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Potential for Reducing the Nutrient Loads from the Catchments of Shallow Lakes in the Waikato Region

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Abstract

The poor water quality of many of the shallow lakes of the Waikato region is of concern. Many of the lakes have intensive land use within their catchments, which has contributed to an overall decline in water quality and a loss of indigenous biodiversity.

We undertook a scoping exercise to determine the extent to which the sediment and nutrient loads within the catchments of 44 shallow lakes of the Waikato region could be reduced. A geographic information system (GIS) was utilised to determine the catchments' extents and land cover.

Water quality data from the regional rivers monitoring programme was used to develop a multiple linear regression model of the relationship between land cover and nutrient load (R^2 = 0.96 for both nitrogen and phosphorus). The resulting coefficients were used with the lakes' catchment land cover data to estimate the nutrient loads to the studied lakes. The modelled nutrient loads were then modified according to hypothetical 'best practice' and 'potential practice' farm management regimes to determine the reductions they would achieve.

Overall, an average reduction of 7% in the nitrogen load was found when moving from 'average' to 'best practice'. Under the more rigorous 'potential practice', this would increase to 36%. For the phosphorus load to the lakes, the 'best practice' management would mean an average reduction of 18% across all lakes. The use of a 'potential practice' farming regime would result in an average reduction of 39% in phosphorus over all the lakes. The results obtained enable the lakes to be identified based on potential reduction in nutrients under the hypothetical farm management regimes.

An estimate of current sediment load to the lakes was calculated based on a national sediment model. Possible reductions in sediment loads to the lakes under different land management practices have not been quantified, so any potential reduction in loads were not calculated for the lakes.

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1 Introduction

1.1 Background

The water quality of shallow lakes in the Waikato region is of concern. There has been a trend of declining water quality in many of the shallow lakes. A key cause of decline in water quality is the increase in nutrients entering the lakes due to land use practices. This decline in water quality has been accompanied in many cases by a loss of indigenous biodiversity (Barnes 2002). The University of Waikato was recently commissioned by Environment Waikato to investigate the possible methods for internal (bottom sediment) nutrient removal and their suitability for use in the Waikato peat lakes (Faithful et al., 2006). Key findings include:

"any technique available to reduce the internal nutrient load will be less effective if the external nutrient load of the target lake is not significantly reduced prior to treatment" (Faithful et al., 2006, p. 80).
and
"Before a pilot study is carried out to reduce internal nutrient load, it is recommended the external nutrient load of the target lake(s) is reduced substantially, to the order of 50% for most lakes where the catchment is highly modified" (Faithful et al., 2006,p. 2).

Faithful *et al.* (2006) also p. 80 recommended that:
"a thorough analysis of the feasibility, methods and costs of reducing external nutrient load are examined and applied to the target lake before utilizing internal nutrient load controls."

1.2 Objectives

The aim of this study was to assess the extent to which the current nutrient and sediment loads to many of the shallow lakes in the Waikato region could be reduced. The specific objectives of this scoping exercise were as follows:

- identify the catchment of each lake
- determine the different types of land cover in the catchment of each of the lakes
- develop a model of the relationship between nutrient load and land cover using river water quality data
- estimate how much nitrogen and phosphorus was entering each lake using the water quality model
- estimate the loads of sediment from the catchment to each lake
- estimate the extent to which the loads of nutrients and sediments could be reduced by altering land management practices within the catchment.

1.3 Approach and limitations

1.3.1 Approach

Internationally, a number of approaches have been used to estimate catchment-scale nutrient loadings (e.g. Gillingham and Thorrold, 2000; van Griensven et al., 2006; McIntyre et al., 2006; Smith et al., 2005). In this study the approach to estimating nutrient loadings was as follows:

1. Catchments of 22 Waikato region surface water quality monitoring sites were identified. For each catchment, the number of hectares of land in each of four land-use types was estimated. The four land-use types were dairy pasture, drystock pasture, surface water, and other land (not agriculturally developed, forested or urban).

2. Monitoring data for nutrient (nitrogen and phosphorus) concentrations in surface waters from the 22 sites was used to derive an empirical relationship between land-use and water quality. This regression equation can be used to predict average nutrient loadings (kg/ha) in surface water of a given Waikato catchment, based on the proportion of land in that catchment which falls into each of the four land-use types: dairy pasture, drystock pasture, surface water, and other land.

3. Catchments of 44 Waikato lakes were identified, and the number of hectares of land in each of four land use types was estimated. The regression equation (see item 2) was then used to estimate the most likely nutrient loads (kg/ha) in each of the 44 lake catchments.

The approach to estimating possible improvements that might be achieved by better dairy or drystock farming practices was as follows:

1. Ledgard and Power (2006) have estimated nutrient loadings for three farm management regimes for both dairy farms, and sheep and beef farms. The regimes include an average farm, a 'best practice' farm, and a ‘potential’ farm (with the last category representing best possible nutrient management). Nutrient losses decrease in moving from 'average' to 'best practice' to 'potential' farming. Nutrient loads under 'average' conditions had been estimated (see item 3 above) and were taken to represent the current baseline condition.

2. For each of the 44 lake catchments, data from Ledgard and Power (2006) was used to estimate improvements possible in moving from 'average' to either 'best practice' or 'potential' farm nutrient management regimes. This was done with regard to the proportion of each type of land (dairy pasture, drystock pasture, surface water, and other land) in each lake catchment. Percentage improvements possible in each catchment were recorded.

1.3.2 Limitations

It should be noted that results of this work apply only at a general level, to give an indication of the magnitude of improvements possible with the better farm nutrient management approaches.

Results of this work may accurately describe the specific situation at any one of the 44 lakes used as part of the data analysis. However, there may also be significant differences between indicative numbers calculated in this desk-top exercise and those observed in any specific lake, depending on the significance of local factors.

Such site-specific factors and other confounding trends that this analysis does not attempt to take in to account might include the following.

- Time delays and buffering that may occur, which may introduce lags in a system between the time better nutrient management is adopted and any resulting improvements down-catchment (Schippers et al., 2006).

- The possibility that in cases where groundwater inputs are significant, they may respond in a different way to surface water inputs[1] (McIntyre et al., 2006).

- The relative significance of intense rainfall events (where rainfall rate exceeds the soil infiltration rate) that are likely to cause overland water flow resulting in a periodic flush of nutrients from farmland to receiving lakes (Drewry et al., 2006).

[1] In this analysis it has implicitly been assumed that whatever the contribution made by groundwater to a given lake, the proportional improvement experienced in surface water would also be seen in groundwater.

- The true efficacy of riparian margins in removing nutrients, which relates to the proportion of total nutrient mass which is present in the dissolved phase compared with that present as particulates (Drewry et al., 2006).

- Whether stock have direct access to waterways, and the proportion of aerially applied fertiliser lost directly by drift into waterways. Cooke (1988) cited by Gillingham and Thorrold (2000) estimated that 20% of the annual phosphorus export from one small catchment could be accounted for by aerially applied fertiliser falling directly onto waterways and permanently saturated soils.

- Factors that may effect the relative amount of nitrogen and phosphorus that are retained in a given lake by being adsorbed to sediments (net inputs), and the fraction which passes through or is released (net exports).

- The relative biological availability and uptake of nutrients from the lake sediment reservoir.[2]

- The extent to which increased sedimentation may (a) bury nutrients stored in older sediments and render them less available, or (b) dilute the concentration of nutrients in new surface sediments; and the significance of these effects.

- The extent to which decreased sedimentation may increase the relative concentration of nutrients in surface sediments, and the significance of this.

- The relative significance of natural sources of phosphate in some catchments (for example, natural phosphate in groundwater of the Taupo region).

- The extent to which specific nutrient management practices are already being adopted on farms in a given catchment, and whether further improvements are possible.[3]

- How large the lake is relative to the catchment, and whether this is important (Smith el at., 2005).

- Sales and use of fertilisers. For example, Gillingham and Thorrold (2000) have reviewed New Zealand research relating to phosphate runoff from pasture. In New Zealand pastoral systems, superphosphate fertilisers represent the primary phosphate source, with excreta from grazing animals providing a secondary recycled source. These authors estimate that diffuse agricultural sources contribute about 91% of total phosphorus entering fresh waters annually. This is significant because sales of superphosphate follow economic conditions, and have increased in recent years relative to earlier periods.

- Trends toward an increased stocking density of dariy farms, which may offset any gains made through better nutrient management (Gillingham and Thorrold, 2000).

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[2] This may include such factors as the proportion of total lake area over which weed beds will grow based on water pressure and light penetration.

[3] The largest proportional impact for a single farm would be in cases where a large farm occupies a significant land area of a small catchment.

2 Sources of information

2.1 Lakes and their catchments

The 44 lakes chosen from the Waikato region for this study are in Table 1 and Figure 1.

Table 1: Lakes used in the study and land cover within their catchments.

Lake	Map number Figure 1	Land use (ha)				
		Dairy pasture	Drystock pasture	Other[4]	Surface water	Total
Areare	1	59	31	0	32	123
Cameron	2	8	17	0	5	31
Hakanoa	3	118	189	246	60	613
Henderson's Pond	4	0	30	0	1	31
Hotoananga	5	43	9	6	14	71
Kainui (D)	6	85	17	0	30	132
Kaituna (B)	7	517	42	5	16	580
Kimihia	8	332	298	806	49	1485
Komakorau	9	548	43	10	18	619
Kopuera	10	46	101	55	47	250
Koromatua	11	48	0	11	9	67
Kuratau	12	197	6480	11572	118	18367
Mangahia	13	309	11	24	10	354
Mangakaware	14	143	77	3	14	238
Maratoto	15	89	18	42	18	168
Milicich	16	9	31	11	2	54
Ngahewa	17	0	528	209	9	746
Ngapouri	18	307	176	129	23	636
Ngaroto	19	1418	270	60	98	1846
Ngarotoiti	20	350	136	15	4	504
Ohinewai	21	198	124	7	18	347
Pataka	22	43	0	7	5	55
Pikopiko	23	18	71	0	5	94
Posa	24	78	1	9	7	95
Rotoaira	25	0	133	12393	1711	14236
Rotokauri	26	344	465	81	43	933
Rotokawa	27	389	425	210	66	1090
Rotokawau	28	832	708	229	36	1804
Rotomanuka	29	332	83	27	38	479
Rotongaro	30	1144	412	97	296	1950
Rotongaroiti	31	1189	463	107	346	2105
Rotongata	32	133	0	5	6	144
Rotopotaka	33	68	1	6	1	76
Rotopounamu	34	0	0	443	84	527
Rotoroa (Hamilton Lake)	35	0	0	204	54	258
Ruatuna	36	104	70	0	15	190
Serpentine	37	66	70	13	14	163
Taharoa	38	0	1723	2215	288	4226
Te Koutu	39	8	183	219	6	416
Tunawhakapeka (E)	40	92	0	0	8	100
Waahi	41	1987	4417	2269	548	9221
Waikare	42	5746	9523	2218	3569	21055
Whakatangi	43	150	16	0	3	170
Whangape	44	3190	23123	4407	1046	31767

[4] 'Other' is an aggregation of non pastoral, forested, urban etc. A full listing of the data types is contained in Appendix I

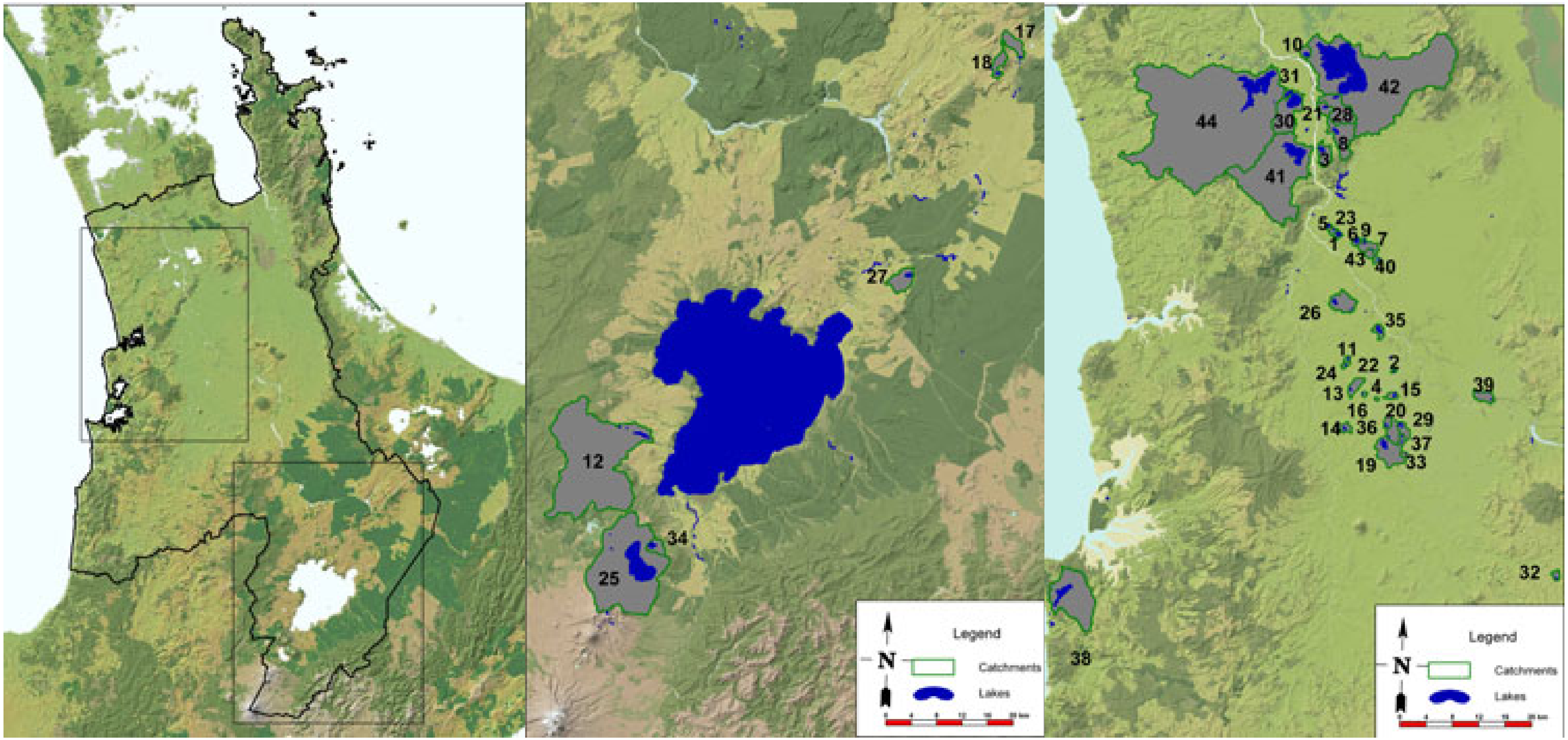

Figure 1: Lakes and their catchments.

2.2 Catchments

Catchment boundaries for the selected lakes were created using a geographic information system (GIS) (Figure 1). The catchments contained within the corporate GIS layer GIS_ALL.PEAT_LAKE_CATCHMENT were used where available (n=23). These catchments were derived from aerial photographs, topographic maps (NZMS260) and information contained in Boswell et al. (1985). The remaining catchments were derived using the NIWA generated River Environments Classification (REC) GIS dataset. This dataset has been developed from a 3-dimensional (20-meter contour) model of New Zealand. The outflow stream reach of each lake was selected and then the sub catchments of all reaches upstream were combined to create the lake catchment. This was achieved using the REC tracer tool developed by Environment Waikato (Clements 2006).

There are two cases where the catchment as derived is different from the actual catchment extent. At times of high levels in the Waikato river, the outflow from Lake Whangape can reverse and flow from the river into the lake, however, this was ignored in the derivation of the catchment and subsequent calculations. Secondly, the inflow to Lake Rotoaira has been artificially altered as part of a power generation scheme, thus the actual contributing catchment area is much larger than that derived. This was also ignored during the calculations.

In several cases a lake's catchment contained a catchment of another lake. In these sub catchment or 'nested' catchment situations, the entire contributing catchment was used including that of the nested catchment.

The catchments for the Regional Rivers Water Quality Monitoring Programme (RERIMP) sites were obtained from the Environment Waikato corporate GIS layer: GIS_ALL.ALLOCATION_CALC_CATCHMENT (Figure 2). These catchments were initially created from the REC GIS dataset.

2.3 Land cover

Land cover within the lakes and RERIMP catchments was calculated using the Land Cover Database 2 (LCDB2) (Terralink 1996) and Agribase (AgriQuality New Zealand Ltd 2001) GIS layers (Table 1 and Table 2). These layers were used to calculate the area of land cover under four categories: 'Dairy pasture', 'Drystock pasture', 'Other' and 'Surface water'.

The LCDB2 layer was used initially to produce three categories: 'Exotic grassland', 'Other' and 'Surface water', for each catchment. The 'Other' and 'Surface water' categories are groupings of multiple land cover classes from the LCBD2. For example, 'Surface water' is the sum of the classes, 'Lake and pond' and 'River'. The groupings of these different land covers can be found in Appendix I.

To separate the 'Exotic grassland' category into 'Dairy pasture' and 'Drystock pasture' the Agribase layer was used. The Agribase layer was queried to provide the area of 'dairy' and 'drystock'[5] farms in each catchment. Next, the union of 'Exotic grassland' (LCDB2) and 'dairy' and 'drystock' (Agribase) was queried to create 'dairy pasture' and 'drystock pasture'. This is the area of land under grassland i.e. the active production land, rather than land which is part of a dairy farm but is planted in trees. However, as Agribase does not achieve full coverage for the region it was necessary to extrapolate the information to provide complete coverage. To achieve this, the percentages of grassland in each land cover were used to apportion the total grassland to the land cover and thus generate complete landcover data for each catchment. For example, the landcover database returns 90.6 ha for 'exotic grassland' for Lake Areare's catchment. The union of 'Dairy' (from Agribase) and 'exotic grassland' is 40.4 ha, while

[5] 'Drystock' was created by aggregating a number of drystock farm types .e.g. sheep, deer and beef (a complete list can be found in Appendix II)

the union of ''Drystock' and 'exotic grassland' is 21.5 ha. This gives a total of 61.9 ha. The total 'exotic grassland' (90.6 ha) is then apportioned to the two land covers: 'Dairy pasture' = 40.4/61.9 * 90.6 = 59.1 ha, 'Drystock pasture' = 21.5/61.9 * 90.6 = 31.5 ha.

The same method was used with the RERIMP catchments to calculate the area of different land classes within each catchment (Table 2).

2.4 RERIMP specific yields

Nutrient yields for the RERIMP catchments were calculated[6], and used to create a surface of yields over the entire region (Figure 2 and Figure 3). The surface was created by interpolation of the data into a 100 m by 100 m grid using kriging. The data from 'Waitoa at Mellon Road' and 'Whakapipi at SH22' catchments were excluded on the basis of large point source influences at these sites. The estimated nutrient loads for each catchment are shown in Table 2.

[6] Monthly concentrations of total nitrogen and total phosphorus (e.g. Smith 2006) during 1990-2004 were combined with continuous records of river flows using the software 'Sedrate' (NIWA Christchurch) to calculate average nutrient loads. See EW document # 997519.

Table 2: RERIMP catchment land cover and nutrient yields. Greyed out data was not included in the analysis. Map numbers refer to RERIMP catchments as shown in Figure 2 and Figure 3.

Catchment	RERIMP Map numbers	Land use (ha)			Nutrient yield kg ha^{-1} yr^{-1}		Nutrient load[7] $t\ y^{-1}$	
		Dairy pasture	Drystock pasture	Other	N Yield	P Yield	N Load	P Load
Kauaeranga at Smiths	*92*	0	591	11330	5.0	0.42	59.1	4.96
Mangaokewa at Te Kuiti Pump Station	*65*	444	12281	4661	10.8	0.75	186	12.8
Mangatangi at SH2	*30*	4257	7166	6244	12.4	0.64	242	12.4
Matahuru at Waiterimu Rd	*20*	2815	6686	986	16.0	1.02	166	10.6
Mokau at Totoro Bridge	*71*	5009	74031	26350	13.8	1.35	1460	143
Ohinemuri at Karangahake	*4*	9200	4106	15145	14.8	0.34	421	9.71
Ohinemuri at Queens Head	*99*	6943	2657	3928	19.3	0.68	260	9.19
Otamakokore at Hossack Rd	*46*	2709	1099	754	10.8	1.49	42.7	5.90
Piako at Paeroa-Tahuna Road	*79*	35503	13573	4595	16.4	1.29	804	63.2
Piako River - Kiwitahi	*83*	6294	2340	1737	20.0	0.74	213	7.96
Pokaiwhenua at Puketurua	*39*	14324	2090	26655	6.8	0.63	286	26.3
Puniu at Pokuru Bridge	*75*	19315	21428	11082	13.1	0.69	676	35.9
Tahunaatara at Ohakuri Rd	*44*	5629	3707	11471	5.2	0.47	110	9.83
Tapu at Tapu-Coroglen Rd	*93*	0	108	2524	3.6	0.38	9.54	1.01
Tauranga-Taupo at Te Kono	*56*	0	0	19698	1.8	0.36	36.0	7.14
Tongariro at Turangi	*5*	0	1537	74884	2.4	0.78	189	61.0
Waitoa at Landsdowne Rd	*81*	7194	4023	954	9.9	0.59	126	7.44
Waihou at Okauia	*33*	31490	12926	35750	15.4	1.23	1240	99.0
Waihou at Te Aroha	*3*	48571	15464	46107	15.1	1.23	1680	137
Waipa at Otewa	*2*	1612	11845	18420	7.2	0.74	230	23.7
Waipa at Whatawhata	*1*	105331	111355	68985	13.6	1.00	3840	282
Waitoa at Mellon Road	-	28433	8585	3898	13.4	2.62	563	110
Whakapipi at SH22	-	308	2589	1648	31.5	0.60	133	2.54
Whareroa Stream at Lake Taupo	*102*	37	4180	1697	6.6	0.32	38.2	1.83

[7] Load is the rate at which material, in this case nitrogen, phosphorus or sediment is transported by the river system.

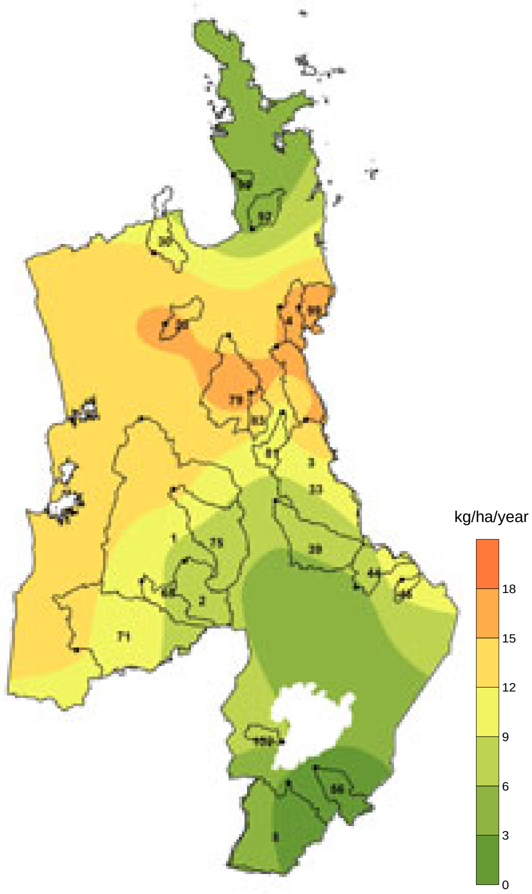

Figure 2: RERIMP nitrogen yield contour plot

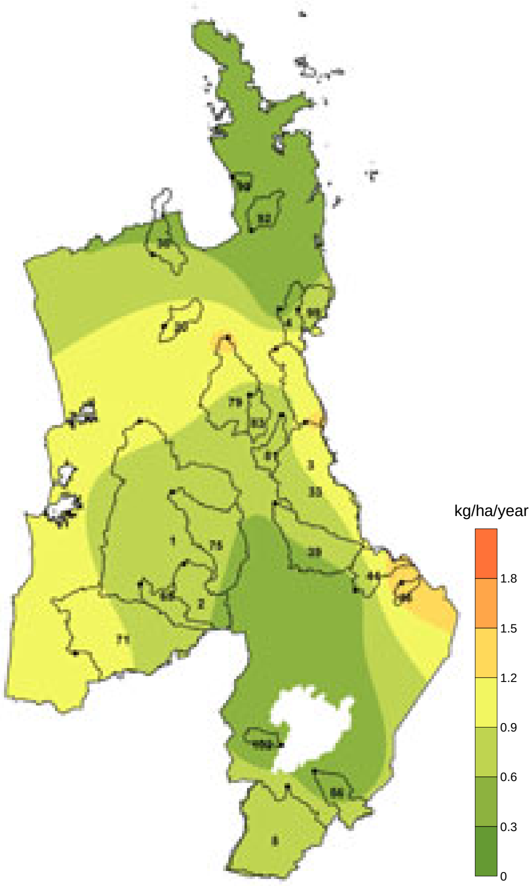

Figure 3: RERIMP phosphorus yield contour plot

2.5 Suspended sediment model (NIWA)

The annual sediment load for each shallow lake catchment was derived from Hicks and Shankar's (2003) sediment model. This model estimates suspended sediment yield based on mean annual rainfall and an “erosion terrain” classification. The "erosion terrain" is based on data on slope, rock-type, soils and erosion processes, along with expert knowledge. A grid of suspended sediment yields of 100 m by 100 m was used in GIS to estimate the annual sediment load for each lake's catchment (Figure 4 and Table 6).

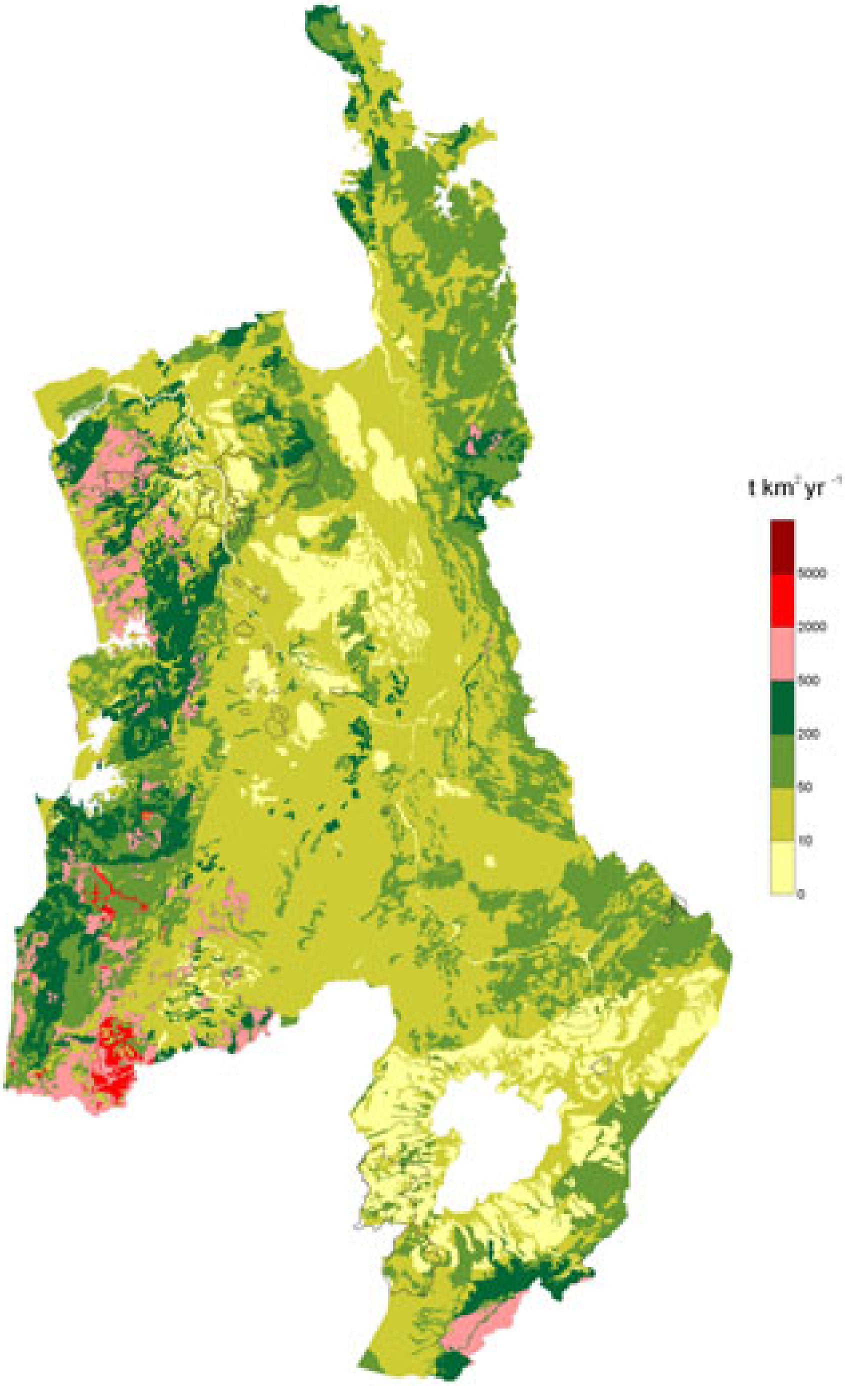

Figure 4: Suspended sediment map and lake catchments

2.6 Best or potential management

AgResearch have estimated nitrogen leaching and phosphorus runoff from typical dairy farms and sheep and beef farms within the Waikato region (Ledgard and Power 2006). These were estimated under 'average', 'best management' and 'potential' mitigation practices using the OVERSEER® nutrient budget model (Table 3). The sources and assumptions for the different farming practice calculations are contained in Appendix VI.

Table 3: Nitrogen and phosphorus losses from 'average farms' in the Waikato region to waterways – from Ledgard and Power (2006)

	Dairy				Sheep & beef			
Management practice	**N (kg ha^{-1} year^{-1})**	**Percent reduction in N**	**P (kg ha^{-1} year^{-1})**	**Percent reduction in P**	**N (kg ha^{-1} year^{-1})**	**Percent reduction in N**	**P (kg ha^{-1} year^{-1})**	**Percent reduction in P**
Average	36	-	0.5	-	13	-	0.3	-
Best practice	33	8%	0.3	40%	12	8%	0.3	0%
Potential practice	20	44%	0.2	60%	8	38%	0.2	33%

The percent reduction under the different management practices indicates the maximum theoretical reduction that is available by changing the management practices. For example, a catchment that is 100% dairy by composition, would achieve a 44% reduction in nitrogen and a 60% reduction in phosphorus in going from average to potential practice. To achieve a greater reduction in nutrients would require a change in the assumptions and/or information used in the calculation of the management practice calculations. Alternatively, a change in land use from an intensive use to a less intensive use would lead to a greater reduction, for example retiring land from dairy to trees.

3 Analysis

3.1 RERIMP nutrient load and land cover model

Nutrient load data from the RERIMP programme was used to develop a multiple linear regression model of land cover and nutrients. The land cover data was aggregated into three groups: 'Dairy pasture', 'Drystock pasture' and 'Other'. Initially the coefficients were calculated with constants included. However, as they were not significant for either N (p=0.96) or P (p=0.34), they were excluded from the final model. Using the results for 22 RERIMP catchments the regression coefficients contained in Table 4 were obtained.

In both cases (N and P), the same three sites, namely Mokau, Tongariro and Waipa at Whatawhata had leverage values > 0.5 (approx 0.7-0.8), suggesting an undue influence. Excluding these three gave satisfactory results for N (Table 5). However, excluding the three for P resulted in a poor regression coefficient for the 'drystock pasture'. Excluding just Tongariro and Waipa gave satisfactory coefficients (i.e. the imprecision arose from excluding Mokau as well). So, despite the high leverage of Mokau in the P regression, it was decided to retain it (n=20) (Table 5).

Table 4: Initial MLR coefficients

	Regression coefficients (std errors)			
	Dairy pasture	Drystock pasture	Other	R^2
N Load (kg ha^{-1} $year^{-1}$)	20.0 (1.9)	14.3 (1.6)	4.2 (1.5)	0.98
P Load (kg ha^{-1} $year^{-1}$)	0.97 (0.20)	1.24 (0.17)	0.85 (0.16)	0.96

Table 5: Final MLR coefficients

	Regression coefficients (std errors)			
	Dairy pasture	Drystock pasture	Other	R^2
N Load (kg ha^{-1} $year^{-1}$)	22.9 (2.8)	9.3 (4.4)	6.8 (2.4)	0.96
P Load (kg ha^{-1} $year^{-1}$)	1.29 (0.27)	1.46 (0.19)	0.71 (0.28)	0.96

3.2 Calculation of lakes' nutrient loads

For each lake, a combination of (1) The coefficients from the multiple linear regression of RERIMP nutrient loads and (2) the lake's land cover was used to estimate the nutrient loads to the lake. For 'Surface water', the figures of 3.7 kg/ha/yr N and 0.38 kg/ha/yr P (Rutherford et al. 1987) were used as representative coefficients of the load from direct rainfall.

Next, the possible reductions under the different management practices were used to estimate the lake nutrient loads under the various scenarios (Table 3). The nutrient load was also expressed areally to remove the effects of catchment size on the results. The percentage reduction in nutrient load under the two management practice regimes was calculated.

Table 6 shows the results obtained.

The lakes were assessed based on actual inlake nutrient measurements from Boswell et al. (1985), Barnes (2002), Smith et al (1993), Smith (2006) and unpublished Environment Waikato data where available to give a qualitative description of lake quality. Lakes were assessed as low, medium, high or data unavailable.

Lake Whangape has the largest modelled nitrogen load per year (420 t $year^{-1}$) but when this is expressed as an areal average it is a mid range figure of 1.3 g m^{-2} $year^{-1}$. The highest areal average (1.9 g m^{-2} $year^{-1}$) was calculated for Kaituna, Rotopotaka and Whakatangi. This high value is a function of the land cover being entirely dominated by dairy pasture and having a small lake area compared to the catchment area.

Three lakes (Rotoaira and Rotopounamu, south of Lake Taupo and Rotoroa in Hamilton city) had a less than 1% reduction under the two management regimes for both nitrogen and phosphorus. This small reduction is due to the catchments being largely non-pastoral to begin with.

The largest potential percent reduction in nitrogen is 8% under best practice and 44% under potential practice. This combination, which is the theoretical maximum based on the AgResearch figures, was found in five cases (Kaituna, Komakorau, Rotongata, Tunawhakapeka and Whakatangi). In the nitrogen calculations, an average reduction of 7% was found with the move from 'average' to 'best practice', while adopting 'potential' farming practices resulted in an average reduction of 36%.

The greatest percent reduction in phosphorus was calculated for Tunawhakapeka, with a 39% reduction under best practice and a 58% reduction under potential practice. The catchment of Tunawhakapeka is entirely in 'dairy pasture' land cover, while the other four catchments are almost entirely in 'dairy pasture'. For the phosphorus calculations, under 'best practice' management the average reduction was 18%. While the use of 'potential' management practice resulted in an average reduction of 39%.

Overall, the total area contained within the 44 lakes' catchments was 118417 ha. The average catchment composition was 45% dairy pasture, 28% drystock pasture, 19% vegetation and 8% open water.

The largest sediment load was calculated for lake Whangape (8841 kt $year^{-1}$), when this value was converted to an areal load to remove the influence of catchment size, it was the second highest value (845 kg m^{-2} $year^{-1}$). The largest sediment load in areally averaged terms was 941 kg m^{-2} $year^{-1}$ from Lake Ngahewa, compared with the lowest figure of 3 kg m^{-2} $year^{-1}$ from Maratoto. There were no available figures to calculate the reduction in sediment load under different land management options.

Table 6: **Modelled nitrogen, phosphorus and sediment loads. Lake quality is a qualitative assessment of the lakes condition based on monitoring data. Modelled load is expressed as total load and areal load (total load divided by catchment area). The reduction in modelled load under 'best' and 'potential' land management is expressed as a percentage.**

Lake	Lake Quality	Nitrogen load			Phosphorus load			Sediment load	
		Modelled	Areal	Reduction	Modelled	Areal	Reduction	NIWA Model	Areal
		t $year^{-1}$	g m^{-2} $year^{-1}$	%	t $year^{-1}$	g m^{-2} $year^{-1}$	%	kt $year^{-1}$	kg m^{-2} $year^{-1}$
Areare	M	1.7	1.4	8 , 40	0.11	0.089	21 , 44	4	13
Cameron	-	0.43	1.4	8 , 39	0.031	0.10	10 , 38	<1	15
Hakanoa	L	6.4	1.0	6 , 33	0.58	0.095	8 , 25	70	116
Henderson's Pond	-	0.44	1.4	8 , 38	0.037	0.12	0 , 33	<1	64
Hotoananga	M	1.0	1.4	8 , 40	0.063	0.088	26 , 46	2	16
Kainui (D)	L	2.0	1.5	8 , 41	0.11	0.083	29 , 49	3	11
Kaituna (B)	L	11	1.9	8 , 44	0.56	0.097	36 , 56	8	53
Kimihia	-	15	1.0	6 , 31	1.4	0.094	9 , 23	175	357
Komakorau	-	11	1.8	8 , 44	0.60	0.097	35 , 56	10	53
Kopuera	L	2.8	1.1	7 , 35	0.24	0.096	8 , 29	5	12
Koromatua	L	1.0	1.5	8 , 41	0.058	0.087	32 , 47	<1	9
Kuratau	M	150	0.82	5 , 25	18	0.098	0 , 15	433	367
Mangahia	L	6.3	1.8	8 , 43	0.34	0.096	35 , 55	2	20
Mangakaware	L	4.0	1.7	8 , 42	0.24	0.10	23 , 48	4	27
Maratoto	M	2.3	1.4	7 , 39	0.15	0.089	23 , 39	<1	3
Milicich	-	0.69	1.3	7 , 37	0.058	0.11	6 , 31	<1	19
Ngahewa	L	8.7	1.2	7 , 34	0.83	0.11	0 , 26	87	941
Ngapouri	L	9.2	1.4	8 , 40	0.63	0.099	19 , 40	51	218
Ngaroto	L	32	1.7	8 , 43	1.8	0.098	31 , 52	32	33
Ngarotoiti	L	8.8	1.7	8 , 43	0.52	0.10	26 , 50	8	232
Ohinewai	L	5.7	1.6	8 , 42	0.36	0.10	21 , 46	4	23
Pataka	-	0.89	1.6	8 , 42	0.050	0.090	33 , 50	<1	10
Pikopiko	-	1.4	1.5	8 , 39	0.11	0.12	6 , 37	3	47
Posa	-	1.6	1.7	8 , 43	0.087	0.092	35 , 52	1	15
Rotoaira	H	63	0.44	0 , 1	11	0.077	0 , 0	618	36
Rotokauri	L	14	1.5	8 , 40	0.99	0.11	13 , 39	29	67
Rotokawa	-	15	1.4	7 , 38	1.1	0.10	14 , 36	15	23
Rotokawau	L	28	1.6	8 , 40	1.9	0.11	17 , 41	53	148
Rotomanuka	M	7.9	1.6	8 , 42	0.46	0.096	28 , 49	14	35
Rotongaro	L	30	1.5	8 , 41	1.8	0.092	24 , 46	31	10
Rotongaroiti	L	32	1.5	8 , 41	1.9	0.090	24 , 45	33	10
Rotongata	-	2.6	1.8	8 , 44	0.14	0.097	38 , 57	6	109
Rotopotaka	-	1.4	1.9	8 , 43	0.072	0.095	36 , 55	1	91
Rotopounamu	H	2.3	0.44	0 , 0	0.41	0.078	0 , 0	6	7
Rotoroa (Hamilton Lake)	M	1.1	0.43	0 , 0	0.19	0.074	0 , 0	4	7
Ruatuna	L	3.1	1.6	8 , 42	0.19	0.10	21 , 46	4	24
Serpentine	M	2.4	1.5	8 , 40	0.17	0.10	15 , 40	4	29
Taharoa	H	36	0.85	5 , 27	4.1	0.097	0 , 17	776	270
Te Koutu	L	3.8	0.91	6 , 29	0.42	0.10	1 , 19	4	72
Tunawhakapeka (E)	L	1.8	1.8	8 , 44	0.092	0.092	39 , 58	2	29
Waahi	L	120	1.3	7 , 36	9.5	0.10	8 , 31	690	126
Waikare	L	270	1.3	7 , 38	21	0.100	11 , 35	1275	36
Whakatangi	-	3.2	1.9	8 , 44	0.17	0.10	35 , 56	2	55
Whangape	L	420	1.3	7 , 37	36	0.11	3 , 32	8841	845

4 Conclusions

The use of water quality data from the regional rivers and GIS land use data enabled the calculation of a multiple linear regression model. The model was used with estimates of reductions in nutrient runoff and leaching for different farming practices to provide estimates of nutrient loads for each of the studied lakes.

For nitrogen, it was found that moving from 'average' to 'best practice' resulted in an average reduction of 7% across all lakes, while adopting 'potential' farming practices resulted in an average reduction of 36%. The maximum reduction in nitrogen was 8% and 44% under the respective practices. Under both hypothetical management regimes, the minimum reduction in nitrogen found was 0%.

In the phosphorus calculations, under 'best practice' management, the average reduction was 18% and the maximum was 39%. Under 'potential' management practice, the average reduction was 39% and the maximum was 58%. The minimum reduction for the two land management practices was 0%.

The magnitude of these reductions was related to the ratios of the different land covers in each catchment. The highest potential reductions were found in catchments that were dominated by dairy pasture. The lakes that achieved no reduction in nutrients under the different land management practices, have catchments with no pastoral farming and thus any changes in farming practice can have no effect on the nutrient load.

The maximum reductions in nutrients are the theoretical upper bounds as defined by the AgResearch information. This highlights the importance of the values estimated from the OVERSEER model for each farming practice. To achieve a greater reduction in nutrients would require a change in the information used to produce the estimates. Alternatively, land use change to a less intensive activity could achieve greater reductions, for example retiring some dairy pasture to drystock or vegetation would reduce the nutrient load to a lake.

These results allow the lakes to be prioritised based on possible reduction in nutrients. A number of the lakes can be excluded on the basis that only a small percentage of their catchment is in pasture and therefore insensitive to any changes in pasture based farming. The delineation of the lake's catchments provides the opportunity to compare two lakes that would have the same potential reduction in nutrients and base the priority on catchment size.

These figures could also be used to estimate the increase in nutrient loading due to conversion from one land use to another for example the effect of changing from non dairy to dairy land use.

As there were no available figures for potential reduction in sediment load, only estimates of current loads were calculated.

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Appendices

Appendix I: LCDB2 data types and the categories they were grouped into for analysis

'Exotic grass'	'Other'	'Surface water'
High Producing Exotic Grassland	Manuka and or Kanuka	Lake and Pond
	Gorse and Broom	River
	Other Exotic Forest	
	Indigenous Forest	
	Pine Forest - Closed Canopy	
	Broadleaved Indigenous Hardwoods	
	Deciduous Hardwoods	
	Orchard and Other Perennial Crops	
	Major Shelterbelts	
	Afforestation (imaged, post LCDB 1)	
	Forest Harvested	
	Pine Forest - Open Canopy	
	Flaxland	
	Sub Alpine Shrubland	
	Mixed Exotic Shrubland	
	Tall Tussock Grassland	
	Grey Scrub	
	Fernland	
	Afforestation (not imaged)	
	Low Producing Grassland	
	Short-rotation Cropland	
	Herbaceous Freshwater Vegetation	
	Urban Parkland/ Open Space	
	Built-up Area	
	Surface Mine	
	Transport Infrastructure	
	Alpine Gravel and Rock	
	River and Lakeshore Gravel and Rock	
	Coastal Sand and Gravel	
	Vineyard	

Appendix II: Agribase classes aggregated to form 'Dry stock'

Beef
Deer
Dairy Dry (Calf or heifer rearing etc.)
Goats
Grazing other peoples' livestock
Horses
Other animal types
Pig farming
Sheep
Sheep 'n' Beef

Appendix III: All farm types and their notation in Agribase

ARA	Arable cropping
ANM	Miscellaneous animals
API	Bees
BEF	Beef
BIS	Bison
CER	Cereals
CRO	Cropping
DAI	Dairy
DRY	Dairy Dry
DEE	Deer
DOG	Dog
EMU	Emu
FIS	Fish (Marine Farm/Hatchery)
FLO	Cut flowers
FOR	Forestry
FRU	Fruit
GOA	Goats
GRA	Grazing other peoples' livestock
HOR	Horses
LIF	Lifestyle block
NAT	Native bush
NEW	Newly registered
NOF	Not farmed eg. bush reserve etc.
NUL	No farm enterprise
NUR	Nursery
OAN	Other animal types
OST	Ostrich
OTH	Any other not covered by codes
PIG	Pig farming
POU	Poultry
SEE	Seeds
SHP	Sheep
SNB	Sheep ’n’ Beef
TOU	Tourism
UNS	Unspecified (farmer didn't specify)
VEG	Vegetable growing
VIT	Viticulture
WOO	Woodlots
ZOO	Zoological gardens

Appendix IV: AGRIBASE data – Different farming types in hectares – Appendix III contains a key.

Summary ha	ARA	BEF	DAI	DEE	DRY	FOR	FRU	GOA	GRA	HOR	LIF	NAT	NEW	NOF	NUR	OAN	OTH	PIG	SHP	SNB	TOU	UNS	VEG	VIT	ZOO
Areare	0.0	21.5	40.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cameron	0.0	3.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hakanoa	0.0	34.8	87.9	0.0	32.0	0.0	0.0	0.0	0.0	0.0	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	103.7	0.0	0.0	0.0	0.0	0.0
Henderson's	0.0	19.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hotoananga	0.0	0.0	10.6	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kainui (D)	0.0	2.1	72.3	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kaituna (B)	0.0	15.3	341.0	4.0	0.0	0.0	0.0	0.0	8.1	0.0	21.5	0.0	0.0	0.0	0.0	0.0	16.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kimihia	0.0	363.7	303.9	0.0	0.0	0.0	0.0	0.0	55.4	0.0	20.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	338.7	0.0	0.0	0.0	0.0	0.0
Komakorau	0.0	15.3	352.0	4.0	0.0	0.0	0.0	0.0	8.1	0.0	21.5	0.0	0.0	0.0	0.0	0.0	16.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kopuera	0.0	60.0	24.1	0.7	0.0	0.0	0.0	0.0	10.8	0.0	10.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.1	0.0
Koromatua	0.0	0.0	63.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kuratau	0.0	129.2	233.9	11.9	0.0	4978.2	0.0	0.0	0.0	0.0	3.0	3194.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8845.8	0.0	0.0	0.0	0.0	0.0
Mangahia	0.0	8.5	271.4	0.0	0.0	0.0	27.7	1.2	0.0	0.0	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Mangakaware	0.0	4.9	104.7	0.0	25.8	0.0	0.0	0.0	25.8	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maratoto	0.0	13.5	69.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Milicich	0.0	0.0	1.3	0.0	5.7	0.0	28.9	0.0	0.0	0.0	0.0	0.0	16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ngahewa	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	168.3	0.0	0.0	0.0	0.0	0.0
Ngapouri	0.0	0.0	310.4	0.0	0.0	3.4	0.0	0.0	0.0	0.0	4.8	0.0	0.0	54.5	0.0	0.0	0.0	0.0	0.0	176.2	0.0	0.0	0.0	0.0	0.0
Ngaroto	0.0	101.0	1129.0	0.0	24.5	0.0	0.0	0.5	58.0	20.2	61.9	0.0	0.0	0.0	0.1	0.0	0.0	0.1	5.4	8.5	0.0	0.0	0.0	0.0	0.0
Ngarotoiti	0.0	57.8	292.0	0.0	15.7	0.0	0.0	0.0	41.5	0.0	28.6	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Ohinewai	0.0	8.1	123.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	8.2	0.0	0.0	0.0	0.0	0.0	66.7	0.0	0.0	0.0	0.0	0.0
Pataka	0.0	0.0	53.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pikopiko	0.0	0.0	7.9	16.9	0.0	0.0	0.0	0.0	15.3	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Posa	0.0	0.0	90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Rotoaira	0.0	0.0	0.0	0.0	0.0	5374.9	0.0	0.0	0.0	0.0	4.7	6302.4	0.0	412.3	0.0	0.0	10.5	0.0	0.0	1030.5	0.0	0.0	0.0	0.0	0.0
Rotokauri	0.0	133.3	224.5	21.6	21.5	0.0	0.0	60.3	21.5	0.0	104.9	0.0	1.1	0.0	0.0	0.0	8.9	0.0	33.7	0.0	0.0	0.0	0.0	0.0	44.0
Rotokawa	0.0	0.0	485.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	149.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	445.9	0.0	0.0	0.0	0.0	0.0
Rotokawau	0.0	507.9	696.2	0.0	0.0	0.0	0.0	0.0	6.7	0.0	3.3	0.0	0.0	10.4	0.0	0.0	0.0	0.0	0.0	164.6	0.0	0.0	0.0	0.0	0.0
Rotomanuka	0.0	53.2	279.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.9	0.0	9.5	0.0	5.4	0.0	0.0	3.1	0.0	14.6	0.0	0.0	0.0	0.0	0.0
Rotongaro	0.0	358.6	1004.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Rotongaroiti	0.0	383.6	1011.3	6.8	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Rotongata	0.0	0.0	142.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rotopotaka	0.0	0.0	47.5	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rotopounamu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	519.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0
Rotoroa	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ruatuna	0.0	1.0	88.3	0.0	58.4	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Serpentine	0.0	52.9	47.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	1.5	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Taharoa	0.0	588.3	0.0	0.0	0.0	324.1	0.0	0.0	0.0	0.0	4.0	565.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1471.7	0.0	0.0	0.0	0.0	0.0
Te Koutu	0.0	33.6	2.3	0.0	0.1	0.0	0.0	0.0	5.4	11.6	22.1	0.0	0.0	0.0	0.6	0.0	3.5	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0
Tunawhakapeka	0.0	0.0	90.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waahi	0.0	2379.0	1662.5	2.0	404.6	170.8	0.0	0.0	371.0	13.2	91.3	0.0	3.5	2.5	0.0	0.0	28.8	0.0	163.8	734.3	0.0	28.2	0.0	0.0	0.0
Waikare	0.0	3474.9	4897.0	61.2	388.2	11.9	0.0	0.0	329.9	3.9	47.1	14.3	31.4	10.4	0.0	0.0	0.0	0.0	356.1	4029.4	0.0	194.4	0.0	0.7	0.0
Whakatangi	0.0	0.0	115.1	4.0	0.0	0.0	0.0	0.0	8.1	0.0	6.2	0.0	0.0	0.0	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Whangape	255.6	8190.5	2740.2	329.0	619.0	227.6	12.3	0.0	394.3	17.1	69.9	0.0	620.6	0.0	0.0	31.9	54.3	0.0	666.4	11287.0	7.6	131.1	4.6	0.0	0.0

Appendix V: LCDB2 data – Landcover in hectares

Summary ha	High Producing Exotic Grassland	Lake and Pond	Manuka and or Kanuka	Gorse and Broom	Other Exotic Forest	Urban Parkland/ Open Space	Herbaceous Freshwater Vegetation	Indigenous Forest	Built-up Area	Pine Forest - Closed Canopy	Broadleaved Indigenous Hardwoods	Surface Mine	Deciduous Hardwoods	Orchard and Other Perennial Crops	Major Shelterbelts
Areare	90.6	32.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cameron	25.3	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hakanoa	307.0	60.4	47.8	20.4	7.4	33.7	23.8	12.5	52.9	3.3	40.1	4.1	0.0	0.0	0.0
Henderson's Pond	29.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hotoananga	52.1	13.7	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kainui (D)	102.1	30.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kaituna (B)	558.6	15.6	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kimihia	630.0	49.0	277.0	91.4	0.0	11.1	34.4	208.7	0.0	72.2	89.9	0.9	20.7	0.0	0.0
Komakorau	591.2	18.2	0.0	0.0	0.0	0.0	9.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kopuera	147.6	47.5	0.0	0.0	0.0	0.0	54.0	0.0	0.7	0.0	0.0	0.0	0.0	0.3	0.0
Koromatua	47.6	8.7	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	8.4	0.0	0.0
Kuratau	6677.3	117.9	644.0	67.9	23.8	0.0	522.9	4706.3	0.0	4100.0	791.7	0.0	56.8	0.0	0.2
Mangahia	320.3	9.7	0.0	0.0	0.0	0.0	8.7	5.0	0.0	0.4	0.0	0.0	0.0	3.7	0.0
Mangakaware	220.8	14.2	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maratoto	107.7	18.2	0.0	0.0	0.0	0.0	42.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Milicich	40.2	2.3	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	8.9	0.0
Ngahewa	528.0	9.3	1.5	1.1	5.2	0.0	0.0	17.0	0.0	0.7	17.1	0.0	22.9	0.0	0.6
Ngapouri	483.1	23.5	0.0	0.0	48.5	0.0	6.2	3.5	0.0	9.6	4.2	0.0	9.0	0.0	0.0
Ngaroto	1687.5	98.0	0.0	0.0	0.7	0.0	0.0	7.1	14.8	2.0	2.2	0.0	31.3	0.2	0.0
Ngarotoiti	486.2	3.5	0.0	0.0	0.0	0.0	0.0	0.0	12.4	0.0	2.2	0.0	0.0	0.0	0.0
Ohinewai	321.9	17.7	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	4.4	0.0	0.0	0.0	0.0
Pataka	43.1	4.8	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Pikopiko	88.9	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Posa	78.7	6.8	0.0	0.0	0.0	0.0	8.6	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Rotoaira	132.6	1691.4	2059.3	24.1	21.5	0.0	563.3	4505.5	2.5	1642.6	231.6	0.0	0.0	0.0	0.0
Rotokauri	809.2	43.0	0.0	0.0	7.9	0.0	1.2	0.0	39.2	2.0	0.0	0.0	28.9	0.0	0.0
Rotokawa	814.3	66.1	62.6	0.0	0.0	0.0	0.0	6.7	0.0	69.3	9.0	0.0	0.0	0.0	5.4
Rotokawau	1539.0	35.9	6.7	8.5	1.5	0.0	106.1	54.6	1.7	1.6	28.4	0.0	17.5	0.0	1.5
Rotomanuka	414.4	38.4	0.0	0.0	0.0	0.0	21.8	3.2	1.4	0.0	0.0	0.0	0.0	0.0	0.0
Rotongaro	1555.8	296.5	30.0	0.0	1.2	0.0	15.7	0.0	0.6	32.2	0.0	0.0	10.9	0.0	5.5
Rotongaroiti	1652.3	345.9	30.5	0.0	1.2	0.0	18.5	0.0	0.6	32.2	0.0	0.0	16.4	0.0	6.7
Rotongata	132.8	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	1.4
Rotopotaka	68.5	1.1	0.0	0.0	0.0	0.0	0.0	0.8	3.5	0.0	0.0	0.0	1.7	0.0	0.0
Rotopounamu	0.0	84.1	0.0	0.0	0.0	0.0	2.1	429.6	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Rotoroa (Hamilton Lake)	0.1	53.9	0.0	0.0	0.0	52.8	0.0	8.2	143.3	0.0	0.0	0.0	0.0	0.0	0.0
Ruatuna	174.7	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Serpentine	135.9	14.0	0.0	0.0	0.0	0.0	11.5	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Taharoa	1722.5	287.8	448.3	73.7	0.0	0.0	96.4	779.8	13.5	78.7	9.3	0.0	14.6	0.0	0.0
Te Koutu	191.1	5.7	11.3	0.0	0.0	17.6	0.0	5.6	184.8	0.0	0.0	0.0	0.0	0.0	0.0
Tunawhakapeka (E)	92.1	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waahi	6403.6	548.0	110.5	749.6	11.7	3.4	26.1	304.8	83.9	82.5	71.7	503.7	115.5	0.0	0.0
Waikare	15268.7	3560.8	227.4	30.8	4.4	18.4	469.6	814.6	68.9	186.5	113.3	0.0	70.0	1.6	3.9
Whakatangi	166.4	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Whangape	26313.0	1044.4	750.6	160.2	38.2	0.0	90.5	1408.6	11.0	159.9	357.9	37.0	571.7	8.0	6.5

Appendix V: LCDB2 data cont.

Afforestation (imaged, post LCDB 1)	Transport Infrastructure	Forest Harvested	Pine Forest - Open Canopy	Flaxland	Low Producing Grassland	Sub Alpine Shrubland	Mixed Exotic Shrubland	Tall Tussock Grassland	Grey Scrub	River	Short-rotation Cropland	Alpine Gravel and Rock	Fernland	River and Lakeshore Gravel and Rock	Coastal Sand and Gravel	Afforestation (not imaged)	Vineyard
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46.8	16.7	60.2	411.1	2.2	4.9	50.5	5.1	60.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
112.5	0.0	1.8	4.4	0.8	20.4	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42.2	0.0	0.0	2.9	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	26.7	315.8	306.4	73.7	89.1	109.9	1270.7	609.5	7.0	19.2	121.8	340.3	71.7	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	36.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.1	0.0	0.0	0.0
1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
421.4	0.0	0.0	124.2	0.0	132.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.6	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100.0	0.0	0.0	96.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.3	0.0	3.6	0.0
7.6	0.0	0.0	5.2	0.0	54.9	0.0	0.0	0.0	0.0	8.4	60.9	0.0	0.0	0.0	0.0	79.6	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
403.0	1.3	24.1	317.5	0.0	24.6	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	35.6	1.4

Appendix VI: AgResearch information sources and assumptions from Ledgard and Power 2006

1. Average dairy farm. This was based on average Waikato farm data from LIC statistics, and average fertiliser data from Dexcel ProfitWatch database (114 kg N/ha/yr and 49 kg P/ha/year). It was assumed that 20% of N fertiliser was applied in winter (relatively high uncertainty for this assumption). Estimates were based on an average for two farm system, one with dairy effluent going to ponds and the other to land application in a ratio of 1:3 according to the current average for the Waikato.

2. Best practice dairy farm. This assumed that all farm dairy effluent was land applied and that no N fertiliser was applied in winter (but that the annual total was unchanged). The effluent block was assumed to receive no N fertiliser and reduced P fertiliser according to maintenance requirements.

3. Potential dairy farm. This was based on further assumptions that the farm was using winter management practices including a winter feed/stand off pad and nitrification inhibitors. It was also assumed that riparian management was used and reduced P losses by c.20%.

4. Average sheep and beef farm. This was based on data from the MAF intensive monitor farm for the Waikato/Bay of Plenty region. Fertiliser use (20 kg N/ha/yr and 24 kg P/ha/year) was based on data from farms in the Monitor farm system and it was assumed that 50% of the N was applied in winter (high uncertainty in the latter estimate).

5. Best practice sheep and beef farm. This assumed that no N fertiliser was applied in winter (but that the annual total was unchanged).

6. Potential sheep and beef farm. This was based on further assumptions of the farm changing cattle to an all male cattle policy, and winter management practices such as the use of nitrification inhibitors. It was also assumed that riparian management was used and reduced P losses by one-third.

NB: There is a wide variation in biophysical properties and management practices used on individual farms. Consequently the N and P losses from individual farms will show a wide variation around the "average" farm presented above. Similarly, the most appropriate practices to reduce N and P losses from farms to waterways will vary with individual farms Economic and social factors will also affect likelihood of uptake of improved practices.