Ruamāhanga Scenario Modelling

Greater Wellington Regional Council

Ecological Health Report

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Jacobs New Zealand Limited

Level 3, 86 Customhouse Quay,
PO Box 10-283
Wellington, New Zealand
T +64 4 473 4265
F +64 4 473 3369
www.jacobs.com

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Contents

GLOSSARY

Term	Description
BAU	Business as usual modelling scenario
DWC	Dry weather concentrations that are applied to baseflow generated from various landuses
EMC	Event mean concentrations that are applied to quickflow (rapid runoff) generated from various landuses
GNS	Geological Nuclear Sciences
Gold	Gold modelling scenario
NIWA	National Institute of Water and Atmospheric Research
NPSFM	National Policy Statement for Freshwater Management 2014 (amended 2017)
Percentile	Statistical observation indicating the value which a given percentage of observations in a group fall below.
Silver	Silver modelling scenario
Tier 1, 2 and 3 (M1, M2, M3)	Nutrient and *E.coli* farm management mitigations modelled by agresearch for dairy, dairy support, arable farms and sheep and beef.
WWTP	Waste water treatment plant

1. Introduction

This report provides a technical summary of the scenario modelling undertaken for the Ruamāhanga Whaitua, with a focus on describing how on farm mitigations have been applied in scenario modelling to lower nutrient concentrations at the 20 reporting sites (**Section 2.3**). Catchment modelling for Ruamāhanga has been undertaken for the baseline condition and nine scenarios. The report is to be read in conjunction with the A3 'fact sheets' that have been created for each constituent (i.e. N03-N, NH4-N, SSC) at each reporting point.

These fact sheets document the key results at each site, including concentrations, percentage changes from the baseline model across the scenarios and where applicable, comparisons to the National Policy Statement for Freshwater Management 2014 (NPSFM) (amended 2017). This report provides the background to why some of the changes observed have occurred at various sites.

Further detailed modelling information can be gathered from the baseline report (Jacobs 2017) and the draft technical scenarios report (Jacobs 2017a).

1.1 Landuse types and functional units

Within the eWater Source model, on farm mitigations and pole planting/retirement has been applied to the functional units, representing landuse and soil drainage combinations that influence nutrient generation and transport within subcatchments. For example, where land (i.e. sheep and beef) has been retired to native bush, this area within the model would have lower input concentrations assigned due to de-stocking.

1.1.1 Primary landuse areas

The dominant Ruamāhanga catchment landuse types have been summarised in **Table 1.1.** These do not represent the functional unit list, only a summary of the dominant landuses.

The landuse type 'Other' includes water, finishing, poultry, recreation, viticulture and horticulture. The dominant landuse in the catchment is sheep and beef, followed by native forest and dairy. The total catchment area is ~354,311 ha.

Table 1.1 : Ruamāhanga landuse areas

Landuse Type	Area (ha)	% of total catchment
Sheep and Beef	146,962	41.5%
Native Forest	83,888	23.7%
Dairy	30,029	8.5%
Other	17,528	4.9%
Mixed	16,725	4.7%
Lifestyle	12,184	3.4%
Plantation Forest	11,143	3.1%
Dairy Support	9,987	2.8%
Beef	8,974	2.5%
Urban	7,999	2.3%
Sheep	4,491	1.3%
Equine	2,036	0.6%
Arable Land	1,656	0.5%
Deer	709	0.2%

Further analysis of the landuse relative to each reporting site has been summarized in **Table A.1** and **Figure B.2**.

1.2 Nutrient modelling approach

Nutrient modelling in SOURCE included the following analytes:

- Total Nitrogen (TN)
- Nitrate-N (NO_3-N)
- Ammoniacal-N (NH_4-N)
- Total Phosphorus (TP)
- Dissolved Reactive Phosphorus (DRP)
- Dissolved Inorganic Nitrogen (DIN) was calculated from results by combining nitrate and ammoniacal-N

Each of these analytes was modelled using an Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) approach, where input concentrations (generation rates) are assigned to each of the 48 functional units in the model. EMC's are associated with the quickflow generated from a landuse type within a subcatchment, while DWC's are associated with the baseflow.

These concentrations were determined through Overseer modelling, literature review, and where no data was available, calculated from local water quality monitoring records. Overseer modelling was undertaken based on 16 representative farm types from within the region, and the resulting nutrient leaching and runoff results, used as inputs to the model, were spatially distributed across 53% of the Ruamāhanga catchment. The spatial distribution of farm types to land use was developed by a Ruamāhanga modelling technical group made up of Greater Wellington Regional Council, Ministry of Primary Industries (MPI), John Bright, and Terry Pariminter

The Overseer annual average nutrient outputs were converted to concentrations using the sub-catchment (and functional units) mean annual flows. The 16 Overseer farm types that were modelled were Sheep and Beef, Dairy, Dairy Support and Arable.

Water quality calibration in the baseline model involved modifying the EMC/DWC generation rates. The adjustments for calibration were informed by literature data and Overseer inputs, so the calibrated EMC/DWC's remained within expected ranges. Calibration also included adjustment of attenuation factors assigned at the subcatchment scale. These attenuation factors represent a range of nutrient loss/transformation processes including denitrification, sedimentation and biological uptake. They are represented as a simple percentage reduction in load lost from the system informed through calibration to observed in-stream data, within acceptable literature ranges.

A more detailed nitrate modelling approach was undertaken that utilised the leaching rates from Overseer farm modelling applied to functional units and nitrate groundwater fluxes (GWF) for lowland stream reaches with strong surface-groundwater connectivity, which was derived from MODFLOW-MT3D.

1.3 Sediment modelling approach

Suspended sediment concentration (SSC) was modelled in Source using a power curve (rating curve) approach informed by annual loads modelled by SedNetNZ, developed for the Ruamāhanga catchment by Landcare Research (Dymond *et al.* 2014). SedNetNZ calculates a catchment-scale sediment budget and derives the average annual sediment yields from each sediment source (e.g. total hillslope (surficial, gully, earthflow and landslide) and streambank erosion)). SedNetNZ was adopted because it spatially represents the sediment yield from different erosion processes, and therefore enables spatially-explicit modelling of mitigations that target specific erosion sources (for example, to target the top 5% of sediment yielding land from surficial erosion).

A sediment rating curve was derived from the observed suspended sediment concentration and gauged flows, of the form:

$$SSC = bQ^a \qquad \text{(Equation 1)}$$

Where SSC is the suspended sediment concentration in milligrams per litre (mg/L), Q is flow in litres per second, *a* and *b* are constants and exponents.

The sediment rating curve was adjusted for each of the 237 subcatchments using modelled flows to deliver a proportion of the annual load derived by SedNetNZ each day for the 22 year modelling period (1/7/1992 to 30/6/2014).

The exponent (*a*) was fixed based on calibration of simulated versus observed SSC concentrations at three sites throughout the catchment. The constant (*b*) was scaled for each catchment to match the average annual SedNetNZ load.

2. Scenarios

2.1 Scenario list

A total of ten different scenario models were run over four different time periods. They are as follows:

- Baseline model (i.e., existing management practices between 1992 and 2014);
- Business as usual (BAU) scenario for 2025, 2040 and 2080;
- Gold scenario for 2025, 2040 and 2080; and
- Silver scenario for 2025, 2040 and 2080.

The baseline model provides the reference point for comparison against scenarios. Each scenario has a number of mitigation ‘options’ applied within a given scenario. Inherently the discrete influence of specific mitigations on water quality results is difficult to discern at downstream catchments which have had a significant amount of inflows from various tributaries, and should be viewed as the cumulative effectiveness of the BAU, Gold or Silver scenarios.

2.2 Scenario descriptions

The following sections provide an overview of the mitigation options applied in each of the scenarios. These were developed by the Ruamāhanga Whaitua Committee.

Table 2.1 : BAU scenario and mitigation option descriptions

Management Option	Description
Land Retirement	Retirement of very steep slopes and reversion to bush on class 7e and 8 (LUC) land. Retirement at a rate of 18 ha/yr.
Pole Planting	Pole (space) planting on steep slopes (class 7 land and above) at a rate of 135 ha/yr.
WWTP	WWTP are discharging partially to land. Discharge to water is allowed only under certain flow conditions (as described in Jacobs 2017a). Proportion of flow volume to be discharged to land: **Masterton:** - 60% (summer) and 5% (winter) by 2025, 100% (summer) and 80% (winter) by 2040, 100% (summer) and 97% (winter) by 2080 **Carterton:** - 35% by 2025, 60% by 2080. **Martinborough:** - 24% by 2025, 100% by 2040 **Greytown** - 20% by 2025, 100% by 2040 **Featherston** -0% (full course of model)

Management Option	Description
Minimum flow rules	Minimum flow rules (cease takes) were applied to all existing agglomerated surface water consents in the SOURCE model, based off Tables 7.1 and 7.2 in the GWRC Proposed Natural Resources Plan (PNRP). These were applied immediately (evident through 2025-2080 models).
Nutrient Mitigations (Tier 1)	Tier 1 (M1) stock exclusion on dairy, dairy support, sheep and beef was considered to occur immediately (any nutrient, *E.coli* and sediment reductions were therefore consistent across the three BAU scenarios).

Table 2.2 : Silver scenario descriptions

Management Option	Description
Land Retirement	Retirement of very steep slopes and reversion to bush on in Eastern Hill Country on the top 5% of erosion prone land. Retire land by 2040.
Pole Planting	Pole (space) planting on steep slopes (class 6e and 7 land) but not including the top 5% of erosion prone land. Pole planting completed by 2040.
WWTP	WWTP are discharging only to land, includes all sites. 60% of the volume by 2025, 100% by 2040. The 40% of load that is discharged to the river (2025) can only occur when flow is greater than 3x the median flow.
Minimum flow rules	Minimum flow rules (cease takes) are the same as applied in the BAU model (see **Table 2.1**).
Nutrient Mitigations (Tier 1, 2 and 3)	Tier 1 (M1) applied immediately (2025 through to 2080). Tier 2 (M2- fertiliser management, constructed wetlands etc) applied by 2040. Tier 3 (5 m riparian buffer) applied by 2080. Mitigations only applied to dairy, dairy support, sheep and beef and arable farm types.

Table 2.3 : Gold scenario descriptions

Management Option	Description
Land Retirement	Retirement of very steep slopes and reversion to bush on in Eastern Hill Country on the top 5% of erosion prone land. Retire land by 2025.
Pole Planting	Pole (space) planting on steep slopes (class 6e and above) but not including the top 5% of erosion prone land. Pole planting completed by 2040.
WWTP	WWTP are discharging only to land, includes all sites. 100% of the volume by 2025.
Minimum flow rules	Minimum flow rules (cease takes) are the same as applied in the BAU model (see **Table 2.1**).
Nutrient Mitigations (Tier 1, 2 and 3)	Tier 1 (M1) and Tier 2 (M2) applied immediately (2025 through to 2080). Tier 3 (10 m riparian buffer) applied by 2040. Mitigations only applied to dairy, dairy support, sheep and beef and arable farm types.

2.3 Scenario reporting points

Discussions with GWRC identified a total of 25 reporting points in the Ruamāhanga catchment. Five of these were lake reporting sites (Wairarapa and Onoke). The 20 remaining sites that were assessed in the scenario modelling are outlined in **Table 2.4.**

Table 2.4 : Reporting points, catchment area and co-ordinates

Reporting site	Total catchment area (ha)	Co-ordinates (NZTM)	
Huangarua River at Ponatahi Bridge	30,239	1809110.9	5433450.9
Kopuaranga River at Stuarts	16,686	1826760.0	5469569.0
Mangatarere River at SH2	11,947	1809768.0	5452160.0
Ruamāhanga River at Pukio	246,366	1796969.7	5429312.4
Ruamāhanga River at Te Ore Ore	31,078	1825238.6	5462371.0
Taueru River at Gladstone	49,244	1824148.0	5450815.0
Tauherenikau River at Websters	14,481	1794221.8	5438960.8
Waingawa River at South Rd	14,969	1824037.5	5456790.2
Waiohine River at Bicknells	39,320	1810473.9	5446861.2
Waipoua River at Colombo Rd Bridge	17,452	1825118.6	5462371.0
Parkvale Stream at weir	5,006	1813384.6	5448900.9
Ruamāhanga River at Wardells	64,284	1824577.7	5457270.2
Ruamāhanga River at Gladstone Bridge	133,694	1819925.6	5449559.8
Ruamāhanga River at Waihenga	236,089	1804111.3	5435911.3
Whangaehu River at 250m from Rua Confluence	14,578	1826209.0	5459282.0
Otukura Stream at Mouth	9,366	1793829.6	5437578.3
Makahakaha Stream at Mouth	6,192	1821065.6	5448899.5
Ruamāhanga River at U/S Lake Wai Outlet	254,496	1784197.9	5423956.4
Tauanui River at Mouth	4,155	1783915.1	5423674.8
Turanganui River at Mouth	6,740	1779267.6	5419205.8

These reporting points are presented in **Figure B1** in **Appendix B.**

2.4 NPSFM Attributes

The NPSFM sets out attribute states for rivers and lakes, providing national bottom line water quality objectives (limits) that protect freshwater ecological values.

In regards to the constituents modelled in Ruamāhanga, attribute states exist for NO_3-N and NH_4-N. No attribute state tables are available for DRP or DIN, however regional councils are required to set appropriate instream concentrations and exceedance criteria for these constituents as they relate directly to periphyton (which does have an attribute state and national bottom line objectives).

The attribute states for NO_3-N and NH_4-N are given in in **Table 2.5**.

Table 2.5 : NPSFM (2017) NO_3-N and NH_4-N attribute tables for instream concentrations (mg/L)

Attribute State (concentrations in mg/L)	Nitrate N (N03-N)		Ammoniacal-N (NH4-N)	
	Annual Median (50th percentile)	Annual 95th percentile	Annual Median (50th percentile)	Annual Maximum
A	≤1.0	≤1.5	≤0.03	≤0.05
B	>1.0 and ≤2.4	>1.5 and ≤3.5	>0.03 and ≤0.24	>0.05 and ≤0.40
C	>2.4 and ≤6.9	>3.5 and ≤9.8	>0.24 and ≤1.30	>0.40 and ≤2.20
National Bottom Line	6.9	9.8	1.30	2.20
D	>6.9	>9.8	>1.30	>2.20

3. Mitigations influencing nutrients and sediment

3.1 Summary

Table 3.1 provides a summary of all the mitigations applied in the Source model that influence nutrients and sediment. This does not include any changes in nutrient concentrations due to flow variations such as minimum flow rules being applied to unrestricted surface water consents, or groundwater abstraction occurring at maximum rates. The impacts of these are considered minor compared to other mitigations applied across the wider catchment and are further discussed in **Section 4**.

Table 3.1 : Summary of mitigations applied in Ruamāhanga scenario modelling

Mitigation		Description	Effects
Land Retirement		Results in conversion of land defined in **Table 2.1** to **Table 2.3** to native bush, reducing nutrient and sediment load.	Immediately lowers load of NO_3-N, NH_4-N, TN, TP, DRP and *E.coli* once land is retired.
			Delayed effect on sediment (SSC), where retired land only reduces load after 10 years of growth.
Pole Planting		Results in pole planting of land defined in **Table 2.1** to **Table 2.3**, reducing phosphorus and sediment load.	Delayed effect on reduced TP, DRP and SSC load only after 15 years of growth following pole planting.
WWTP land treatment		Treatment of WWTP timeseries point source discharges by land assumed to remove certain percentage of nutrient loads based on literature data. The remaining load is then discharged to the river.	Immediately decreases load of NO_3-N, NH_4-N, TN, DRP, TP, SSC and *E.coli*.
On farm mitigations applied to dairy, dairy support, sheep and beef and arable farm types only (as described in Muirhead *et al.* 2016)	Tier 1	Stock exclusion and deferred or low rate effluent irrigation.	Immediately reduces load of all constituents described in **Section 1.2** and *E.coli*. Load reductions compound through mitigations (Tier 1 to 3). No sediment reductions are achieved at Tier 3, as these are applied at Tier 1 and 2.
	Tier 2	Numerous mitigations, however primarily constructed wetlands, optimal fertilizer and effluent use, efficient irrigation.	
	Tier 3	Grass/clover swards, riparian planting buffer strips, sediment traps, off paddock wintering, duration controlled crop grazing.	

3.2 Nutrient Mitigations

On farm mitigations (Tier 1, Tier 2 and Tier 3) were modelled for the 16 farm types in Overseer by Agresearch (Muirhead *et al.* 2016). The mitigations were applied to Dairy, Dairy Support, Arable and Sheep and Beef. The resulting output was 16 different leaching rate reductions for each mitigation (i.e. a total of 48 leaching rate reductions for M1, M2, M3). This was simplified down to four reductions in each mitigation (one for each landuse type) through a weighted average based on the area each farm represented in the catchment.

For example, out of the 16 representative farms, 6 of these characterise Dairy farming, totaling 7,100 ha in the entire catchment. However, farm type 'number 4' only represented 5.4% of the total dairy area (~383 ha), so the effect of mitigations on these farm types (which resulted in slightly less nutrient leaching than the other farms) had less influence on the overall weighted average.

The 16 farm types where nutrient mitigations were applied represent~ 53% of the total area. Modelling of mitigations are consistent with the Agresearch report, and could be considered conservative in its application as mitigations were not applied to the other relevant farming functional units such as Sheep, Beef and Deer (representing >4% of the catchment), nor any cropping.

3.2.1 Mitigations Reductions Table

The Overseer leaching mitigations were converted into weighted average percentage reductions. These were applied to the baseline EMC/DWC's for the relevant functional unit type during scenario modelling.

The mitigations table (**Table 3.2**) is outlined below. For nitrogen species, Overseer N leaching is represented by DWC concentrations, therefore, mitigation reductions were applied to the DWCs. Conversely, phosphorus species are informed by Overseer runoff rates and mitigations are applied to EMCs.

Table 3.2 : Tier 1 (M1), 2 (M2) and 3 (M3) mitigations and their applications to nutrient concentrations

Reductions applied	Mitigations applied to input concentrations		Percentage (%) reduction from baseline concentrations			
	Species	Scenario	Dairy	Sheep and Beef	Arable Farm	Dairy Support
Cumulative (i.e. application of Tier 3 includes Tier 1 and 2 effects)	TN, NH_4-N, NO_3-N (DWC's)	Baseline	-	-	-	-
		Tier 1 (BAU/Gold/Silver)	4.1	0.1	0.0	1.6
		Tier 2 (Gold/Silver)	23.9	3.8	4.8	23.3
		Tier 3 5m buffer (Silver)	23.9	3.8	9.5	24.1
		Tier 3 10m buffer (Gold)	23.9	3.8	9.5	25.7
	TP, DRP (EMC's)	Baseline	-	-	-	-
		Tier 1	16.8	1.5	0.0	5.9
		Tier 2	26.6	13.3	0.0	11.9
		Tier 3 5m buffer	27.5	80.1	20.0	23.8
		Tier 3 10m buffer	29.8	80.1	20.0	23.8
Individually (Tier 1 is	Sediment (see	Baseline	-	-	-	-
		Tier 1 (net bank erosion reduction)	80%	80%	80%	80%

Reductions applied	Mitigations applied to input concentrations		Percentage (%) reduction from baseline concentrations			
	Species	Scenario	Dairy	Sheep and Beef	Arable Farm	Dairy Support
applied to bank erosion layer, Tier 2 to hillslope layers)	**Section 1.3** for a description of SedNetNZ).	Tier 2 (constructed wetlands, applied after pole planting to hillslope layers)	6.4%	20.7%	0.0%	5.8%
		Tier 3 (riparian planting, no change, as captured in Tier 1 with stock exclusion)	-	-	-	-

3.2.2 Tier 1, 2 and 3 descriptions (M 1, 2, 3)

As described in Muirhead *et al.* 2016, Tier 1 mitigations include:

- Stock exclusion from streams and wetlands (all four farm types)
- Deferred and or low rate effluent irrigation (dairy farms only)

Tier 2 mitigations are numerous; however, the primary mitigations include:

- Facilitated or constructed wetlands
- Optimal fertiliser and effluent application
- Efficient water irrigation

Tier 3 mitigations that have been modelled by Agresearch (Muirhead *et al.* 2016) include:

- split grass/clover swards, riparian planted buffer strips
- sediment traps, duration controlled crop grazing and off paddock wintering.

In regards to riparian planting, Agresearch had modelled 5 m riparian buffers (applicable to the Silver Scenario only) on the 16 Overseer representative farm models. Agresearch had applied a 26 m/ha average stream length on productive land that was not flat or free draining brown soils. To verify if this was representative of the streams within the catchment, an assessment was undertaken on the REC stream length across productive land, which totaled ~4,412 km. Inclusion of flat and free draining soils (using the 26 m/ha rule applied to farm block) resulted in a total stream length of 6,875 km.

Following the method defined by Agresearch, the stream density based on productive land that was not flat or free draining was 5,188 km, closer to the REC stream lengths. This was considered acceptable to proceed with Overseer modelling given time constraints.

This stream density was applied to the Overseer representative farm models to recalculate nutrient reductions from Silver and Gold 5 and 10 m buffers.

Riparian planting/buffer strips (Tier 3) had no additional reductions to sediment, as this has been assumed to be captured during the stock exclusion mitigations (Tier 1) following advice from John Dymond, (John Dymond 2017 Pers. Comm., 1 June. In reality, these two activities may occur as a staged approach (stock exclusion first) or concurrently during mitigation work at the catchment level. Riparian planting would enhance bank stability through root distribution, and fencing alone would likely have less impact on sediment reduction at the stream bank level as a coupled approach.

3.3 Land Retirement

Retirement of land was informed by the Land Use Classification (LUC) data for BAU scenarios, and in addition the top 5% of erosion prone land for Gold and Silver scenario's (See **Table 2.1** – **Table 2.3)**. GIS analysis was undertaken to identify the relevant LUC classes for each scenario and retiring land starting with the steepest slope class, by converting the baseline landuse to native Bush FU type. Retirement essentially effects Sheep and Beef farms, given most retirement focused on steep and eroding slopes as per descriptions in **Table 2.1** to **Table 2.3.** Retirement was undertaken first, followed by pole planting. It was assumed that land that is retired cannot be pole planted.

This is undertaken through a land use area change in the model, i.e. Sheep and Beef decreases by 50 ha, Native Bush increases by 50 ha. Where this occurs, the Native_Bush EMC/DWC input parameters for all constituents except sediment would be applied to the land that has been retired, thereby decreasing the loads from that particular area in the model.

Table 3.3 : Land retirement effects on nutrients and sediment

	Sediment	Nitrogen	Phosphorus	*E.coli*
Retired <10 years old	No change	Change to Native_Bush input concentrations as applied in the baseline model.		
Retired >10 years	Change to Native_Bush input concentrations. For Sediment, a 90% reduction in load is applied to the landslide, gully and earthflow SedNetNZ layers for the retired areas in GIS as advised by Dymond *et al.* 2014.			

The modelling assumptions described in **Table 3.3** meant that for nutrients, the effect of retirement was considered immediate. However, for sediment (treated separately through SedNetNZ), the 'effective' retired area is delayed by 10 years when catchment annual average loads were calculated. Retired land less than 10 years old was not included in the sediment load reductions.   Phosphorus was also assumed to be reduced in concentration immediately following retirement, primarily due to reductions in fertilizer, increased grass and vegetation growth and less disturbance of land from stock. However, it could be argued that given phosphorus is often entrained with suspended sediment, then it could have been modelled as having no change until 10 years of growth is achieved. For the purposes of these scenarios, the effects on phosphorus concentration reductions is that it will occur at a faster rate (i.e. a greater reduction by 2040).

The total area of land that is retired upstream of each reporting point is described in **Table C.1** in **Appendix C**. Retirement of land mitigation option will effect both median (50^{th}) and 95^{th} percentile concentrations.

3.4 Pole Planting

Pole planting (space planting) occurred at a rate of 135 ha/yr in BAU on steep slopes of class 7 land and above. The steepest land was pole planted first. GWRC provided a map of the current pole planted areas in the catchment, which was also incorporated into BAU modelling. Based on the BAU pole planting rate, 8,500 ha of the modelled catchment could be pole planted by 2080.

Following discussions with John Dymond and literature reviews (Dymond *et al.* 2014), it was agreed that pole planting primarily affects sediment and phosphorus, but results in no change to nitrogen (and its species) and *E.coli*. The application of mitigations to SednetNZ sediment yields was agreed with John Dymond (John Dymond 2017 pers, comm., 9 June) and are described in **Table 3.4.**

Table 3.4: Pole planting methodology for nutrients and sediment

	Sediment	Nitrogen	Phosphorus	*E.coli*
Pole planted <15 years	No change from baseline			
Pole planted >15 years	• Add the landslide, gully, earthflow and surficial layers in SedNetNZ • Apply a 70% reduction to the annual load for the landuse types that have been pole planted. • Apply the reduction at the lumped polygon scale (the parcel or property scale). • This process is undertaken in GIS.	No change from baseline	• Change the pole planted area to Native_Bush, determine the EMC concentration from this landuse type • Subtract the Native_Bush EMC concentration from the existing (pre pole planted) concentration • The difference is then reduced by 70% • The left over amount (30%) is then added to the Native_Bush EMC conc for TP or DRP. • This process is undertaken in excel	No change from baseline

The approach above results in changing the nutrient generation rates rather than the landuse areas to avoid doubling up of the mitigation effects on other unmitigated nutrient types. Nitrogen species are considered to remain the same given farming will continue under the pole planted areas, where TP/DRP are strongly influenced by sediment and are therefore have been assumed to be treated with the same reductions.

As per the retirement methodology (**Section 3.3**), the above analysis was compounded by the delayed effect of pole planting by 15 years. This meant that in all scenarios (Gold, Silver and BAU), pole planting had no effect on the 2025 results, while retirement had a very small effect. The mitigation effects become evident in 2040 and 2080, where pole planting and retirement of steep land begin to reduce nutrient and sediment concentrations. Gold and Silver have the same pole planted areas, as they both completed planting by 2040.

While Silver planted land on LUC class 6e to 7 land, Gold planted land is on LUC class 6e and above (**Table 2.2** and **Table 2.3)**. This LUC class which separated the scenarios had no effects on the final areas planted, as all land above class 7 was effectively retired first (i.e. fell within the top 5% or erodible land). Therefore, these two scenarios have the same pole planting influences on sediment, TP and DRP.

The values in **Table C.2** in **Appendix C** present the pole planted areas relative to the 20 reporting points.

3.5 WWTP

WWTP mitigations varied depending on the scenario being modelled, as outlined in **Section 2** and further described in Jacobs 2017a. However, all scenarios included the following approaches:

- WWTP flow and load were increased based on population growth assessments for the region (from statistics NZ).
- Receiving water flows were assessed to determine when discharge could occur to the river. When it could not, it was assumed to be land treated.

- The proportion of flow that was land treated was multiplied with the WWTP timeseries concentration to create a load. This load was then attenuated based on information gathered from consents, Overseer and literature data that was verified and agreed on with all district councils. I.e. 77% reduction to Nitrogen, 95% reduction *E.coli*.
- The revised 'attenuated' load was then recalculated as a concentration, and imported back into Source model with the revised flow (corrected for population increase). The resulting decrease in load represents land treatment.

The effects of the WWTP mitigations are most evident at the modelled links (reaches) directly downstream, however their effects propagate throughout the catchment. It is worth noting that there is no reporting point downstream of the Featherston WWTP, so the changes in receiving waters here are only captured in Lake Wairarapa quality.

The attenuation factors applied to nutrients in each of the WWTP's are described in **Table 3.5.**

Table 3.5 : Nutrient reduction due to land treatment

Contaminant	Attenuation factor (%)	Assumptions	Source
Carterton			
Nitrogen	73	140 kg/N/Ha/yr is applied to land and 38 kg/N/Ha/yr is lost to water as per Overseer modelling.	EQO (2016)
Phosphorus	98	35 kg/P/Ha/yr is applied to land and 0.8 kg/P/Ha/yr is lost to water as per Overseer modelling.	EQO (2016)
E. coli	95	*E. coli* attenuation rates will be similar to those likely to be observed at the Masterton WWTP (i.e., 95% of *E. coli* will die off within the soil).	Green (2007)
Total suspended solids	100	All TSS applied to land will be attenuated before reaching the water table.	NA
Featherston			
Nitrogen	88	Average of 237 kgN/Ha/yr is applied to land and 38.8 kg/N/Ha/yr is lost to water as per Overseer modelling. It is noted that this is representative of the discharge regime upon completion of Stage 2B of the upgrades at the Featherston WWTP.	LEI (2017)
Phosphorus	100	All phosphorus is removed from site via plant uptake.	LEI (2017)
E. coli	95	Assumed *E. coli* attenuation rates will be the similar to those likely to be observed at the Masterton WWTP.	Green (2007)
Total suspended solids	100	All TSS applied to land will be attenuated before reaching the water table.	NA
Greytown, Martinborough, Masterton			
Nitrogen	77	Concentration of nitrogen discharged from the Masterton WWTP is 11.5 mg/L and modelled drainage is 2.7 mg/L.	Green (2007)
Phosphorus	94	Concentration of phosphorus discharged from the Masterton WWTP is 3.2 mg/L and modelled drainage is 0.2 mg/L.	Green (2007)
E. coli	95	95% of *E. coli* will die off within the soil.	Green (2007)
Total suspended solids	100	All TSS applied to land will be attenuated before reaching the water table.	NA

The primary influence on reducing WWTP loads is whether land treatment is occurring. Throughout BAU there is a mixture of land and water discharge, while Gold and Silver are primarily land treatment at all the WWTP, which would therefore lead to a greater decrease in concentrations (both median and 95th).

4. Assumptions/Limitations

4.1 Flow calibration

Loads in the Source model are driven by the flow generation. The Source model uses flows from a range of inputs. The flow development framework includes:

- TOPNET (NIWA) provides total stream flow generated from the Hill catchments;
- Irricalc (Aqualinc) provides quickflow inputs from the plains catchments and irrigation surface water demands (unrestricted).
- MODFLOW-SFR-MT3D (GNS) system, developed in parallel to the Source model, provided groundwater flux and nitrate loads for input to river links (reaches);
- Point-source inputs (discharge and effluent concentrations) from five wastewater treatment plants (WWTP) derived from monitoring data and included as inflow nodes within the node-link network
- Surface water abstraction annual allocation and minimum low flow limits were modelled within Source and applied total daily abstraction (agglomerated per subcatchment) along the river links.

The subsequent calibration of these flows series was undertaken by each of the respective parties above, with Jacobs compiling the flow series in Source for the water quality modelling. At a number of sites, calibrations to observed data have often led to an over simulation of flow for many reaches. An accurate flow model is important to ensure generated loads are correctly attenuated. Subsequently, good calibrations of water quality data to observed information are increasingly difficult to achieve if the flows are inaccurate.

4.2 Baseline model nutrient calibration

The approach undertaken for calibrating the water quality model is outlined briefly in **Section 1.2** and further described in detail in Jacobs (2017). The water quality calibration is driven by the suitability of the flow modelling (as described in **Section 4.1**), where simulations of higher or disproportionate (i.e. disparity between quick and baseflow representation) flows will lead to an over or under prediction in nutrient loads in the catchment. Calibration of attenuation rates to fit the model to the observed water quality data can compensate for some inaccuracies in the modelled flows. However, these attenuation rates are constrained within the bounds of published literature. A higher flow (and higher load) may mean an attenuation factor is applied that is larger than what is realistically occurring in the catchment to help calibrate simulated concentrations to the observed data.

4.3 Pole planting and retirement delayed effects

As described in **Section 3, Table 3.3** and **Table 3.4**, pole planting and retirement had delayed effects on sediment, and was assumed to occur only at maturity within the model. An alternative approach, given a more comprehensive literature review, could have been to apply a linear increase in reductions up to their threshold values of 70 and 90%. Literature suggests that pole planting generally has little effect on sediment reduction when poles are <7 years old and they reach maturity at 15 years (Douglas *et al.* 2010). However once the roots are established after 7 years, each year of growth could have been assumed to have an increasing portion of sediment reduction.

4.4 Catchment areas

Catchment delineation was dictated by accommodating several sources of flow inputs and therefore resulted in aggregation of REC catchments that resulted in the exclusion of some reporting locations on small tributary sites or those that did not align with flow input locations.

To improve on this would require updates of the hydrological models (TOPNET runoff, MODFLOW GWFlux and Irricalc quickflow) which was not possible in the project timeframes.

Overall, the effects of this are considered minor given the proportionate catchment size and that downstream points would have been calibrated to include this additional load (i.e. a higher attenuation rate would have been applied in the model to calibrate sites to observed data).

4.5 Landuse change and flow impacts

Generally, the Source software accommodates changes in functional unit areas (i.e. landuse areas) for scenario modelling (thereby representing a change in the rainfall-runoff and water quality generation rates more directly). However, due to time constraints and difficulties associated with re-running all the flow models (TOPNET, Irricalc and MODFLOW), the landuse area changes (essentially retirement and pole planting) were not incorporated into any recalculation of flows.

The only changes in the flow series were due to:

- New GWF's provided by GNS for each scenario, which was primarily for revisions of the Nitrate-N loads entering the reaches (due to revisions of the Nitrate-N BAU, Gold and Silver leaching maps). These flow series encompassed any control rules applied to groundwater takes as modelled by GNS and irrigation being modelled at 100% of consented abstraction rates (description of this is not covered within this report).
- Increased flow from the WWTP's due to simulated population increase.

Overall, these flow changes were relatively minor when compared against the baseline model. Realistically, landuse change would influence the hydrology of an area, particularly where retirement, pole planting and plantation forests (deforestation/reforestation) are considered. In addition, no scenarios (Gold, Silver or BAU) encompassed landuse change in the lower catchment, such as intensification (conversion to dairy or cropping).

4.6 WWTP land discharge

Each of the scenarios had various land treatment applications of the WWTP loads. In some situations (BAU and Silver models), this was also driven by the receiving river flows and various discharge control rules. An assessment of the river flows was undertaken to determine when discharge could occur under these scenarios and is further described in Jacobs 2017a**.**

In some circumstances WWTP loads could not be discharged to a river (due to flow restrictions) yet the proportionate amount that was allowed to be discharged to land (under the scenario) had been allocated. In this situation, it was assumed the discharge control rules took priority, and the WWTP loads were discharged to land.

Additionally, some of the control rules set by the Ruamāhanga Whaitua Committee were challenging to meet due to the receiving water flow series being unsuitable for WWTP loads discharge to water (Carterton in particular).

This influences described above occurred in the following situations:

- Carterton WWTP – BAU (all scenarios) and Silver 2025.
- Featherston WWTP – Silver 2025.
- Masterton WWTP – BAU 2025.

See Jacobs (2017a) for a full description on how the discharge criteria differs between the planned versus actual scenarios.

4.7 Lakes model inputs/outputs

The constituent and flow outputs from Source catchment modelling were provided to the University of Waikato, whom developed hydrodynamic and biophysical models for Lakes Wairarapa and Onoke.

Given time constraints and additional steps involved in incorporating the lake outputs back into the Source model to transfer flow and nutrients from Lake Wairarapa to Onoke, the University undertook this by incorporating the flows/loads from the Lake Wairarapa with the river/stream flows/loads provided through Source, to determine the inflows that feed into Lake Onoke.

5. Summary

The purpose of this document is to provide supporting information on nutrient modelling undertaken in the Ruamāhanga Catchment. This includes the modelling approach and how mitigations have been applied throughout the BAU, Silver and Gold scenarios.

Results for each of the reporting sites for each constituent are presented as 'fact sheets', which include results of the scenario modelling, a summary of the influencing landuse types, and degree of pole planting and retired land for each scenario.

The relative change between the baseline and scenarios (i.e. percentage change) provides value to the decision making process on water quality limit setting, as while there maybe uncertainties in the model, it inherently represents key sources of nutrients and landuse practices. Subsequently, the on farm mitigations and effects of retiring and pole planting land are a realistic representation of what can be feasibly achieved within the catchment to inform the direction of change in nutrient reductions from each of the mitigation options considered.

This will help inform the water quality objectives that the Whaitua may want to achieve at various locations within the catchment, as part of a multiple lines of evidence approach considered in conjunction with cultural aspects, economic, ecological and lake model results.

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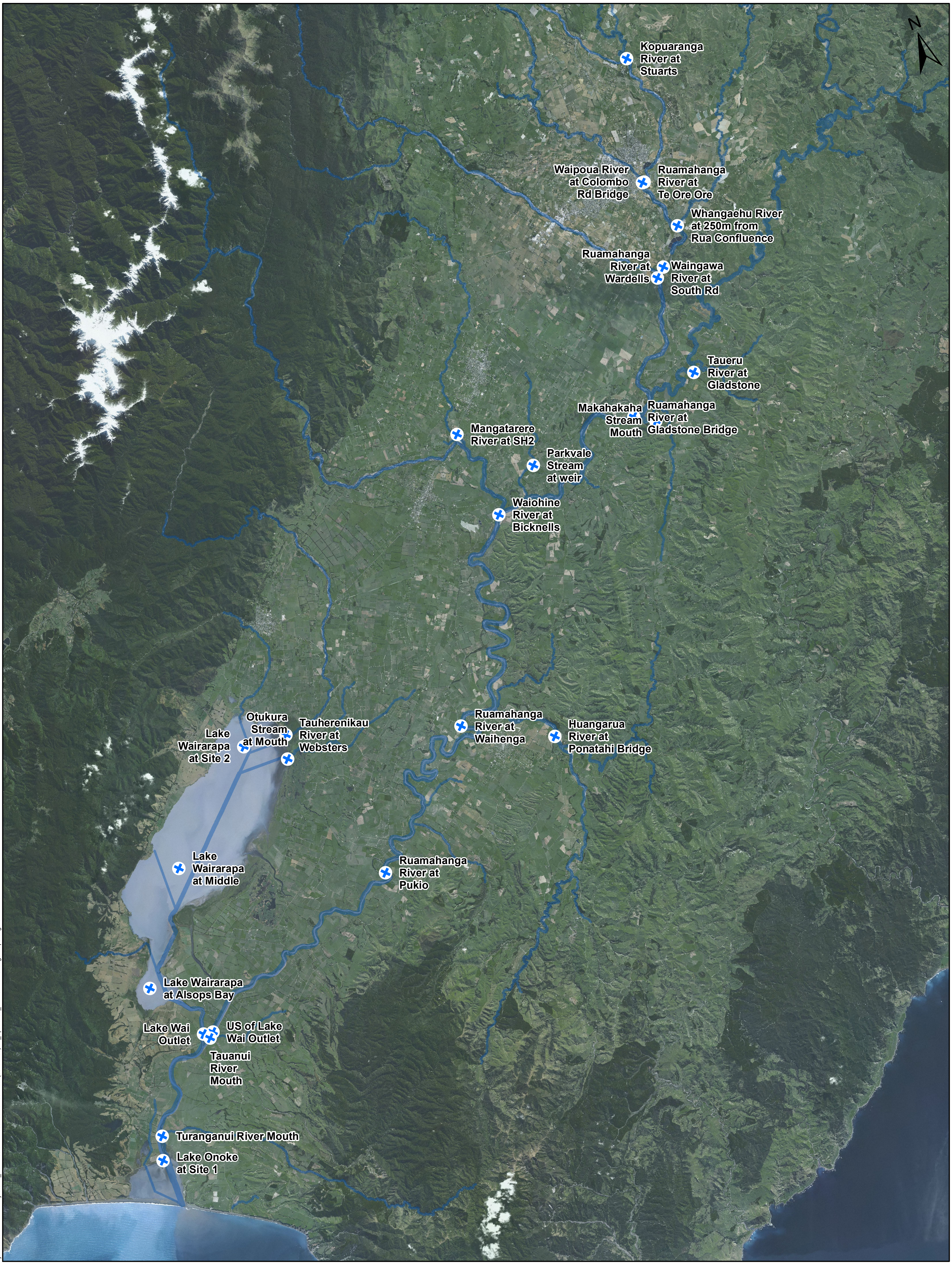
Appendix A. Landuse area table

Table A.1 : Landuse area in the baseline model relative to each reporting site. Units are hectares and percentage of total upstream catchment area (bracketed values).

Reporting Site	Dairy	Dairy Support	Arable	Sheep and Beef	Native Bush	Other**	Total***
Huangarua River at Ponatahi Bridge	-	46 (0.2)	-	25581 (84.6)	693 (2.3)	3918 (13.0)	30239
Kopuaranga River at Stuarts	808 (4.8)	281 (1.7)	-	14103 (84.5)	154 (0.9)	1339 (8.0)	16686
Mangatarere River at SH2	2842 (23.8)	357 (3.0)	40 (0.3)	2515 (21.0)	4190 (35.1)	2003 (16.8)	11947
Ruamāhanga River at Pukio	14438 (5.9)	5867 (2.4)	1556 (0.6)	132684 (53.9)	45104 (18.3)	46717 (19.0)	246366
Ruamāhanga River at Te Ore Ore	1115 (3.6)	549 (1.8)	3 (0.0)	17950 (57.8)	7487 (24.1)	3974 (12.8)	31078
Taueru River at Gladstone	298 (0.6)	246 (0.5)	587 (1.2)	39655 (80.5)	242 (0.5)	8217 (16.7)	49244
Tauherenikau River at Websters	267 (1.8)	419 (2.9)	-	944 (6.5)	11255 (77.7)	1596 (11.0)	14481
Waingawa River at South Rd	215 (1.4)	127 (0.9)	-	2389 (16.0)	9856 (65.8)	2382 (15.9)	14969
Waiohine River at Bicknells	6070 (15.4)	1036 (2.6)	227 (0.6)	3595 (9.1)	23641 (60.1)	4750 (12.1)	39320
Waipoua River at Colombo Rd Bridge	173 (1.0)	670 (3.8)	113 (0.6)	9862 (56.5)	2802 (16.1)	3832 (22.0)	17452
Parkvale Stream at weir	1246 (24.9)	553 (11.0)	-	980 (19.6)	42 (0.8)	2185 (43.6)	5006
Ruamāhanga River at Wardells	2322 (3.6)	1518 (2.4)	161 (0.3)	38490 (59.9)	10298 (16.0)	11495 (17.9)	64284
Ruamāhanga River at Gladstone Bridge	3564 (2.7)	2095 (1.6)	791 (0.6)	81249 (60.8)	20401 (15.3)	25593 (19.1)	133694
Ruamāhanga River at Waihenga	13451 (5.7)	5413 (2.3)	1487 (0.6)	128058 (54.2)	44818 (19.0)	42862 (18.2)	236089
Whangaehu River at 250m from Ruamāhanga Confluence	915 (6.3)	299 (2.1)	45 (0.3)	10335 (70.9)	5 (0.0)	2979 (20.4)	14578
Otukura Stream at Mouth	2790 (29.8)	2454 (26.2)	-	1611 (17.2)	83 (0.9)	2428 (25.9)	9366
Makahakaha Stream at Mouth	129 (2.1)	389 (6.3)	38 (0.6)	5155 (83.3)	4 (0.1)	477 (7.7)	6192
Ruamāhanga River at U/S Lake Wai Outlet	16146 (6.3)	6139 (2.4)	1556 (0.6)	136133 (53.5)	47016 (18.5)	47506 (18.7)	254496
Tauanui River at Mouth	-	-	-	617 (14.9)	2535 (61.0)	1003 (24.1)	4155
Turanganui River at Mouth	260 (3.9)	38 (0.6)	-	1810 (26.8)	3491 (51.8)	1141 (16.9)	6740

** ‘Other’ landuse refers to all remaining landuse types within Ruamāhanga (including forestry, horticulture, urban etc.)
*** The landuse area will change in BAU, Silver and Gold Scenarios due to retirement of land (**Table C.1**). Nearly all retirement occurs on sheep and beef and in some instances ‘Other’ landuse classes such as sheep farms (on their own). To approximate the area draining to a watershed during scenarios, obtain the retired land area from **Table C.1**, and subtract this off sheep and beef. The retired land is added to the native bush area. An example would be 107 ha of retirement in Huangarua River at Ponatahi Bridge in BAU. Sheep and Beef area would decrease to 25,364 ha (**Table A.1**), and native bush would increase another 107 ha

Appendix B. Figures



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CLIENT GWRC	
PROJECT Ruamahanga SOURCE Model	
SCALE 1:200,000 @ A3	DATE 17/10/2017

Legend

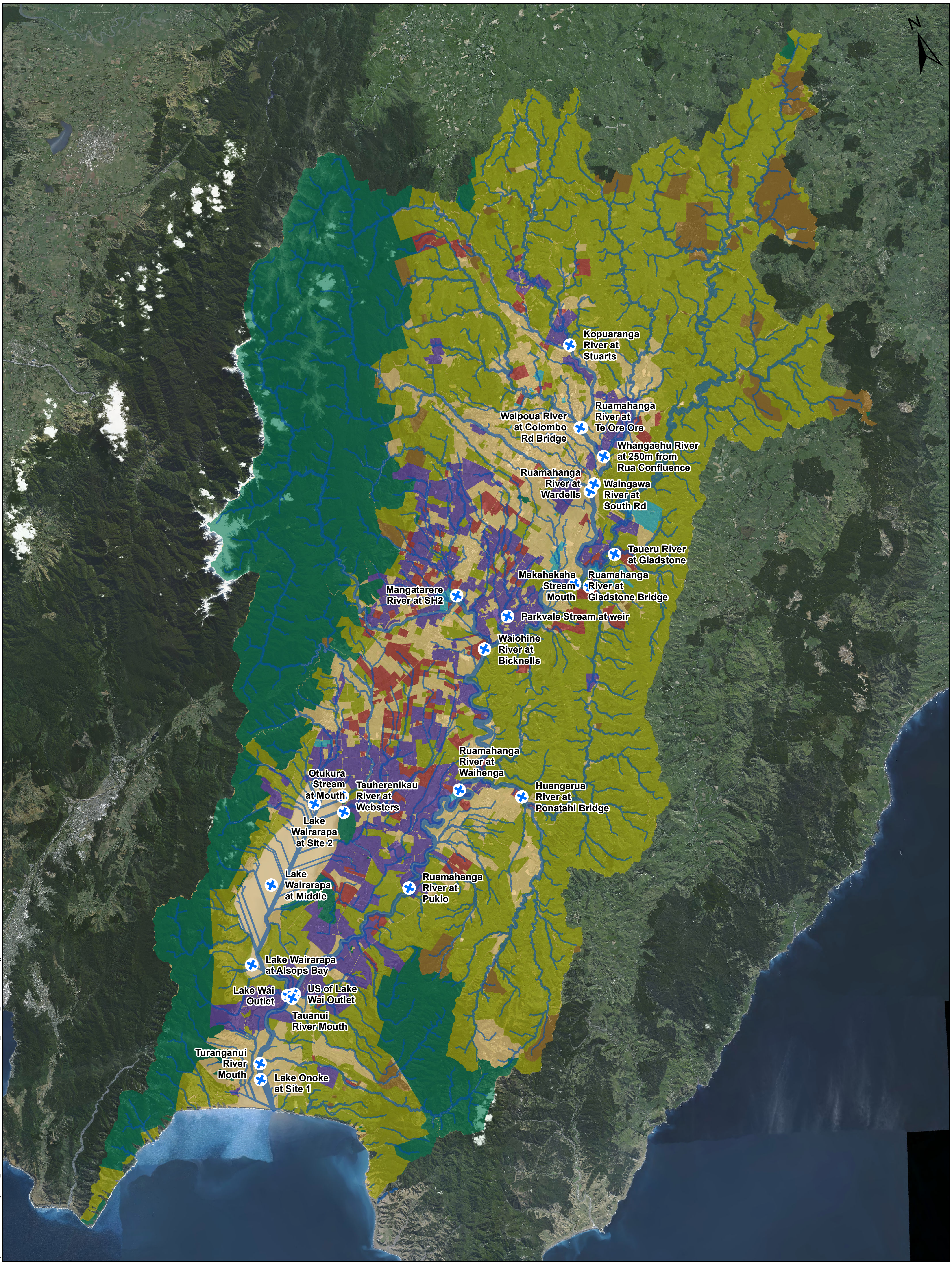
River

Reporting Points

Ruamāhanga Whaitua
Figure B1. Reporting Points

0 1 2 3 4 5 km

JACOBS



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CLIENT					
GWRC		Reporting Points	Arable	**Ruamāhanga Whaitua**	JACOBS
PROJECT		River	Native Bush	**Figure B2. Land Use**	
Ruamahanga SOURCE Model		Sheep and Beef Farming	Forestry		
SCALE	DATE	Dairy Farming	Other	0 1 2 3 4 5 km	
1:300,000 @ A3	17/10/2017	Dairy Support			

Appendix C. Retired and pole planted land

Table C.1 : Retired land (hectares) at each reporting point, in each scenario. The values are cumulative, where lowland sites such as Pukio include all the areas upstream of this site. The total (TA) and effective areas (EA, >10 years old) have been reported to understand the amount of land retirement that has occurred, versus what is having an effect on nutrient reductions at a particular point in time.

Reporting Site	BAU 2025		BAU 2040		BAU 2080		Silver 2025		Silver 2040		Silver 2080		Gold 2025		Gold 2040		Gold 2080	
	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)
Huangarua River at Ponatahi Bridge	107	0	107	107	107	107	2285	0	3240	2285	3240	3240	3240	0	3240	3240	3240	3240
Kopuaranga River at Stuarts	0	0	0	0	0	0	353	0	1068	353	1068	1068	1068	0	1068	1068	1068	1068
Mangatarere River at SH2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ruamāhanga River at Pukio	107	0	245	107	347	271	5376	0	10812	5376	10812	10812	10812	0	10812	10812	10812	10812
Ruamāhanga River at Te Ore Ore	0	0	52	0	61	52	452	0	1244	451	1244	1244	1244	0	1244	1244	1244	1244
Taueru River at Gladstone	0	0	0	0	0	0	1213	0	3310	1213	3310	3310	3310	0	3310	3310	3310	3310
Tauherenikau River at Websters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Waingawa River at South Rd	0	0	7	0	7	7	0	0	5	0	5	5	5	0	5	5	5	5
Waiohine River at Bicknells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Waipoua River at Colombo Rd Bridge	0	0	79	0	163	105	314	0	454	314	454	454	454	0	454	454	454	454
Parkvale Stream at weir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ruamāhanga River at Wardells	0	0	132	0	225	158	1241	0	3008	1241	3008	3008	3008	0	3008	3008	3008	3008
Ruamāhanga River at Gladstone Bridge	0	0	138	0	231	164	2468	0	6340	2468	6340	6340	6340	0	6340	6340	6340	6340
Ruamāhanga River at Waihenga	107	0	245	107	347	271	5272	0	10637	5272	10637	10637	10637	0	10637	10637	10637	10637
Whangaehu River at 250m from Ruamāhanga Confluence	0	0	0	0	0	0	452	0	1286	452	1286	1286	1286	0	1286	1286	1286	1286
Otukura Stream at Mouth	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	1	1	1
Makahakaha Stream at Mouth	0	0	0	0	0	0	218	0	341	218	341	341	341	0	341	341	341	341
Ruamāhanga River at U/S Lake Wai Outlet	107	0	245	107	347	271	5634	0	11092	5634	11092	11092	11092	0	11092	11092	11092	11092
Tauanui River at Mouth	0	0	0	0	0	0	5	0	8	5	8	8	8	0	8	8	8	8
Turanganui River at Mouth	2	0	67	67	152	67	123	0	131	123	131	131	131	0	131	131	131	131

Table C.2 : Pole planted land (hectares) at each reporting point, in each scenario. The values are cumulative. The total (TA) and effective areas (EA, >15 years old) have been reported to understand the amount of planting that has occurred, versus what is having an effect on nutrient reductions at a particular point in time.

Reporting Site	BAU 2025		BAU 2040		BAU 2080		Silver 2025		Silver 2040		Silver 2080		Gold 2025		Gold 2040		Gold 2080	
	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)	TA (ha)	EA (ha)
Huangarua River at Ponatahi Bridge	204	0	1243	204	1669	1669	1697	0	3956	1697	3956	3956	1702	0	3956	1702	3956	3956
Kopuaranga River at Stuarts	2	0	2	2	4	2	526	0	899	526	899	899	526	0	899	526	899	899
Mangatarere River at SH2	0	0	0	0	1234	784	1467	0	1527	1467	1527	1527	1467	0	1527	1467	1527	1527
Ruamāhanga River at Pukio	926	0	2927	926	6920	5761	8993	0	27679	8993	27679	27679	8998	0	27679	8998	27679	27679
Ruamāhanga River at Te Ore Ore	2	0	2	2	231	3	1016	0	2424	1016	2424	2424	1016	0	2424	1016	2424	2424
Taueru River at Gladstone	658	0	1351	658	2242	2242	1415	0	8203	1415	8203	8203	1415	0	8203	1415	8203	8203
Tauherenikau River at Websters	0	0	0	0	247	34	473	0	530	473	530	530	473	0	530	473	530	530
Waingawa River at South Rd	0	0	0	0	611	324	1530	0	2489	1530	2489	2489	1530	0	2489	1530	2489	2489
Waiohine River at Bicknells	2	0	2	2	1333	873	1600	0	2629	1600	2629	2629	1600	0	2629	1600	2629	2629
Waipoua River at Colombo Rd Bridge	8	0	8	8	451	301	914	0	1548	914	1548	1548	914	0	1548	914	1548	1548
Parkvale Stream at weir	1	0	1	1	33	1	41	0	1284	41	1284	1284	41	0	1284	41	1284	1284
Ruamāhanga River at Wardells	49	0	287	49	959	581	2445	0	5917	2445	5917	5917	2445	0	5917	2445	5917	5917
Ruamāhanga River at Gladstone Bridge	707	0	1638	707	3813	3147	5390	0	16758	5390	16758	16758	5390	0	16758	5390	16758	16758
Ruamāhanga River at Waihenga	926	0	2927	926	6920	5761	8790	0	26501	8790	26501	26501	8794	0	26501	8794	26501	26501
Whangaehu River at 250m from Rua Confluence	37	0	274	37	274	274	513	0	1751	513	1751	1751	513	0	1751	513	1751	1751
Otukura Stream at Mouth	0	0	0	0	0	0	1	0	12	1	12	12	1	0	12	1	12	12
Makahakaha Stream at Mouth	3	0	3	3	3	3	3	0	3	3	3	3	3	0	3	3	3	3
Ruamāhanga River at U/S Lake Wai Outlet	926	0	2927	926	6920	5761	8994	0	28734	8994	28734	28734	8998	0	28734	8998	28734	28734
Tauanui River at Mouth	0	0	0	0	0	0	9	0	279	9	279	279	9	0	279	9	279	279
Turanganui River at Mouth	70	0	71	70	99	99	739	0	831	739	831	831	739	0	831	739	831	831

Important note about your report

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