Ruamahanga Catchment

Assessment of background instream nutrient yields

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9 October 2018

Document history and status

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Ruamahanga Catchment

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1. Introduction

Greater Wellington Regional Council (GWRC) are setting freshwater objectives (FWOs) for in-stream nutrients across the Ruamāhanga Catchment. OVERSEER has been used to derive nutrient yields off various land use, soil and climate combinations within the catchment. These yields have been incorporated as inputs in Source modelling (see Jacobs 2018) as a calibrated baseline daily flow and water quality model. Reductions of the OVERSEER baseline nutrient and runoff yields from land use change and infrastructure mitigations has been incorporated into Source scenario models (i.e. Business as Usual, Silver or Gold scenario), and compared to the baseline model representing Ruamāhanga in its current state.

The magnitude of the nutrient and contaminant changes in modelling has helped inform the Whaitua on the in-stream FWO's they would like to achieve at various locations in the catchment, at management zones known as Freshwater Management Units (FMU's). At each FMU there are in-stream concentrations that vary depending on the scenario applied, and a chosen FWO can link directly to the OVERSEER inputs for the appropriate chosen scenario (and its mitigations package). The OVERSEER yields for that scenario are used to calculate the FMU's annual average load (tonnes/year) which are then assigned as a limit or target to be achieved by a certain date.

To assist in this process and provide more context on how OVERSEER inputs in the models compare to background observed (natural) loads, Jacobs have undertaken an assessment of background yields of in-stream nitrogen (N), phosphorus (P) and their sub-species (i.e. nitrate-nitrogen and dissolved reactive phosphorus) from areas of the catchment that are predominantly in native forest.

This assessment includes:

- a desktop literature search to assess the likely N and P contributions to to rivers and streams in the Ruamahanga catchment (or river catchment) from native forest

- Analysis of observed N and P concentrations in rivers, which are then converted to annual yields for the monitoring sites representing catchments under native forest and mixed land uses. This considers two methods:

    - Method 1: a generalised approach using mean/median concentrations against mean annual flows to estimate annual yields (kg/ha/yr).

    - Method 2: a flow-weighted approach which allocates the monthly water sample concentrations into ten flow 'bins' that are related to the flow duration curve and then calculates annual loads from this data. This follows the method of Roygard, McArthur and Clark (2012).

- A review and comparison of OVERSEER modelled N and P yields with observed yields, for the native forested catchments with monitoring data.

The objective of this work is to identify if the OVERSEER loads are suitable to be used as background natural loads, representing an unmodified system prior to human development. What this would allow is a partitioning of a Freshwater Management Unit's (FMU) N and P loads into a background natural load, a "native" load (if native forest is present) and a "non-native" load, with the latter being the additional load due to agriculture and point source discharges. Subsequently, the adoption of targets and limits to meet the FWOs in streams and lakes would then be applied to the non-native load only, and will ensure the reductions required in loads do not extend beyond FMU's natural generation rates.

2. Background information

The Ruamāhanga catchment has three distinct physiographical units, defined by the topography, the geology and the rainfall (Begg *et al*. 2005). These three units are shown on Figure 2.1, and include the central valley, the Tararua and Remutaka ranges to the west, and the Eastern Wairarapa hill country.

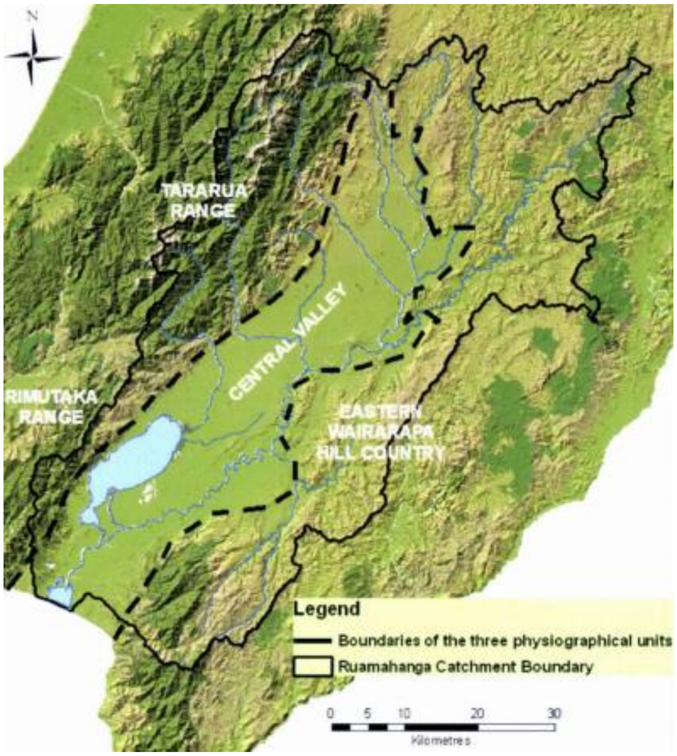

Figure 2.1 - Location of three physiographical units in the Ruamāhanga catchment (Begg *et al*. 2005)

2.1 Land use

Land use and soil maps (S-map) were obtained from GWRC, with the land use map developed from regional knowledge and site visits by staff. Soils were divided into poorly drained, imperfectly drained and well drained types, and were merged with land use to capture the spatial variability in nutrient leaching and runoff, illustrated in Figure 2.2.

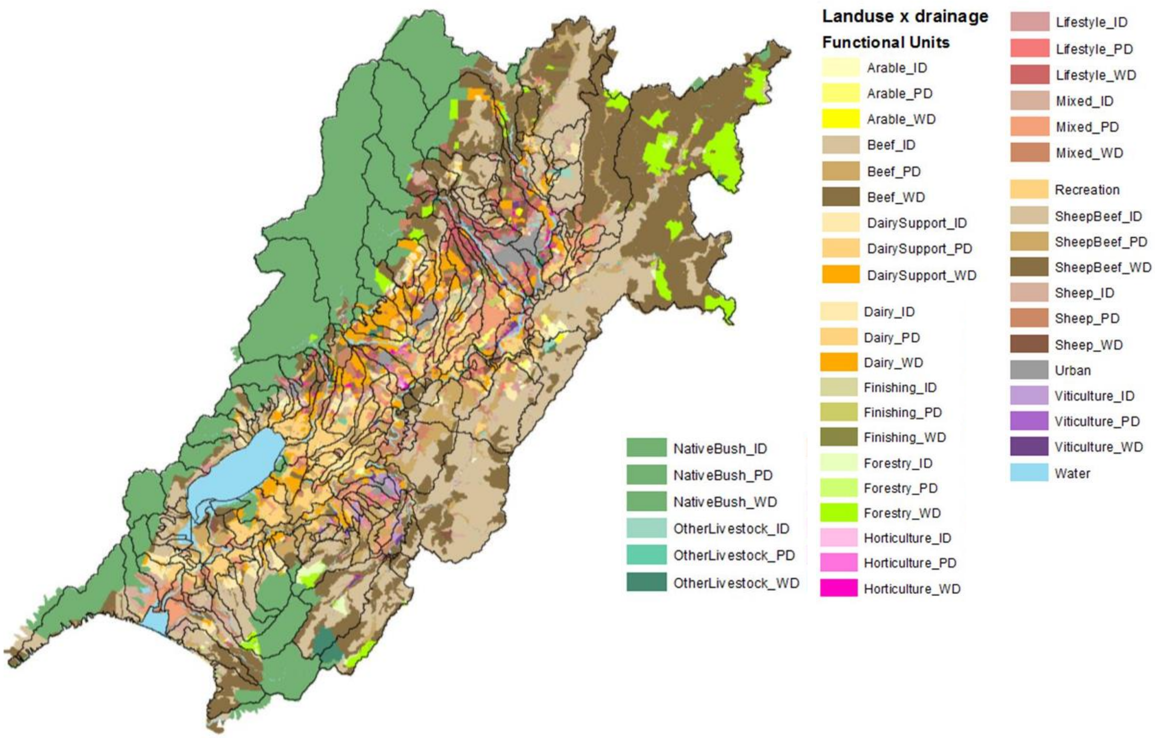

Figure 2.2 : Land use and drainage categories (IP = Imperfectly drained, PD = Poor drained, WD = Well drained)

2.2 Soils

The Ruamāhanga River catchment has a wide range of soil types within the catchment, as shown on Figure 2.3.

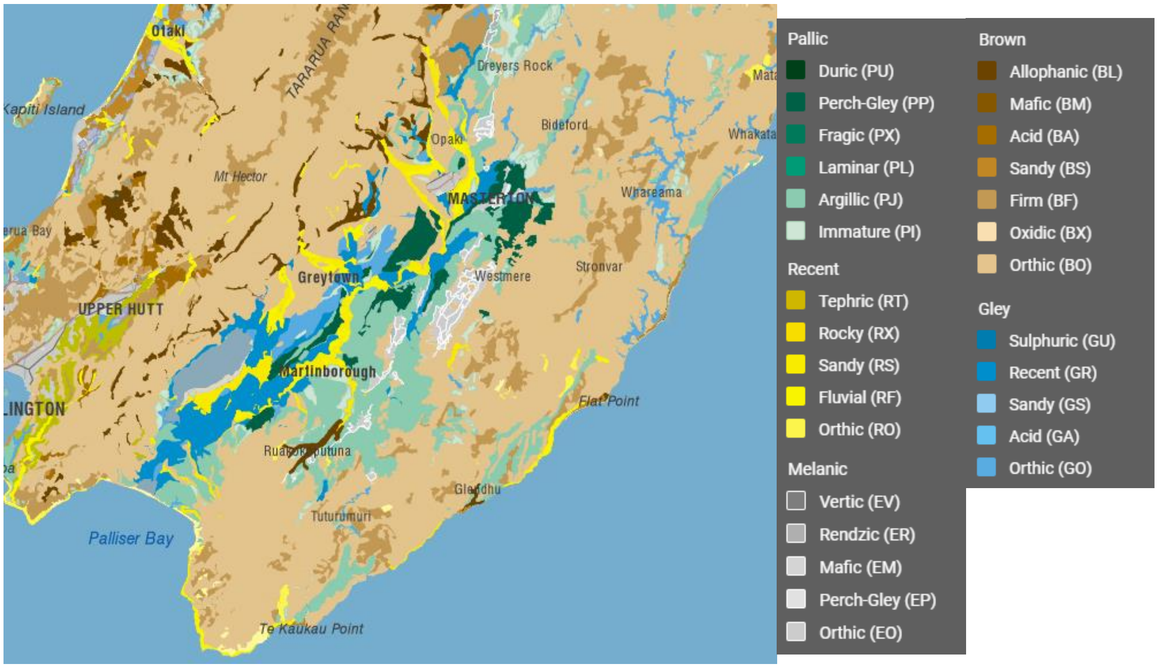

Figure 2.3 - Soils in the Ruamāhanga catchment (https://soils-maps.landcareresearch.co.nz)

2.3 Rainfall

The mean annual rainfall across the region has been mapped by GWRC, as shown in Figure 2.4. The figure indicates that the highest rainfall in the catchment occurs in the Tararua Range.

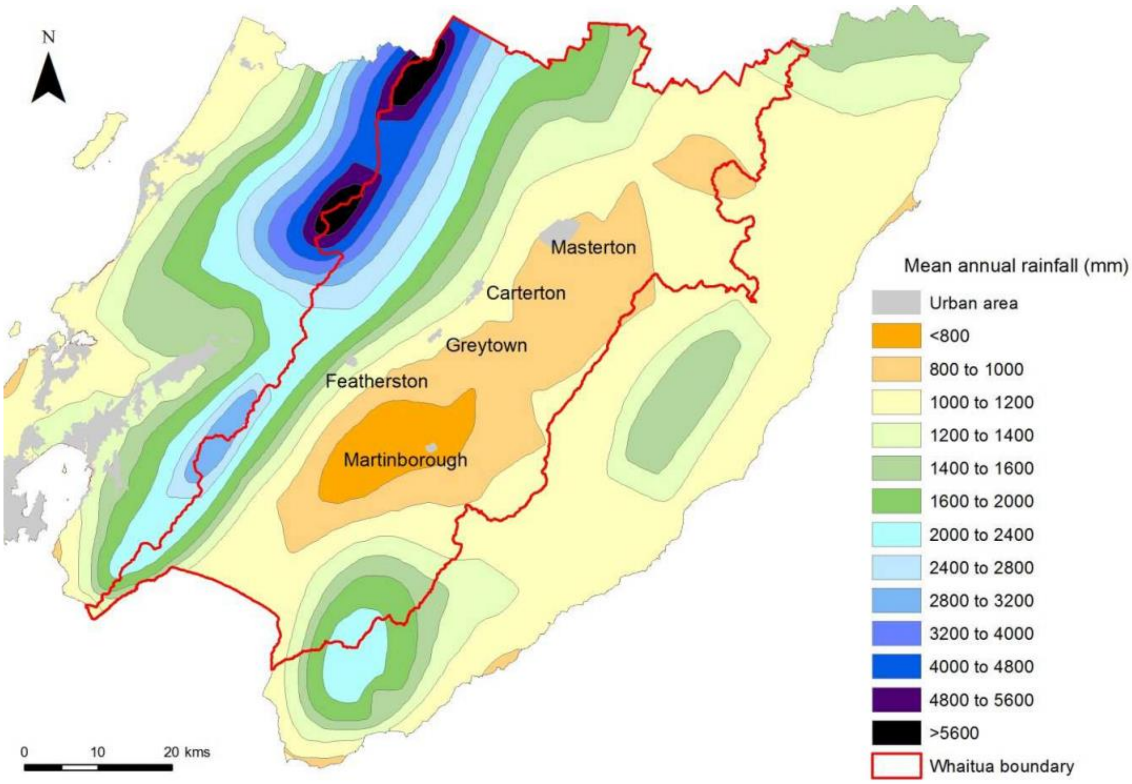

Figure 2.4 - GWRC mean annual rainfall in the Ruamāhanga catchment (http://www.gw.govt.nz/assets/Plans--Publications/Regional-Plan-Review/Whaitua/SUMMARY-REPORT-The-climate-of-the-Ruamāhanga-catchment.pdf)

3. OVERSEER-derived N and P loads

Nutrient generation from different land uses in the Source model are informed by OVERSEER modelling of representative farms combined with information from the literature (see Jacobs 2018). These represent the un-attenuated concentrations generated from a particular land use and soil drainage category. The nutrient budget calculated by OVERSEER provides nitrate-nitrogen (nitrate-N) and total phosphorus (TP) loss to water. This value is calculated from a combination of sources including leaching of urine patches and other sources; runoff; direct inputs from animals, drains and ponds; border dyke outwash; and septic tank overflow.

In most cases nitrate-N loss to water was generally due to leaching, while TP losses to water were calculated using the runoff values which represents the majority of OVERSEER derived phosphorus. These values were incorporated into the SOURCE model as Dry Weather Concentrations (DWC's) for nitrate-N, and Event Mean Concentrations (EMC's) for TP. See Jacobs 2018 for more detail.

The average nitrate-N leaching and TP runoff were then mapped across the Ruamāhanga catchment based on the spatial variability in rainfall, soil types and land use which are considered Functional Units (FUs) in the Source model. These results are shown in Figure 3.1 and Figure 3.2.

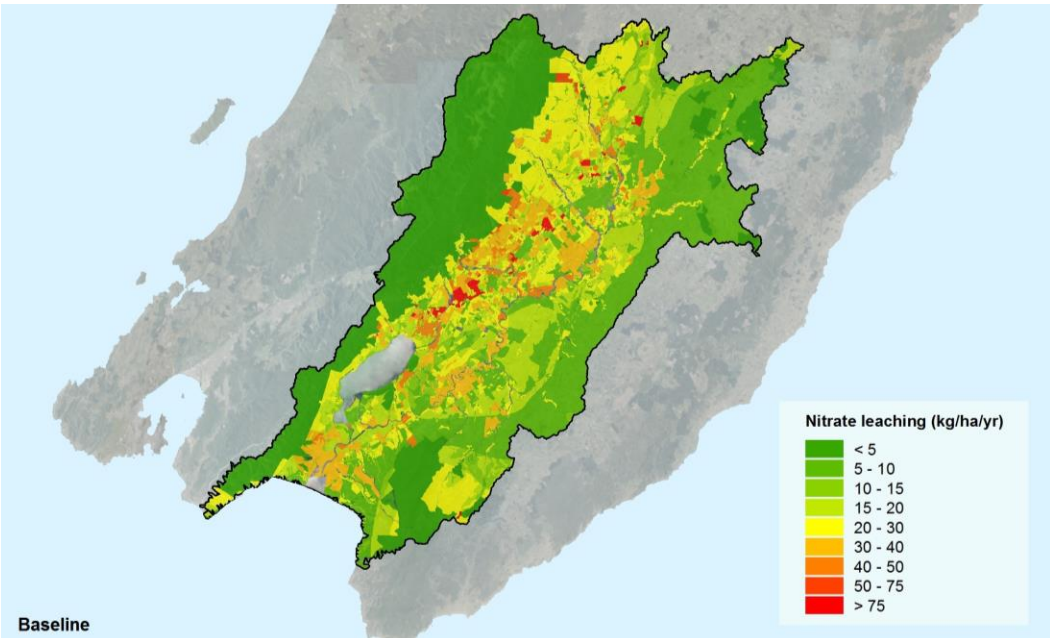

Figure 3.1 - Mean annual nitrate-N leaching loads derived from OVERSEER modelling

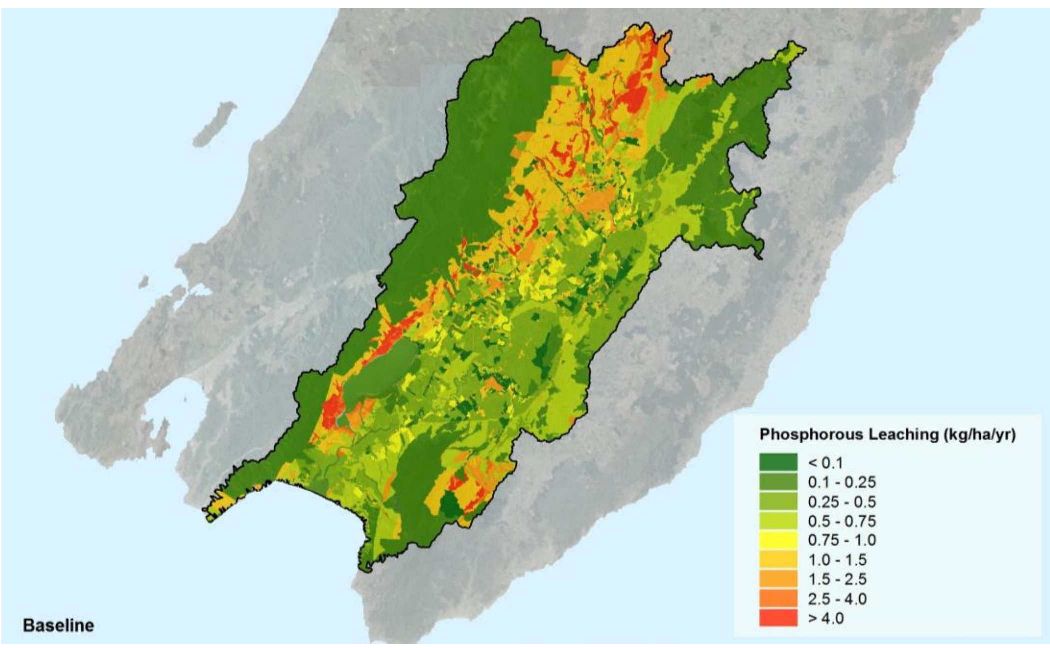

Figure 3.2 - Mean annual TP runoff loads derived from OVERSEER modelling

The OVERSEER input data for landcover corresponding to native forest used values of 1.0 kg/ha/yr of nitrate-N and <0.18 kg/ha/yr of TP. The resulting OVERSEER modelled nitrate-N:TP ratio for generated yields (without attenuation) is ~5.5:1 for native forest.

4. Representative Native Bush monitoring sites

There are a number of water quality monitoring sites within the Ruamāhanga that have native land use catchments, these are summarized in Table 4.1. These sites have also been compared to downstream sites with mixed land use catchments where available. A proxy location has been adopted upstream of Tauherenikau at Websters, immediately downstream of the native forest. In addition, a mixed native forest and plantation forestry site to the east of the Ruamāhanga catchment (Motuwaireka headwaters) has been included to provide some indication of potential water quality for the eastern hills.

Table 4.1 – Representative monitoring sites for native land use, with corresponding downstream monitoring site

Native catchment monitoring site			Downstream mixed		
Site name	**Area (ha)**	**Land use**	**Site name**	**Area (ha)**	**Land use (%)**
Tararua and Remutaka ranges					
Waiohine at Gorge	18,250	Native bush (99.4%) / pasture/other (0.6%)	**Waiohine River at Bicknells**	39,110	Native bush (60%) / pasture (27%) / other (12%)
Beef Creek at Headwaters	300	Native bush (93%) / pasture (5%) / other (2%)			
Waiorongomai at Forest Park	2,630	Native bush (96.8%) / pasture (2%) / other (1%)	-	-	-
Ruamāhanga River at McLays	7,340	Native bush (96.8%) / pasture (2%) / other (2%)	**Ruamāhanga at Te Ore Ore**	30,810	Native bush (24%) / pasture (65%) / other (11%)
Proxy	11,100	Native bush (98.2%) / pasture/other (2%)	**Tauherenikau at Websters**	14,270	Native bush (79%) / pasture (11%) / other (10%)
Eastern hills					
Tauanui River at Whakatomotomo	2,190	Native bush (99.7%) / pasture/other (0.3%)	-	-	-
Motuwaireka headwaters	336	Native bush (65%) / Forestry (34%) / other(12%)	-	-	-

These sites were monitored on a monthly basis by GWRC for a number of analytes including Total Nitrogen (TN), nitrate-N and TP. The proxy site upstream of Tauherenikau at Websters has never been monitored by GWRC. However, the data from Waiohine at Gorge has been adopted due to the similar amount of native bush and close location of these catchments.

Monthly nutrient concentration data between 2012 – 2017 has been analysed to determine the mean and median concentrations at each site for TN, nitrate-N, ammoniacal-nitrogen (ammoniacal-N), TP and dissolved reactive phosphorus (DRP). These are shown in Table A.1 to Table A.3 in Appendix A.

4.1 Nitrate-N and TN

Nitrogen is introduced to rivers and streams from terrestrial sources. In areas of undisturbed native bush, sources of nitrogen are atmospheric deposition in rainfall and nitrogen fixation by plants (Pariff *et al*. 2006). It enters rivers through leaching of soluble nitrogen and erosion of soil.

TN in streams and rivers is derived from forms of organic and inorganic nitrogen, including dissolved organic nitrogen (DON), nitrate-N, nitrite-N and ammoniacal-N.

A study of in-stream nitrate-N across unpolluted old-growth forests in New Zealand (McGroddy et al. 2008) found that TN is dominated by organic forms (DON) and only approximately 13% nitrate-N. This is roughly consistent with the observed concentrations found in the Ruamāhanga forested catchments, with in-stream nitrate-N averaging 15–36% of TN (see Table A.2).

An estimate of in-stream nitrogen concentrations from forested catchments was undertaken using values from McGroddy et al. 2008, applied to relevant geology within the Ruamāhanga (see Table 4.2).

Table 4 2: Estimated Ruamāhanga N concentrations for native forest land use from McGroddy *et al*. (2008)

Characteristic/determinand	Ruamāhanga catchment		
	Central valley	Tararua Range	Eastern hills
Catchment geology	Alluvium (Greywacke)	Greywacke	Mudstone/ siltstone/sandstone
DON concentration	0.068 mg/L	0.068 mg/L	0.038 mg/L
nitrate-N concentration	0.025 mg/L	0.025 mg/L	0.034 mg/L
ammoniacal-N concentration	0.003 mg/L	0.003 mg/L	0.005 mg/L
TN concentration	0.095 mg/L	0.095 mg/L	0.078 mg/L
nitrate-N % of TN	26%	26%	43%

Table A.2 in Appendix A shows that rivers with catchments in native forest have a different proportion of nitrate-N to TN than the downstream, mixed-land use sites. At the outlet of native forest catchments, nitrate-N in-stream concentrations on average comprise approximately 30% of TN; however, further downstream where the land use changes and farming increases, nitrate-N increases to approximately 60% of TN. The value of 30% nitrate-N:TN is comparable to the estimates in Table 4.2.

4.2 TP and DRP

Phosphorus delivered to rivers and streams occurs in three forms, that is phosphorus contained in suspended sediment particles, DRP and dissolved organic phosphorus (DOP); DRP is generated in native forests through the dissolution of P in rocks and soils.

Phosphorus is highly dependent on the characteristics of the rocks and soils in respect to mineral composition and resistance to weathering, although slope and vegetation can also contribute to the phosphorus yield from a catchment (McGroddy *et al*. 2008). Phosphorus can be exported in dissolved and particulate forms and can be exported through leaching of phosphorus in groundwater, and through inputs of soil through erosion.

Table A.3 in Appendix A indicates that the rivers with catchments in native forest have a different ratio of DRP to TP than the mixed land use downstream sites. Directly at the outlet of native forest catchments in Ruamāhanga, DRP comprises approximately 50% of the TP within the water; however, further downstream as the land use becomes increasingly dominated by agriculture, DRP declines to approximately 30% of the TP (most likely uptaken by plants and algae).

While the proportion of DRP to TP in the downstream, mixed land use sites is less than at native forest catchments, the actual average concentrations are significantly greater, with TP and DRP concentrations ~4x and 2x larger, respectively.

A study was undertaken by Parfitt *et al.* 2008b to review the phosphorus budget for New Zealand at regional scales. The average annual P yield in rivers across New Zealand is 1.6 kg/ha, with sediment-bound P the major component (this includes erosion, effluent and runoff). The study included the Wairarapa.

DRP+DOP (Dissolved Organic Phosphorus) losses in soluble P runoff was approximated through an approach derived from N:P ratios, with the Wellington region having a value of 200 tonnes/year. This was equivalent to ~0.25 kgP/ha/yr of soluble P losses across the Wellington region (Parfitt *et al.* 2008b). The total annual river yield for the Wellington region was estimated to be 1.1 kgP/ha with the soluble load making up 23%.

Equating these values to a concentration is approximate at best, given this is a regional based approach used to provide indicative annual totals with a number of assumptions in the calculations.

For interest purposes, this has been undertaken assuming an annual average runoff in the catchment from Figure 2.4; the data is contained in Table 4.3.

Table 4.3 shows this equates to soil soluble P runoff of ~0.025 mg/L for the centre of the catchment, ~0.008 mg/L for the west of the catchment in the Tararua Range and 0.017 mg/L for the south-east of the catchment. Assuming a 60% attenuation, this could lead to in-stream DRP values of ~0.010 mg/L for the centre of the catchment, ~0.003 mg/L for the west and ~0.006 mg/L for the south-east. These values are comparable to concentrations observed in Table A.1.

Table 4.3 : Wellington region P yields and estimated Ruamāhanga P concentrations from Parfitt *et al.* (2008b)

Characteristic/determinand	Ruamāhanga catchment region		
	Central valley	Tararua range	Eastern hills
Soluble P yield	0.25 kgP/ha/yr		
Erosion P yield	0.8 kgP/ha/yr		
Total river P yield	1.1 kgP/ha		
Annual average rainfall (Figure 2.4)	1000 mm/yr	1500 mm/yr	3000 mm/yr
Estimated DRP runoff concentration (no attenuation)	0.025 mg/L	0.008 mg/L	0.017 mg/L
Estimated DRP runoff concentration (60% attenuation)	0.010 mg/L	0.003 mg/L	0.006 mg/L

4.3 Nitrate to phosphorus ratio

To analyse the background nitrate-N:TP ratios in rivers with native forest catchments we compared the average and median concentrations for nitrate-N and TP at the native forest representative monitoring sites, as well as the corresponding downstream mixed monitoring sites (see Table A.4 and Table A.5 in Appendix A).

The comparison shows that for the native forest sites (excluding Taueru River at Castlehill) the ratio of nitrate-N:TP averaged 4:1, while at the downstream mixed sites this ratio increased to 11:1.

Analysis of the median concentrations (Table A.5) to determine the nitrate-N:TP ratios resulted in a larger ratio for the native and downstream sites, increasing to 5:1 and 18:1 respectively. This may be due to the average concentrations being skewed due to higher concentrations of nitrate-N and TP that occur during winter leaching.

These ratios cannot be directly compared to the OVERSEER ratios described in Section 3, as this is based off in-stream concentrations that have been attenuated through mechanisms such as denitrification and benthic stream bed processes, while the OVERSEER data is land yields (i.e. generation rates) without attenuation.

4.4 River flows for yield calculations

The sites detailed in this section are existing water quality monitoring sites and some of these are also flow recording stations. The sites with long flow records have been assessed to determine the average annual flow and this result has then been scaled to other sites based upon the upstream catchment area. The flow assessment is required in order to undertake a scaling approach to determine annual average loads in some of the native and downstream (mixed) catchments which do not have any flow records.

Table 4.4 – Mean annual flows (MAF) in Megalitres/year (ML/yr) for representative native and downstream (mixed) monitoring sites

Flow site			
Site name	**Area (ha)**	**MAF (ML/yr)**	**MAF/ha (ML/ ha/yr)**
Kopuaranga at Stuarts	16,700	116,052	6.9
Ruakokopatuna at Iraia	1,579	21,103	13.4
Ruamāhanga at Wardells	64,280	745,511	11.6
Ruamāhanga at Waihenga	236,090	2,555,677	10.8
Ruamāhanga at McLays	7,280	301,957	41.5
Mangatarere at Gorge	3,420	59,288	17.3
Mangatarere at SH2	11,950	137,812	11.5
Otukura Weir	3,100	17,660	5.7
Taueru River at Gladstone	49,240	192,054	3.9
Waiohine at Gorge	19,000	747,403	41.0
Waingawa-Kaituna	7,650	314,729	41.1

For most native forestry sites the specific MAF for Waiohine at Gorge has been adopted as a proxy site to calculate annual average loads under Method 1 (see Section 1). This has been adopted also for downstream mixed sites Waiohine River at Bicknells and Tauherenikau at Websters, given these sites are similar in catchment area to Waiohine at Gorge.

For Ruamāhanga at McLays water quality monitoring site, the specific flows (ML/ha/yr) of the nearby downstream site Ruamāhanga at Mt Bruce have been used. For Ruamāhanga at Te Ore Ore, the downstream specific flows (ML/ha/yr) of Ruamāhanga at Wardells have been used.

The site Tauanui River at Whakatomotomo is located in the south-east of the greater Ruamāhanga Catchment in the Haurangi Ranges, and has very different rainfall depths than the Tararua sites (Figure 2.4). As such, the flow for the adjacent catchment of Ruakokopatuna at Iraia has been utilised as a proxy for this water quality monitoring site. This flow has also been adopted for the Motuwaireka headwaters catchment as the previous flow correlation site (NIWA Kaiwhata station) was decommissioned in 2013 and therefore did not overlap with the water quality monitoring period. It is accepted there are limitations in using Ruakokopatuna at Iraia as a proxy given the distance from the Motuwaireka catchment. However, for this initial comparison it is considered sufficient.

Table 4.5 –MAFs for representative native forest and downstream (mixed land use) monitoring sites

Native forest monitoring site			Downstream mixed		
Site name	**Area (ha)**	**MAF (ML/yr)**	**Site name**	**Area (ha)**	**MAF (ML/yr)**
Tararua and Remutaka ranges					
Waiohine at Gorge	18,250	747,400	Waiohine River at Bicknells	39,110	1,601,910
Beef Creek at Headwaters	300	12,200			
Wairongomai at Forest Park	2,630	107,780	N/a	-	-
Ruamāhanga River at McLays	7,280	301,957	Ruamāhanga at Te Ore Ore	30,810	357,370
Proxy	*11,100*	*454,440*	Tauherenikau at Websters	14,270	584,674
Eastern hills					
Tauanui River at Whakatomotomo	2,190	29,279	N/a	-	-
Motuwaireka headwaters	336	4,495	N/a	-	-

5. Method 1 Results

5.1 Description

Method 1 utilises the information in Section 4 to determine an annual nutrient yield (kg/ha/yr) from the observed water quality monitoring data. This is based off a 'coarse' approach of using average concentrations from the water quality record (described in Sections 4.1 – 4.3 and in Appendix A) coupled with MAF calculations from Table 4.4, corrected by catchment area and an attenuation rate.

5.2 Attenuation rate

The attenuation factor for each analyte is not known, and modelling in Jacobs (2018) has applied a range of factors necessary to achieve calibration in each of the subcatchments. For nitrate-N, this ranged from 0.4–0.8, while the TP calibration used a much lower attenuation factor of 0.25 to achieve a suitable calibration. Literature widely recommends attenuation factors of ~0.5 as a starting assumption, which will vary depending on many influencing environmental factors.

For the purposes of this assessment, we have adopted a value of 0.5 as the attenuation factor for nitrate-N and TP in order to provide a first pass estimate of the potential native forest catchment yield, back calculated from the observed water quality monitoring data.

5.3 Annual yield

The annual yield at each site has been estimated from the observed mean water quality data, the catchment area (hectares) and the assumed MAF, this is shown in Table 5.1. These results account for attenuation that would be occurring within the stream, soil and aquifers and thus a correction factor could be applied to estimate the nutrient generation rates at the source.

Table 5.1 – Estimated annual yields under Method 1 at representative native and downstream mixed monitoring sites (corrected with an attenuation factor of 0.5)

Native forest monitoring site					Downstream mixed				
Site name	Yield (kg/ha/yr)				Site name	Yield (kg/ha/yr)			
	TN	nitrate-N	TP	DRP		TN	nitrate-N	TP	DRP
Tararua and Remutaka ranges									
Waiohine at Gorge	6.6	2.4	0.6	0.2	Waiohine River at Bicknells	41	33	1.9	1.1
Beef Creek at Headwaters	7.7	2.3	1.0	0.7					
Waiorongomai at Forest Park	8.7	2.5	0.7	0.2	N/a	-	-	-	-
Ruamāhanga River at McLays	12.9	2.0	0.4	0.2	Ruamāhanga at Te Ore Ore	13.8	10.1	0.7	0.2
Proxy	6.6	2.4	0.6	0.2	Tauherenikau at Websters	12.7	4.3	2.9	0.2
Average	**9.0**	**2.3**	**0.7**	**0.3**	**Average**	**22.5**	**15.8**	**1.8**	**0.5**
Eastern hills									
Tauanui River at Whakatomotomo	2.2	0.4	0.2	0.2	N/a	-	-	-	-
Motuwaireka headwaters	4.4	1.7	0.3	0.1	N/a	-	-	-	-
Average	**3.3**	**1.1**	**0.24**	**0.15**	**Average**	-	-	-	-

* Proxy site adopts Waiohine at Gorge flows and concentrations, and thus the yields are the same as Waiohine. This site has not been included in determining the average yields.

Table 5.1 indicates that under Method 1:

- The Western Hills (Tararuas and Remutakas) have in-stream nitrate-N and TP yields averaging 2.3 and 0.7 kg/ha/yr respectively.
- The Eastern Hills (Haurangis) have lower in-stream nitrate-N and TP yields averaging 1.1 and 0.24 kg/ha/yr, respectively.

The difference in nutrient yields between the western ranges and the Eastern Hills is a reflection of differences in rainfall and resulting mean annual flows. Method 1 provides an initial approach to assess natural yields, and this can be refined through the flow weighted approach of Method 2.

6. Method 2 Results

6.1 Description

This yield assessment following Roygard, McArthur and Clark (2011) incorporates a greater range of data to improve the accuracy of the yield (and subsequent catchment load) estimates. The steps involved are as follows:

1. Using a daily mean flow timeseries, develop flow duration curves for the chosen period (i.e. 2012–2017)
2. The flow duration curve (FDC) is split into 10 ‘bins’ representing every 10th percentile of exceedance. These bins partition flows between a range (e.g. 5 to 7 m^3/s for 20–30th percentile).
3. Water quality concentration data is sorted by date and time to the corresponding flow record, and plotted within each ‘bin’. See Figure 6.1.
4. The average concentration of each constituent is calculated for each flow bin, resulting in ten values across a range of flows.
5. The average flow within each bin is also calculated, and multiplied with the corresponding concentration to estimate a load per bin (kg/s).
6. Finally, all the load values are averaged to determine the ‘average flow weighted load’ in kg/s, which is then converted to an annual load and yield (by dividing by the catchment area).

This approach ensures that equal weighting is given to water quality records across the entire flow timeseries, which is particularly important if there are limited samples within upper or lower flow bins. Method 1 would average all the concentration data, and this may result in the outputs being skewed depending on the abundance of samples across the flow timeseries, with most samples likely to be taken between the 20th and 80th percentiles.

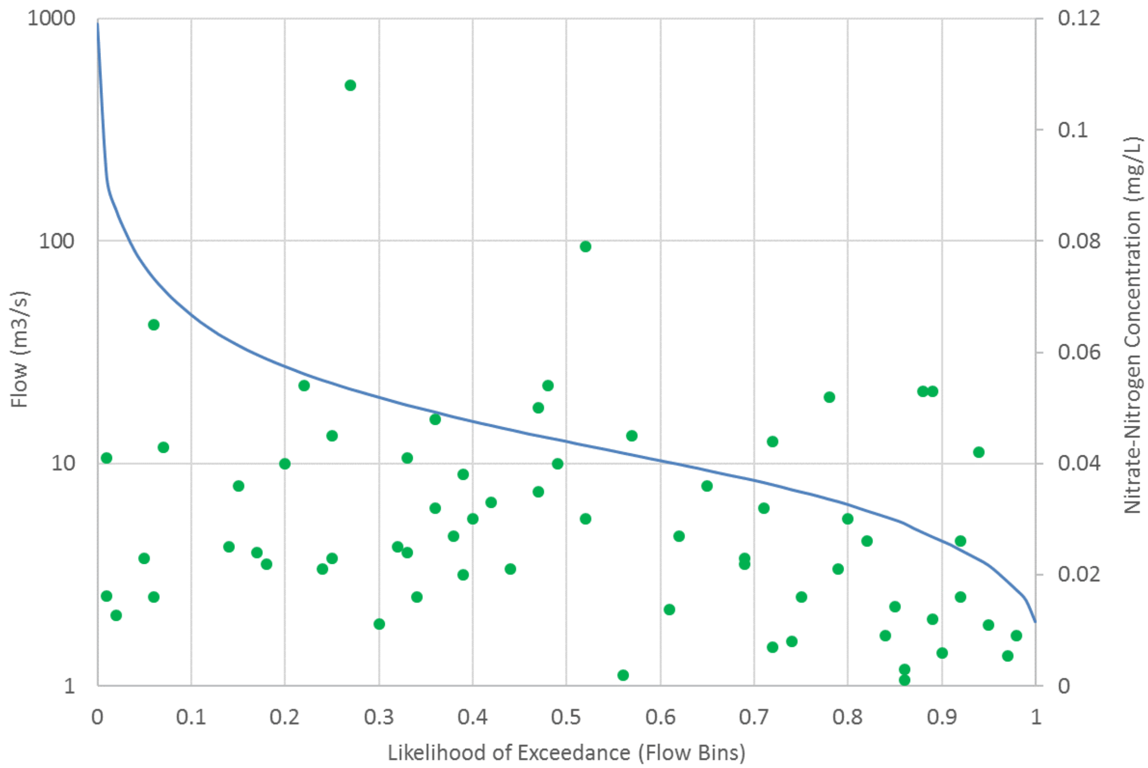

Figure 6.1 : Waiohine River at Gorge FDC and nitrate-N samples from 2012–2017, partitioned into flow bins.

6.2 Attenuation Rate

As described in Section 5.2, an attenuation factor of 0.5 was applied to nitrate-N and TP for consistency.

6.3 Annual Yield

Table 6.1 presents the flow binning results to estimate native forest and mixed downstream water quality site yields. This information shows lower nitrate-N and higher TP yields in the Western Hills, when compared to Method 1. The Eastern Hills have higher nitrate-N and TP yields when compared to Method 1.

Table 6.1 Estimated annual yields under Method 2 at representative native and downstream mixed monitoring sites (corrected with an attenuation factor of 0.5)

<table>
<tr><th colspan="5">Native catchment monitoring site</th><th colspan="5">Downstream mixed</th></tr>
<tr><th rowspan="2">Site name</th><th colspan="4">Yield (kg/ha/yr)</th><th rowspan="2">Site name</th><th colspan="4">Yield (kg/ha/yr)</th></tr>
<tr><th>TN</th><th>nitrate-N</th><th>TP</th><th>DRP</th><th>TN</th><th>nitrate-N</th><th>TP</th><th>DRP</th></tr>
<tr><td colspan="10">Tararua and Remutaka ranges</td></tr>
<tr><td>Waiohine at Gorge</td><td>8.1</td><td>2.6</td><td>1.2</td><td>0.2</td><td rowspan="2">Waiohine River at Bicknells</td><td rowspan="2">20.1</td><td rowspan="2">14.2</td><td rowspan="2">1.5</td><td rowspan="2">0.5</td></tr>
<tr><td>Beef Creek at Headwaters</td><td>7.7</td><td>2.3</td><td>1.0</td><td>0.7</td></tr>
<tr><td>Wairongomai at Forest Park</td><td>3.9</td><td>1.0</td><td>0.5</td><td>0.1</td><td>N/a</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Ruamāhanga River at McLays</td><td>9.5</td><td>1.7</td><td>0.8</td><td>0.2</td><td>Ruamāhanga at Te Ore Ore</td><td>25.0</td><td>14.7</td><td>2.6</td><td>0.3</td></tr>
<tr><td>Proxy*</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Tauherenikau at Websters</td><td>8.9</td><td>2.2</td><td>1.2</td><td>0.1</td></tr>
<tr><td>Average</td><td>7.3</td><td>1.9</td><td>0.8</td><td>0.3</td><td>Average</td><td>18</td><td>10.4</td><td>1.8</td><td>0.3</td></tr>
<tr><td colspan="10">Eastern hills</td></tr>
<tr><td>Tauanui River at Whakatomotomo</td><td>4.0</td><td>0.6</td><td>0.4</td><td>0.2</td><td>N/a</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Motuwaireka headwaters</td><td>4.4</td><td>1.7</td><td>0.3</td><td>0.1</td><td>N/a</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Average</td><td>4.2</td><td>1.2</td><td>0.35</td><td>0.15</td><td>Average</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

* Proxy site not assessed as values not used in averages, as outlined in Table 5.1.

7. Comparison of Method 1 and 2 against OVERSEER

Table 7.1 and Table 7.2 show the average nitrate-N yields from observed water quality monitoring data in the Western Hills (and mixed land use sites) compare well to the predicted OVERSEER values. OVERSEER values of nitrate-N yields are generally less than 1.7 kg/ha/yr for native sites and the inclusion of Beef Creek site (which has 7% pasture and other land use) increases the average yields.

Method 2 (flow binning) is considered the more accurate approach, and comparisons show OVERSEER performs well when calculating annual yields. This provides confidence in the nitrate-N input rates generated by OVERSEER and used in the Ruamāhanga SOURCE nutrient modelling for river sites with catchments predominantly in native forest in the Tararua and Remutaka ranges.

The Eastern Hills are limited to one site within the Ruamāhanga catchment (for which OVERSEER data was available), Tauanui River at Whakatomotomo Road. This is a pristine bush site, and the water quality data shows yields of nitrate-N are low (0.6 kg/ha/yr for Method 2). Subsequently in this location, OVERSEER may be overestimating loads. However, the effects of this on modelling would be minor, given some intensive dairy pasture in the Ruamāhanga catchment has nitrate-N yields >30 kg/ha/yr.

TP yields on the other hand are being significantly underestimated in OVERSEER, by a factor of 3–4 times in the native forest catchments, and ~2 times in the mixed land use monitoring sites (depending on the method used). This is particularly evident in the Western Hills, where the higher rainfall, steep slopes and erosion are likely to be carrying entrained phosphorus with sediment. In addition, parts of the Tararua and Remutaka ranges have allophanic soil, which naturally has high P retention (see Figure 2.3). However, there was little particulate sediment and phosphorus data to confirm this assumption.

Therefore, while the current modelling utilises OVERSEER as the primary input of TP, future model updates should include a sediment-derived phosphorus load due to erosion. OVERSEER has limitations in its Phosphorus sub-models as described in Freeman *et al.* 2016. A key limitation is that it does not model P loss to water from river/stream bank erosion or mass flow events (i.e. landslides).

The OVERSEER rates were used in SOURCE catchment modelling (Jacobs 2018) to simulate in-stream nutrient concentrations. While this has resulted in lower input TP concentrations (than the observed data indicates), this is offset through the calibration process which subsequently applied a smaller attenuation factor (than is likely occurring in reality), to ensure in-stream concentrations were calibrated to observed water quality data. Subsequently, for simulating mitigations and deriving FWOs, the model factored in the TP uncertainty from OVERSEER and thus can still be a useful tool for evaluating in-stream concentrations.

Table 7.1 : Comparison of generated yields (kg/ha/yr) for Method 1 and 2 at native forest catchment water quality monitoring sites versus input values from Ruamāhanga OVERSEER modelling

Watershed Location	Site Name	Nitrate-N yields (kg/ha/yr)			Total Phosphorus yields (kg/ha/yr)		
		OVERSEER	Method 1	Method 2 (flow bins)	OVERSEER	Method 1	Method 2 (flow bins)
Western Hills (Tararuas and Remutakas)	Waiohine at Gorge	1.1	2.4	2.6	0.2	0.6	1.2
	Beef Creek at Headwaters	3.4	2.3	2.3	0.3	1.0	1.0
	Wairongomai at Forest Park	1.4	2.5	1.0	0.2	0.7	0.5
	Ruamāhanga River at McLays	1.7	2.0	1.7	0.2	0.4	0.8
	Average	**1.9**	**2.3**	**1.9**	**0.2**	**0.7**	**0.9**
Eastern Hills (Haurangis)	Tauanui River at Whakatomotomo	1.0	0.4	0.6	0.2	0.2	0.4

Table 7.2 : Comparison of generated yields (kg/ha/yr) for Method 1 and 2 at mixed land use water quality monitoring sites versus input values from Ruamāhanga OVERSEER modelling

Watershed Location	Site Name	Nitrate-N yields (kg/ha/yr)			Total Phosphorus yields (kg/ha/yr)		
		OVERSEER	Method 1	Method 2 (flow bins)	OVERSEER	Method 1	Method 2 (flow bins)
Western Hills (Tararuas and Remutakas)	Waiohine River at Bicknells	12.1	33	14.2	0.7	1.9	1.5
	Ruamāhanga at Te Ore Ore	15.5	10.1	14.7	1.5	0.7	2.6
	Tauherenikau at Websters	6.9	4.3	2.2	0.4	2.9	1.2
	Average	**11.5**	**15.8**	**10.4**	**0.9**	**1.8**	**1.8**

7.1 Application to FWO and Load Targets

The main application of this natural yield assessment relates to setting load targets and limits for Freshwater Management Units (FMU) within Ruamāhanga, and assigning a portion of the load that is considered to be the 'background natural'. In essence, a typical FMU nitrate-N or TP load may have:

- Native load generated from native forested land (if it exists within an FMU);
- 'Background natural' load (equivalent to the native load) that is assumed to continue to be generated from the land that was deforested for human use; and
- 'Non-native' load generated from all other land use practices on the deforested land, including additional leaching from stock and fertilisers.

The comparison of yields between Method 1, 2 and OVERSEER in Table 7.1 and Table 7.2 indicates we could assign a 'background natural' load for nitrate-N based off the OVERSEER data. However, at this preliminary stage, we have only assessed sites in the upper reaches and would need to evaluate the reliability of OVERSEER data in lowland, fully mixed catchments. If the calculated loads for the lowland catchments at the water quality monitoring sites begin to diverge significantly from the OVERSEER loads, this may indicate that:

- OVERSEER upper catchment native forest yields are not appropriate for background natural loads in areas with different soils, and;
- The non-native farming and lifestyle OVERSEER leaching and runoff inputs that feed into these mixed monitoring sites are not representative of the current land use and actual leaching/runoff rates.

However, the current OVERSEER data used in the Source modelling is considered to be the best available information of leaching and runoff in the catchment at the time of this project, and any inaccuracies in these values are corrected to a degree by larger or smaller attenuation factors assigned at the catchment scale during calibration of the model to observed in-stream concentrations. The current approach used in SOURCE modelling considers the OVERSEER load generated off a farm to be the total load leached off that land use/soil and climatic combination. This total load includes both the non-native load and the background natural load, and this total load may be set as a limit or target per FMU within Ruamāhanga Catchment.

Partitioning of the total load into the non-native and background-natural components would mean the reductions required to achieve FWO's (i.e. 30% nitrate-N total load reduction by 2040) would then be assigned only to the non-native loads, when the current approach applies this to the total load. This may mean a greater reduction (e.g. 35%) is required against the non-native load to achieve the same objective.

Uncertainty in the background natural load may mean the non-native load is greater (or smaller) than it should be, and thus mitigations applied at the catchment scale may extend beyond what is feasible or alternatively, have little impact on reducing loads (e.g. if the background load from OVERSEER is too small). For example, if TP OVERSEER yields of 0.18 kg/ha/yr were used, this would result in an underestimated background natural load and subsequently a much larger non-native load that farmers would be required to mitigate to achieve the FWO (when in reality, a high portion of this could be from naturally bound TP in sediment).

OVERSEER runoff data for TP cannot be used on its own to consider background natural loads, and needs to be considered in conjunction with erosion processes carrying sediment and phosphorus. This process would have been exacerbated on farmed land due to deforestation reducing slope stabilisation.

Therefore, until further assessment of nitrate-N in the lowland reaches is undertaken, OVERSEER sub-models for TP are improved and the sediment/phosphorus dynamics in the native reaches are better understood, background natural loads will not be assigned to the FMU's.

8. Conclusions

An assessment of instream nitrate-N and TP yields (kg/ha/yr) generated from native forest catchments and downstream mixed land use catchments, using water quality monitoring data, was undertaken to compare against OVERSEER modelling data, which will be used in setting load targets within Ruamāhanga FMU's. The sites were primarily based in the Western Hills (Tararua and Remutaka Ranges), with one site also present in the Eastern Hills (Haurangi Ranges). The Central Valley with lower elevation and variations in soil and climate was not assessed in this investigation due to the lack of suitable long term native water quality monitoring sites.

Two methods were considered to determine the yields from the catchment upstream of the various monitoring sites. Both methods utilised flow data from either concurrent flow and water quality stations, or in the absence of flow data, nearby catchments. A generic attenuation factor (representing processes such as in-stream removal and denitrification) of 0.5 was applied to both methods to translate 'attenuated' loads (kg/yr) to un-attenuated loads and yields generated off the land. This allows direct comparison to the OVERSEER yields assigned in modelling for nitrate-N and TP.

Method 1 utilised mean concentrations from the last 5 years of water quality monitoring data, mean annual flows and the attenuation factor to generate un-attenuated yields. Method 2 involved the assignment of water quality samples to ten 'flow bins', which are represented by each 10th percentile from a flow duration curve. The average flow and concentration within each bin were then used to compute an average flow-weighted load, and then translated into a yield.

The results from both methods showed nitrate-N yields in the native forest catchments compares well to OVERSEER input data when an attenuation factor of 0.5 was assigned. The flow binning approach of Method 2 (which incorporates more detail in load and yield assessments than Method 1) proved to be the most consistent with OVERSEER data in both the native and mixed sites. Mixed sites have increased agricultural inputs and higher nitrate-N yields, and the simplicity of Method 1 as lumped mean annual flows and concentrations begins to unravel with increased divergence from Method 2 and OVERSEER data.

TP results from water quality monitoring data highlighted a significant amount of uncertainty in the input data for native forest TP runoff in OVERSEER. Method 1 and 2 showed the native monitoring sites were on average 3–4 times greater in TP yields than OVERSEER was simulating. This was attributed to the high erosion within these catchments carrying particulate phosphorus, which is not incorporated in OVERSEER sub models. Downstream, the difference reduces, with the mixed monitoring sites ~2 times greater than the OVERSEER data. This was likely due to the reduced TP loads from less erosion on the flatter land, greater river flow buffering concentrations and increased accuracy of the OVERSEER phosphorus models developed for farmland.

Background native loads for nitrate-N could potentially be assigned to FMU's within Ruamāhanga after further research is conducted on lowland mixed sites. This would allow a load target to be set to meet an in-stream FWO, which would be partitioned into a background natural load and a non-native load. The latter represents all loads induced from human influences in the catchment and would be the load targeted by catchment mitigations to improve water quality. In its current state, the total load target or limit for an FMU incorporates the background natural load that would be generated naturally under a forested regime. Applying mitigations to this combined load may under-estimate the reductions that need to occur to achieve objectives. For example, a 20% reduction in nitrate-N load in an FMU may actually be 25% if the background natural load was removed and only the non-native load was considered as viable for reductions.

Use of a total OVERSEER load for setting targets at an FMU scale is considered acceptable until further refinements are made on:

1. the OVERSEER P sub models and sediment bound phosphorus loads in Ruamahanga

2. the assessments of downstream mixed lowland reaches to attempt to quantify the background natural load from these areas, which differ geologically and climatically to the Western and Eastern Hills.

9. References

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Appendix A. N and P Concentrations

Table A.1 : Mean and median measured nutrient concentrations (mg/L) at representative monitoring sites (2012 –2017)

Site Name	TN (mg/L)		nitrate-N (mg/L)		ammoniacal-N (mg/L)		TP (mg/L)		DRP (mg/L)	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Native catchment sites (Tararua and Remutaka ranges)										
Waiohine at Gorge	0.080	0.055	0.029	0.026	0.004	0.005	0.007	0.005	0.003	0.003
Beef Creek at Headwaters	0.094	0.055	0.028	0.025	0.004	0.005	0.012	0.011	0.008	0.008
Wairongomai at Forest Park	0.106	0.055	0.031	0.021	0.005	0.005	0.008	0.006	0.003	0.003
Ruamāhanga River at McLays	0.155	0.130	0.024	0.023	0.004	0.005	0.005	0.002	0.002	0.002
Native catchment sites (Eastern hills)										
Tauanui River at Whakatomotomo	0.082	0.055	0.014	0.010	0.004	0.005	0.008	0.008	0.006	0.006
Motuwaireka headwaters	0.163	0.120	0.065	0.029	0.010	0.010	0.010	0.006	0.005	0.004
Downstream mixed sites (Tararua and Remutaka ranges)										
Waiohine River at Bicknells	0.500	0.465	0.403	0.365	0.012	0.005	0.023	0.018	0.014	0.011
Ruamāhanga at Te Ore Ore	0.596	0.510	0.435	0.350	0.005	0.005	0.029	0.013	0.007	0.006
Tauherenikau at Websters	0.155	0.120	0.053	0.039	0.004	0.005	0.036	0.006	0.003	0.002

Table A.2 : Average Total Nitrogen and nitrate-N at representative native and downstream (mixed) monitoring sites

Native catchment sites (mg/L)				Downstream mixed sites (mg/L)			
Site name	TN	nitrate-N	% nitrate-N	Site name	TN	nitrate-N	% nitrate-N
Tararua and Remutaka ranges							
Waiohine at Gorge	0.080	0.029	36%	Waiohine River at Bicknells	0.5	0.403	81%
Beef Creek at Headwaters	0.094	0.028	30%				
Wairongomai at Forest Park	0.106	0.031	29%	N/a	-	-	-
Ruamāhanga River at McLays	0.155	0.024	15%	Ruamāhanga at Te Ore Ore	0.596	0.435	73%
Proxy[1]	*0.080*	*0.029*	*36%*	Tauherenikau at Websters	0.155	0.053	*34%*
Eastern hills							
Tauanui River at Whakatomotomo	0.082	0.014	17%	N/a	-	-	-
Motuwaireka headwaters[2]	0.163	0.065	40%	N/a	-	-	-
Average	**0.100**	**0.026**	**27%**	Average	**0.417**	**0.297**	**63%**

1 – Proxy adopts concentrations from Waiohine at Gorge
2 – Catchment contains 34% forestry and is not included in the average

Table A.3 : Average (mean) TP and DRP at representative native and downstream (mixed) monitoring sites

Native catchment sites (mg/L)				Downstream mixed sites (mg/L)			
Site name	TP	DRP	DRP%	Site name	TP	DRP	DRP%
Tararua and Remutaka ranges							
Waiohine at Gorge	0.007	0.003	43%	Waiohine River at Bicknells	0.023	0.014	61%
Beef Creek at Headwaters	0.012	0.008	67%				
Wairongomai at Forest Park	0.008	0.003	38%	N/a	-	-	-
Ruamāhanga River at McLays	0.005	0.002	40%	Ruamāhanga at Te Ore Ore	0.039	0.007	18%
Proxy[1]	*0.007*	*0.003*	*43%*	Tauherenikau at Websters	0.036	0.003	*8%*
Eastern hills							
Tauanui River at Whakatomotomo	0.008	0.006	75%	N/a	-	-	-
Motuwaireka headwaters[2]	0.010	0.005	50%	N/a	-	-	-
Average	**0.008**	**0.004**	**51%**	Average	**0.033**	**0.008**	**29%**

1 – Proxy adopts concentrations from Waiohine at Gorge
2 – Catchment contains 34% forestry and is not included in the average

Table A.4 : Average concentration of nitrate-N and TP to derive ratios at representative native and mixed monitoring sites

Native catchment sites (mg/L)				Downstream mixed sites (mg/L)			
Site name	**nitrate-N**	**TP**	**Ratio**	**Site name**	**nitrate-N**	**TP**	**Ratio**
Tararua and Remutaka ranges							
Waiohine at Gorge	0.029	0.007	4	Waiohine River at Bicknells	0.403	0.023	18
Beef Creek at Headwaters	0.028	0.012	2				
Wairongomai at Forest Park	0.031	0.008	4	N/a	-	-	-
Ruamāhanga River at McLays	0.024	0.005	5	Ruamāhanga at Te Ore Ore	0.435	0.029	15
Proxy[1]	*0.029*	*0.007*	*4*	Tauherenikau at Websters	0.053	0.036	1
Eastern hills							
Tauanui River at Whakatomotomo	0.014	0.008	2	N/a	-	-	-
Motuwaireka headwaters[2]	0.065	0.010	7	N/a	-	-	-
Average concentrations	**0.026**	**0.008**	**4**	Average	**0.297**	**0.036**	**11**

1 – Proxy adopts concentrations from Waiohine at Gorge
2 – Catchment contains 34% forestry and is not included in the average

Table A.5 : Median concentrations of nitrate-N and TP to derive ratios at representative native and mixed monitoring sites

Native catchment sites (mg/L)				Downstream mixed sites (mg/L)			
Site name	**nitrate-N**	**TP**	**Ratio**	**Site name**	**nitrate-N**	**TP**	**Ratio**
Tararua and Remutaka ranges							
Waiohine at Gorge	0.026	0.005	5	Waiohine River at Bicknells	0.365	0.018	20
Beef Creek at Headwaters	0.025	0.011	2				
Wairongomai at Forest Park	0.021	0.006	4	N/a	-	-	-
Ruamāhanga River at McLays	0.023	0.002	12	Ruamāhanga at Te Ore Ore	0.350	0.013	27
Proxy[1]	*0.026*	*0.005*	*5*	Tauherenikau at Websters	0.039	0.006	7
Eastern hills							
Tauanui River at Whakatomotomo	0.010	0.008	1	N/a	-	-	-
Motuwaireka headwaters[2]	0.029	0.006	5	N/a	-	-	-
Average	**0.022**	**0.005**	**5**	Average	**0.251**	**0.021**	**18**

1 – Proxy adopts concentrations from Waiohine at Gorge
2 – Catchment contains 34% forestry and is not included in the average