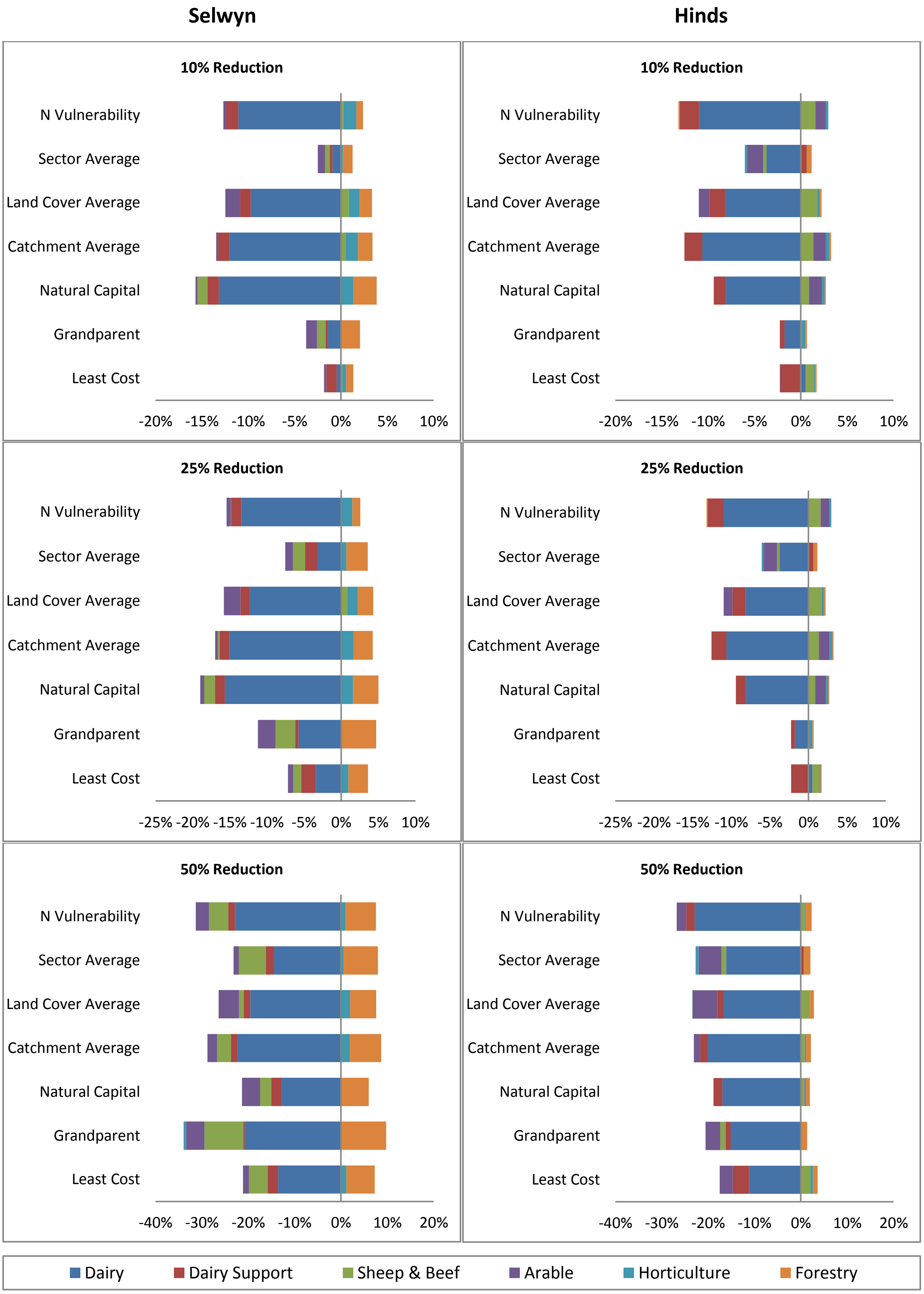

Figure 3. Percent change in catchment land use net revenue from baseline by land use for varying allocation approaches and N reduction targets (note there are scale differences across reduction targets).

Decreases in net revenue range between 14% and 24% in both catchments for the 50% N reduction target, and the total loss in net revenue is more than twice the impacts of the 25% target for almost every allocation approach. This indicates that the impacts of the N reduction targets are generally non-linear. The pattern of net revenue loss also differs from the other two N reduction targets. For example, S&B face higher losses in net revenue in the Selwyn catchment across all allocation approaches, and horticulture and forestry is estimated to benefit more in the Selwyn catchment. This is due to the difference in land use mix between the two catchments. In addition, the distribution of land use-level impacts differs from the less stringent targets, as natural capital is now estimated to be the least disruptive approach, after the least cost option, in both catchments (Fig. 3).

A rank ordering of the total impact to land-based net revenue in the two catchments for each allocation approach is listed in Table 8, highlighting the relative efficiency of each approach. Grandparenting is generally the second or third best approach after the least cost option, with the exception of the 50% target in Selwyn, as many low-leaching land uses do not have the mitigation technology available to reduce their N by the specified amount without switching to a less profitable land use. Sector averaging is estimated to be more efficient in the Selwyn catchment than the Hinds due to the current land use mix. Nutrient vulnerability (i.e. allocating more NDAs to low-leaching soils) is one of the highest cost or least efficient approaches because it often allocates excess allowances to landowners who are already operating under their allocated NDAs, while others farming on more vulnerable soils must reduce their N leaching by more than other allocation approaches.

Table 8. Rank order of allocation approaches by catchment and policy target (1 = least cost or lowest cost/reduction in overall catchment net farm revenue)

	Hinds Catchment			Selwyn Catchment		
Allocation	**10%**	**25%**	**50%**	**10%**	**25%**	**50%**
Least cost	1	1	1	1	1	1
Grandparent	2	2	3	3	3	7
Natural capital	4	3	2	7	7	2
Catchment average	6	6	6	6	6	5
Land cover average	5	5	4	4	4	4
Sector average	3	4	5	2	2	3
Nutrient vulnerability	7	7	7	5	5	6

Land management and land use change

Another aspect to consider when deciding on an allocation approach, factoring in equity considerations, is to examine the ability of different sectors to reduce their rate of N leaching by implementing alternative mitigation practices. The abatement potential can be illustrated by deriving N leaching abatement curves (Fig. 4). These curves show how cost-effective abatement potential can vary by land use, which is indicated by their shape over the different reduction targets. For context, we can use the shadow price of the constraint in Equation 8 to estimate the marginal cost of N leaching that landowners face under the least-cost policy scenario. These are estimated to be $7, $19, and $40/kgN for Selwyn respectively for the 10%, 25%, and 50% reduction targets, and $7, $17 and $31/kgN for Hinds.

Dairy support in Figure 4 is estimated to have the greatest ability to reduce N leaching at the derived marginal costs, followed by dairy and arable land uses. S&B is only able to reduce N leaching by up to 10% of their current N leaching levels. Horticulture and forestry essentially maintain the same N leaching rate regardless of the reduction target, indicating that they do not have any cost-efficient mitigation options. However, the lack of mitigation options for these land uses is not necessarily an issue as they typically leach less than their allocated NDAs and thus are not affected by the policy and could even benefit from having the option for expansion.

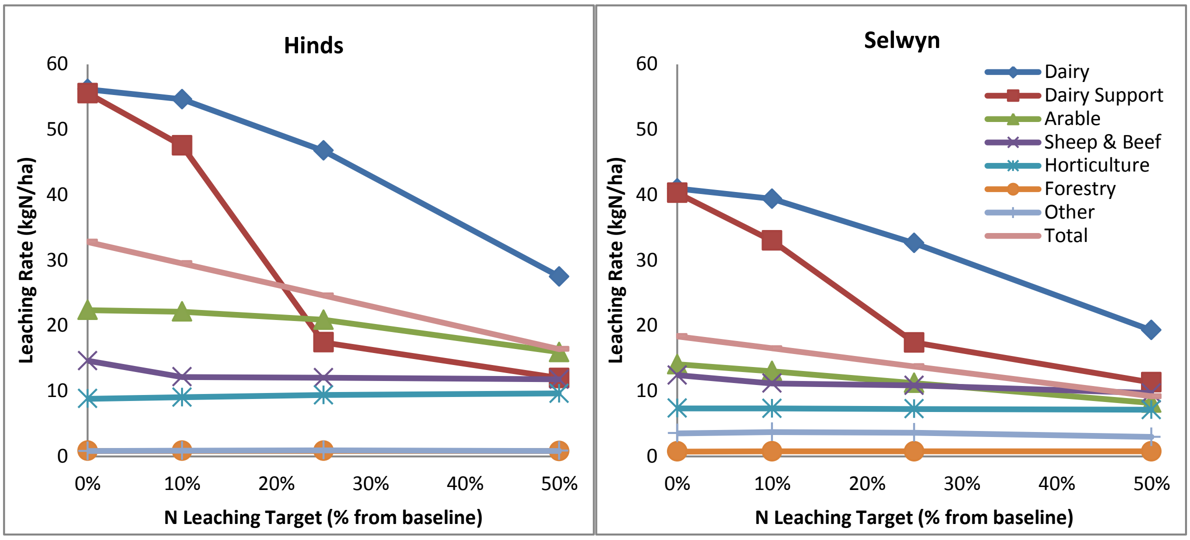

Figure 4. Mean N leaching rates by land use – least-cost scenario (flat lines indicate little abatement potential and downward curves indicate higher abatement potential).

APPENDIX – NUTRIENT VULNERABILITY AND NATURAL CAPITAL ALLOCATION DETAILS

Nutrient vulnerability allocation approach

The nutrient vulnerability allocation approach allocates NDAs according to the level of filtering service provided by the different soils. Webb et al. (2010) describe a simple model for nitrate leaching vulnerability for Canterbury soils. Soils with very high vulnerability reflect the soils' poor capacity for filtering nitrate, and soils with low vulnerability indicate soils with relatively high filtering capacity. This relative capacity is quantified by normalising modelled N leaching results from the nutrient budgeting model, OVERSEER (the very vulnerable soils have 30% of the filtering capacity of the least vulnerable soils).

This vulnerability-based NDA allocation approach comprises two steps. The first is to assign an initial allowance sufficient to allow a landowner to run a dryland S&B farming system. In most catchments the cumulative load from 100% dryland S&B farms will be less than the catchment's target load. When this is the case, the difference in the load is then redistributed in a second step according to the level of filtering service provided by the soil. Soils with a high filtering capacity are allocated more of the remaining load (proportional to their filtering capacity), thereby encouraging intensification on the least leaky soils or soils with the highest filtering capacity. Soils with poor filtering capability are allocated a smaller portion of the remaining load potentially limiting the intensification of these leakier soils. Land that has severe limitations to intensive agricultural production (e.g. too steep) is not given any additional load.

The total allowance is the sum of the initial NDA value and the amount allocated in the second step (if any). This allocation approach means all land owners including those with the leakiest soils will still be able to farm (dryland S&B) – but may not be able to intensify to other land uses, and any intensification is encouraged on the less leaky soils.

Natural capital allocation approach

Under the natural capital approach NDAs are based on the physical characteristics of the land or the soil type. This typically reflects the land's productive potential, and is independent of existing land use. The theory is that this approach supports the sustainable use of both land and water resources by favouring land areas that have good productive potential (Clothier et al. 2007).

We use the productivity potential of eight LUC classes as derived from S-map[8] and the New Zealand Land Resource Inventory[9] as a proxy for natural capital (Lilburne et al. 2013). As with the nutrient vulnerability approach, the natural capital allocation approach comprises two steps. The first is to assign an initial allowance sufficient to allow a landowner to run a dryland S&B farming system. In most catchments the cumulative load from 100% dryland S&B farms will be less than the catchment's target load. When this is the case, the difference in the load is then redistributed in a second step according to LUC. Land with a higher LUC is allocated more of the remaining load, thereby encouraging intensification on the most productive land. Land with lower LUC ratings is allocated a smaller portion of the remaining load potentially limiting the intensification of these less productive areas. More details on this approach are provided in Lilburne et al. (2013).

---

[8] http://smap.landcaresearch.co.nz

[9] http://lris.scinfo.org.nz

REFERENCES

Brown P 2013. Survey of rural decision makers. Landcare Research NZ Ltd. Available: www.landcareresearch.co.nz/science/portfolios/enhancing-policy-effectiveness/srdm. DOI: http://dx.doi.org/10.7931/J2D798B3

Clothier B, Mackay A, Carran A, Gray R, Parfitt R, Francis G, Manning M, Duerer M, Green S 2007. Farm strategies for contaminant management. Report by SLURI, the sustainable land use research initiative, for Horizon's Regional Council.

Daigneault A, McDonald H, Elliott S, Howard-Williams C, Greenhalgh S, Guysev M, Kerr S, Lennox J, Lilburne L, Morgenstern U, Norton N, Quinn J, Rutherford K, Snelder T, Wilcock B 2012. Evaluation of the impact of different policy options for managing to water quality limits. Report to the Ministry of Primary Industries, Wellington, New Zealand. Contract number 15564.

Dake CKG 2011. The econometrics of New Zealand pastoral agriculture: with special reference to greenhouse gas emissions. MAF Technical Paper No: 2011/38. Ministry of Agriculture and Forestry, Wellington, New Zealand.

Everest M 2013. Hinds catchment nutrient and on-farm economic modelling, prepared for Environment Canterbury. Environment Canterbury Report No. R13/109.

de Frahan, BH, Buysse J, Polom EP 2007. Positive mathematical programming for agricultural and environmental policy analysis: review and practice. In: Weintraub A, Bjorndal T, Epstein R, Romero C eds Handbook of operations research in natural resources, Vol. 99. Berlin, Springer. Pp. 129–154.

GAMS 2015. CONOPT solver. Washington, DC, GAMS corporation. Available online: http://www.gams.com/dd/docs/solvers/conopt/ [accessed 16 May 2015].

Greenhalgh S, Daigneault A, Samarasinghe O, Sinclair R 2012. Capitalizing on climate and water policies in the New Zealand agricultural and forestry sectors. The International Journal of Climate Change: Impacts and Responses 3(2): 15–32.

Kerr S, Olssen A. 2012. Gradual land-use change in New Zealand: results from a dynamic econometric model. Motu Working Paper 12-06, Available from URL: http://motu-www.motu.org.nz/wpapers/12_06.pdf [accessed 16 May 2015].

Lilburne L, MacKay A, Mercer G, Lynn I, Wheeler D. 2013. Applying the 'natural capital' approach to nutrient allocation the Selwyn-Waihora Zone in Canterbury. Landcare Research contract report LC1569.

Lynn I, Manderson A, Page M, Harmsworth G, Eyles G, Douglas G, Mackay A, Newsome P 2009. Land Use Capability Survey Hand-book: a New Zealand handbook for the classification of land. Hamilton, Agresearch; Lincoln, Landcare Research; Lower Hutt, GNS Science.

Webb T, Hewitt A, Lilburne L, Close M, McLeod M 2010. Mapping of vulnerability of nitrate and phosphorus leaching, microbial bypass flow, and soil runoff potential for two areas of Canterbury. Landcare Research LC0910/141 & ECan R10/125.