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Economic studies joint venture project - Waikato land allocation model

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Executive summary

- The Waikato Economic Impact Joint Venture Studies project was a collaboration between central government, Waikato Region Council (WRC), the Waikato River Authority and industries.
- The project aims to provide a basis that can support decision-making on the potential impacts of setting freshwater objectives and limits in the Waikato-Waipa River catchment.
- One output of the project is a catchment-level economic model (called the Waikato Land Allocation Model) that will be made available to the WRC's Healthy Rivers Plan for Change/Wai Ora project.
- This report provides the documentation of the Waikato Land Allocation Model (WLAM).
- The documentation covers the model's three main components: the logic behind the model in terms of conceptual framework; the algorithm in terms of how the model works; and the baseline data used, together with the assumptions in each component.
- The underlying problem that informed the joint venture project and this model is the fact that nutrients/contaminants are being discharged into the river through non-point sources and point sources, with consequential effects on ecological health and human values associated with the river.
- The studies involve modelling the cost-effective management of land use allocation and point source discharges (primary, secondary, tertiary treatments, land fill) required to meet given targets.
- WLAM has been developed with the aim of providing a tool to analyse the policy effects of restoring and maintaining water quality targets in the Waikato-Waipa river catchment of Waikato Region. In terms of logic, WLAM is a constrained optimisation model such that nutrient leaching at farm level and contaminant discharge at point sources for each sub-catchment are constrained incrementally to simulate the mitigations required (up to and including changes in land use) and the cost implications at the catchment level.
- The smallest unit of analysis in the WLAM is the sub-catchment, of which 66 are defined for the Waikato-Waipa Catchment. The model has been coded to aggregate these sub-catchments into four main zones: Upper Waikato (Lake Taupo to Karapiro); Waipa (Waipa River Catchment); Central Waikato (Karapiro Dam to Ngaruawahia); and Lower Waikato (Ngaruawahia to Tasman Sea).
- Areas under different farm types, systems, mitigation options, mitigation levels and the corresponding costs of mitigation are endogenously determined.
- The model captures the respective contributions of water pollution from farming activities, municipality wastewater treatment plants (WWTPs) and industries such that the implications of meeting a water quality target can be investigated using the model.
- The essential components of the model are presented with an acknowledgement that the real world is far too complex to be represented in full detail in a model. For example, this is a quantitative model where some qualitative information and concepts have replaced with assumptions or measured by proxies.
- A particular feature of the model is considered is the use of primary data gathered directly from farmers. These data have been extrapolated with secondary processed regional data. This allows for generalisation without losing the specific focus.
- Also, the hydrology and production functions of technical input output coefficients are not represented at this stage but there is scope for incorporating these in future. This would broaden the potential applications of the model in future. However, the model's conceptual framework and the assumptions are also coded in such a way that they can be updated at a reasonable cost when new information and/or more critical views become available.
- The algorithm also allows a wide range of possible assumptions to be tested if there is a lack of data.
- A limitation of the model as a result of aggregation to catchment level is that the results will be relative values rather than absolute. The implication is that the results are to evaluate different policy approaches rather than to predict economic cost of setting water quality

limits or targets. In addition, the model has been pragmatically calibrated in its current form, but it is acknowledged that its validation capability will depend on the scenarios being investigated.

1 Introduction

The Waikato Economic Impact Joint Venture Studies Project was a collaboration between the central government, the Waikato Region Council (WRC), the Waikato River Authority and industry. The project aimed to inform decision-making on the potential impacts of setting freshwater objectives and limits in the Waikato-Waipa River Catchment. One output of that project is a catchment-level economic model that will be made available to the WRC's Healthy Rivers Plan for Change/Wai Ora project.

This report is a documentation of the model, Waikato Land Allocation Model (WLAM). The documentation covers the model's three main components: the logic behind the model in terms of its conceptual framework; the algorithm in terms of how the model works; and the baseline data used together with the assumptions in each component.

1.1 The Problem

The underlying problem that informed the joint venture economic studies project and this model is the fact that nutrients/contaminants being discharged into the river through the non-point sources and point sources affect ecological health and human health, and values associated with the river. This consequently calls for policies that try to balance the use and management of land and water resources with economic activities in the region.

The primary non-point source of nutrients in the catchment is pastoral farming while the point sources include industrial sites and the municipal waste water treatment plants (WWTPs). Therefore the particular focus of the joint venture economic studies is to evaluate the cost of reducing nutrient losses from agriculture and contaminants discharged from factories and WWTPs. Hence the studies involve modelling the cost-effective management of land use allocation and point source discharges (primary, secondary, tertiary treatments, land fill) required to meet given targets.

WLAM has been developed with to analyse the costs of policies to achieve water quality targets in the Waikato-Waipa river catchment. The model can be used to assess how land management could be expected to change under different environmental policies and targets. WLAM combines information on agricultural land use (dairy and dairy support, sheep and beef, horticulture, forestry and on-farm forestry), point source discharges; relationship between on-farm nutrient leaching and the level of nutrients that eventually runs off into the water bodies; water quality policy instruments in terms of targets and constraints on the nutrient discharge activities. The model when applied to a particular water quality target would indicate how changes in water quality targets will affect land use among different land use options, in terms of changes to farm industry structure and the effect of those changes on land use profitability. The workings of the model are briefly described below with full details of major components in the later sections of this report.

1.2 The Conceptual Framework

In terms of logic (the conceptual framework), WLAM is a constrained optimisation model, such that nutrient leaching at farm level and contaminant discharge at point sources for each sub-catchment are constrained incrementally to simulate potential changes in land use and the cost implications at catchment level. This means that, to achieve a water quality target, WLAM will predict change in land use type, farm systems, mitigation options, mitigation level and cost of mitigation at minimum cost to achieve that water quality target. Figure 1 shows the schematic structure of WLAM to visualise the activities in the model. The model, when run, finds the optimum solution in terms of minimising the cost of reaching specific nutrient targets. It follows the land allocation and management (LAM) framework proposed by Doole 2015. This model is also similar to the model built for the joint venture economic studies phase one (Doole, 2014). However, at this stage, WLAM can only be used to study targets with focus on N and P at farm level and point sources. This is because the nutrient discharges at the source have not been linked to nutrient concentration in the river. This means the hydrology aspect has not been populated with data though a place holder has been placed in the model.

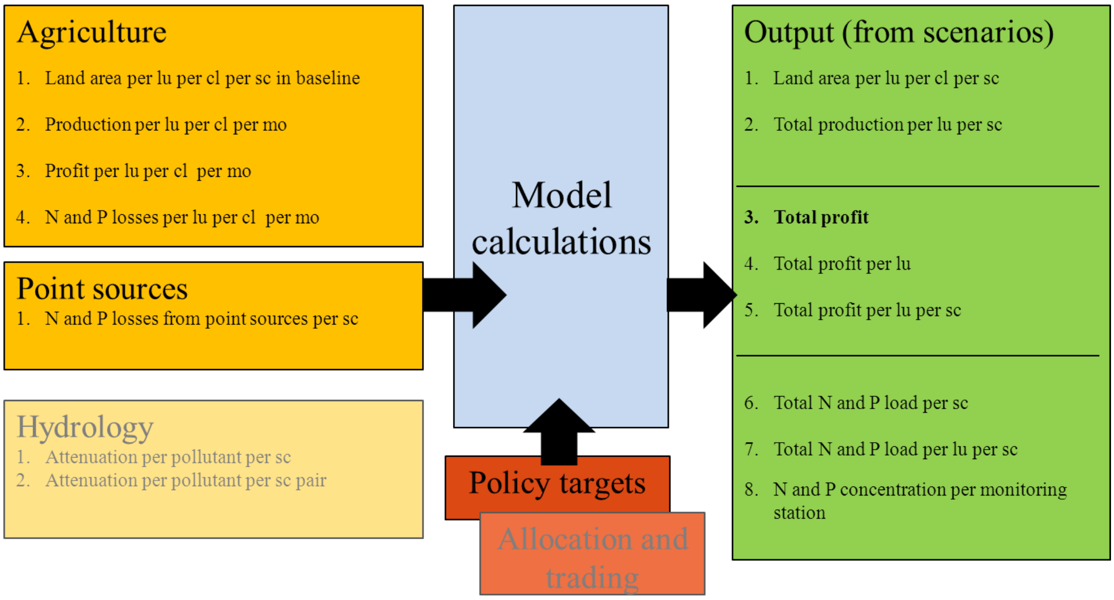

Figure 1: WLAM schematic diagram [1]

The smallest unit of analysis in the WLAM is the 66 sub-catchments of the Waikato-Waipa Catchment (See the map in Figure 2). The model has been coded to aggregate these sub-catchments into the four main river catchment services zones namely Upper Waikato (Lake Taupo to Karapiro) Waipa (Waipa River Catchment), Central Waikato (Karapiro Dam to Ngaruawahia) and Lower Waikato (Ngaruawahia to Tasman Sea).

Areas under different farm type, systems, mitigation options, mitigation levels and the corresponding costs of mitigation are endogenously determined. It is a static (single year) model defined such that the endogenous variable is area (ha) allocated to a land use type with a mitigation option and at a level of mitigation in a particular sub-catchment. Another specification in the model is that the main decision that can be explored is changes in management (mitigation options, level of intensity, changes in capital infrastructure, etc) within existing land uses. Although, the model can allow for land use change to meet a particular environmental targets.

This type of model is widely used to capture the relationship between land use activities such as farming and environmental outcomes of such activities either at farm level, catchment, regional or national level (McCarl and Spreen (1980; Eloffson, 2003; Qiu 2005; Adamson et al; 2007; Nordblom et al, 2010; Doole, 2012; Roberts et al, 2012). The popularity of this type of modelling in agricultural policy evaluation is based on a number of characteristics of this modelling type. Firstly, the modelling approach allows evaluation of imposing resource use constraints by revealing both economic and environmental outcomes of such policies. The modelling technique also allows capturing the fixed proportion production technology that characterise some agricultural production activities (Howitt, 1995). Also, this type of modelling allows incorporation of alternative production activities or specifically mitigation practices in case of evaluating mitigation scenarios. In addition, programming modelling allows detailed analysis of the effects of policy changes across commodities, regions, and production systems unlike other modelling techniques (for example, econometric approaches) that allow for detail modelling of

[1] No data for attenuation yet

a particular commodity at a time. Most importantly they allow for limited data which usually characterise regional or catchment-level policy analysis as opposed to farm-level analysis.

However, this modelling technique suffers from overspecialisation or calibration problem where constant marginal rate of transformation among production systems regardless of level of input availability is usually assumed. This always makes the model to allocate resources to activities that has highest benefit for example highest net returns. Specifying cost function, as opposed to resource allocation constraints on the model, has been a means to minimise this problem in this type of modelling (USDA, 2007). This approach has been implemented widely with positive mathematical programming (PMP) calibration approach (Howitt, 1995) with several applications in literature (Paris and Howitt, 1998; Olubode-Awosola, 2006; Daigneault, et al, 2011, 2012, 2013). Recent development in this regards has been application of maximum entropy calibration approach (Paris and Howitt, 1998) where more than one observation on activity levels can be used. This means more data requirements.

The current structure of WLAM is such that the input and output coefficient functions usually specified in a non-linear cost function (Bauer 1988; Bauer and Kasnakoglu 1990) are not specified. However to minimise overspecialisation problem, flexible resource constraints in terms of using upper and lower bounds were used as a calibration approach and that serves the purpose of this project. In WLAM, the type of production activities that will be forgone are a function of the level of environmental outcomes desired and the level of net profit attributable from different production activities. This is to achieve the purpose of the study – to reveal cost of meeting water quality targets. In WLAM, the objective function at the catchment level was specified in two stages such that in stage 1, the net profit of farming activities are maximised with only flexible constraints as a means of calibration and no environmental constraints. At the second stage, the objective function is the minimisation of the loss in farm income (difference between the base level unconstrained farm income and the constrained optimised farm income) and the cost of mitigation by the point source subject to environmental constraints. The equilibrium and optimum simulated by the model is partial because other factors are held fixed when leaching or discharge is constrained. The constrained cost minimisation levels of simulated water quality levels, crops and livestock production is specified in the appendix. Details on specification with related assumptions are presented in the Appendix.

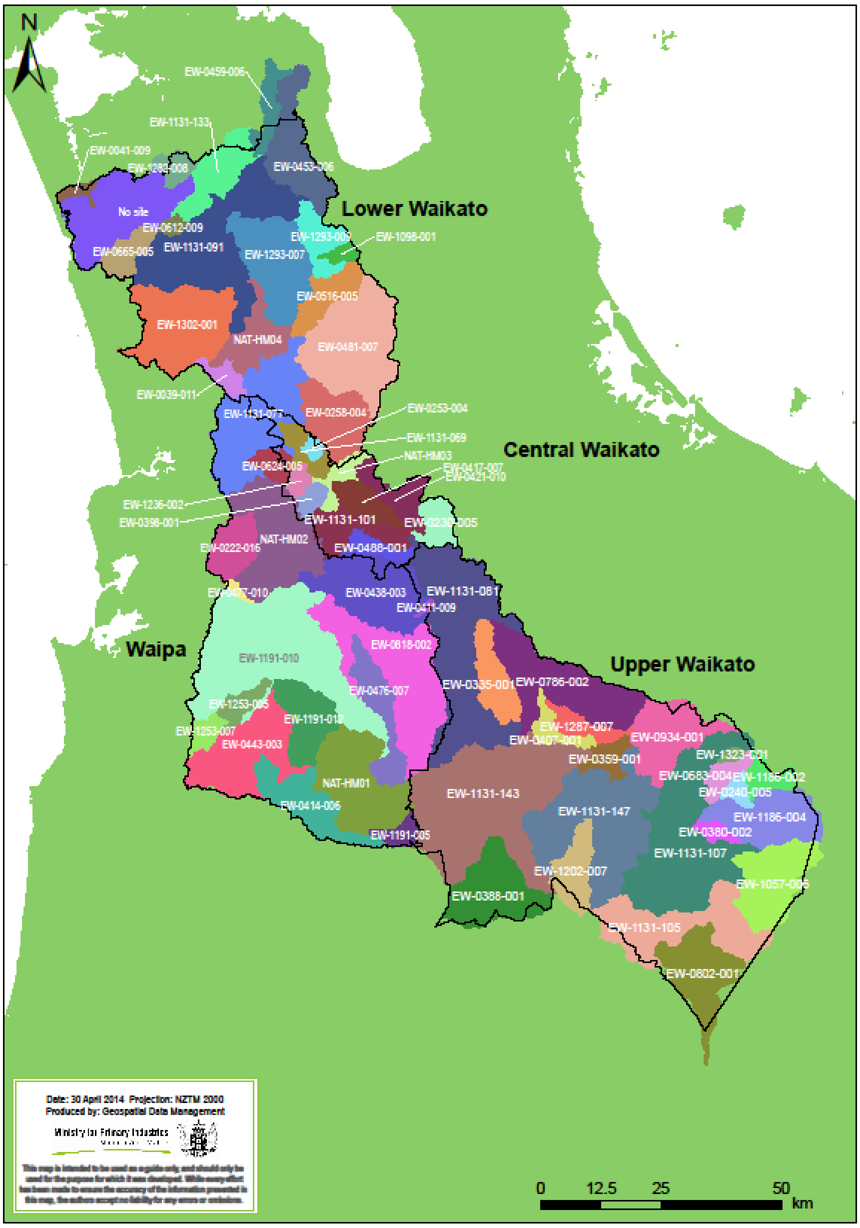

Figure 2: Sub-catchments in Waikato-Waipa River Catchment of Waikato region

1.3 The Procedure

In terms of algorithm (the procedure), the WLAM is written and maintained in GAMS (General Algebraic Modeling System) as a modelling language (GAMS Development Corporation, 2021). The operation of the model works in two stages. First it maximise the total operating surplus subject to the constraints that land use remains as in the baseline. The purpose is to estimate the baseline operating surplus and nutrient loads in the current situation, on each sub-catchment. In the second stage, when nutrient constraints are imposed, WLAM minimises the total mitigation cost, subject to the constraints defined in the model. The same as in Doole (2014a), the primary decision variables in the model are those representing the area allocated to each management option within each land use. The total operating surplus is determined through multiplication of the area of each land use option employed and its associated level of operating surplus per ha. The total nitrogen and phosphorus loads for each sub-catchment are computed through the multiplication of the area of each land use option employed and nutrient yield per ha associated with each management option.

In terms of how the model is applied to a scenario, WLAM receives a series of input files (see the Appendix) that describe current land uses, farm level data (baseline and mitigated options) and point sources and a target level of nutrient loss. The model is then run to find the optimum solution. Once it finds the optimum solution, it then generates an output file containing a rich description of the results (see the Appendix). Details on specification with related assumptions are presented in the Appendix.

1.4 The Data

The model has been populated with data from the major land use type (farm types), representative systems within each land use, level of nutrient use and leaching, a variety of nutrient mitigation options and scenarios in terms of level of mitigation. This information/data are at farm-level but regional agricultural statistics and other industry databases (dairybase, agribase, agricultural census data, etc.) are used to scale the representative farm-level data up to catchment level.

For each of the land use type, the biological feasibility of the systems and mitigation scenarios have been modelled and examined with a farm management tool, FARMAX® . Then the nutrient budgets were generated with a nutrient budget tool, OVERSEER®. These tools have a library of information on soil and climate on which management practices including mitigation options can be evaluated. The tools used information on specific fertilizer use and rates, crop and pasture yields, and nutrient losses on farm. These are farm level tools that are used to determine the economic and environmental implications of the land use options represented in the model. Similarly, for forestry options, forestry investment finder (a forestry model) was used to estimate the costs and returns to forestry land use and a proxy for on-farm tree planting. However data on the on-farm losses of N and P to ground and run off to water bodies have not been incorporated into the current version of WLAM although the specification has been incorporated as a place holder. Regarding the point source discharge, the model includes the sources of discharge, the waste water treatment plants, the industries and their means of treating the contaminants before discharging into a water body as well as spatial distribution of these sources.

Also, details on data with related assumptions are presented in the later part of this documentation.

2 Data input and sources

In this section, details on the data and sources of data are presented in terms of model parameters and variables, the structural characteristics of the farm types and the point source contribution to N leaching and P loss in the catchment. Data on production, management, and nutrient loads associated with each land use and management options were supplied by different organisation. Different but coherent means have been used although with different but close base year data (2011/12 to 2012/13). For dairy and dry stock farming, these were determined using FARMAX® and OVERSEER® modelling by DairyNZ and WRC respectively. For horticulture, the AgriBussiness Group with input from HortNZ used Gross Margin analysis and OVERSEER®. For forestry, New Zealand Forestry Institute (known as SCION) used discounted cash flow modelling. Finally, for the point sources, the input data (N and P loads and mitigation cost) was obtained from Waikato Regional Council (2015) but updated with on-going work at WRC.

2.1 Pollution Sources

Data from different regional land use database, case studies and representation database are pooled together to represent income and leaching (total N and P) from different pollution sources. Details on sources and methods of arriving at representative data are presented in separate reports written for this project. However these data were reconciled in WLAM in terms of biophysical calibration such that land use data were checked with regional production and supply of agricultural products. Here we present a summary of those data. These are base line data.

2.1.1 Point sources

In contrast to other studies or modelling of economic and environmental outcomes of land use options, this modelling exercise considered pollution from both point sources and non-point sources. The point sources include the major municipal waste water treatment plants (WWTPs) and industrial sites such as dairy processing factory, meat processing factory, etc that have a resource consent to discharge treated waste into the river (See Waikato Regional Council 2015 for details). Based on their 10 year level of discharge, data from top 20 point sources, comprising 11 WWTPs and 9 factories were fed into the model. For each of these point sources, two different mitigation options were considered. The assumption here is that the waste can be partially treated, or go to land disposal, which is assumed to result in zero discharge into the river but is relatively expensive compared to non-land disposal treatment (Table 1).

2.1.2 Non-point sources

The non-point sources are the different land use options. There were different streams of work for the four main land use which are farming activities. Work streams involved representative sampling or case study analysis of farming activities to identify and represent different systems of each land use option. It also included relevant mitigation options based on the farming system and the associated demographic and climate characteristics. For example, the dairy work stream identified 26 dairy farming systems across the region and 18 mitigation options that any of the dairy system could practice. There were 10 dairy support systems on dairy farms. For dry stock farming, 5 systems were represented with each having relevant mitigation options (see details in Olubode et al 2014). Horticulture was represented by 3 'typical' rotations and 7 mitigation options (See details in AgriBusiness Group, 2014). Forestry was represented by only pinus radiata plantation but this was also adjusted for on-farm tree planting as a mitigation options on dry stock farms that typically have steep slope area (See details in Yao and Harrison 2014). The last land use activity represented is miscellaneous or 'other' land use. More details on these land use activities are summarised in Section 2.3. Regional data to which farm-level data were either aggregated or extrapolated are presented in the next section, 2.2.

Table 1: Point source and non-point source representation in the model

Pollution sources representation	Number of cluster	Number of mitigation options
Non-point sources		
Dairy farming	26	5-18
Dairy support on dairy farms	10	1
Dry stock farming	5	5
Horticulture	3	7
Forestry	1	1
Miscellaneous	1	1
Point sources		
Waste water treatment plant	11	2
Industry	9	2

2.2 Baseline Data at Catchment Level

2.2.1 Land distribution among the land use farming activities

Table 2 shows the distribution of effective land area under the different non-point sources as represented in the study area, Waikato-Waipa Catchment. Dairy with dairy support farming currently (2011/12) uses about 350,000ha at a ratio of 4 to 1 dairy platform to run off (dairy support) on dairy farms. Dry stock farms currently use about 285,000ha of land followed by forestry that occupied about 160,000ha of land. Horticulture used least area, about 5,000 ha. About 260,000ha are under miscellaneous uses. This is a large amount of land which includes a lot of water bodies, roads plus 'utility', mining, and some natural forest. These are aggregated land use categories or primary farm use data obtained from MPI. These data were represented in the model at sub-catchment level. They have been aggregated here at zone level for the purpose of summarisation. This shows the distribution of land use farming activities across the zones. In terms of area of land use, dairy and forestry is more prominent in the upper Waikato where there is no horticulture farming. This is followed by Waipa, Lower Waikato and central Waikato in that order.

Table 2: Total area* ('000ha) under different land use at base level

Land use	Upper Waikato	Waipa	Central Waikato	Lower Waikato	Total*
Dairy	101	99	20	63	283
Dairy support	25	25	5	16	71
Sheep and Beef	87	98	7	92	285
Horticulture	0	1	1	4	5
Forestry	142	7	0	9	157
Miscellaneous	85	76	28	71	260
Total	440	306	61	254	1,061

* rounding error

2.2.2 Nitrogen (N) leaching from pollution sources

In Table 3, the distributions of N leaching contribution from sources are presented. The total non-point sources account for about 96% of Nitrogen discharges, while the remaining 4% is from the point sources. Of the 96% total discharge from non-point sources, dairy with dairy support farms contributes about 70%. This is followed by dry stock farming, which contributes 20%. A large proportion of the N discharge among the non-point sources happen in the Upper Waikato zone (40%), followed by Waipa (32%) and Lower Waikato (21%). Central Waikato accounts for only 5%. The 4% N discharge from point sources is almost equally distributed between the industrial factories and municipal WWTPs. This distribution pattern is also observed in the Waipa and Lower Waikato Zones. However industrial sites contribute about more than 85% of point source discharges in Upper Waikato, while the reverse is the case in the Central Waikato where municipality waste water treatment plants contribute more than 88% of the point source N discharge.

Table 3: Nitrogen (N) leaching (tonne/ha) at base level

Pollution sources	Upper Waikato	Waipa	Central Waikato	Lower Waikato	Total*
Non-point source					
Dairy	4,071	3,335	562	1,665	9,633
Dairy support	682	479	85	331	1,577
Sheep and Beef	1,023	1,006	83	952	3,064
Horticulture	30	38	39	252	359
Forestry	566	28	1	35	630
Miscellaneous	212	191	71	177	650
Total	***6,585***	***5,077***	***840***	***3,411***	***15,913***
Point source					
Industry	203	59	33	71	366
Waste water treatment plant	32	55	244	42	373
Total	***236***	***114***	***277***	***113***	***739***
TOTAL	**6,820**	**5,191**	**1,117**	**3,523**	**16,652**

* rounding error

2.2.3 Phosphorous loss from pollution sources

In Table 4, the distributions of Phosphorous (P) loss contribution are presented. The total non-point sources account for more than 80% of P loss into the water bodies while the remaining 20% is from the point sources. Of the 80% total discharge from non-point sources, diary and dairy support on dairy farms contributes about half of the loss. This is followed by dry stock farming which contributes about 12%. Similar to the distribution of N leaching among the farming activities, nearly 50% of the P loss among the non-point sources happen in Upper Waikato zone, followed by Waipa and Lower Waikato in that order while Central Waikato accounts for 20% of the P loss. The distribution of the total 20% P loss from the point source is fairly similar between the industrial factories and municipality waste water treatment plants although WWTPs contribute slightly higher. This pattern is also observed in the Central and Lower Waikato Zones. However industrial factories contribute more than 80% in Upper Waikato whereas the reverse is the case in the Waipa Zone where municipality WWTPs contribute more than 80% of the point source P loss.

Table 4: Phosphorous (P) loss (tonne/ha) at base level

Pollution source	Upper Waikato	Waipa	Central Waikato	Lower Waikato	Total
Non-point source					
Dairy	235	71	16	57	379
Dairy support	10	12	4	4	31
Sheep and Beef	66	82	6	77	232
Horticulture	1	1	1	5	7
Forestry	42	2	0	3	47
Miscellaneous	34	31	11	28	104
Total	***388***	***198***	***39***	***174***	***799***
Point source					
Industry	33	12	11	15	71
Waste water treatment plant	7	56	14	20	97
Total	***40***	***68***	***26***	***35***	***168***
Total	**428**	**224**	**107**	**209**	**967**

* rounding error

2.2.4 Leaching from miscellaneous land uses

There are few data sources for N and P loss from non-pasture land use in the lower Waikato. Data form other regions had to be used to generate rough estimates. At Wharekawa River on the Coromandel, the measured yield exported from the catchment is about 3.5 kg/ha for N and 0.3 for P. On the eastern side of Taupo the exported yield is about 2 for N and 0.4 for P (Sandy Elliot, per communication). Quinn and Stroud (2002) report found 0.58 for P, 2.1 for N for a native catchment at Whatawhata. The site has quite a bit of sediment, which probably elevated the P level however, if it is a high-erosion site, the P level will be higher (Sandy Elliot, per communication) . Based on this limited information, an average of 2.5kg/ha and 0.4kg/ha were assumed for N and P respectively across the region for the miscellaneous land use area.

2.2.5 Distribution of farm income in the region

Generally as would be expected, dairy generate most income in the region (Table 5). This is followed by sheep and beef while horticulture and forestry have similar income level at about $18m on annual basis. Based on the distribution of grazed land in Table 1 above and the distribution of income in Table 5, dairy, using about 55% of the grazed land generate about 80% of income from grazed land in the catchment. Drystock farming use the remaining 44% of grazed land to generate the remaining 20% income from grazed land.

Table 5: Profit ($/ha) among different land use at base level

Total profit ($m/yr)	Upper Waikato	Waipa	Central Waikato	Lower Waikato	Total
Dairy	224	270.9	46.2	133.3	674.4
Dairy support	41	8.8	1.6	5.5	56.8
Sheep and Beef	48.9	46.8	3.7	47.9	147.2
Horticulture	1.1	1.5	1.5	13.3	17.5
Forestry	15.6	1.3	0	1.2	18.2
Total	**330.6**	**329.2**	**53**	**201.2**	**914.1**

2.3 Farm Level Data

The baseline data in the model were sets of farm-level data including physical economics and environmental outcomes. In this section we present such data. These serve as building blocks of the model and a guide for a priori expectations and model validation in a scenario analysis. The levels of input use at farm level were estimated for each farm type using FARMAX® where the biological feasibility of the systems were checked and nutrients budgets were estimated with OVERSEER® model. The data use for the farm types range from year 2011/12 to 2012/13.

2.3.1 Dairy farming

For each of the 26 dairy farm types used to represent dairy farming in the model, there are a number of parameters, details of which cannot be presented in this report. In Table 6 some of those parameters are summarised in terms of average value, the minimum and maximum to indicate the range and the standard deviation to give idea about the level of uncertainty in each parameter. The effective farm size range from about 60ha to 600ha dairy platform. Also a dairy typical farm would have a run-off area for dairy support of area ranging from about 80ha to 200ha but there is not much variation in terms of area of run-off that the dairy farms have as the standard deviation of the dairy support area is low relative to average (Table 7). While the average figures in these tables cannot be interpreted directly, there might be some insights gained from the standard deviation of some primary parameters being large relative to the average. For example, for primary input data, such as farm size, effective farm area and nitrogen fertilizer use, the standard deviation is large relative to average. That implies that a wide range of variation in farming systems among dairy farms was represented in the model.

Table 6: Parameters, dairy farming

parameter	Average	Min	Max	Standard Deviation
Farm size (ha)	183.5	59.0	612.0	126.1
Farm effective area (ha)	168.3	55.0	572.0	118.8
Operating profit ($/ha)	2,076.0	626.0	4,205.0	765.0
N leaching (kg/ha)	25.4	9.0	58.9	9.8
P losses (kg/ha)	1.4	0.3	6.1	1.3
milk solids (kg MS/ha)	989.3	503.0	1,466.0	192.9
stocking rate (peak milking cows /ha)	2.7	1.7	3.6	0.4
cows grazing off (heads/ha)	0.5	-	3.0	0.6
cows stood-off (heads/ha)	1.3	-	3.6	1.4
nitrogen fertilizer use (kg N/ha)	68.5	-	237.0	60.2
supplementary feed (t/ha)	2.1	-	6.1	1.6
labour (FTE/ha)	0.02	0.01	0.03	0.01
rising 1 year olds (heads/ha)	0.6	0.4	0.7	0.1
rising two year olds (heads/ha)	0.5	0.4	0.7	0.1
Extra capital investment in standoff facilities ($/ha)	1,074.76	-	4,385.37	1,230.42

Table 7: Parameters, dairy support

Parameter	Average	Min	Max	Standard Deviation
Farm size (ha)	148.24	84.20	222.0	54.4
Farm effective area (ha)	133.1	81.0	212.0	49.5
Operating profit ($/ha)	466.93	- 149.2	1,618.0	606.5
N leaching (kg/ha)	20.86	12.4	28.2	5.7
P losses (kg/ha)	0.5	0.2	1.1	0.3
cows grazing off (heads/ha)	1.8	-	8.0	2.4
nitrogen fertilizer use (kg N/ha)	48.6	-	152.0	45.0
labour (FTE/ha)	0.2	0.1	0.5	0.1
rising 1 year olds (heads/ha)	3.1	0.9	9.6	2.7
rising two year olds (heads/ha)	1.8	0.9	3.3	0.8

2.3.2 Dry stock farming

Case studies analyses were performed to come up with 5 'typical' dry stock farms represented in the model. Table 8 shows the average, the range and how much of the diversity among the farms were captured in the data collection and input in the model. Based on a recently Waikato Regional Council's survey of 450 dry stock farms in the region (see details in Kaine 2013), 20 farms were purposely selected sampled for case studies, to cover the region spatially and the farm systems clusters identified in the previous 450 farms survey. Farm level information, animal transactions information, etc. were collected during the survey. These data were extrapolated with regional climate and financial data for the purpose of generalisation. Data from 13 case study farms were complete and used to represent the 5 'typical' farm systems across the region. The data typify empirical data which contain quality information, although lack statistical properties. The farm-level data were complemented with appropriate data-validating techniques such as literature and expert knowledge from farmers, rural consultants and scientists. We also collected feedback from industry representatives to gather some insights.

The farm level data were scaled to the catchment level by approximation in terms of pastoral area, number of dry stock farms and the farm size distribution in the districts that make up the catchment. For example, in terms of land areas under different land use, the lower Waikato Catchment approximately consists of 70% of Waikato District and 5% of Matamata-Piako District land areas; Central Waikato Catchment(approximately consists of 100% Hamilton City, 45% of Waipa District and 5% of Waikato district land areas; Waipa Catchment approximately consists of 60% of Otorohanga district; 35% of Waipa District; 5% of Waikato District and 20% of Waitomo district land areas and Upper Waikato Catchment approximately consists of 40% of Taupo district; 45% of Rotorua district; 60% of South Waikato District; 10% of Otorohanga district and 25% of Waipa district land areas.

In summary, the effective farm size range from about 40 to 270ha dairy platform with a relatively high standard deviation relative to average; so also is N use ranging from none to about 140kg/ha (Table 10). There is not much variation in nutrient loss among the farm types represented in the model (Table 8).

Table 8: Parameters, dry stock farming

parameter	Average	Min	Max	Standard Deviation
Farm size (ha)	135. 0	50.0	350.0	123.7
Farm effective area (ha)	104.0	38.5	269.5	95.3
EBITR ($/ha)	967.0	325.0	2,802.4	946.4
N leaching (kg/ha)	12.6	7.5	27.9	6.5
P losses (kg/ha)	0.7	0.3	1.0	0.3
N fertilizer used (kg/ha)	26.6	-	140.7	46.9
Sheep stock units (u/ha)	4.1	-	8.5	3.0
Cattle stock units (u/ha)	3.7	1.1	11.8	2.3
dairy cows grazing (heads/ha)	0.1	-	0.4	0.2
dairy rising 1 year olds (heads/ha)	0.1	-	0.3	0.1
dairy rising two year olds (heads/ha)	0.02	-	0.06	0.03
wool production (kg /ha)	23.3	-	44.5	16.3
carcass mutton production (kg /ha)	63.2	-	145.0	48.9
carcass lamb production (kg /ha)	17.2	-	70.3	28.8
carcass beef production (kg /ha)	89.4	17.3	517.2	97.0
carcass bull beef production (kg /ha)	94.3	-	298.7	117.7

2.3.3 Horticulture

Three horticulture farm types were represented in the model. On behalf of the MPI and the Horticulture NZ, the AgriBusiness Group (See Agribusiness Group, 2014 for details) collected physical, financial and environmental data on horticulture farming to compile representative models (rotations) of vegetable systems which predominantly happen in the Lower Waikato sub-catchment. The data were run through OVERSEER® and a financial model to determine the physical and financial baseline parameters. Of the three rotations, rotation 1 is the most extensive, growing the major large scale crops. Rotation 2 is more intensive, with the inclusion of more green crops. Rotation 3 represents the traditional market garden growers. Three mitigation techniques were represented. Mitigation 1 – Limiting N application, this mitigation technique limited any one application of N to 80 kgN/ha per month. Mitigation 2 sequentially reducing N application by 10% to 40% and reducing the yield by an amount determined by reference to research reports and grower experience. Mitigation 3 is active water management by applying only the amount of water required by the crop. The summary is presented in Table 9 showing average farm size of 89ha however the data capture incidence of loss though with a gross margin of about $500/ha or average with a huge variation. The N leaching is also substantial relative to other land uses.

Table 9: Parameters, Horticulture

parameter	Average	Min	Max	Standard Deviation
Farm size (ha)	89.7	2.0	120.0	34.1
Operating profit ($/ha)	-1,064.0	-6,626.6	3,409.4	3,361.3
GM ($/ha)	521.4	- 5,496.0	4,540.0	3,240.1
N leaching (kg/ha)	59.7	47.0	91.0	10.4
P losses (kg/ha)	1.3	1.1	1.9	0.2
Potato (kg/ha)	792.6	-	1,500.0	490.5
Onion (kg/ha)	820.8	-	1,350.0	384.0
Carrots (kg/ha)	684.0	-	1,800.0	796.9
Squash (kg/ha)	456.0	-	750.0	211.4
Barley (kg/ha)	75.6	-	210.0	89.6
Broccoli (kg/ha)	82.5	-	216.0	95.0
Lettuce (kg/ha)	68.7	-	180.0	79.2
Cabbage (kg/ha)	6.7	-	100.0	25.8
Spinach (kg/ha)	1.3	-	20.0	5.2
Cauliflower (kg/ha)	0.7	-	10.0	2.6
Nitrogen fertilizer use*	202.5	126.0	360.0	58.8

* over the whole farm (kg N/ha)

2.3.4 Forestry and on-farm treat planting

New Zealand Forestry Institute (SCION) used Forest Investment Modelling with the LCDB3.3 to predict profit for large- and small-scale forestry over the next 12 months (See Yao and Harrison 2014; Harrison and Yao, 2014 for details). In these study, SCION applied special analysis to locate the area covered by major land use capability 6 and 7 in the region to determine the size as approximately 100,331 hectares. The Forest Investment Finder model was used to estimate the net present value (NPV) with the assumption that *pinus radiata* forest would be grown is planted at a plantation scale with carbon credit revenue in addition to forestry. The second case is where *pinus radiata* is planted as an on-farm nutrient loss mitigation option on dry stock farms where carbon credits were not sold, such that revenue is only from forestry. The annualised forestry income at a plantation scale was estimated at approximately $200/ha (Table 10). It is lower ($150/ha) at on-farm small-scale tree planting. The variation in table 3 is due to differences in growth potential and costs associated with each of the 66 sub-catchments.

Table 10: Parameters, for plantation forestry

parameter	Average	Min	Max	Standard Deviation
Annualized NPV ($/ha)	195.4	-34.2	456.9	110.8
N leaching (kg/ha)	4.0	4.0	4.0	-
P losses (kg/ha)	0.3	0.3	0.3	0.0
S1 logs (‘000m3)	2,127.9	48.4	12,682.5	2,370.8
S2 logs (‘000m3)	4,643.8	75.5	20,384.2	4,595.5
S3 logs (‘000m3)	4,705.2	64.8	18,689.3	4,642.1
Pulp (‘000m3)	3,077.2	47.0	12,473.3	3,021.8
Waste (‘000m3)	217.5	3.2	934.9	215.6
Carbon sequestration (CO_2-eq ton/ha)	43.74	35.01	54.30	4.34

2.4 Point Sources

Waikato Regional Council has records of reports on annual discharge from the point sources. From the reports, the council's water Quality Scientist (Bill Vant) prepares best estimates of nutrient discharge into water bodies by the industries and municipal WWTPs. Based on these estimates and the report by Waikato Regional Council (2015), 20 of these point sources are represented in the model as these are the major discharge contributors. The annual discharge of N and P vary from 0.6t/year of N and 0.7ton of P from Ohaaki power station to 188.8ton/year of N and 46.3t of P from Hamilton sewage. From Waikato Regional Council (2015) report, it costs on average $1m to achieve zero discharge in the first year with an initial capital investment of $0.4m and subsequently operating & maintenance cost about $0.6m. This can be as high as $15m in some cases.

Table 11: Parameters by, Point Source

Parameter	Average	Min	Max	Standard Deviation
Total N load (tn N / year)	38.5	0.6	188.8	50.7
Total P load (tn P / year)	8.6	0.23	46.3	10.8
Marginal operating & maintenance cost (M$/year)	0.6	-	14.4	2.2
Marginal capital investment (M$)	0.39	`	12.6	1.6

3 Conclusion

This documentation has presented the workings of the WLAM and the building blocks (data) developed to inform water quality and policies in the Waikato Region. The model capture how water pollution from farming activities, municipality WWTPs and industries are related such that the implications of meeting a water quality target can be investigated using the model. The essential components of the model have been presented with an acknowledgement that the real world is far too complex to be represented in full details in a model. For example this is a quantitative model where some qualitative information and concepts have been carefully assumed away or at best with proxies. Therefore the strength of the model lies in the data used as most of the data were gathered from farmers. However, the data has been extrapolated with secondary processed regional data. This allows for generalisation without losing the specific focus. Also, the hydrology and production functions of technical input output coefficients are not represented at this stage but there are scopes for incorporating these later on. This will broaden the applications of the model in future. The model's conceptual framework and the assumptions are also coded in such a way that they can be updated by at a bearable cost when more critical views have been arrived at. The algorithm also allows a wide range of imaginable assumptions can be applied to the model with minimal work required.

The limitation of the model as a result of aggregation to catchment level is that the results will be relative values rather than absolute. The implication is that the results are to evaluate rather than to predict economic cost of setting water quality limits or targets. In addition, the model has been pragmatically calibrated in its current form however; it is acknowledged that its validity will depend on the scenarios being investigated.

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Appendix: WLAM Specifications

In this section WLAM coding and the algebraic equations are presented. This section has been put in the appendix as it would only be interesting to those who have some familiarity with GAMS coding and mathematical specification of the model. Here we define the sets, parameters, variables and equations. The sets are building block of WLAM. This means the sets are the hearts of WLAM as they define the dimensions of the model with respect to spatial coverage of the model, pollution discharge sources (point source and non-point source), farming activities, mitigation options, etc.

All the data input as organised in an excel spreadsheet from where the GAMS code read them in before computation and optimisation. The results after optimisation are also written out into excel spreadsheets from where different presentations of the results can be achieved. This approach of having inputs data in excel file and writing the results into excel file is an attempt to make the coding of WLAM as clear as possible to follow for a wider audience. It also allow for appreciation of data input and possible data gap that might be of relatively high consequence for results and interpretation of results. It's also a clear way to capture the assumption behind the model especially where there are no specific data. Below are a list of set name, description and elements.

A1 Input and Output Files

The farm information is stored in Microsoft(R) Excel files, which are labelled as "Input" folder. Such folder must be kept in the same folder as the .gms file. The input files are presented in Table A1. In the same vein, output files generated each time the model is run are written into an Excel file. The content of the output file is detailed in Table A2.

A2 Set Definitions

Set definitions are presented in Table A3. The basic spatial unit of analysis is sub-catchment. They are defined as a set 'sc' (for the 66 sub-catchments across the study area (See Fig 1 in the earlier section of this report). These are aggregated to four zones (Lower Waikato, Central Waikato Waipa and Upper Waikato) with set 'cat'. The land use in the baseline is defined in terms of area allocated to each land use as define by set 'lu' and when applicable, to different clusters within land use.

Each of the land use has a number of representative or farm types which are define over a set. For example, the dairy farming activities are defined as dairy clusters set 'cld' representing 1 to 26 clusters. A dairy farming activity has a number of mitigation options which are defined as set 'mod' with 1 to 7-18[2] options. Subsequently, each dairy farming activity has a set of input (data fields) defined as set 'dai'. The dedicated dairy support activities on dairy farms are defined as set 'dsu'. There are 10 clusters of them and they are defined as set 'clu'. There is no mitigation option for those. The data fields are defined as set 'dsi'.

Similarly, the set of sheep and beef land use activities are defined over 5 dry stock clusters 'cls'. Each cluster has a unique mitigation options which are defined as set 'mos'. The data fields for dry stock farming activities are defined over a set 'sbi'. For the horticulture land use activity, there are three clusters of set 'clh' with a set of 1 to 7 mitigation options defined as set 'moh' and the data fields are defined as set 'hoi'. The forestry land use has only one representative, *radiata pine plantation* and no mitigation option. Its data field are define as set 'foi'.

[2] The number of mitigation options varies (5 to 18) with the different clusters

A3 Equations

The main equations in the model are presented in GAMS code below.

A3.1 Dairy

The total are on dairy [$areaT_{(sc,"dai")}$] on each sub-catchment is calculated as the sum over clusters and mitigation options:

eAreaDaiT$_{(sc)}$..   areaT$_{(sc,"dai")}$ =e= sum[(cld, mod),areaDai$_{(sc, cld, mod)}$];

The area on each dairy cluster is equated to the original dairy area in the baseline plus new area converted from forestry (*DonF*) minus area converted from dairy into
forestry (*FonDa*):

eAreaDai1$_{(sc, cld)}$..   sum[mod, areaDai$_{(sc, cld, mod)}$] =e= LUda$_{(sc,cld)}$ + sum[mod,DonF$_{(sc,cld,mod)}$] - FonDa$_{(sc,cld)}$;

Where:

eDonFsc$_{(sc)}$..   DonFsc$_{(sc)}$ =e= sum[$_{(cld,mod)}$,DonF$_{(sc,cld,mod)}$];
eFonDasc$_{(sc)}$..   FonDasc$_{(sc)}$ =e= sum[cld, FonDa$_{(sc,cld)}$];

A constraint (*eAreaDai2*) was added to ensure that area converted from forestry into dairy maintains the same proportionality between clusters as in the baseline. This constrains applies on every sub-catchment where there are dairy activities in the baseline:

eAreaDai2$_{(sc, cld)}$\$(UBarea$_{(sc,"dai")}$ > 0 and xDonF > 0)..   sum[mod,DonF$_{(sc,cld,mod)}$] / DonFsc$_{(sc)}$ =e= LUda$_{(sc,cld)}$ / UBarea(sc,"dai");

Where xDonF is parameter activating eAreaDai2 when conversion of forestry into dairy is allowed. Zero when not allowed /0/;

Conversion from dairy into sheep and beef is not considered at this stage. This would need modelling work to determine how the new sheep and beef on former, highly productive, dairy land would look like. The effective area on dairy farming is calculated by considering the proportion of effective ovet total area on each dairy cluster, as:

*eareaDaiE$_{(sc, cld, mod)}$.. areaDaiE$_{(sc, cld, mod)}$=e= areaDai$_{(sc, cld, mod)}$ * [IDa$_{(cld,"1","fed")}$/IDa$_{(cld,"1","fad")}$];*

A3.2 Sheep and Beef

The total are on sheep and beef [$areaT_{(sc,"sab")}$] on each subcatchment is calculated as the sum over clusters and mitigation options:

eareaSabT$_{(sc)}$..   areaT$_{(sc,"sab")}$ =e= sum[(cls, mos),areaSab$_{(sc, cls, mos)}$];

The area on each sheep and beef cluster is equated to the original sheep and beef area in the baseline plus new area converted from forestry (*SbonF*) minus area converted from sheep and beef into forestry (*FonSb*):

eAreaSab1$_{(sc, cls)}$..   sum[mos, areaSab$_{(sc, cls, mos)}$] =e= LUsb$_{(sc,cls)}$ + sum[mos,SbonF$_{(sc,cls,mos)}$] - FonSb$_{(sc,cls)}$;

Where

$eSbonFsc_{(sc)}$.. $SbonFsc_{(sc)}$ =e= sum[$_{(cls,mos)}$,$SbonF_{(sc,cls,mos)}$];
$eFonSbsc_{(sc)}$.. $FonSbsc_{(sc)}$ =e= sum[cls,$FonSb_{(sc,cls)}$];

A constraint (*eAreaSab2*) was added to ensure that area converted from forestry into sheep and beef maintains the same proportionality between clusters as in the baseline. This constrains applies on every subcatchment where there are sheep and beef activities in the baseline:

$eAreaSab2_{(sc, cls)}$\$($UBarea_{(sc,"sab")}$ > 0 and xSbonF > 0).. sum[mos, $SbonF_{(sc,cls,mos)}$] / $SbonFsc_{(sc)}$ =e= $LUsb_{(sc,cls)}$ / $UBarea_{(sc,"sab")}$;

Where xSbonF is a parameter activating eAreaSab2 when conversion of forestry into sheep and beef is allowed. Zero when not lowed /0/;

The effective area on sheep and beef farming is calculated by considering the proportion of effective over total area on each sheep and beef cluster, as:

$eareaSabE_{(sc,cls,mos)}$.. $areaSabE_{(sc,cls,mos)}$ =e= $areaSab_{(sc,cls,mos)}$ * [$lSb_{(cls,"1","fes")}$/$lSb_{(cls,"1","fas")}$];

A3.3 Dairy Support

The total are on dairy support [$areaT_{(sc,"dsu")}$] on each subcatchment is calculated as the sum over all clusters:

$eareaDsuT_{(sc)}$.. $areaT_{(sc,"dsu")}$ =e= sum[clu,$areaDsu_{(sc,clu)}$];

The area on each dairy support cluster is equated to the original dairy support area in the baseline plus new area converted from forestry (*SuonF*) minus area converted from dairy support into forestry (*FonSu*):

$eAreaDsu1_{(sc, clu)}$.. $areaDsu_{(sc, clu)}$ =e= $LUsu_{(sc,clu)}$ + $SuonF_{(sc,clu)}$ - $FonSu_{(sc,clu)}$;

Where

$eSuonFsc_{(sc)}$.. $SuonFsc_{(sc)}$ =e= sum[clu,$SuonF_{(sc,clu)}$] ;
$eFonSusc_{(sc)}$.. $FonSusc_{(sc)}$ =e= sum[clu,$FonSu_{(sc,clu)}$];

A constraint (*eAreaDsu2*) was added to ensure that area converted from forestry into dairy support maintains the same proportionality between clusters as in the baseline. This constrains applies on every subcatchment where there are dairy support activities in the baseline:

$eAreaDsu2_{(sc, clu)}$\$($UBarea_{(sc,"dsu")}$ > 0 and xSuonF > 0).. $SuonF_{(sc,clu)}$ / $SuonFsc_{(sc)}$ =e= $LUsu_{(sc,clu)}$ / $UBarea_{(sc,"dsu")}$;

Where *xSuonF is a parameter activating eAreaDsu2 when conversion of forestry into dairy support is allowed. Zero when not lowed /0/;*

The effective area on dedicated dairy support is calculated by considering the proportion of effective over total area on each dairy support cluster, as:

$eareaDsuE_{(sc,clu)}$.. $areaDsuE_{(sc,clu)}$ =e= $areaDsu_{(sc,clu)}$ * [$lDs_{(clu,"feu")}$/$lDs_{(clu,"fau")}$];

A3.4 Horticulture

The total are on dairy support [$areaT_{(sc,"hor")}$] on each subcatchment is calculated as the sum over all clusters:

$eareaHorT_{(sc)}..\quad areaT_{(sc,"hor")} =e= sum[(clh,moh), areaHor_{(sc,clh,moh)}];$

At this stage, no land use changes were represented in area currently on horticulture:
$eareaHor1_{(sc,clh)}..\ sum[moh, areaHor_{(sc,clh,moh)}] =e= LUho_{(sc,clh)};$

The effective area in horticulture is calculated by considering the proportion of effective over total area on each horticulture cluster, as:

$eareaHorE_{(sc,clh,moh)}..\quad areaHorE_{(sc,clh,moh)} =e= areaHor_{(sc,clh,moh)} * [lHo_{(clh,"1","feh")}/lHo_{(clh,"1","fah")}];$

A3.5 Forestry

At this stage, only land use changes into and out to plantation forestry are represented in the model.

$eAreaFos_{(sc)}..\ areaT_{(sc,"fos")} =e= UBarea_{(sc,"fos")}$
$+ FonDasc_{(sc)} - DonFsc_{(sc)}$
$+ FonSbsc_{(sc)} - SbonFsc_{(sc)}$
$+ FonSusc_{(sc)} - SuonFsc_{(sc)};$

A3.6 Miscellaneous land uses

All land uses other that farming, are collated in a single category. The size of this area is maintained constant, at the baseline level, in all scenarios.

$eareaMisT_{(sc)}..\quad areaT_{(sc,"mis")} =e= UBarea_{(sc,"mis")};$

A3.7 Nutrient loads and yields

N load from farming and miscellaneous land uses
Nitrogen load (tn) from farming on each subcatchment is calculated by adding the loads from all land uses:

$eTNlfarm_{(sc)}..\ TNlfarm_{(sc)} =e=$
$\{sum[(cld, mod), areaDai_{(sc, cld, mod)} * lDa_{(cld,mod,"nld")}] +$
$sum[clu, areaDsu_{(sc,clu)} * lDs_{(clu,"nlu")}] +$
$sum[(cls,mos), areaSab_{(sc,cls,mos)} * lSb_{(cls,mos,"nls")}] +$
$sum[(clh,moh), areaHor_{(sc,clh,moh)} * lHo_{(clh,moh,"nlh")}] +$
$areaT_{(sc,"fos")} * lFo_{(sc,"nlf")} +$
$areaT_{(sc,"mis")} * lMi_{(sc,"nlm")}\}/1000;$

The total N load (tn) per land use type ($NloadLUsc_{(sc,lu)}$), on each subcatchment is calculated as:

$eNloadDaisc_{(sc,"dai")}..\ NloadLUsc_{(sc,"dai")} =e= sum[(cld, mod), areaDai_{(sc, cld, mod)} * lDa_{(cld,mod,"nld")}]/1000;$
$eNloadSusc_{(sc,"dsu")}..\ NloadLUsc_{(sc,"dsu")} =e= sum[clu, areaDsu_{(sc,clu)} * lDs_{(clu,"nlu")}]/1000;$
$eNloadSbsc_{(sc,"sab")}..\ NloadLUsc_{(sc,"sab")} =e= sum[(cls,mos), areaSab_{(sc,cls,mos)} * lSb_{(cls,mos,"nls")}]/1000;$
$eNloadHosc_{(sc,"hor")}..\ NloadLUsc_{(sc,"hor")} =e= sum[(clh,moh), areaHor_{(sc,clh,moh)} * lHo_{(clh,moh,"nlh")}]/1000;$
$eNloadFosc_{(sc,"fos")}..\ NloadLUsc_{(sc,"fos")} =e= areaT_{(sc,"fos")} * lFo_{(sc,"nlf")}/1000;$
$eNloadMisc_{(sc,"mis")}..\ NloadLUsc_{(sc,"mis")} =e= areaT_{(sc,"mis")} * lMi_{(sc,"nlm")}/1000;$

The N load (tn) per land use type $_{(lu)}$, for the whole catchment is the sum over all the subcatchments:

$eNloadLU_{(lu)}$.. $NloadLU_{(lu)}$ =e= sum(sc,$NloadLUsc_{(sc,lu)}$);

The average N leaching (kg N/ha), or yield, per land use on each subcatchment is calculated as the total N load from that land use divided by the total area on the land use in the subcatchment:

*$eNyieldLUsc_{(sc,lu)}$.. $NyieldLUsc_{(sc,lu)}$ =e= $NloadLUsc_{(sc,lu)}$*1000/($areaT_{(sc,lu)}$);*

Similarly, the average N yield per land use is calculated as the total N load (all subcatchments) from that land use divided by the total area on the land use:

*$eNyieldLU_{(lu)}$.. $NyieldLU_{(lu)}$ =e= $NloadLU_{(lu)}$*1000 / (sum(sc, $areaT_{(sc,lu)}$));*

P load from farming and miscellaneous land uses
Phosphorous load (tn) from farming on each subcatchment is calculated by adding the loads from all land uses:

$eTPlfarm_{(sc)}$.. $TPlfarm_{(sc)}$ =e=
*{sum[(cld, mod), $areaDai_{(sc, cld, mod)}$ * $lDa_{(cld,mod, "pld")}$] +*
*sum[clu, $areaDsu_{(sc,clu)}$ * $lDs_{(clu,"plu")}$] +*
*sum[(cls,mos), $areaSab_{(sc,cls,mos)}$ * $lSb_{(cls,mos,"pls")}$] +*
*sum[(clh,moh), $areaHor_{(sc,clh,moh)}$ * $lHo_{(clh,moh,"plh")}$] +*
*$areaT_{(sc, "fos")}$ * $lFo_{(sc, "plf")}$ +*
*$areaT_{(sc, "mis")}$ * $lMi_{(sc, "plm")}$}/1000;*

The P load (tn) per land use type (lu), for the whole catchment is the sum over all the subcatchments:

$ePloadDaisc_{(sc,"dai")}$.. $PloadLUsc_{(sc,"dai")}$ =e= sum[(cld, mod), $areaDai_{(sc, cld, mod)}$ * $lDa_{(cld,mod, "pld")}$]/1000;

$ePloadSusc_{(sc,"dsu")}$.. $PloadLUsc_{(sc,"dsu")}$ =e= sum[clu, $areaDsu_{(sc,clu)}$ * $lDs_{(clu,"plu")}$]/1000;

$ePloadSbsc_{(sc,"sab")}$.. $PloadLUsc_{(sc,"sab")}$ =e= sum[(cls,mos), $areaSab_{(sc,cls,mos)}$ *
$lSb_{(cls,mos,"pls")}$]/1000;

$ePloadHosc_{(sc,"hor")}$..$PloadLUsc_{(sc,"hor")}$ =e= sum[(clh,moh), $areaHor_{(sc,clh,moh)}$ * $lHo_{(clh,moh,"plh")}$]/1000;

$ePloadFosc_{(sc,"fos")}$.. $PloadLUsc_{(sc,"fos")}$ =e= $areaT_{(sc, "fos")}$ * $lFo_{(sc, "plf")}$/1000;
*$ePloadMisc_{(sc,"mis")}$.. $PloadLUsc_{(sc,"mis")}$ =e= $areaT_{(sc, "mis")}$ * $lMi_{(sc, "plm")}$/1000;*

The P load (tn) per land use type (lu), for the whole catchment is the sum over all the subcatchments:

$ePloadLU_{(lu)}$.. $PloadLU_{(lu)}$ =e= sum(sc,$PloadLUsc_{(sc,lu)}$);
The average P leaching (kg N/ha), or yield, per land use on each subcatchment is calculated as the total N load from that land use divided by the total area on the land use in the subcatchment:

$ePyieldLUsc_{(sc,lu)}$.. $PyieldLUsc_{(sc,lu)}$ =e= $PloadLUsc_{(sc,lu)}$*1000/($areaT_{(sc,lu)}$);

The average N yield per land use is calculated as the total N load (all subcatchments) from that land use divided by the total area on the land use:

$ePyieldLU_{(lu)}$.. $PyieldLU_{(lu)}$ =e= $PloadLU_{(lu)}$*1000 / (sum(sc, $areaT_{(sc,lu)}$));

A3.8 Loads from point sources

The assumption here is that the waste can be treated as in baseline or partially go to land disposal. This may need to be revised in future versions.

This constraint ensures that all N and P load, ON each point source, is accounted for:
$ePSc1_{(sc, ps)}$\$($IPs_{(sc,ps,"1","tnp")}$ > 0)..   sum(to, $pst_{(sc,ps,to)}$)=e=1;

Nitrogen
The total N load (tn) on each sub-catchment is the sum of the loads from all point sources in the sub-catchment, each multiplied by the proportion of the waste treated with each option [pst(sc,ps,to, to being baseline of land disposal] and by the reduction in N load obtained from each option [redNPs(sc,ps,to)]:

$eTNps_{(sc)}$.. $TNps_{(sc)}$ =e= sum[(ps,to), $IPs_{(sc,ps,"1","tnp")}$ * $pst_{(sc,ps,to)}$ * (1-$redNPs_{(sc,ps,to)}$)];

Phosphorous
The total P load (tn) on each subcatchment is the sum of the loads from all point sources in the subcatchment, each multiplied by the proportion of the waste treated with each option [$pst_{(sc,ps,to)}$, to: being baseline or land disposal] and by the reduction in P load obtained from each option [redPPs(sc,ps,to)]:

$eTPps_{(sc)}$.. $TPps_{(sc)}$ =e= sum[(ps,to), $IPs_{(sc,ps,"1","tpp")}$ * $pst_{(sc,ps,to)}$ * (1-$redPPs_{(sc,ps,to)}$)];
Total loads from farming, miscellaneous land uses and point sources

A3.9 Total loads

Nitrogen
The total N load, from all sources, per subcatchment is:

$eTNlsc_{(sc)}$.. $TNlsc_{(sc)}$ =e= $TNlfarm_{(sc)}$ + $TNps_{(sc)}$;

And the total N load over the whole catchment is:

eTotNl.. TotNl =e= sum(sc,$TNlsc_{(sc)}$);

Phosphorous
The total P load, from all sources, per subcatchment is:

$eTPlsc_{(sc)}$.. $TPlsc_{(sc)}$=e= $TPlfarm_{(sc)}$ + $TPps_{(sc)}$;

And the total P load over the whole catchment is:

eTotPl.. TotPl =e= sum(sc,$TPlsc_{(sc)}$);

A3.10 Nutrient reduction constraints

At the moment, only simple scenarios have been implemented. This constraint, for example, establishes an upper limit for the total N load over the whole catchment (TotNl):

cTotNL.. TotNl =l= TotNlLim;

The total en load limit in turn, is established by first solving the model without any N load constrains, giving TotNlBaseline. In the mitigates scenarios, different levels of reduction relative to the baseline load [$NLossRed_{(scenarios)}$] are tested, so that:

$TotNlLim = TotNlBaseline*(1-NLossRed_{(scenarios)})$

Also, once the baseline scenario is solved, the parameter is calculated:

$TNlLimsc_{(sc)} = TNLbaselinesc_{(sc)}$;

Also, the following constraint to ensure that no subcatchment increases its N load:

$cTNlsc_{(sc)}$.. $TNlsc_{(sc)}$ =l= $TNlLimsc_{(sc)}$;

A3.11 Objective function

For the baseline scenario, total farm profit is maximised ($M):
solve WLAM2 using nlp maximising **ti**;

Total farm profit is per subcatchment is calculated as:

$etisc_{(sc)}$ .. $tisc_{(sc)}$ =e=
{sum[(cld, mod), $areaDaiE_{(sc, cld, mod)}$ * $IDa_{(cld,mod, "opd")}$] +
sum[clu, $areaDsuE_{(sc,clu)}$ * $IDs_{(clu,"opu")}$] +
sum[(cls,mos), $areaSabE_{(sc,cls,mos)}$ * $ISb_{(cls,mos,"ops")}$] +
sum[(clh,moh), $areaHorE_{(sc,clh,moh)}$ * $IHo_{(clh,moh,"oph")}$] +
$areaT_{(sc, "fos")}$ * $IFo_{(sc, "opf")}$}/1000000;

The total farm profit (ti) is:

OF1.. **ti** =e= sum[sc, $tisc_{(sc)}$] ;

The parameter baselineTi (Total profit from farming on the baseline) is saved:
baselineTi = ti.L;

On the mitigated scenarios, the total mitigation cost is minimized:

solve WLAM2micOST using nlp minimising **til**;

OF2.. **til** =e= baselineTI - ti + sum[sc,$tPScSc_{(sc)}$];

Where $tPScSc_{(sc)}$ is the total marginal cost for point source extra treatment (i.e. land disposal), calculated as:

$etPScSc_{(sc)}$.. $tPScSc_{(sc)}$ =e= sum{(ps,to), [$IPs_{(sc,ps,to,"mcp")}$ + $IPs_{(sc,ps,to,"momp")}$] * $pst_{(sc,ps,to)}$};

Table A1: Input files read into the models (..\Input*.xlsx)

File	Contains	Sheets	sets
InputDairy.xlsx	Input data for dairy farms	info	sc,cl,mo,dai
InputDryStock.xlsx	Input data for dry stock farms	info	sc,cl,mo,sbi
InputHort.xlsx	Input data for hortulture farms	info	sc,cl,mo,hoi
InputForestry.xlsx	Input data for plantation forestry	info	sc,foi
InputPointSources.xlsx	Input data fo point sources	info	sc, ps, psi
LandUse.xlsx	Total area on dry stock	dry	sc, cls
Land use in the baseline	Total area on Dairy (platform + support)	da	sc
(ha)	Proportion of the total Dairy platform area represented by each cld	da2	sc, cld
	Proportion of the total Dairy support area represented by each clu. For UW, input from the pilot study was retained. No time to re-do the work.	da3	sc, clu
	Total area on horticulture	hor	sc, clh
	Total area on forestry	fos	sc
	Total area on other land uses	mis	sc
	Total area	total	sc

Table A2: Output files (..\Output\Results.xlsx)

Sheet	Content	Sets	Variables (*)
OUTPS	Output for point sources - N load (tn N)	(ps, scenarios)	N load per point source (tn N)
OUTUT	Output in general for the whole catchment	(*,scenarios)	N load Reduction Farm + point sources N load (tn N) Farm + point sources P load (tn N) Farm N load (tn N) Farm P load (tn P) Point source N load (tn N) Point source P load (tn P) Farm profit (M$) Cost point sources (M$) Objective funtion ($M) Area on Dairy (ha) Area on Dairy Sup (ha) Area on S&B (ha) Area on Horticulture (ha) Area on plant Forestry (ha) Area on other LU (ha) Forestry on dairy (ha) Forestry on dairy support (ha) Forestry on S&B (ha) Cows out of catchment (heads) Dairy Cows on support (heads) Dairy Cows on S&B (heads) Cows grazed off (heads) Cows on stand-off (heads) Dairy cows (heads)

Sheet	Content	Sets	Variables (*)
			Stocking rate Dairy (cow/ha effective area) Supplementary feed on dairy (tn) Maize silage dairy-Purchased (tn) Maize silage dairy-Produced (tn) Maize silage dairy-Fed (tn) Total N fert use (tn) Ave N leaching dairy (kg/ha) Ave N leaching dairy sup (kg/ha) Ave N leaching S&B (kg/ha) Ave N leaching hort (kg/ha) Ave N leaching forestry (kg/ha) Ave N leaching other LU (kg/ha) Ave P leaching dairy (kg/ha) Ave P leaching dairy sup (kg/ha) Ave P leaching S&B (kg/ha) Ave P leaching hort (kg/ha) Ave P leaching forestry (kg/ha) Ave P leaching other LU (kg/ha) Ave Profit Dairy ($/ha eff) Ave Profit Dairy support ($/ha eff) Ave Profit S&B ($/ha eff) Ave Profit Horticulture ($/ha eff) Ave Profit Forestry ($/ha) Total milk solids (tn) wool production (tn) carcass mutton production (tn) carcass lamb production (tn) carcass beef production (tn) carcass bull beef production (tn) S1 logs (m3) S2 logs (m3) S3 logs (m3) Pulp (m3) Waste (m3) Total Carbon (tn CO2-eq) Potato (tn) Onion (tn) Carrots (tn) Squash (tn) Barley (tn)

Sheet	Content	Sets	Variables (*)
			Broccoli (tn) Lettuce (tn) Cabbage (tn) Spinach (tn) Cauliflower (tn)
OUTPUTCAT	Output per catchment	(*,cat, scenarios)	Farm + point source N load (tn N) Farm N load (tn N) Area on Dairy (ha) Area on Dairy Sup (ha) Area on S&B (ha) Area on plant Forestry (ha) Farm P load (tn N) Farm + psFarm P load (tn N) Farm profit ($M)
OUTPUTDAI	Output for dairy land use per cld per mod(ha)	(cld,mod,scenarios)	Area per cld per mod (ha)
OUTPUTHOR	Output for horticulture land use per clh per moh(ha)	(clh,moh,scenarios)	Area per clh per moh (ha)
OUTPUTSAB	Output for s&b land use per cls per mos(ha)	(cls,mos,scenarios)	Area per per cls per mos (ha)
OUTPUTSC	Output per sc	(scenarios, sc, *)	Farm + point source N load (tn N) Farm N load (tn N) Area on Dairy (ha) Area on Dairy Sup (ha) Area on S&B (ha) Area on plant Forestry (ha) Farm P load (tn N) Farm + point source P load (tn N) Farm profit ($M)

*Indicates the different variables included in the sheet

Table A3: Set used in the model

Set	Set of:	Levels
cat	Catchments	uw: Upper Waikato, wai: Waipa, cw: Cetral Waikato, lw: Lower Waikato
sc	Sub catchments	1-66
lu	Land uses	dai: dairy, dsu: dedicated dairy support, sab: sheep and beef, hor: horticulture, fos: forestry and , mis: other land uses.
cld	Clusters for dairy farms	1-26
clh	Clusters dry horticulture farms	1-3
cls	Clusters dry stock farms	1-5
clu	Dairy Support Clusters	1-10
ps	Point source	1-20
mod	Mitigation options for dairy	1-18

Set	Set of:	Levels
moh	Mitigation options for horticulture farms	1-7
mos	Mitigation options for dry stock farms	1-6
to	Treatment option for point sources	1-2
dai	Dairy Information data fields	fad: Farm size (ha) fed: Farm effective area (ha) opd: Operating profit ($/ha) nld: N leaching (kg/ha) pld: P losses (kg/ha) msd: milk solids (kg MS/ha) srd: stocking rate (peak milking cows /ha) god: cows grazing off (heads/ha) ocd: cows stood-off (heads/ha) nfd: nitrogen fertilizer use (kg N/ha) spd: supplementary feed (t/ha) lad: labour (FTE/ha) r1d: rising 1 year olds (heads/ha) r2d: rising two year olds (heads/ha) efd: Extra capital investment in effluent system ($/ha) (not available) sod: Extra capital investment in standoff facilities ($/ha) ims: imported maize silage (t/ha) pms: produced maize silage (t/ha)
dsi	Dairy support information data fields	fau: Farm size (ha) feu: Farm effective area (ha) opu: Operating profit ($/ha) nlu: N leaching (kg/ha) plu: P losses (kg/ha) gou: cows grazing off (heads/ha) nfu: nitrogen fertilizer use (kg N/ha) spu: supplementary feed (t/ha) lau: labour (FTE/ha) r1u: rising 1 year olds (heads/ha) r2u: rising two year olds (heads/ha)
foi	Forestry information data fields	opf: Anualized NPV ($/ha) nlf: N leaching (kg/ha) plf: P losses (kg/ha) S1: S1 logs (m^3) S2: S2 logs (m^3) S3: S3 logs (m^3) Pulp: Pulp (m^3) Waste: Waste (m^3) Carbon : Carbon sequestration (CO_2-eq tn/ha)
hoi	Horticulture farm information data fields	fah: Farm size (ha) feh: Farm effective area (ha) oph: Operating profit ($/ha) gmh: GM ($/ha) nlh: N leaching (kg/ha) plh: P losses (kg/ha) poh: Potato (kg/ha) onh: Onion (kg/ha)

Set	Set of:	Levels
		carh: Carrots (kg/ha) sqh: Squash (kg/ha) bah: Barley (kg/ha) brh: Broccoli (kg/ha) leh: Lettuce (kg/ha) cah: Cabbage (kg/ha) sph: Spinach (kg/ha) cauh: Cauliflower (kg/ha) nfh: nitrogen fertilizer use over the whole farm (kg N/ha)
scenarios	Nutrient reduction scenarios	Variable

Table A4: Parameters

Id	Domain	Text
baselineTi		Total profit fr4om farming on the baseline
convToForUp		It could be 0 (no conversion allowed) or 100000
err2	sc, lu	Error: discrepancies in LU area between UNcalibrated baseline minus Optimum baseline
err3	sc	Error: discrepancies in N load from agriculture between UNcalibrated baseline minus Optimum baseline
err4	sc	Error: discrepancies in dairy cow nrs between UNcalibrated baseline minus Optimum baseline
IDa	cld, mod, dai	Dairy farm information (cld mod dai)
IDs	clu, dsi	Dairy support information (clu dsi)
IFo	sc, hoi	Forestry Information (sc hoi)
IHo	clh, moh, hoi	Dry stock farm Information (clh moh hoi)
IMi	sc, mi	Information for Miscellaneous land uses (sc mii)
IPs	sc, ps, to	Point source information (sc ps to psi)
ISb	cls, mos	Dry stock farm Information (cls mos sbi)
LUda	sc, cld	Dairy platform area on each cld (ha) (sc cld)
LUho	sc, clh	Land use in horticulture (ha) (sc clh)
LUsb	sc, cls	Land use in dry stock (ha)(sc cls)
LUsu	sc, clu	Dairy support area on each clu (ha) (sc clu)
NLossRed	scenarios	Required redution in N load
propOutBase		Proportion of cows going out of the catchment for wintering in the baseline
pScCa	sc, cat	Proportion of ewach sc on each cat (cat sc)
redNPs	sc, ps, to	Reduction of TN in point source due to treatment to(2) = land disposal (sc ps to)
redPPs	sc, ps, to	Reduction of TP in point source due to treatment to(2) = land disposal (sc ps to)
TNLbaselinesc	sc	Total N load from agriculture and point sources in the baseline in tn $_{(sc)}$
TNlfarmLim	sc	Upper limit for total N leaching from agriculture in tn $_{(sc)}$
TNlLimsc	sc	Upper limit for total N load from agriculture and point sources in tn $_{(sc)}$
TotNlBaseline		Total N from agriculture and point sources in the baseline
TotNlLim		Upper limit for total N load from agriculture and point sources in tn
UBarea	sc, lu	Area of each lu on each sub-catchment (ha) (UNCALIBRATED BASELINE)

Id	Domain	Text
UBTCsc	sc	Total number of dairy cows per sc (Heads) (sc) (UNCALIBRATED BASELINE)
UBTNlfarm	sc	Total N leaching from agriculture in tn (UNCALIBRATED BASELINE)(sc)
xDonF		Parameter activating eAreaDai2 when conversion of forestry into dairy is allowed. Zero when not lowed
xSbonF		Parameter activating eAreaSab2 when conversion of forestry into S&B is allowed. Zero when not lowed
xSuonF		Parameter activating eAreaDsu2 when conversion of forestry into dairy support is allowed. Zero when not lowed
OUTPS	ps, scenarios	Output for point sources - N load (tn N)
OUTPUT	*,scenarios	Output in general for the whole catchment
OUTPUTCAT	*,cat, scenarios	Output per catchment
OUTPUTDAI	cld,mod,scenarios	Output for dairy land use per cld per mod(ha)
OUTPUTHOR	clh,moh,scenarios	Output for horticulture land use per clh per moh(ha)
OUTPUTSAB	cls,mos,scenarios	Output for s&b land use per cls per mos(ha)
OUTPUTSC	scenarios, sc, *	Output per sc

*Indicates the different variables included in the matrix

Table A5: Endogenous variables

Id	Domain	Text
areaDai	sc, cld, mod	ha allocated to dairy land use (sc cld mod)
areaDaiE	sc, cld, mod	Effective area allocated to dairy land use (sc cld mod)
areaDsu	sc, clu	ha allocated to dedicated dairy support (sc clu)
areaDsuE	sc, clu	Effective area allocated to dedicated dairy support (sc clu)
areaHor	sc, clh, moh	ha allocated to horticulture (sc clh moh)
areaHorE	sc, clh, moh	Effective area allocated to horticulture (sc clh moh)
areaSab	sc, cls, mos	ha allocated to dry-stock (sc cls mos)
areaSabE	sc, cls, mos	Effective area allocated to dry-stock (sc cls mos)
areaT	sc, lu	Area of each lu on each sub-catchment (ha)
DonF	sc, cld, mod	ha allocated to dairy on land converted from forestry (sc cld mod)
DonFsc	sc	ha allocated to dairy on land converted from forestry
FonDa	sc, cld	ha to forest on land converted from dairy (sc cld)
FonDasc	sc	ha to forest on land converted from dairy
FonSb	sc, cls	ha to forest on land converted from sheep & beef (sc cls)
FonSbsc	sc	ha to forest on land converted from sheep & beef
FonSu	sc, clu	ha to forest on land converted from support (sc cls)
FonSusc	sc	ha to forest on land converted from support
NloadLU	lu	Total N load per LU for the whole (tn N)
NloadLUsc	sc, lu	Total N load per LU for each sc (tn N)
NyieldLU	lu	Average N yield per LU for the whole (kg N per total ha)
NyieldLUsc	sc, lu	Average N yield per LU for each sc (kg N per total ha)
PloadLU	lu	Total P load per LU for the whole (tn P)
PloadLUsc	sc, lu	Total P load per LU for each sc (tn P)
propOut		Proportion of cows going out of the catchment for wintering (±10% G.Doole pers com)
pst	sc, ps, to	Proportion of the waste from point sources treated with each option (0-1)

Id	Domain	Text
PyieldLU	lu	Average P yield per LU for the whole (kg P per total ha)
PyieldLUsc	sc, lu	Average P yield per LU for each sc (kg P per total ha)
R1goSb		Total dairy R1 grazed off on sheep and beef farms (Heads)
R1goSu		Total dairy R1 grazed off on support (Heads)
R2goSb		Total dairy R2 grazed off on sheep and beef farms (Heads))
R2goSu		Total dairy R2 grazed off on support (Heads))
SbonF	sc, cls, mos	ha allocated to sheep & beef on land converted from forestry
SbonFsc	sc	ha allocated to sheep & beef on land converted from forestry
SuonF	sc, clu	ha for support on converted land from forestry
SuonFsc	sc	ha for support on converted land from forestry
TC		Total number of dairy cows (Heads)
TCCat	cat	Total number of dairy cows (in Heads) (cat)
TCgo		Total mature dairy cows grazed off (Heads)
TCgoSb		Total mature dairy cows grazed off on sheep and beef farms (Heads)
TCgoSu		Total mature dairy cows grazed off on support (Heads)
TCsc	sc	Total number of dairy cows per sc (Heads)
TCso		Total mature dairy cows on stand-off (Heads)
ti		Objective funcion 1: total farm profit minus marginal in the baseline (millions $)
til		Objective funcion 2: loss in farm profit plus marginal cost for point source extra treatment for mitigated scenarios (millions $)
tisc	sc	total farm profit in each sc ($)
TNlfarm	sc	Total N leaching from agriculture in tn
TNlsc	sc	total N load from agriculture and point sources per sc in tn
TNps	sc	Total N from point sources in tn
TotNl		Total N load from agriculture and point sources in tn
TPlfarm	sc	Total P loses from agriculture in tn
TPlsc	sc	total P load from agriculture and point sources per sc in tn
TPps	sc	Total P from point sources in tn
tPScSc	sc	Total marginal cost for point source extra treatment (i.e. land disposal)
TR1go		Total dairy R1 grazed off (Heads)
TR2go		Total dairy R2 grazed off (Heads)

Table A6: List of the equations in the model

Id	Domain	Text
cTNlfarm	sc	Constraint total N leaching from agriculture in tn
cTNlsc	sc	Constraint total N load from agriculture and point sources per sc in tn
cTotNL		Constraint total N load from agriculture and point sources in tn over the whole catchment
eAreaDai1	sc, cld	Constraint area allocated to dairy to maintain proportionality between cld (sc cld)
eAreaDai2	sc, cld	Constraint area allocated to dairy to maintain proportionality between cld in convertion (sc)
eareaDaiE	sc, cld, mod	Calculate Effective area allocated to dairy land use (sc cld mod)
eAreaDaiT	sc	Calculate Total area allocated to dairy land use per sc
eAreaDsu1	sc, clu	Constraint area allocated to dairy support to maintain proportionality between cls (sc clu)
eAreaDsu2	sc, clu	Constraint area allocated to dairy support to maintain proportionality between cld in convertion (sc clu)
eareaDsuE	sc, clu	Calculate Effective area allocated to dedicated dairy support (sc clu)

Id	Domain	Text
eareaDsuT	sc	Calculate Total area allocated to dairy support
eAreaFos	sc	Calculate area allocated to plantation forestry (sc)
eareaHor1	sc, clh	Constraint area allocated to horticulture to maintain proportionality between clh (sc clh)
eareaHorE	sc, clh, moh	Calculate Effective area allocated to horticulture (sc clh moh)
eareaHorT	sc	Calculate Total area allocated to horticulture land use per sc
eareaMisT	sc	Constraint area allocated to miscellaneous to be the same as baseline
eAreaSab1	sc, cls	Constraint area allocated to sheep and beef to maintain proportionality between cls (sc cls mos)
eAreaSab2	sc, cls	Constraint area allocated to sheep and beef to maintain proportionality between cld in convertion (sc cls)
eareaSabE	sc, cls, mos	Calculate Effective area allocated to dry-stock (sc cls mos)
eareaSabT	sc	Calculate Total area allocated to sheep and beef per sc
eDonFsc	sc	Calculate total ha of dairy on forestry land per sc
eFonDasc	sc	Calculate total ha of forestry on dairy land per sc
eFonSbsc	sc	Calculate total ha of forestry on sheep and beef land per sc
eFonSusc	sc	Calculate total ha of forestry on support land per sc
eNloadDaisc	sc, lu	Calculate total N load from dairy for each sc (tn N)
eNloadFosc	sc, lu	Calculate total N load for forestry for each sc (tn N)
eNloadHosc	sc, lu	Calculate total N load for horticulture for each sc (tn N)
eNloadLU	lu	Calculate total N load per LU for the whole (tn N)
eNloadMisc	sc, lu	Calculate total N load for miscelaneus LUs for each sc (tn N)
eNloadSbsc	sc, lu	Calculate total N load for shee & beef for each sc (tn N)
eNloadSusc	sc, lu	Calculate total N load for dairy support for each sc (tn N)
eNyieldLU	lu	Calculate average N yield per LU for the whole (kg N per total ha)
eNyieldLUsc	sc, lu	Calculate average N yield per LU for each sc (kg N per total ha)
ePloadDaisc	sc, lu	Calculate total P load from dairy for each sc (tP P)
ePloadFosc	sc, lu	Calculate total P load for forestry for each sc (tn P)
ePloadHosc	sc, lu	Calculate total P load for horticulture for each sc (tn P)
ePloadLU	lu	Calculate total P load per LU for the whole (tn P)
ePloadMisc	sc, lu	Calculate total P load for miscelaneus LUs for each sc (tn P)
ePloadSbsc	sc, lu	Calculate total P load for shee & beef for each sc (tn P)
ePloadSusc	sc, lu	Calculate total P load for dairy support for each sc (tn P)
ePSc1	sc, ps	Constraint making that all N-P load from point sources gets accounted for
ePyieldLU	lu	Calculate average P yield per LU for the whole (kg P per total ha)
ePyieldLUsc	sc, lu	Calculate average P yield per LU for each sc (kg P per total ha)
eR1goSb		Calculate total dairy R1 grazed off on sheep and beef farms (Heads)
eR1goSu		Calculate total dairy R1 grazed off on support (Heads)
eR2goSb		Calculate total dairy R2 grazed off on sheep and beef farms (Heads)
eR2goSu		Calculate total dairy R2 grazed off on support (Heads)
eSbonFsc	sc	Calculate total ha of sheep and beef on forestry land per sc
eSuonFsc	sc	Calculate total ha of support on forestry land per sc
eTC		Calculate total number of dairy cows (Heads)
eTCCat	cat	Calculate total number of dairycows (in Heads) (cat)
eTCgo		Calculate total mature dairy cows grazed off (Heads)
eTCgoBal		Constraint to balance the nr of cows grazing off

Id	Domain	Text
eTCgoSb		Calculate total mature dairy cows grazed off on sheep and beef farms (Heads)
eTCgoSu		Calculate total mature dairy cows grazed off on support (Heads)
eTCsc	sc	Calculate total number of dairy cows per sc (Heads)
eTCso		Calculate total mature dairy cows on stand-off (Heads)
etisc	sc	Calculate total farm profit per sc
eTNlfarm	sc	Calculate total N leaching from agriculture in tn
eTNlsc	sc	Calculate total N load from agriculture and point sources per sc in tn $_{(sc)}$
eTNps	sc	Calculate total N from point sources in tn
eTotNl		Calculate total P load from agriculture and point sources in tn
eTPlfarm	sc	Calculate total P loses from agriculture in tn
eTPlsc	sc	Calculate total P load from agriculture and point sources per sc in tn
eTPps	sc	Calculate total P from point sources in tn
etPScSc	sc	Calculate total marginal cost for point source extra treatment (i.e. land disposal)
eTR1go		Calculate total dairy R1 grazed off (Heads)
eTR2go		Calculate total dairy R2 grazed off (Heads)
OF1		Calculate objective function 1: total farm profit minus marginal in the baseline (millions $)
OF2		Calculate objective function 2: loss in farm profit plus marginal cost for point source extra treatment for mitigated scenarios (millions $)