Te Awarua-o-Porirua (TAoP) Collaborative Modelling Project:

CLUES modelling of rural contaminants

Prepared for Greater Wellington Regional Council

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Executive summary

This report documents the application of the Catchment Land Use for Environmental Stability (CLUES) model as part of the Te Awarua-o-Porirua (TAoP) Collaborative Modelling Project (CMP). The modelling falls under Workstream 1 (Catchment Diffuse Contaminant Loads) of the CMP. The core task for CLUES modelling is estimation of mean annual loads of TN, TP and *E. coli* loads from rural diffuse sources located in the TAoP Whaitua. A secondary task is estimation of the mean annual sediment load from the rural diffuse sources as a check on sediment loads estimated using the Dynamic SedNet model. The model outputs will be used to inform other modellers involved in the project to give an indication of freshwater and coastal water quality (i.e., Workstream 8: Freshwater concentration based attributes; and Workstreams 5 and 6: Coastal waters, nutrients and microbiological contamination).

CLUES is a steady-state annual load model that operates at the catchment scale and contains three submodels; Overseer, SPASMO and SPARROW, that are responsible for different aspects of water quality modelling. It has been developed as a tool for catchment management and planning and allows users to create both land use and farm management scenarios to assess the impacts of land use change and mitigation on catchment water quality. CLUES has a GIS platform for handling and displaying spatial data and is provided with a geospatial dataset containing all the data needed for the model to operate.

CLUES was run for this application for the CMP current land use scenario with no farm mitigations. The land use scenario was derived in partnership with GWRC and Jacobs from several sources including the Land Cover Database v. 4 (LCDB4) to delineate urban areas, agriculture and forest and GWRC land use data and the CLUES default land use layer to split the LCDB4 land covers into land use classes. Rural land uses make up around 80% of the harbour catchment area. Sheep and beef farming accounts for 40% of the catchment area and forest and scrub around 30%.

CLUES model results by reach and land use class have been provided to GWRC as a MS Excel workbook for further modelling. The workbook contains separate worksheets for each contaminant and presents the area of each land use class within each REC2 sub-catchment and the associated source yield estimated by CLUES for each land use and sub-catchment. This report presents maps of the total generated contaminant yields from rural land uses for each sub-catchment and instream or cumulative loads estimated for a set of reporting sites provided by GWRC. The model outputs predominantly reflect slope and land use and to a lesser extent rainfall and soil drainage.

Instream loads are also compared to the loads determined from water quality monitoring in order to give an indication of model performance. Sufficient water quality monitoring data (monthly sampling) and concurrent flow data were available for two rural water quality monitoring sites in the catchment, Pauatahanui Stream at Elmwood Bridge and Horokiri Stream at Snodgrass. An R script was used to estimate the median annual concentrations and the mean annual instream loads of TN, TP and *E. coli* for these sites. Since there were only two sites, it was not possible to do a statistical evaluation of the model results. However, the CLUES instream loads and concentrations estimated for the sites were of the same order of magnitude with the exception of the *E. coli* instream load estimate for the Pauatahanui site which was underestimated.

1 Background

The Greater Wellington Regional Council (GWRC) has engaged NIWA to apply the Catchment Land Use for Environmental Stability (CLUES; Elliott et al., 2016; Semadeni-Davies et al., 2016) model to all streams and rivers in the Te Awarua-o-Porirua (TAoP) Whaitua[1] in order to estimate the annual loads and yields of total nitrogen (TN), total phosphorus (TP), *E. coli* and sediments discharging to the streams and harbour from rural diffuse sources. The CLUES modelling is part of the TAoP Collaborative Modelling Project (CMP).

1.1 Modelling context and scope

The CMP has been set up and coordinated by the GWRC to generate information on the environmental, social, economic and cultural effects and implications of alternative approaches to catchment management. The CMP structure is shown inFigure 1-1. The information generated by the models will be presented to the TAoP Committee, which includes representatives of local Maori, elected representatives of the city and regional councils and community members. The Committee considers information from the CMP, alongside their knowledge of community and cultural values, agriculture, biodiversity, recreation, urban and economic interests to make recommendations on land and water management in the catchment. These recommendations will guide the preparation by the GWRC of regional plan provisions. The process is iterative with the Committee providing the modellers with management scenarios and the modellers providing model outputs for further consideration.

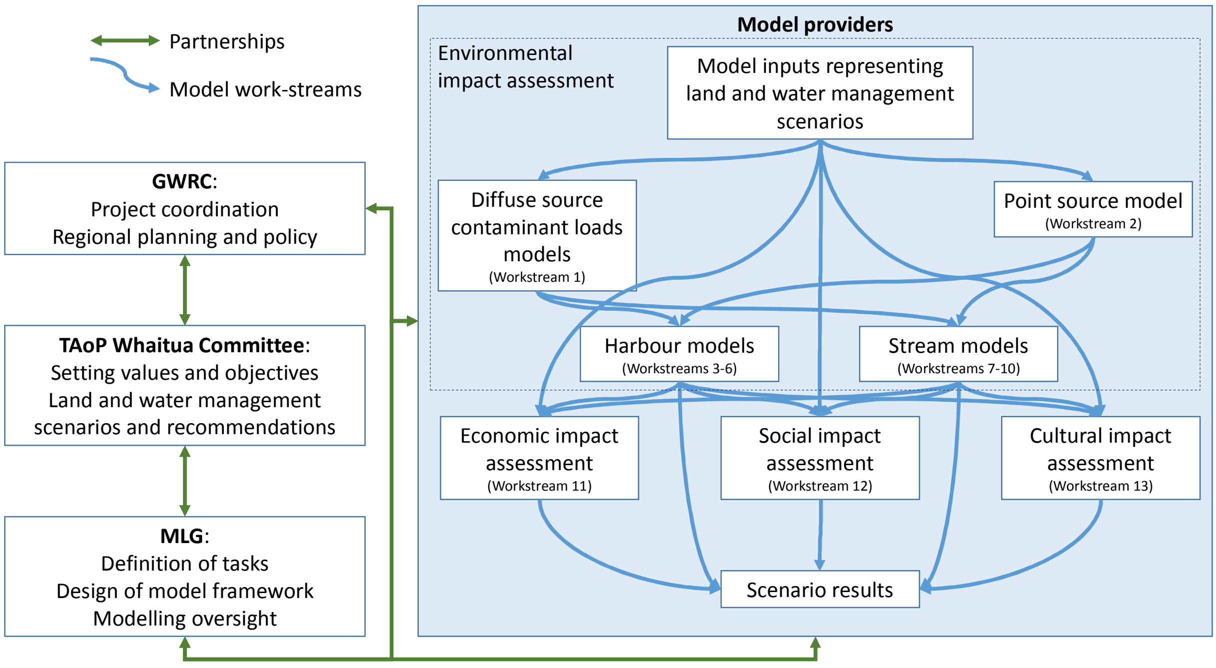

Figure 1-1: Structure of the Te Awarua-o-Porirua Collaborative Modelling Project. Linkages between model workstreams and partnerships between model providers, GWRC the Waitua Committee and the Modelling Leadership Group are indicated by arrows.

[1] Designated space or catchment area

Technical support is provided to the Committee by the Modelling Leadership Group (MLG) who liaise between the Committee and the modellers. The MLG includes experts in the fields of freshwater and marine water quality, coastal processes, hydrology, social science and economics and a Ngāti Toa cultural advisor. The MLG is responsible for identifying the modelled information required by the committee; defining the model tasks needed to provide that information; screening available models to ensure they are fit-for-purpose; overseeing the work of modellers and translating committee land and water management scenarios into model inputs.

Modelling is undertaken by a range of service providers including research institutes and consultancies. Each model block shown in Figure 1-1 contains a suite of models charged with different modelling tasks. The location of CLUES modelling within the CMP is Workstream 1 (Catchment Diffuse Contaminant Loads) Task C (Rural Contaminants). The core task for CLUES modelling is estimation of mean annual loads of TN, TP and *E. coli* loads from rural diffuse sources located in the Whaitua. These modelled loads will be used to inform other modellers involved in the project to give an indication of freshwater quality (i.e., Workstream 8: freshwater concentration based attributes; and Workstreams 5 and 6: Coastal waters, nutrients and microbiological contamination). A secondary task is estimation of the mean annual sediment load from the rural diffuse sources as a check on sediment loads estimated using the Dynamic SedNet model[2].

In this application, CLUES has been run for the current land use scenario to show the contaminant yields associated with different land uses. The effects of future land use change and farm mitigation practices required for the Business as Usual (BAU) and alternative scenarios will be assessed using the yields from this work within Workstream 8.

The modelling extent is mapped in Figure 1-2, the map also shows the stream channels modelled and the rural / urban boundaries. Relief is indicated on the map using a hillshade cover derived from a 30-m resolution elevation raster.

Although CLUES was run for the entire Whaitua, the emphasis in this report is on contaminants loads and yields from rural diffuse sources (i.e., agriculture, horticulture and forest) on the understanding that contaminant loads and yields from urban areas and point sources will be supplied separately by other model providers in the CMP (Workstream 1, Tasks A and B: urban contaminants; and Workstream 2, Point discharges and Wastewater overflows). While the model results have been supplied by land use and sub-catchment for further modelling, these results have been aggregated for this report to the CMP stream reporting points as supplied by GWRC.

1.2 Report structure

The rest of this report is broken into the following sections:

Section 2 – Overview of the CLUES model including model structure, input data and sources of uncertainties.

Section 3 – Development of the current land use scenario used for CLUES modelling

Section 4 – Overview of water quality data available for comparison against model results and description of the methods used to calculate mean annual instream loads from these data.

[2] This modelling is being undertaken by Jacobs in a separate project for the CMP

Section 5 – Model results including a comparison against contaminant loads estimated from water quality data.

Section 6 – Report summary.

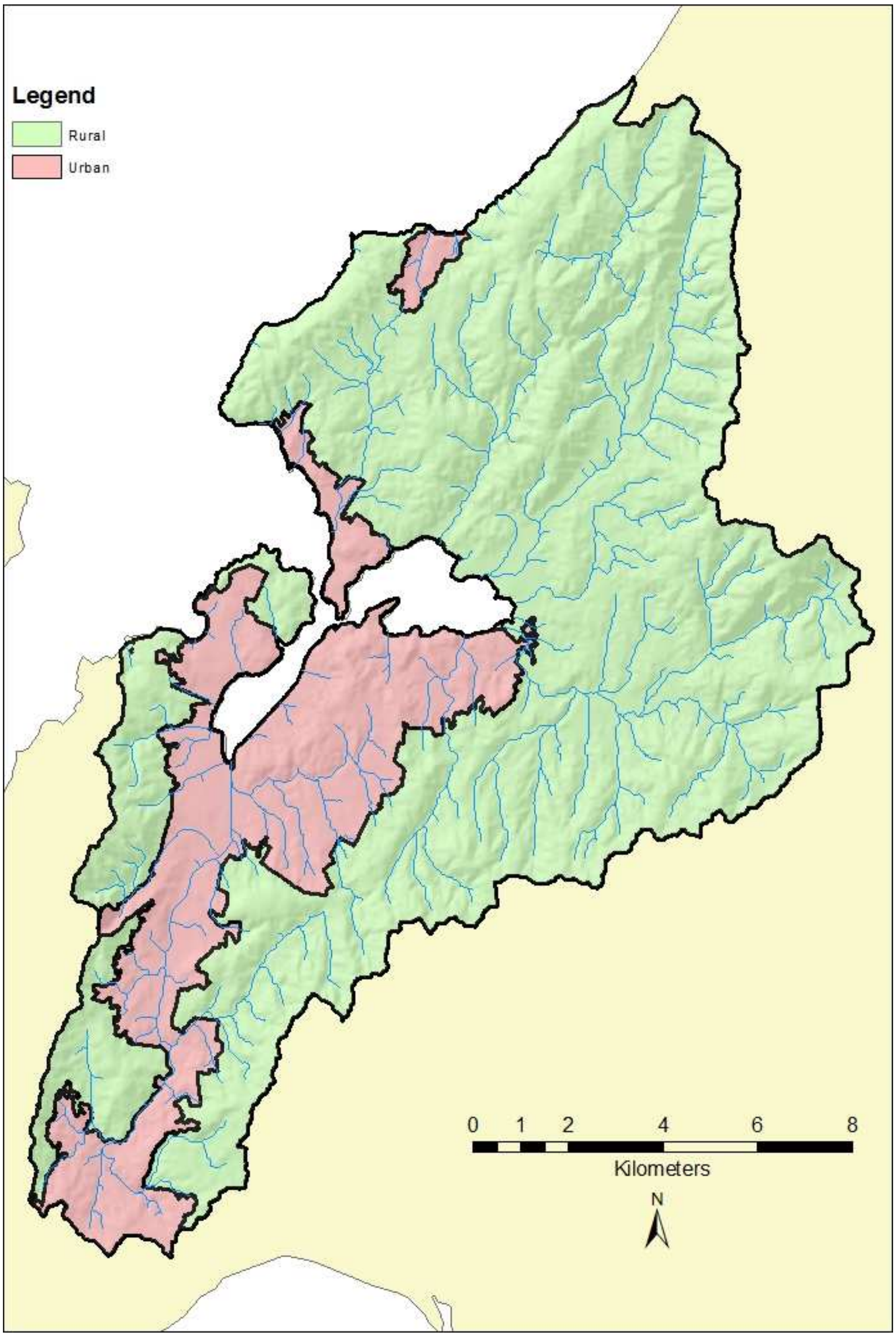

Figure 1-2: Modelling extent showing modelled stream channels and rural / urban boundaries of Te Awarua-o-Porirua Whaitua.

2 CLUES model overview

CLUES is an annual steady-state model-framework that has been developed as a tool for the rapid assessment of the impacts of land use and land management on water quality at the catchment scale (~10 km^2 to 10000 km^2) to inform policy making, environmental assessment and catchment planning. Water quality is indicated by estimates of annual instream yields and loads of total nitrogen (TN) and phosphorus (TP), sediment and *E. coli*. CLUES was first released in 2006 (Woods et al., 2006) and the version used in this project is CLUES 10.3.1 released in December 2016 (Elliott et al., 2016; Semadeni-Davies et al., 2016).

The CLUES model has been applied at the national, regional and catchment scales in New Zealand, largely for catchment planning and policy making. Applications of CLUES with land use and mitigation scenarios include: AgResearch (Semadeni-Davies and May, 2014); Parliamentary Commissioner for the Environment (Parshotam et al., 2013); Waikato Regional Council (Semadeni-Davies and Elliott, 2012; Semadeni-Davies and Elliott, 2014); Bay of Plenty Regional Council (Collins and Semadeni-Davies, 2015) and Environment Southland (Monaghan et al., 2010; Semadeni-Davies and Elliott, 2011; Hughes et al., 2013). CLUES has also been assessed for use in the implementation of the National Policy Statement for Freshwater Management (NPSFM; Ministry for the Environment, 2014) for Auckland Council (Semadeni-Davies, Hughes, et al., 2015). CLUES has previously been applied to Porirua Harbour as part of initial catchment contaminant load assessments (Green et al., 2014).

2.1 Model framework

The CLUES model-framework consists of the following components within the ArcMap (ESRI software) Geographic Information System (GIS) platform: a geodatabase containing model inputs and outputs; a user interface for river reach selection, scenario creation, run control, and output display options; a suite of sub-models responsible for different modelling routines; and reporting and display tools. CLUES allows users set-up and run land use change and land management scenarios on the basis of spatial data. Land use change scenarios modify the areas of different land use types whereas land management scenarios alter stock rates or source yields for a specific land use by a user specified percentage to simulate increases (intensification) or decreases (mitigation) in contaminant loads. CLUES results are reported as maps (shape files / geo-database files) and tables (text files) which can be exported to other applications for further analysis or reporting. The GIS platform means that the input and output data can be displayed and interrogated using standard tools supplied with ArcMap. A steady-state rather than dynamic modelling approach was adopted to reduce input data needs and run times in order to enable rapid scenario assessment to facilitate catchment planning applications.

The CLUES modelling framework and geospatial data provided with CLUES is illustrated in Figure 2-1. There are three water modelling components within CLUES; OVERSEER®, SPASMO and SPARROW. CLUES uses a customised, pre-parameterised, and simplified version of OVERSEER version 6.1 (Shepherd and Wheeler, 2013; Shepherd et al., 2013; Roberts and Watkins, 2014; Wheeler et al., 2014) to compute annual average nutrient loss for pastoral land uses. SPASMO (Rosen et al., 2004) is a daily time-step model used to predict the fate of surface-applied chemicals. Mean annual losses derived from SPASMO are used within CLUES to estimate nitrogen losses from cropping and horticultural areas. These losses were determined by running SPASMO for various combinations of crop types, rainfalls and soil types. The SPARROW component estimates nutrient losses from sources not modelled by OVERSEER and SPASMO and sediment and *E. coli* loads generated by all source types. SPARROW is also used to route all contaminants downstream taking into account attenuation. SPARROW uses a statistical relationship between land use and various catchment characteristics to determine source yields for each land use class. The modelling approach and calibration is discussed in relation to sediment in (Elliott et al., 2008) and to nutrients in Elliott et al. (2005). The *E. coli* model was recalibrated in October 2015 to make use of new data.

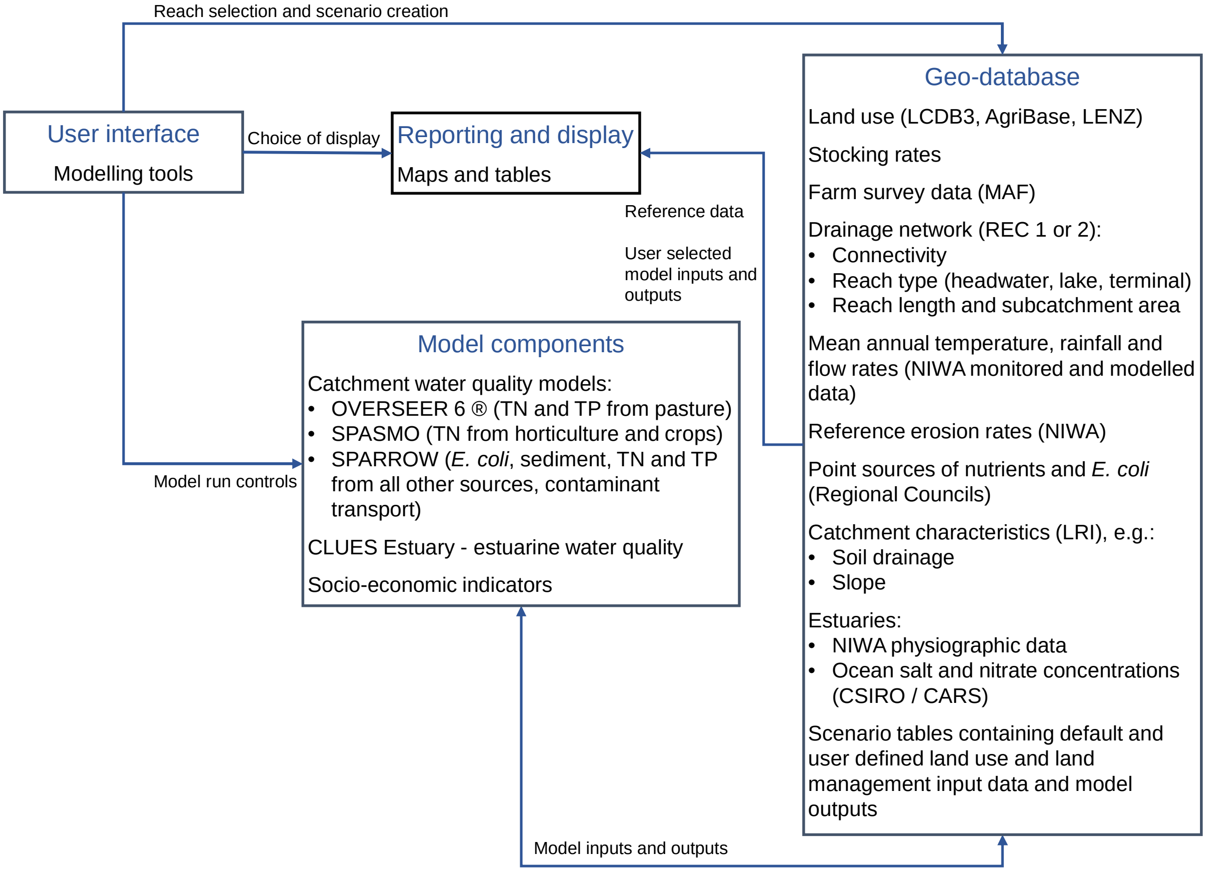

Figure 2-1: CLUES model framework showing model components and input data sets.

2.2 Geodatabase

CLUES is a spatially semi-distributed model with a vector (or polygon) geo-database. The spatial datasets used as input to CLUES are listed in Figure 2-1. These data include the drainage network, land use, climate (rainfall) and catchment characteristics.

The spatial structure of CLUES is based on New Zealand River Environments Classification version 2 (REC2; Snelder et al., 2010) drainage network. The REC2 was developed from a 30-m digital elevation model (DEM) and describes the spatial characteristics and topology of streams in New Zealand including stream type (headwater, lake inlet or outlet, terminal reach), length and connectivity. The CLUES geodatabase also contains a number of physical attributes for each REC2 reach sub catchment, such as average rainfall from the NIWA Virtual Climate Station Network (Cichota et al., 2008) and slope and soil drainage class derived from the LRI (LRI, Newsome et al., 2008). These data were obtained by intersecting the underlying datasets and calculating the area-weighted mean values for each REC2 reach. Mean annual flow rates have been estimated for each reach from raster surfaces (30x30 m) of rainfall, potential evapotranspiration, and empirical relationships between runoff and the ratio of rainfall to potential evapotranspiration (Woods et al., 2006).

Land use within CLUES is divided into 19 classes representing primarily rural activities, those present in the Whaitua are presented in Section 3. Classes assume land use is established and stable e.g. plantation or exotic forest assumes a mature forest unaffected by harvesting or forestry road development. For each sub-catchment, the proportion of the area within each land use class is specified, but the location of the land use within the sub-catchment is not represented explicitly. The default land use scenario table provided with CLUES 10.3.1 relates to the baseline year 2008 and was developed with extensive reference to the Land Cover Database v.3 (LCDB3, Landcare Research ltd, 2013), AgriBase (AsureQuality, 2008 base-line year)[3], and the Land Environments of New Zealand (LENZ, Leathwick et al., 2002) geodatabases. AgriBase and LENZ were used to split the LCDB grassland land covers into pastoral land uses for different stock types that are characterised by different contaminant yields (e.g., lowland intensive, hill country and high country sheep and beef farming) on the basis of a priori knowledge. While this study replaced the default scenario (see Section 3), the default was used to split pastoral land use in to stock types in some areas.

[3] https://www.asurequality.com/ - date of last access 17 May 2016, Agribase with a baseline year 2008 is used under licence to Agrisure.

2.3 Sources of model uncertainty and uncertainty

All models have inherent uncertainty and error. Model uncertainty relates to the representation of physical process in a model and are related to, for example, the choice and representation of processes modelled, the choice of model spatial and temporal resolution, the choice of input data and the methods used for parametrization. Error refers to, for example, inaccuracies in input and calibration data and mistakes in coding. A generalized discussion of modelling errors and uncertainty with respect to decision support tools in can be found in (Walker et al., 2003).

The sources of uncertainties within CLUES were recently overviewed in Elliott et al. (2016). These include: absence of groundwater simulation, limited spatial resolution and inaccuracy in input data (e.g., point sources, land use, catchment characteristics, drainage network).

The OVERSEER™ and SPASMO modules within the CLUES model framework contain inherent uncertainties (e.g., Overseer; Shepherd et al., 2013), and were pre-calibrated nationally before inclusion into CLUES. These components are responsible for estimating the TN generated loads from pasture and horticulture and TP generated loads from pasture.

The Sparrow component of CLUES, which calculates TP generated loads from non-pastoral land uses and *E. coli* and sediment generated loads from all land uses, was calibrated using national water quality datasets. SPARROW is also used to route contaminant loads. The calibration is used to estimate the yields associated with the land uses not covered by Overseer and SPASMO as well as the rainfall and drainage coefficients and stream and reservoir attenuation factors associated with each contaminant. SPARROW calibration was restricted to water quality monitoring sites where there is a sufficient length of paired flow data to enable calculation of mean annual contaminant loads, which means that the model calibration may be weak or not be valid for some regions or catchments. These data have been sources from the National River Water Quality Network database maintained by NIWA and from regional council state of environment reporting.

There were 183 sites with sufficient records for TN calibration, 141 for TP, 128 for *E. coli* and 214 for sediment. Of these, 17 sites located in the Greater Wellington region had sufficient data for TN, TP and *E. coli* calibration. There were 12 Greater Wellington sites with sufficient data for the sediment calibration, including the Pauahatanui site. The Greater Wellington sites include the Pauahatanui at Elmwood Bridge and Porirua Stream at Milk Depot (which is an urban site) water quality monitoring sites in the Whaitua.

CLUES estimates median TN and TP concentrations from the mean annual loads on the basis of a statistical relationship with flow (Elliott and Oehler, 2009; Oehler and Elliott, 2011). There are insufficient data nationally to derive a statistical relationship for the calculation of *E. coli* and sediment concentrations.

The model performance in the Whaitua is discussed further in Section 5.3.

2.4 Contaminant tracing

New to CLUES 10.3.1 are contaminant tracing tables that allow users to determine the loads of TN, TP and sediment from each land use within each sub-catchment and to trace the relative contribution of each land use type to in-instream load. Loads are provided for all 19 CLUES land use classes for TN. However, the classes are aggregated into broad land use groups for TP (six classes) and for sediment (four classes). This is due to the different way in which contaminants from non-pastoral sources have been calibrated and modelled in CLUES. For example, urban land use had been grouped with other non-pastoral land uses for TP and sediment calculation, which has implications in this study which seeks to model only rural land use. Similarly, native forest, plantation forest and scrub are aggregated into a single forest land use class for both TP and sediment modelling and assume a stable cover e.g., mature forest with no harvesting or land disturbance activities. Moreover, the TP loads also include background loads, i.e., the input of phosphorus from soil erosion. This meant that the grouped reach loads estimated by CLUES had to be manually disaggregated into separate land use classes to provide generated yields for each reach and land us for Workstream 8. Since the land use groups have the same calibrated source yields, loads from each of the land use classes in each group were separated from the group total by multiplying the total load by the fraction of the urban area to the total area for the land use group.

Tracing tables are not yet available for *E. coli*. For this reason, *E. coli* reach loads were calculated in Excel for each land use class using the same relationship as used in the SPARROW component of CLUES.

The urban component of the instream loads for TP, sediment and *E. coli*, was determined for each reach using an Excel version of the SPARROW routing model. The instream loads from urban sources were then subtracted from the total reach load calculated by CLUES.

3 Current land use scenario

As noted above, the default CLUES land use scenario, which has a baseline year of 2008, was replaced by a custom land use scenario based on more recent land use data. The scenario was developed for the Collaborative Modelling Programme by NIWA and Jacobs using the Landcare Research Land Cover Database v.4 (LCDB4; baseline year 2012) with reference to land use data provided by GWRC and the default CLUES land use scenario. The process followed was to:

1. Delineate broad land cover classes (i.e., urban areas, forest and scrub, horticulture and pasture) using the Land Cover Data Base version 4 (LCDB4) with relates to the baseline year 2012.

2. Split these land cover covers into CLUES land use classes using land use data supplied by GWRC where data were available and compatible to the CLUES land use classes.

3. Where GWRC land uses were not compatible with CLUES, reassign the land use to the closest CLUES land use class. For example, horses and life-style blocks were assigned as the *other stock types* land use class in CLUES.

4. Where GWRC land use data were not available, split the LCDB4 pastoral and agricultural land covers into CLUES land use classes using the default land use layer from CLUES under the assumption that if the land cover is unchanged between LCDB3 and LCDB4[4], then it is likely the area has the same land use. A visual comparison of Google Earth images showed very little difference between LCDB3 and LCDB4 in the Waitua.

The final land use was presented to GWRC and approved for use for modelling. The CLUES land use classes present in the Waitua are listed and described in Table 3-1. The CLUES default stocking rates for sheep, beef and deer for North Island farms is given by LRI slope class in XXXXX. The CLUES scenario was created by intersecting the land use shapefile with the REC2 sub-catchment boundaries and then calculating the relative area of each land use class within each sub-catchment. The area breakdown is plotted in Figure 3-1 for each CLUES land use class present in the Whaitua. Land use is further mapped by broad class in Figure 3-2.

[4] A visual check of LCDB3 and LCDB4 land covers showed very little difference between 2008 and 2012 at the catchment scale.

Table 3-1 CLUES land use classes present in the Whaitua.

CLUES land use class	Description
SBINTEN	Sheep and beef: intensive farming on lowland farms (flat to rolling country with slopes less than 16°)
SBHILL	Sheep and beef: hill country (strongly rolling to steep country with slopes between 16-25 °)
DEER	Deer
PAST_OTH_ANIM	Other stock types (Includes areas mapped as horses and lifestyle blocks in the GWRC land use data).
ONIONS	Vegetables (based on onions)
APPLES	Pip fruit (e.g., apples, pears)
LC_EXOTIC	Plantation or exotic forest
LC_NATIVE	Native forest
LC_SCRUB	Scrub including fern-land, manuka and kanuka
LC_URBAN	Urban (note, there are no sub-urban classes)
OTHER	Other land covers (e.g., ice, water, bare soil etc.)

Table 3-2: CLUES default North Island stocking rates (animals per ha) by LRI slope class for sheep, beef and deer.

Slope Class		Slope range	Beef	Sheep	Deear
A	Flat to gently undulating	0–3°	2.00	11.99	4.56
B	Undulating	4–7°	1.37	10.50	4.61
C	Rolling	8–15°	1.14	8.79	2.49
D	Strongly rolling	16–20°	0.54	6.43	1.30
E	Moderately steep	21–25°	0.16	3.28	0.53
F	Steep	26–35°	0.00	0.80	0.13
G	Very steep	>35°	0.00	0.00	0.00

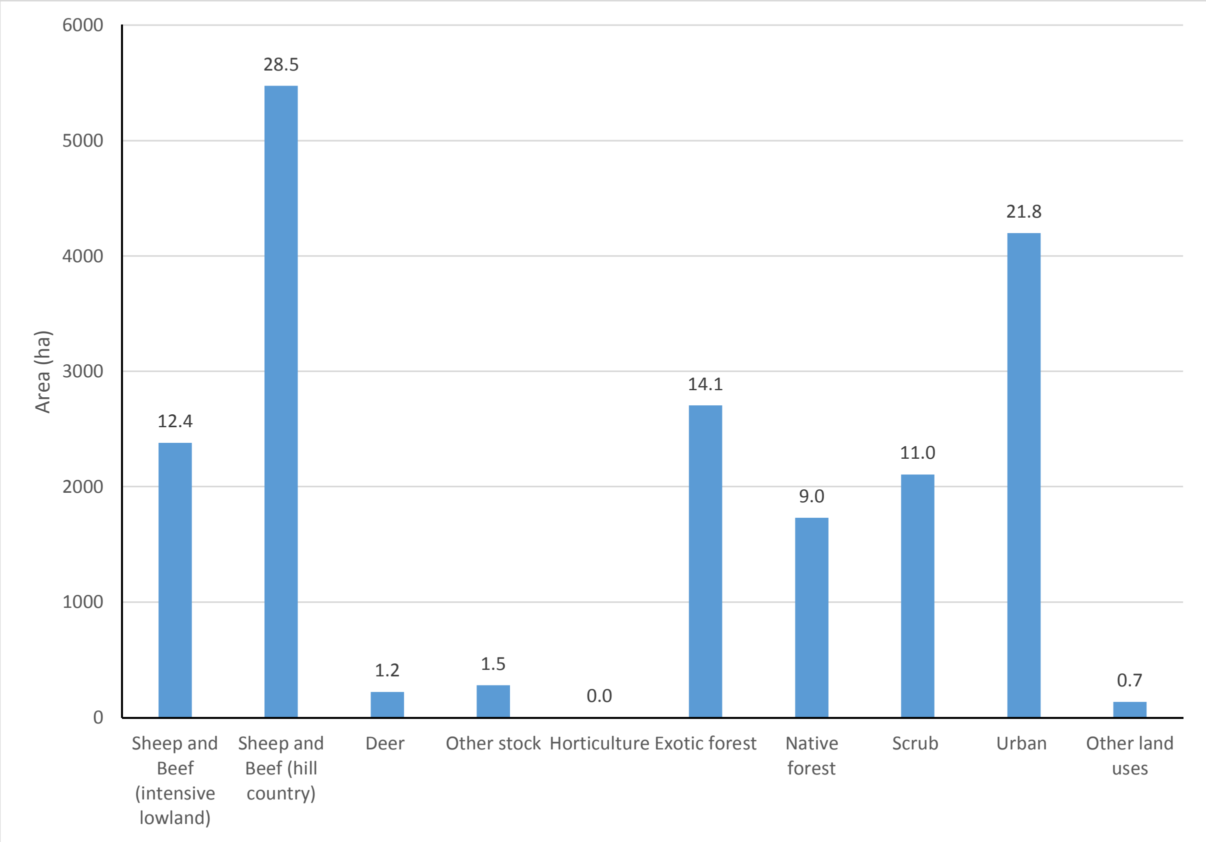

Figure 3-1: Area breakdown of CLUES land use classes present in the Porirua Catchment. Percentage cover is labelled for each land use class.

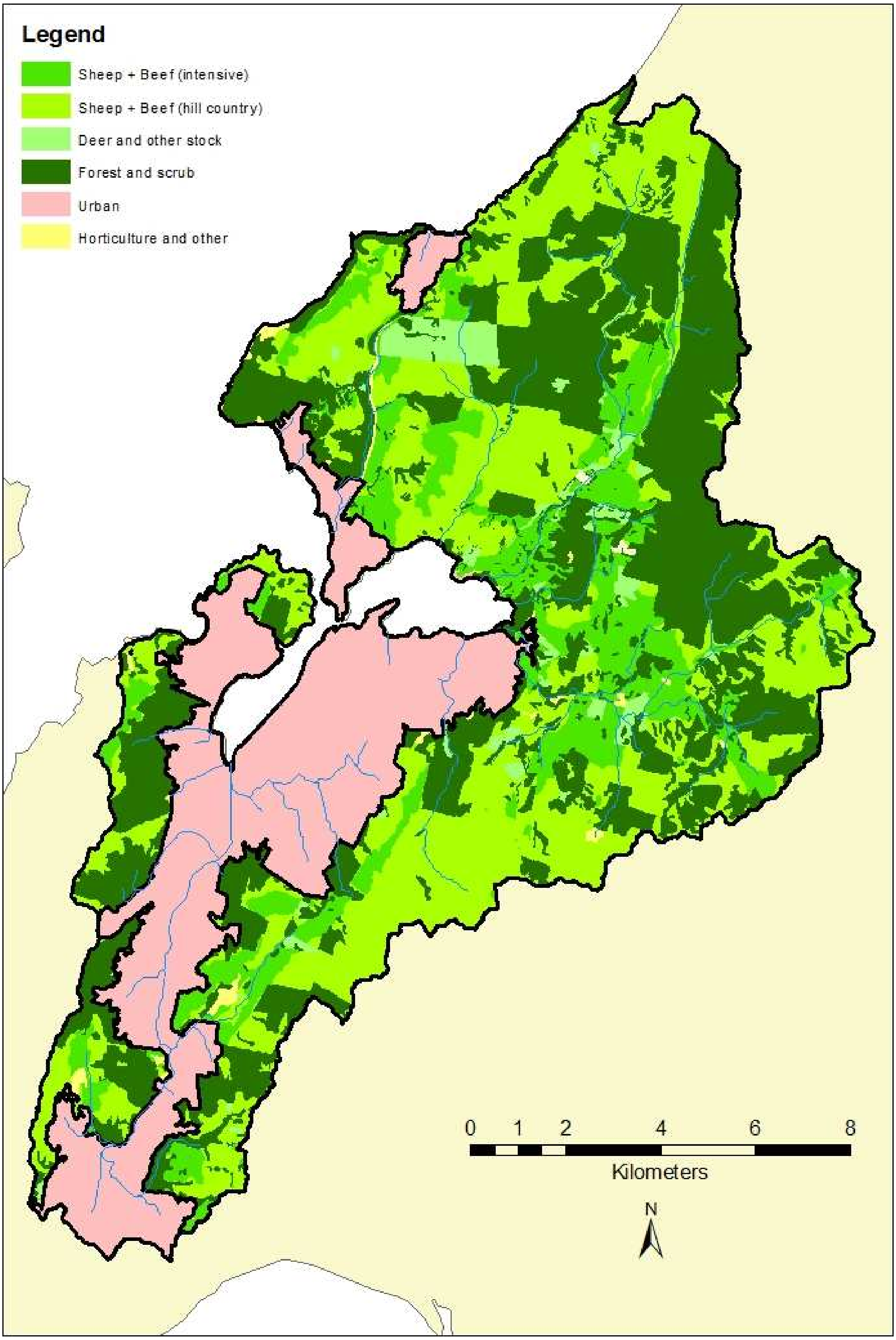

Figure 3-2: Current land use scenario developed for rural contaminant load modelling. Main stream channels (stream order two and over) are shown for reference. Rural and urban areas are delineated with a bold line.

4 Water quality monitoring concentration and load calculations

To give an indication of the performance of CLUES in the TAoP Whaitua, the CLUES instream loads for core task contaminants (i.e., nutrients and *E. coli*) were compared to mean annual contaminant loads calculated from long-term paired flow and monthly concentration data. The data come from rural water quality monitoring sites located in the Whaitua that have sufficient water quality and flow monitoring data available for load estimation.

CLUES median concentrations for TN and TP were also compared to median concentrations determined using the Hazen method for the same water quality monitoring sites. CLUES does not estimate *E. coli* concentrations.

Flow and water quality monitoring data up to December 2015 were provided for this study by GWRC. There are 15 water quality sites in the Whaitua, however most of these are either no longer active or have event rather than long-term monitoring data that is unsuitable for calculating mean annual loads. Futhermore, most of the sites are located downstream of urban areas. There are four active water quality monitoring sites in the Whaitua that have predominantly rural land uses upstream: Stebbings Stream, Horokiri at Snodgrass, Pauatahanui Stream at Gorge and Pauatahanui Stream at Elmwood Bridge. With the exception of Stebbings Stream, which is 600m downstream of the Stebbings reporting point, these sites are located at reporting points as listed and mapped in Section 5 below. Note that the two Pauatahanui sites are located in the same sub-catchment and are roughly 650 m apart. Since there are few samples from the Gorge site (less than 10 samples between 2012-2015), the site was not included in the analysis. However, flow data for the Elmwood Bridge site comes from flow monitoring at the Gorge site; there are no major tributaries between the sites. Likewise, the Stebbings site was excluded both as there are fewer than 10 water quality samples in the data provided and there is no nearby flow monitoring. Flow data for the Horokiri at Snodgrass monitoring site comes from the Horikiri at Ongly flow monitoring site located roughly 1 km downstream. The Ongly site is likely to have higher flows than the Snodgrass monitoring site as it is takes flow from a tributary of the Horokiri Stream that has its confluence just downstream of the Snodgrass site.

Mean annual contaminant loads were estimated using a method that fits a rating curve to the natural log of measured concentrations against the natural log of the flow rate using the following equation:

$$\ln(C) = s(t) + s(\ln(Q)) + s(\mathrm{S}) \qquad \textbf{\textit{(1)}}$$

Where C is the median concentration, s is a cubic spline smoothing function, Q is the hourly flow rate for the time the sample was collected, t is time (in years), and S is a categorical variable representing season. Cubic spline smoothing from the R statistical package was used, with a fixed effective degrees of freedom of two to restrict curvature. The fitted curves for the two sites are shown in Appendix A.

Equation (1) was then applied to the hourly flow time-series over the period of the flow record to derive a time-series of concentrations, which was then multiplied by volume (from flow x time over the flow monitoring time step) and summed to give the mean annual load. To account for retransformation bias, the load was adjusted using the non-parametric smearing factor of Duan (1983).

The suitability of the rating curve derived loads for model calibration were assessed by generating confidence intervals (90%) and standard deviations for the mean annual loads by repeating the rating curve procedure using a boot-strapping approach. This approach repeatedly took random samples of the original water quality data and estimated the mean annual load for each of these. Mean annual loads were calculated using both the full flow record and the 90th percentile upper and lower flow records (i.e., the bottom and top 10% of flow rates removed). The upper and lower 90th percentile loads assess whether the bulk of loads are associated with high or low flows. The calculation also provides the fraction of the load associated with flows below 99th percentile flow rate (Q99) and the fraction of the annual load calculated for flows within the same range of flows represented in the rating curves. The reliability of the load calculation is further assessed by the standard deviation of the log-transformed loads. A value > 1 signals that the mean load calculated is likely to be unrepresentative of actual load for the site.

5 Model results

This section presents maps of the total generated or source yields from rural land uses for each sub-catchment and instream loads estimated for a set of reporting sites provided by GWRC. Generated or catchment loads from each reach sub-catchment are calculated as the generated yield for each land use mulitiplied by the land use area within the sub-catchment. With the exception of *E. coli*, there is no-within catchment attenuation calculated. *E. coli* generated loads are subject to a catchment attenuation related to annual rainfall and soil drainage.

Instream or cumulative loads are also compared to the loads determined from water quality monitoring (see Section 4) in order to give an indication of model performance. Instream loads are calculated by routing the contaminant loads downstream, they are subject to instream attenuation, however, since there are no large lakes and the streams are relatively short – attenuation in the Whaitua is minimal.

Note that model results by reach and land use class have been provided to GWRC as a MS Excel workbook. The workbook contains separate worksheets for each contaminant and presents the area of each land use class within each REC2 sub-catchment and the associated source yield estimated by CLUES for each land use and sub-catchment. These results will be used to estimate yields for current and future land uses and model instream concentrations throughout the Whaitua as part of Workstream 8.

5.1 Generated loads and yields

The total generated load modelled by CLUES for each land use class present in the Whaitua is given in Table 5-1. Note that not all of this load will reach the harbour due to instream attenuation and, for *E. coli*, die-off in the stream network. The load reflects both the modelled generated yield and the area covered (see Figure 3-1) by each of the land use classes. For this reason, generated yields give a better indication of the importance of land use on contaminant generation.

Table 5-1: Total CLUES modelled generated load by land use class.

Land use class	TN (kg/y)	TP (kg/y)	Sediment (t/y)	*E. coli* (10^{12} /y)
	Total load	Total load	Total load	Total load
Sheep and beef - intensive	15009	3671	3699	1.909
Sheep and beef - hill country	30393	11476	16824	4.135
Deer	1791	293	610	0.206
Other stock	935	68	294	0.001
Horticulture	102	1	2	0.000
Exotic Forest	11971	675	1967	0.014
Native Forest	7562	421	1332	0.008
Scrub	8800	515	1798	0.010
Urban	33586	997	3463	6.165
Other	515	36	208	0.001

The average generated yields (and standard deviations) associated with each land use are given in Table 5-2. The variation in yields across the Whaitua are due to the effect of other factors, notably slope and rainfall. The highest modelled TN generated yields are associated with horticulture which is largely due to the application of fertiliser modelled by the SPASMO component. This is followed by deer and sheep and beef farming. The highest modelled TP generated yields are associated with sheep and beef and deer farming. The other land uses have similar calibrated TP yields. The high generated *E. coli* yield associated with urban land use could be due to the impact of overflows from combined sewers and wastewater treatment plants in the calibration data. Another potential pathogen source we have identified in *E. coli* modelling for the Waikato River (Semadeni-Davies and Elliott, 2014; Semadeni-Davies, Elliott, et al., 2015) is waterfowl living along stream banks in parks. While the highest modelled generated sediment yields are for hill country sheep and beef farming, this is likely due to the steep slopes on land dominated by this land use. That is, previous modelling has shown that sediment loads in the model are more sensitive to slope and erosion terrain than to land use. This would also account for the high variation seen in the modelled generated yields for all the land use types.

Table 5-2: Average generated yields and standard deviations for CLUES land use classes present in the Whaitua. Reaches where the land use is not present were excluded from the calculations.

Land use class	TN (kg/ha/y)		TP (kg/ha/y)		Sediment (t/ha/y)		*E. coli* (10^{12} /ha/y)	
	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev
Sheep and beef - intensive	6.0	1.9	1.73	0.73	2.2	2.3	0.803	0.208
Sheep and beef - hill country	5.7	1.6	1.96	0.75	4.1	18.0	0.801	0.207
Deer	8.0	1.8	1.31	0.60	1.7	1.4	0.876	0.210
Other stock	3.9	5.1	0.24	0.01	1.4	1.4	0.005	0.001
Horticulture	20.5	16.8	0.23	0.01	0.8	0.1	0.005	0.001
Exotic Forest	4.3	0.6	0.25	0.01	1.0	4.9	0.005	0.001
Native Forest	4.2	0.7	0.24	0.01	0.7	1.3	0.005	0.001
Scrub	4.3	0.8	0.24	0.01	1.1	5.0	0.005	0.001
Urban	8.0	0.3	0.24	0.01	1.2	1.7	1.468	0.000
Other	3.4	4.1	0.24	0.01	1.5	2.6	0.005	0.001

The total generated yields for rural sources are mapped in Figure 5-1 for nutrients and Figure 5-2 for sediment and *E. coli*. The yields were determined by summing the loads generated by the rural land uses in each reach and then dividing the total load by the total area of rural land cover in each sub-catchment. The yields for sub-catchments that intersect the rural/urban boundary are calculated only for the rural sources and areas although they are mapped for the entire sub-catchment. There are also several sub-catchments within the urban boundary that have albeit minor contaminant yields (e.g., reach 9260073), this is largely due to small pockets of forest and scrub that have been modelled by CLUES as rural land uses.

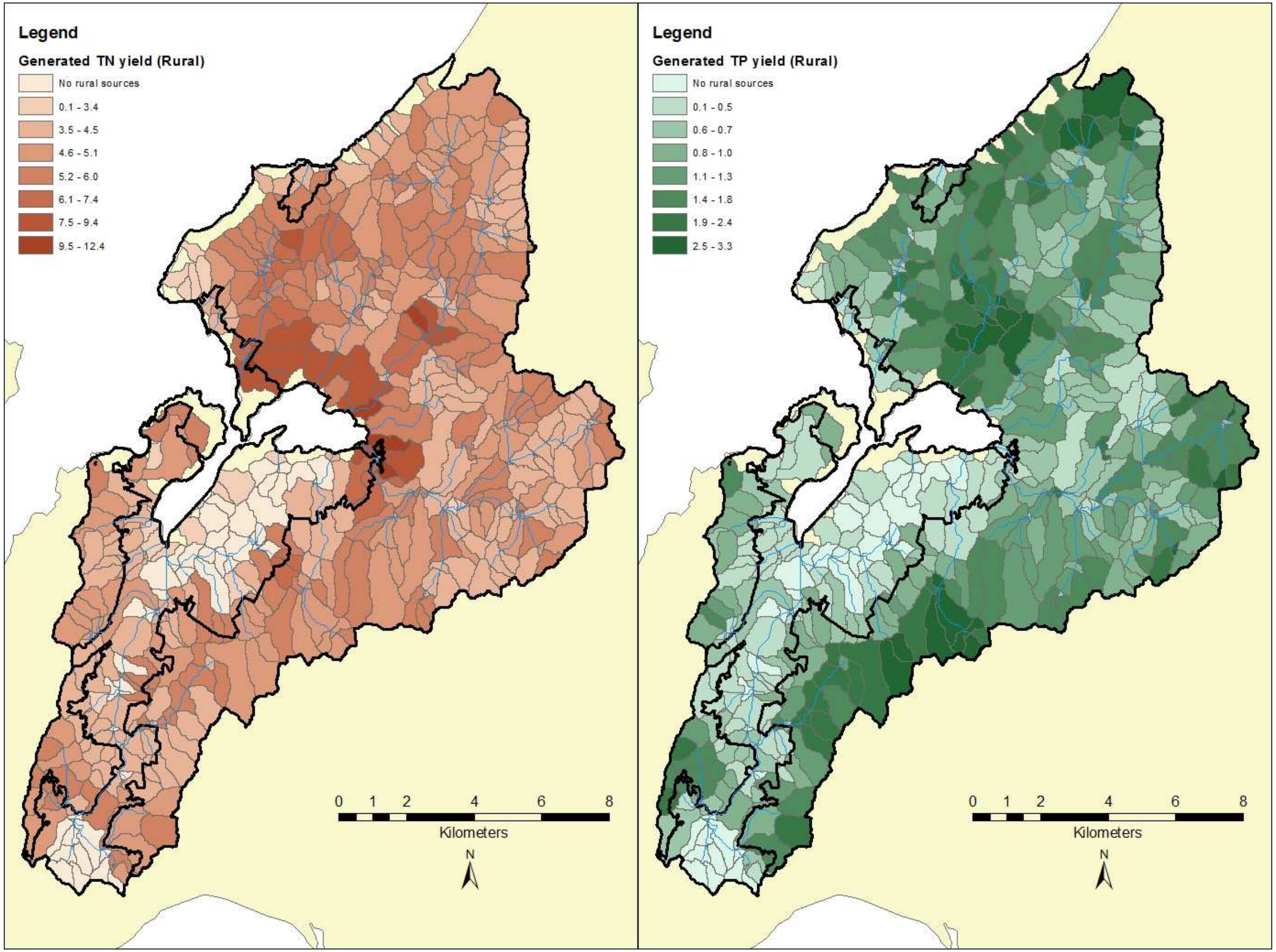

Figure 5-1: Sub-catchment CLUES estimated median annual yields (kg/ha/y) from rural diffuse sources for TN and TP. Main stream channels (stream order two and over) are shown for reference. Rural and urban areas delineated with bold line.

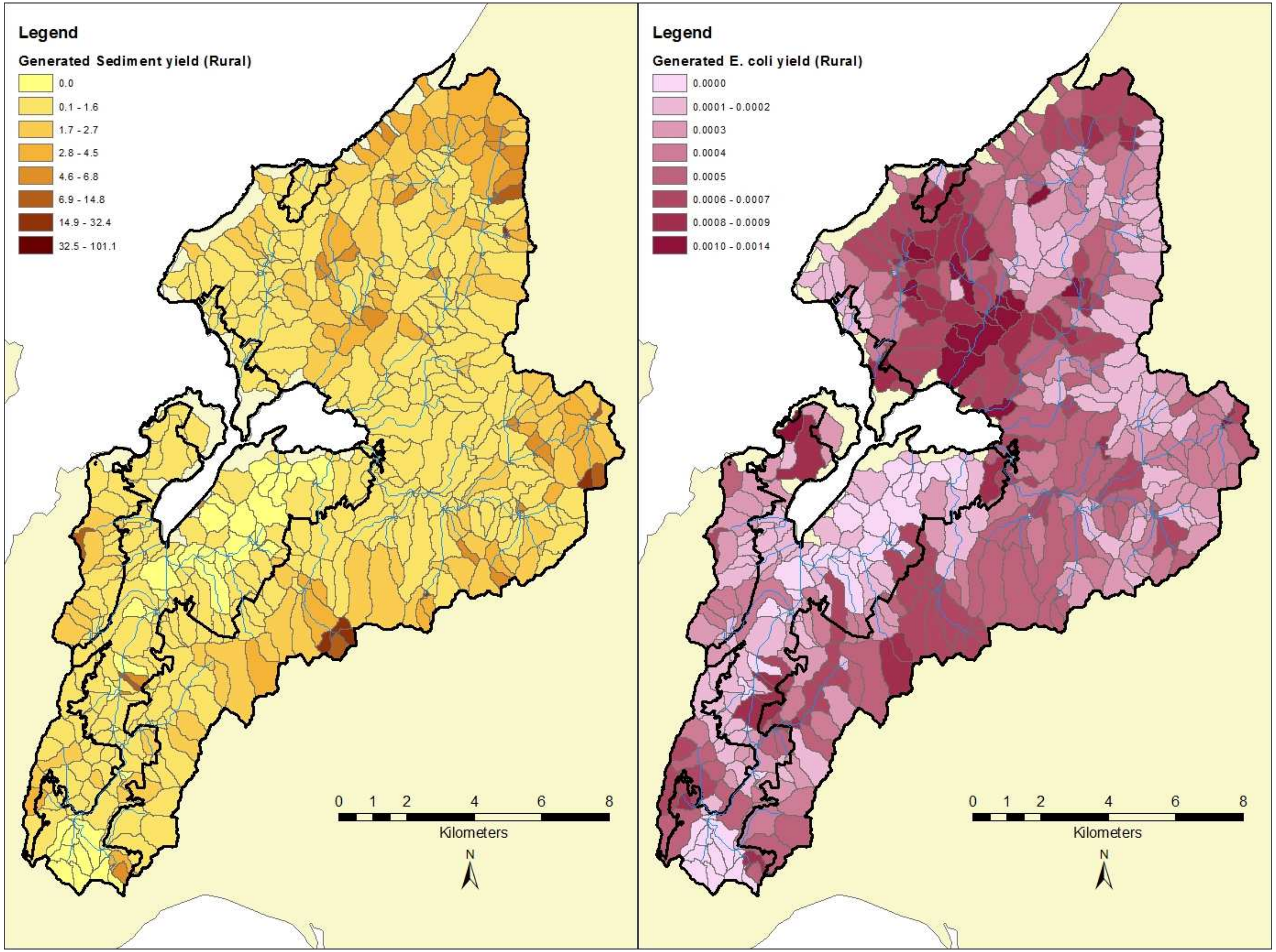

Figure 5-2: Sub-catchment CLUES estimated median annual yields from rural diffuse sources for sediment (t/ha/y) and *E. coli* (10^{15} organisms /ha/y). Main stream channels (stream order two and over) are shown for reference. Rural and urban areas delineated with bold line.

As was noted above, the generated yields reflect variable catchment characteristics such as soil type, rainfall and slope as well as land use. This is particularly noticeable for sediment which does not have the same spatial pattern of generated yields seen for the other contaminants that are more influenced by land use.

5.2 Reporting point instream loads

In-stream loads are estimated by the SPARROW component of CLUES by routing the contaminant loads discharged by each sub-catchment into the steam network downstream taking into account reservoir attenuation and, for *E. coli*, in-stream decay due to die-off.

The instream loads reported here relate to the reaches where the reporting points are located. The reporting points are mapped and listed in Figure 5-3 and Table 5-3. There are 55 reporting points, 21 of which are considered rural as they have an upstream area dominated (≥90%) by rural land uses. The two rural monitoring sites with data suitable for comparison to the CLUES results (Horokiri at Snodgrass and Pauahatanui at Elmwood Bridge; see Section 4) are also mapped in Figure 5-3. Note that several of the reporting points are coastal outlets that are not associated with an REC reach and there are, therefore, no model results available for them. These points are identified in Table 5-3. The proportion of the upstream (cumulative) area classed as rural land use is given in Table 5-3 and points that are considered rural are shaded.

The instream loads estimated for the stream reaches where the rural reporting sites are located is given in Table 5-4. Loads for all the reporting sites are given in Appendix B. Table 5-4 gives the total load estimated by CLUES and the load less contaminant contributions from urban areas. Background TP loads from soil erosion are given for TP. Again, the load largely reflects the proportion of agricultural land upstream and slope. Since the instream loads are cumulative, downstream sites will have higher loads than those upstream.

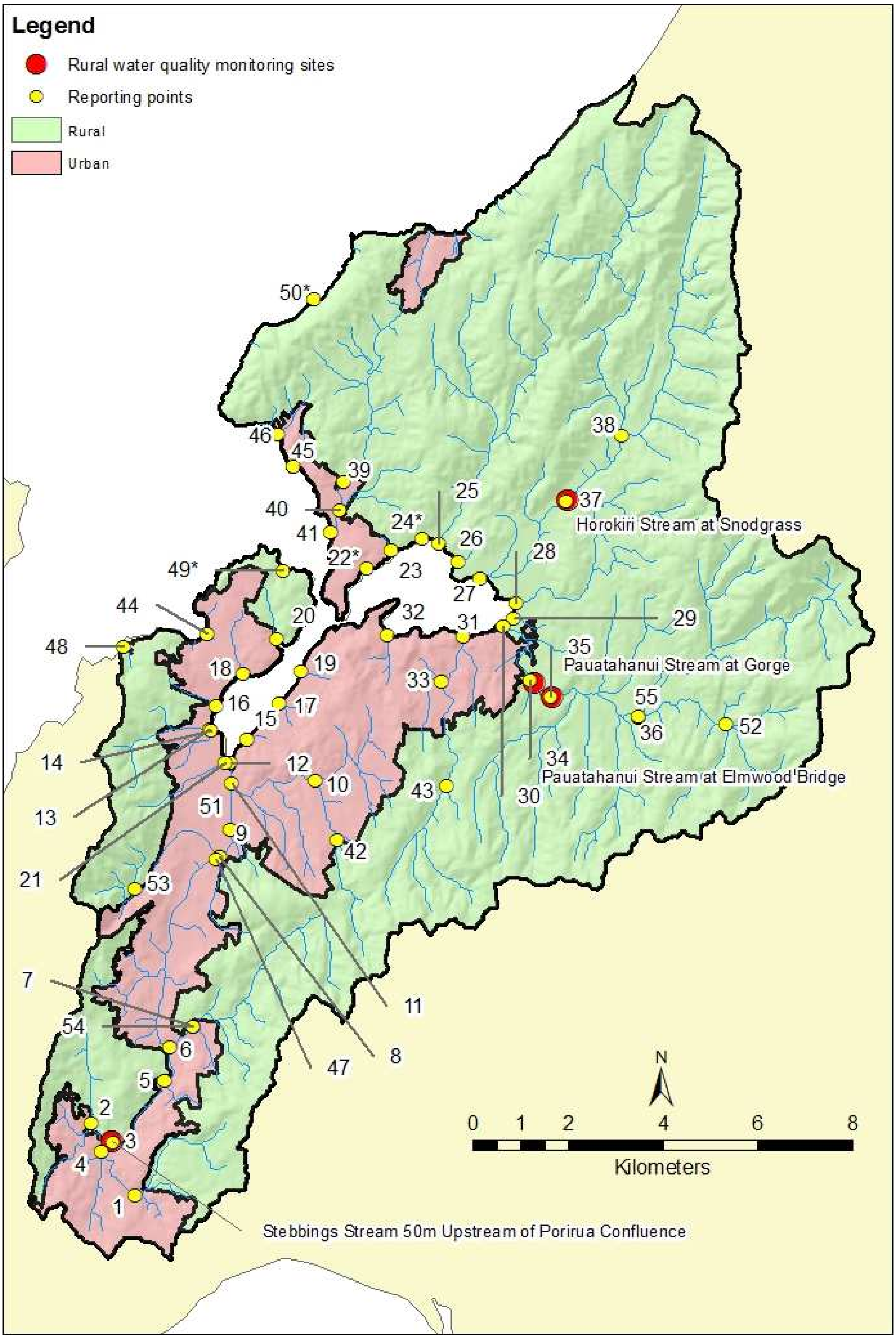

Figure 5-3: Reporting points and rural water quality monitoring sites. Reporting point labels refer to the ID numbers listed in Table 5-3. *Coastal point not associated with a REC2 reach.

Table 5-3: Reporting points. Rural points (cumulative upstream area ≥ 90% of total area) are shaded. Map ID refers to Figure 5-3.

Map ID	Point Name	REC2 reach	Cumulative area (ha)		
			Total	Rural	% rural
1	Belmont	9262562	533	318	60%
2	Stebbings	9262155	244	235	96%
3	Porirua B	9262515	726	318	44%
4	Porirua A	9262562	533	318	60%
5	Porirua C	9262013	1559	819	53%
6	Porirua D	9261915	2509	1665	66%
7	Takapu B	9261896	98	57	58%
8	Mitchell	9260915	3878	2256	58%
9	Porirua F	9260915	3878	2256	58%
10	Kenepuru A	9260508	466	122	26%
11	Kenepuru B	9260669	1264	417	33%
12	Porirua H	9260544	5358	2747	51%
13	Mahinawa Stream	9260370	253	218	86%
14	Onepoto Fringe E	9260383	107	37	35%
15	Onepoto Fringe C	9260397	50	0	0%
16	Hukatai Stream	9260124	98	58	59%
17	Onepoto Fringe B	9260256	88	0	0%
18	Onepoto Fringe F	9259774	143	8	6%
19	Onepoto Fringe A	9260073	77	0	0%
20	Whitireia A	9259616	98	58	60%
21	Onepoto Fringe D	9260536	167	86	51%
22	Pauatahanui Fringe A*	-	-	-	-
23	Pauatahanui Fringe B	9259404	43	23	54%
24	Pauatahanui Fringe C*	-	-	-	-
25	Kakaho	9259174	1251	1251	100%
26	Horokiri and Motukaraka D	9259475	44	44	100%
27	Horokiri and Motukaraka C	9259581	3320	3320	100%
28	Ration	9259625	692	692	100%
29	Pauatahanui F	9259837	50	45	91%
30	Pauatahanui E	9259849	4183	4072	97%
31	Lower Duck Creek B	9259898	1032	735	71%
32	Pauatahanui Fringe D	9259893	133	0	0%

Map ID	Point Name	REC2 reach	Cumulative area (ha)		
			Total	Rural	% rural
33	Lower Duck Creek A	9260132	685	634	93%
34	Pauatahanui D (Pauatahanui Stream at Elmwood Br)	9260167	3861	3861	100%
35	Pauatahanui C (Pauatahanui Stream at Gorge)	9260167	3861	3861	100%
36	Pauatahanui B	9260297	884	884	100%
37	Horokiri and Motukaraka B (Horokiri Stream at Snodgrass)	9259111	2945	2945	100%
38	Horokiri and Motukaraka A	9258896	2684	2684	100%
39	Taupo Swamp A	9259104	840	793	94%
40	Taupo Swamp B	9259279	1120	1009	90%
41	Taupo Swamp C	9259279	1120	1009	90%
42	Upper Kenepuru	9260727	317	250	79%
43	Upper Duck Creek	9260132	685	634	93%
44	Titahi A	9259883	31	0	1%
45	Hongoeka to Pukerua C	9258915	90	56	62%
46	Hongoeka to Pukerua B	9258800	135	109	81%
47	Porirua E	9261009	3465	2005	58%
48	Titahi B	9259956	55	51	93%
49	Whitireia B*	-	-	-	-
50	Hongoeka to Pukerua A*	-	-	-	-
51	Porirua G	9260668	4073	2329	57%
52	Pauatahanui A	9260339	600	600	100%
53	Rangituhi	9261062	84	84	100%
54	Takapu A	9261896	98	57	58%
55	Moonshine	9260261	1171	1171	100%

*Coastal point not associated with a REC2 reach.

Table 5-4: Instream loads estimated by CLUES for the GWRC rural reporting sites. Loads are provided for all diffuse sources and for rural land uses only. Background TP loads from soil erosion are also provided. The percentage of the total load from rural sources is indicated. Estimates relate to the downstream confluence of each reach. The loads are subject to attenuation, albeit minor in the Whaitua.

ID number	Name	REC2 reach	TN (kg / y)			TP (kg / y)				Sediment (t/y)			*E. coli* (10^{10} organisms / y)		
			Total	Rural	% rural	Total	Background	Rural	% rural	Total	Rural	% rural	Total	Rural	% rural
2	Stebbings	9262155	1269	1197	94%	374	42	330	88%	335	327	98%	56430	50551	90%
25	Kakaho	9259174	7117	7117	100%	2346	273	2073	88%	2690	2690	100%	299310	299294	100%
26	Horokiri and Motukaraka D	9259475	254	254	100%	80	9	71	89%	34	34	100%	13970	13962	100%
27	Horokiri and Motukaraka C	9259581	17850	17850	100%	4433	777	3656	82%	7044	7044	100%	443690	443690	100%
28	Ration	9259625	3317	3317	100%	596	111	485	81%	492	492	100%	96130	96130	100%
29	Pauatahanui F	9259837	509	471	93%	25	6	18	72%	25	25	100%	9620	7765	81%
30	Pauatahanui E	9259849	20774	19886	96%	4453	468	3959	89%	6923	6888	99%	451130	405135	90%
33	Lower Duck Creek A	9260132	3458	3048	88%	1276	138	1126	88%	2999	2962	99%	88050	71356	81%
34	Pauatahanui D	9260167	18235	18235	100%	4283	429	3854	90%	6781	6781	100%	373200	373200	100%
35	Pauatahanui C	9260167	18235	18235	100%	4283	429	3854	90%	6781	6781	100%	373200	373200	100%
36	Pauatahanui B	9260297	4029	4029	100%	897	98	799	89%	1438	1438	100%	90860	90860	100%
37	Horokiri and Motukaraka B	9259111	15224	15224	100%	3850	712	3138	82%	6638	6638	100%	383630	383630	100%
38	Horokiri and Motukaraka A	9258896	13216	13216	100%	3486	675	2811	81%	6220	6220	100%	303220	303220	100%
39	Taupo Swamp A	9259104	5045	4664	92%	992	99	882	89%	905	884	98%	136540	119780	88%
40	Taupo Swamp B	9259279	7391	6509	88%	1301	146	1130	87%	1177	1131	96%	229780	183936	80%
41	Taupo Swamp C	9259279	7391	6509	88%	1301	146	1130	87%	1177	1131	96%	229780	183936	80%
43	Upper Duck Creek	9260132	3458	3048	88%	1276	138	1126	88%	2999	2962	99%	88050	71356	81%
48	Titahi B	9259956	295	266	90%	88	11	76	86%	82	77	94%	14520	12030	83%
52	Pauatahanui A	9260339	2704	2704	100%	644	71	573	89%	1106	1106	100%	65950	65950	100%
53	Rangituhi	9261062	406	406	100%	84	18	66	79%	119	119	100%	5260	5260	100%
55	Moonshine	9260261	5534	5534	100%	1512	156	1356	90%	3033	3033	100%	118080	118080	100%

5.3 Comparison against observed water quality data

The CLUES estimates of nutrient and *E. coli* loads and nutrient median annual concentrations are compared in this section to the mean annual loads and median concentrations calculated, as described in Section 4, from water quality monitoring data. Since suitable water quality data were only available for two sites, it is not possible to undertake a robust statistical evaluation of the model performance for the Whaitua. Instead, these should be viewed as indicators of model performance only for the two points identified above (i.e., Horokiri at Snodgrass and Pauahatanui at Elmwood Bridge).

Median concentrations for TN and TP are given in Table 5-5 and Table 5-6 respectively. The tables show the median concentrations calculated for the two sites using the full data record for each site and five- and 11-year time periods. The CLUES concentrations are in the same order of magnitude to those calculated from the monitored water quality data. However, the CLUES concentrations are underestimated by up to a half for TN and are three times those for TP. The underestimation of TP concentrations and overestimation of TN concentrations suggests either the yield and load calculated by CLUES is not correct or that the calibrated statistical relationship used to estimate concentrations is not valid for the Whaitua – however, this metric is not used for further modelling under the CMP.

Table 5-5: TN median concentrations (g/m3) calculated from monitored water quality. Number of samples used in calculation in brackets.

Site	5-year	11-year	All samples	CLUES
Horokiri at Snodgrass	0.80 (62)	0.67 (135)	0.68 (166)	0.34
Pauahatanui at Elmwood Bridge	0.53 (58)	0.52 (131)	0.59 (174)	0.37

Table 5-6: TP median concentrations (mg/m3) calculated from monitored water quality. Number of samples used in calculation in brackets.

Site	5-year	11-year	All samples	CLUES
Horokiri at Snodgrass	0.02 (62)	0.02 (135)	0.02 (165)	0.07
Pauahatanui at Elmwood Bridge	0.03 (58)	0.03 (131)	0.03 (173)	0.09

The mean annual instream loads for TN, TP and *E. coli* are compared in Table 5-7 to Table 5-9 respectively. The CLUES loads are in the same order of magnitude as the loads calculated from the water quality data except for the *E. coli* load estimated for Pauatahanui at Elmwood Bridge. The CLUES estimated loads for TN and *E. coli* are within the upper and lower confidence intervals calculated from the water quality data for Pauahatanui and Hororiki, respectively. All the other CLUES loads are outside the confidence intervals. The modelled TN load for Horokiri is around 70% of that estimated from the monitored data and 88% of that estimated for Pauahatanui. The TP load is underestimated for both sites and is around half that calculated using the monitored data. *E. coli* is also underestimated and is about 85 % of the load estimated from the monitored data for Hororiki at Snodgrass and 40% of the load estimated for Pauahatanui.

Table 5-7: TN load (kg/y) calculated from monitored water quality against CLUES estimates.

Value	Horokiri at Snodgrass	Pauahatanui at Elmwood Bridge
CLUES load (t/y)	15.22	18.24
Mean annual load (t/y)	21.46	20.64
Load fraction within rating range	0.97	0.58
Load fraction below Q99	0.68	0.67
Mean annual load lower 90 (t/y)	18.61	17.45
Mean annual load upper 90 (t/y)	23.29	22.90
Standard deviation of log-transformed mean annual load	0.075	0.076

Table 5-8: TP load calculated from monitored water quality against CLUES estimates.

Value	Horokiri at Snodgrass	Pauahatanui at Elmwood Bridge
CLUES load (t/y)	3.85	4.28
Mean annual load (t/y)	1.82	1.98
Load fraction within rating range	0.79	0.36
Load fraction below Q99	0.27	0.44
Mean annual load lower 90 (t/y)	1.23	1.28
Mean annual load upper 90 (t/y)	3.28	2.17
Standard deviation of log-transformed mean annual loads	0.27	0.18

Table 5-9: *E. coli* load calculated from monitored water quality against CLUES estimates.

Value	Horokiri at Snodgrass	Pauahatanui at Elmwood Bridge
CLUES load (10^{12}/y)	383	373
Mean annual load (10^{12}/y)	450	1012
Load fraction within rating range	0.41	0.12
Load fraction below Q99	0.28	0.17
Mean annual load lower 90 (10^{12}/y)	271	866
Mean annual load upper 90 (10^{12}/y)	1887	4686
Standard deviation of log-transformed mean annual load	0.572	0.590

The underestimation of *E. coli* loads reflects the difficulty in modelling pathogens as the yield of microbes from diffuse and point sources is highly variable in time and space (Wilcock, 2006; Muirhead, 2015) making determination of average annual catchment loads and concentrations difficult.

It should be noted that although all of the sites have a standard deviation of the log-transformed loads less than one, the loads calculated from the water quality data are subject to error and may not be representative of the true mean annual load. The rating curves (Appendix A) for Horokiri indicates that few flow samples are available for high flows so that the curve may not represent the true relationship between concentration and flows for the site. Similarly, some 58% of the TN load calculated for Pauahatanui at Elmwood Bridge were calculated for flows outside those represented in the flow rating curves and both sites have around 30% of the load attributed to extreme flows greater than the 99^{th} percentile flow rate in the flow record.

There are discrepancies between the loads modelled by CLUES and those derived from water quality, particularly for TP. However the results of the comparison are inconclusive given the paucity of long term paired water quality and flow data suitable for estimating instream loads. A regional validation or recalibration of CLUES may be possible using long term data from state of the environment monitoring sites in the greater Wellington region. However, doing so is outside the scope of the CMP.

6 Summary

This report documents the application of the CLUES model to the Te Awarua-o-Porirua Whaitua as part of the TAoP CMP. The core task for CLUES modelling is estimation of mean annual loads of TN, TP and *E. coli* loads from rural diffuse sources located in the Whaitua. A secondary task is estimation of the mean annual sediment load from the rural diffuse sources as a check on sediment loads estimated using the Dynamic SedNet model.

The model outputs presented in this report are the total generated contaminant yields from rural land uses for each sub-catchment and instream loads estimated for a set of reporting sites provided by GWRC. These outputs reflect land use. Instream loads are also compared to the loads determined from water quality monitoring in order to give an indication of model performance. Model results by reach and land use class have been provided to GWRC as a MS Excel workbook.

There are only two rural water quality monitoring sites in the Whaitua with sufficient paired flow data to estimate median annual concentrations and instream loads for comparison with the CLUES outputs. This meant that it was not possible to statistically evaluate the model. The instream mean annual loads and median concentrations estimated for the sites were in the same order of magnitude as those modelled by CLUES with the exception of the *E. coli* instream load estimate for the Pauatahanui site. The TN loads for the two sites were underestimated, however, the load for Pauahatanui were within the confidence interval of the load estimated from the monitored data. The CLUES TP loads were roughly twice those estimated from the monitored data. The differences between the modelled loads and those derived from the monitored data could be due either model uncertainty or to uncertainties in the load calculations or to a combination of both.

7 Acknowledgements

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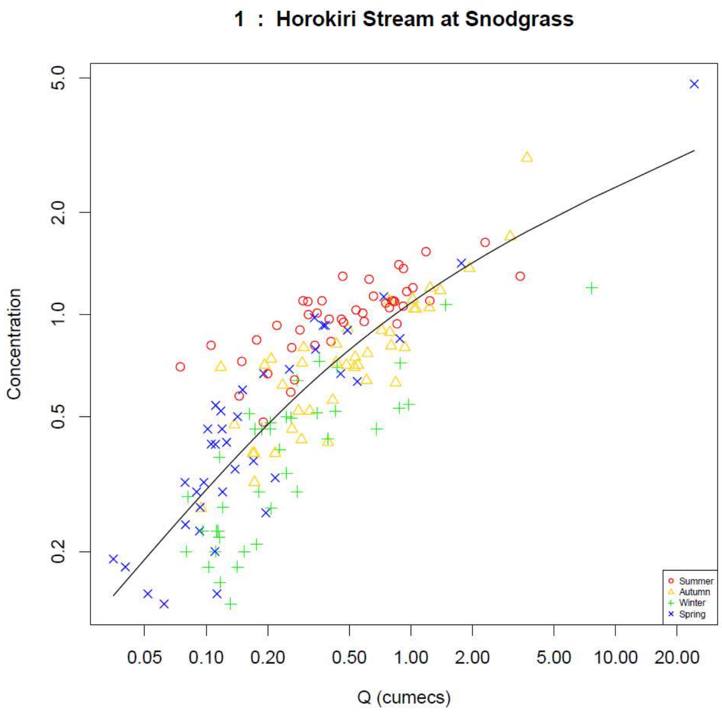
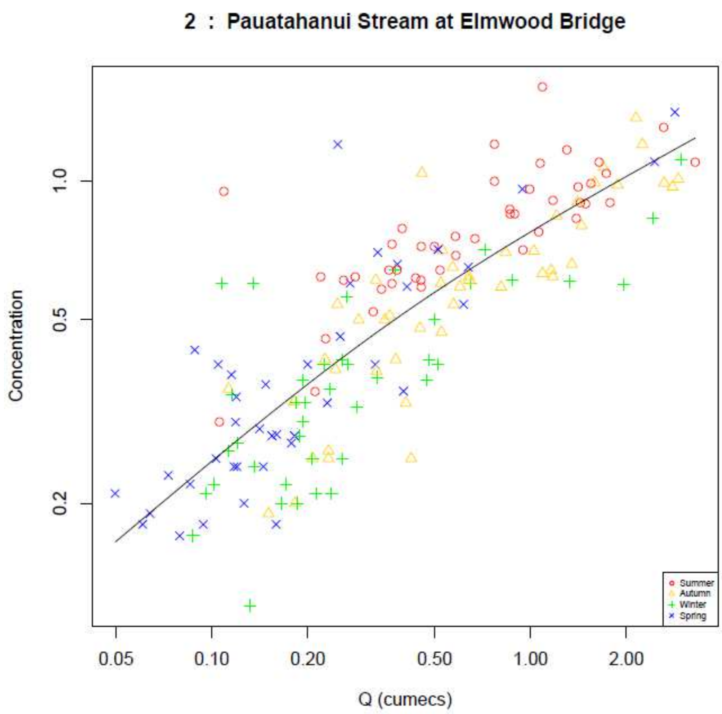
Appendix A Flow Rating Curves or load calculation

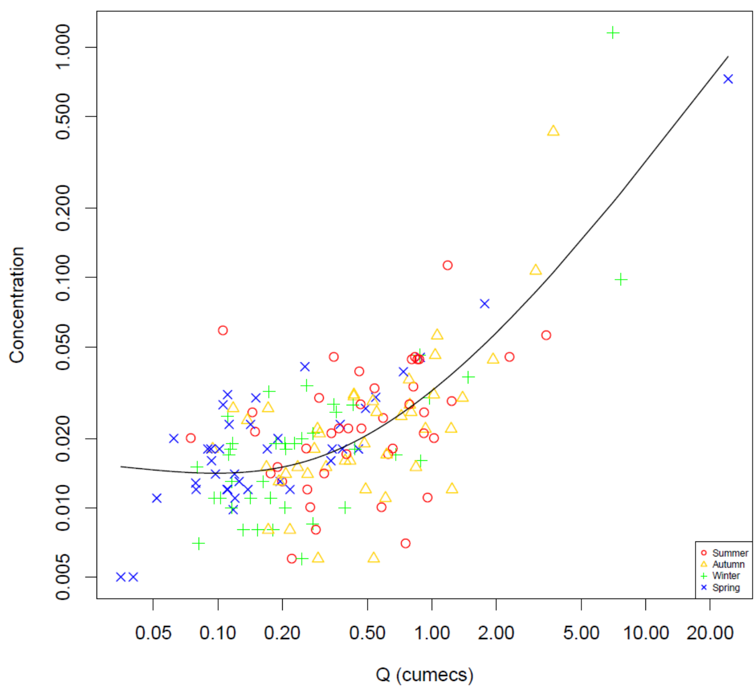
TN



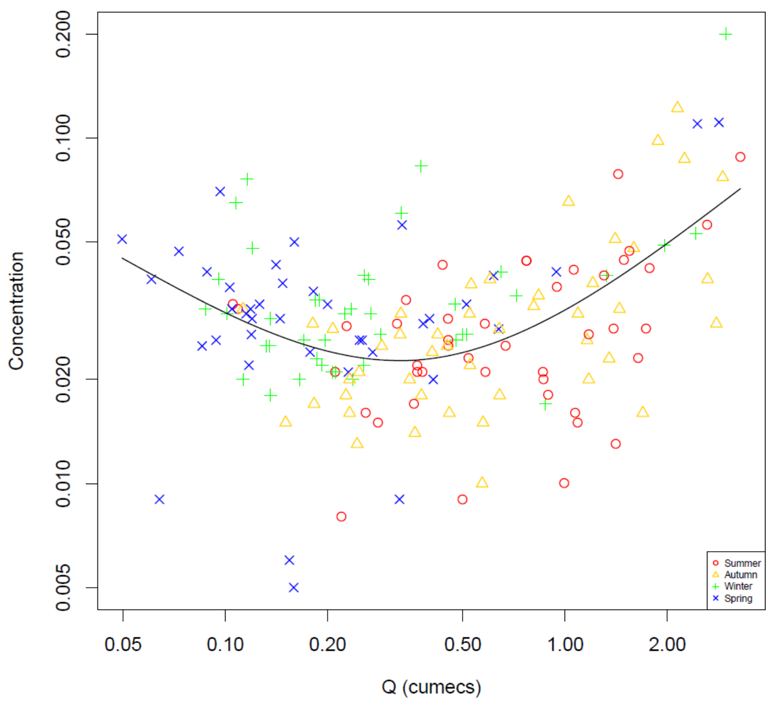


TP

1 : Horokiri Stream at Snodgrass

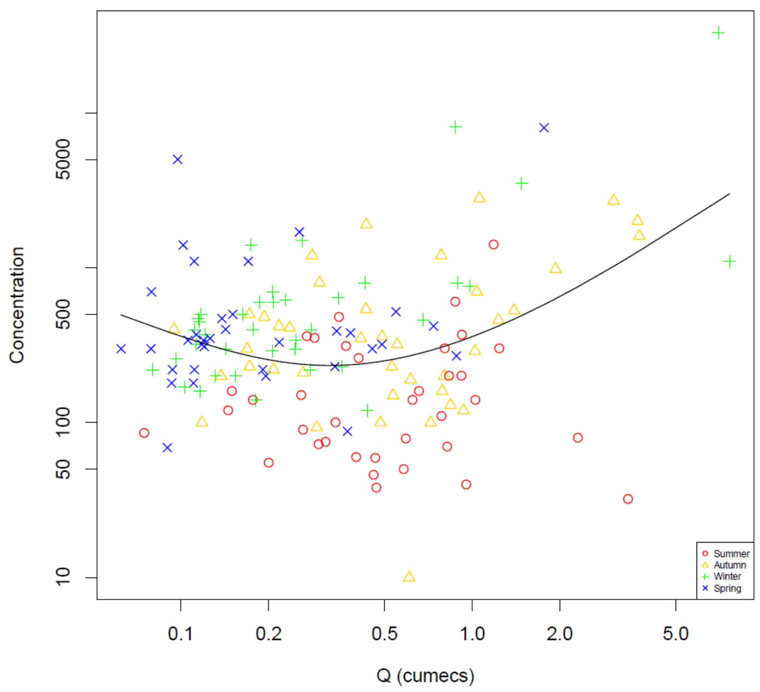


2 : Pauatahanui Stream at Elmwood Bridge

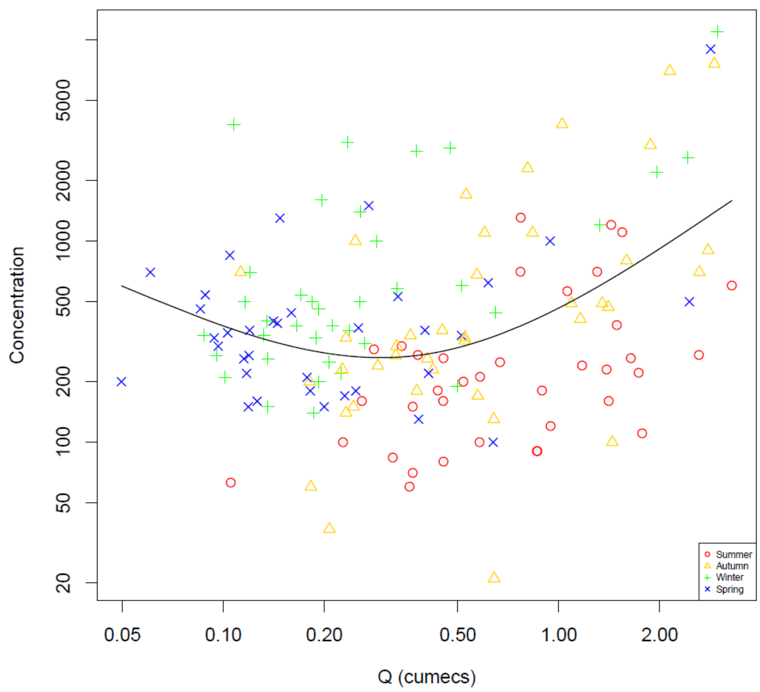


E. coli

1 : Horokiri Stream at Snodgrass



2 : Pauatahanui Stream at Elmwood Bridge



Appendix B Instream loads for all sites

Table B-1: Instream loads estimated by CLUES for all GWRC reporting sites. Loads are provided for all diffuse sources and for rural land uses only. Background TP loads from soil erosion are also provided The percentage of the total load from rural sources is indicated. Estimates relate to the downstream confluence of each reach. Rural sites are shaded.

ID number	Name	REC2 reach	TN (kg / y)			TP (kg / y)				Sediment (t/y)			*E. coli* (10^{10} organisms / y)		
			Total	Rural	% rural	Total	Background	Rural	% rural	Total	Rural	% rural	Total	Rural	% rural
1	Belmont	9262562	3345	1628	49%	570	54	463	81%	749	282	38%	177740	51779	29%
2	Stebbings	9262155	1269	1197	94%	374	42	330	88%	335	327	98%	56430	50551	90%
3	Porirua B	9262515	4891	1628	33%	622	57	464	75%	926	282	30%	264070	46968	18%
4	Porirua A	9262562	3345	1628	49%	570	54	463	81%	749	282	38%	177740	51779	29%
5	Porirua C	9262013	9975	4055	41%	1510	196	1132	75%	2174	989	45%	466170	110910	24%
6	Porirua D	9261915	14720	7966	54%	2983	377	2399	80%	3619	2298	63%	630760	224076	36%
7	Takapu B	9261896	569	244	43%	59	13	36	61%	182	78	42%	32300	4552	14%
8	Mitchell	9260915	23601	10623	45%	3710	526	2790	75%	4910	2848	58%	1076190	275327	26%
9	Porirua F	9260915	23601	10623	45%	3710	526	2790	75%	4910	2848	58%	1076190	275327	26%
10	Kenepuru A	9260508	3479	727	21%	255	46	128	50%	331	140	42%	119440	15725	13%
11	Kenepuru B	9260669	8916	2141	24%	1018	146	672	66%	1185	726	61%	338820	55795	16%
12	Porirua H	9260544	34000	13111	39%	4846	697	3521	73%	6195	3623	58%	1473470	325053	22%
13	Mahinawa Stream	9260370	1282	1004	78%	187	50	129	69%	500	473	95%	35580	18512	52%
14	Onepoto Fringe E	9260383	702	142	20%	30	5	9	30%	49	9	19%	27370	40	0%
15	Onepoto Fringe C	9260397	401	0	0%	19	7	0	0%	32	-1	-4%	34340	0	0%
16	Hukatai Stream	9260124	569	247	43%	48	10	29	60%	37	17	46%	20530	2919	14%
17	Onepoto Fringe B	9260256	704	0	0%	30	9	0	0%	65	-2	-3%	53970	0	0%
18	Onepoto Fringe F	9259774	1118	39	4%	38	3	4	11%	24	2	9%	65350	2184	3%
19	Onepoto Fringe A	9260073	619	0	0%	20	2	0	0%	30	0	-1%	48830	0	0%
20	Whitireia A	9259616	612	298	49%	71	19	43	61%	48	24	50%	20520	4439	22%
21	Onepoto Fringe D	9260536	1006	355	35%	59	17	23	39%	202	77	38%	48600	730	2%
22	Pauatahanui Fringe A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	Pauatahanui Fringe B	9259404	335	177	53%	26	8	13	50%	15	9	59%	22050	7592	34%
24	Pauatahanui Fringe C	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	Kakaho	9259174	7117	7117	100%	2346	273	2073	88%	2690	2690	100%	299310	299294	100%
26	Horokiri and Motukaraka D	9259475	254	254	100%	80	9	71	89%	34	34	100%	13970	13962	100%
27	Horokiri and Motukaraka C	9259581	17850	17850	100%	4433	777	3656	82%	7044	7044	100%	443690	443690	100%
28	Ration	9259625	3317	3317	100%	596	111	485	81%	492	492	100%	96130	96130	100%
29	Pauatahanui F	9259837	509	471	93%	25	6	18	72%	25	25	100%	9620	7765	81%
30	Pauatahanui E	9259849	20774	19886	96%	4453	468	3959	89%	6923	6888	99%	451130	405135	90%
31	Lower Duck Creek B	9259898	5563	3413	61%	1368	158	1142	83%	3093	2915	94%	166980	73308	44%
32	Pauatahanui Fringe D	9259893	1061	1	0%	35	3	1	3%	70	0	0%	48610	0	0%

			TN (kg / y)			TP (kg / y)				Sediment (t/y)			*E. coli* (10^{10} organisms / y)		
ID number	**Name**	**REC2 reach**	**Total**	**Rural**	**% rural**	**Total**	**Background**	**Rural**	**% rural**	**Total**	**Rural**	**% rural**	**Total**	**Rural**	**% rural**
33	Lower Duck Creek A	9260132	3458	3048	88%	1276	138	1126	88%	2999	2962	99%	88050	71356	81%
34	Pauatahanui D	9260167	18235	18235	100%	4283	429	3854	90%	6781	6781	100%	373200	373200	100%
35	Pauatahanui C	9260167	18235	18235	100%	4283	429	3854	90%	6781	6781	100%	373200	373200	100%
36	Pauatahanui B	9260297	4029	4029	100%	897	98	799	89%	1438	1438	100%	90860	90860	100%
37	Horokiri and Motukaraka B	9259111	15224	15224	100%	3850	712	3138	82%	6638	6638	100%	383630	383630	100%
38	Horokiri and Motukaraka A	9258896	13216	13216	100%	3486	675	2811	81%	6220	6220	100%	303220	303220	100%
39	Taupo Swamp A	9259104	5045	4664	92%	992	99	882	89%	905	884	98%	136540	119780	88%
40	Taupo Swamp B	9259279	7391	6509	88%	1301	146	1130	87%	1177	1131	96%	229780	183936	80%
41	Taupo Swamp C	9259279	7391	6509	88%	1301	146	1130	87%	1177	1131	96%	229780	183936	80%
42	Upper Kenepuru	9260727	1722	1183	69%	567	57	494	87%	594	553	93%	87180	52442	60%
43	Upper Duck Creek	9260132	3458	3048	88%	1276	138	1126	88%	2999	2962	99%	88050	71356	81%
44	Titahi A	9259883	243	1	0%	8	1	0	0%	6	0	6%	23530	1	0%
45	Hongoeka to Pukerua C	9258915	509	234	46%	46	15	23	50%	46	26	56%	24400	2528	10%
46	Hongoeka to Pukerua B	9258800	664	457	69%	107	16	85	79%	122	103	84%	22710	9408	41%
47	Porirua E	9261009	21121	9440	45%	3404	463	2585	76%	4412	2508	57%	989150	256053	26%
48	Titahi B	9259956	295	266	90%	88	11	76	86%	82	77	94%	14520	12030	83%
49	Whitireia B	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	Hongoeka to Pukerua A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	Porirua G	9260668	24917	10968	44%	3822	550	2849	75%	4999	2897	58%	1140370	281722	25%
52	Pauatahanui A	9260339	2704	2704	100%	644	71	573	89%	1106	1106	100%	65950	65950	100%
53	Rangituhi	9261062	406	406	100%	84	18	66	79%	119	119	100%	5260	5260	100%
54	Takapu A	9261896	569	244	43%	59	13	36	61%	182	78	42%	32300	4552	14%
55	Moonshine	9260261	5534	5534	100%	1512	156	1356	90%	3033	3033	100%	118080	118080	100%