

# EXAMINATION OF THE NEED FOR AN ADDITIONAL DAIRY SOURCE TERM FOR NITROGEN IN CLUES

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## Abstract

The CLUES model is a catchment scale model that allows community, social and economic inputs when assessing the effects of land use and land use change on water quality. Estimates of N loadings for pastoral farms are achieved using a version of the OVERSEER<sup>®</sup> nutrient budget model within CLUES that has preloaded farm data for 5 farm types. CLUES makes use of the SPARROW regression model to combine the loading from various pastoral and non-pastoral sources of N in a catchment and to attenuate N as it passes down the stream network. The SPARROW model requires a source term for dairy land of 11.2 kg N/ha/yr, implying an error in estimating N loading. Analysis of the data indicates that the reason for the continuing need for a source term is partly due to differences in land use intensity between actual intensity and typical land use intensity modelled in the OVERSEER-CLUES model. The lack of actual farm data from most catchments means that it was not possible to identify how many catchments this may affect. Other reasons include underestimation of loads from the OVERSEER-CLUES model, or overestimation of attenuation in dairy catchments by the SPARROW model, or a combination of both. It was not possible to separate these reasons due to co-linearity between these two terms. It is also recommended that any predictions based on CLUES should be used with due recognition of the degree of approximation with the models.

## Introduction

The CLUES model (Woods et al. 2006, McBride et al. 2008) requires farm nitrogen (N) loadings to estimate an N loading for a given catchment. Although land use data is available to CLUES, actual on-farm data is not. Estimates of N loadings for pastoral farms are achieved using a version of the OVERSEER<sup>®</sup> nutrient budget model (Wheeler et al. 2006) within CLUES that has preloaded farm data for 5 farm types (dairy, lowland sheep/beef, hill country sheep/beef, high country sheep/beef, deer), hereafter referred to as the OVERSEER-CLUES model. The farm data are based on regional MAF monitor farm data for sheep/beef and deer farms, and Livestock Improvement data for dairy farms. Farm type, as well as soil type and rainfall are supplied by the CLUES model.

CLUES also makes use of the SPARROW model (Elliot et al. 2005) to combine the loading from various pastoral and non-pastoral sources of N in a catchment to attenuate N as it passes down the stream network. The parameters for this part of the model are derived from a regression procedure that fits the model predictions to total N loads measured at various locations in the stream network. The attenuation term takes account of loss and/or dilution of N from the source to the point of measurement, and is dependent on the size of water courses and distance from source to the point of measurement.

The SPARROW regression analysis has previously indicated that to develop the best fit to the measured data, losses from dairy land use needed to be higher than those estimated by the

OVERSEER nutrient budget component of CLUES (the OVERSEER-CLUES model). This is shown by the requirement for an extra source term (constant) for dairy land use in the regression output, implying an error in estimating N loading under dairy land use. The objective of this project was to look more closely at this extra term in the SPARROW regression, and to gain insight into why it appears and whether it is necessary.

### **Methodology**

The approach used in this study was to run the SPARROW regression using sites in NIWA's National Rivers Water Quality Network and additional sites within the Waikato Region but outside the Waikato River basin (Environment Waikato 2006) for calibration data.

The predicted catchment loads (kg N/yr) for a number of selected stream monitoring locations were extracted from CLUES (Table 1). The locations were selected to have either a high fraction of dairying in the catchment (generally greater than 50%), or a high fraction of non-dairy pasture land use (>65%) with a low fraction of dairy (<10%). This put the focus on the dairying catchments, and the differences between dairying and non-dairying sites. Three dairy Focus Farm catchments (Wilcock et al. 2006) were included in this set of sites (see Table 1). Other Focus Farm catchments where the catchment boundary from CLUES differed significantly from that reported by Wilcock et al. (2006) were excluded.

Measured and predicted loads (kg/ha/yr) were extracted from CLUES and are shown in Table 2, along with the OVERSEER-CLUES component of the predicted load.

### **Results and discussion**

Statistics from fitting two models, one where the extra term was allowed, and one where it was excluded, are shown in Table 3. The fitted source term was 11.2 kg N/ha/yr for dairy catchments (Table 3). The inclusion of the source term only had a small effect on the overall fit, but did change the size of the error. Thus, for example, the mean error for dairy and non-dairy pasture was 4% and -7% respectively when the source term was included, and -8% and 1% when the source term was excluded. The model tended to compensate for the presence or absence of the source term by increasing or decreasing the attenuation coefficients. Elliott et al. (2005) mentions the trade off between source and attenuation coefficients (co-linearity), and that the National river water quality network (RWQN) may not be sufficiently nested to enable SPARROW to adequately separate the two.

In an earlier analysis using an older version of the OVERSEER<sup>®</sup> nutrient budget model, the source term was 17 kg N/ha/yr (Woods et al. (2006). This suggests that the most up-to-date version of the model should be used.

#### *Comparison between measured and predicted loads*

The CLUES model, using source terms and attenuation constants predicted catchment measured load well (Table 3). The predicted load included the contribution from OVERSEER-CLUES, as well as non-pastoral sources (such as trees). On average, the sparrow- OVERSEER-CLUES model over-predicting measured yield by 0.77 kg N/ha/yr on both dairy and non-dairy pastoral land use when the extra source term was included, and on average under predict dairy catchments by 2.33 kg N/ha/yr and non-dairy catchments by 1.29 kg N/ha/yr, again reflecting that the model predicted measured data well. However, there were discrepancies. For example, the Whareroa stream, Waikohu and Otamakokore catchments, the model consistently over-predicted measured yield when using the extra source term. Reasons for these are given in following sections.

**Table 1.** Catchment sites, catchment type, data source, percentage of catchment area that is as dairy or other pasture, and catchment area.

Site <sup>1</sup>	Type	Sources	Dairy (%)	Other pasture (%)	Area (km <sup>2</sup> )
Ohinemuri at Queens Head	Dairy	Waikato region	47	16	135.6
Otamakokore at Hossack Rd	Dairy	Waikato basin	55	28	45.7
Piako at Paeroa-Tahuna Road	Dairy	Waikato region	70	22	536.7
Piako River – Kiwitahi	Dairy	Waikato region	68	15	108.1
Waihou at Te Aroha	Dairy	Waikato region and national	45	12	1101.7
Waipa at Whatawhata	Dairy	Waikato basin and national	39	36	2862.7
Waitoa at Mellon Road	Dairy	Waikato region	70	20	409.3
Puniu at Bartons Corner	Dairy	Waikato basin	43	35	518.7
Waingongoro at SH45	Dairy	National (Taranaki)	80	11	226.7
Wairua at Purua	Dairy	National (Northland)	37	27	544.7
Bog Burn	Dairy	Focus farm	28	26	24.8
Waiokura	Dairy	Focus farm	88	6	20.9
Toenepi	Dairy	Focus farm, Waikato region	89	10	15.8
Manganui at SH3	Part Dairy	National (Taranaki)	18	4	13.7
Mangaokewa at Te Kuiti Pump Station	Other pasture	Waikato basin	3	70	174.1
Mokau at Totoro Bridge	Other pasture	Waikato region	11	65	1054.7
Whareroa Stream at Lake Taupo	Other pasture	Waikato basin	5	66	59.4
Waikohu at No 1 Br	Other pasture	National (Gisborne)	0	78	26.5
Tukituki at Red Bridge	Other pasture	National (Hawkes Bay)	4	74	2457.5
Manawatu at Weber Rd	Other pasture	National (Manawatu)	8	81	710.9
Opihi at Rockwood	Other pasture	National (South Canterbury)	3	67	410.6
Ruamahunga at Wardells	Other pasture	National (Wellington/Wairarapa)	6	66	641.5
Opihi at Waipopo	Other pasture	National (South Canterbury)	4	64	2376.4

<sup>1</sup> Waikato Region sites are those within the Waikato Region but outside the Waikato River basin. National sites are those in NIWA's National Rivers Water Quality Network.

**Table 2.** For each catchment, measured yield, total predicted yield using the attenuated model with extra source term, and OVERSEER-CLUES estimated unattenuated and attenuated loads.

Site	Type	Measured load (kg N/ha/year)	Predicted load (kg N/ha/year)	OVERSEER-CLUES load (kg N/ha/year)		Estimated catchment attenuation (%)
				Unattenuated	Attenuated	
Ohinemuri at Queens Head	Dairy	19.2	20.0	20.9	16.1	23
Otamakokore at Hossack Rd	Dairy	8.8	18.4	21.5	15.0	30
Piako at Paeroa-Tahuna Road	Dairy	15.0	18.6	17.9	10.4	42
Piako River – Kiwitahi	Dairy	19.8	15.7	16.3	10.8	34
Waihou at Te Aroha	Dairy	16.0	15.8	15.1	9.9	34
Waipa at Whatawhata	Dairy	13.8	14.3	17.1	10.5	38
Waitoa at Mellon Road	Dairy	13.8	17.1	20.7	11.7	63
Puniu at Bartons Corner	Dairy	13.0	14.1	17.8	11.2	37
Waingongoro at SH45	Dairy	24.6	20.5	26.3	15.4	40
Wairua at Purua	Dairy	17.7	17.4	13.3	9.1	32
Bog Burn	Dairy	8.5	9.3	5.4	3.2	42
Waiokura	Dairy	25.5	24.5	36.9	20.2	45
Toenepi	Dairy	21.5	22.4	19.2	13.4	30
Manganui at SH3	Part Dairy	14.7	16.1	8.4	7.6	9
Mangaokewa at Te Kuiti Pump Station	Other pasture	10.7	10.0	14.8	9.7	35
Mokau at Totoro Bridge	Other pasture	13.8	12.3	16.3	11.0	33
Whareroa Stream at Lake Taupo	Other pasture	6.4	11.5	16.1	11.1	31
Waikohu at No 1 Br	Other pasture	4.8	10.9	14.0	10.7	23
Tukituki at Red Bridge	Other pasture	7.4	5.4	11.0	5.0	54
Manawatu at Weber Rd	Other pasture	7.0	6.4	11.5	6.1	48
Opihi at Rockwood	Other pasture	2.8	1.5	5.6	1.3	77
Ruamahunga at Wardells	Other pasture	8.1	7.6	9.8	5.8	61
Opihi at Waipopo	Other pasture	1.0	1.7	5.1	1.1	78

### *Catchment characteristics*

The size of errors could not be correlated with catchment size or the soil type expected to be found in a catchment. Removing catchments with high error terms from the analysis had little effect on the source term. However, the source term for the Waikato-only catchments was close to zero (data not shown), suggesting that the 'pressure' in the model for an additional dairy source term arises from sites outside the Waikato region.

The OVERSEER-CLUES term by itself does not include other sources (such as from bush or scrub), which would tend to increase the predicted load (OVERSEER-CLUES deals only with the pasture sources). However, as non-pastoral inputs tend to be furthest from the point of measurement, it was attenuated by in-stream processes.

The relationship between the difference between attenuated OVERSEER-CLUES load and measured load, and the percentage of dairy in a catchment is shown in Figure 2. At 100% dairy, the difference is about 10 kg N/ha/yr, which is similar to the source term. In catchments with less than 20% dairy, the difference is relatively constant at about 2 kg N/ha/yr, as indicated in the previous section. The catchments where differences are greater than zero (Whareroa, Waikohu and Otamakokore) are discussed in the following sections.

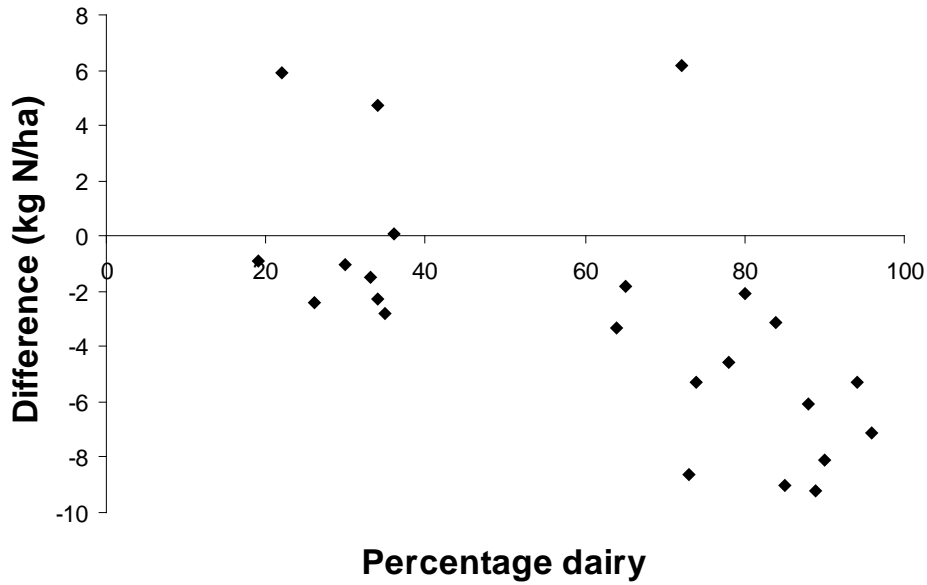
### *Non-dairy (other pasture) catchments: comparison between OVERSEER-CLUES and measured loads*

The relationship between measured and OVERSEER-CLUES model load for non-dairy catchments is shown in Figure 2.

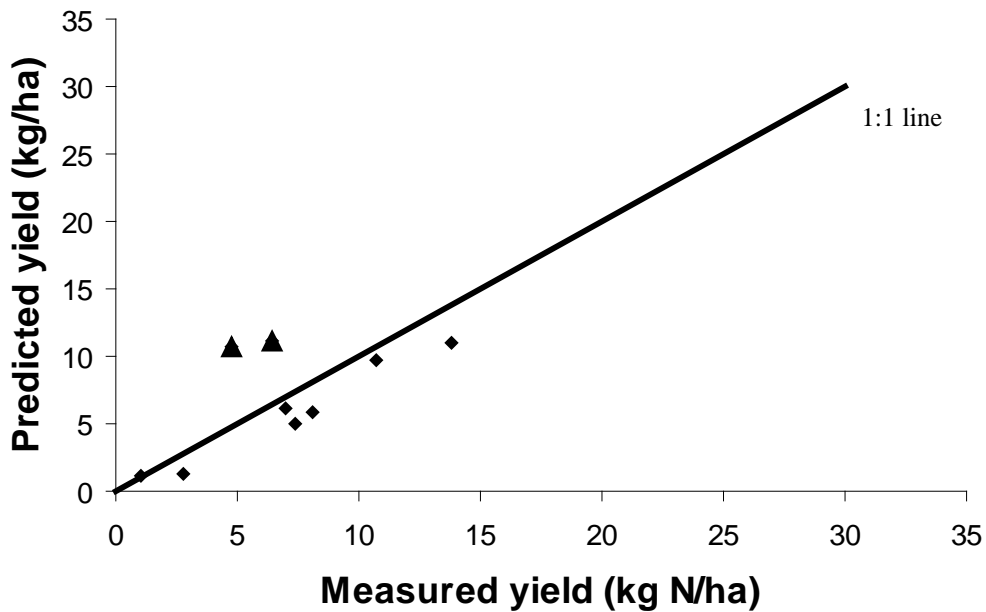
**Table 3.** Statistics from SPARROW regression where two models were fitted, one where the extra term was included, and one where it was excluded.

	Ratio predicted/measured	
	Extra source terms	No extra source terms
Median all catchments	1.035	0.960
Median dairy	1.038	0.919
Median other pasture	0.933	1.010
Median national <sup>1</sup>	0.984	0.975
Median non-national	1.066	0.950
Median dairy national	0.98	0.84
Median dairy non-national	1.09	0.95
Calibration R <sup>2</sup>	0.949	0.946
Extra dairy source term (SE of estimate) (kg/ha/y)	11.2 (5.6)	0

<sup>1</sup> National sites are those in NIWA's National Rivers Water Quality Network.



**Figure 1.** The relationship between the percentage of catchment that is dairy pasture land use and the difference between measured and attenuated OVERSEER-CLUES load.



**Figure 2.** Measured and attenuated OVERSEER-CLUES model yield (kg N/ha/yr) for non-dairy catchments. Whareroa stream and Waikohu catchments are shown as large triangles. The axes extend beyond the data range for comparison with Figure 3.

Ignoring the Whareroa stream and Waikohu catchments, the difference between measured and attenuated OVERSEER-CLUES loads ranged from 0.1 to -5.9 kg N/ha/yr, with an average of -1.5 kg N/ha/yr. The reason for over-estimation in the Whareroa stream is not known, but streams in the lake Taupo catchment are known to contain water that is relatively old (20+ years). This older water probably contains less N, as indicated by measured load

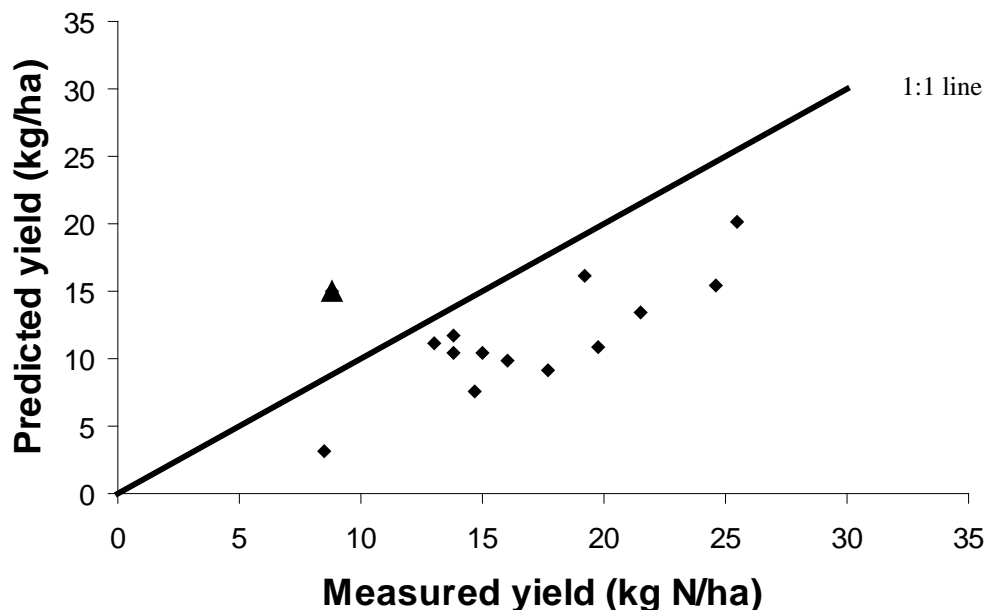
(Table 2), because farming intensity was lower. In addition, dairy in the Whareroa catchment is less intensive than the typical value for the Waikato region, and the area in dairy in the CLUES database (5%) is higher than that from an Environment Waikato survey (1%), all resulting in over-estimation of the OVERSEER-CLUES load.

The Opihi catchments, particularly the lower catchment, have the potential for ingress and exchange of groundwater from less contaminated catchments, hence resulting in small measured loadings (1 kg N/ha/yr). The SPARROW model currently does not take into account groundwater transfer between surface-water catchments. The upper Opihi catchment has farming systems akin to high country rather than Otago hill country, and hence OVERSEER-CLUES are likely to over-estimate losses.

*Dairy catchments: comparison between OVERSEER-CLUES and measured loads*

Except for the Otamakokore catchment, the difference between measured and attenuated OVERSEER-CLUES loads ranged from 1 to 10 kg N/ha/yr (see Figure 3), with an average difference of 5.7 kg N/ha/yr (OVERSEER-CLUES loads smaller than measured). The Piako River at Kiwitahi, Waingongoro, Wairua, Toenepi and Manganui catchments had differences of > 8 kg N/ha/yr.

The over-estimation of measured load by the OVERSEER-CLUES model at Otamakokore at Hossack Rd catchment is probably due to higher attenuation of N in the swamp area of the catchment.



**Figure 3.** Measured and attenuated OVERSEER-CLUES model yield (kg N/ha/yr) for predominately dairy catchments. Otamakokore catchment is shown as a large triangle.

The Toenepi catchment in the Waikato and the Waingongoro catchment in Taranaki (a lowland spring-fed stream) had numerous outlets from oxidation ponds (Wilcock 2007). The upper tributaries in the Waingongoro were also accessible by stock. The OVERSEER-CLUES model assumes that best management practices of using spray irrigation and excluding stock are applied. The use of oxidation ponds could add an additional 1-2 kg

N/ha/yr to average catchment losses, depending on how many farms used oxidation ponds within the catchment.

The OVERSEER-CLUES model used average farm data for the regions. Data that are more accurate could be obtained using specific farm data for the catchments. Such data was available for some catchments. For the Bog Burn catchment in Southland, the average catchment leaching loss based on OVERSEER<sup>®</sup> nutrient budget model estimates for individual farms was about 10 kg N/ha/yr (R Monaghan pers. comm.). This is similar to the measured catchment load. The indication is that the discrepancy between measured and the OVERSEER-CLUES model is due largely to dairy runoff blocks that have high losses as they carry high stock numbers over winter. These blocks are probably coded as non-dairy blocks in clues land use database but they have higher losses than the typical beef system for that region.

Disparity between actual land use intensity in the Toenepi catchment and the load predicted by the OVERSEER nutrient budget model for individual farm types was about 6 kg N/ha/yr greater than the measured load, which is the opposite to that for the OVERSEER-CLUES model. Again, this would indicate that land use intensity in the Toenepi is greater than the average for the Waikato region. The Wairau catchment dairy farms are probably also farmed more intensively than typical Northland farms, but this difference in intensity would not account for all of the differences for this catchment.

In the Manganui catchment, OVERSEER-CLUES loading under-estimated measured catchment loadings but measured and predicted total yield were similar. This catchment is predominately non-pasture (18% dairy, 4% non-dairy pasture), and hence it is probable that the higher actual catchment loading is coming from a non-pasture source.

A desktop exercise indicated that the predicted loadings on these catchments where land use intensity was known to vary was within 1-2 kg N/ha/yr of measured loadings when actual land use intensity was taken into account.

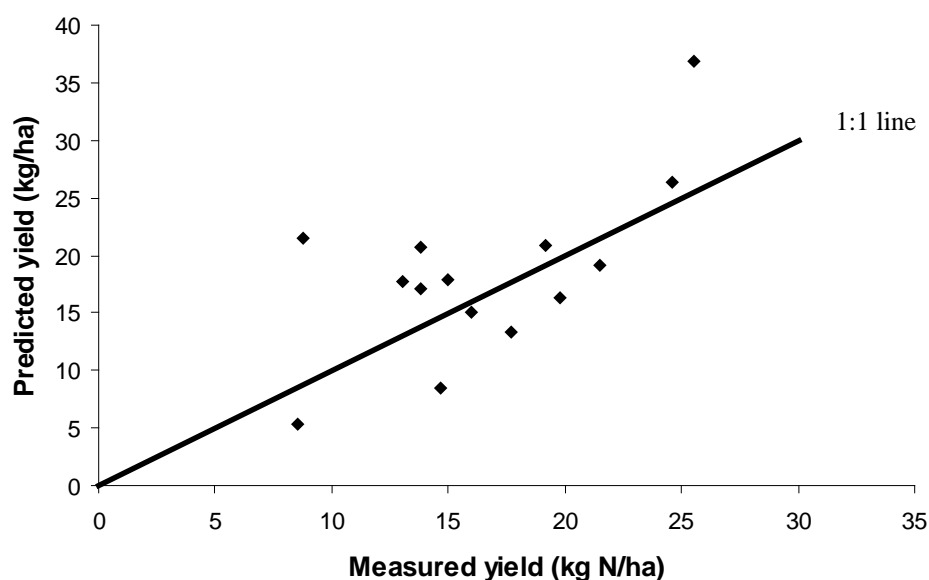
#### *Attenuation*

The whole catchment attenuation rates were estimated from the difference between attenuated and unattenuated OVERSEER-CLUES model catchment loads (Table 2). Excluding the Opihi catchments, attenuation decreased estimated loads by, on average, 36% (range 9%-61%), which is within the range of measured attenuation rates. On the Opihi catchment, estimated attenuation was 77%, and probably due to ingress and exchange of groundwater.

The unattenuated OVERSEER-CLUES load estimates for dairy catchments were centred on the 1:1 line with the measured load as shown in Figure 4. If the OVERSEER-CLUES load estimates were correct, this would suggest a very low attenuation rate on dairy catchments. Theoretically, attenuation rates for a given flow rate and stream length may be lower in streams from predominately dairy catchments, and is consistent with concepts of N uptake processes becoming saturated at high concentrations due to increased N saturation. This is typically observed below strong point discharges but has not been confirmed for dairying catchments, and there was no evidence of this in this data. If attenuation is lower in dairying streams, the SPARROW model could be over-estimating attenuation and increasing the dairy sources to compensate (co-linearity as discussed by Elliot et al. 2005).

Comparing Figures 3 and 4 suggests that the source term in the SPARROW model could be due under-estimation of loads from the OVERSEER-CLUES model, over-estimation of attenuation in dairy catchments by the SPARROW model, or a combination of both.

Additional research data from sites to validate the OVERSEER-CLUES model would assist in elucidating this by providing further assurance regarding the source terms. Attenuation coefficients are difficult to measure and validate. This remains an area for ongoing research, and cannot be resolved with current information.



**Figure 4.** Measured and unattenuated OVERSEER-CLUES model load (kg N/ha/yr) for dairy catchments.

### Conclusions

The analysis indicates the need for a source term (constant) for dairy land use in the SPARROW regression model of 11.2 kg N/ha/yr. As most catchments are only part dairy, this is equivalent to an average difference for dairy catchments of about 6 kg N/ha/yr.

Factors that contributed to the variation about the fit included:

- differences in actual land use intensity or effluent management from the typical values used by OVERSEER-CLUES;
- possible small under- or over-estimations of N losses by the OVERSEER nutrient budget model in areas for which there is little or no data for independent validation; and
- possible contributions from non-pastoral sources (e.g. in the Manganui catchment).

Within the clues model, the effect of ground water transfers between catchments is not modelled, and this may also be a factor. It is probable that decreasing variability by taking account of these factors would also result in a decrease in the source term.

The analysis identified that the reason for the continuing need for a source term is partly due to differences in land use intensity between actual intensity and typical land use intensity modelled in the OVERSEER-CLUES model. The lack of actual farm data from most catchments means that it was not possible to identify how many catchments this may affect.

Other reasons include underestimation of loads from the OVERSEER-CLUES model, overestimation of attenuation in dairy catchments by the SPARROW model, or a combination of both. It was not possible to identify which factor was more important due to co-linearity between these two terms. Additional work on improving estimation of loads from the OVERSEER-CLUES model is the easier approach to decreasing the extra source term as the estimation of attenuation in streams is difficult.

The OVERSEER<sup>®</sup> nutrient budget model will undergo continued development, and improvements will be made as new research information is made available. This, and the improvement in the source term when the new version was used, indicates the desirability of using the latest version of the OVERSEER<sup>®</sup> nutrient budget model with the OVERSEER-CLUES link.

It is also recommended that any predictions based on CLUES should be used with due recognition of the degree of approximation within the models.

### **Acknowledgements**

The work was funded by Dairy Insight under the project EN625: Tools for Improving Environmental Planning: Catchment Scale Tools.

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