Appendix 9: Farms

1. Introduction

Analysis of the current state of the Waikato River and catchment lakes concluded that water quality and habitat are degraded (see Section 3), and fall short of the Maaori aspirations held for the river (see Section 4). Increased pollutant run-off and loss of riparian vegetation as a result of land-use change and farming activities has a major influence on these impacts (see Section 3) and actions on farms to restore water quality and habitats are to be a key element in meeting the overall vision of a healthy and well river (see Section 5).

Farms in the Waikato catchment are a major source of contaminants to the river. Farm run-off can contain nitrogen (N), phosphorus (P), sediment, and faecal microorganisms, which can all have a significant adverse effect on river water quality. Restoration actions for water quality need to primarily focus on lowering the transfer of contaminants from farmland to tributary streams of the river – "*fix the veins that feed the awa* [river] *and you will fix the awa itself*". There is sufficient scientific evidence to show the water-quality benefits of implementing various practices on the farm and within riparian margins to either reduce the mobilisation of contaminants in the first place or to intercept those contaminants before they reach the waterways. Several of the key studies that provide this evidence have been carried out in the region, including the Toenepi dairy-catchment study near Morrinsville (Monaghan et al., 2009; Wilcock et al., 2007) and sheep and beef hill-country studies at Scotsmans Valley (Smith, 1989) in the Waipa catchment (Donnison et al., 2004; Quinn et al., 2007; Hicks and Hill, 2010). This scientific understanding has been encapsulated into various computer models that allow predictions to be made of the water-quality benefits and costs (including any effects on farm profitability) of implementing different sets of restoration actions.

In order to identify actions that could be undertaken to reduce inputs of farm contaminants to the river, eight model farm types representative of existing farms in the Waikato catchment have been developed. For each of these farms, assessments have been made of the costs associated with actions which could be taken to reduce pollutant losses. The following economic and environmental indicators were derived for each of these model farms during this process:

1. Nitrogen (N), phosphorus (P), sediment, and faecal microorganism losses to water.
2. Farm profitability.
3. Additional capital requirements for mitigating farm pollutant losses.

These model outputs feed into the water quality modelling (see Appendix 13: Water Quality) and economic modelling (see Appendix 31: Economic Modelling) to enable analysis of the effects of on-farm actions on Te Ture Whaimana – the Vision and Strategy for the Waikato River.

2. Model farms

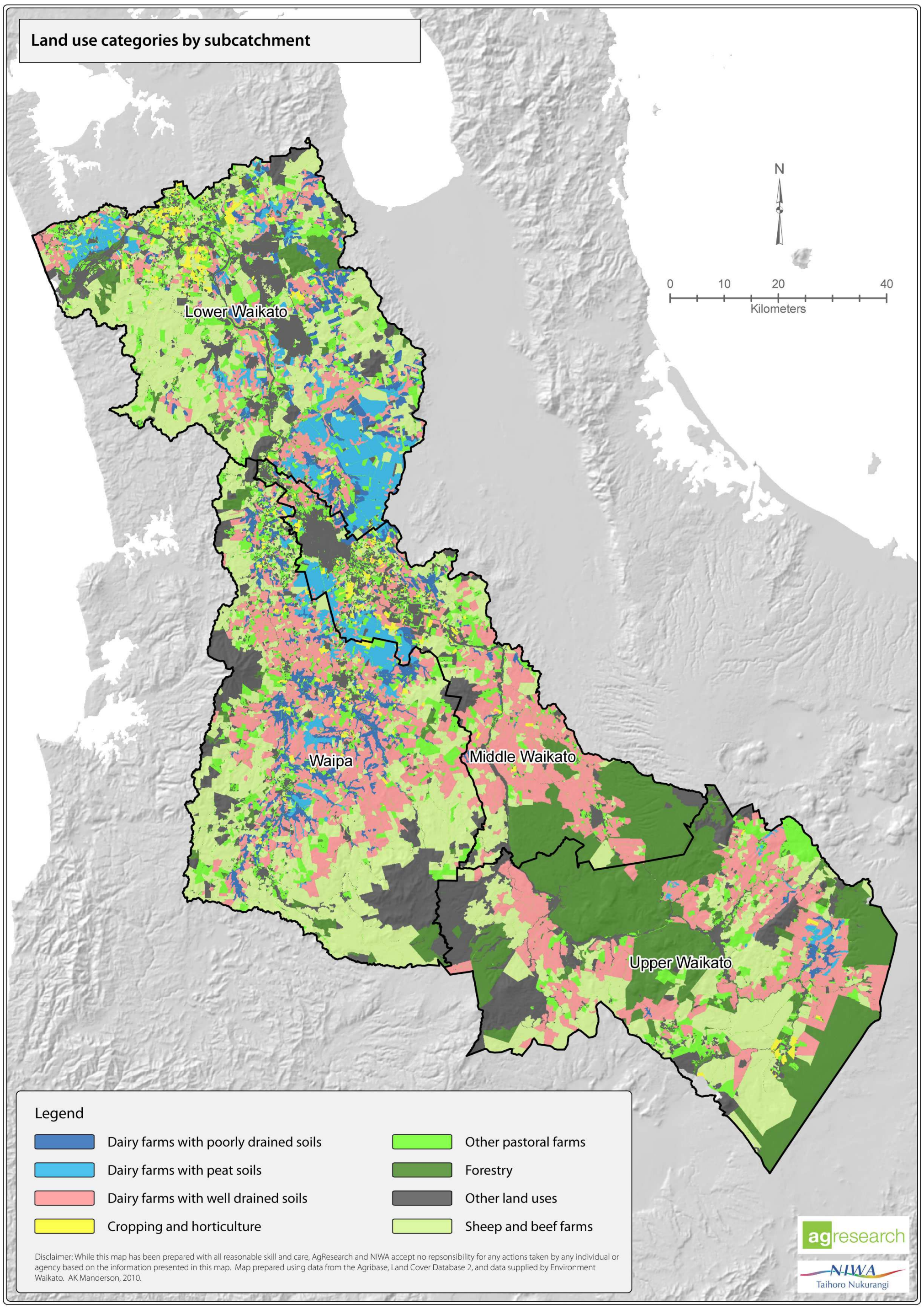
Descriptions of eight model farms have been developed. Three are dairy (on either free-draining, poorly-draining or peat soils), three are sheep-beef farms (on landscapes of contrasting steepness and thus stocking rates), one is a forestry farm and the last is a horticulture-cropping farm. Attributes of the dairy and sheep-beef farms are shown in Tables 1 and 2, respectively, and the spatial locations of the sheep-beef and different dairy farm types is shown in Figure 1.

Various information sources were used to define these models. For the dairy farms, dairy statistics (LIC, 2009) were used as a guide for stocking rates, milksolids production and farm areas. This was supplemented with farm management information from sources such as the Toenepi dairy catchment study (e.g., Monaghan et al., 2009; Wilcock et al., 2007) plus local and institutional knowledge. The modelled dairy farms represented most of the total area needed to grow feed for the typical Waikato dairy herd (i.e., areas used for maize production were included in the farm hectares). Being sourced from abroad, palm kernel expeller (PKE) was not considered in this calculation of total dairy system area. All replacement stock was assumed to be reared and wintered on-farm. The stocking rate and milk production figures shown in Table 1 are therefore slightly less than those given in LIC (2009).

Characteristics of the model sheep-beef farms were derived from model farms defined by Meat and Wool New Zealand Limited (MWNZ, 2010):

- A Class 3 farm is defined as North Island Hard Hill Country, which is 80 percent steep hill country and low fertility sedimentary soils with most farms carrying six to 10 stock units per hectare (su/ha). Although some stock are finished, a significant proportion are sold in store condition.
- Class 4 is North Island Hill Country, which is 80 percent easy hill country with more fertile volcanic soils than Class 3, mostly carrying between eight to 13 stock units per hectare. A high proportion of sale stock sold is in forward store or prime condition.
- Class 5 is North Island Intensive Finishing farms, which is easy contour rolling farmland on volcanic soils with the potential for high production; most carry

between eight to 14 stock units per hectare. A high proportion of stock is sent to slaughter and replacements are often brought in.



Disclaimer: While this map has been prepared with all reasonable skill and care, AgResearch and NIWA accept no repsonsibility for any actions taken by any individual or agency based on the information presented in this map. Map prepared using data from the Agribase, Land Cover Database 2, and data supplied by Environment Waikato. AK Manderson, 2010.

Figure 1: Distribution of farm types and forestry within the Waikato River Study area (from AgriBase, courtesy of AgResearch). Note that spatial information of the distribution of subclasses of sheep and beef farms are not available for mapping.

With the assistance of Dr Andrew Manderson from AgResearch Grasslands, actual data inputs (farm stocking rates, coverage and major soil group present) for each of the model farms were refined using a GIS (geographical information system) analysis of farms identified as sheep-beef units within the Waikato River catchment.

Table 1: Attributes of the model dairy farms.

Farm attribute	Units	Free-draining	Poorly-draining	Peat
Main block	ha	114	114	114
Effluent block	ha	17	17	17
Maize	ha	8	8	8
Total farm area	ha	139	139	139
Topography		Rolling	Flat	Flat
Cows		339	327	314
Stocking rate	cows/total ha	2.44	2.35	2.26
Coverage[1]	ha	224,521	47,885	47,950
Milksolids	kg/cow	359	361	372
	kg/ha	879	848	840
Fertiliser N, P, K	kg/ha/year	115, 49, 56	115, 49, 56	119, 49, 56
Imported PKE[2]	kg DM/ha/year	870	835	726

[1] Estimate of area occupied by model farm within the Waikato River catchment from AgriBase (see Fig. 1).

[2] Palm kernel expeller.

Financial metrics for the forestry model farm were supplied by Brian Bell of Nimmo-Bell & Company Limited. These were used to calculate gross margins, from which mitigation costs could be derived (described in Appendix 31: Economic Modelling).

Attributes of the horticultural farm were derived by Dr Tony van der Weerden, AgResearch, Invermay; and cropping records were taken from Kerr et al., (2006) and Ministry of Agriculture and Forestry (2009). This information was used to construct a representative model farm that consisted of potatoes (25 hectares), onions (19 hectares), kiwifruit (5 hectares) and sweetcorn (two hectares).

Table 2: Attributes of the model sheep-beef farms.

Farm attribute	Units	Class 3	Class 4	Class 5
Total farm area	ha	635	290	300
Topography		Steep hill	Easy hill	Rolling and easy hill
Stocking rate	su/ha	8	10.5	12
Coverage[1]	ha	176,198	96,108	48,054
Fertiliser N, P, K	kg/ha/year	0, 17, 2	10, 27, 12	50, 29, 19

[1] Estimate of area occupied by model farm within the Waikato River catchment (provided by Dr Andrew Manderson, AgResearch, Grasslands).

3. Modelling approach

3.1 Dairy farms

Five key indicators were derived for each of the model farms:

1. Farm profitability, dollars per hectare per year ($/ha/year).
2. Nitrogen leaching losses to water, kilograms of nitrogen per hectare per year (kg/N ha/year).
3. Phosphorus loss to water, kilograms of phosphorus per hectare per year (kg P/ha/year).
4. Sediment loss to water, kilograms per hectare per year (kg/ha/year).
5. Losses of the faecal bacteria *Escherichia coli* (*E. coli*) to water, most probable number (MPN) multiplied by 10^9 per hectare per year.

The Farmax Dairy Pro model (Bryant et al., 2010) was used as the modelling tool to define the base milksolids production and profitability of each model dairy farm. This approach ensured that farms maintained feasibility as successive mitigation interventions were introduced. The Farmax Dairy Pro model also provided assessments of cash operating profit, which was used as the key financial indicator of farm economic success. A milksolids payout of $6 per kilogram was used in all the modelling of mitigation actions. Actions were grouped to represent different cost-effectiveness profiles.

Four sources of farm-derived contaminants were considered in the modelling:

- Paddock losses.
- Direct deposition of faecal material to unfenced streams.
- Run-off from tracks and laneways.
- Losses due to mismanagement of the farm dairy effluent (FDE) system.

The Overseer® Nutrient Budgeting model (hereafter referred to as *Overseer*) was used to derive estimates of nitrogen and phosphorus losses from paddocks to water. Inputs from direct deposition of cow excreta into unfenced streams (56 percent of stream length (Storey, 2010)) were derived using algorithms contained in the BMPToolbox (Monaghan, 2009) and added to the *Overseer* estimates. Run-off from tracks and laneways was then added to this combined figure, based upon results and assumptions given in Smith and Monaghan (2009). A final contribution from effluent mismanagement was added, assuming that current accident rates due to negligence and management inaccuracies result in one percent of FDE being transferred directly to streams.

Estimates of sediment yields from each of the model dairy farms were derived using the Revised Universal Soil Loss Equation, assuming slopes of 6^o, 3^o and 2^o for farms on free-draining, poor-draining and peat soils, respectively, and soil erodibility factors of 0.01, 0.02 and 0.01, respectively (Renard et al., 1997).

Inventories of sources and pathways of *E. coli* transfers from farms to water were constructed to help make an assessment of the effectiveness of mitigation practices on reducing these losses from the free-draining and poorly-draining model dairy farms; the model dairy farm on peat soil was not considered in this analysis due to a lack of data and understanding about how peat soils behave with respect to losses of faecal bacteria in drainage/overland flow. Eight distinct potential sources were however identified for the other two model dairy farms:

1. Overland flow, discharging the equivalent of 8×10^9 or 224×10^9 *E. coli* per hectare per year from free- and poorly-drained soils, respectively.
2. Subsurface pipe drainage systems on the poorly-drained soils, discharging 116×10^9 *E. coli* per hectare per year.
3. Groundwater seepage to the stream discharging the equivalent of 3×10^9 or 1×10^9 *E. coli* per hectare per year from free- and poorly-drained soils, respectively.
4. Direct deposition of cow excreta to streams, potentially depositing the equivalent of 207×10^9 *E. coli* per hectare per year.

5. Discharges from two-pond treatment systems. It was assumed that 20 percent of farms remained on a two-pond treatment system, potentially discharging the equivalent of 18 x 10^9 *E. coli* per hectare per year.

6. Direct drainage of farm dairy effluent through pipe drainage systems on the poorly-drained soils, potentially discharging 234 x 10^9 *E. coli* per hectare per year.

7. Run-off from tracks and laneways, potentially discharging the equivalent of 12 x 10^9 or 24 x 10^9 *E. coli* per hectare per year for farms on free- or poorly-drained soils, respectively.

8. Inputs due to accidents or mismanagement of the FDE system, potentially discharging the equivalent of 13 x 10^9 *E. coli* per hectare per year.

For modelling the actions described below, it was assumed that Action bundle A (Table 4) would remove sources 4, 5 and 6 listed above; the implementation of Action bundle B was assumed to also remove source number 7. Inputs from source number 8 were assumed to reduce to 6 x 10^9 and 1 x 10^9 *E. coli* per hectare per year under dairy farm Actions A and B, respectively.

3.2 Sheep and beef farms

As for dairy farms, cash operating profit, and nitrogen, phosphorus and sediment losses to water were estimated for each of the model sheep-beef farms based on available information (Table 3). Due to a paucity of data, area-specific yields of *E. coli* to water were not able to be derived. Proportional reductions in faecal yields due to assumed mitigation interventions (described in Section 4.2 of this Appendix) were instead estimated based on information in Table 3. Research findings and expert opinion were similarly used to make estimates of reductions in nitrogen, phosphorus and suspended sediment for each mitigation action evaluated (Table 3).

The Farmax® Pro model (White et al., 2010) was used as the modelling tool to define the base production and profitability of each model sheep-beef farm. The profitability figures reported in the accompanying summary table have had an annual management wage deducted. *Overseer* was again used to derive estimates of nitrogen and phosphorus losses from paddocks to water. Inputs from direct deposition of sheep excreta into unfenced streams (61 percent of stream length on sheep-beef farms; from Storey, 2010) were derived using algorithms contained in the BMPToolbox and assuming that 0.75 percent of sheep excreta was deposited directly to streams (Monaghan, 2009). These direct inputs were added to the *Overseer* estimates of nitrogen and phosphorus loss to calculate total farm losses.

Table 3: Rationale and estimated reductions in *E. coli*, suspended sediment (SS), total phosphorus (TP), and total nitrogen (TN) in response to mitigation actions on sheep and beef farms

Mitigations	*E.coli* reduction	SS redn	TP redn	TN redn	Rationale
Stream fencing cattle out	40%[1], 20-35%[2]	30%[3], 30-90[2]	10%[3],	7%[3]	[1]Calc from cattle faeces @ 2% defecation in streams (Bagshaw, 2002; Collins et al., 2007); [2]= P21 stocktake (McKergow et al., 2007); [3]= *medians* of non-storm samples *concentrations* at site PW3 at Whatawhata in years 0–3 post establishment before poplar effects were strong (Quinn, unpublished data).
Stream fencing cattle out and streambank poplars	40%[1]	55%[2]	15%[2]	10%[2]	[1]Calc from cattle faeces @ 2% def in streams and 2% on banks; [2]as median of non-storm sample concentrations at PW3 in years 6–8 post establishment after poplar effects developed (Quinn, unpublished data).
Stream fencing all stock out	60%	50%	15%	15%	Estimates based on cattle fenced out above and assuming sheep have lesser direct input and bank damage than cattle.
5 m wide unplanted buffer and wetlands fenced	65%	55%	45%	20%	Informed particularly by Smith (1989); Quinn and Stroud (2002); Collins et al., (2004, 2005); Dodd et al., (2008) and McKergow et al., (2007).
5 m planted buffer and wetlands fenced	65%	60%	55%	35%	Informed particularly by Smith (1989); Quinn and Stroud (2002); Collins et al., (2004, 2005); and Dodd et al., (2008).
15 m planted buffer and wetlands fenced	75%	65%	65%	40%	Informed particularly by Smith (1989); Quinn and Stroud (2002); Collins et al., (2004, 2005); and Dodd et al., (2008).
Troughs and non-riparian shade	10%	10%	5%	3%	Estimated assuming this reduces stock access to water by about 25% (Byers et al., 2005).
Pine afforestation	80%[3]	65%	65%	60%	[3]Based on Donnison et al., (2004). Others informed particularly by Quinn and Ritter, (2003) (Purukohukohu); Dodd et al., (2008) (WW modelling) and Quinn and Stroud (2002); tempered by afforested (PW2) findings at WW where reduction in median <20% in first 8 years after pine planting (Quinn, unpublished data).

3.3 Forestry farm

Production and financial metrics for the forestry model farm were supplied by Brian Bell of Nimmo-Bell and Company Limited (see Appendix A at the end of this appendix). Yields of nitrogen and phosphorus from this model farm are estimates representing the average for a plantation life cycle (i.e., spread over growth and harvest phases). These estimates were derived from values reported in the literature (Wilcock, 1986; Cooper and Thomsen, 1988; Quinn and Ritter, 2003). Estimates of sediment yields were again derived using the Revised Universal Soil Loss Equation, assuming a slope of 17^{o} and a soil erodibility factor of 0.01 (Renard et al., 1997). Due to a paucity of data, area-specific yields of *E. coli* to water were not able to be derived. Proportional reductions in faecal yields due to assumed mitigation interventions (described later) were instead estimated based on expert opinion.

3.4 Horticulture and cropping farm

Production and management characteristics of the horticulture-cropping model farm were based on the expert opinion of Dr Tony van der Weerden, AgResearch, Invermay. This information was used to construct *Overseer* nutrient budgets for each of the component cropping blocks. Estimates of nitrogen and phosphorus losses to water were taken from these nutrient budgets. Estimates of the profitability of each component crop were obtained from local expert opinion (Crop and Food, Pukekohe and Ministry of Agriculture and Forestry, 2009).

Estimates of sediment yields were again derived using the Revised Universal Soil Loss Equation, assuming a slope of 2^{o}, a soil erodibility factor of 0.01 and a crop management factor of 0.2 (Renard et al., 1997; Basher et al., 1997). Due to a paucity of data, area-specific yields of *E. coli* to water were not able to be derived.

3.5 Stream characteristics

Stream density

One of the key metrics influencing the costs of stock exclusion on farms is the density of streams (i.e., length in metres per hectare). Initially, GIS data was used to compile an assessment of stream lengths for some of the landscapes relevant to each model farm. However, it soon became apparent that these estimates were too low. Storey and Wadhwa (2009) document some of the reasons why this is so and provide an indication as to how currently mapped stream densities within GIS data layers could be scaled to provide a closer approximation of actual stream lengths (see also Appendix 11: Riparian Aesthetics). Scaling for the model farms in the Waikato River catchment provided the following stream densities that were used for our modelling assessments:

- 35 metres per hectare for dairy farms.
- 60, 50 and 40 metres per hectare for Class 3, 4 and 5 sheep-beef farms, respectively.
- 60 metres per hectare for the forestry farm.

Stock exclusion

The assumed extent of stock exclusion from streams on the model farms was taken from Storey (2010). This survey suggested that 44 percent of stream lengths on dairy farms were currently fenced to exclude stock (i.e., 56 percent of lengths remained to be fenced), and 39 percent of stream lengths on sheep-beef farms were currently fenced to exclude stock (i.e., 61 percent of stream lengths remained to be fenced).

4. Mitigation practices

4.1 Dairy farms

Four mitigation actions (numbered A–D in the accompanying results table) were developed for the model dairy farm types. Actions A, B and D represented a progressive level of adoption of best management practices on a conventional dairy unit. In contrast, Action C represented a transition from the base farm to an organic dairy unit, but with all of the relevant Accord-type best management practices modelled in Action A also implemented. This organic dairy option was evaluated as a potential strategy for mitigating nitrogen losses and was not assumed to have any major effect on phosphorus, sediment or *E. coli* losses (other than the benefits gained from implementing Action A, which is not specific to an organic system). The specific management practices modelled for each mitigation action are described in Table 4 and the predicted effects on cash profit and contaminant reductions of these actions are shown in Table 5.

Table 4: Summary of dairy farm actions

Action	Description
A	Full stock exclusion from streams using single-wire fencing.
A	Soil Olsen phosphorus levels reduced from 38 to 32 (economic optimum).
A	Effluent areas enlarged appropriate to effluent potassium loading rates.
A	Additional one month's effluent pond storage; low application depth.
B	All Action A managements adopted.
B	Use of nitrification inhibitors (five percent pasture production response assumed).
B	Wetlands installed on one percent of farm area (fencing out of seeps and bogs).
B	Five-metre buffers around all stream reaches, planted in natives.
B	Berms on sections of lanes to direct run-off away from streams.
B	No nitrogen fertiliser applied in winter months.
C	Base farm change to an organic dairy unit: assumed milksolids premium for organic milk of $1.05 per kilogram MS. Farm inputs of purchased feed and fertiliser nitrogen reduced to nil. Profitability assessments relative to base farm made using the comparative study reported by Shadbolt et al., (2009).
D	All Action B managements adopted.
D	Winter grazing of paddocks for four hours only, then herds returned to a herd shelter (capital cost of $1,350 per cow).

Each action was run through the Farmax Dairy Pro and *Overseer* models to derive estimates of likely changes in farm productivity and nutrient loss. These modelling steps were necessary to account for likely changes in pasture growth rates and thus cow stocking rates and nutrient losses.

The financial costs associated with each mitigation action were assessed. These were separated into capital costs (e.g., fencing materials, larger effluent ponds or a herd shelter) and the annualised cost associated with introducing each mitigation management. The latter considered the opportunity cost of capital (eight percent), depreciation, maintenance, additional labour and feed requirements, and revenue foregone as a result of land lost to production. Any financial benefits expected from implementing measures were deducted from the net overall annualised cost. These benefits can be important where a measure reduces farm operational costs (e.g., reduced fertiliser costs).

Table 5: Summary of costs and contaminant reductions associated with dairy farm mitigations; values are percent (%) reductions from modelled base farm scenario.

Indicator	Actions	Free-draining	Poorly-draining	Peat
Cash profit	Action A	20	-2	3
	Action B	4	12	19
	Action C	13	13	11
	Action D	22	30	28
Nitrogen	Action A	16	17	26
	Action B	62	44	64
	Action C	43	45	43
	Action D	66	50	69
Phosphorus	Action A	75	61	35
	Action B	89	74	63
	Action C	75	61	35
	Action D	89	74	63
Sediment	Action A	15	15	7
	Action B	51	52	77
	Action C	15	15	7
	Action D	51	52	77
E coli	Action A	79	45	Nd
	Action B	93	57	Nd
	Action C	79	45	Nd
	Action D	93	57	Nd

Nd = Not determined.

4.2 Sheep and beef farms

Four mitigation actions were developed for each of the model sheep-beef farms (Table 6). Actions A–D represents a progressive level of adoption of best management practices.

Table 6: Summary of sheep-beef farm actions, associated costs and catchment scale contaminant reductions[1], allowing for existing fencing/protection.

Action	Description
Action A	Exclusion of cattle from streams using single-wire electric fencing ($2/m) and provision of stock troughs and water supply ($2/m). Total cost = $6/m of stream to fence both sides. Assumed catchment scale reductions in N, P, sediment and *E. coli* yields: 4, 6, 18 and 24%, respectively.
Action B	As per Action A, but with poplar plantings (with sleeves) at 10 m spacings on each side of streams. Total cost = $8/m of stream to fence both sides. Assumed reductions in N, P, sediment and *E. coli* yields: 6, 9, 34 and 24%, respectively.
Action C	Full stock exclusion from stream using an 8-wire post and batten fence, allowing a 5 m buffer planted with natives at 2,500 plants/ha (pb2[2]). Total cost = $59/m of stream to fence both sides. Assumed reductions in N, P, sediment and *E. coli* yields: 20, 33, 36 and 40%, respectively.
Action D	Full stock exclusion from stream using an 8-wire post and batten fence, allowing a 15 m buffer planted with natives at 2,500 plants/ha (pb2). This larger buffer made the riparian area compliant for obtaining Kyoto compliant carbon credits[3]. Total cost = $108/m of stream to fence both sides. These costings (excluding carbon credits) include components for site preparation, weed control and monitoring of plant establishment and survival ($40,000 per equivalent ha). Assumed reductions in N, P, sediment and *E. coli* yields: 24, 47, 40 and 45%, respectively.

From a practical point of view, and with the exception of Action B, implementation of these actions was considered as independent options that could be adopted by a farmer. Thus, an individual could choose to implement Action C if they chose to, but is then unlikely to choose to implement Action D at a later date given the high capital and labour costs already incurred when implementing Action C. Similarly, an individual is unlikely to choose to implement Action A today, then Action D at a later date because they would in effect have wasted money on the single wire fencing that would be made redundant when/if Action D was implemented.

4.3 Forestry farm

One action was modelled for the forestry farm. This addressed the impacts of forest harvesting on pollutant losses. For this modelling assessment, the Study team

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[1] Estimated catchment scale reductions are 39 percent lower than in Table 3 because actions are assumed not to be applied to riparian areas already fenced or fenced and planted.

[2] pb2 = the size of seedlings planted – fit a size 2 plastic bag.

[3] For mixed native forest plantings mean annual carbon dioxide sequestration is likely ca. 9 tonne per hectare per year. Ministry of Agriculture and Forestry: http://www.maf.govt.nz/forestry/pfsi/carbon-sequestration-rates.htm

assumed that future best practice for the forestry industry would be to minimise the disturbance of forest streams by leaving a five metre un-harvested buffer along each stream. The general principles of this approach have been agreed to by the industry and are in draft document form (as a Ministry for the Environment National Environmental Standard for Forestry). For our model farm stream density of 60 metres per hectare, this would affect six percent of the forest area. Assuming that half of this buffer area would have been non-productive anyway, the net consequence of the implementation of the un-harvested buffers was a three percent reduction in harvestable area. The main benefits of this mitigation strategy are related to improved stream shading and habitat protection and reduced sediment yields (20 percent reduction). Only modest reductions in nitrogen (10 percent) and phosphorus (15 percent) yields were assumed and modelled here.

4.4 Horticulture and cropping farm

One action was modelled for the horticulture-cropping farm. This addressed fertilisation and soil management practices that aimed to reduce nitrogen, phosphorus and sediment losses. The assumed management improvements were:

- Nitrogen fertilisation of the potato crop was reduced from 570 to 250 kilograms of nitrogen per hectare per year. Phosphorus fertilisation of the potato crop was reduced from 55 to 10 kilograms of phosphorus per hectare per year to make use of the considerable reserves of soil phosphorus (Olsen phosphorus test of 200 assumed).

- Nitrogen fertilisation of the onion crop was reduced from 156 to 106 kilograms of nitrogen per hectare per year. Phosphorus fertilisation of the onion crop was reduced from 112 to 45 kilograms of phosphorus per hectare per year to make use of the considerable reserves of soil phosphorus (Olsen phosphorus test of 200 assumed).

- Improved soil management techniques increased the value of the product of the cropping x support practice factors used in the RUSLE from 0.2 to 0.5. Contour planting, contour drainage, cover crops, bunding and grassed waterways are some of these improved management techniques that are known to reduce sediment transport from soils used for market gardening (Basher et al., 1997; Ministry for the Environment, 2001; Environment Waikato, 2010).

5. Results

The key findings from this modelling assessment are summarised below in terms of mitigation of nitrogen and phosphorus, sediment, and faecal bacteria losses from the various types of farm land. Cost abatement graphs for each of these mitigations are summarised in Figures 1–3.

5.1 Nitrogen and phosphorus mitigation

- Because of the very high nitrogen and phosphorus fertilisation rates used (and thus consequently high per hectare nitrogen and phosphorus losses) on the horticulture model farm, improved fertilisation techniques represent the easiest and most cost-effective way of reducing nitrogen and phosphorus losses in the catchment (although only by a maximum of about four percent of whole catchment loads).

- The next most cost-effective measure is the implementation of Action A on all dairy farms. This has the multiple benefits of significantly reducing nitrogen, phosphorus and faecal bacteria losses from these farms (particularly from the poorly-drained dairy farms).

- Mainly from a nitrogen mitigation perspective the next most cost-effective action is to implement Action B (nitrification inhibitors, wetlands and track/laneway containment) on all dairy farms. Thereafter, the simple stock exclusion measures (Actions A and B) on Class 5, 4 and 3 sheep-beef farms become the next cost-effective measures for reducing nitrogen in the catchment, in that order. The implementation of Action D on sheep-beef farms and poorly-drained dairy farms, and the implementation of the single forestry action (five metre un-harvested stream buffers), are estimated to be the least cost-effective measures for mitigating N loss. Organic dairy production proved to be another reasonably cost-effective option for nitrogen mitigation, costing between \$15 and \$23 per kilogram of nitrogen conserved, depending on farm type. Assuming that Action A had first been implemented on all dairy farms, and that dairy Actions B and C are mutually exclusive, organic dairy production was in fact the next most cost-effective nitrogen mitigation measure at a whole-catchment level.

- From a phosphorus mitigation perspective alone for further phosphorus mitigation, the implementation of Action B on sheep-beef farms is estimated to be a more cost-effective way of decreasing phosphorus losses than implementing Action A. Thereafter, the costs for additional phosphorus mitigation jump considerably (to in excess of \$300 per kilogram of phosphorus) for the other modelled actions.

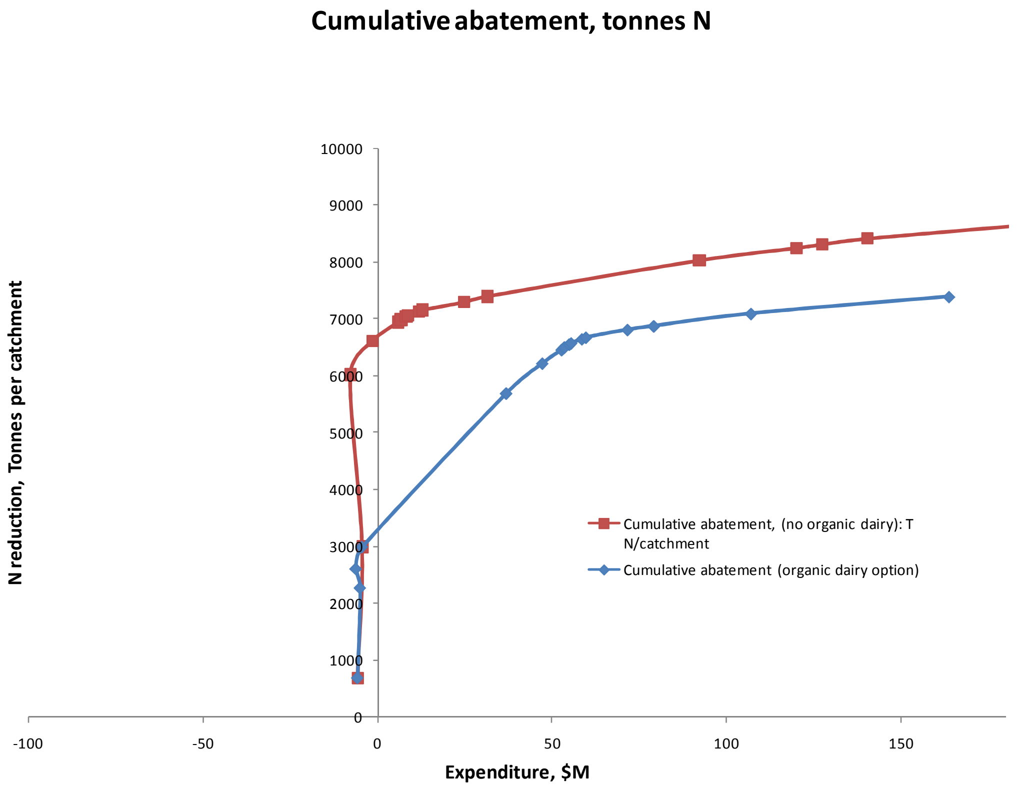

Figure 2: Cumulative nitrogen abatement curve for two management actions for farms within the Waikato River catchment: (a) following a conventional production system for model dairy farms (red line), and (b) following an organic dairy production system (blue line), assuming all dairy Action A mitigations are first in place.

5.2 Sediment mitigation

- Improved soil management techniques were estimated to be the most cost-effective approach for reducing sediment transport from soils used for market gardening. The Study team do note however that the estimate of net financial cost (in this case a negative value, or a net financial benefit) associated with implementation of the single action for horticulture-cropping is solely due to the reduced fertilisation costs; the costs associated with the sediment control measures assumed for this action are assumed to be fully off-set by the value of retained topsoil and topsoil fertility under this improved management action.

- The next most cost-effective measures for sediment are then to implement Actions A and B on the sheep-beef farms, followed by implementation of the single forestry action, and then Action A on all dairy farms. The implementation of Action D on all the sheep-beef model farms was the least cost-effective sediment mitigation option (ignoring Action C for these sheep-beef farms).

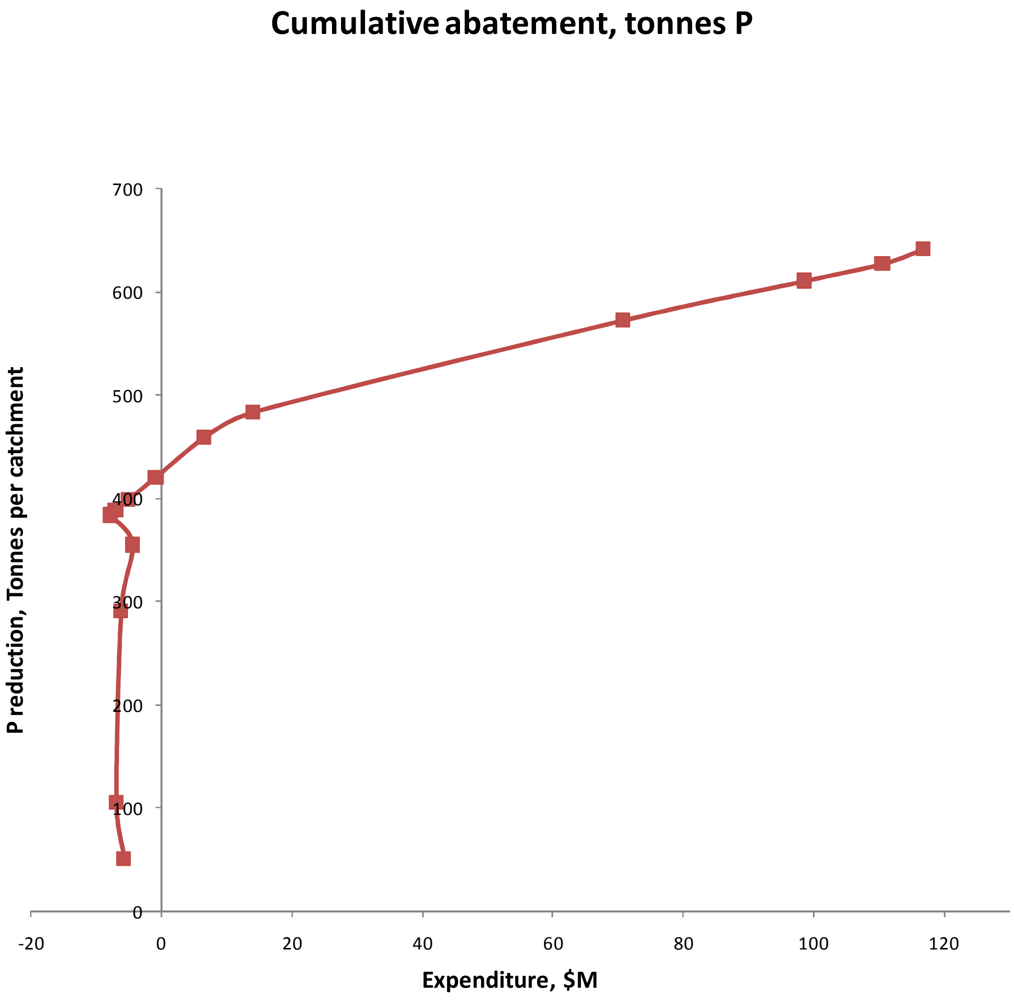

Figure 3: Cumulative phosphorus abatement curve for farms within the Waikato River catchment.

A consistent finding from the modelling analysis was that Action D for the sheep-beef farms was a more cost-effective approach for reducing nitrogen, phosphorus and sediment losses than Action C. This indicates that the wider riparian buffers under Action D reduced nitrogen, phosphorus and sediment yields by an incrementally greater amount than the incremental cost associated with installing the wider buffer margins. Although a carbon credit was included in the costings associated with Action D, this credit was only worth an annual value of between $15 and $23 per hectare and did little to off-set the large annualised costs attached to Action D mitigation ($346, $310 and $264 per hectare per year for Class 3, 4 and 5 sheep-beef farms, respectively).

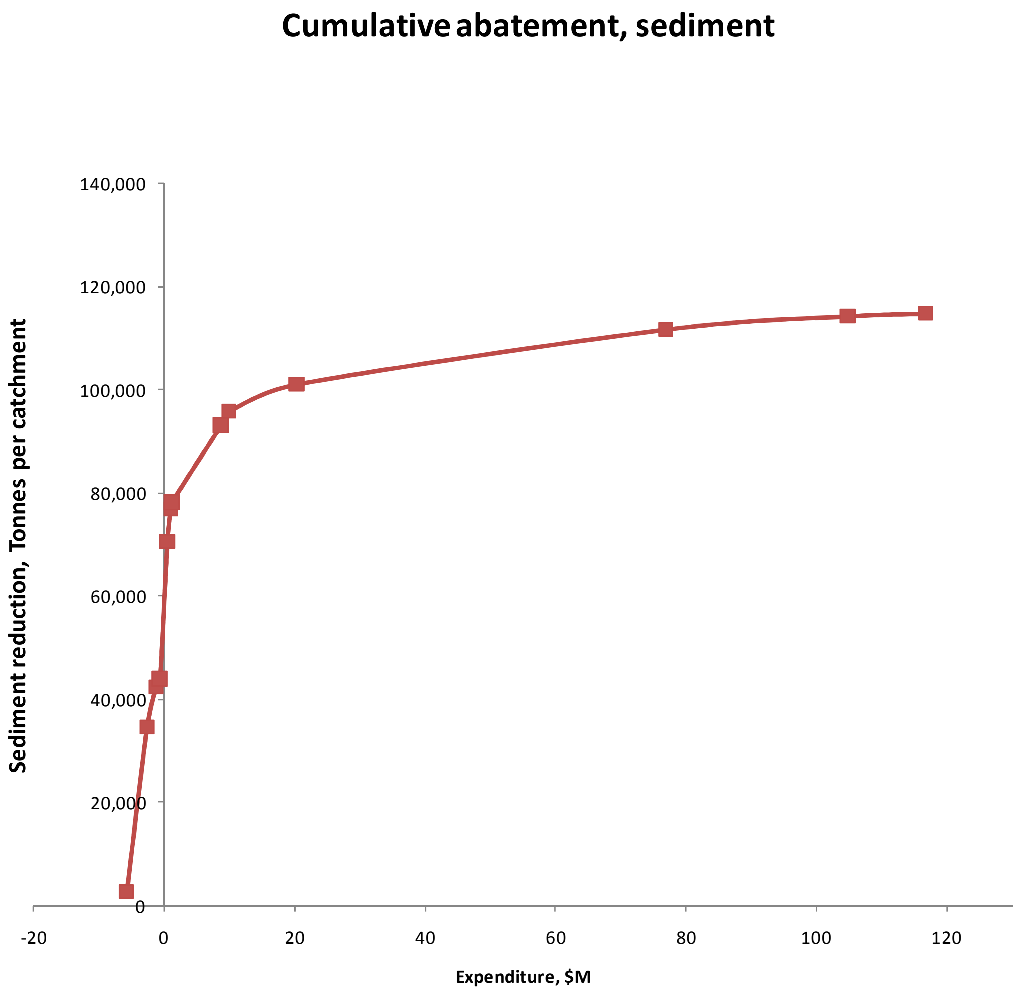

Figure 4: Cumulative sediment abatement curve for farms within the Waikato River catchment.

5.3 Faecal bacteria mitigation

Due to the limited information available and differences in the indicators derived for each model farm, it is difficult to make direct comparisons of cost-effectiveness for *E. coli* mitigation between model farms and actions.

However, for dairy farms the Study team can conclude that:

- Single wire fencing is a very effective and cost-effective approach for reducing *E. coli* losses.
- The improved management of FDE on farms with poorly-drained soils is also a very effective and cost-effective approach for reducing *E. coli* losses.

- The installation of berms on laneways to prevent run-off directly entering streams is also a very cost-effective measure.

For the sheep-beef farms the Study team can conclude that:

- Single wire fencing is a very effective and cost-effective approach for reducing *E. coli* losses.
- Additional riparian protection measures can also help to significantly reduce losses, but at significantly greater expense.

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Appendix A: Financial attributes of the forestry model farm.

Forestry												
Year	**Total**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**26**
Prunned regime												
Costs												
Land rent/ op. cost	**0**											
Land prep costs	**26,000**	26,000										
Planting	**120,000**	120,000										
Releasing	**23,000**	23,000										
Pruning costs 1st prune	**82,500**					82,500						
Pruning costs 2nd prune	**67,500**							67,500				
Pruning costs 3rd prune	**64,000**									64,000		
Thin to waste	**42,000**									42,000		
Annual costs	**260,000**		10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Harvest	**1,404,000**											1,404,000
Transport	**718,200**											718,200
Carbon admin	**0**		0	0	0	0	0	0	0	0	0	
Total costs	**2,807,200**	**169,000**	**10,000**	**10,000**	**10,000**	**92,500**	**10,000**	**77,500**	**10,000**	**116,000**	**10,000**	**2,132,200**
Revenue												
Pruned	**2,030,000**											2,030,000
Unpruned	**2,200,000**											2,200,000
Pulp	**588,000**											588,000
Carbon	**0**		0	0	0	0	0	0	0	0	0	
Land	**0**											
Total revenue	**4,818,000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4,818,000**
Net revenue	**2,010,800**	**-169,000**	**-10,000**	**-10,000**	**-10,000**	**-92,500**	**-10,000**	**-77,500**	**-10,000**	**-116,000**	**-10,000**	**2,685,800**
Gross margin	**$2,010,800**	Or $773	/ha/yr	Stumapge/ha	$26,958		(log revenue at mill/FOB less harvest and transport costs)					