# Appendix 9: Farms

## 1. Introduction

The degraded state of the Waikato River is seen to be a major cause for concern to Maaori (NIWA et al., 2009). Farms in the Waikato catchment are a major source of contaminants to the river. Farm runoff can contain nitrogen (N), phosphorus (P) sediment and faecal micro-organisms which can all have a significant adverse effect on river water quality. 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. Farm profitability.

2. Additional capital requirements for mitigating farm pollutant losses.

3. Nitrogen (N), phosphorus (P), sediment and faecal microorganism losses to water.

## 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.

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 6–10 stock units per hectare (su/ha). While 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 8–13 su/ha. 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 8–14 su/ha. A high proportion of stock is sent to slaughter and replacements are often brought in.

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 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.
[2]Palm kernel expeller.

Financial metrics for the forestry model farm were supplied by Brian Bell of Nimmo-Bell & Company Ltd. These were used to calculate gross margins, from which mitigation costs could be derived (described later).

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 MAF (2009). This information was used to construct a representative model farm that consisted of potatoes (25 ha), onions (19 ha), kiwifruit (5 ha) and sweetcorn (2 ha).

**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 per 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, $/ha/year.
2. N leaching losses to water, kg/N ha/year.
3. P loss to water, kg P/ha/year.
4. Sediment loss to water, kg/ha/year.
5. Losses of the faecal bacteria *Escherichia coli* (*E. coli*) to water, MPN x $10^9$/ha/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 kg 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 un-fenced streams.
- Runoff from tracks and laneways.
- Losses due to mis-management of the farm dairy effluent (FDE) system.

The Overseer® Nutrient Budgeting model (hereafter referred to as *Overseer*) was used to derive estimates of N and P losses from paddocks to water. Inputs from direct deposition of cow excreta into un-fenced streams (56 percent of stream length (Storey, 2010)) were derived using algorithms contained in the BMPToolbox (Monaghan, 2009) and added to the *Overseer* estimates. Runoff 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 mis-management was added, assuming that current accident rates due to negligence and management inaccuracies results in 1 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, 3 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 2 model dairy farms:

1. Overland flow, discharging the equivalent of 8 x $10^9$ or 224 x $10^9$ MPN/ha/year from free- and poorly-drained soils, respectively.
2. Subsurface pipe drainage systems on the poorly-drained soils, discharging 116 x $10^9$ MPN/ha/year.

3. Groundwater seepage to the stream discharging the equivalent of 3 x $10^9$ or 1 x $10^9$ MPN/ha/year from free- and poorly-drained soils, respectively.

4. Direct deposition of cow excreta to streams, potentially depositing the equivalent of 207 x $10^9$ MPN/ha/year.

5. Discharges from 2-pond treatment systems. It was assumed that 20 percent of farms remained on a 2-pond treatment system, potentially discharging the equivalent of 18 x $10^9$ MPN/ha/year.

6. Direct drainage of farm dairy effluent through pipe drainage systems on the poorly-drained soils, potentially discharging 234 x $10^9$ MPN/ha/year.

7. Runoff from tracks and laneways, potentially discharging the equivalent of 12 x $10^9$ or 24 x $10^9$ MPN/ha/year for farms on free- or poorly-drained soils, respectively.

8. Inputs due to accidents or mis-management of the FDE system, potentially discharging the equivalent of 13 x $10^9$ MPN/ha/year.

For modelling the actions described below, it was assumed that action A would remove sources 4, 5 and 6 listed above; the implementation of action 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 $10^9$ MPN/ha/year under dairy farm actions A and B, respectively.

### 3.2 Sheep and beef farms

As for dairy farms, cash operating profit, and N, P and sediment losses to water were estimated for each of the model sheep-beef farms. 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 the expert opinion (Table 3). This expert knowledge and opinion was similarly used to make estimates of N, P and sediment reductions for each mitigation action evaluated (Table 3).

**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] | [i]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 & 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), |

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 N and P losses from paddocks to water. Inputs from direct deposition of sheep excreta into un-fenced streams (61 percent of stream length; 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 N and P loss to calculate total farm losses.

### 3.3 Forestry farm

Production and financial metrics for the forestry model farm were supplied by Brian Bell of Nimmo-Bell and Company Ltd (see Appendix A at the end of this paper). Yields of N and P 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 N and P 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 MAF (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 (m) per ha). 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. Scaling for the model farms in the Waikato River catchment provided the following stream densities that were used for our modelling assessments:

- 35 m/ha for dairy farms.
- 60, 50 and 40 m/ha for class 3, 4 and 5 sheep-beef farms, respectively.
- 60 m/ha 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 N losses and was not assumed to have any major effect on P, 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 |
|---|---|
| Action A | Full stock exclusion from streams using single-wire fencing. |
| | Soil Olsen P levels reduced from 38 to 32 (economic optimum). |
| | Effluent areas enlarged appropriate to effluent K loading rates. |
| | Additional 1 month's effluent pond storage; low application depth. |
| Action B | All action A managements adopted. |
| | Use of nitrification inhibitors (5% pasture production response assumed). |
| | Wetlands installed on 1% of farm area (fencing out of seeps and bogs). |
| | 5 m buffers around all stream reaches, planted in natives. Berms on sections of lanes to direct runoff away from streams. |
| Action C | Base farm change to an organic dairy unit: assumed milksolids premium for organic milk of $1.05/kg MS. Farm inputs of purchased feed and fertiliser N reduced to nil. Profitability assessments relative to base farm made using the comparative study reported by Shadbolt et al., (2009) |
| Action D | All action B managements adopted. |
| | Winter grazing of paddocks for 4 hours only, then herds returned to a herd shelter (capital cost of $1350 per cow) for shelter. |

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 (8 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 |
| | | | | |
| N | Action A | 16 | 17 | 26 |
| | Action B | 62 | 44 | 64 |
| | Action C | 43 | 45 | 43 |
| | Action D | 66 | 50 | 69 |
| | | | | |
| P | 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 and associated costs and contaminant reductions.

| 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.<br>Assumed reductions in N, P, sediment and *E. coli* yields: 7, 10, 30 and 40%, 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.<br>Assumed reductions in N, P, sediment and *E. coli* yields: 10, 15, 55 and 40%, 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 2500/ha (pb2). Total cost = $59/m of stream to fence both sides.<br>Assumed reductions in N, P, sediment and *E. coli* yields: 15, 15, 56 and 60%, 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 2500/ha (pb2). This larger buffer made the riparian area compliant for obtaining a carbon credit ($25 per tonne) at an assumed equivalent carbon accumulation rate of 5 tonnes per hectare per year. Total cost = $108/m of stream to fence both sides. These costings include components for site preparation, weed control and monitoring of plant establishment and survival ($40,000 per equivalent ha).<br>Assumed reductions in N, P, sediment and *E. coli* yields: 40, 65, 65 and 75%, 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, we assumed that future best practice for the forestry industry would be to minimise the disturbance of forest streams by leaving a 5 m un-harvested buffer around each stream. The general principles of this approach have been agreed to by the industry and are in draft document form (National Standards for Forestry). For our model farm stream density of 60 m/ha, this would affect 6 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 3 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 N (10 percent) and P (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 N, P and sediment losses. The assumed management improvements were:

- Nitrogen fertilisation of the potato crop was reduced from 570 to 250 kg N/ha/year. Phosphorus fertilisation of the potato crop was reduced from 55 to 10 kg P/ha/year to make use of the considerable reserves of soil P (Olsen P test of 200 assumed).

- Nitrogen fertilisation of the onion crop was reduced from 156 to 106 kg N/ha/year. Phosphorus fertilisation of the onion crop was reduced from 112 to 45 kg P/ha/year to make use of the considerable reserves of soil P (Olsen P 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; MfE, 2001; EW, 2010).

## 5. Results

The key findings from this modelling assessment are summarised below in terms of mitigation of N and P, 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 N and P mitigation

- Because of the very high N and P fertilisation rates used (and thus consequently high per hectare N and P losses) on the horticulture model farm, improved fertilisation techniques represent the easiest and most cost-effective way of reducing N and P losses in the catchment (although only by a maximum of about 4 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 N, P and faecal bacteria losses from these farms (particularly from the poorly-drained dairy farms).

- Mainly from a N 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 N 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 (5 m 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 N mitigation, costing between $15 and $23 per kg of N 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 N mitigation measure at a whole-catchment level.

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

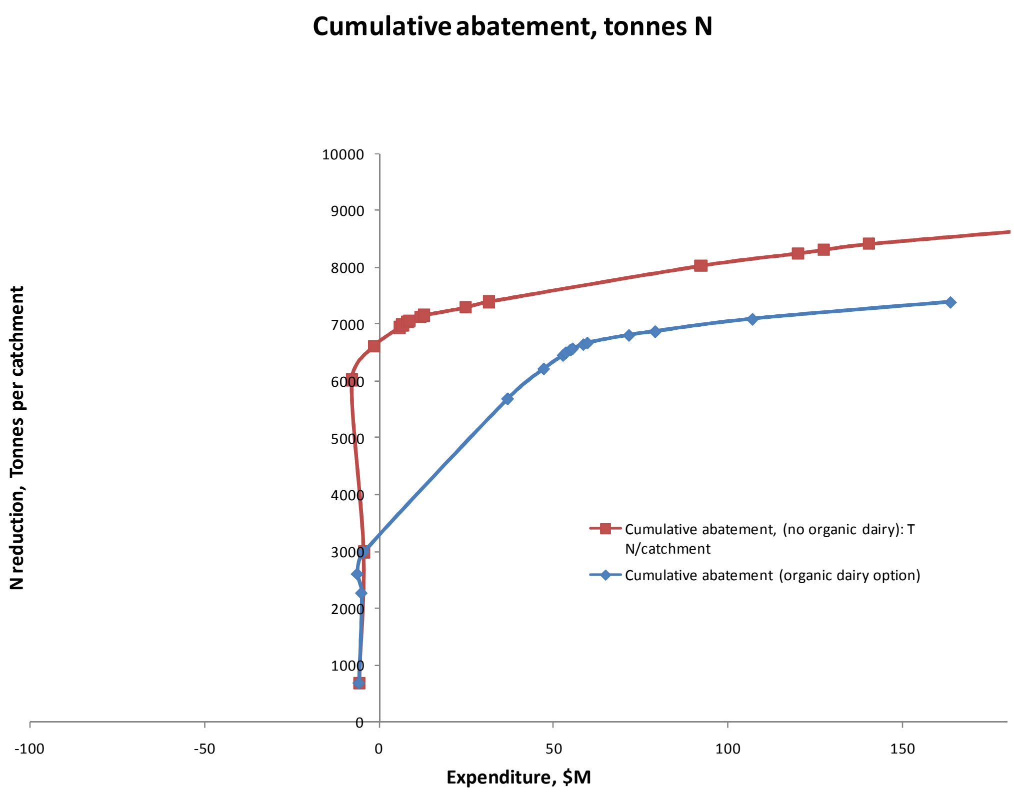


**Figure 1:** Cumulative N abatement curve for 2 management actions for farms within the Waikato River catchment: (a) following a conventional production system for model dairy farms (red line), and (b) following an organic dairy production system (blue line), assuming all dairy action A mitigations 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. We 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).

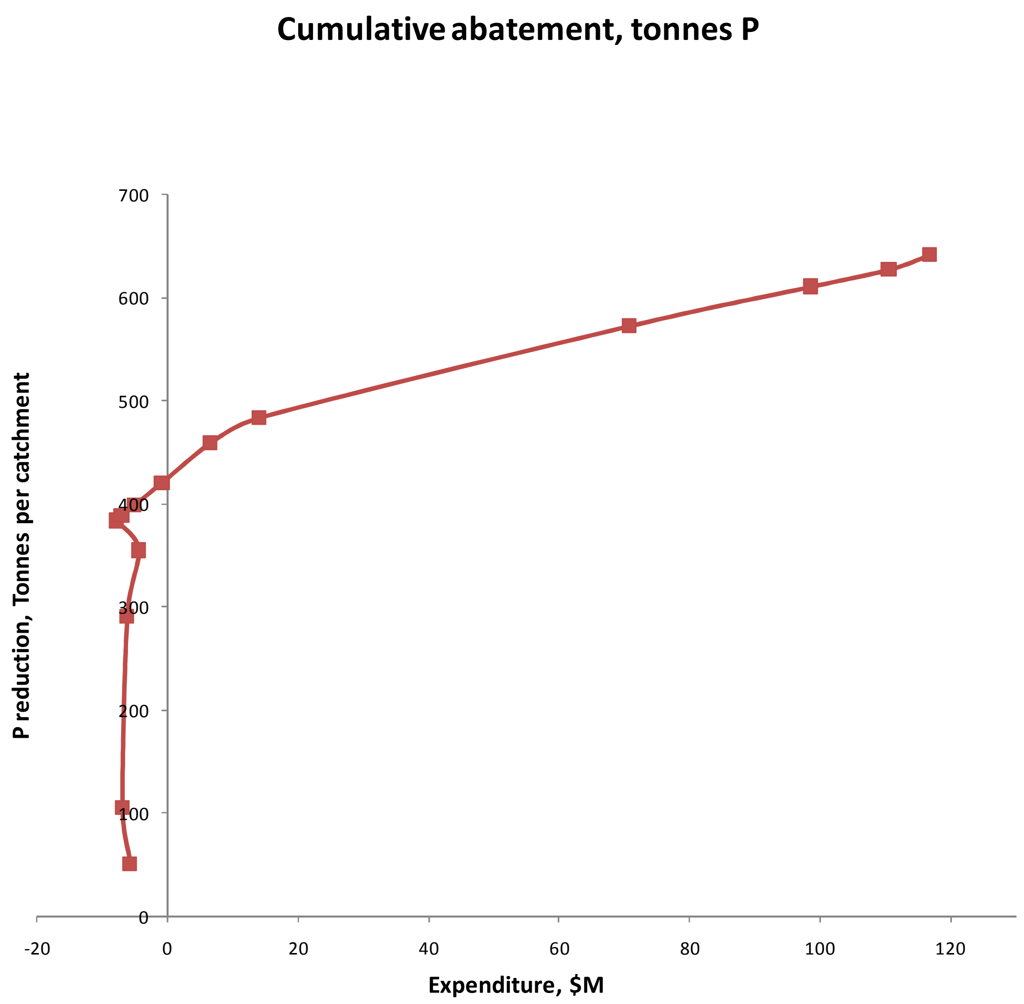


**Figure 2:** Cumulative P abatement curve for farms within the Waikato River catchment.

A consistent finding from the modelling analysis was that action D for the sheep-beef farms was a more cost-effective approach for reducing N, P and sediment losses than action C. This indicates that the wider riparian buffers under action D reduced N, P 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 to $23 per hectare and did little to off-set the large annualised costs attached to action D mitigation (346, 310 and 264 $/ha/year for class 3, 4 and 5 sheep-beef farms, respectively).

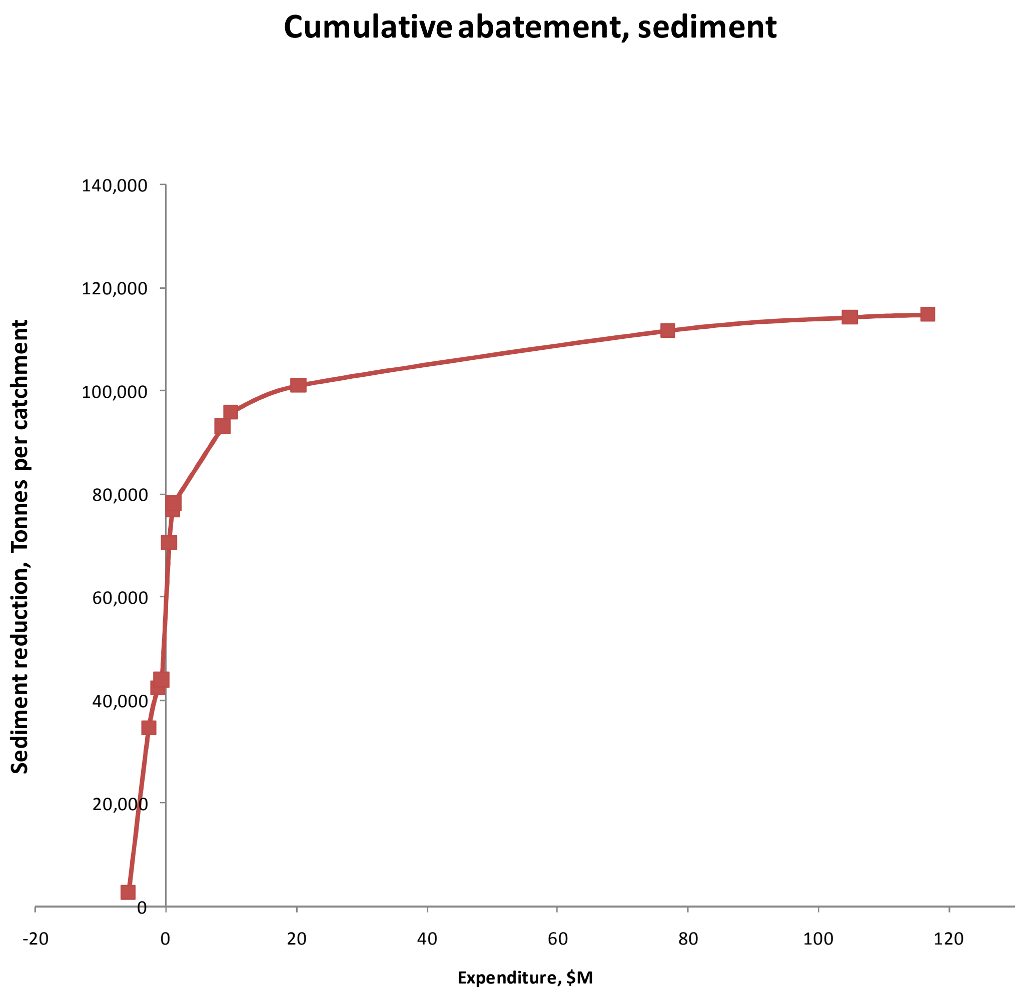


**Figure 3:** Cumulative sediment abatement curve for farms within the Waikato River catchment.

### 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 we 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 runoff directly entering streams is also a very cost-effective measure.

For the sheep-beef farms we 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.

## 6. References

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**Appendix A:** Financial attributes of the forestry model farm**.**

| Forestry<br>Year ending | 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** | **-<br>169,000** | **-10,000** | **-10,000** | **-10,000** | **-92,500** | **-10,000** | **-77,500** | **-10,000** | **-<br>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) | | | | | |

# Appendix 10: Pathogens

**Note:** This appendix should be read in conjunction with Appendix 9: Farms.

## 1. Introduction

The safety of drinking water and water used for contact recreation is of major concern to the community (Rutherford and Williamson, 2010). Drinking water needs to be of sufficient quality that it can be consumed or used without risk of immediate or long term harm. Similarly the water quality in which contact recreation activities occur (swimming, skiing, paddling, kayaking), needs to be such that accidental ingestion of small quantities of the water does not result in illness and that contact with the water does not lead to conditions like skin rashes.

Drinking water is abstracted from the Waikato River, tributaries and groundwater in many places. It must be treated to remove particulate matter (e.g., fine sediment, phytoplankton), and disinfected to inactivate pathogens (bacteria, viruses and protozoa).[1] While river iwi aspire to drink untreated water directly from the Waikato River the Study team does not view this as a likely or realistic option, given this country's high reported rate of zoonoses (Till and McBride, 2004; Rutherford and Williamson, 2010).[2] There is also some evidence of contamination of drinking water sources by viruses shed by humans (Williamson et al., 2010). These could arise either from relatively inefficient upstream community wastewater treatment plants or from on-site wastewater systems.

The combination of high nutrient concentrations (as a result of inputs from farmland and discharges) and long residence times in the hydro lakes results in high phytoplankton biomass and occasional 'blooms' of toxic cyanobacteria (blue-green algae). The associated toxins can affect public water supplies and cause adverse health effects to recreational water users (Rutherford and Williamson, 2010). While routine toxin monitoring has been infeasible, new techniques using 'spat bags' to accumulate cyanobacterial toxins are showing promise (see Appendix 20: Cyanotoxin Treatment).

[1] Pathogens are micro-organisms that cause illness.
[2] New Zealand has a rather high reported zoonoses rate—illnesses caused by pathogens derived from animals (cattle, sheep) that are infectious to humans.

It is often difficult and impractical to measure the level of pathogens in the water directly.[3] Instead, levels of 'indicator bacteria' are measured that provide an indication on the likely pathogenicity of the water, providing a feasible monitoring approach. For freshwaters the indicator micro-organism used is *Escherichia coli* (*E. coli*) which is found in the gut of humans, farm animals and wildlife, and is a useful indicator of faecal pollution and associated health risks.[4] Some diseases—zoonoses—can be caused by microorganisms shed by animals. This can occur by direct animal contact or, more commonly, through contaminated food and water. High *E. coli* concentrations in rivers and lakes, whether of human or animal origin, therefore indicate a risk to public health (Rutherford and Williamson, 2010).

Environment Waikato specifies that for safe contact recreation "the median concentration of *E. coli* of at least seven samples taken throughout the bathing season (1 December to 1 March) in dry weather conditions shall not exceed 126 *E. coli* per 100 millilitres…"[5]

Explicit water-quality standards for drinking-water *sources* do not exist, it being assumed that water treatment systems can provide a sufficient degree of treatment in the supplied water to comply with the New Zealand Drinking Water Standards. The degree of treatment required does therefore require knowledge of the degree of contamination of the source waters.

## 2. Description of action(s)

### On-farm measures

These are described in Table 3 below (for more details see Appendix 9: Farms). There are five options available, the first being to maintain the *status quo* (i.e., do nothing further). Increasing restorative actions are applied from the status quo up to Action C. Action D also includes organic dairy farming being introduced (Monaghan, 2010).

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[3] Nevertheless some direct pathogen monitoring can be desirable, e.g., for human viruses (as reported for the Waikato River at Huntly by Williamson et al., 2010), *Campylobacter* and *Cryptosporidium*.

[4] However, national guidelines recommend that pathogen assays be carried out in situations where human exposure takes place in close proximity to discharges of treated sewage.

[5] http://ew.govt.nz/Policy-and-plans/Regional-Plan/Waikato-Regional-Plan/3-Water-Module/32-Management-of-Water-Resources/324-Implementation-Methods---Water-Management-Classes-and-Standards/.

**Table 1:** On-farm management options for dairy and sheep-beef farms (Monaghan, 2010).

| | Dairy | Sheep-beef |
|---|---|---|
| **Status quo** | Present or base situation. | Present or base situation. |
| **Action A** | Full stock exclusion from streams using single-wire fencing.<br>Soil Olsen P levels reduced from 38 to 32 (economic optimum).<br>Effluent areas enlarged appropriate to effluent K (potassium) loading rates.<br>Additional 1 month's effluent pond storage; low application depth.<br>Nil winter N fertiliser. | Exclusion of cattle from streams using single-wire electric fencing and provision of stock troughs and water supply. |
| **Action B** | All of Action A managements adopted.<br>Use of nitrification inhibitors (5 percent pasture production response assumed).<br>Wetlands installed on 1 percent of farm area (fencing out of seeps and bogs).<br>Berms on sections of lanes to direct runoff away from streams.<br>5 metre buffer on each side of streams, planted with natives. Existing fences relocated to protect the natives. | As per Action A.<br>Wetlands installed on 1 percent of farm area (fencing out of seeps and bogs).<br>Poplar plantings (with sleeves) at 10 m spacings on each side of streams. |
| **Action C** | Base farm change to an organic dairy unit: assumed milksolids premium for organic milk of $1.05/kg MS.<br>Farm inputs of purchased feed and fertiliser N reduced to nil. | Full stock exclusion from stream using an 8-wire post and batten fence, allowing a 5 m buffer planted with natives at 2,500 per ha. |
| **Action D** | All Action C managements adopted.<br>Winter grazing of paddocks for 4 hours only, then herds returned to a herd shelter for shelter. | Full stock exclusion from stream using an 8-wire post and batten fence, allowing a 15 m buffer planted with natives at 2500/ha. This larger buffer made the riparian area compliant for obtaining a carbon credit at an assumed equivalent carbon accumulation rate of 5 tonnes per hectare per year. |

**Table 2:** Faecal loss yields MPN[6] per hectare per year (x10) (Monaghan, 2010) and the percentage reductions in yields for Actions A to D as compared to the status quo. Only percentage reductions were given for sheep and beef (i.e., no actual yields). No data were available for Dairy – Peat soils but because peat soils have the same drainage type as Dairy – Poor drainage (viz. impeded drainage), the reductions calculated for Dairy – Poor drainage were used for Dairy – Peat soils.

| | Dairy – Free draining | Dairy – Peat soils | Dairy – Poor drainage | Sheep and beef - Intensive | Sheep and beef – Hill country |
|---|---|---|---|---|---|
| Status quo | 151 | | 643 | | |
| Action A | 32<br>79% | 45% | 352<br>45% | 40% | 40% |
| Action B | 11<br>93% | 57% | 274<br>57% | 40% | 40% |
| Action C | 32<br>79% | 45% | 352<br>45% | 65% | 65% |
| Action D | 10<br>93% | 57% | 275<br>57% | 75% | 75% |

Table 4 shows the faecal loss yields and percentage reductions for Actions A to D for the various land uses outlined above.

Figure 3 (see the end of this Appendix) shows the median concentrations of *E. coli* in the Study area for 2003−2007 (Unwin et al., 2010).[7] Figures 4, 5, 6 and 7 show median concentrations of *E. coli* in the Study area for Action A to D respectively. These were calculated by using the CLUES package (Catchment Land Use for Environmental Sustainability, Semadeni-Davies et al., 2009). CLUES has been developed as a tool for assessing the effects of land use and land use change on water quality at a minimum scale of sub-catchments (~10 km2 and above). CLUES runs within a GIS platform (ArcGIS) and currently predicts loads, concentrations and yields of two nutrients (nitrogen and phosphorus), sediment loads and yields, and loads of a microbial health risk indicator (*E. coli*). Because CLUES predicts average annual *E. coli* loads - not concentrations - the concentrations in Figures 4 to 7 were obtained by multiplying Unwin et al's. concentrations by the proportional reduction in loads as compared to the Base Farm as predicted by CLUES.

These results, as summarised in Figure 1, show that the biggest gain in terms of a reduction in faecal contamination occurs in moving from a status quo position

6 MPN: Most Probable Number.

7 The figure shows results for whole-of-year measurements, for wet or dry weather.

to Action A. Thereafter gradual improvements are seen with the optimal gain occurring with Action D as expected.

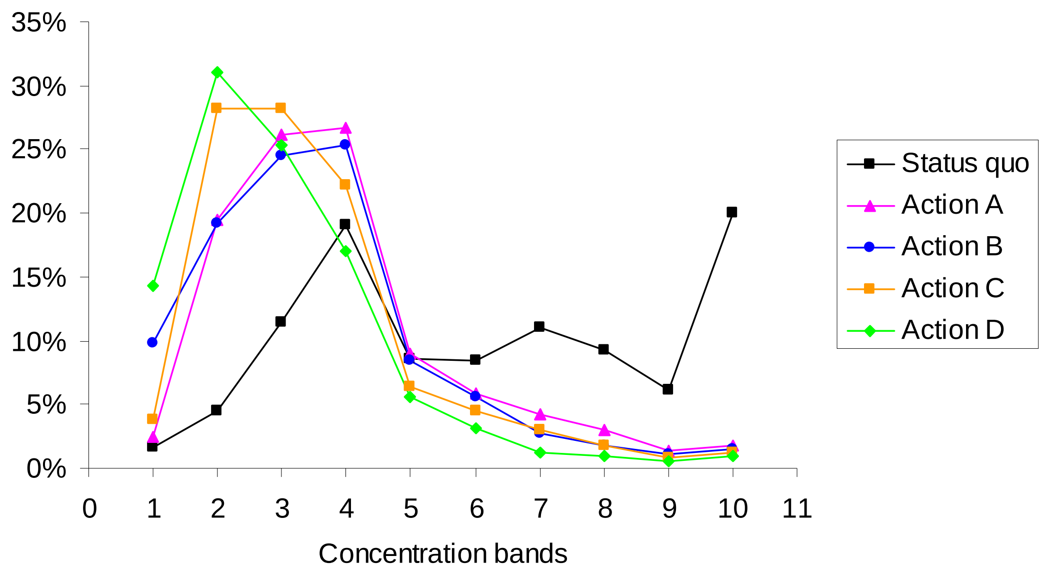


**Figure 1:** The percentage of streams that lie within the various *E. coli* concentration (per 100 millilitres) bands or ranges (see Figures 1 (b) – 5 (b) and Table 2). On the *X*-axis, 1 corresponds to ≤ 55 per 100 millilitres, 2 corresponds to 56 – 126, 3 corresponds to 127 – 200, 4 corresponds to 201 – 300, 5 corresponds to 301 – 350, 6 corresponds to 351 – 400, 7 corresponds to 401 – 450, 8 corresponds to 451 – 500, 9 corresponds to 501 – 550, and 10 corresponds to > 550.

**Table 3:** The percentage of streams in the study area that lie within the various *E. coli* concentration (per 100 millilitres) ranges (see Figures 3 (b) – 7 (b) and 1).

| **Concentration band (*E. coli* per 100 ml)** | **≤ 55** | **56–126** | **127–200** | **201–300** | **301–350** | **351–400** | **401–450** | **451–500** | **501–550** | **> 550** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Status quo** | 2% | 4% | 11% | 19% | 9% | 8% | 11% | 9% | 6% | 20% |
| **Action A** | 3% | 19% | 26% | 27% | 9% | 6% | 4% | 3% | 1% | 2% |
| **Action B** | 10% | 19% | 24% | 25% | 8% | 6% | 3% | 2% | 1% | 2% |
| **Action C** | 4% | 28% | 28% | 22% | 6% | 5% | 3% | 2% | 1% | 1% |
| **Action D** | 14% | 31% | 25% | 17% | 6% | 3% | 1% | 1% | 1% | 1% |

**On-site wastewater system measures**

More regular cleaning of septic tanks would also ensure better effluent quality for a proportion (40 percent) of the existing systems that clean less frequently. For the unknown number of systems that are sited poorly, remedial actions could include installation of outlet filters and disinfection devices, or replacement by a more sophisticated system.

## 3. How will the action(s) be done?

All of the on-farm mitigation measures evaluated require action at the farm scale. Farm-specific management plans would be required to ensure that actions are compatible with the current farm system (soils, management systems) and tailored to the goals of each land owner/manager. Many of the mitigation measures evaluated can be considered industry 'good practice' (e.g., Dairy industry targets set within the Clean Streams Accord). Generally speaking, many of these measures involve minimal or no cost and some even incur a net benefit. Continued or increased industry, regulatory and peer pressures to ensure these measures are fully adopted may deliver considerable benefits in a relatively short space of time. Other measures that incur greater cost, and target farming systems that are less profitable, will be more difficult to implement e.g., full stock exclusion on the more extensive sheep-beef farms.

## 4. Where in the catchment will the actions occur?

On-farm actions have been simulated using the CLUES model by applying Actions A to D in terms of percentage reductions in *E. coli* yields (*E. coli* yields were equated with faecal yields in Table 2) to current land uses for dairy, sheep and beef.

Mitigation zones (see Figure 2) were obtained using the CLUES model as follows. Soils in the study area have been split into three drainage types (free drainage, impeded drainage and not classified − see Figure 3) obtained from the New Zealand Land Resource Inventory (LRI).[8] The dairy land use type in CLUES was then split into the three categories (free draining, poor draining and peat soils see Appendix 9: Farms) using the spatial location of the soil types shown in Figure 2. This was done as follows (see Figure 2):

- Land use that was 'dairy' in CLUES, classified as 'free drainage' by the LRI and categorised as 'free draining' in Monaghan, 2010 (see Appendix 9: Farms) was designated 'Diary − Free draining' in the model.
- Land use that was 'dairy' in CLUES, classified as 'impeded drainage' by the LRI and categorised as 'peat soils' in Monaghan (2010) (see Appendix 9: Farms) was designated 'Diary – Peat soils' in the model.

[8] http://www.landcareresearch.co.nz/databases/lris.asp

- Land use that was ‘dairy’ in CLUES, classified as ‘impeded drainage’ by the LRI and categorised as ‘poor draining’ in Monaghan (2010) (see Appendix 9: Farms) was designated ‘Dairy – Poor drainage’ in the model.

Sheep and beef farms were also categorised into three categories by Monaghan (2010) based on Meat and Wool New Zealand Limited’s classifications (MWNZ, 2010). These categories were steep hill country, easy hill country and easy rolling country (see Appendix 9: Farms). The CLUES model also has three types of sheep and beef farms, namely high country, hill country and low land intensive. In the model (see Figure 2):

- Land use that was ‘low land intensive’ in CLUES and categorised as ‘easy rolling country’ in Monaghan (2010) (see Appendix 9: Farms) was designated ‘Sheep and beef – intensive’.
- Land use that was ‘hill country’ in CLUES and categorised as ‘easy hill country’ in Monaghan (2010) (see Appendix 9: Farms) was designated ‘Sheep and beef – hill country’.
- Land use that was ‘high country’ in CLUES and categorised as ‘steep hill country’ in Monaghan (2010) (see Appendix 9: Farms) was designated ‘Sheep and beef – high country’. According to CLUES, there was no ‘high country’ in the Study area hence ‘Sheep and beef – high country’ not being shown in Figure 2.

Horticulture and forestry have not been considered in this analysis as their faecal contribution is minimal.

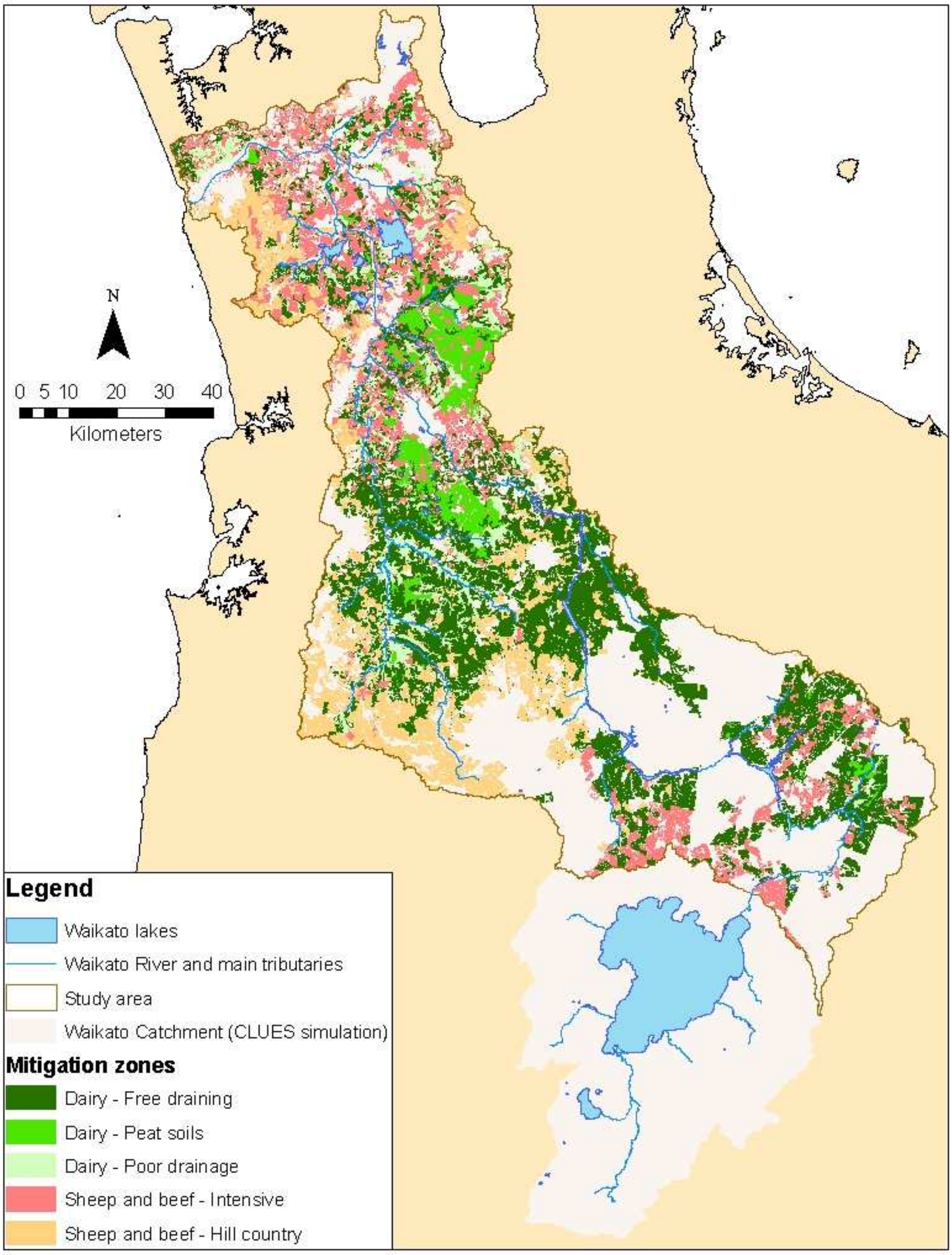


**Figure 2:** The mitigation zones in the model as generated within CLUES.

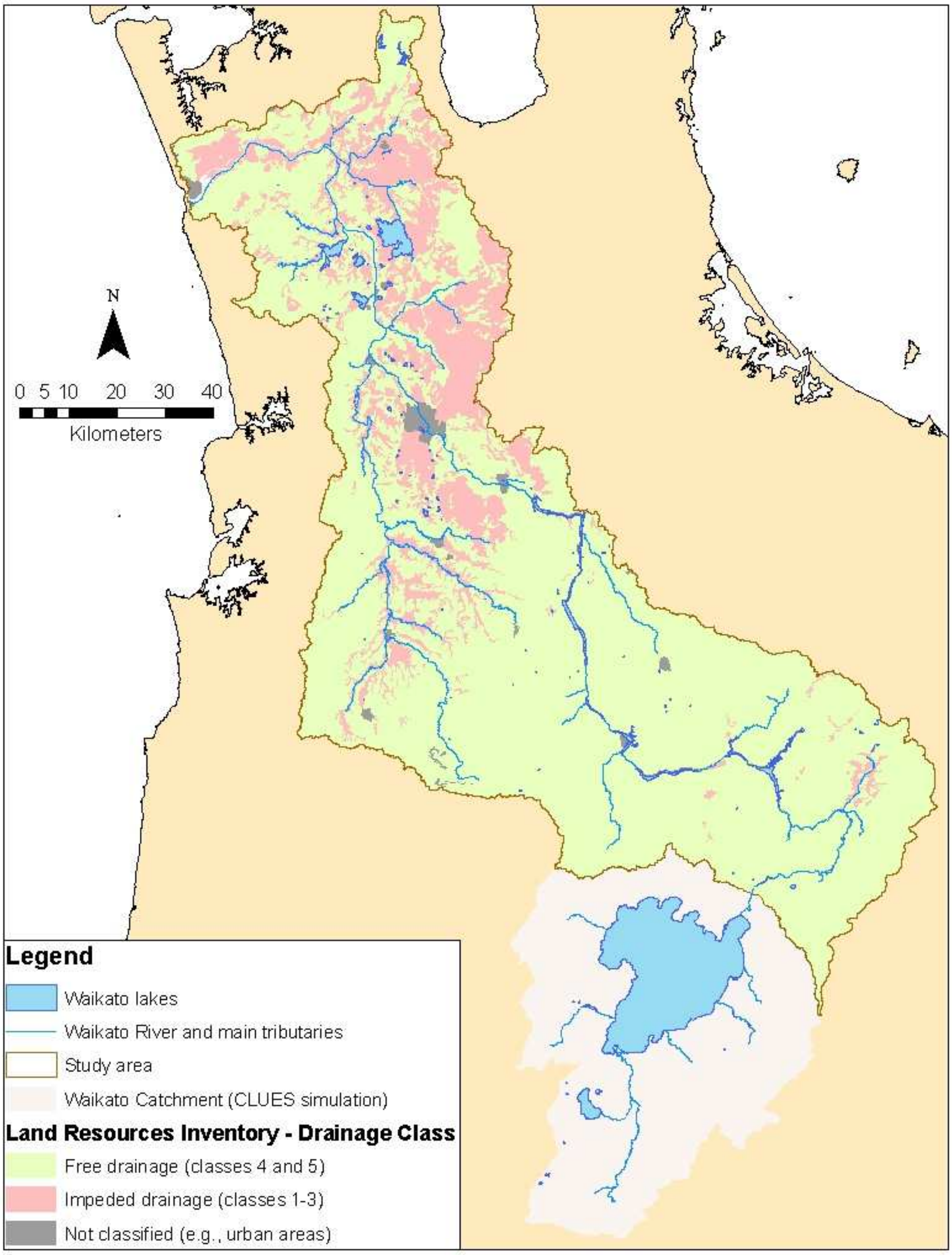


**Figure 3:** The New Zealand Land Resource Inventory drainage classes for the study area as generated within CLUES. CLUES simulates the whole of the Waikato River – from its source (Lake Taupoo) to the mouth (Te Puuaha Waikato). Therefore CLUES models not only the Study area but also the area designated 'Waikato Catchment (CLUES simulation)' in the figure.

## 5. What is the cost?

On-farm costs are given in Table 4 on the next page.

**Table 4:** The approximate costs of proposed on-farm actions within the Waikato River catchment[9].

| Farm type | Action | Capital cost, $/ha | Annualised cost, $/ha/year |
|---|---|---|---|
| Dairy[1] | Single-wire fence | 47 | 5 |
| | Enlarged effluent ponds | 83–123 | 7–10 |
| | Fencing out wetlands | 68 | 22 |
| | Laneway berms | 10 | 2 |
| | Herd shelter | 3,400 | 136–270 |
| | Change to organic dairy | Minor | 184 |
| | Planting 5 m riparian buffers | 686 | 80 |
| Sheep-beef[2] | Single-wire fence | 146–220 | 12–18 |
| | Single-wire fence & poplars | 200–301 | 16–24 |
| | 8-wire fence and natives, 5 m buffer | 1,427–2,141 | 123–177 |
| | 8-wire fence and natives, 15 m buffer | 2,799–4,198 | 264–346 |

[1]Varies between model farm types depending on soil type.
[2]Varies between model farm types depending on assumed stream density.

The Proposed National Environmental Standard for On-site Wastewater Systems Discussion Document (MfE, 2008) proposed regulating their management with a warrant of fitness approach, as a method of reducing failures from the operation of the tanks. This approach however, ignores the vital role of correct design and installation of on-site systems. The cost over the next 30 years of increased cleaning of septic tanks, so that all are cleaned every 2–3 years is estimated as $18.9 million. Average annual total costs of inspection of at-risk systems, compliance and administration range from $3.4 million to $5.2 million over 20 years. Total estimated costs range from $31.9 million to $48.9 million (COVEC, 2007).[10]

[9] See Appendix 9: Farms.
[10] This estimate is that for 'Option 2' in a proposed National Environmental Standard for On-site Wastewater Treatment Systems (http://www.mfe.govt.nz/publications/rma/nes-proposed-onsite-wastewater-systems-2009/html/).

## 6. Who could do it and how long would it take?

Primarily the on-farm mitigation actions need to come from the farmers themselves. River iwi and other interested parties may also wish to help with riparian fencing and planting. The length of time for the mitigation measures to be fully implemented depends on the willingness of farmers to cooperate and their financial ability to do so. If the premium for organic milk were to increase markedly then this would be a good incentive for dairy farmers to convert to the organic farming scenario (Action D), although this change may not have much effect on pathogens in water draining the land.

Ensuring correct design and installation of on-site wastewater systems could be achieved by developing policies consistent with the principles of AS/NZS1547 (AS/NZS 2000) and the proposed manual for wastewater treatment by ARC (ARC, 2004). Performance of on-site wastewater treatment systems could be assessed by trained inspectors and contractors.

## 7. What are the interactions with other activities (co-benefits, draw-backs)

The various actions proposed for the different farm types would reduce the leaching of nutrients such as nitrogen and phosphorus from the farms and therefore could be expected to reduce the magnitude and frequency of cyanobacteria blooms producing toxins. Similarly riparian planting and fencing would help prevent land erosion and therefore reduce the deposition of sediment into the streams.

## 8. Uncertainties and information gaps

- Predicting catchment-wide *E. coli* concentrations from predicted average annual *E. coli* loads. This is currently performed using a rather crude approximation, which is the best available technique at present.
- The possibility that a reduction in *E. coli* concentrations from farming operations may lead to a *greater* reduction in pathogens[11].
- The extent to which failing on-site wastewater systems contribute to viral contamination of drinking water sources and recreational water.
- The costs of replacement of failing on-site wastewater treatment systems by more sophisticated upgrades are unknown at this time.

[11] Some work suggests that reducing farm contamination will reduce not only pathogen concentrations but also pathogen prevalence (McBride and Chapra, in prep.).

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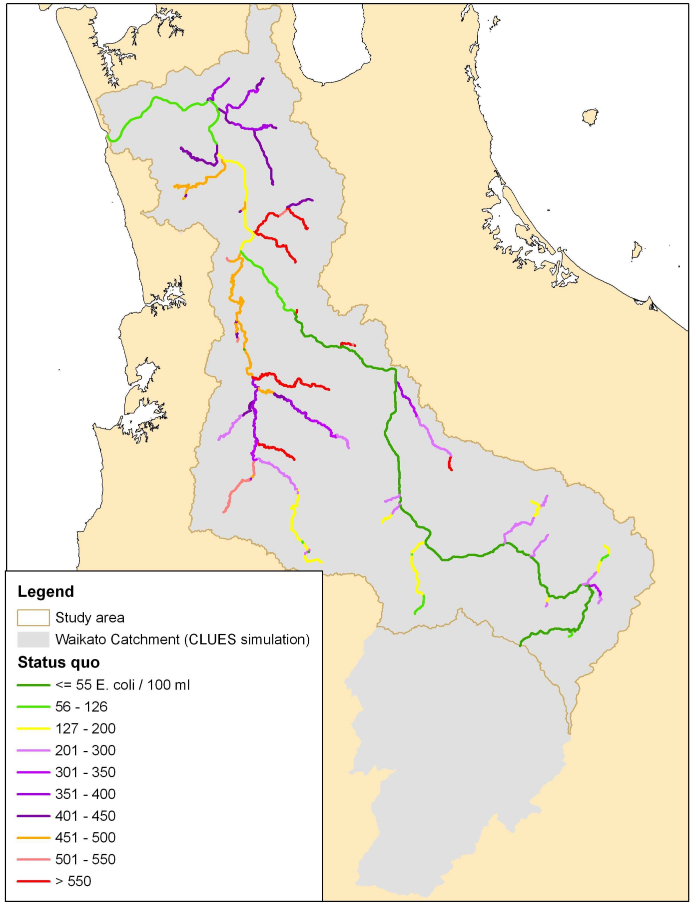
(a)

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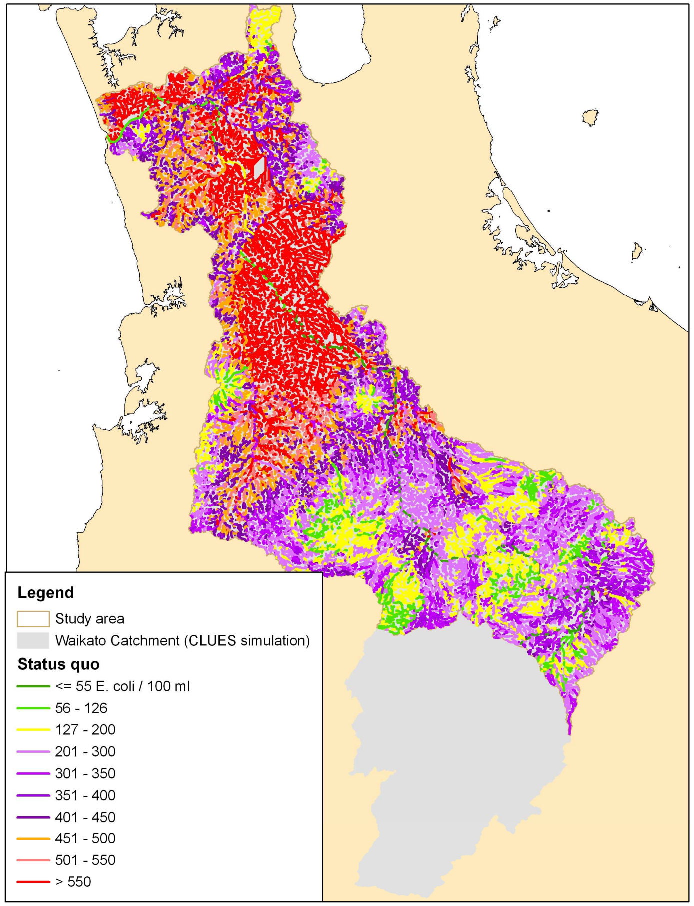



**Figure 4:** Maps generated within the CLUES (v3.0.0) model showing median *E. coli* concentrations (per 100 millilitres) for the Base Farm in: **(a)** the main rivers of the study area; **(b)** all the streams of the study area.

(a) (b)

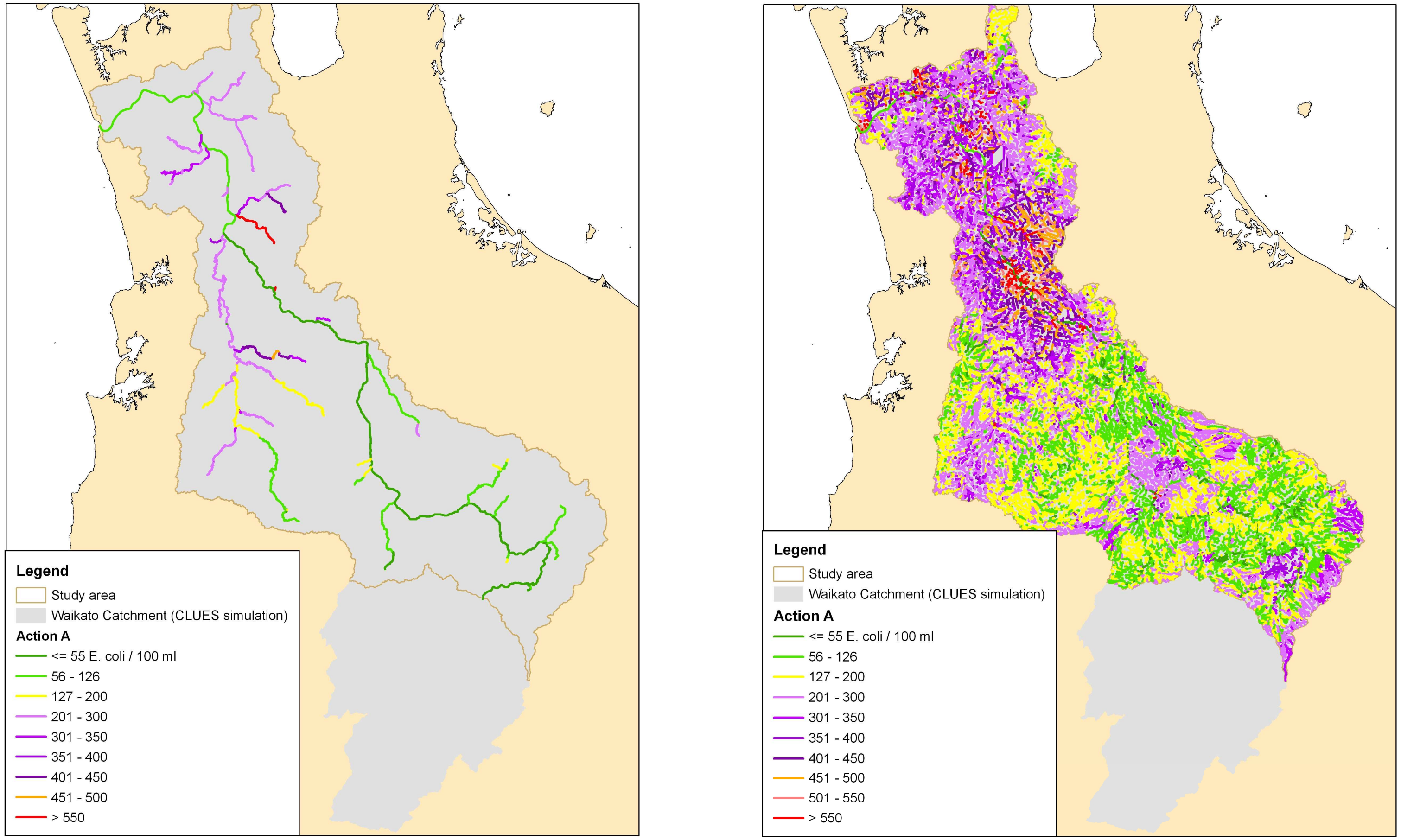
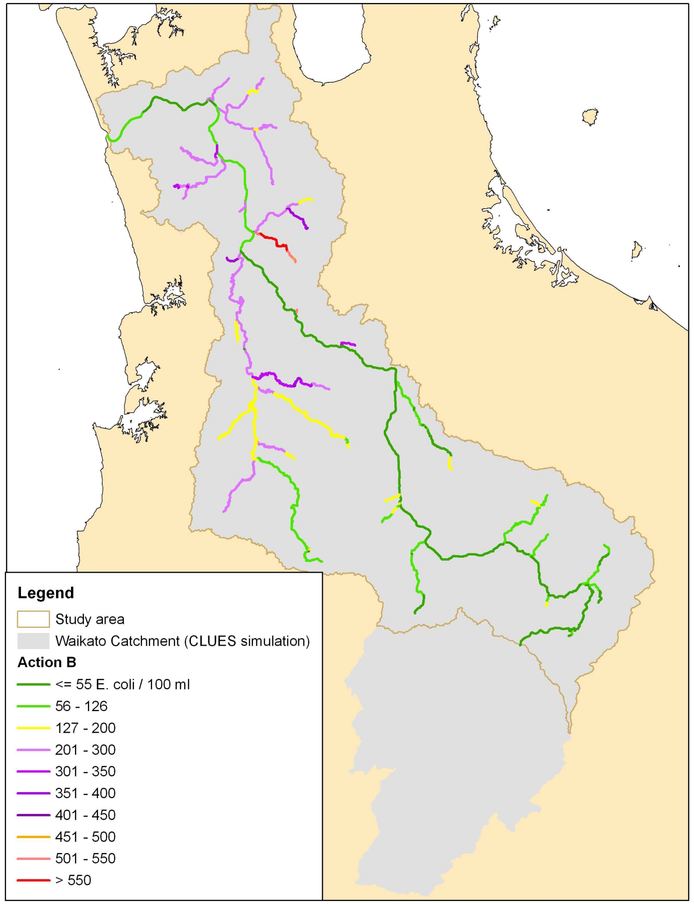



**Figure 5:** Maps generated within the CLUES (v3.0.0) model showing median *E. coli* concentrations (per 100 millilitres) for Current Best Practice in: **(a)** the main rivers of the study area; **(b)** all the streams of the study area.

(a)

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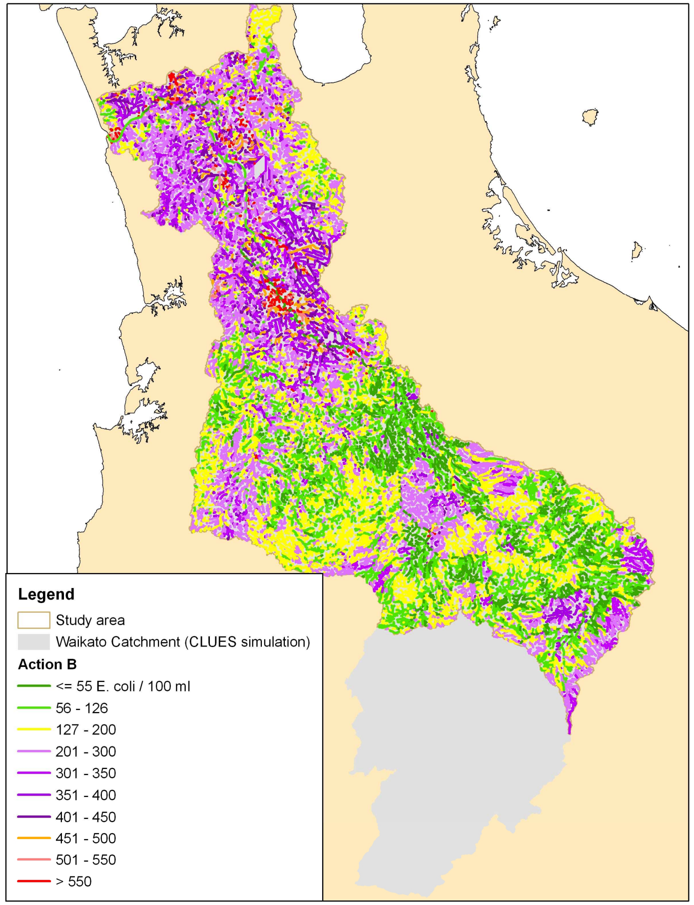



**Figure 6:** Maps generated within the CLUES (v3.0.0) model showing median *E. coli* concentrations (per 100 millilitres) for Future Best Practice 1 in: **(a)** the main rivers of the study area; **(b)** all the streams of the study area.

(a) (b)

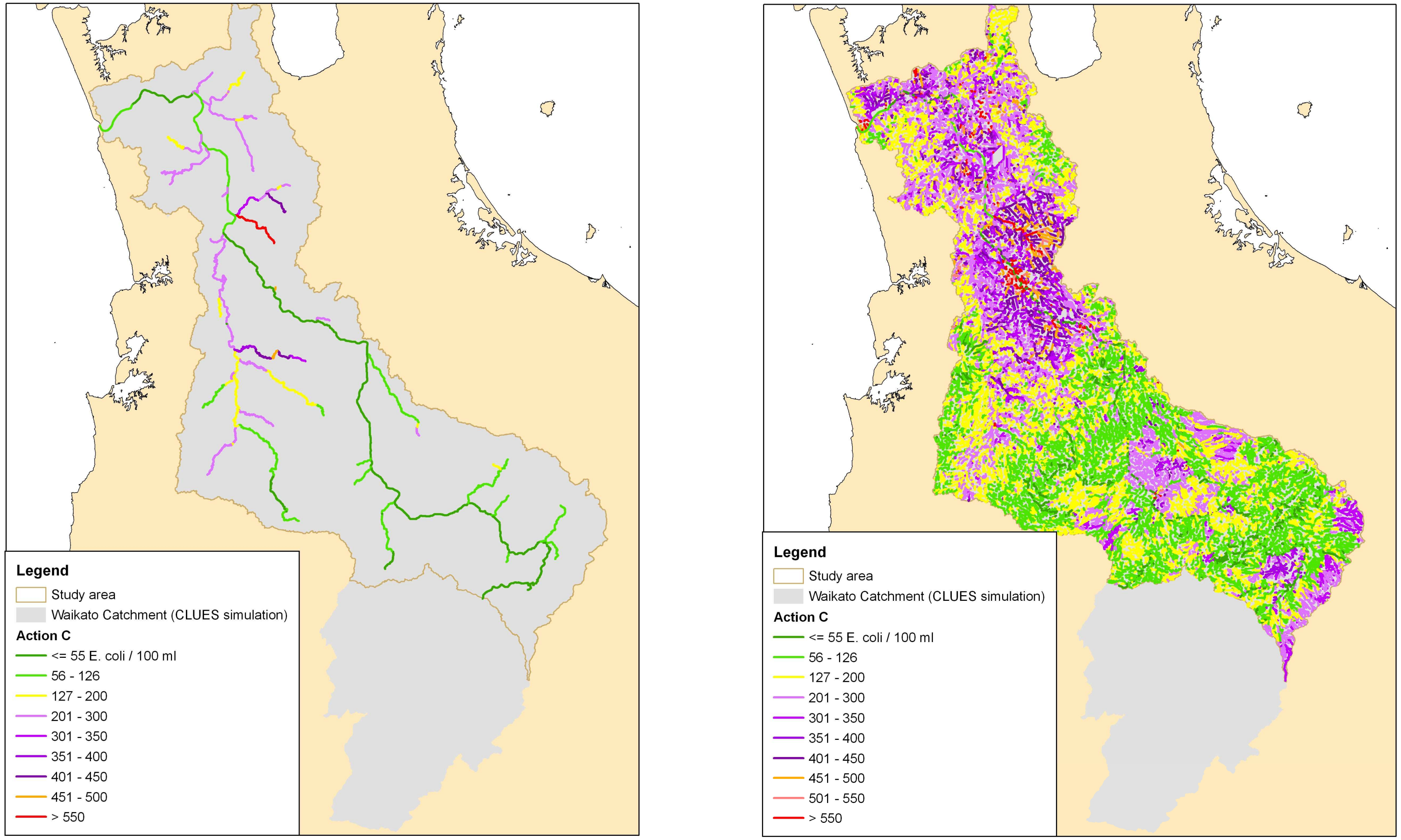



**Figure 7:** Maps generated within the CLUES (v3.0.0) model showing median *E. coli* concentrations (per 100 millilitres) for Future Best Practice 2 in: **(a)** the main rivers of the study area; **(b)** all the streams of the study area.

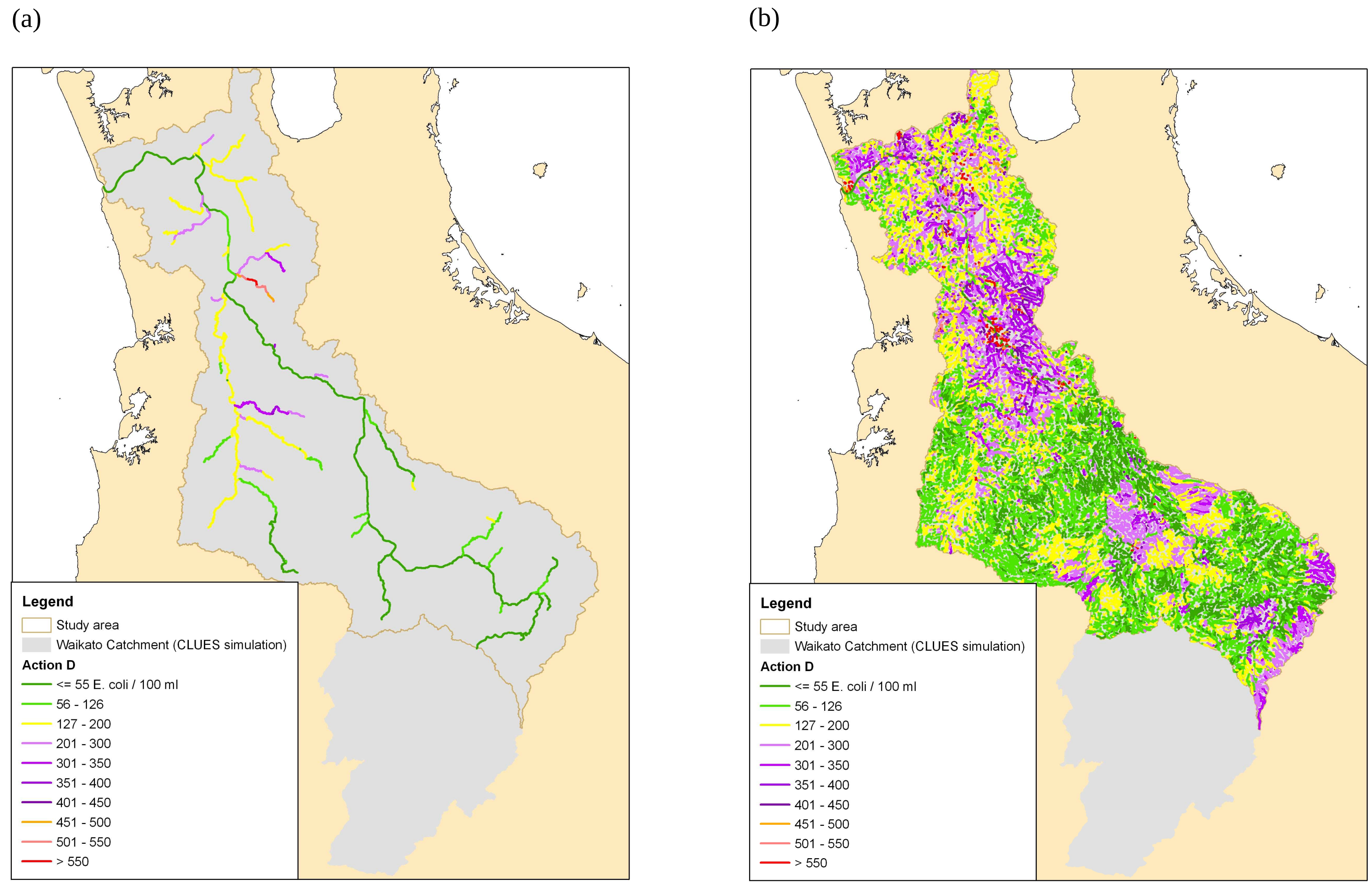



**Figure 8:** Maps generated within the CLUES (v3.0.0) model showing median *E. coli* concentrations (per 100 millilitres) for Future Best Practice 3 in: **(a)** the main rivers of the study area; **(b)** all the streams of the study area.

# Appendix 11: Riparian Aesthetics

## 1. Introduction

The high level vision of the Guardians Establishment Committee (GEC) for the Waikato River is:

*Tooku awa koiora me oona pikonga he kura tangihia o te maataamuri”*

*“The river of life, each curve more beautiful than the last”*

This highlights the importance of restoring the aesthetics of the river. Comments made during hui (NIWA et al., 2009) also emphasised the importance to Maaori of the aesthetics of the mainstem of the Waikato between the Taupoo outlet and the sea. Several factors combine to determine river aesthetics, including landscape setting, riparian vegetation, water colour and clarity, channel character and flow types, visual diversity, the knowledge that the river is in a healthy state (Mosley, 2004). However riparian vegetation is arguably one of the largest, manageable, influences on river aesthetics.

The Riparian Management Classification (RMC) (Quinn, 2009) includes rating systems for riparian influences on stream recreational and aesthetic values (Tables 1 and 2). The influences of riparian vegetation on **recreation** are generally more important along medium-large streams (the opposite to influences of diffuse contaminant inputs, that are greatest in low order streams) with access to safe swimming, fishing and boating spots, and in areas of high human access, such as urban streams and reserves. Overhanging willows and large wood can be hazardous for boating, whereas native planting plays a particularly important role in enhancing recreational use. Walkways, picnicking facilities (tables and seating), weed control (especially blackberry and other invasives) and vehicle parking areas are all important for enhancing recreational use. Angling use requires particular attention to riparian planting design to provide both overhanging cover and low vegetation to allow casting when fly-fishing. Poorly managed riparian areas that are overgrown by weeds, such as blackberry, detract from aesthetics (Parkyn and Quinn, 2006) and recreational use, through influences on access, and navigability and fishability.

**Table 1:** The RMC rating guide for enhancing recreational use of stream/riparian area.

| | |
|---|---|
| 0 | Riparian area covered in blackberry and other invasive weeds making stream edge inaccessible and downstream passage in canoes hazardous. |
| 1 | Minimal natural vegetation cover along small streams (e.g., <3 m wide channels) that are relatively inaccessible and not used for angling, swimming or boating on for walking areas (e.g., headwaters on farmland). |
| 2 | Native vegetation along small streams that are not used for angling or boating on relatively inaccessible areas such as headwaters on farmland away; or monocultures of exotic vegetation along streams and rivers used for fishing, boating, swimming or walking. |
| 3 | Varied exotic vegetation or patchy native vegetation along streams and rivers used for fishing, boating, swimming or walking. |
| 4 | Mix of native and exotic forest/wetland vegetation continuous along streams and rivers used for fishing, boating, swimming or walking. |
| 5 | Native forest along streams and rivers used for fishing, boating, swimming or walking. |

Riparian management can enhance landscape **aesthetics** substantially by providing vegetation diversity with ribbons of green within developed pastoral and urban landscapes (Mosley, 1989; Mosley, 2004). Shrubs and trees have generally greater aesthetic appeal than pasture grass, and native vegetation has more appeal than exotic vegetation (Table 2). However, aesthetics are landscape dependent (e.g., tussocks may be more aesthetically desirable than trees in inland Canterbury high country streams) and vary amongst individuals.

**Table 2:** RMC rating guide for enhancing stream aesthetics.

| | |
|---|---|
| 0 | Bare ground or covered in blackberry and other invasive weeds. |
| 1 | Pasture with unconstrained livestock access to the stream, no trees. |
| 2 | Fenced pasture grasses without livestock access to the stream; or pasture with livestock access and a 1–2 types of exotic trees (e.g., willows and/or poplars). |
| 3 | Varied exotic dominated vegetation, limited livestock access. |
| 4 | Native shrubs or wetland is dominant vegetation type. |
| 5 | Native forest is dominant vegetation. |

This Appendix reviews the current state of riparian vegetation in Waikato pasture streams and the costs and aesthetic benefits of applying riparian management. It draws on the Riparian Management Classification (RMC; Quinn, 2009) to define goals and uses available information in GIS databases and from stream surveys conducted by Environment Waikato (EW) in 2007 (Storey, 2010).

# 2. Methods

## 2.1 Assessing aesthetic condition of Waikato pastoral streams

To provide an initial assessment of the current state and restoration potential for the Waikato River catchment streams the RMC rating systems above were applied to information from Environment Waikato's 2007 survey of riparian characteristics along 1 km long reaches at 310 sites (91 on dairy farms and 211 on drystock farms) first to sixth order streams[1] in pastoral land throughout the Waikato (Storey, 2010). These surveys did not include the mainstem of the Waikato (7$^{th}$ order). In this analysis the data were examined for the following zones of the river:

- Lower Waikato - downstream of Ngaaruawaahia (32 km surveyed).
- Middle Waikato - from Ngaaruaawahia to Karaapiro Dam (10 km surveyed).
- Upper Waikato - from Karaapiro to Taupoo outlet (62 km surveyed).
- Waipa - (70 km surveyed).

The categorisation of riparian vegetation type used in the 2007 EW survey (Table 3) does not correspond directly with that in the RMC ratings (Table 2), but nevertheless provides the basis for a preliminary assessment of current aesthetic condition.

Percentage riparian vegetation cover data from the EW 2007 survey were converted to stream lengths by scaling using the REC (the NIWA River Environment Classification) stream length and the proportion of pastoral land cover from CLUES (a GIS-based land use effects catchment model; Semadeni-Davies et al., 2009).

[1] Stream order is used to describe the size of a stream or river. Smallest streams are referred to as 'first order'. A 'second order' stream is formed at the junction of two first order streams, and a 'third order' stream is formed by the junction of two second order streams, etc.

**Table 3:** Description of categories in several parameters used in the EW 2007 riparian survey (Storey, 2010) and RMC aesthetic scores (in brackets) assigned (after Quinn, 2009, see Table 2).

| Parameter | EW Category (RMC score assigned) | Description |
|---|---|---|
| Vegetation type | Woody native (4.5) | Predominance of native trees/shrubs. |
| | Woody willow (2) | Predominance of willow species. |
| | Woody exotic (3) | Predominance of exotic (non-native) tree and shrub species. |
| | Pastoral grass (1) | Consisting of low (<1m) grass and/or weed species. |
| | Native grasses (4.5) | Consisting of native grass species. |
| Vegetation structure | Forest | Tall dense vegetation, trees close together. |
| | Treeland | >3m high, widely spaced trees with grass in between. |
| | Scrub | Low stature vegetation (<3m) and close together. |
| | Shrubland | Low stature (<3m), widely spaced, grass in between. |
| | Grasses | Grass including small, low lying weeds <1m in height. |
| | Wetland | Raupoo/sedges. |

## 2.2 Assessing aesthetic condition of mainstems of the Waikato and Waipa Rivers

In the absence of available detailed survey data on the riparian vegetation along the Waikato mainstem (i.e., Taupoo to Port Waikato), the New Zealand Land Cover Database 2 (LCDB2; 15 m grid resolution, developed from satelite images in 2001) was evaluated to provide an initial categorisation of the vegetation layer in 15 m wide bands on either side of the 7$^{th}$ order mainstem of the Waikato River and along the 6$^{th}$ order mainstem of the Waipa between Otorohanga and Ngaaruawaahia. Within this band the LCDB2 vegetation types were categorised and summed for each of the Waikato River subregions.

## 2.3 Costings used in cost abatement calculations

Costs of riparian fencing, plants, planting and maintenance for a range of restoration actions were calculated as per Table 4.

**Table 4:** Costs used in cost abatement calculations.

| Action | Description of action | Costs | Comments |
|---|---|---|---|
| A | 5 m wide native revegetation buffer for **dry stock** farm streams currently having grass riparian vegetation | **$58,500**/km for post and batten fences ($18/m = $36k/km stream) + 8 troughs ($250 ea) per km stream + native PB2 grade plants @ 2500 stems/ha ($5 planted) + maintenance to year 3 ($8k/ha) | Minimum width buffers for aesthetics requiring more ongoing vegetation maintenance and weeding than 10 m wide buffers. Post and batten fences needed to exclude sheep |
| B | 5 m wide native revegetation buffer for **dairy** farm streams currently having grass riparian vegetation | **$32,500**/km for 3 wire electric fences ($5/m = $10k/km stream) + 8 troughs ($250 ea) per km stream + native PB2 grade plants @ 2500 stems/ha ($5 planted) + maintenance to year 3 ($8k/ha) | Minimum width buffers for aesthetics requiring more ongoing vegetation maintenance and weeding than 10 m wide buffers. Electric fences needed to exclude cows |
| C | 10 m wide native revegetation buffer for **dry stock** farm streams currently having grass riparian vegetation | **$79,000**/km for post and batten fences ($18/m = $36k/km stream) + 8 troughs ($250 ea) per km stream + native PB2 grade plants @ 2500 stems/ha ($5 planted) + maintenance to year 3 ($8k/ha) | Optimal compromise width buffers for aesthetics. Post and batten fences needed to exclude sheep. Wider buffers particularly beneficial on larger streams. |
| D | 10 m wide native revegetation buffer for **dairy** farm streams currently having grass riparian vegetation | **$53,000**/km for 3 wire electric fences ($5/m = $10k/km stream) + 8 troughs ($250 ea) per km stream + native PB2 grade plants @ 2500 stems/ha ($5 planted) + maintenance to year 3 ($8k/ha) | Optimal compromise width buffers for aesthetics. Electric fences needed to exclude cows. Wider buffers particularly beneficial on larger streams. |
| E | **Willow removal** then fencing and native revegetation as above | Appropriate options above **+ $14,000/km** along 1st-2$^{nd}$ order streams **or + $24,000/km** along ≥3$^{rd}$ order streams | Willow removal is cheaper per km along small streams where machinery can operate from one bank (estimates pers. comm. Bruce Peploe EW) |

# 3. Results and discussion

## 3.1 Stream riparian vegetation cover

The results of the EW survey of streams in pastoral areas are summaried by major subcatchments in Figure 1. Native grasses and native woody vegetation occupied on average 3.4 percent and 8.5 percent, respectively, of pastoral stream length (Figure 1A). This indicates that approximately 12 percent of stream length would have RMC aesthetic ratings of 4 or 5 out of 5 (Table 2, Figures 2 and 3). Pasture grass was dominant (54 percent; RMC aesthetic ratings of 1 out of 5) and exotic woody vegetation (33 percent, RMC aesthetic ratings of 2–3 out of 5) subdominant (Figure 1A).

Forest and wetland vegetation covered about 8 percent of the pastoral stream length on average, but varied from 3 percent in the Lower Waikato to 13 percent in the Middle Waikato (Figure 1B). Woody vegetation (including willows) cover averaged 42 percent of the streambank (Figure 1A) but varied from 23 percent in the Lower Waikato to 57 percent in the Upper Waikato (Figure 3). Woody vegetation also tended to increase with stream order (Storey, 2010).

The actual river lengths by vegetation type are shown in Figure 2 for each of the four Waikato zones. This provides an estimate of about 6,000 km of stream (about 12,000 km of streambank) that is currently in pasture that could potentially be revegetation in native vegetation to enhance stream aesthetics.

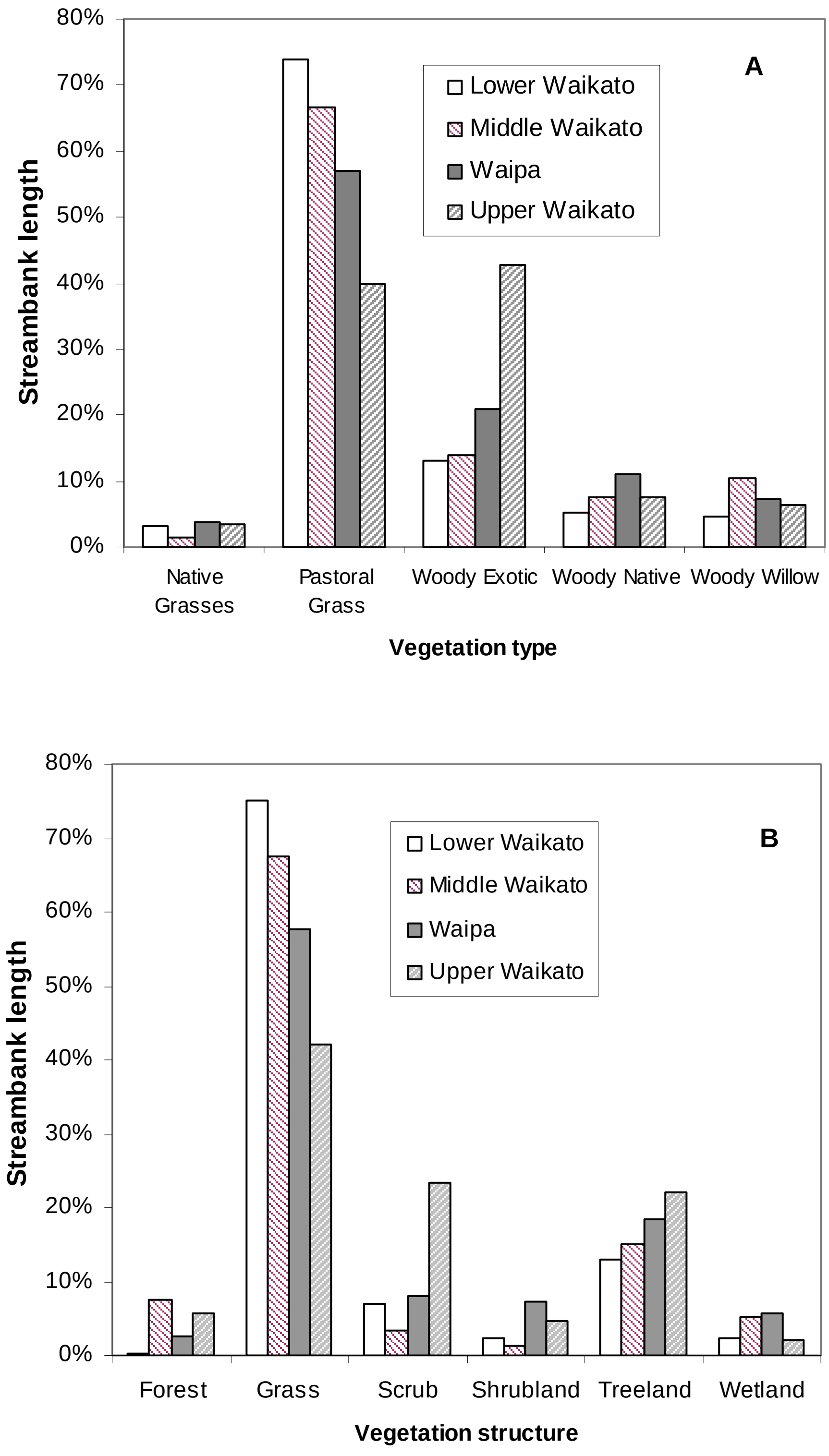



**Figure 1:** Percentage of total bank length of pastoral streams covered by riparian vegetation of different type and structure in the Waikato Region survey in 2007. From EW survey data summarised in Storey (2010). See Table 3 for vegetation category definitions.

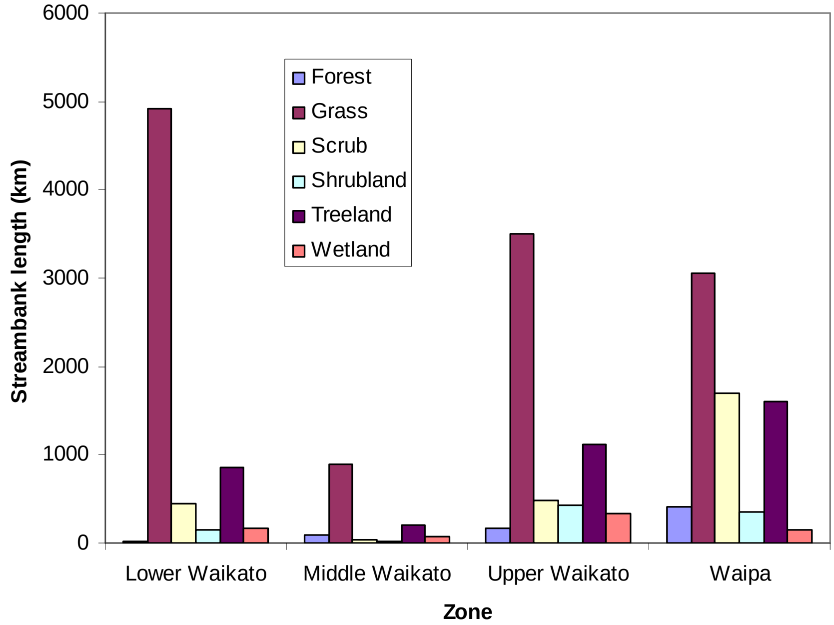



**Figure 2:** Stream length of varying vegetation type along pastoral streams in different Waikato River zones. Calculated using % stream bank cover data in EW 2007 survey and REC of stream lengths, and CLUES pastoral land cover for subregions. Note that streambank length equals twice the stream length.

### 3.2 Waipa and Waikato mainstem riparian vegetation cover

The New Zealand Land Cover Database 2 (LCDB2) indicates that, in 2001, pastoral grassland dominated the riparian vegetation along the mainstem of the Waikato and Waipa Rivers (Figure 3). The Upper Waikato had almost as much native forest cover as grassland and also has substantial riparian cover of exotic (predominantly pine) forest and deciduous trees. Middle Waikato had 16 km of river bank in each of urban parkland/open space and built up areas. LCDB2 indicates that the Waipa riparian areas are particularly dominated by pastoral grassland.

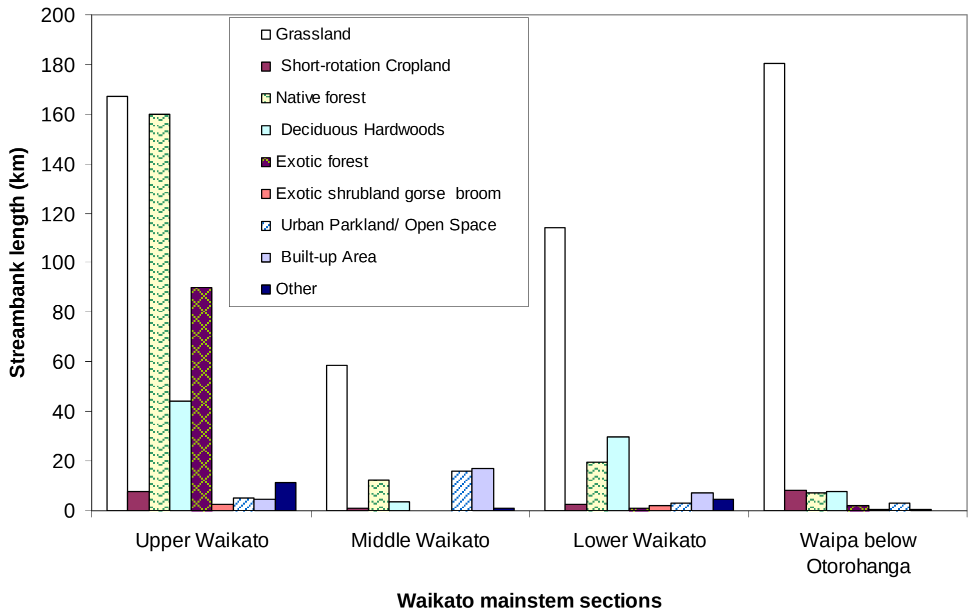



**Figure 3:** Summary of LCBD2 information on riparian vegetation along Waikato and Waipa River mainstem sections in 2001. Note that streambank length equals twice the river length.

However, visual inspection of riparian vegetation type using satellite imagery (Google Maps) indicates substantially more tree cover than indicated by LCDB2 in Figure 3, suggesting that the LCDB2 may be unreliable for identifying riparian vegetation cover. For example, a visual scan indicated approximately 50 percent tree cover along the Waipa below Otorohanga (predominantly as a single line of deciduous trees), compared with 8 percent estimated by LCBD2 (Figure 3). Similarly scanning the satellite imagery for the Middle Waikato section indicates <20 percent grassland (without any riparian trees) and a predominance of willows and alders, whereas LCDB2 indicates 59 percent pastoral grassland (Figure 3). This suggests that the 15 m pixel size of the satellite imagery used to derive LCDB2 was too coarse to pick up tree vegetation that often occurred as a single line of deciduous riparian trees. Thus the LCDB2 data appears to provide only indicative information on the relative amounts of different vegetation covers between sub-regions and a minimum estimate of riparian tree cover along the mainstem reaches.

### 3.3 Aesthetic scores

RMC aesthetic scores for the four zones are shown in Figures 4A and 4B. These data indicate considerable scope for enhancing river aesthetics through riparian management within the Waikato River catchment, where the overall weighted RMC score was 43 percent. Aesthetic scores were low in the Lower Waikato (catchment below Ngaaruawaahia, excluding parts in ARC region; RMC aesthetic score = 34 percent) and Middle Waikato (catchment between Karaapiro and Ngaaruawaahia

RMC aesthetic score = 37 percent)), intermediate in the Waipa (RMC aesthetic score = 44 percent) and greatest in the Upper Waikato (catchment above Karaapiro but excluding Lake Taupoo; RMC aesthetic score = 53 percent)) (Figure 4B).

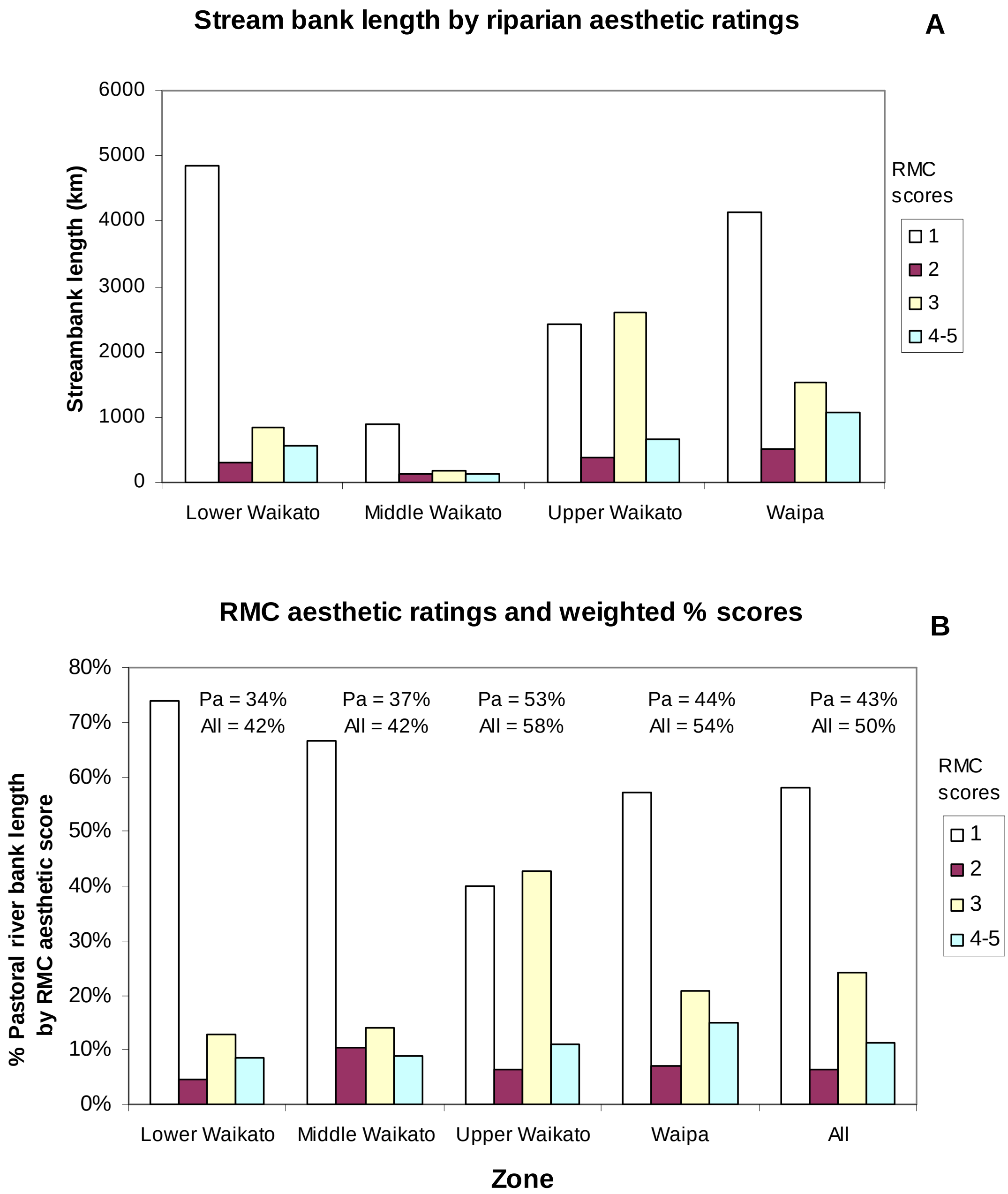



**Figure 4:** Pastoral stream RMC aesthetic ratings (see Table 2) inferred from Environment Waikato's 2007 surveys of streams throughout the Waikato Region (data summarised in Storey, 2010). (A) Scaled by REC stream lengths, and (B) as percentages and overall weighted percentage scores for pasture streams (Pa) and all streams (All) in the Waikato River catchment and zones.

### 3.4 Priorities

#### 3.4.1 Stream size

The GEC's high level vision statement indicates that the Waikato River mainstem is the key priority for restoration of the aesthetics. The small size of 0–2nd order streams, and restricted access to them in rural settings, reduces their use for recreation by the general public unless they are within urban areas. Once streams get to about 3rd order (e.g., Kaniwhaniwha at Limeworks Loop Road, Figure 5) they are large enough to be more accessible and suitable for swimming, kayaking and fishing using a variety of methods. Consequently, after first prioritising the 7th order mainstem Waikato River, riparian vegetation restoration should then focus on 3rd to 6th order streams and rivers, with lesser emphasis on headwater 0–2 order streams.

**Figure 5:** Example of a third order Waikato Stream (Kaniwhaniwha Stream upstream of Limeworks Loop Road).

#### 3.4.2 Stream vegetation type

The greatest aesthetic benefit is likely to be achieved by fencing and planting native vegetation in riparian areas that have livestock access and pasture grass vegetation, with the aim of raising the REC aesthetic score from 1 to 5 (Table 2), then replacing willows with native plantings (raising RMC scores from 2 to 5).

### 3.4.3 Implications for stream length

Analysis of the River Environment Classification (REC) database on stream length distribution amongst stream orders (Figure 6) shows that the decision on which stream sizes to target for restoration has significant implications for the total stream length and therefore costs. The river includes 340 km of 7$^{th}$ order reaches (along the mainstem of the Waikato, 7$^{th}$ order stream density = 0.2 m/ha), whereas the total length of 3$^{rd}$ to 7$^{th}$ order streams is 4,448 km (3-7$^{th}$ order stream density = 3 m/ha). The total length of REC mapped streams is 17,112 km, equivalent to a stream density of 15.5 m/ha. However, the actual stream length is substantially longer than that mapped by REC because it does not plot streams until they have a catchment over 20 ha, which underestimates the length of headwater streams. A comparison at Whatawhata of the stream density using the REC data, the 1:50,000 scale topographic map (that does not included streams shorter than 500 m), and the field mapping gave stream densities of 14, 24 and 70 m/ha, respectively (Quinn et al., 2000). However, if the prioritisation suggested above is applied (i.e., focusing on ≥3$^{rd}$ order streams), the exclusion of headwater streams from 1:50,000 scale topographic maps and the REC is not an issue for restoring aesthetic values (although it has a big influence on the stream length for riparian management to control diffuse contaminant inputs from runoff and animal access).

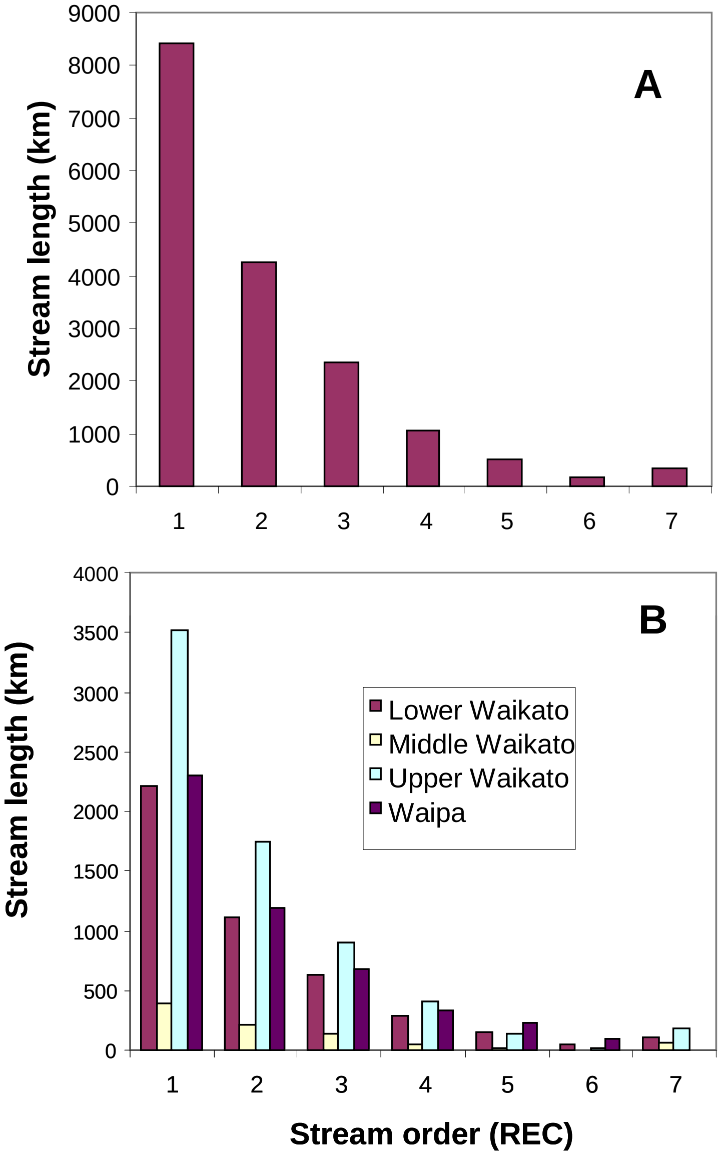



**Figure 6:** Distribution of REC mapped stream length amongst stream of different orders within the Waikato River catchment study area downstream of Taupoo Gates.

The percentage of the stream length surveyed by EW (Storey, 2010) that is fenced was higher in the Upper Waikato than elsewhere in the study area (Figure 7) and tended to be slightly higher along 4$^{th}$ to 6$^{th}$ order streams than 1$^{st}$ to 3$^{rd}$ order streams (Storey, 2010). Waterways classified as "drains" in the EW survey had less than half the percentage fencing (15 percent) than the 1$^{st}$ to 6th order streams (Figure 15 in Storey (2010)).

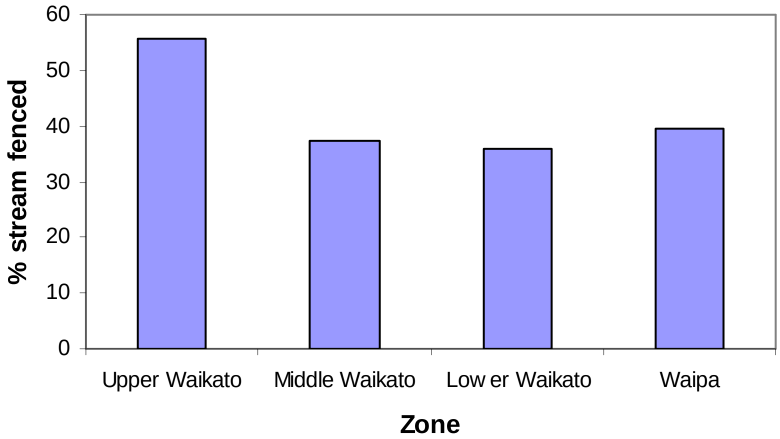
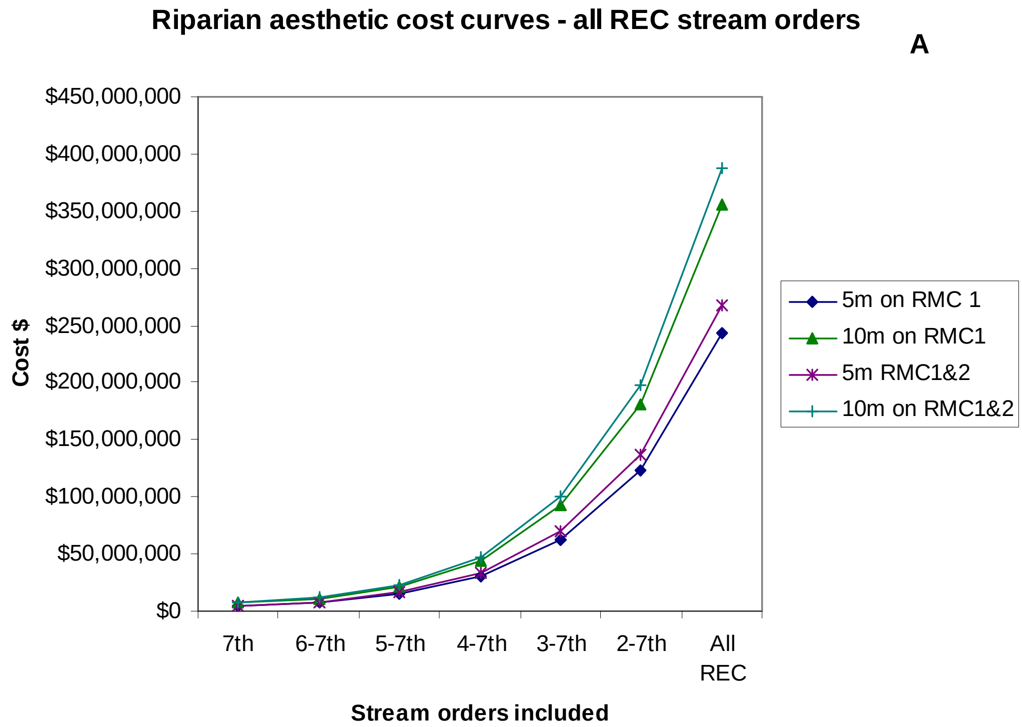



**Figure 7:** Variations in stream length fenced in 2007 amongst different areas of the Waikato and Waipa Catchments (from data in Appendix 5 of Storey (2010)).

### 3.5 Cost abatement curves

Costs were estimated for riparian fencing using post and batten fences (suitable for dry stock farms) or 3 wire electric fences (suitable for dairy farms), and establishing native vegetation buffers of 5 or 10 m width, to about 58 percent of the pasture stream length that has pasture grass and 6.4 percent that has willows in the riparian area (Figure 8). Costs increase exponentially as the size of stream included decreases from 7$^{th}$ order (i.e., mainstem of Waikato) to 1$^{st}$ order as defined by the REC.



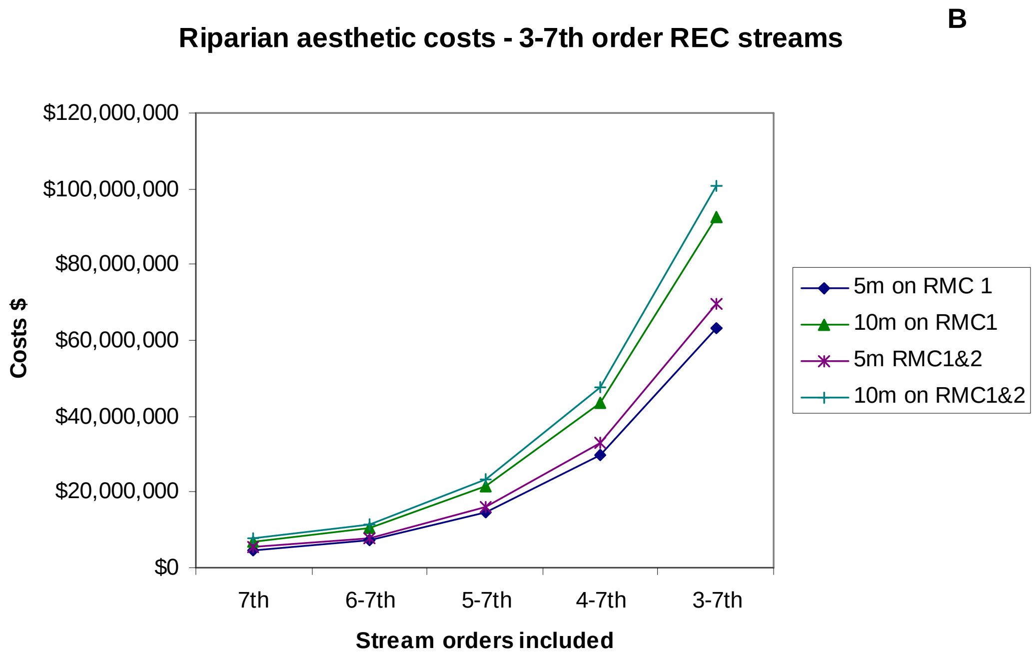




**Figure 8:** Estimated direct costs (fencing, planting, maintenance) of riparian vegetation management to enhance stream aesthetics in the Waikato River catchment. (A) All REC streams, and (B) 3rd to 7th order streams included.

Different fencing types and costs were used in these estimates for the 31.4 percent of the catchment area in dairying (3-wire electric fences at $5/m) and the 24.5% in sheep and beef (post and batten fences at $18/m).

The actual fencing costs may be lower than these estimates if existing fences along some grassed (unplanted) streambanks could be moved and upgraded to protect native plantings. This is most likely to be possible on dairy farms where 52 percent of total bank length was fenced in 2010 although 62 percent of streambanks were in grass (Storey, 2010). Using these existing electric fences, or upgrading them (e.g., 1 to 3 wires) would reduce the fence material costs that comprise 37 percent and 23 percent of dairy stream/planting costs for 5 m and 10 m wide buffers, respectively. However, it is likely that this would only reduce the estimated costs by up to 15 percent across all pastoral streams. Deer farms comprised only 1.2 percent of the catchment area and were not included in this analysis.

Predictions of the aesthetic recovery that could be achieved through the establishment of native forest in riparian areas of pastoral streams that are currently in pasture grass or willows is shown in Figure 9. Predictions are shown with and without weightings to reflect the greater aesthetic benefit of restoring riparian vegetation on larger (high order) rivers and the greater need for wider (10 m) buffers on larger streams (see Table 5).

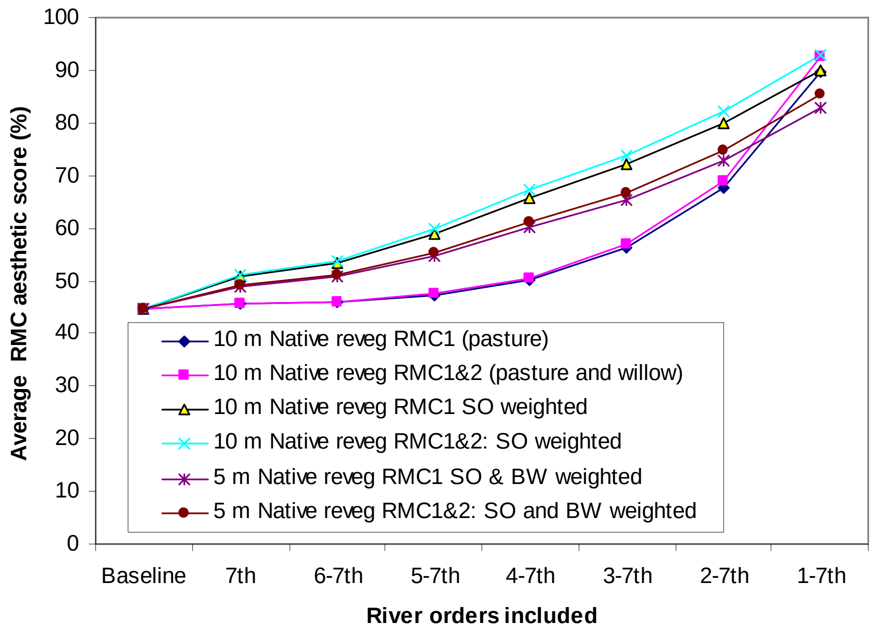



**Figure 9:** Influence on the overall average Waikato RMC aesthetic score of native revegetation of riparian buffers of different width (BW) along streams of different size (stream order, SO) that are currently in pasture grass or willows. The SO and BW weighted values (Table 5) reflect greater aesthetic benefit of restoring riparian vegetation on larger (higher order) rivers and different influences of BW across stream orders.

**Table 5:** RMC aesthetic score weightings (based on professional opinion) applied in Figure 9 to reflect higher aesthetic benefits of native revegetation of riparian buffers on larger (higher order) streams and rivers and differing benefits of narrower (5 m wide) buffers on large and small streams.

| REC Stream order | 7th | 6th | 5th | 4th | 3rd | 2nd | 1st |
|---|---|---|---|---|---|---|---|
| Size weights | 7 | 5.5 | 4 | 2.5 | 1 | 0.7 | 0.45 |
| 5 m buffer width weights (relative to 10 m buffers) | 0.7 | 0.7 | 0.7 | 0.8 | 0.85 | 0.95 | 1 |

The average aesthetic scores do not reach 100 percent in Figure 9 because it was not considered cost-effective for aesthetic enhancement to change to native vegetation the non-willow, exotic, woody vegetation (rated 3/5 or in the RMC, Table 2) that covering 30 percent of Waikato pasture stream banks in 2007 (Figure 1A). Buffers of 5m width are predicted to produce less improvement in the average Waikato River pastoral stream than 10 m buffers (Figure 9).

These improvements in stream aesthetics will take decades to centuries to be fully realised as the riparian buffer vegetation grows and natures. Improvements will be somewhat slower on larger than small streams because the smaller relative scale of the riparian vegetation to the stream size on large rivers. For example, canopy closure over first and second order streams after native revegetation is likely to occur within a decade of planting whereas this takes longer as channel width increases (Quinn and Wright-Stow, 2008; Quinn et al., 2009). However, significant improvements in aesthetics will occur with the exclusion of livestock and associated faecal inputs and streambank damage and after about 3–5 years post-planting when significant growth of plants will become apparent (e.g., plantings in Figure 5). Implementation of riparian planting at the full catchment scale is also likely to take at least 1–2 decades. This will be limited by the need to upscale existing industry support (fencing, plant nurseries and plant maintenance) to support catchment-wide riparian restoration. Replacement of willows with natives will need to be done with care/over time at sites where these were planted for streambank erosion control.

Riparian management involving riparian fencing without planting in the hope that natural regeneration of natives would occur is unlikely to have significant aesthetic benefits and, without careful weed control, may result in proliferation of weed species such as blackberry that detract from recreational use (Table 1). Hence the costs of this riparian management option were not calculated. The same goes for single wire fencing to exclude cattle but not sheep from streams without planting. This is not expected to alter the dominance of pasture grass riparian vegetation (due to continued sheep grazing of the riparian area) and hence riparian aesthetics will not change greatly.

Cost-abatement plots based on the findings presented in Figures 8 and 9 are shown in Figure 10. The calculated benefits to stream aesthetics are predicted to increase steadily as treatments are extended from 7th to successively smaller order streams (Figure 10). Although native revegetation of the mainstem only affects a very small proportion of the whole stream length (and therefore has a small impact on the Waikato average pastoral stream weighted RMC aesthetic score (Figure 9), this relatively inexpensive action (cost between $5 and $8M for 10 m buffers, Figure 8) would likely have a major impact on perceptions of the river aesthetics as this is probably the most used part of the river.

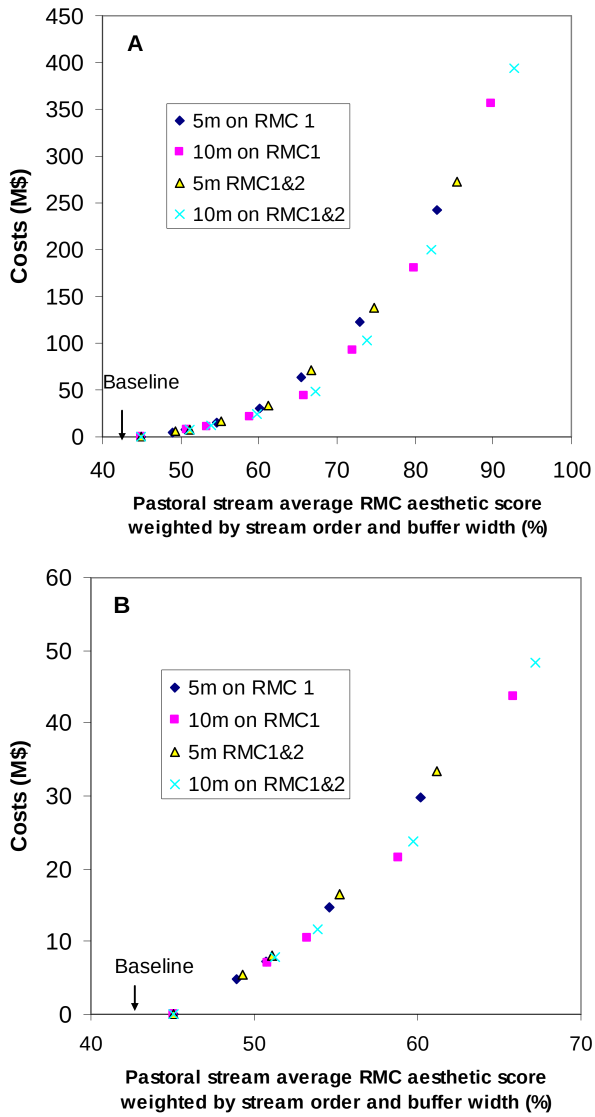



**Figure 10:** Estimated cumulative costs of achieving predicted average weighted RMC aesthetic scores (weighted for stream order and buffer width) of Waikato pastoral streams (i.e., once forest is established in 30–100 years post-planting) achieved by applying 5 or 10 m wide riparian fencing and native revegetation to streams that are currently in grass (current aesthetic RMC = 1) or grass and willows (current aesthetic RMC = 1 and 2). Estimates incorporate different fencing costs for the pastoral areas in dairy and sheep and beef farming. (A) All REC stream orders, and (B) 7th to 4th REC stream orders only.

The co-benefits of riparian restoration by fencing and native revegetation are summarised in Table 6. Benefits of stream fencing on runoff of farm contaminants are addressed in Appendix 9: Farms.

**Table 6:** Riparian native revegetation key co-benefits.

| Co-benefits | Comments |
|---|---|
| **Diffuse contaminant inputs** (N, P, SS, pathogens, agrichemicals) | Most important in smallest streams (zero (i.e., <20 ha catchments for REC) and first order) that have most stream edge length (Figure 6). |
| **Stream temperature control** | Most important in small-medium streams (0–3rd order, <15 m wide) where canopy closure or high shade level achievable. |
| **Stream habitat** (input of leaf litter and wood, shade managing nuisance growth of instream plants, cover for fish, whitebait spawning sites) | Most important in small-medium streams (0–3rd order, <15 m wide) where canopy closure or high shade level achievable but also important along large rivers as cover for fish and spawning for iinanga. |
| **Flood flow peak reduction** | Forest/wetland vegetation increases resistance to flow when riparian area inundated in storm flows, reducing downstream flood peaks. |
| **Stream bank stability** | Vegetation reinforces banks. |
| **Terrestrial biodiversity** | Increase plant diversity on pasture land and associated increase in general biodiversity (birds, insects etc.). |
| **Production and traditional resources benefits** | Pasture edge plantings of medicinal plants for livestock browsing (e.g., flax for intestinal worm control); traditional medicine plant resources; maanuka for high value honey production; traditional art and craft resources; reduced livestock losses through drowning; easier livestock mustering; wind breaks and livestock shelter during extreme weather. |

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# Appendix 12: Shallow Lakes

## 1. Introduction

The Waikato River catchment system is interconnected with shallow lake environments, the backwaters of the hydro lake chain, peat lakes linked via drainage networks and the riverine lakes that lie within the floodplain of the Waikato River. Also unconnected are dune lakes located along the west coast formed in depressions amongst sand dunes. Waterbodies are influenced by, and in turn provide, ecological services to the river that include sediment settling, nutrient removal, flood flow mediation and a nursery or feeding grounds for fisheries. Just as river iwi regard the Waikato River as a tupuna (ancestor) and its wai (water) as the lifeblood of that ancestor, the riverine lakes are viewed by river iwi as the 'lungs and kidneys' of their ancestor.

The health and wellbeing of most Waikato shallow lakes is now substantially degraded. Causes of this degradation include:

- High loads of diffuse contaminant inputs of nutrients, sediment and bacteria from runoff and livestock access to the lake.
- Internal regeneration of nutrients from sediment re-suspension (by wind action or pest fish) and/or release of nutrients as a result of low oxygen events at the lake bed.
- High abundance of pest fish (e.g., koi carp and catfish), and/or aquatic weeds (willow, alligator weed, oxygen weed, hornwort).
- Reduced water depth due to drainage and/or reduced flushing due to water control structures and artificial regimes such as the Lower Waikato Flood Control Scheme.
- Past development of large exotic weed beds that create deoxygenation events and a switch to turbid, nutrient enriched conditions.
- Removal of vegetation filtering potential in the catchment through drainage of marginal wetland vegetation, agricultural development and grazing access.

Analysis of available water quality datasets for 134 New Zealand lakes showed eight of the 18 most nutrient enriched lakes in the country (i.e., hypertrophic) were shallow lakes in the Waikato Region (Hamill and Lew, 2006). Shallow Waikato lakes have many attributes which, if adversely affected, will contribute to their health and poor water quality condition. They include a high proportion of the catchment being in pasture cover, the lakes haaving a shallow depth (<10 m), a warm Waikato regional climate and low altitude (Sorrell and Unwin, 2007).

Out of 52 lakes in the Waikato River catchment that have been assessed by LakeSPI (a measure of lake condition), nine riverine lakes and 16 peat lakes were decribed as 'non-vegetated' (Edwards et al., 2009). This signals that the survival of widespread submerged plants is no longer possible and, therefore, habitat for native fisheries has been lost. In contrast, the condition of the hydro lakes was reduced by high abundances of exotic water weeds, with implications to lake uses and ecological values in shallow areas.

Abundant populations of pest fish have established widely within the shallow Waikato lakes and while their direct impacts on native fisheries are not well documented, they are known to contribute to degraded water quality (Rowe, 2007) and an absence of submerged vegetation (de Winton et al., 2003).

Now few of the shallow Waikato lakes are suitable for recreational contact, or are attractive for passive recreation. Some are inaccessible and surrounded by private land. Even though many are also surrounded by associated reserve land unimpeded access is not always possible.

This appendix considers options for restoring the Waikato shallow lakes. A range of actions are presented, together with their costs and likely effectiveness.

## 2. Goals for restoration

The restoration of shallow lakes will go some way to meeting the following goals which address a large number of the values and attributes identified for the Waikato River catchment.

1. Improved water clarity and indicator bacteria to meet bathing standards in fine weather.

2. Improvement of lake nutrient and chlorophyll concentrations meeting meso-trophic condition or better.

3. Improvement of lake aesthetics in terms of marginal plants and water colour and clarity.

4. Expansion of habitat that enhances New Zealand native biodiversity for aquatic and terrestrial plants, and aquatic biota (including waterfowl).

5. Restoration of native macrophytes in lake margins and bottom, which will contribute to restoration and expansion of iinanga habitat.

6. Expansion of the tuna fishery.

The specific goals that could be met by restoration in six representative lakes are summarised in Table 1. In addition to these, all lake margins could be restored to some extent by fencing, planting, afforestation, and allowing flooding to occur.

**Table 1:** Possible goals for shallow lake restoration in six representative Waikato lakes.

| Lake (type) | Tuna | Iinanga | Recreation bacterial standards | Recreation clarity | Aquatic plants | Control or eliminate pest fish |
|---|---|---|---|---|---|---|
| Serpentine (Peat) | - | Yes | Yes | No[1] | Yes | Yes |
| Ohinewai (Small riverine disconnected) | Yes | Yes | Yes | Yes | Yes | Yes |
| Otamatearoa (Dune) | No[2] | No | Yes | Yes | Yes | - |
| Whangapee (Large riverine connected) | Yes | Yes | Yes | Yes | Yes | Yes |
| Ohakuri (Hydro) | Yes | No | - | - | No | No |
| Puketirini (Weavers) (artificial) | Yes | ? | Yes | Yes | Yes | Yes |

[1] Natural peat staining of the water will limit the improvement that can be achieved.
[2] Can only be achieved by stocking with tuna.

# 3. Restoration methods

## 3.1 Overall approach

There are five categories of shallow lakes; peat, small riverine, large riverine, dune, hydro and artificial. An example lake from each category, for which there were data available, was chosen and restoration options scoped. These options could then be extrapolated to other similar lakes (Table 2).

For each lake three restoration options were considered:

1. Option 1: Maintaining existing water quality (if reasonable) or seeking to improve by standard practices.

2. Option 2: Applying proven solutions which are highly likely to achieve improvements, with the aim of restoring lakes to a prior water quality condition (e.g., to 1950s water quality for dune lakes as described by Cunningham et al., 1953)

3. Option 3: Appling novel or theoretical approaches to make substantial and fast acting improvements. This may include extreme actions such as complete retirement of lake catchments to forest.

**Table 2:** Example lakes for which restoration options were developed.

| Lake type | Example | Other lakes of this type |
|---|---|---|
| Peat | Serpentine | Rotomaanuka, Ruatuna, Ngaroto, Mangakaware, Kaituna, Kainui |
| Small Riverine (disconnected[a]) | Ohinewai | Rotongaroiti, Rotokawau, Okowhao, Kopuera |
| Dune | Otamatearoa | Parkinson, Taharoa, Puketi, Rotoroa, Whatihua |
| Large Riverine (connected[a]) | Whangapee | Waahi, Waikare, Hakanoa, Rotongaro |
| Hydro Lakes | Ohakuri | Other hydro lakes |
| Artificial | Puketirini (Weavers) | Okoko |

[a]Connected or disconnected to the river.

### 3.2 Restoration actions

Narrative tables (Section 1.4) consider the actions and combinations of actions required for each lake example, and associated costs, but a general description of the potential actions is provided below.

#### 3.2.1 Reduce nutrient and sediment inputs

**Action 1.** a) Fence and plant riparian buffers around the lake margin[a] and the majority of major tributaries and drains entering the lake, b) directly treat larger inflow sources via constructed basins and wetlands.

Establishment of riparian buffers of sufficient extent to intercept and process nutrients, bacterial and sediment loads from the catchment are likely to have major benefits for water quality of the shallow lakes. Expected reductions in loadings are likely to be in the order estimated for 5–15 m riparian buffers on pasture streams with reduced yields of 15–40 percent Nitrogen, 15–65 percent Phosphorus, 56–65 percent sediment and 60–75 pecent *E. coli* respectively (see Appendix 9: Farms). The scale of restoration activity will vary from a shoreline buffer for lakes without major inflows, to additional fencing and retirement along inflowing drains and waterways for larger systems, through to potentially retiring an entire lake catchment where significant and rapid recovery is sought. The required buffer width will need to be determined on a case-by-case basis taking into account local conditions of slope (with wider buffers on steeper slopes), and major inflows may need to be targeted as a priority. Wider buffers are likely to be more effective (e.g., >10–50 m) and will have greater co-benefits for aesthetics and water fowl habitat.

Related actions include fencing against stock access, whilst active planting is strongly recommended to minimise weed problems, maximise aesthetic and biodiversity

[a] With allowance for public access points and corridors for wind passage to mix and oxygenate lakes.

values and for long-term vegetation sustainability. More information on required planting composition, plant grade and density is outlined in Appendix 11: Riparian Aesthetics. Costings for riparian retirement in the catchment are contained in Appendix 9: Farms, however, specific costings for lake buffers have been included here and based on estimated areas for buffers, land value, and costs of fencing, planting and weed maintenance for about 3 years.

Lakes with catchments dominated by native or plantation forest are likely to have better water quality than those dominated by agricultural use (Sorrell et al., 2007), therefore afforestation of whole catchments is likely to have significant benefits. Economic benefits under the Emissions Trading Scheme may offset lost opportunities from loss of agricultural production, particularly in marginal land areas. However, caution is advised in the case of dune lakes that may be vulnerable to water table changes under exotic forestry and impacts from added fertilisers, common in plantation forestry on sand country.

Additionally, legislation to prevent or restrict intensification, such as a cap on dairy conversions or a review of discharge consents, may be advocated.

Catchment based initiatives on their own may not be sufficient to significantly improve the water quality of receiving lakes. Other solutions might include the construction of basins to allow for processing by wetland systems or infiltration of nutrients (de Winton et al., 2007), or ring drains to divert first flush or nutrient rich inflows. The required scale of these works is subject to site-specific water flows and loadings.

> **Action 2.** Prevention of internal regeneration of nutrients by a) sediment capping treatments to lock nutrients in the lake bed[b], b) drainage and removal of nutrient-rich surface layer.

Information on sediment capping technologies for the hydro lakes is provided in Appendix 21: Toxic Contaminants. As well as the ability to sequester compounds of potential toxicity, capping can substantially reduce internal loading of nutrients, particularly phosphorus (P). Four P-inactivation agents that are currently available are alum, allophane, Phoslock™, and modified zeolite, with required dose rates of these products being highly site-specific according to lake and sediment character (Hickey and Gibbs, 2009). Sediment tests and an initial efficacy trial are therefore recommended before wide-scale treatment. The scale of treatment (whole lake or deeper areas only) and requirement for multiple treatments would also be site-specific and likely to be dependent on initial results.

[b] May need to address pest fish and wind/wave re-suspension of sediments in conjunction with this initiative to maintain integrity of the cap.

Internal nutrient loading from wind or pest fish induced re-suspension of bottom sediments and nutrients would be addressed by other actions (see actions 4 and 6).

A more extreme and costly engineering solution may be to suction dredge, or drain, dry and excavate the surface sediments where nutrient loads are concentrated. This latter approach has been used in the USA (Helsel and Zagar, 2003; Helsel et al., 2003). The logistics are complex and may include the need to pump out water/slurry, bund construction to prevent back filling and transport and disposal of spoil. Large impacts on lake values would be expected, at least in the short term and may include a flush of nutrients released upon re-filling (Stephens et al., 2004). Draw-down could also improve the feasibility of targeting and destroying pest fish (James et al., 2002) as outlined in action 4.

**Action 3.** Hydrologic manipulations to a) optimise water level regimes[c], b) increase flushing flows.

Shallow lakes are vulnerable to water level reductions through excessive drainage, water table losses (e.g., dune lakes) and peat soil drying, decomposition and subsidence (peat lakes). The minimum action undertaken is generally the construction of a weir on lake outlets that helps to set a minimum lake level. However, potential exists to use structures to manipulate lake levels in restoring earlier levels, a prior water table level, or more natural fluctuations/flooding. These additional actions may be necessary for peat lakes where long-term sustainability of lakes is threatened (de Winton et al., 2007). An adaptive management approach is likely to be needed to identify optimal water level regime for specific lakes and identified goals.

For the riverine lakes that are interconnected to the Waikato River, the possibility of routing river water into lakes to increase flushing of nutrients, sediment loads and algal populations has previously been raised. Currently, the water quality of the Waikato River is not good enough to make substantial benefits to lakes via increased flushing.

Connectivity between the riverine lakes and the lower Waikato River is currently limited by flood schemes. However, we note a conflict between restorative actions (e.g., removal of stop banks and pump stations) and other actions aimed at removing exotic pest species from the lakes, because of their almost certain re-introduction with flood flows (see action 4).

Removal of dams on the Waikato River would result in the loss of lake habitat and a return to riverine conditions. We would expect water quality to be improved by

[c] Weir construction may be accompanied by the need to allow fish passage (see action 4).

increased flushing rate, and whilst pest fish and weeds would still be present, weed bed extent would be reduced.

> **Action 4**. Pest fish control by a) netting, electrofishing, b) encouraging a commercial market, or c) eradication using rotenone, but d) allowing for differential fish passage[d].

The aim of reducing and controlling pest fish population size to minimise their impacts on shallow lakes would be an ongoing requirement and cost. In the absence of New Zealand information, we would suggest approximate pest fish reductions of 75 percent (Perrow et al., 1997) or to a biomass of <150 kg $ha^{-1}$ (Hosper and Jagtmen, 1990). Methods for the intensive removal of fish are likely to involve netting or electrofishing. A commercial market for koi carp has briefly operated in the past and remains a possibility, however, commercial fishing relies upon availability of the catch species at an economical level, and so alone it is unlikely to reduce pest population to levels low enough to provide significant benefits to the lakes. There is also a risk that additional populations of pest fish would be intentionally established for economic gain. Alternatively, agencies may fund pest fish harvest, with a commercial market operating for cost recovery. This may require licensing of fishing activities, with remuneration via a bounty scheme or wages.

The alternative of a one-off eradication of pest fish from lake systems is possible in small lakes with limited tributary/drainage networks, but would be more difficult with increasing size and connectivity of lakes. Currently the most likely method is use of the piscicide rotenone, which is already registered for use in aquatic systems in New Zealand. Effective rotenone use would require sufficient concentrations to penetrate all fish habitats connected to the lake (e.g., drains, tributaries, wetlands). Rotenone is not selective for pest fish alone, but the recovery and revival of affected native fish is theoretically possible. Feasibility of successful rotenone treatment of lakes would increase if lake levels can be substantially lowered to reduce the treated volume/area (see action 2). Eradication feasibility must also consider the ongoing risk of reintroduction/reinvasion by pest fish. For example, eradication is not currently considered feasible for large riverine lakes with flood flow connectivity with the Waikato River due to almost certain re-introduction of pests.

Associated with eradication attempts (or intensive fishing) may be the requirement to isolate lakes from connected fish sources and differential fish passage to allow valued native fish (e.g., tuna) to move in and out of lakes, but exclude pest species. Current fish pass solutions can allow access by native fish with climbing abilities, but research on migratory abilities of other native and pest fish would be required to scope and design any differential fish pass for species such as iinanga and mullet.

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[d] Would require major barriers for riverine lakes within the river floodplain to prevent pest fish ingress.

**Action 5.** Control or eradicate invasive weeds by a) application of herbicides, b) introduction of grass carp.

Exotic weeds in and around shallow lake environments include trees (e.g., willows), submerged (e.g., egeria, hornwort) and marginal weeds (e.g., alligator weed). The future abundance of some weeds may change with lake management initiatives. In particular, a significant improvement in water quality that creates a habitat with sufficient water transparency for submerged plant growth may well result in exotic weed dominance in the absence of control measures. These submerged weeds may be a future threat to shallow lake usage and biodiversity, and also to water quality. For example, in eutrophic Lake Omapere, large unstable weed beds caused de-oxygenation events that led on to internal nutrient loading events, turbid water and cyanobacterial blooms (Champion and Burns, 2001).

Herbicides are already registered and available for treatment and reduction of biomass of aquatic weeds and ongoing treatments will progress towards reduced impacts by these species. For emergent and marginal weeds eradication or near eradication is an appropriate goal of herbicide use. One consideration is appropriate application techniques in sensitive areas (e.g., use of more expensive drill and inject methods for willow instead of aerial spraying where native wetland values are high). Rehabilitation actions in association with control measures (e.g., native plantings after willow control) will make additional control gains.

For submerged weeds, herbicide treatment is proven for amenity purposes, to reduce interference around boat ramps, jetties and swimming beaches. However, the eradication of submerged weeds by herbicide is not a feasible goal in most cases. Nevertheless, research is identifying situations where whole-of-water-body herbicide treatment, or sequential applications, can eradicate some weeds from small lakes. The selective nature of herbicide action against weeds with limited off-target damage to indigenous vegetation means a herbicide approach would be an advantage where native vegetation values are high.

Currently the most certain option for eradication of submerged weeds is by stocking herbivorous grass carp; an exotic fish that is highly unlikely to breed naturally within New Zealand waterways. Fish are stocked at a rate depending on the vegetated area of weed present and are capable of removing all submerged vegetation within 2–5 years. However, in the absence of a proven method to remove them, fish may exert an ongoing grazing pressure in a lake for the rest of their lifespan - up to 20 years. Associated with the use of grass carp may be the need for fish screens or barriers to contain them within a lake.

**Action 6.** Re-establish native submerged or emergent plants by a) active planting of founder colonies, b) provision of wave barriers.

Once initiatives are undertaken to improve lake water quality and reduce or remove pest species, an opportunity exists to re-introduce a native vegetation that adds cultural values (e.g., reed beds of kuta and raupoo), fish habitat, or provides other ecosystem services such as lake bed stabilisation or wave buffering. Prerequisite to the establishment of native submerged vegetation is sufficient water clarity to allow widespread plant growth, and pest fish control to a level where their disturbance does not prevent plant establishment. In large lakes with a long wind fetch it is also likely that barriers to wave action will need to be constructed to provide protected shallow areas for plants to establish. Active planting of founder colonies of submerged plants will be needed in most cases due to the absence of viable reserves of seed left in the lake sediments. Targeted planting of emergent species will also enhance their re-establishment[e].

**Action 7.** Provision of public access.

There is a need to integrate public assess needs with other initiatives (e.g., riparian plantings) around the lake edge. These would be built on existing reserves where present, and may require development of paper roads, or purchase of land from adjacent landowners. In most cases this would include the minimum of vehicular access and parking, picnic and toilet facilities and, depending on appropriateness, either a boat ramp or jetty facility (see Appendix 25: Boat Ramps). Other public access needs such as board walks or tracks and other additional facilities are best considered on a site by site basis via a lake management plan. Another consideration is the associated increased risk of re-introduction of pest species to treated lakes by human activities, which will require public education and local signage.

**Action 8.** Monitoring for progress towards goals.

Confirmation of progress towards goals requires ongoing monitoring of the outcomes of initiatives. Ideally lake specific and measurable goals (e.g., reduction in TLI measure by 1 within 10 years), would be laid out in a lake management plan, which integrates catchment level management objectives. Amongst reporting measures that are considered suitable for shallow lakes are the Lake Trophic Level Index (TLI) which indicates nutrient status based on four water quality parameters sampled 4–8 times per year, and LakeSPI that indicates ecological condition based on Submerged Plant Indicators. Baseline and future report cards for shallow lakes should incorporate one or both of these measures.

## 4. Benefits/outcomes

Where possible, the benefits of actions are outlined for each example lake in Tables 3–8. Specific and measurable benefits for lakes cannot be identified for each action because significant benefits usually depend upon a chain of actions. Additionally

[e] Requires fencing against stock access.

some outcomes are not certain, or are site-specific. For example, restoration of water clarity for re-establishment of widespread native submerged vegetation in Lake Whangapee is likely to depend on the removal of substantial nutrient loads (external and internal), a radical reduction in pest fish, exclusion or control of submerged weeds, and temporary or more sustained reduction in wave action.

Removal of major loadings of nutrients, sediments and bacteria from the catchment are highly likely under restoration options 2 and 3. Flow on benefits for lake water quality (improved clarity and suitable for swimming) will occur, but the timeframe for such outcomes is not so clear. This is because nutrients will have accumulated in the lake sediments over decades and net export or burial of these deposits may take comparable timeframes. Under restoration option 2 benefits would be expected within 30 years. The additional actions under options 3 (e.g., sediment capping and dredging) are likely to not only increase the level of improvement but also to speed recovery to within 5–10 years by removing or capping the nutrient-laden sediments.

Greatest benefit may come from actions in priority areas, for example, addressing condition and impacts from the Whirinaki arm of Lake Ohakurii would have large downstream benefits for the rest of the hydro lake chain.

Co-benefits of actions to restore shallow lake environments include:

- Reduced release of toxic substances from hydro lake sediments following sediment capping (see Appendix 21: Toxic Contaminants).
- Re-establishment of culturally important plant species (e.g., kuta).
- Increased habitat for waterfowl, with larger resident populations, in response to increased size of riparian buffers.

## 5. Risks and probability of success

In New Zealand, lake restoration has never been attempted on the scale required to make significant improvements to the more degraded shallow lakes of the Waikato system. There are significant uncertainties about the outcome of actions, whilst the complexity and level of interacting factors mean a high level of unpredictability in these systems, particularly in the larger lakes where feasibility of undertaking actions alone would be a challenge. In most cases an adaptive management approach will be required with a sequential series of actions, with assessment at each step and reconsideration/adjustment of subsequent steps. Generally, smaller, more isolated lakes are considered most feasible to restore, because pest re-invasion is less likely, fishing activities can be better targeted, and wind/wave mediated impacts on water quality are limited.

One example of the complexity and level of problems can be seen when considering the large riverine lake, Lake Waikare, which would be a much more difficult restoration target than our example lake, Lake Whangapee. Lake Waikare is three times the size of Lake Whangapee and has an open shoreline configuration, lacking the sheltered arms of Lake Whangapee, which creates extensive wind fetch and impacts of wave action on the lake bed and shores. Consequently the lake has high levels of suspended solids that contribute to poor water quality, although, even if all suspended solids were removed, water clarity and light penetration would still be low due to high levels of chlorophyll a and humic staining (Reeves et al., 2002). A wave model for the lake suggested that increasing the lake level by 1 m would reduce the quantity of sediment re-suspended by waves, but fine clays that are more easily suspended may still drive disproportionately high levels of turbidity. Direct wave action is also a major limitation for the development of marginal and submerged vegetation in the shallow areas of Lake Waikare. The large Matahuru Stream inflow contributed 95 percent of sediment load to Lake Waikare. Options to intercept and treat via wetland filters or silt traps were limited by scale of treatment required and site constraints. Nevertheless, riparian initiatives were recommended for the stream and tributaries to intercept or prevent sediment and nutrient loading to the Matahuru Stream. Natural geothermal inputs to Lake Waikare result in elevated levels of heavy metals in the lake bed (N. Kim, EW, pers comm., 2002), which may be an issue for dredging options and disposal of spoil. It was concluded that the number and scale of problems made it a poor candidate for rehabilitation (Stephens et al., 2004).

Some actions are at odds with other possible goals. For example a suggested aspiration for increased connectivity between water bodies compromises the goal to prevent the introduction/reintroduction of pest fish and weeds. Limiting connectivity to prevent pest ingress would also limits the reinstatement or improvement of some fisheries (e.g., iinanga, mullet) due to corresponding barriers to their migration. Other restoration actions involving manipulating lake levels and hydrology would reduce flood control capacity, with implications for adjacent land areas.

There is a high risk of reinfestation by natural, accidental or deliberate introduction of pest fish and weeds to lakes, which may necessitate further rehabilitation efforts in the future. Other risks associated with restoration actions include the possibility of a return to exotic weed dominance if a improved water clarity is achieved in the riverine lakes. Contingency for weed control or eradication should be considered as part of the restoration sequence.

# 6. Costs and timelines

Narrative tables (Tables 3–8) present the specific actions required for each lake example and their associated costs within the three restoration options. Costings include lake buffer zones of differing extent, but do not include riparian fencing and planting in the catchment (see Appendix 9: Farms). Note that costs associated with riparian fencing and planting in the catchment will vary considerably from lake to lake, with no cost for a dune lake such as Lake Otamatearoa that has no tributary or drain inflows, to a substantial amount for lakes with large catchments such as Lake Whangapee (31,684 ha). Summary costs for the example lakes are outlined in Table 9. Within the Waikato River catchment 54 lakes of 2 ha or more in size were identified that could be categorised into one of the six shallow lake types. In Table 10 costs based on the example lakes have been extrapolated to the wider group of lakes that might represent priorities for restoration.

No attempt has been made to estimate costs for the possible decommissioning and removal of Ohakurii dam. Such costs would include marginal value (as the cost of generating power elsewhere), the cost of removal of plant and equipment, and impacts on operational costs at downstream power stations (D. Scarlet, Mighty River Power Ltd, pers comm.). Other unknowns are the maintenance cost of fencing and riparian plantings beyond 3 years, site-specific requirements of dose rate, testing and multiple treatments for sediment capping, and costs for consents and permits (e.g., for herbicide/piscicide application, species collection and translocation, grass carp effects assessment) which will vary widely depending on the required level of detail and/or consultation. Likewise, costs for lake management plans have not been included in this exercise. Potential cost recovery via a commercial market for pest fish are unclear. Another example is containment costs for grass carp (such as barriers at all inlets and outlets) which are likely to be highly site specific.

**Table 3:** Lake Serpentine: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Fencing and Planting** | | | | | |
| 1a. Fence margins for 10 m wide functional buffer and stock exclusion | 3 string electric $5 / m | Nil | Already fenced | | |
| 1b. 10 m planted riparian margin | Native plantings[f] $20,500/ ha | Nil | Already planted | | |
| **1. Total (OPTION 1)** | | | **Nil** | | **Already completed** |
| 2a. Fencing margins for 50 m wide functional buffer and stock exclusion | 3 string electric $5 / m | 4.6 km perimeter[g] | $23,045 | Addition to current 20 m planted buffer will see substantial improvement in nutrient interception and filtering. | High |
| 2b. 50 m planted riparian margin | Native plantings $20,500/ ha | 6.4 ha[h] | $131,200 | 50 m buffer recommended to protect/contribute to peat dams that ensure lake persistence. Addition to current 20 m planted buffer will see substantial improvement in nutrient interception and filtering. Additional aesthetic values and significant increase in bird habitat. | Moderate to high buffer role in peat protection and accretion is not assured and additional steps may be required long-term – see below. |
| 2c. Land production lost | 90% $1,403per ha per annum, 10% $1,473 per ha per annum[i] | 26.9 ha[j] | $37,860 per annum | | Low-moderate (multiple owners, dairy and lifestyle). |

[f] PB2 grade plants @ 2500 stems/ ha ($5 planted) + maintenance to year 3 ($8,000/ha).
[g] Estimated 50 m wide margin around lake complex .
[h] Estimated area not currently planted within the 50 m + wetland margins around the lake complex.
[i] Based on values from Appendix 9: Farms. 90 percent catchment in dairy peat drain $1,403 per ha and 10% catchment in lifestyle (dairy poor drain) $1,473 per ha.
[j] 50 m+ area = 37.2 ha less WONI database lake area = 10.347 ha.

**Table 3 (cont.):** Lake Serpentine.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **2. Total (OPTION 2)** | | | **$103,045 + $89,060 operating** | | |
| 3a Fenced margins of entire catchment | Post & batten fences $18 / m | 5.88 km[k] | $105,840 | Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings | High. |
| 3b Afforestation of entire catchment | Native plantings $20,500/ ha | 139.4 ha[l] | $2,857,700 | Very significant aesthetic benefits as well as function in reducing nutrient loadings. Very significant contribution to conserving peat and lake persistence. Significantly improved water quality. Creation of significant bird habitat. | High. Water clarity will remain naturally low due to peat. |
| 3c Land production lost | 90% $1,403 per ha per annum, 10% $1,473 per ha per annum[m] | 110 ha[n] | $155,100 per annum | | Low-moderate (multiple owners, dairy and lifestyle). |
| **3. Total (OPTION 3)** | | | **$1,848,340 + $1,270,300 operating** | | |

[k] Estimated catchment perimeter.
[l] WONI database catchment area = 160 ha minus WONI database lake area of 10.3 ha minus Wildlands consultants report 2009 catchment in native vegetation = 8%
[m] Based on values from Appendix 9: Farms. 90% catchment in dairy peat drain $1,403 per ha and 10% catchment in lifestyle (dairy poor drain) $1,473 / ha.
[n] WONI database catchment area = 160 ha minus WONI database lake area = 10.3 ha minus reserve area ~40 ha.

**Table 3 (cont.):** Lake Serpentine.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Access** | | | | | |
| 4. Public access to lake; entrance, car park, jetty, single toilet and picnic area | $105,000[o] + consent fees + $25,000 maintenance per annum | 1 | $105,000 + $25,000 maintenance per annum | | High. |
| **4. Total (OPTION 2)** | | | **$105,000 + $25,000 operating** | | |
| **Monitoring** | | | | | |
| 5a. Lake monitoring using LakeSPI | $2,100 | 1 | $2,100 | Monitor native and exotic submerged vegetation as an indicator of lake health. | High. |
| **5a. Total (OPTION 2)** | | | **$2,100 operating** | | |
| 5b. Lake monitoring using LakeSPI and Trophic Lake Index | $2,100 pa + $9,235 pa for four visits | 1 | $11,235 | Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor trophic level index as an indicator of lake health. | High. |
| **5b. Total (OPTION 3)** | | | **$11,235 operating** | | |

[o] Based on cost estimates from Waipa District Council for similar projects completed by Council.

**Table 3 (cont.):** Lake Serpentine.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Farm contaminants** | | | | | |
| 6. Infiltration filters or ring drain | Backfill and construct filters ($2.5-5k each) or ring drain ($6-7.5k ) for major drains | c. 2–4 filters 1 ring drain (intercepting 5 drains) | $11,000–$27,500 | Nutrient loads likely to be further reduced by removing channelised flows to the lake and allows opportunity for infiltration and maximal nutrient processing in the buffer zone where fluctuating water table. | Moderate. |
| **6. Total (OPTION 2)** | | | **$27,500 + 10% operating** | | |
| **Pest fish** | | | | | |
| 7a. i) Pest fish control by intensive netting. Cost may be partially recovered through commercial harvesting (agency driven) of pest fish | ~$30,000 per annum [p] | 1 | $30,000 per annum | Flow on effects for reduced internal nutrient loading, improved water clarity and habitat for submerged plants. | Moderate. |
| 7a. ii) Selective fish pass for tuna, lamprey, iinanga and other galaxiids (whitebait) / pest fish barrier | 5 m ramp | 1 | $50,000 + $10,000 maintenance per annum | Allows upstream fish passage. Eel passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked but smelt should be able to develop a land locked population. | High (in association with pest fish control/eradication). |
| **7a. Total (OPTION 2)** | | | **$50,000 + $40,000 operating** | | |

[p] Lake Serpentine Management Action Plan report.

**Table 3 (cont.):** Lake Serpentine.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 7b i) Pest fish eradication by piscicide | Low cost of material and application, cost determined by consent process estimated at $100,000 | 1 | $100,000 | Significant reduction in internal nutrient loading, improved water clarity and habitat for submerged plants. | Moderate |
| 7b. ii) Selective fish pass for tuna, lamprey, iinanga and other galaxiids (whitebait) / pest fish barrier | Up to a 5 m ramp | 1 | $50,000 + $10,000 maintenance per annum | Allows upstream fish passage. Passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked but smelt should be able to develop a land locked population. | High (in association with pest fish control/eradication). |
| **7b. Total (OPTION 3)** | | | **$150,000 + $10,000 operating** | | |
| **Sediment capping** | | | | | |
| 8. Sediment capping whole lake with modified zeolite (Aqua-P) | $2,400 per tonne Aqua-P + sediment test, calibration, monitoring + consent costs | 31 tonnes Aqua-P | $400,000 | Little improvement to current water quality except possibly in South Lake | Moderate – Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment capping. |
| **8. Total (OPTION 3)** | | | **$400,000** | | |

**Table 3 (cont.):** Lake Serpentine.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Water level control** | | | | | |
| 9a. Alterations to weir to raise and re-instate common water level | $200,000[q] | 1 | $200,000 | Reconnection of the 3 basins and deeper lake depths is likely to confer long-term protection to lakes against drainage/subsidence. | Moderate |
| 9b. Construction of a bund (1.3 km long, 1.5 m high) and backfilling of outlet drain across lower catchment to preserve peat deposits | $440,000[r] + consent, tip fees, design, landscaping and management costs | 1 | $440,000 + consent, tip fees, design, landscaping and management costs. | Long-term sustainability of the lakes improved by protection and accretion of peat by raised water table to near ground surface around lakes and immediate downstream peat deposits. | Moderate |
| **9. Total (OPTION 3)** | | | **$640,000** | | |

[q] Estimate from Environment Waikato for water level control structures.
[r] Beca Engineering Ltd estimate.

**Table 4:** Lake Ohinewai: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Fencing and Planting** | | | | | |
| 1a. Fence 1 m margin for stock exclusion | 3 string electric $5/m | 1,902 m lake perimeter[s] | Nil, already fenced | | |
| 1b. 1 m wide planted riparian margin | Native plantings[t] $20,500/ha | 1.9 ha | Nil, already planted | | |
| 1c. Land production lost | - | - | - | | |
| **1. Total (OPTION 1)** | | | **Nil** | | **Already completed.** |
| 2a. Fence margins for 10 m wide functional buffer and stock exclusion | 3 string electric $5/m | 2.150 km perimeter | $10,750 | Reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. | Moderate-High. |
| 2b. 10 m wide planted riparian margin | Planting $20,500/ha | 3.6 ha | $73,800 | Significant aesthetic benefits as well as function in reducing nutrient loadings. | Moderate-High. |
| 2c. Land production lost | $1,473 per ha per annum[u] | 3.6 ha | $5,300 per annum | | |
| **2 Total (OPTION 2)** | | | **$55,750 + $34,100 operating** | | |
| 3a. Fencing margins for 50 m+ contour wide functional buffer and stock exclusion | 3 string electric $5/m | 3.7 km perimeter | $18,500 | Significant reduction in indicator bacteria and nutrient loadings. Delay in lake water quality likely until residual nutrient load is exported or treated (see 5 below). | Moderate-High. |

[s] WONI database value of 1,902 m lake perimeter.
[t] PB2 grade plants @ 2500 stems/ ha ($5 planted) + maintenance to year 3 ($8,000/ha).
[u] Based on catchment in dairy poor drain $1,473 per ha, values from Appendix 9: Farms.

**Table 4 (cont):** Lake Ohinewai.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 3b. 50 m + contour and planted riparian margin | Planting $20,500/ ha | 28.6 ha | $586,300 | Significant aesthetic benefits as well as function. Significant reduction in indicator bacteria and nutrient loadings. Creation of significant bird habitat. | Moderate-High. |
| 3c. Land production lost | $1,473 per ha per annum | 28.6 ha | $42,130 per annum | | |
| **3 Total (OPTION 3)** | | | **$376,000 + $270,930 operating** | | |
| 4a Fenced margins of entire catchment | 3 string electric $5 / m | 11.52 km[v] | $57,600 | Very significant reduction in indicator bacteria and nutrient loadings. Delay in lake water quality likely until residual nutrient load is exported or treated (see 5 below). | High. |
| 4b Afforestation of entire catchment | Planting $20,500/ ha | 313.8 ha[w] | $6,432,900 | Very significant aesthetic benefits as well as function; very significant reduction in indicator bacteria and nutrient loadings. Creation of very significant bird habitat. | |
| 4c Land production lost | $1,473 per ha per annum | 63.30[x] | $93,240 per annum | | |
| **4 Total (OPTION 3)** | | | **$3,980,100 + $2,603,640 operating** | | |

[v] WONI database value of 11,520 m catchment perimeter.
[w] WONI catchment area 3,309,300 $m^2$ less WONI lake area 170,711 $m^2$.
[x] Wildlands Consultants report 2009 is 68.3 ha – lake area of 5 ha.

**Table 4 (cont.)**: Lake Ohinewai.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Access** | | | | | |
| 5. Public access to lake; entrance, car park, toilet, picnic area and jetty | $105,000 + $25,000 pa maintenance[y] | 1 | $105,000 + $25,000 pa maintenance | Significant access and recreational benefits. | High. |
| **5 Total (OPTION 2)** | | | **$105,000 + $25,000 operating** | | |
| **Monitoring** | | | | | |
| 6a. Lake monitoring using LakeSPI | $2,100 pa | 1 | $2,100 | Monitor native and exotic submerged vegetation as an indicator of lake health. | High. |
| **6a Total (OPTION 2)** | | | **$2,100 operating** | | |
| 6b. Lake monitoring using LakeSPI and Trophic Lake Index | $2,100 pa + $9,235 pa for four visits | 1 | $11,235 | Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor trophic level index as an indicator of lake health. | High. |
| **6b Total (OPTION 3)** | | | **$11,235 operating** | | |
| **Farm contaminants** | | | | | |
| 7. Infiltration filters | Backfill 2 major drains and construct infiltration filter at c. $4–5 k each[z] | 2 major drains | ~$10k + ~$1k maintenance costs | Additional benefits to riparian buffer in intercepting and treating nutrient sources. | Moderate. |

[y] Based on cost estimates from Waikato District Council, Waipa District Council and Beca Engineering Ltd.
[z] Lake Serpentine Management Action Plan report.

**Table 4 (cont.):** Lake Ohinewai.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **7 Total (OPTION 2)** | | | **$10,000 + $1,000 operating** | | |
| **Sediment capping** | | | | | |
| 8. Sediment capping whole lake with alum followed by modified zeolite (Aqua-P) | $650 per tonne alum; $2,400 per tonne Aqua-P; + sediment test, calibration, monitoring + consent costs | 25.6 tonnes alum; 51.2 tonnes Aqua-P | $479,120 + consent costs | Significantly improved water quality and reduced nutrients in water column and lake bed, particularly phosphorus. Alum removes phosphorus from water column. Aqua P removes phosphorus, arsenic, mercury and some ammonia, creates a thick cap on lake bed so that sediments are unlikely to become re-suspended. | Moderate - Catchment nutrient sources and pest fish need to be reduced, plus selective fish pass in conjunction with sediment capping. |
| **8 Total (OPTION 3)** | | | **$479,120** | | |
| **Pest fish** | | | | | |
| 9a. i) Pest fish control by intensive netting. Cost may be partially recovered through commercial harvesting (agency driven) of pest fish | $100k initial control then $60k per annum [aa] | | $100k+ $60k per annum | Flow on effects for reduced internal nutrient loading, improved water clarity and habitat for submerged plants. | Moderate. |

[aa] Based on Serpentine Lakes estimate scaled up for Lake Ohinewai.

**Table 4 (cont.):** Lake Ohinewai.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | **Cost item** | **Quantity** | **Total cost** | | |
| 9a. ii) Electrofishing | Nil[bb] | Test | Likely to be nil but not ongoing | Flow on effects for reduced internal nutrient loading, improved water clarity and habitat for submerged plants. | Moderate. |
| 9a. iii) Selective fish pass for tuna, lamprey iinanga and other galaxiids (whitebait) / pest fish barrier | Up to 5 m ramp | 1 | $50k + $10k maintenance per annum | Allows upstream fish passage. Eel passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked but smelt should be able to develop a land locked population. | High. |
| **9a Total (OPTION 2)** | | | **$50k + $170k operating** | | |
| 9b. i) Pest fish eradication by piscicide | Low cost of material and application, cost determined by consent process estimated at $100k | | $100k | Significant reduction in internal nutrient loading, improved water clarity and habitat for submerged plants. | Moderate |
| 9b. ii) Selective fish pass for tuna, lamprey iinanga and other galaxiids (whitebait) / pest fish barrier | Up to 5 m ramp | 1 | $50k + $10k maintenance per annum | Allows upstream fish passage. Eel passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked but smelt should be able to develop a land locked population. | High |
| **9b Total (OPTION 3)** | | | **$150k + $10k operating** | | |

[bb] Lake Ohinewai identified as possible test lake for pest fish reduction under University of Waikato research.

**Table 4 (cont):** Lake Ohinewai.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Aquatic plants** | | | | | |
| 10. Re-establish founder submerged plant communities | \$22k per 10 $m^2$ + species translocation permit costs | Either $10m^2$ or 10 enclosures | \$22k | Would require improved water quality to attempt. Significant benefits to water quality, aesthetics and fish habitat are likely | Moderate |
| **10 Total (OPTION 3)** | | | **\$22k** | | |

**Table 5:** Lake Otamatearoa: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Fencing and Planting** | | | | | |
| 1a. Fencing margins for stock exclusion | 3 string electric $5/m | 900 m lake perimeter[cc] | $4,500 | Measurable reduction in indicator bacteria (some residual bacteria from waterfowl).[dd] Improved swimmable standard. | High |
| 1b. 1 m wide planted riparian margin | Native plantings[ee] $20,500/ha | 900m$^2$ | $18,450 | Little aesthetic benefit over current condition. | High |
| 1c. Land production lost | - | - | - | | |
| **1 Total (OPTION 1)** | | | **$15,750 + $7,200 operating** | | |
| 2a. Fencing margins for 10 m wide functional buffer and stock exclusion | 3 string electric $5/m | 1.026 km perimeter | $5,130 | Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. | Moderate-High |
| 2b. 10 m wide planted riparian margin | Planting $20,500/ha | 1.13 ha[ff] | $23,165 | Significant aesthetic benefits as well as function in reducing nutrient. | Moderate-High |
| 2a. Land production lost | $323 per ha per annum[gg] | 1.13 ha | $365 per annum | | |
| **2 Total (OPTION 2)** | | | **$19,255 + $9,405 operating** | | |

[cc] WONI database value of 845m lake perimeter.
[dd] Need for some margins to be maintained as open habitat for rare plants by grazing/mowing/herbicide.
[ee] PB2 grade plants @ 2500 stems/ ha ($5 planted) + maintenance to year 3 ($8,000/ha).
[ff] Estimated 10 m buffer area = 6 ha less area of lake, WONI database = 4.87 ha.
[gg] Based on catchment in sheep and beef class 4 $323 per ha, values from Appendix 9: Farms.

**Table 5 (cont.):** Lake Otamatearoa

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 3a. i) Fencing margins for 50 m functional buffer and stock exclusion | 3 string electric $5/m | 1.28 km perimeter | $6,420 | Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. | Moderate-High |
| 3a. ii) 50 m planted riparian margin | Planting $20,500/ha | 5.23 ha[hh] | $107,215 | Significant aesthetic benefits as well as function in reducing nutrient loadings. Improved water quality. Creation of significant bird habitat. | Moderate-High |
| 3a. iii) Land production lost | $323 per ha per annum | 5.23 ha | $1,690 per annum | | |
| **3a Total (OPTION 3)** | | | **$71,795 + $43,530 operating** | | |
| 3b i) Fenced margins of entire catchment | 3 string electric $5 / m | 3.42 km | $17,100 | Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. | Moderate-High |
| 3b ii) Afforestation of entire catchment | Planting $20,500/ha | 40.5 ha | $830,250 | Very significant aesthetic benefits as well as function in reducing nutrient loadings. Significantly improved water quality. Creation of significant bird habitat. | Moderate-High |
| 3b iii) Land production lost | $323 per ha per annum | 40.5 ha | $13,080 per annum | | |
| **3b Total (OPTION 3)** | | | **$523,350 + $337,080 operating** | | |

[hh] Estimated 50 m buffer area = 10.1 ha less area of lake, WONI database = 4.87 ha.

**Table 5 (cont.):** Lake Otamatearoa

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Weed control** | | | | | |
| 4a. Herbicide eradication of weed | Endothall product cost of $28 per litre for 800 L[ii] (recommended 3 ppm), applicator costs of $4k per application, compliance costs[jj] | 4 ha vegetated | $26,400 | Eradication of weed considered likely, but could be increased with repeat applications at lower concentration (higher cost), No/minimal impacts on marginal and native submerged vegetation. | Moderate. |
| **4a Total (OPTION 2)** | | | **$26,400** | | |
| 4b. Stock grass carp for weed eradication | $25 per 25 cm fish, 40 fish per vegetated ha + AEE + $7,000[kk] no containment costs | 4 vegetated ha | $11,000 | Eradication of weed within 2–5 years, but impacts on submerged and marginal vegetation values will occur until fish can be removed (questionable) or attrition by mortality (15–20 years). | High. |
| **4b Total (OPTION 3)** | | | **$11,000** | | |
| **Access** | | | | | |
| 5a. Public access to lake; entrance, car park, toilet, picnic area and jetty | $105,000 + $25,000 pa maintenance[ll] | 1 | $105,000 + $25,000 per annum maintenance | Significant access and recreational benefits | High. |

[ii] WONI database lake area = 4.87 ha.
[jj] Depending on level of consultation required.
[kk] Depending on level of consultation required.
[ll] Based on cost estimates from Waikato District Council, Waipa District Council and Beca Engineering Ltd.

**Table 5 (cont.):** Lake Otamatearoa

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 5b Purchase of land for access way | $4,037.50/ha[mm] | 0.5 ha | $2,020 | | Moderate. |
| **5 Total (OPTION 2)** | | | **$185,000 +** **$25,000 operating** | | |
| **Monitoring** | | | | | |
| 6a. Lake monitoring using LakeSPI | $2,100 pa | 1 | $2,100 | Monitor native and exotic submerged vegetation as an indicator of lake health. | High. |
| **6a Total (OPTION 2)** | | | **$2,100 operating** | | |
| 6b. Lake monitoring using LakeSPI and Trophic Lake Index | $2,100 pa + $9,235 pa for four visits | 1 | $11,235 | Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor trophic level index as an indicator of lake health. | High. |
| **6b Total (OPTION 3)** | | | **$11,235 operating** | | |

[mm] Based on sheep and beef class 4 $323 discounted at 8 percent over 30 years, values from Appendix 9: Farms.

**Table 6:** Lake Whangapee: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Fencing and Planting** | | | | | |
| 1a. Fencing margins for stock exclusion | 3 string electric $5/m | 29.5 km lake perimeter[nn] | Nil, required by EW rule | Reduced grazing pressure on turf plant communities. Limited reduction in indicator bacteria. Improved swimmable standard. | High. |
| 1b. 1 m wide planted riparian margin | Native plantings[oo] $20,500/ ha | 3 ha | $61,500[pp] | Little aesthetic benefit over current condition. | - |
| **1 Total (OPTION 1)** | | | **$37.5k + $24k operating** | | |
| 2a. Fencing margins for 10 m wide functional buffer and stock exclusion | 3 string electric $5/m | 29.6 km perimeter | Nil, required by EW rule | Reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. Reduced grazing pressure on turf plant communities. | Moderate-High. |
| 2b. 10 m wide planted riparian margin | Planting $20,500/ha [qq] | 29.5 ha | $604,750[rr] | Significant aesthetic benefits as well as function in reducing nutrient. | Moderate-High. |
| 2c. Land production lost | $1,467 per ha per annum[ss] | 29.5 ha | $43,280 per annum | | |
| **2 Total (OPTION 2)** | | | **$368,750 + $427,280 operating** | | |

[nn] GIS value of 29,544 m lake perimeter.
[oo] PB2 grade plants @ 2,500 stems/ ha ($5 planted) + maintenance to year 3 ($8,000/ha).
[pp] Includes 3 years of maintenance costs following planting.
[qq] PB2 grade plants @ 2,500 stems/ ha ($5 planted) + maintenance to year 3 ($8,000/ha).
[rr] Includes 3 years of maintenance costs following planting.
[ss] Based on dairy free drain $1,467 per ha, values from Appendix 9: Farms.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 3a. Fencing margins for 50 m + contour wide functional buffer and stock exclusion | 3 string electric $5/m | 124.1 km perimeter | $620,500 | Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. Reduced grazing pressure on turf plant communities. | Moderate-High. |
| 3b. 50 m + wetland & planted riparian margin | Planting $20,500/ ha | 1,730 ha | $35,465,000 | Significant aesthetic benefits as well as function in reducing nutrient loadings. Improved water quality. Creation of significant bird habitat. Reduced grazing pressure on turf plant communities. | Moderate-High. |
| 3c. Land production lost | $1,467 per ha per annum[tt] | 1,730 ha | $2,537,910 per annum | | |
| **3 Total (OPTION 3)** | | | **$22,245,500 + $16,377,910 operating** | | |
| 4a Fencing catchment margins | Post & batten fences $18 / m | 135 km catchment perimeter | $2,430,000 | Extreme reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. | High |
| 4b Planting of catchment | Planting $20,500/ ha | 28,105 ha[uu] | $576,152,500 | Very significant aesthetic benefits as well as function in reducing nutrient loadings. Significantly improved water quality. Creation of significant bird habitat. Reduced grazing pressure on turf plant communities. | High |

[tt] Based on dairy free drain $1,467 per ha, values from Appendix 9: Farms.
[uu] GIS total catchment area 31,721.4 ha less Wildlands consultants report 2009 8% catchment in native vegetation less WONI database lake area 1,078.62 ha.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | **Cost item** | **Quantity** | **Total cost** | | |
| 4c Land production lost | 90% of area $180 per ha per annum, 10% $1,467 per ha per annum[vv] | 29,295 ha[ww] | $9,043,205 per annum | | |
| **4 Total (OPTION 3)** | | | **$353,743,350 + $233,882,355 operating** | | |
| **Access** | | | | | |
| 5. Public access to lake; entrance, car park, toilet, picnic area and boat ramp | $505,000 + $25,000 per annum maintenance[xx] | 1 | $505,000 + $25,000 per annum | Significant access and recreational benefits. | |
| **5 Total (OPTION 2)** | | | **$505,000 + $25,000 operating** | | |
| **Monitoring** | | | | | |
| 6a. Lake monitoring using LakeSPI | $2,100 per annum | 1 | $2,100 per annum | Monitor native and exotic submerged vegetation as an indicator of lake health. | High |
| **6a Total (OPTION 2)** | | | **$2,100 operating** | | |

[vv] Based on 90% catchment in sheep and beef class 3 $180 per ha, 10% catchment in dairy free drain $1,467 per ha, values from Appendix 9: Farms.
[ww] GIS total catchment area 31,721.4 ha less 1,348.3 ha designated DOC reserve, Waikato District Council proposed plan 2009 less WONI database lake area 1,078.62 ha.
[xx] Based on cost estimates from Waikato District Council, Waipa District Council and Beca Engineering Ltd.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 6b. Lake monitoring using LakeSPI and Trophic Lake Index | $2,100 per annum + $9,235 per annum for 4 visits | 1 | $11,235 per annum | Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor trophic level index as an indicator of lake health. | High. |
| **6b Total (OPTION 3)** | | | **$11,235 operating** | | |
| **Willow control** | | | | | |
| 7a. i) Willow treatment aerial spraying followed by spot spraying (30% of area) | $600 / ha aerial spraying; $1,200 / ha spot spray[yy] + 10% maintenance costs + consent costs | 1,133 ha[zz] | $1,087,680 + 108,770 maintenance costs + consent costs | Significant aesthetic benefits as well as function in removal of a pest plant replaced by native wetland vegetation. Some non-target spray damage to native vegetation. | Moderate – high. Crack willow eradicated; grey willow spreads via seed so needs ongoing control. |
| 7a. ii) Replant treated willow area with flax wetland and kahikatea forest | Planting $20,500/ ha | 1,133 ha | $23,226,500 | Significant aesthetic benefits. Creation of significant bird habitat. Potential creation of harakeke resource for cultural harvest. | Moderate – high. |
| **7a Total (OPTION 2)** | | | **$15,250,180 + $9,172,770 operating** | | |

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[yy] Estimated costs from Waikato Conservancy Office, Department of Conservation: $600 / ha boom spray entire area; $1,200/ha spot spraying.
[zz] Estimated from aerial photographs area = 1,133 ha plus 50 percent repeat spray.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 7b. i) Willow treatment aerial spraying followed by spot spraying (30% of area) and drill & inject (30% of area)[aaa] | $600 / ha aerial spraying; $1,200 / ha spot spray[bbb]; $25,000 / ha drill & inject herbicide[ccc] + 10% maintenance costs + consent costs | 1,133 ha | $9,585,180 + $958,520 maintenance costs + consent costs | Significant aesthetic benefits as well as function in removal of a pest plant replaced by native wetland vegetation. Little non-target spray damage to native vegetation. | Moderate – high Crack willow eradicated; grey willow spreads via seed so likely to need ongoing control. |
| 7b. ii) Replant treated willow area with flax wetland and kahikatea forest | Planting $20,500/ha | 1,133 ha | $23,226,500 | Significant aesthetic benefits. Creation of significant bird habitat. Potential creation of harakeke resource for cultural harvest. | Moderate – high. |
| 7b. iii) Continue weed control of replanted willow area for a further 10 years | $700/ ha | 1,133 ha | $793,100 | Significant aesthetic benefits. Creation of significant bird habitat. Potential creation of harakeke resource for cultural harvest. | Moderate – high. |
| **7b Total (OPTION 3)** | | | **$23,747,680 + $10,815,620 operating** | | |

[aaa] Drill and inject can be used in sensitive areas where aerial spraying is not an option.
[bbb] Estimated costs from Waikato Conservancy Office, Department of Conservation: $600/ha boom spray entire area; $1,200 / ha spot spraying 30 percent of area.
[ccc] Cost estimates based on Waitakere City Council willow control drill and inject 2009/2010 to follow up 30 percent of area.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Farm contaminants** | | | | | |
| 8a. Constructed wetlands at lake inflows with infiltration filter[ddd] | $250,000/ha[eee] + $495/ha maintenance [fff] | 4 filters over 3.5 ha | $1,000,000[ggg] + $1,733 maintenance per annum | Removal of 80% sediments, 60% nitrogen and phosphorus, removal of organic forms of nitrogen and phosphorus, greater reduction of suspended sediments and E. coli.[hhh] Removes channelised flows to the lake and allows nutrient processing in the buffer zone. | Low-moderate. |
| 8a. Purchase of land for constructed wetlands at lake inflows with infiltration filter | $18,337.50/ha [iii] | 3.5 ha | $64,181 | | Low-moderate. |
| **8a Total (OPTION 2)** | | | **$1,064,181 + $1,733 operating** | | |
| 8b. Constructed wetlands at lake inflows with infiltration filter[jjj] | ii) $250,000/ha[kkk] + $495/ha maintenance [lll] | 7 filters over 6 ha | $1,750,000 [mmm] + $2,970 maintenance pa | Removal of 80% sediments, 60% N and P, removal of organic forms of nitrogen and phosphorus, greater reduction of suspended sediments and E. coli.[nnn] Removes channelised flows to the lake and allows nutrient processing in the buffer zone. | Moderate. |

[ddd] Maintenance costs and consent costs additional.
[eee] Based on indicative costs for Lake Mangahia; Bodmin et al., (2008). Lake Mangahia management recommendations for lake level, marginal vegetation and nutrient removal. Client report for EW.
[fff] Costs from McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance = $15/ha pa. Woodchip filter $4,800 / ha * 6 ha lasts for ten years then replace.
[ggg] Information on nutrient levels and drainage flows are required to calculate infiltration filter size plus consent costs.
[hhh] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.
[iii] Based on dairy free drain $1,467 per ha discounted at 8% over 30 years, values from Appendix 9: Farms.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 8b. Purchase of land for constructed wetlands at lake inflows with infiltration filter | $18,337.50/ha | 6 ha | $110,025 | | Low-moderate. |
| **8b Total (OPTION 3)** | | | **$1,860,025 + $2,970 operating** | | |
| 8c. Constructed wetlands at lake inflows[ooo] | $7,500/ha construction + $180/ha[ppp] land production lost + $15/ha maintenance [qqq] | 3% of catchment area = 921 ha[rrr] | $6,904,800 + $165,780 per annum lost production + $13,815 per annum maintenance | Removal of 80% sediments, 60% nitrogen and phosphorus, and ~90% *E. coli*[sss], | Moderate. |
| **8c Total (OPTION 3)** | | | **$6,904,800 + $179,595 operating** | | |

[jjj] Consent costs additional.
[kkk] Based on indicative costs for Lake Mangahia; Bodmin et al., (2008). Lake Mangahia management recommendations for lake level, marginal vegetation and nutrient removal.
[lll] Costs from McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance = $15 / ha pa. Woodchip filter $4,800 / ha * 6 ha lasts for ten years then replace.
[mmm] Information on nutrient levels and drainage flows are required to calculate infiltration filter size plus consent costs.
[nnn] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.
[ooo] Consent costs additional.
[ppp] Based sheep & beef class 3 $180 per ha, values from Appendix 9: Farms.
[qqq] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance $15 / ha pa.
[rrr] Based on indicative areas from McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.
[sss] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Sediment capping and removal** | | | | | |
| 9a. Sediment capping whole lake with alum followed by modified zeolite (Aqua-P) | $2,400 per tonne Aqua-P; + sediment test, calibration, monitoring + consent costs | 3,237 tonnes Aqua-P | $10,217,560 + costs for consents, management and monitoring | Reduce nutrients in water column and lake bed, particularly phosphorus. Aqua P removes phosphorus, arsenic, mercury and some ammonia, creates a thick cap on lake bed so that sediments are unlikely to become re-suspended. | Moderate. Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment capping. |
| **9a Total (OPTION 3)** | | | **$10,217,560** | | |
| 9b. Drain, dig out sediment, dry out. Possibly use for wave barrier? | $5,600,000 to $9,700,000[ttt] | 1 | $5,600,000 to $9,700,000 dependent on sediment disposal | Reduce nutrients and suspended sediment in lake water to improve water clarity and habitat for submerged plants. Option to reduce pest fish and aquatic weed whilst water levels lowered. | Moderate. Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment removal. |

[ttt] Beca Engineering Ltd estimate.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **9b Total (OPTION 3)** | | | **$9,700,000** | | |
| **Pest fish** | | | | | |
| 10a. Pest fish control by intensive netting. Cost may be partially recovered through commercial harvesting (agency driven) of pest fish | $50,000 equipment + $200,000 per annum [uuu] | 1 | $50,000 + $200,000 per annum | Decrease grazing and disturbance pressure on important native turf plant communities. | Low to moderate – risk of reinvasion from tributaries and Waikato River when flooding. |
| **10a Total (OPTION 2)** | | | **$50,000 + $200,000 operating** | | |
| 10b. Pest fish control treat lake and tributaries with piscicide followed by intensive netting. Cost may be partially offset by commercial harvesting of pest fish | Estimated at $1,000k[vvv] treat lake + $50k equipment + $200k per annum | 1,079 ha full lake + tributaries | $1,050,000 + $200,000 per annum | Significant decrease in grazing and disturbance pressure on important native turf plant communities, although ongoing control required to keep pest fish numbers down. | Low.[www] |
| **10b Total (OPTION 3)** | | | **$1,050,000 + $200,000 operating** | | |

[uuu] Based on Serpentine Lakes estimate scaled up for Lake Whangapee.
[vvv] Based on Lake Ohinewai estimates scaled up for Lake Whangapee.
[www] Pest fish re-introduced when Waikato River floods; difficult to kill all pest fish in tributaries; fish re-introduced from human activity.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Water level control** | | | | | |
| 11a. Bund along Glen Murray Rangiriri Rd with gates and fish pass | $3,000,000[xxx] | Bund 5 m[yyy] high and ~150 m long | $3,000k + $300k maintenance + consents + design, tip fees, landscaping and management costs | Allow greater water level fluctuations similar to historical levels, larger habitat area for fish, wetlands and lake margin vegetation. May improve water clarity. | Moderate. |
| **11 Total (OPTION 3)** | | | **$3,000k + $300k operating** | | |
| **Wave control** | | | | | |
| 12a. Wave barriers across arm entrances of lake using manuka brush barriers | $20,000 | 1 | $20,000 + $100,000 maintenance | Protect re-establishing submerged plants; reduce turbidity of water; improve water clarity. | Low-moderate will aid water within arms but little effect on main lake body. |

[xxx] Estimate based on gates and pass at Lake Waikare plus bund cost from Beca Engineering Ltd.
[yyy] Based on Waikato River fluctuations of 4 m from the Rangiriri flow gauge, Environment Waikato website.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **12a Total (OPTION 2)** | | | **$20,000 + $100,000 operating** | | |
| 12b. Wave barriers (causeway type) across arm entrances of lake (if sediment is suitable) | $4,182,060 [zzz] + ~10% maintenance | 3–4 | $16,728,240 + $1,672,825 operating | Protect re-establishing submerged plants; reduce turbidity of water; improve water clarity. | Low-moderate will aid water within arms but little effect on main lake body. |
| 12c. Replant emergent plants along lake shallows | $33,900 per ha + species translocation permit costs[aaaa] | 2.1 ha[bbbb] | $42,360 + $28,560 operating | Co-benefits to water quality, aesthetics and fish habitat are likely. Act as shelter belts of founder populations of submerged plants. | Moderate – would require improved water quality and pest fish control to attempt. |

[zzz] Based on cost estimates for Lake Waikare by Beca Engineering Ltd.
[aaaa] Estimated costs root trainer 10,000 plants / ha ($20,300 planted) + maintenance to year 3 ($13,600/ha) from Wildlands Consultants Ltd. These estimates exclude management costs, plant delivery costs, travel and expenses.
[bbbb] 10.42 km shoreline and 2 m wide plantings.

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 12d. Re-establish founder submerged plant communities | $22,000 per 10 $m^2$ + species translocation permit costs[cccc] | 40 m2 | $88k | Co-benefits to water quality, improved water clarity, aesthetics and fish habitat are likely. | Moderate. Would require improved water quality and pest fish control to attempt. |
| **12b-d Total (OPTION 3)** | | | **$16,858,600 + $1,701,385 operating** | | |
| **Weed control** | | | | | |
| 13a. Weed control of hornwort and egeria using herbicide (diquat) | $1,600/ha for diquat product and application + compliance costs | Treat 30% of lake, 324 ha[dddd] + annual control 10% of lake 108 ha[eeee] | $518,400[ffff] + annual control $172,640 | Reduced interference with recreational activities and access. Control of weed considered likely, but could be increased with repeat applications at lower concentration (higher cost), minimal impacts on marginal and native submerged vegetation. | Moderate[gggg]. |

[cccc] Based on Lake Ohinewai cost estimates.
[dddd] Lake area 1,079 ha from WONI database.
[eeee] Based on current practice in hydro lakes.

[ffff] Based on one full treatment.
[gggg] If actions improve water clarity, aquatic weeds will flourish and require control (depends on weed extent).

**Table 6 (cont.):** Lake Whangapee.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **13a Total (OPTION 2)** | | | **$518,400 + $172,640 operating** | | |
| 13b. Stock grass carp for weed control | $25 per 25 cm fish, 40 fish per vegetated ha, + AEE + costs for compliance and containment | Weed bed estimate 80% of lake, 864 ha | $864,000 | Eradication of weed within 2–5 years, but reinvasion will occur when the Waikato River floods. Grass carp will impact on marginal vegetation values until fish can be removed (questionable) or attrition by mortality (15–20 years). | Low[hhhh] |
| **13b Total (OPTION 3)** | | | **$864,000** | | |

[hhhh] If actions improve water clarity, aquatic weeds will flourish and require control. Re-establishment risk from Waikato River, tributaries and human activity such as boats.

**Table 7:** Lake Ohakurii: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | **Cost item** | **Quantity** | **Total cost** | | |
| **Fencing and planting** | | | | | |
| 1a. Fencing margins for stock exclusion in Whirinaki Arm | 3 string electric $5/m | 14.15 km lake perimeter[iiii] | $70,750 | Measurable reduction in indicator bacteria (some residual from waterfowl). | High. |
| 1b. 1 m wide planted riparian margin in Whirinaki Arm | Native plantings[jjjj] $20,500/ha | 1.4 ha | $28,700 | Little aesthetic benefit over current condition. | High. |
| **1 Total (OPTION 1)** | | | **$88,250 +$11,200 operating** | | |
| 2a. Fencing margins for 10 m wide functional buffer and stock exclusion main lake | 3 string electric $5/m | 25 km perimeter[kkkk] | Covered in Appendix 9: Farms | Reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. | Moderate-High. |
| 2b. 10 m wide planted riparian margin on main lake (5 m planting) | Planting $20,500/ha | 25 ha * 0.5 | $256,250 | Significant aesthetic benefits as well as function in reducing nutrient. | Moderate-High. |
| 2c. Land production lost on main lake (5 m covered in Appendix 9: Farms) | 80% $1,473 per ha per annum, 20% $180/ha/annum[llll] | 25 ha * 0.5 | $15,180 per annum | | |
| **2 Total (OPTION 2)** | | | **$156,250 + $15,280 operating** | | |

[iiii] Estimated perimeter of Whirinaki Arm 14,150 m.
[jjjj] PB2 grade plants @ 2,500 stems/ ha ($5 planted) + maintenance to year 3 ($8,000/ha).
[kkkk] Estimated perimeter of Lake Ohakuri excluding Whirinaki Arm 25,117 m.
[llll] Based on 80% catchment in dairy poor drain $1,473 per ha, 20% in sheep & beef class 3 or forestry $180 per ha, values from Appendix 9: Farms.

**Table 7 (cont):** Lake Ohakurii.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 3a Fencing margins for 50 m + contour wide functional buffer and stock exclusion of main lake | 3 string electric $5/m | 33 km catchment perimeter [mmmm] | $164,900 | Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. | High. |
| 3b 50 m+ wetland and planted riparian margin of main lake (5 m covered in Appendix 9: Farms) | Planting $20,500/ha | 144 ha[nnnn] | $2,949,950 | Very significant aesthetic benefits as well as function in reducing nutrient loadings. Significantly improved water quality. Creation of significant bird habitat. | High. |
| 3c Land production lost on main lake (5 m covered in Appendix 9: Farms) | $180 per ha per annum[oooo] | 144 ha | $25,900 per annum | Avoid increase in sediment and nutrients at time of forestry harvest. | Moderate. |
| **3 Total (OPTION 3)** | | | **$1,963,650 + $1,177,100 operating** | | |
| 4a. Fencing margins for 50 m+ contour wide functional buffer and stock exclusion in Whirinaki Arm | 3 string electric $5/m | 14 km perimeter | $70,000 | Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. Reduced grazing pressure on turf plant communities. | Moderate-High. |
| 4b. 50 m+ wetland and planted riparian margin in Whirinaki Arm | Planting $20,500/ha | 61.1 ha[pppp] | $1,252,550 | Significant aesthetic benefits as well as function in reducing nutrient loadings. Improved water quality. Creation of significant bird habitat. Reduced grazing pressure on turf plant communities. | Moderate-High. |

[mmmm] Estimated 50 m perimeter of Lake Ohakurii excluding Whirinaki Arm 45,540 m less fencing of 5 m buffer covered in Appendix 9: Farms 12,560 m.
[nnnn] Estimated 50 m+ buffer for Lake Ohakurii excluding Whirinaki Arm 1,096.4 ha less WONI database lake area 939.976 ha m less 5 m planted buffer covered in Appendix 9: Farms 12.5 ha.
[oooo] Based on Appendix 9: Farms value for sheep and beef class 3 land and forestry estimated at similar land value $180 per ha.
[pppp] Estimated area 50 m+ buffer = 151 ha less lake area for Whirinaki Arm = 89.9 ha.

**Table 7 (cont):** Lake Ohakurii.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 4c. Land production lost in Whirinaki Arm | 80% $1,473 per ha per annum, 20% $180/ha/annum | 61.1 ha | $74,200 per annum | | |
| **4 Total (OPTION 3)** | | | **$833,750 + $563,000 operating** | | |
| 5a Fencing catchment margins in Whirinaki Arm | Post & batten fences $18/m | 86.4 km catchment perimeter [qqqq] | $1,555,200 | Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings . | High |
| 5b Planting of catchment in Whirinaki Arm | Planting $20,500/ha | 16,372 ha[rrrr] | $335,626,000 | Very significant aesthetic benefits as well as function in reducing nutrient loadings. Significantly improved water quality. Creation of significant bird habitat. Reduced grazing pressure on turf plant communities. | High |
| 5c Land production lost in Whirinaki Arm | 80% $1,473 per ha per annum, 20% $180 per ha per annum | 16,372 ha | $19,882,160 per annum | | |
| **5 Total (OPTION 3)** | | | **$206,205,200 + $150,858,160 operating** | | |

[qqqq] GIS Whirinaki Arm catchment perimeter = 86.4 km.
[rrrr] GIS Whirinaki catchment area 16,461 ha less lake area for Whirinaki Arm = 89 ha.

**Table 7 (cont):** Lake Ohakurii.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Access** | | | | | |
| 6. Public access to lake; entrance, car park, toilet, picnic area and boat ramp | Completed | | $25k pa maintenance | Already completed. | - |
| **6 Total (OPTION 2)** | | | **Nil** | Already completed. | |
| **Monitoring** | | | | | |
| 7a. Lake monitoring using LakeSPI | $2,100 pa | 1 | $2,100 | Monitor native and exotic submerged vegetation as an indicator of lake health. | High. |
| **7a Total (OPTION 2)** | | | **$2.1k operating** | | |
| 7b. Lake monitoring using LakeSPI and Trophic Lake Index | $2,100 pa + $9,235 pa for four visits | 1 | $11,235 | Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor trophic level index as an indicator of lake health. | High. |
| **7b Total (OPTION 3)** | | | **$11,235 operating** | | |

**Table 7 (cont):** Lake Ohakurii.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Farm contaminants** | | | | | |
| 8. Constructed wetlands at lake inflows in Whirinaki Arm | $7.5k/ha construction + $1,473/ha pa lost land production[ssss] + $15/ha maintenance [tttt] | 3%[uuuu] of catchment area = 491 ha | $3,682,500 + $727,660 pa land production + $7,410 pa maintenance | Removal of 80% sediments, 60% nitrogen and phosphorus, and ~90% *E. coli*[vvvv] | Moderate. |
| **8 Total (OPTION 2)** | | | **$3,682,500 + $735,070 operating** | | |
| **Sediment capping** | | | | | |
| 9a. Sediment capping Whirinaki Arm with alum followed by modified zeolite (Aqua-P) | $650 per tonne alum; $2,400 per tonne Aqua-P; + management + consent costs | 135 tonnes alum; 270 tonnes Aqua-P | $1,200,700 + costs for consents, management and monitoring | Reduce nutrients in water column and lake bed, particularly phosphorus. Aqua P removes phosphorus, arsenic, mercury and some ammonia, creates a thick cap on lake bed so that sediments are unlikely to become re-suspended. | Moderate. [wwww] |
| **9a Total (OPTION 3)** | | | **$1,200,700** | | |

[ssss] Based on Appendix 9: Farms, value for dairy poor drain value $1,473 per ha.
[tttt] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance $15 / ha pa.
[uuuu] 3% based on McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. GIS Whirinaki catchment area 16,461 ha = 494 ha.
[vvvv] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.
[wwww] Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment capping.

**Table 7 (cont):** Lake Ohakurii.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | **Cost item** | **Quantity** | **Total cost** | | |
| 9b. Sediment capping main lake body with alum followed by modified zeolite (Aqua-P) | $650 per tonne alum; $2,400 per tonne Aqua-P; + management + consent costs | 1,410 tonnes alum; 2,820 tonnes Aqua-P | $9,623,050 + costs for consents, management and monitoring | Reduce nutrients in water column and lake bed, particularly phosphorus. Aqua P removes phosphorus, arsenic, mercury and some ammonia, creates a thick cap on lake bed so that sediments are unlikely to become re-suspended. | Moderate. [xxxx] |
| **9b Total (OPTION 3)** | | | **$9,623,050** | | |
| **Weed control** | | | | | |
| 10. Whirinaki Arm weed control using herbicide: endothall for hornwort, diquat for egeria (one full treatment + follow up one third the area) | $5,600/ha[yyyy] for endothall + applicator costs + compliance costs; $1,600/ha for diquat product and application | Weed bed estimate[zzzz] 25% of lake for hornwort (62.5 ha) and egeria (62.5 ha) | $585,000 + $40,000 per annum | Reduced interference with recreational activities and access. No/minimal impacts on marginal and native submerged vegetation. | High. |
| **10 Total (OPTION 2)** | | | **$585,000 + $40,000 operating** | | |

[xxxx] Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment capping.
[yyyy] Based on the rates used at Lake Otamatearoa.
[zzzz] Wells et al., (2000). Mighty River Power aquatic weeds: issues and options.

**Table 7 (cont):** Lake Ohakurii.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| 11. Weed control using herbicide: endothall for hornwort, diquat for egeria (one full treatment + follow up half the area) | $5,600/ha[aaaaa] for endothall + applicator costs + compliance costs; $1,600/ha for diquat product and application | Weedbed estimate[bbbbb] 25% of lake for hornwort (235 ha); 10% lake for egeria (94 ha) | $2,199,600 + $150,400 per annum | Reduced interference with recreational activities and access. No/minimal impacts on marginal and native submerged vegetation. | High. |
| **11 Total (OPTION 2)** | | | **$2,199,600 + $150,400 operating** | | |
| **Dam removal** | | | | | |
| 12. Remove dam, lake reverts to river with flushing flows | $ lost power generation + dam decommission costs | 1 | $ lost power generation + dam decommission costs | Aquatic weeds largely removed. Habitat changes from lake to river environment. Changes to recreational activities. Disruption of entire ecosystem with reduced water clarity for many years. | Low. |
| **12 Total (OPTION 3)** | | | **$ Extensive** | | |

[aaaaa] Based on the rates used at Lake Otamatearoa.
[bbbbb] Wells, R., Clayton, J., Schwarz, A., Hawes, I., Davies-Colley, R. (2000). Mighty River Power aquatic weeds: issues and options.

**Table 8:** Lake Puketirini (Weavers): summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome.

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Fencing and Planting** | | | | | |
| 1a. 10 m wide planted riparian margin stabilisation and aesthetics | Native plantings[ccccc] $20,500/ h[a] | 2.8 ha | $57,400 | Very significant aesthetic benefits. Maintain or improve water quality. Creation of significant bird habitat. | High. |
| 1b. Land production lost | $180 per ha per annum[ddddd] | 2.8 ha | $500 per annum | Very significant aesthetic benefits. Maintain or improve water quality. Creation of significant bird habitat. | High. |
| **1. Total (OPTION 2)** | | | **$35,000 + $22,900 operating** | | |
| 2a. Extend plantings on mine tailings for stabilisation and aesthetics | Native plantings $20,500/ ha | 70 ha[eeeee] | $1,435,000 | Very significant aesthetic benefits. Maintain or improve water quality. Creation of significant bird habitat. | High. |
| 2b. Land production lost | $180 per ha per annum | 70 ha | $12,600 per annum | Very significant aesthetic benefits. Maintain or improve water quality. Creation of significant bird habitat. | High. |
| **2. Total (OPTION 3)** | | | **$875,000 + $572,600 operating** | | |

[ccccc] PB2 grade plants @ 2,500 stems/ ha ($5 planted) + maintenance to year 3 ($8,000/ha).
[ddddd] Based on catchment in sheep & beef class 3 $180 per ha, values from Appendix 9: Farms.
[eeeee] Estimated catchment area 112 ha less lake area 41.6 ha.

**Table 8 (cont):** Lake Puketirini (Weavers).

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **Pest fish** | | | | | |
| 3a. Pest fish control by intensive netting. Cost may be partially recovered through commercial harvesting (agency driven) of pest fish | $70,000 initial control then $30,000 per annum[fffff] | 1 | $70,000 + $30,000 per annum | Flow on effects for reduced internal nutrient loading, improved water clarity and habitat for submerged plants | Low-moderate.[ggggg] |
| 3b. Selective fish pass for tuna, lamprey iinanga and other galaxiids (whitebait) / pest fish barrier | Up to 5 m ramp $50,000 + annual maintenance $10,000[hhhhh] | 1 | $50,000 + annual maintenance $10,000 | Allows upstream fish passage. Eel passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked. A fish passage to allow native but not exotic fish would require further research. | Moderate. [iiiii] |
| **3. Total (OPTION 2)** | | | **$50,000 + $110,000 operating** | | |
| **Weed control** | | | | | |
| 4a. Weed control using herbicide | $1,600/ha for diquat product and application | 2.8 ha[jjjjj] | $4,480 + consent costs + annual maintenance | Reduced interference with recreational activities, access. No/minimal impacts on marginal and native submerged vegetation. | Moderate.[kkkkk] |

[fffff] Based on cost estimated by DOC for Serpentine Lakes (See Lake Serpentine Management Action Plan report).
[ggggg] Difficult to capture due to lake depth, unknown risk of flooding allowing passage of pest fish from Lake Waahi.
[hhhhh] As estimated by Dr. Jacques Boubée, NIWA.
[iiiii] Unknown risk of flooding allowing passage of pest fish from Lake Waahi.
[jjjjj] Estimated area of *Egeria densa* and *Ceratophyllum demersum* weedbeds averaged at 10 m wide around lake perimeter of 2.803 km.
[kkkkk] Risk of reinvasion from Lake Waahi and from recreation boat traffic likely to be high.

**Table 8 (cont):** Lake Puketirini (Weavers).

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **4a. Total (OPTION 2)** | | | **$4,480 operating** | | |
| 4b. Stock grasscarp for weed eradication | $25 per 25 cm fish, 40 fish per vegetated ha + AEE and containment costs | 2.8 ha | $2,800 | Eradication of weed within 2–5 years, but impacts on marginal vegetation values, including native vegetation, will occur until fish can be removed (questionable) or attrition by mortality (15–20 years). | Moderate.[lllll] |
| **4b. Total (OPTION 3)** | | | **$2,800** | | |
| **Erosion** | | | | | |
| 5. Reduce shoreline disturbance by boater speed limit or access to shoreline; plant 2 m marginal reed beds around lake | $20,300 / ha[mmmmm] | 0.56 ha | $11,370 | Current extent of marginal plants unknown. Enhance native vegetation fringe around lake, improved aesthetics and habitat for waterfowl | Moderate.[nnnnn] |
| **5. Total (OPTION 3)** | | | **$11,370** | | |
| **Access** | | | | | |
| 6. Public access to lake; picnic area | $5k[ooooo] | 1 | $5k + $25k per annum maintenance for all public facilities | Enhanced public access and recreational facilities. Current facilities include access, car park, toilets, 2 jetties and a slipway. | High. |

[lllll] Re-establishment risk from Lake Waahi and from recreation boat traffic likely to be high.
[mmmmm] Estimated costs root trainer 10,000 plants ha ($20,300 planted) + maintenance to year 3 ($13,600/ha) from Wildlands Consultants Ltd. These estimates exclude management costs, plant delivery costs, travel and expenses.
[nnnnn] Little other suspended sediment or nutrient loading sources.
[ooooo] Based on cost estimates from Waikato District Council for similar projects completed by Council.

**Table 8 (cont):** Lake Puketirini (Weavers).

| Action | Costs | | | Benefit | Certainty of outcome |
|---|---|---|---|---|---|
| | Cost item | Quantity | Total cost | | |
| **6. Total (OPTION 2)** | | | **$5,000 + $25,000 operating** | | |
| **Monitoring** | | | | | |
| 7a. Lake monitoring using LakeSPI | $2,100 | 1 | $2,100 | Monitor native and exotic submerged vegetation as an indicator of lake health. | High. |
| **7a. Total (OPTION 2)** | | | **$2,100 operating** | | |
| 7b. Lake monitoring using LakeSPI and Trophic Lake Index | $2,100 pa + $9,235 pa for four visits | 1 | $11,135 | Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor trophic level index as an indicator of lake health. | High. |
| **7b. Total (OPTION 3)** | | | **$11,235 operating** | | |

**Table 9:** Summary of estimated costs for six example lakes, giving ranges based on three restoration options.

| **Lake** | **Size** | **Option 1** | | | **Option 2** | | | | **Option 3** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **ha** | **Upper** | | | **Lower** | **Upper** | | | **Lower** | **Upper** | **Upper** | |
| | | **CAPEX** | **OPEX** | **Frequency of OPEX ys** | **CAPEX** | **CAPEX** | **OPEX** | **Frequency of OPEX ys** | **CAPEX** | **CAPEX** | **OPEX** | **Frequency of OPEX ys** |
| Ohakurii | 940 | $88,250 | $3,733 | 3 | $4,444,975 | $4,444,975 | $33,333 | 3 | $8,094,025 | $223,695,225 | $44,042,400 | 3 |
| | | | $25k | 30 | | | $792,352 | 30 | | | $20,804,766 | 30 |
| Serpentine | 10 | $0 | $0 | 3 | $469,045 | $485,545 | $17,067 | 3 | $2,622,840 | $3,170,840 | $371,733 | 3 |
| | | | $0 | 30 | | | $127,709 | 30 | | | $224,085 | 30 |
| Puketirini | 42 | $0 | $0 | 1 | $90,000 | $90,000 | $70,000 | 1 | $932,800 | $944,168 | $70,000 | 1 |
| | | | $0 | 3 | | | $7,467 | 3 | | | $186,667 | 3 |
| | | | $25k | 30 | | | $72,084 | 30 | | | $91,374 | 30 |
| Ohinewai | 17 | $0 | $0 | 1 | $220,750 | $220,750 | $100,000 | 1 | $1,142,120 | $4,746,220 | $0 | 1 |
| | | | $0 | 3 | | | $9,600 | 3 | | | $836,800 | 3 |
| | | | $0 | 30 | | | $103,403 | 30 | | | $140,476 | 30 |
| Otamatearoa | 5 | $15,750 | $2.4k | 3 | $152,677 | $152,677 | $3,013 | 3 | $189,817 | $641,372 | $108,000 | 3 |
| | | | $0 | 30 | | | $27,465 | 30 | | | $49,317 | 30 |
| Whangapee | 1,079 | $37.5k | $0 | 1 | $17,258,111 | $17,258,111 | $0 | 1 | $70,381,575 | $415,939,260 | $0 | 1 |
| | | | $8k | 3 | | | $3,100,000 | 3 | | | $77,977,520 | 3 |
| | | | $0 | Yr 4 on | | | $793,100 | Yr 4 on | | | $793,100 | Yr 4 on |
| | | | $0 | Yr 11 on | | $518,400 | $172,640 | Yr 11 on | | $952,000 | | Yr 11 |
| | | | $0 | 30 | | | $480,877 | 30 | | | $12,390,378 | 30 |

**Table 10:** Estimated costs for restoration of selected shallow Waikato lakes, by lake type.

| Lake type | Number | Lake | Lake size | Option 2 | | | Option 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | (of lakes) | | (ha) | CAPEX | OPEX | Frequency of OPEX ys | CAPEX | OPEX | Frequency of OPEX ys |
| Hydro | 1 | Ohakurii | 940 | $4,444,975 | $33,333 | 3 | $13,483,025 | $33,333 | 3 |
| | | | | | $752,099 | 30 | | $761,234 | 30 |
| Peat | 4 | Serpentine | 100 | $485,545 | $17,067 | 3 | $2,943,340 | $371,733 | 3 |
| | | | | | $127,709 | 30 | | $201,335 | 30 |
| | | 3 generic peat lakes | 600 | $1,214,588 | $210,000 | 1 | $6,412,988 | $0 | 1 |
| | | | | | $102,400 | 3 | | $102,400 | 3 |
| | | | | | $426,610 | 30 | | $785,263 | 30 |
| Dune | 2 | Otamatearoa | 5 | $157,055 | $3,013 | 3 | $194,195 | $13,947 | 3 |
| | | | | | $27,465 | 30 | | $37,924 | 30 |
| | | 1 other dune lake | 5 | $157,055 | $3,013 | 3 | $194,195 | $13,947 | 3 |
| | | | | | $27,465 | 30 | | $37,924 | 30 |
| Large riverine | 2 | Whangapee | 1,079 | $2,142,436 | $215,600 | 3 | $32,654,170 | $4,789,600 | 3 |
| | | | | | $46,270 | Yr 4 on | | $46,270 | Yr 4 on |
| | | | | | $518,400 | Yr 11 | $952,000 | $0 | Yr 11 |
| | | | | | $290,765 | 30 | | $1,932,051 | 30 |
| | | Waahi | 445 | $432,890 | $38,000 | 3 | $7,146,844 | $4,624,000 | 3 |
| | | | | | $2,800 | Yr 4 on | | $2,800 | Yr 4 on |
| | | | | | $177,829 | Yr 11 | $443,658 | $0 | Yr 11 |
| | | | | | $254,624 | 30 | | $523,610 | 30 |
| | | **Total CAPEX** | | $9,034,544 | | | $64,424,416 | | |

### 6.1 Cost abatement

Abatement costs for restoring six shallow lakes have been calculated. Costs are based on total capital and operational costs over 30 years discounted at 8 percent. Operational costs for planting have been estimated over 3 years. The difficulty in identifying specific environmental outcomes for each lake resulted in using $ per hectare restored comparisons. Abatement costs have been calculated for both restoration options 2 and 3.

**Table 10:** Total and per ha costs for restoring shallow lakes under restoration option 2**.**

| Lake name | Lake size (ha) | Net Present Value (NPV) $ | $ per ha |
|---|---|---|---|
| Lake Ohakurii | 940 | 13,121,748 | 13,960 |
| Lake Puketirini | 42 | 978,897 | 23,531 |
| Lake Whangapee | 1,079 | 37,274,443 | 34,558 |
| Lake Ohinewai | 17 | 1,485,817 | 87,043 |
| Lake Otamatearoa | 5 | 458,328 | 94,113 |
| Serpentine Lakes | 10 | 1,931,276 | 186,597 |

For option 2, the most cost-effective per hectare combined restoration actions are Lake Ohakurii and Puketirini. The most expensive per hectare action to restore are the Serpentine Lakes - by a factor of nearly 14 times when compared to the cheapest action. This is caused by the relative high restoration costs for any particular lake and the small size of the Serpentine Lakes. Lake Whangapee and Ohakurii are relatively cost-effective to restore, because of the large size of these lakes averaging around 1,000 ha each, whereas all other lakes are relatively small, averaging between 5 to 42 ha.

In terms of total costs, the most cost-effective actions are to restore Lake Otamatearoa, and Puketirini. By far the most expensive restoration is Lake Whangapee. This cost comparison can be used if the per hectare comparison is thought to be limiting in terms of environmental improvements achieved as result of restoration.

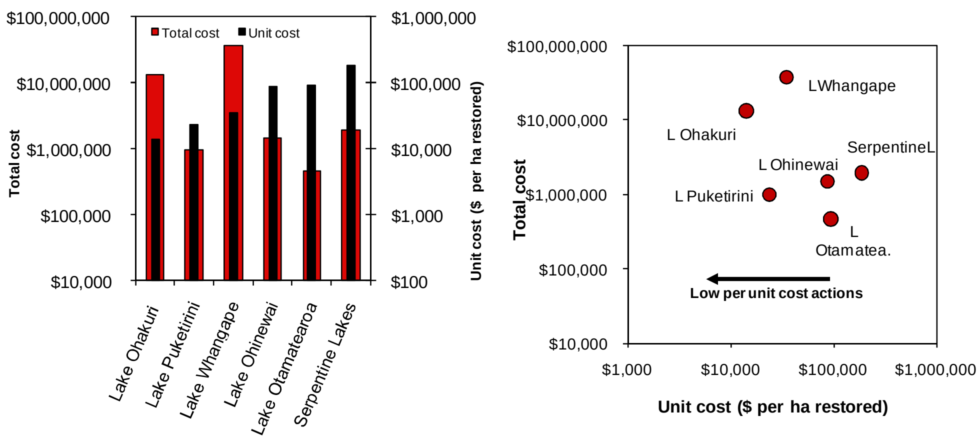


**Figure 1:** Total and per ha costs for restoring shallow lakes under restoration option 2.

The table below shows the total capital and operational costs for restoring all six shallow lakes for the EBMP scenario.

**Table 11:** Total and per ha costs for restoring shallow lakes under restoration option .3

| Lake name | Lake size (ha) | Net Present Value (NPV) ($thousands) | $ per ha |
|---|---|---|---|
| Lake Puketirini | 41.60 | 2,438 | 58,612 |
| Lake Otamatearoa | 4.87 | 1,427 | 293,097 |
| Lake Ohinewai | 17.07 | 8,133 | 476,427 |
| Lake Whangapee | 1,078.62 | 597,299 | 553,762 |
| Lake Ohakurii | 939.98 | 554,842 | 590,270 |
| Serpentine Lakes | 10.35 | 6,417 | 619,967 |

For option 3, the most cost-effective per hectare combined restoration action is Lake Puketirini followed by Lake Otamatearoa. The latter is more expensive to restore per hectare by a factor of 5 due to the smaller size of this lake. The most expensive per hectare action to restore are the Serpentine Lakes and Lake Ohakurii, followed by Lake Whangapee and Ohinewai. Most lakes have similar per hectare abatement costs apart from Lake Puketirini and Otamatearoa, which are the most cost effective to restore on per hectare basis.

In terms of total costs, the most cost-effective actions are to restore Lake Otamatearoa and Puketirini. By far the most expensive restoration actions are Lake Ohakurii and Whangapee by a factor of between 68 to 73 than the next most cost effective option (Lake Ohinewai).

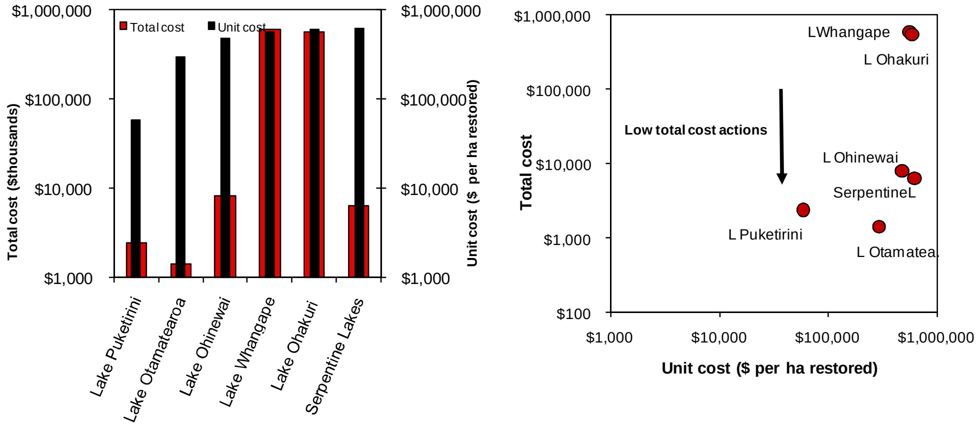


**Figure 2:** Total and per ha costs for restoring shallow lakes under restoration option 3.

It is difficult to compare both options 2 and 3 in terms of costs, as there is a very large difference in total restoration costs and related actions. However, to implement option 3, costs are larger for all lakes – by a factor of between 3 to 14 times more expensive on a per hectare basis.

An important point is that lake restoration activities will interact with and be affected by other restoration actions. For example is riparian fencing and protection is not undertaken in the upper catchment nutrient rich water will continue to flow into the lakes downstream hampering any attempts to control nutrients within the lakes. Therefore the cost of undertaking those other restoration activities needs to be considered in conjunction with the costs identified here for lake restoration.

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