Te Awarua-o-Porirua Collaborative Modelling Project

Customisation of urban contaminant load model and estimation of contaminant loads from sources excluded from the core models

Prepared for Greater Wellington Regional Council

March 2017

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NIWA CLIENT REPORT No: 2017050AK
Report date: March 2017
NIWA Project: WRC17103

Quality Assurance Statement		
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Executive summary

This report describes the results of analyses to deliver on task A of the Te Awarua-o-Porirua Collaborative Modelling Project (CMP) work brief 1 (modelling catchment diffuse contaminant loads). There were two components of this task: firstly, the customisation and addition of certain contaminant yields for use by the urban contaminant load model (CLM) employed in the project; and, secondly, the estimation of loads of diffuse contaminants from sources excluded from the core catchment models used in the project.

Customisation of CLM yields

Default yields of total suspended solids (TSS), zinc (Zn) and copper (Cu) used by the CLM are derived from a range of Auckland-based studies. Customisation aimed to take account of existing data from the Porirua whaitua, Wellington region and national datasets to improve the reliability of the models for supporting the Whaitua Committee's decisions. The results of customisation include the following:

- The proposed Zn yields for roads carrying in excess of 5000 vehicles per day, derived from comparison with the results of the NZTA's Road Stormwater Screening model, are higher than the CLM's default yields;
- The proposed Cu yields for all roads, derived from an assessment of the Zn:Cu ratio in road runoff samples from across New Zealand, are lower than the CLM's default yields;
- The proposed TSS yields for urban grassland and trees and construction sites, derived from modelling using the Revised Universal Soil Loss Equation (RUSLE), are generally higher than the CLM's default yields; and
- The proposed Zn and Cu yields for urban grassland and trees and construction sites, derived from assessment of soils data from the whaitua and wider Wellington region, are higher than the CLM's default yields.

In addition to TSS and metals, the CLM will also be used to model urban-derived diffuse loads of total phosphorus (TP), total nitrogen (TN) and *E. coli*. Because the CLM does not contain default yields of TP, TN and *E. coli*, yields of these contaminants have been developed for all land cover classes. A number of methods were investigated for developing these yields, with the proposed yields derived according to the following approaches:

- The proposed yields for TP are generally calculated from TSS yields, because of a relatively strong regression relationship between these two parameters in stormwater;
- In contrast, the proposed yields for TN and *E. coli* are generally based on analysis of a national water quality data set supplemented with recent data from Kapiti Coast, because of the agreement between these data and international data sources;
- The proposed TN and TP yields for construction sites are based on analyses of the proportion of TN and TP in urban greywacke soils.

All of the yields developed here are subject to various sources of uncertainty and there may be value in considering their further revision as part of model implementation and sensitivity testing. Such testing will form part of the implementation of the CLM and its use to model the "business as usual"

(BAU) land cover and stormwater management characteristics for the whaitua, the details of which have yet to be specified.

Estimation of contaminant loads from sources excluded from core models

Contaminant loads have been estimated from the following sources excluded from the core Te Awarua-o-Porirua models:

- TSS, Zn, and Cu loads from roads outside urban limits;
- TN and TP loads during the earthworks phase of the Transmission Gully (TG) motorway project; and
- TN, TP and *E. coli* loads from roads within the TG corridor during the operational phase of the motorway.

These loads have been estimated at the REC sub-catchment scale to allow aggregation with loads estimated by the core models. Also excluded from the core whaitua models are loads of Cu and Zn from pervious land covers outside the urban limits. These loads are to be delivered later, as they will be derived from estimates of sediment loads produced during modelling to be conducted once the BAU characteristics are confirmed.

1 Introduction

1.1 Scope

This report describes the results of analyses conducted by NIWA and Jacobs to deliver on task A of the Te Awarua-o-Porirua Collaborative Modelling Project (CMP) work brief 1 (modelling catchment diffuse contaminant loads). There were two components of this task, the first of which had two further sub-components:

1. To customise and add certain contaminant yields to the urban contaminant load model (CLM) used in the project, involving:

   - customising certain default yields of sediment (or total suspended solids: TSS), copper (Cu) and zinc (Zn); and

   - developing yields for total nitrogen (TN), total phosphorus (TP) and *E. coli* for which the CLM does not contain default yields; and

2. Estimating loads of diffuse contaminants from sources excluded from the core catchment models used in the project.

A set of figures provided in Appendix A show how these tasks feature in the overall delivery of work brief 1.

1.2 Background

1.2.1 Customisation of the CLM

The CLM was developed by Auckland Regional Council from the results of a range of monitoring studies conducted in the Auckland region (ARC, 2010). While the model has been employed in a range of studies located elsewhere in New Zealand, its developers explicitly caution its transfer to locations outside of Auckland without giving consideration to potential differences in contaminant yields. In particular, the developers of the CLM noted that TSS yields may differ as a reflection of regional differences in soils and rainfall (ARC, 2010). While yields for the generation of chemical contaminants were considered to be more transferable between urban areas, the model's developers recommended taking account of local data where available.

The Te Awarua-o-Porirua Whaitua Committee has indicated a strong interest in the use of relevant local information to guide the work of the CMP and the project has adopted the guiding principle to:

> *"Customise models based on catchment-specific information, in order to best manage uncertainty and maximise the reliability of the models for supporting the Whaitua Committee's decisions."*

Reflecting this principle and the recommendations of the CLM's developers, the CMP's Modelling Leadership Group (MLG) determined that the CLM should be subject to appropriate customisation prior to its use for modelling contaminant loads from urban areas of the Porirua whaitua.

A second limitation of the adoption of the CLM for use in the Porirua CMP is that, as it stands, the model does not provide a basis for the estimation of diffuse-source loads of TN, TP and *E. coli* generated in urban areas. These loads are required in order for the project to arrive at estimates of total (rural + urban + point source) loads and concentrations of these contaminants within the stream network and delivered to the harbour. The MLG therefore also determined that analyses of relevant local and complementary sources of data should be conducted to develop urban yields of TN, TP and *E. coli* so that the CLM can be used to model urban diffuse-source loads of these contaminants.

1.2.2 Estimation of loads excluded from core models

The CMP is using the following models to estimate loads of diffuse contaminants generated in the Porirua whaitua:

- CLM to model loads of TSS, Cu, Zn, TN, TP and *E. coli* from urban areas;
- CLUES and Daily SedNet to model loads of TSS, TN, TP and *E. coli* from rural areas; and
- The results of previous Transmission Gully Motorway (TGM) modelling for loads of TSS during the earthworks phase of TGM and loads of TSS, Cu and Zn during the operational phase.

While this combination of models ensures that the (anticipated) principle sources of contaminants are estimated, other sources are not accounted for. These include: rural roads as a source of all contaminants, TGM as a source of TN, TP and *E. coli*; and rural soils as a source of Cu and Zn. While it is expected that these sources generate only a minor proportion of total catchment loads, the MLG determined that contaminant loads from these sources should be estimated in order to provide as complete a picture of loads from all sources as possible. In the event that these loads are indeed a relatively minor proportion of the catchment total (<1%), then the MLG has suggested that they be held constant in modelling future development scenarios.

1.3 Contents of this Report

Sections 2 (TSS, Cu and Zn) and 3 (TN, TP and *E. coli*) of this report describe the customisation of the CLM to prepare it for implementation for estimating loads of urban-derived diffuse contaminants in the Porirua whaitua. Review comments on the methods and results of customisation were received from Morphum Environmental in memos dated 18 January 2017 and 28 February 2017. Where we have considered it appropriate, this report takes account of recommendations made in those review documents[1].

We recognise that the yields developed here may be subject to further revision. That is because the implications of adopting these yields has not yet fully been tested. Such testing forms part of the implementation of the CLM and its use to model the “business as usual” (BAU) land cover and stormwater management characteristics, the details of which have yet to be specified. In particular, until the model is run it is not possible to fully assess:

- the sensitivity of catchment contaminant load estimates to some of the more uncertain yields; and
- the extent to which estimated loads of contaminants not previously included in the CLM (TN, TP and *E. coli*) are consistent with observed and expected relationships between variations in urban land uses and stormwater quality.

Further comments are made in relevant parts of Sections 2 and 3 of the report on ways in which the planned implementation and use of the CLM may involve further revision of the yields. Section 4 of

[1] Our response to points raised by the reviewers is provided in an annotated copy of Morphum’s memo of 28 February.

the report describes the estimation of loads of diffuse contaminants from sources excluded from the core catchment models used in the project.

2 Customisation of TSS, Cu and Zn Yields

2.1 Default yields

Table 2-1 presents the default TSS, Cu and Zn yields used in the CLM. The yields that we have investigated for replacement with custom values are highlighted in yellow. The following sections describe the analyses conducted to develop the custom yields and the rationale for not customising other yields.

2.2 Roofs

We have not investigated customising the yields relating to roofs. The CLM's roof yields were derived from measured contaminant concentrations in samples of runoff collected from each type of roofing material (Kingett Mitchell and Diffuse Sources, 2003), assuming mean annual runoff of 1000 mm (ARC, 2010). We are not aware of any data from the Wellington region on contaminant concentrations in roof runoff to compare with the Auckland data, nor is there a compelling reason why concentrations might differ markedly. The mean annual rainfall totals at two GWRC rain gauges located in the urban areas of the Porirua Harbour catchment are 1065mm (Tawa Pool) and 1145mm (Seton Nossiter Park), respectively, indicating that the mean annual roof runoff depth of 1000mm used to develop the CLM yields can be considered representative of the approximate average annual roof runoff in the catchment (allowing for the fact that not all rainfall generates runoff). Accordingly, we have not made any concentration-based or runoff volume-based adjustment to the yields of TSS, Cu and Zn associated with roofs.

In their review of our proposed methods, Morphum Environmental recommended comparing the data used in developing the CLM default yields with data from other New Zealand and international studies. We have relied on two comparisons conducted by others to respond to this recommendation. Firstly, to a limited extent, the developers of the CLM undertook comparison with literature data and found that the concentrations of TSS, Zn and Cu in New Zealand roof runoff were low compared with overseas (ARC, 2010). They attributed this to differences in roofing materials and rainfall acidity.

Assessments of the contribution of roofs to catchment stormwater contaminant loads tend to focus on zinc and, specifically, the role of high-yielding galvanised steel roofs. That is because roofs tend to be a relatively minor source of TSS and copper but the major source of zinc in urban catchments. For example, in a study informing the development of the Proposed Auckland Unitary Plan (PAUP), roof derived TSS, Cu and Zn loads were estimated to be 1.7%, 3.1% and 50.9% of the catchment total under the existing land use, respectively (Moores, 2015). Accordingly, the reliability of zinc yields in the CLM has received more scrutiny than the other contaminants. In evidence presented at hearings on the PAUP, New Zealand Steel commented on the extent of variation in measurements of zinc in roof runoff in Auckland and overseas, noting that such variation is to be expected because of differences in corrosivity and weathering[2]. In that evidence, NZ Steel reached the conclusion that "CLM zinc loads for the various steel roofing products are appropriate, because they reflect the practical utilisation of these products in the Auckland Region[3]."

[2] Proposed Auckland Unitary Plan Independent Hearings Panel, Topic 49 – Discharges, Stormwater and Wastewater. Primary Statement of Evidence of Bryan Shedden on Behalf of New Zealand Steel Limited, 21 July 2015, Section 33.1.

[3] Proposed Auckland Unitary Plan Independent Hearings Panel, Topic 49 – Discharges, Stormwater and Wastewater. Primary Statement of Evidence of Bryan Shedden on Behalf of New Zealand Steel Limited, 21 July 2015, Section 33.2.

Table 2-1: CLM default yields of TSS, Cu and Zn (ARC, 2010). Yields investigated for customisation are highlighted in yellow, while the CLM will not be used to model loads from the source types highlighted in red.

Source	Source Type	Yields ($g/m^2/a$)		
		TSS	Zinc	Copper
Roofs	Galvanised steel unpainted	5	2.24	0.0003
	Galvanised steel poorly painted	5	1.34	0.0003
	Galvanised steel well painted	5	0.2	0.0003
	Galvanised steel coated(Decramastic)	12	0.28	0.0017
	Zinc/aluminium unpainted (Zincalume)	5	0.2	0.0009
	Zinc/aluminium coated (Colorsteel/Colorcote)	5	0.02	0.0016
	Concrete	16	0.02	0.0033
	Copper	5	0	2.12
	Other materials	10	0.02	0.002
Roads (vpd)	<1000	21	0.0044	0.00148
	1000-5000	28	0.0266	0.00887
	5000-20000	53	0.1108	0.03695
	20000-50000	96	0.2574	0.08579
	50000-100000	158	0.4711	0.15703
	>100000	234	0.7294	0.24314
Paved surfaces other than roads	Residential	32	0.195	0.036
	Industrial	22	0.59	0.107
	Commercial	32	0	0.0294
Urban grasslands and trees	Slope < 5	45	0.0016	0.0003
	5 < Slope < 10	92	0.0032	0.0006
	Slope > 10	185	0.0065	0.0013
Urban stream channel	length x width	6000	0.021	0.042
Construction site open for 12 months/year	Slope < 5	2500	0.088	0.018
	5 < Slope < 10	5600	0.196	0.039
	Slope > 10	10600	0.371	0.074
Exotic production forest	Slope < 10	35	0.0012	0.0002
	10 < Slope < 20	104	0.0036	0.0007
	Slope > 200	208	0.0073	0.0015
Stable forest	Slope < 10	14	0.0005	0.0001
	10 < Slope < 20	42	0.0015	0.0003
	Slope > 200	83	0.0029	0.0006
Farmed pasture	Slope < 10	152	0.0053	0.0011
	10 < Slope < 20	456	0.016	0.0032
	Slope > 200	923	0.032	0.0065
Retired pasture	Slope < 10	21	0.0007	0.0001
	10 < Slope < 20	63	0.0022	0.0004
	Slope > 200	125	0.0044	0.0009
Horticulture	Volcanic soil	50	0.0018	0.0004
	Sedimentary soil	100	0.0035	0.0007
	Unknown soil type	100	0.0035	0.0007

While the comments made by the CLM developers and the NZ Steel witness do not confirm that Auckland-derived yields are necessarily appropriate for Wellington, they do indicate that any adjustment of the CLM default yields would need to be based on an understanding of differences in weathering processes between Auckland and Wellington. In the event that roof source control of zinc is contemplated as a stormwater mitigation practice in the Whaitua process, it may be worth undertaking some local roof runoff sampling of different roof materials at various stages of weathering to inform assessment of the efficacy of such an intervention.

2.3 Roads

2.3.1 Background

The CLM yields for roads were largely derived from road runoff sampling conducted at a single location: Richardson Road in Auckland (ARC, 2010). The data from that study was used to estimate vehicle emission factors of TSS and Zn which were in turn used to estimate road yields (mass from a unit area) of these contaminants, as a function of vehicle numbers and representative road widths. Yields of copper were estimated from the Zn yields, based on a Zn:Cu ratio of 3:1 that was considered to be representative of untreated road runoff (ARC, 2010).

In a more recent study commissioned by the NZTA, vehicle emissions factors derived from a number of additional NZ road runoff sampling studies were used to estimate road-derived loads of Cu and Zn in the Porirua Harbour catchment as part of a case study evaluation of the Road Stormwater Screening (RSS) model (Gardiner et al., 2016). These estimates are influenced by traffic flow characteristics (with congested roads having higher emission rates of Zn and Cu than free-flowing roads) and are independent of road width. They provide an alternative, potentially more reliable estimate of the road derived loads of Cu and Zn than CLM estimates, as the CLM does not take account of variation in traffic flow. In addition, differences between the assumed representative road widths underlying the CLM's calculations and actual widths in the Porirua Harbour catchment might also be contributing to uncertainty in the CLM estimates.

2.3.2 Methods

We compared road-derived loads of zinc and copper at the REC[4] sub-catchment scale, estimated by the following methods:

(1) CLM, using default yields and road areas estimated using CLM default road widths;

(2) CLM, using default yields and custom-derived road areas developed by Jacobs[5];

(3) RSS model, prior to attenuation by treatment devices and the drainage network; and

(4) RSS model, following attenuation by treatment devices and the drainage network.

As expected, the loads calculated for data set (4) were markedly lower than for data sets (1) to (3), because none of these first three methods factor in any stormwater treatment. The comparison therefore focused on data sets (1) to (3).

Differences in relationships between CLM and RSS loads were investigated in sub-catchments containing solely local roads (largely 1000 vpd and 1000-5000 vpd classes), solely state highways (5000-20,000 vpd and >20,000 vpd classes) and a mix of both local roads and state highways.

[4] River Environment Classification system: https://www.niwa.co.nz/freshwater-and-estuaries/management-tools/river-environment-classification-0

[5] These road areas were calculated by buffering the following distances either side of the road centreline: 3m for one lane roads and lanes, 6m for two lane roads and 10m for the motorway. Checks against aerial photos were carried out, with minor edits undertaken, e.g. to remove walkways and paper roads. Unsealed roads and pedestrian access ways were not included.

Differences between the loads estimated by the different methods were further investigated at the scale of individual roads. This involved:

- Changing road widths in the CLM road classes <1000 vpd and 1000-5000 vpd to investigate the influence of reduced road widths on load estimates; and
- Changing the Zn:Cu ratio to investigate the influence of lower copper yields on load estimates.

2.3.3 Results and Discussion

Table 2-2 shows the ratios between the total loads (all relevant sub-catchments combined) of zinc and copper estimated by the CLM with default road widths, the CLM with Jacobs' custom-derived road areas and the RSS model.

Table 2-2: Ratios between loads of zinc and copper estimated by CLM with default road widths, Jacobs CLM and RSS model (with RSS loads equal to 1). Bold table entries are discussed in the text.

	CLM default : RSS		Jacobs CLM : RSS	
	Zn	Cu	Zn	Cu
All sub-catchments	1.12	2.38	0.86	1.83
Sub-catchments with local roads only	1.70	3.40	**1.00**	2.03
Sub-catchments with state highways only	0.94	2.05	**0.85**	1.86

Zinc

Overall, zinc loads estimated using the CLM with default road widths are higher than the RSS model estimates (by 12%) while loads estimated by Jacobs using customised road areas are lower than the RSS model estimates (by 14%). The influence of road width is most noticeable on local roads, in the <1000 vpd and 1000-5000 vpd categories. For these roads, the CLM estimates of total Zn loads using default road widths are 70% higher than the RSS model estimates. In contrast, Jacobs' customised CLM estimates of total Zn loads match the results from the RSS model (highlighted ratio of 1.00 in Table 2-2). The further analysis conducted at the scale of individual roads confirmed that reducing the CLM's default road widths for these categories of roads (from the default of 17m to illustrative widths of 7m and 10m for <1000 vpd and 1000-5000 vpd categories, respectively) markedly reduced the loads estimated using the CLM. Based on the agreement between the RSS model results and Jacobs CLM, no adjustment is considered necessary to the CLM's Zn yields for roads in the <1000vpd and 1000-5000vpd classes. This is because Jacob's method for estimating road areas has dealt with the potential overestimation of Zn loads from these roads.

In the case of state highways (road classes 5000-20,000 vpd and >20,000 vpd), the zinc loads estimated using the CLM default road widths and Jacobs' road widths are both lower than RSS model estimates, by 6% and 15%, respectively. Unlike the case for local roads, CLM road widths do not appear to be a source of over-estimation of loads in these road classes.

The further analysis conducted at the scale of individual roads suggests that the higher RSS model estimates arise because many parts of the state highways are classified in that model as being subject to congested traffic flows. In the RSS model, metal loads are estimated from vehicle emission factors (VEFs in units of mg/veh/km) that are higher on congested roads than on roads with interrupted or free flowing traffic. The CLM makes no such distinction. The reason that the default CLM estimates for state highways are, overall, more similar to the RSS model estimates than the

Jacobs CLM estimates probably reflects Jacobs adopting a slightly narrower road width for these road classes than the CLM default. However, because it is the CLM with Jacobs' road areas that will be implemented and used in this project, it is the difference between the Jacobs CLM loads and RSS loads that are relevant in customising the yields. Based on the results presented in Table 2-2, we have therefore proposed to multiply the Zn yield for roads in classes 5000-2000 vpd and above by a factor of 1.17 (the inverse of 0.85) to account for the congested nature of these roads that is not taken into account in the CLM default yields.

Copper

All the estimates of copper loads produced by the CLM (both default and Jacobs' road widths) are markedly higher than the RSS model estimates. This is because the default copper yields in the CLM were estimated by adopting a Zn:Cu ratio of 3:1 (ARC, 2010). The RSS model adopts VEFs which have a Zn:Cu ratio closer to 6:1, based on the results of additional sampling completed subsequently to that on which the CLM yields are based (Moores et al., 2010). Thus, any difference between CLM and RSS model estimates for zinc are doubled for copper. Further analysis conducted at the scale of individual roads confirmed that increasing the default Zn:Cu ratio in the CLM to 6:1 results in closer agreement between RSS and CLM estimates.

The Urban Runoff Quality Information System (URQIS)[6] holds the results of analyses of 569 samples of untreated road runoff from New Zealand studies. The zinc to copper ratios in these samples are 5.2:1 and 4.8:1, based on mean and median concentrations, respectively. This analysis supports adopting a 5:1 Zn:Cu ratio for customising Cu yields in the CLM, rather than the slightly higher 6:1 used in the RSS (and which is based on a smaller data set). We therefore propose to adopt Cu yields based on multiplication of the customised Zn yield for each road class by 0.2.

TSS

The RSS model does not estimate TSS loads so does not provide a basis for independently evaluating the loads of road-derived TSS estimated using the CLM default yields. In our proposal for this customisation exercise, we considered adjusting the TSS yields in proportion to any adjustments developed for zinc and/or copper. The rationale for such an approach was based on the fact that road runoff sampling has found Cu and Zn to be predominantly in the particulate forms (e.g. Moores et al., 2010), such that a change in metal Zn yields could also be applied to TSS yields. This would preserve the sediment to metal ratio at a level consistent with the underlying measurements used to develop the CLM yields.

On further consideration, we propose to make no adjustment to the default TSS yields for roads. The principal reason for this is that, in previous modelling studies, roads have been found to be a relatively minor source of sediments. In an application of the CLM in an entirely urban catchment in west Auckland, road derived TSS was only 2-4% of the catchment total, varying by model scenario (Moores, 2015). Where rural sediment sources are also present, road-derived sediment can be expected to be an even less significant contribution to the catchment total. In the Porirua whaitua, road-derived TSS may well be less than 1% of the catchment total. In view of this, making adjustments to road-derived TSS yields can be viewed as an exercise in spurious accuracy that will have virtually no bearing on modelling results. Sensitivity testing can be undertaken to confirm this.

[6] http://urqis.niwa.co.nz/

2.3.4 Summary

Table 2-3 gives the proposed set of yields of road-derived TSS, zinc and copper for use in implementation of the CLM in the Porirua whaitua. Increases of 17% are proposed for the zinc yields in road classes 5000-20000 vpd and above, reflecting the factoring in of congestion effects on metal emissions from vehicles. Decreases of 40% and 30% are proposed for the copper yields of road classes up to 5000 vpd and greater than 5000 vpd, respectively. This reduction reflects the calculation of copper yields from the customised zinc yields according to a 5:1 zinc to copper ratio. Zinc yields for low-trafficked roads and all TSS yields remain as per the CLM defaults.

Table 2-3: Default and customised CLM yields for estimating loads of TSS, zinc and copper from roads. Percentage difference from default yields shown in brackets.

Road vpd class	Default yields ($g/m^2/a$)			Custom yields ($g/m^2/a$)		
	TSS	Zn	Cu	TSS	Zn	Cu
<1000	21	0.0044	0.00148	21 (0%)	0.0044 (0%)	0.00088 (-40%)
1000-5000	28	0.0266	0.00887	28 (0%)	0.0266 (0%)	0.00532 (-40%)
5000-20000	53	0.1108	0.03695	53 (0%)	0.1296 (+17%)	0.02593 (-30%)
20000-50000	96	0.2574	0.08579	96 (0%)	0.3012 (+17%)	0.06023 (-30%)
50000-100000	158	0.4711	0.15703	158 (0%)	0.5512 (+17%)	0.11024 (-30%)
>100000	234	0.7294	0.24314	234 (0%)	0.8534 (+17%)	0.17068 (-30%)

2.4 Other paved surfaces

Unlike the yields for roofs and roads, the CLM yields for residential, commercial and industrial paved surfaces were not derived from direct sampling of stormwater discharged from these surfaces. Instead, these yields were estimated as part of the calibration of the CLM: the results of sampling at catchment outlets were used to estimate total catchment loads and the contribution from paved surfaces was then estimated as the difference between the total loads and the loads estimated from roofs and roads (ARC, 2010). While they appear in the CLM as yields for paved surfaces, loads calculated from these yields are in reality the loads from paved surfaces plus all other unaccounted-for contaminant sources contributing to the total load at the catchment outlet and/or compensating for errors in the yields of other contaminant sources.

The true yields for paved surfaces alone are therefore uncertain and, were suitable local data available, we would attempt customisation of these yields. Ideally, this would involve estimating yields from the results of targeted sampling of runoff from paved surfaces. We are not aware of any such data. A second approach would be to use the results of sampling at the outlets of residential, commercial and industrial sub-catchments to estimate loads from these sub-catchments and then, following the method used to develop the CLM yields, estimate paved surface yields from the difference between the catchment loads and the loads of all other sources. Although concentrations of TSS, Cu and Zn have been measured in samples collected at locations in the Porirua Harbour catchment (e.g. Milne and Watts 2008), these sites are downstream of areas of mixed land use, rather than representative residential, commercial and industrial areas. There are also insufficient data to attempt to calculate loads other than for the Porirua Stream catchment.

Since there is no obvious basis for estimating locally-specific paved surface yields that provides a better level of certainty than the CLM default yields, we have not investigated customisation of these yields.

However, we do propose one adjustment to these yields and, as part of implementing the CLM, will also investigate the influence of uncertainty in these yields on catchment contaminant loads. The adjustment involves revising the Zn yield for commercial paved surfaces. The default value is zero, which presumably means that the total catchment Zn load in the CLM's commercial catchment was fully accounted for by the estimated loads from roofs and roads. In reality, the Zn yield from paved surfaces is unlikely to be zero. The Zn yields for residential and industrial paved surfaces are approximately 5.5 times the equivalent copper yields (see Table 2-1). On this basis, we consider it appropriate to use a commercial paved surfaces Zn yield of 0.162, being 5.5 times the equivalent copper yield.

In support of this adjustment, we have analysed the limited data on runoff quality from commercial paved areas (car parks) held in the URQIS database (131 samples for zinc and 130 for copper). The zinc to copper ratios in these samples are 6.2:1 and 6.8:1, based on mean and median concentrations, respectively. While slightly higher than the Zn:Cu ratio evident on in the CLM paved yields, these data provide support for adopting the commercial paved yield that is proposed above.

To investigate the influence of uncertainty in these yields on catchment contaminant loads we will undertake sensitivity testing as part of implementing the CLM. This will involve varying the paved yields in the range (say) ±50% of the default CLM yields to examine the extent of the resultant variation in the estimates of the total catchment loads.

Furthermore, there will be a feedback loop between the catchment modelling undertaken to deliver on work brief 8 and the average annual CLM loads developed under work brief 1. In work brief 8, modelling the event mean concentrations for Zn and Cu will be informed by wet weather stormwater outfall sampling undertaken in Kapiti over a ten year period between 2006 and 2016. The catchment model developed for work brief 8 will calculate sub-catchment loads (for comparison with the CLM's predictions at the REC sub-catchment scale. It is expected that a calibration factor (representing uptake etc.) will be required between the predicted in-stream loads and catchment loads, however the catchment load may also be adjusted where the measured data indicates that such an adjustment is warranted.

2.5 Urban grassland and trees and construction sites

2.5.1 TSS

Background

The CLM's TSS yields for urban grassland and trees were also derived as part of the calibration of the model and are also recognised to be somewhat uncertain (ARC, 2010). The TSS yields for construction sites were estimated from the results of running the GLEAMS hillslope sediment generation model for catchments in the Auckland region. Differences in soil type between the Auckland catchments represented in the CLM default yields and the Porirua whaitua have the potential to have a marked influence on these yields. Accordingly, we have investigated customisation of the TSS yields for urban grassland and trees and construction sites to better reflect the characteristics of soils found in the whaitua.

Method

For separate tasks (work briefs 1B and 8), Jacobs has adopted the Source water quality model with a dSedNet plugin to calculate annual and event sediment loads. This model allows for the calculation of daily flow and daily sediment loads. The dSedNet plugin uses the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) factors as an input to predict daily sediment loads from hillslope erosion. The RUSLE produces annual sediment loss estimates, and these have been spatially calculated for vegetated land covers and construction sites within the urban limits for this exercise.

The results presented in this report are preliminary. The results will be finalised once the following tasks have been undertaken:

- Land-cover categories and urban/rural divide are agreed upon with the Te Awarua-o-Porirua (TAoP) Modelling Leadership Group (MLG),
- Review comments have been received and the methodology confirmed for the dSedNet daily sediment load estimates to be produced from workbrief 1 task B and workbrief 8 modelling,
- Spatially varied rainfall (e.g. NIWA VCSN) is available and processed, and rainfall-runoff modelling completed (required inputs to the dSedNet plugin).

The RUSLE calculates average soil loss to erosion by water as:

$$E = R * K * L * S * C * P$$

Equation 1

Where:

E is soil loss (t ha^{-1} yr^{-1}),

R is rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1})

K is a soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}),

L is the slope length factor (dimensionless),

S is the slope steepness factor (dimensionless),

C is the cover management factor (dimensionless),

P is support practices factor (dimensionless).

A brief outline of the methodology for the development of each RUSLE factor is described below.

R factor

The *R* factor is related to the erosivity of rainfall. For this exercise, a global R factor has been derived from the mean annual rainfall recorded at Seton Nossiter Park following the methodology of Klik et al. (2016). It is expected that when NIWA VCSN data has been purchased and processed this will be updated to use a spatially varied *R* factor. It is likely that changes in estimated sediment load will be relatively minor, given that the major urban areas in the whaitua area are within close proximity to the Seton Nossiter gauge.

K factor

The *K* factor is related to the erodibility of the soil. *K* factor values for most land cover types have been derived following NZUSLE (Dymond, 2010), mapped to the soil textures in the NZLRI soils database GIS layer. However, in the Porirua whaitua catchment, the soils are shallow in many places, and construction activities may result in working in the underlying soil and rock which may have lower *K* values. Accordingly, for estimating earthworks sediment yields, we have adopted the mean *K* value (0.026) from testpits in the whaitua area from the TG study (n=167) to reflect underlying soils (rather than topsoils). This *K* value may be conservative (giving overestimates of sediment yields) because the only two TG test pits in urban areas produce a significantly lower *K* value (0.0066), suggesting reduced erodibility for urban soils where construction sites are most likely. The *K* factor is likely to be site specific, depending on the location and nature of the construction site.

L and S factors

The *L* and *S* factors are related to topography. They have been calculated following the approach of Moore & Burch (1986) and Moore & Wilson (1992), using the national 15m resolution DEM developed by the Otago University School of Surveying.

C factor

In the RUSLE, the C-factor accounts for how land cover, crops and crop management cause soil loss to vary from those losses occurring in bare fallow areas (Kinnel, 2010). *C* factor values have been adapted from NZUSLE (Dymond et al. 2016) and applied spatially to the LCDB v4.1. Urban vegetated land covers have a *C* factor of 0.01, construction sites are assumed to be analogous to bare earth, and have a *C* factor of 1.0.

To define urban vegetated land covers, the LCDB class 'Built up area' was classified as either vegetated or non-vegetated (paved and roofs) using supervised aerial imagery classification. These vegetated urban areas are combined with the LCDB class 'Urban Parkland/Open Space' to define urban vegetated land cover extent.

Spatial data defining construction sites is currently unavailable. To derive sediment yields, a construction scenario has been used, where all of the urban area within the whaitua boundaries defined by the LCDB class 'Built up area' has been classified as construction site (bare earth). Results are therefore representative of all possible construction sites within the urban limits.

P factor

The *P* factor is related to farm management techniques (contouring, terracing etc.). Because there is negligible farmland in the project catchments, the P factor is assumed to be equal to 1 for all scenarios.

Results and discussion

Equation 1 has been calculated across the whaitua catchments using GIS layers at 15m resolution to produce the mean yields in each slope class displayed in Table 2-4 and Table 2-5.

Yields for urban grasslands and trees will vary with soil type (*K* factor), which has been spatially averaged to produce the yields in Table 2-4. There are three soil textures in the NZLRI soils GIS layer within the whaitua area – silt loam, stony sandy loam, and the 'town' class, which is assumed to be loam following Dymond (2016). If all other RUSLE factors are equal, sediment yield estimates for stony sandy loam and loam will equal silt loam estimates multiplied by factors of 0.67 and 0.83, respectively. As noted in the previous section, a single *K* value has been adopted for the estimation of earthworks yields, so there is no similar variation by soil type.

The estimated sediment loads for construction sites are higher than what was previously predicted in the default CLM. This is due to the increase in the *C* factor from 0.01 for urban grasslands to 1.0 for bare earth following NZUSLE (Dymond, 2010), a factor of 100. Previous work in NZ has assumed a factor of 50 (ARC, 2014). A further influence is the assumption that the current topography, reflected in the *L* and *S* factors, has been maintained during construction. For residential construction scenarios, it is likely that terracing will flatten the topography and therefore reduce the *L* and *S* factors and sediment yield estimates. For these various reasons we consider that the sediment yields presented in Table 2-4 and Table 2-5 are likely to be conservative, upper end estimates.

Other sediment sources, such as gully, landslide, and streambank erosion are not accounted for in the RUSLE. However these processes are not evident in urban areas within the project catchments in the NZLRI erosion or NZSedNet (described in Dymond, 2016) GIS layers, and can be assumed to be negligible.

Table 2-4: Sediment yield estimates for urban grasslands and trees.

Slope	RUSLE Urban grasslands and trees ($g/m^2/a$)	CLM Default urban grasslands and trees ($g/m^2/a$)
slope < 5	37	45
5 < slope < 10	108	92
slope > 10	260	185

Table 2-5: Sediment yield estimates for construction sites.

Slope	RUSLE Construction site ($g/m^2/a$)	CLM Default construction site ($g/m^2/a$)
slope < 5	2800	2500
5 < slope < 10	8291	5600
slope > 10	19305	10600

2.5.2 Metals

The CLM's zinc and copper yields for urban grassland and trees and construction sites were developed by multiplying the estimated TSS yields by representative background soil concentrations of copper and zinc found in Auckland (35 and 7 mg^{-1} kg, respectively; ARC, 2010).

Recognising that background concentrations of trace metals vary by soil type, we have investigated sources of data on concentrations of Zn and Cu in soils within the Porirua whaitua boundaries and the Wellington region more widely. URS (2003) reported background concentrations of Zn and Cu in twelve samples taken from greywacke-derived soils, the principal soil type found in the Porirua whaitua (see Table 2-6). Of these samples, six were collected within the boundaries of the whaitua. Median and maximum concentrations measured in the whaitua samples were lower than those from the full data set of twelve samples.

Table 2-6: Concentrations of zinc and copper in soil samples, Wellington region.

Soil type	No. of samples	Zinc (mg/kg)			Copper (mg/kg)		
		Minimum	Median	Maximum	Minimum	Median	Maximum
Greywacke – Porirua Whaitua[1]	6	24	37.5	74	3	8.5	18
Greywacke - Wellington region[1]	12	24	52.5	105	3	9	25
Various – dry stock farmland[2]	23	31	58	120	3	9.8	25
Various - native forest[2]	17	40	66	104	6	12	22

Sources: [1] URS (2003); [2] Sorensen (2012).

In a more recent study Sorensen (2014) reported concentrations of zinc and copper in soil samples according to land use type. Samples collected in the Porirua whaitua were from areas of dry stock farmland (4 of 23 samples from the Wellington region) and native forest (3 of 17 samples from the Wellington region). While reflecting a range of soil types, the results for dry stock and native forest land uses provide another source of information to compare with the greywacke-specific results reported in URS (2003).

We propose to adopt values of 52.5 mg kg^{-1} and 9 mg kg^{-1} as representative background concentrations of zinc and copper, respectively (compared with 35 mg kg^{-1} and 7 mg kg^{-1}, respectively, in the default CLM yields). Yields of zinc and copper for urban grassland and trees and construction sites have been calculated by multiplying the customised TSS yield for each slope class (reported in Section 3.4.1) by these representative concentrations of zinc and copper. The resulting yields are presented in Table 2-7. Reflecting the higher TSS yields and background soil concentrations of Zn and Cu adopted for the Porirua whaitua, the customised Zn and Cu yields for urban grassland and trees and earthworks sites are 11% to 173% higher than the default yields, with the greatest differences in the highest slope class.

Table 2-7: Customised yields of TSS, Zn and Cu for urban grassland and trees and construction sites.

CLM land use type	Slope class	Customised yields		
		TSS	Zn	Cu
		$g/m^2/a$	$g/m^2/a$	$g/m^2/a$
Urban grasslands and trees	Slope < 5	37	0.0019	0.0003
	5 < Slope < 10	108	0.0057	0.0010
	Slope > 10	260	0.0137	0.0023
Construction site open for 12 months/year	Slope < 5	2800	0.1470	0.0252
	5 < Slope < 10	8291	0.4353	0.0746
	Slope > 10	19305	1.0135	0.1737

The proposed representative background concentrations of zinc and copper are the median concentrations measured in samples from greywacke soils collected across the Wellington region, recognising that the lower concentrations found in the Porirua whaitua are based on a more limited number of samples (URS, 2003). The land use-based results (Sorensen, 2012) are in reasonable agreement with the proposed concentrations and thus provide a valuable reality check. While recognising that this latter reference is a more uncertain data source for deriving representative concentrations specifically for greywacke soils, this cross-checking exercise attempts to address an important point made by the reviewers on the limited size of the URS (2003) data set. However, it is also relevant to take into account the likely influence of pervious sources on the total catchment loads of copper and zinc. In the west Auckland application of the CLM referred to previously, pervious land covers were estimated to contribute 1.8% and 5.6% of the catchment zinc and copper load, respectively. Initial runs of the CLM for the Porirua whaitua BAU scenario will reveal the relative importance of pervious sources in this study. A determination can then be made as to whether sensitivity testing, involving varying the zinc and copper yields from pervious sources, or further investigation of the representativeness of the URS (2003) sampling results is worth conducting.

2.6 Urban stream channels

The CLM's contaminant yields for urban streams are also recognised to be highly uncertain (ARC, 2010). However, we have not investigated adjustment of these yields because, in this project, the CLM will only be used to estimate contaminant loads generated from the land surface. The modelling of the addition or attenuation of sediments and other contaminants once in the stream network will be taken care of as part of the calibration of the SOURCE model to be undertaken by Jacobs (as part of the delivery of work brief 8) . This calibration exercise aims to achieve a good level of agreement between modelled and observed contaminant loads and concentrations, and implicitly takes account of in-stream processes.

2.7 Rural land uses

The CLM will not be used to calculate loads of contaminants from areas of rural land use in the whaitua. Accordingly we have not investigated making any revisions to the CLM's yields for forests, pasture or horticulture.

3 Development of Yields for Nitrogen, Phosphorus and *E. coli*

3.1 Introduction

There are four groups of TN, TP and *E. coli* sources in the catchment: rural diffuse; rural point; urban diffuse; and urban point sources. The CLUES model will provide estimates of TN, TP and *E. coli* loads from rural sources (diffuse and point) while Wellington Water's network model will provide estimates of loads from urban point sources, being wastewater overflow discharge points. While CLUES can produce estimates of diffuse loads of TN, TP and *E. coli* from urban areas, CLUES is not intended to be used in settings where urban areas make up a significant proportion of catchment land use, nor do the urban loads discriminate between the contribution of diffuse and point sources of contaminants.

This section therefore describes the development of yields for total nitrogen (TN), total phosphorus (TP) and *E. coli* that will enable the CLM to be used to estimate loads of urban-derived diffuse contaminants in the Porirua whaitua, based on multiplication of these yields by the areas of urban land use.

3.2 Approach to Development of TN, TP and *E. coli* Yields

We have investigated three methods for calculating the yields of TN, TP and *E. coli* from diffuse urban sources:

- Estimate a mean contaminant concentration from the results of water quality sampling and multiply this by the mean annual runoff from 1 m^2 of land surface;
- Estimate catchment (or sub-catchment) contaminant loads from available concurrent concentration and flow measurements and divide the load by the catchment area to estimate the yield. Where there are insufficient measured concentration data to provide a reliable basis for estimating the catchment load, develop a synthetic time series of concentrations based on measured flow-concentration relationships; and
- Investigate relationships between measured concentrations of TN, TP and *E. coli* and concentrations of contaminants for which the CLM already contains yields and which are likely to originate from similar sources. TSS has been investigated as being likely to be the most promising contaminant, because TN, TP and *E. coli* levels are at least partly generated from sources which also generate solids (vegetation, soil). In contrast, Cu and Zn vary in response to factors such as building materials and traffic flow, factors which are unlikely to influence levels of TN, TP and *E. coli*. If a relationship between TP (for instance) and TSS is evident in monitoring data, then this ratio could be used to generate the yield.

In addition, we have investigated contributions of TN and TP from pervious sources (urban grassland and trees, construction sites) from data on background soil concentrations, similar to the method described for copper and zinc (Section 2.5.2).

Because we anticipated there being significant uncertainty in the development of urban TN, TP and *E. coli* yields, due to limitations in the extent and nature of the available data, we have pursued all of the methods. We have also reviewed relevant international literature (including the US NSQD) in order to provide an indication of the concentrations (and degree of variation from place to place) of TN, TP and *E. coli* measured elsewhere and to investigate the relativity in concentrations of TN, TP and *E. coli* in relation to different urban land uses and/or contaminant sources.

3.3 Method 1: Yields from mean annual contaminant concentrations

Stormwater quality data was obtained from the URQIS stormwater database. The data were mainly from Northland, Southland and Auckland, with a few data points from Nelson. TP data from the Taranaki region was removed as there were several sites with very high TP, potentially related to an upstream fertiliser plant. There were no data from the Wellington region in the original URQIS data set but, for this analysis, we have supplemented it with recent data from Kapiti Coast DC (KCDC) stormwater monitoring conducted by Jacobs.

While there are some apparent differences in water quality between different land uses in the URQIS data set (Table 3-1 and Figure 3-1), these may be explained by differences in data sources. For example, for TN, 14 of the 16 medium-density residential data points are from Northland while the rest of the data are from Southland and Nelson, so the difference between medium-density residential and other land uses may reflect a regional difference rather than a land use difference. Similarly, for *E. coli*, the medium-density residential data are sourced from Northland while data for other land uses are not. Furthermore, many of the low-density residential data points also have rural land in the catchment while the low-density residential data from Auckland (24 data points) are from a catchment with known combined sewer overflows (CSOs).

Given that many of these apparent differences between land use may be due to regional differences or other reasons, we consider that there is insufficient data to generate different yields for different urban land use types. Instead, we have generated summary statistics based on monitoring data from all urban land uses combined, after some data filtering (Table 3-2 and Table 3-3).

Table 3-1: Summary of differences in TP, TN and *E. coli* between land uses in NZ and international stormwater quality data.

Parameter	URQIS data set	International review (Duncan, 1999)
TP	Light industrial & low-density residential appear higher than medium-density residential	Residential slightly higher than industrial, commercial and other high urban
TN	Appears lower in medium-density residential than other land uses	No significant differences in TN between roads, low urban and high urban land use groups
E. coli	Appears higher in catchments from low-density residential, light industrial and commercial, compared to medium-density residential data	Higher in residential catchments than industrial and commercial

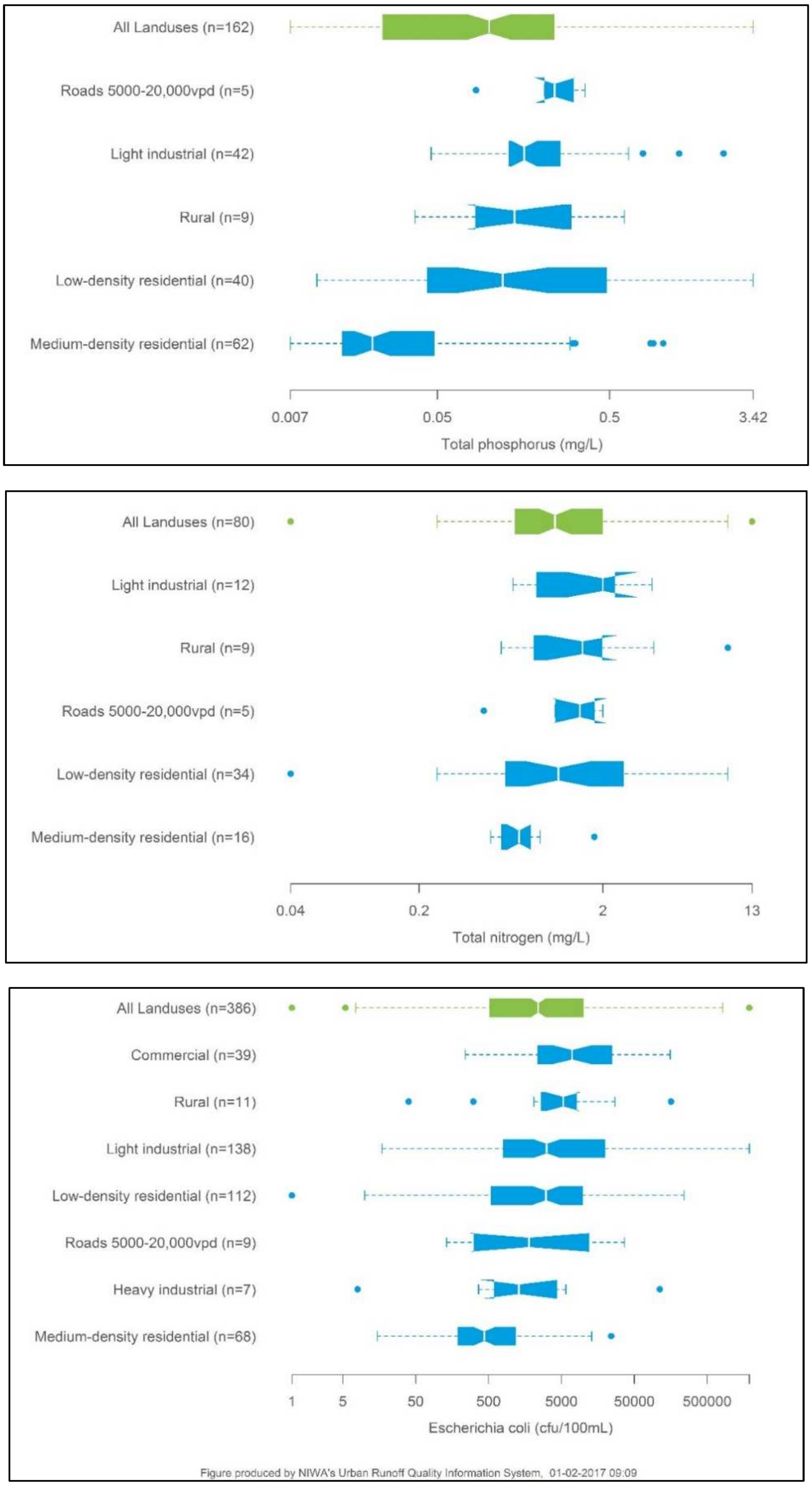

Figure 3-1: TP, TN and *E. coli* concentrations in New Zealand stormwater samples from catchments with varying land use.

Table 3-2: URQIS data included for assessment of TP, TN, and *E. coli* concentrations.

Type	Included (✓) or Excluded (×)	Comment
Urban stream	×	
Stormwater – treated	×	Excluded as require yields for untreated stormwater
Stormwater – untreated	✓	
Storm flows	✓	
Baseflow	×	
Known CSOs upstream	×	Excluded as loads from wastewater overflows are to be calculated separately to stormwater
No known CSOs upstream	✓	
Unknown if CSOs upstream	✓	Included as there are a lot of data in this class and it is likely that most don't have overflows upstream, or at the time of sampling
Dominant land use is rural	×	Rural land use being modelled by CLUES and Sednet, not CLM
Wellington data	✓	
Data from other regions	✓	Insufficient data from Wellington on its own

Table 3-3: Summary statistics for concentrations of TP, TN, and *E. coli* in NZ stormwater.

Parameter	TP (g/m^3)	TN (g/m^3)	*E. coli* *(No./100ml)*
N	207	160	541
Median	0.14	1.4	2300
Mean	**0.25**	**1.9**	**10,000**
Minimum	0.01	0.04	1
10%ile	0.032	0.36	100
25%ile	0.058	0.61	580
75%ile	0.25	2.3	7600
90%ile	0.57	4.0	23,000
Maximum	3.4	13	242,000

Table 3-4 compares the results of the URQIS data analysis with summary statistics of data from other sources, including data from the Kapiti Coast and international databases. This comparison indicates that the KCDC stormwater samples have lower concentrations of TP and TN than NZ as a whole, while TP concentrations in NZ stormwater samples are slightly lower than in stormwater from US and elsewhere. TN concentrations in NZ samples are also slightly lower than those in the US, but very similar to the range of concentrations in the international BMP. The median and mean (except BMP database) *E. coli* counts are very similar for all data sets, though upper values are much more variable between studies. Based on this comparison, the use of Method 1 to derive yields appears to be better justified for TN and *E. coli* than for TP.

Table 3-4: Comparative statistics for concentrations of TP, TN, and *E. coli* in NZ-wide data, KCDC data and international databases.

Parameter	TP (g/m³)				TN (g/m³)				*E. coli* (No./100ml)			
	NZ data	KCDC[a]	NSQD (US)[b]	BMP database (international)[c]	NZ data	KCDC[a]	NSQD (US)[b]	BMP database (international)[c]	NZ data	KCDC[a]	NSQD (US)[b]	BMP database (international)[c]
N	207	40	7943	8414	160	40	1208	3651	541	188	139	539
Median	**0.14**	**0.07**	**0.25**	**0.20**	**1.4**	**0.52**	**2.1**	**1.4**	**2300**	**2350**	**1520**	**2420**
Mean	**0.25**	**0.12**	**0.39**	**0.36**	**1.9**	**0.90**	**2.8**	**1.9**	**10,000**	**6230**	**5769**	**278,000**
Minimum	0.01	0.02	<0.01	<0.002	0.04	0.14	0.15	0.005	1	22	5	<1
10%ile	0.032	0.03	0.08	0.05	0.36	0.26	0.6	0.57	100	194	94	50
25%ile	0.058	0.04	0.14	0.10	0.61	0.40	1.2	0.9	580	775	475	425
75%ile	0.25	0.13	0.44	0.39	2.3	1.1	3.4	2.2	7600	5525	4170	12,500
90%ile	0.57	0.22	0.76	0.79	4.0	1.8	5.4	3.4	23,000	15,000	17,000	65,000
Maximum	3.4	0.57	21	14	13	4	90	53	242,000	88,000	66,000	16,600,0000

Notes: [a] Stormwater data collected at Kapiti Coast District Council sites from 2006 to 2017; [b] National Stormwater Quality Database, United States (to January 2015); [c] Data on untreated stormwater samples held in Stormwater Best Management Practice database, from international studies.

The mean and median concentrations from the NZ data set were used to calculate annual yields (Table 3-5) according to the following formula:

$$Y = \frac{CV}{A}$$

Equation 2

where Y = yield in g/m^2/a, C = mean or median concentration (g/m^3), V = annual runoff volume (m^3/a) and A = area (m^2).

The annual runoff volume was calculated based on the rational formula

$$V = P\ F\ Rc\ A$$

Equation 3

where P = annual precipitation (m); F = factor for rainfall that does not result in runoff (dimensionless); and Rc = runoff coefficient (dimensionless).

We estimated the annual precipitation as 1100 mm (based on annual rainfall at the Tawa Pool (1065mm) and Seton Nossiter Park (1145mm) rainfall sites. A factor of 0.9 was used to account for the rainfall that does not result in runoff (Schueler, 1987). An overall runoff coefficient was estimated for urban land use, based on an indicative average impervious:pervious split in urban land uses of 71:29 (Moores et al. 2013) and runoff coefficients of 0.95 for impervious and 0.35 for pervious (Capacity Infrastructure Services, 2012). This resulted in an overall runoff coefficient of 0.78. An area of 1 ha was used in the calculations.

Table 3-5: Estimated yields of TP, TN, and E. coli based on URQIS water quality mean and median concentrations.

	TP	TN	*E. coli*
Mean (g/m^3, No./100ml)	0.25	1.9	10,000
Yield (g/m^2/a, No./m^2/a)	0.19	1.5	80,000
Median (g/m^3, No./100ml)	0.14	1.4	2300
Yield (g/m^2/a, No./m^2/a)	0.11	1.1	18,000

3.4 Method 2: Yields calculated from long-term monitoring of water quality and flow

The second method involved developing yields from long-term water quality and flow monitoring data. For this method, a concentration model was produced for each water quality parameter based on flow, seasonal differences and trend over time (generalized additive model). From these models, a synthetic estimate of water quality was produced for each time that flow was measured. The overall load discharged from the catchment was then estimated from this synthetic record, which included estimates at very high flows which are typically not sampled. This method includes the load discharged during low stream flows (baseflow discharges) that are sourced from groundwater or slow flow sources, rather than exclusively stormwater / quickflow sources.

Water quality data was obtained for the Porirua Stream at Milk Depot monitoring site (January 2008 to December 2015) while flow data was obtained for the same period for the Porirua Stream at Town Centre monitoring site. Although these monitoring sites are in slightly different locations, the assumption was made that the water quality at Town Centre would be approximately the same as the water quality at the Milk Depot site, slightly further upstream.

Table 3-6 presents the estimated loads of TN, TP and *E. coli*, along with yields estimated by dividing the loads by the area of the Porirua Stream catchment upstream of the flow monitoring location (approximately 4000 ha).

Table 3-6: Yields of TP, TN, and *E. coli* calculated from the estimated annual loads (mean annual load and 90% confidence interval) discharged from the Porirua Stream catchment.

Parameter	TP	TN	*E. coli*
Estimated annual load (tonnes/a; million *E. coli*/a)	1.8 (1.3 – 3.3)	28 (26 – 32)	130,000 (58,000 – 420,000)
Yield (g/m²/a; No./m²/a)	0.045 (0.033 – 0.084)	0.69 (0.65 – 0.80)	3,200 (1,400 – 11,000)

There are two factors that should be considered in relation to these yield estimates:

- The Porirua Stream catchment land use is not 100% urban, which means these estimates are affected by the other land use in the catchment (including forestry and sheep and beef farming). This may result in the yields being either higher or lower than expected for solely urban land use.
- The yields estimated by this method include nutrients and bacteria contributed by wastewater overflows and cross-connections (i.e., sewer pipes wrongly connected into the stormwater network and hence, discharging into Porirua Stream).

3.5 Method 3: Yields estimated from relationships between TSS and TN, TP and *E. coli*

We investigated relationships between TSS (for which urban yields are available in the CLM) and the other parameters, using urban stream and stormwater quality data available from the Wellington region. Urban stream data was provided by GWRC and includes sites on 7 streams with urban land use in the catchment (meaning >15% urban land use, consistent with Larned et al. 2004; 2016). The results are presented as scatter plots of log-log relationships (Figure 3-2).

We also investigated relationships in NZ-wide stormwater quality data obtained from the URQIS stormwater database (Figure 3-3). These data are mainly from Northland, Southland and Auckland, with a few data points from Nelson. As mentioned in Section 3.1, TP data from the Taranaki region was removed as there were several sites with very high TP, potentially related to an upstream fertiliser plant. There were no data from the Wellington region in the URQIS data but, as described previously, we were able to supplement it with KCDC stormwater monitoring data provided by Jacobs. Prior to undertaking the analysis, TSS data that were below the detection limit (i.e., censored data) were replaced by imputed data, using the “regression on statistics” method (Helsel, 2012) within R. There were no censored data for TP, TN or *E. coli*.

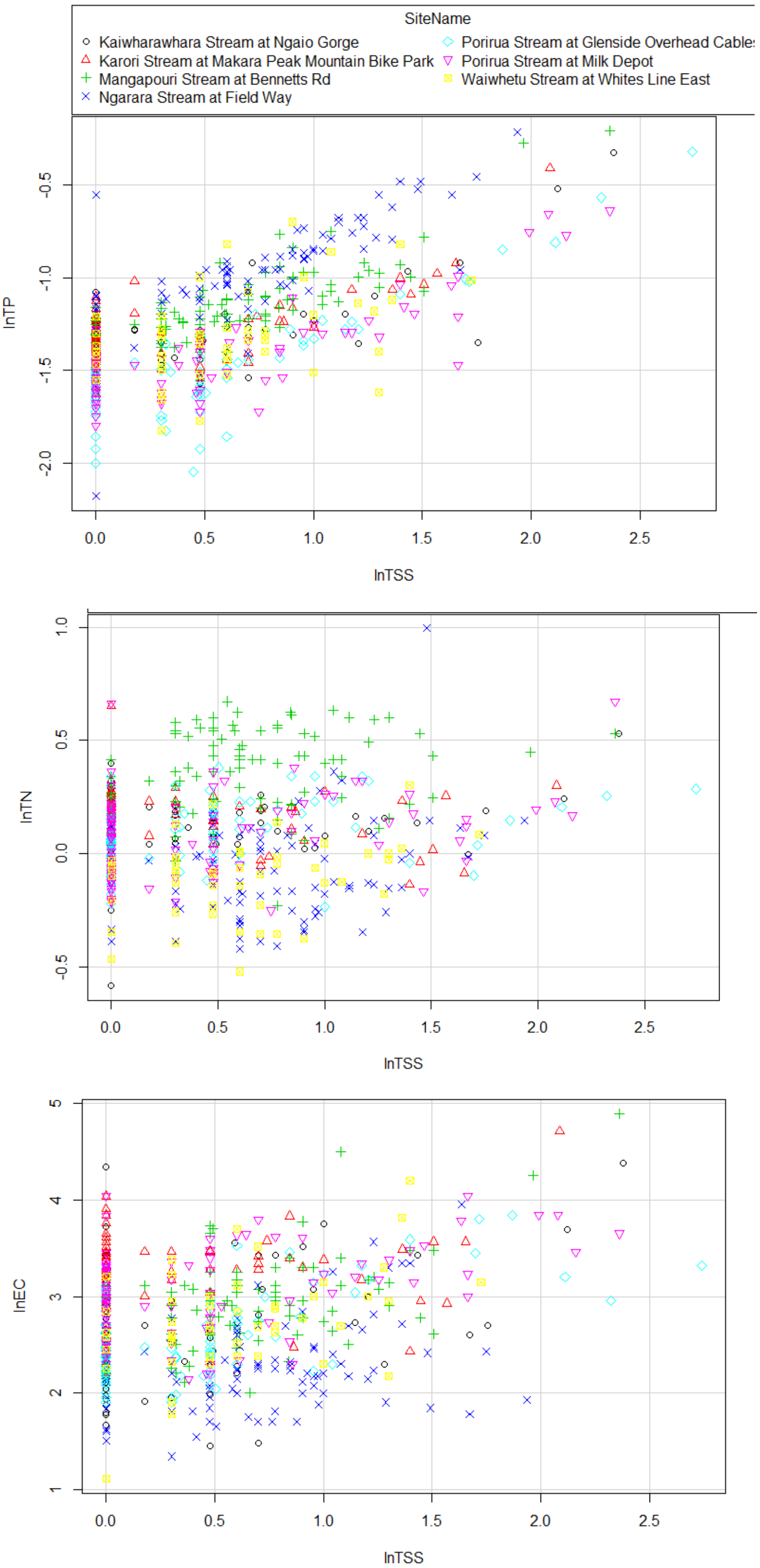

Figure 3-2: Relationships between TP, TN and *E. coli* and TSS in Wellington urban streams.

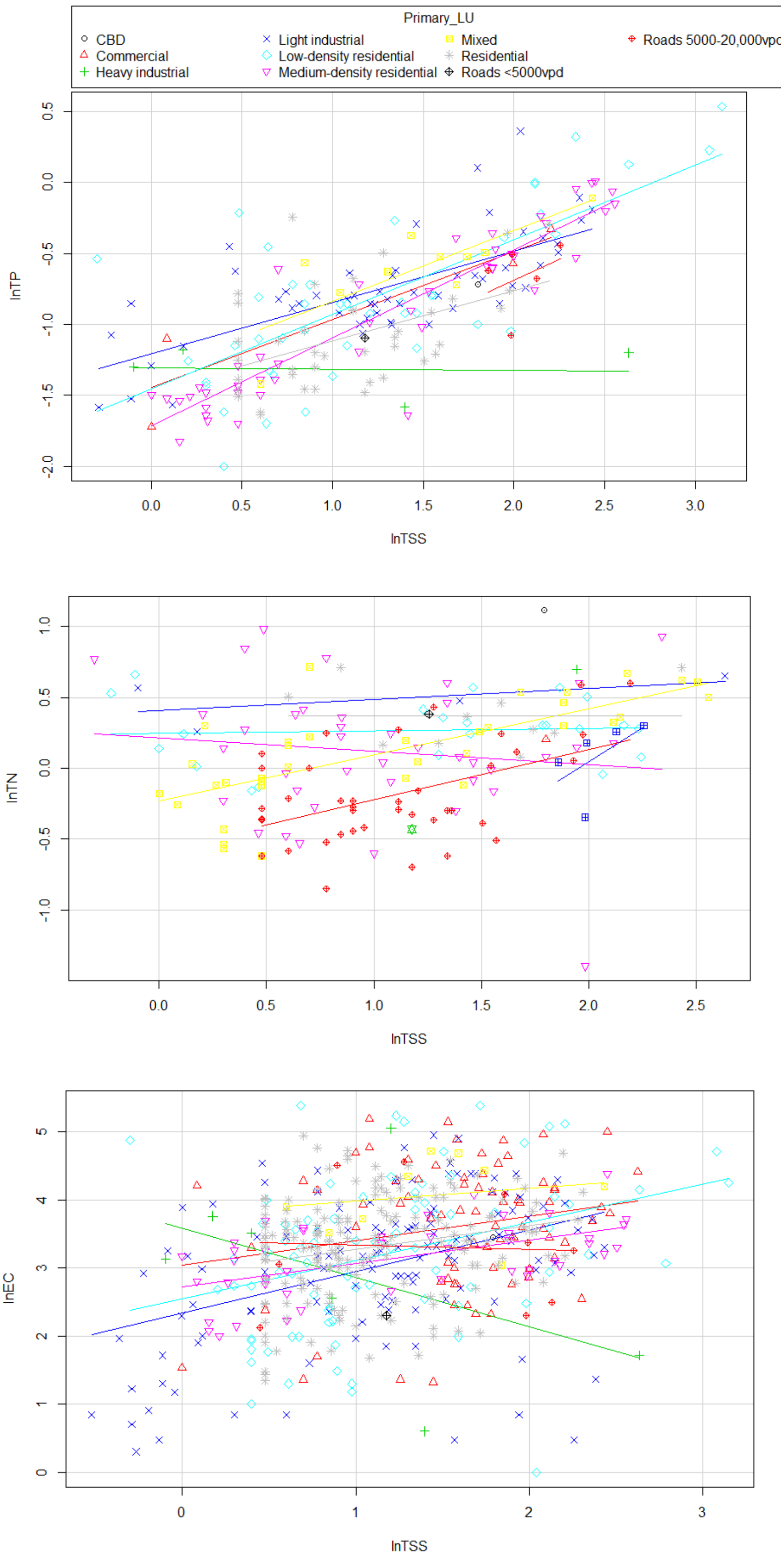

Figure 3-3: Relationships between TP, TN and *E. coli* and TSS in NZ stormwater.

This analysis suggested a reasonable relationship between TP and TSS in both urban streams and stormwater, but a poor relationship between both TN and *E. coli* and TSS.

The relationships were investigated further through linear regression (Table 3-7). This was undertaken for the data from all land use groups pooled together, for the following reasons:

- The plots did not provide sufficient evidence for differing regressions between land use groups, given the scatter in the data for each group;
- The data comes from sites that are not solely from a single land use, for example, although a site may be characterised as medium-density residential, there could be a large proportion of industrial land use within the catchment; and
- Some of the apparent differences between land use types may be due to differences in the data sources (e.g., data from different regions, see Section 3.3).

The regression was undertaken on log-transformed data (e.g., $\log_{10}$(TP) against $\log_{10}$(TSS)).

Table 3-7: Results of linear regression between TP, TN, *E. coli* and TSS. Values in bold are statistically significant.

Parameter	Slope	Intercept	R^2 adjusted
Log(TP)	**0.48**	**-1.47**	0.53
Log(TN)	0.17	-0.10	0.07
Log(*E. coli*)	**0.46**	**2.7**	0.10

The results suggested significant relationships for TP and *E. coli* against TSS but not for TN. The R^2 values were low for both TN and *E. coli*, indicating little explanatory power and a high degree of variability. These findings are consistent with Duncan (1999), who similarly reported a fair relationship between TSS and TP but poor explanatory power for the relationship between TSS and TN and *E. coli*. On this basis, it was considered that TP yields could be more reliably estimated from the relationship with TSS yields than is the case for TN and *E. coli* yields.

TP yields were calculated from the equation:

$$TP = 10^{0.48\log(SS)-1.47}$$

Equation 4

These yields are provided in Table 3-8, along with the TSS yields for each land cover.

Adoption of these yields will result in differing overall yields for different land uses (e.g., residential vs commercial). For example, the overall yield for a low-density residential land use is estimated as 0.23 g/m^2/a, compared with 0.17 g/m^2/a for commercial and industrial land use, based on representative land cover mixes developed previously by NIWA (Moores et al. 2013). This is consistent with the findings by Duncan (1999) who reported similar differences in TP between land use types.

While proposing that TP yields be derived according to this method, we agree with two modifications recommended by Morphum Environmental as part of their review. Firstly, in relation to roofs, there are three roof types that have higher default TSS yields than other roof materials, resulting in higher calculated TP yields (Table 3-8). However, we consider that the additional TSS from these roofs is likely to be from the weathering of roofing materials (as opposed to deposited soil particles) and is therefore unlikely to contribute significant additional TP. While it is also possible that some of the additional TSS relating to these roofs is organic matter (for example from lichen) which would contain additional TP, we have insufficient evidence to confirm the relative importance of organic sources of TSS. For these reasons, we propose a single TP yield for all roof types (0.07 g/m^2/a), in agreement with the reviewers (Table 3-8).

Table 3-8: Yields of TP as calculated from the TSS yields based on the linear regression, and as recommended for use.

Source	Source Type	Yields (g/m^2/a)		
		TSS	Calculated TP	Recommended TP
Roofs	Galvanised steel unpainted	5	0.07	0.07
	Galvanised steel poorly painted	5	0.07	0.07
	Galvanised steel well painted	5	0.07	0.07
	Galvanised steel coated (Decramastic)	12	0.11	0.07
	Zinc/aluminium unpainted (Zincalume)	5	0.07	0.07
	Zinc/aluminium coated (Colorsteel/Colorcote)	5	0.07	0.07
	Concrete	16	0.13	0.07
	Copper	5	0.07	0.07
	Other materials	10	0.10	0.07
Roads (vpd)	<1000	21	0.15	0.15
	1000-5000	28	0.17	0.15
	5000-20000	53	0.23	0.15
	20000-50000	96	0.30	0.15
	50000-100000	158	0.38	0.15
	>100000	234	0.46	0.15
Paved surfaces other than roads	Residential	32	0.18	0.18
	Industrial	22	0.15	0.15
	Commercial	32	0.18	0.18
Urban grasslands and trees	Slope < 5	37	0.19	0.19
	5 < Slope < 10	108	0.32	0.32
	Slope > 10	260	0.49	0.49

Secondly, the CLM's default TSS yields increase by road vpd class. As suggested by the reviewers, we agree that the increase in TSS by road class would largely arise from the greater wear of vehicle components and road surfaces associated with higher traffic numbers. These TSS sources are not likely to generate proportionate increases in TP. Other sources of TSS on roads include soils and vegetation from neighbouring land uses and atmospheric deposition. These sources are expected to remain the same irrespective of VPD. Therefore, we propose a TP yield of 0.15g/m^2/a for all vpd classes, based on the TSSv TP relationship for the road class < 1000 vpd (Table 3-8).

3.6 Comparison of TP, TN and *E. coli* yields estimated by the different methods

The TP, TN and *E. coli* yields estimated by the three methods described above are compared in Table 3-9, along with yields sourced from the literature. This shows a wide variation in estimated yields for urban land uses, with differences of an order of magnitude for some parameters. It will be important that the extent of this variation and associated uncertainty is taken into account when undertaking the CLM modelling and when using the results in all 'downstream' models and assessments (discussed further below).

For *E. coli*, the recommended yield incorporates the influence of illegal or cross connections of wastewater into the stormwater network. It does not, however, incorporate the influence of wastewater overflows, as these will be explicitly modelled by Wellington Water. As noted by the reviewers, changes to infrastructure may be of more importance than landuse for *E. coli* yields. We therefore suggest that for scenarios associated with network infrastructure upgrades, such as removal of cross-connections, the CLM modelling uses a lower *E. coli* yield of 18,000 /m^2/a, based on the median of NZ stormwater data. We consider that this median is likely to reflect diffuse stormwater sources of *E. coli* only, and so can be adopted to represent situations in which wastewater contamination of stormwater is absent.

Table 3-9: Urban yields of TP, TN and *E. coli* developed for the Porirua CMP, compared with literature-based yields. Yields in bold are those proposed for use in the customised CLM (refer Section 3.8)**.**

Method or source of yield	TP (g/m^2/a)	TN (g/m^2/a)	*E. coli* (No. /m^2/a)
Method 1 - URQIS WQ data (mean)	0.19	**1.5**	**80,000**
Method 1 - URQIS WQ data (median)	0.11	1.1	18,000
Method – 2 Porirua Stream data	0.045	0.69 (0.65 – 0.80)	3,200 (1,400 – 11,000)
Method 3 - TP:TSS relationship	**0.17-0.23**	-	-
Literature sources			
Williamson (1993)	0.04, 0.08, 0.16 (low, average, high)	0.25, 0.8, 1.1 (low, average, high)	-
Auckland Regional Council (2002)	0.046-0.15	0.13-0.88	-
CLUES urban land use	-	-	150,000
KCDC mean WQ data	0.0001 - 0.065	0.002 - 0.68	1,100– 95,200
KCDC median WQ data	0.0001 - 0.063	0.002 - 0.75	100– 5,800

3.7 TP and TN yields from construction sites

An estimate of TP and TN yields associated with construction sites is required, but not of *E. coli*, which we consider likely to be negligible.

Sorensen (2012) reported median TN in the upper 10 cm of soils sampled in the Wellington region as between 0.17 and 0.54%, depending on land use (all of which were rural). TP was not measured in this study, though Olsen P was reported as between 0.0011% and 0.014%. Looking beyond the

Wellington region, ARC (2001) reported mean TN in Auckland urban soils of 0.16% to 0.37%, depending on soil type. Similarly, mean TP was reported as 0.025 – 0.12%.

In that Auckland study, the mean TN for greywacke soils, which are the dominant soil type in the Porirua harbour catchment, was 0.16%. The mean TP was 0.04%. We propose to adopt these as the basis for developing TN and TP yields for construction sites. The TN yields represent a conservative approach that will likely over-estimate the TN released from the construction site soils. This is because the majority of N in soils is in the organic matter, while only 1-6% is in the clay minerals (McLaren & Cameron 1996). Once topsoil has been removed, the TN yield from the exposed areas of bare earth on a construction site can therefore be expected to be lower.

However, it is also relevant to note that the % TN and TP used to derive the construction site yields are lower by 1-2 orders of magnitude than % TN and TP calculated from the yields for urban grasslands and trees land cover classes (TN yield/TSS yield and TP yield/TSS yield). In other words, the construction sites yields do, to an extent, reflect the lower organic content that would be expected in sediment runoff from earthworks activities.

The estimated TN and TP yields for construction sites are given in Table 3-10.

Table 3-10: TSS and recommended TP and TN yields for different slope classes of construction sites..

Slope class	TSS ($g/m^2/a$)	TP ($g/m^2/a$)	TN ($g/m^2/a$)
Slope < 5	2800	1.1	4.5
5 < Slope < 10	8291	3.3	13.3
Slope > 10	19305	7.7	30.9

3.8 Proposed Yields of TP, TN and *E. coli*

For the modelling of urban diffuse sources of TP, TN and *E. coli* in the Porirua whaitua, we propose to adopt the yields shown in bold in Table 3-9, and copied in Table 3-11, for the following reasons:

- We recommend that yields for TP are generally based on the TSS yields (Method 3), because of the relatively strong regression relationship between these two parameters in stormwater. This results in differences in yields by land cover type (Table 3-8).
- In contrast, for TN and *E. coli*, we recommend using the yields developed from the water quality data sourced around New Zealand and supplemented with data from Kapiti Coast (Method 1, with the exception of yields from construction sites, see below). The concentration data from which these yields are derived agrees reasonably well with international data sources. This results in the same TN and *E. coli* yield for all urban land cover types (roofs, roads, paved surfaces and urban grasslands). These yields could be updated as new stormwater quality data becomes available.
- We recommend that the TN and TP yields for construction sites are based on analyses of the proportion of TN and TP in Auckland urban greywacke soils. These yields could be updated using Wellington-based data if that becomes available.

Table 3-11: Proposed CLM yields of TP, TN and *E. coli*.

Source	Source Type	Yields ($g/m^2/a$, except *E. coli* – No./m^2/a)		
		TP	TN	*E. coli**
Roofs	Galvanised steel unpainted	0.07	1.5	80,000
	Galvanised steel poorly painted	0.07	1.5	80,000
	Galvanised steel well painted	0.07	1.5	80,000
	Galvanised steel coated(Decramastic)	0.07	1.5	80,000
	Zinc/aluminium unpainted (Zincalume)	0.07	1.5	80,000
	Zinc/aluminium coated (Colorsteel/Colorcote)	0.07	1.5	80,000
	Concrete	0.07	1.5	80,000
	Copper	0.07	1.5	80,000
	Other materials	0.07	1.5	80,000
Roads (vpd)	<1000	0.15	1.5	80,000
	1000-5000	0.15	1.5	80,000
	5000-20000	0.15	1.5	80,000
	20000-50000	0.15	1.5	80,000
	50000-100000	0.15	1.5	80,000
	>100000	0.15	1.5	80,000
Paved surfaces other than roads	Residential	0.18	1.5	80,000
	Industrial	0.15	1.5	80,000
	Commercial	0.18	1.5	80,000
Urban grasslands and trees	Slope < 5	0.19	1.5	80,000
	5 < Slope < 10	0.32	1.5	80,000
	Slope >10	0.49	1.5	80,000
Construction site open for 12 months/year	Slope < 5	1.1	4.5	-
	5 < Slope < 10	3.3	13.3	-
	Slope > 10	7.7	30.9	-

*Assuming stormwater is contaminated with wastewater from cross-connections etc. Where wastewater contamination is absent, a lower *E.coli* yield of 18,000 m^2/a is proposed.

There is considerable uncertainty in these yield estimates, of at least a factor of two and in some cases a factor of 10. It will be important that this uncertainty is communicated to the Whaitua Committee and to all providers of 'downstream' models and assessments.

The implications of the uncertainty around these yields depend on the relative proportion of loads of TN, TP and *E. coli* from diffuse urban sources compared with other sources (i.e. rural sources and wastewater overflows). In the event that the diffuse urban loads make up only a small proportion of total catchment loads, then the uncertainty associated with these yields may be considered acceptable.

However, in the event that the diffuse urban loads are found to contribute a significant part of the nutrient and/or *E. coli* loads in any sub-catchment, then the uncertainty of these estimates must be factored in when interpreting the modelling results. This will be of particular importance in catchments where nutrients or *E. coli* are predicted to have effects on attributes of interest to the Whaitua Committee (whether ecological or recreational) and where mitigation is predicted to change these effects. Sensitivity testing may be useful in addressing this uncertainty.

4 Estimation of loads excluded from core models

4.1 Introduction

This section summarises contaminant load estimates from the following sources excluded from the core Te Awarua-o-Porirua models:

- TSS, Zn, and Cu loads from roads outside urban limits;
- TN and TP loads during the earthworks phase of Transmission Gully (TG); and
- TN, TP and *E. coli* loads from roads within the TG corridor during the operational phase.

TN, TP, and *E. coli* loads from vegetated land covers within the TG corridor during the operational phase are also discussed and alternative modelling methods to those set out in work brief 1 task A are recommended.

A further contaminant source excluded from the core whaitua models are loads of Cu and Zn from pervious land covers outside the urban limits. These are to be delivered later, as they will be derived from estimates of sediment loads produced during dSedNet modelling for task B of work brief 1.

The loads described here will be aggregated with loads produced by running the core whaitua models at REC sub-catchment scale. To provide for this, contaminant loads from rural roads, the TG construction corridor, and the TG motorway have been intersected with REC sub-catchments. This approach assumes that drainage for these areas will follow topographic catchment boundaries.

4.2 TSS, Zn, and Cu loads from roads outside urban limits

TSS, Zn, and Cu yields from roads have been investigated and customised during the CLM customisation (see Table 2-3, Section 2.3.4)

Rural road areas were calculated by buffering the road centreline; 3m for one lane roads and lanes, 6m for two lane roads and 10m for the motorway. Checks against aerial photos were carried out, with minor edits undertaken, e.g. to remove walkways and paper roads. Unsealed roads and pedestrian access ways were not included. VPD categories have been derived from the Jacobs SATURN traffic model (2011 baseline). Minor roads not included in the SATURN model are assumed to experience less than 1000 VPD.

The yields from Table 2-3 have been applied to rural roads in the Whaitua catchments. The resulting estimates of loads are summarised in Table 4-1. TSS loads per REC sub-catchment are displayed in Figure 4-1; a similar pattern is evident for Zn and Cu, as higher loads are the result of a larger road area and/or high VPD roads within a sub-catchment.

Table 4-1: Contaminant loads from roads outside the urban limits.

VPD category	Road Length (m)	Road Area (m2)	Load (kg/yr)		
			TSS	Zn	Cu
< 1000	92203	429700	9024	1.9	0.4
1000-5000	3874	22482	630	0.6	0.1
5000-20000	21691	173980	9221	22.6	4.5
20000-50000	17595	162099	15562	48.8	9.8
Total	135363	788262	34436	73.9	14.8

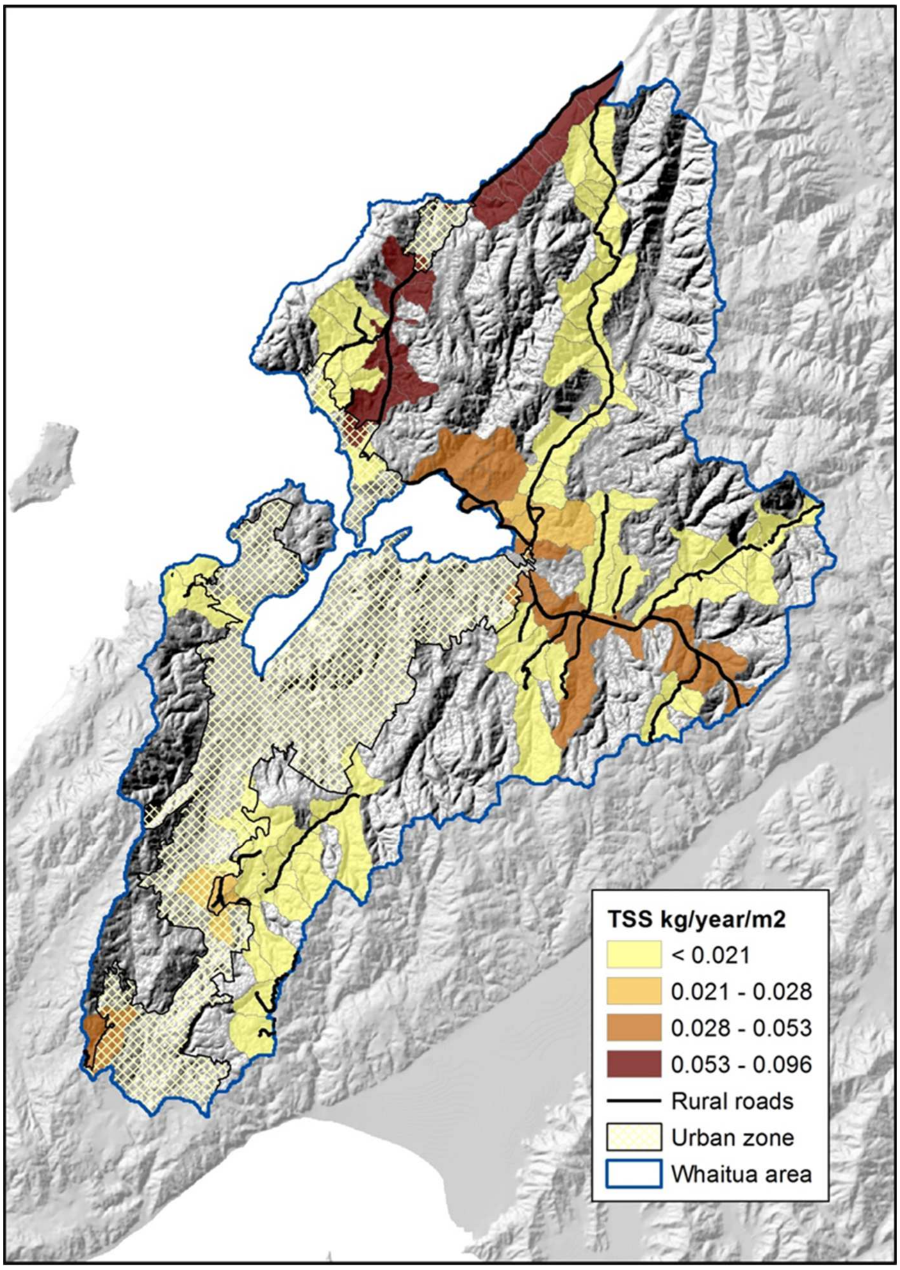

Figure 4-1: Road derived rural yields for TSS, normalised to catchment area.

4.3 TN & TP loads during the earthworks phase of TG

TN and TP loads during the earthworks phase of TG have been derived from sediment yields developed during the TG study (SKM, 2012) and the ratios of TSS:TN and TSS:TP developed in the CLM customization.

The TG study calculated sediment yields for five areas of road construction within the whaitua catchments. The areas correspond to the areas that were assessed as part of either the streams or coastal effects assessments and are within the Kenepuru, Duck, Pauatahanui, Ration, and Horokiri catchments. The assessment was undertaken for a TG road design which has since been superseded; however the original road design follows approximately the same alignment as more recent (2015) design strings. Therefore the original assessment and road design has been used to produce the estimates presented here.

For construction sites, the CLM customisation used sediment proportions of 0.16% for TN and 0.04% for TP (see Section 3.7). These proportions have been applied here. Table 4-2 shows the sediment yield from the TG study (with sediment treatment in place) and the derived TN and TP yields for catchments within the Whaitua area.

Table 4-2: Construction sediment yield from the TG study and derived TP and TN yields following the CLM customisation.

Catchment	Sediment yield - treated (kg/ha/yr)	TP yield (kg/ha/yr)	TN yield (kg/ha/yr)
Duck	11811	4.7	18.9
Horokiri	35253	14.1	56.4
Pauatahanui	9694	3.9	15.5
Ration	12161	4.9	19.5
Kenepuru	4362	1.7	7.0
Porirua	14656*	5.9	23.5

* Sediment yields use mean value from the other catchments

Yields for each REC sub-catchment have been adopted from the parent catchment (Table 4-2). The resulting estimates of TN and TP load per REC sub-catchment per year is given in Appendix B. Road construction zones per year from the TG study and total TN load across all years per sub-catchment are displayed in Figure 4-2.

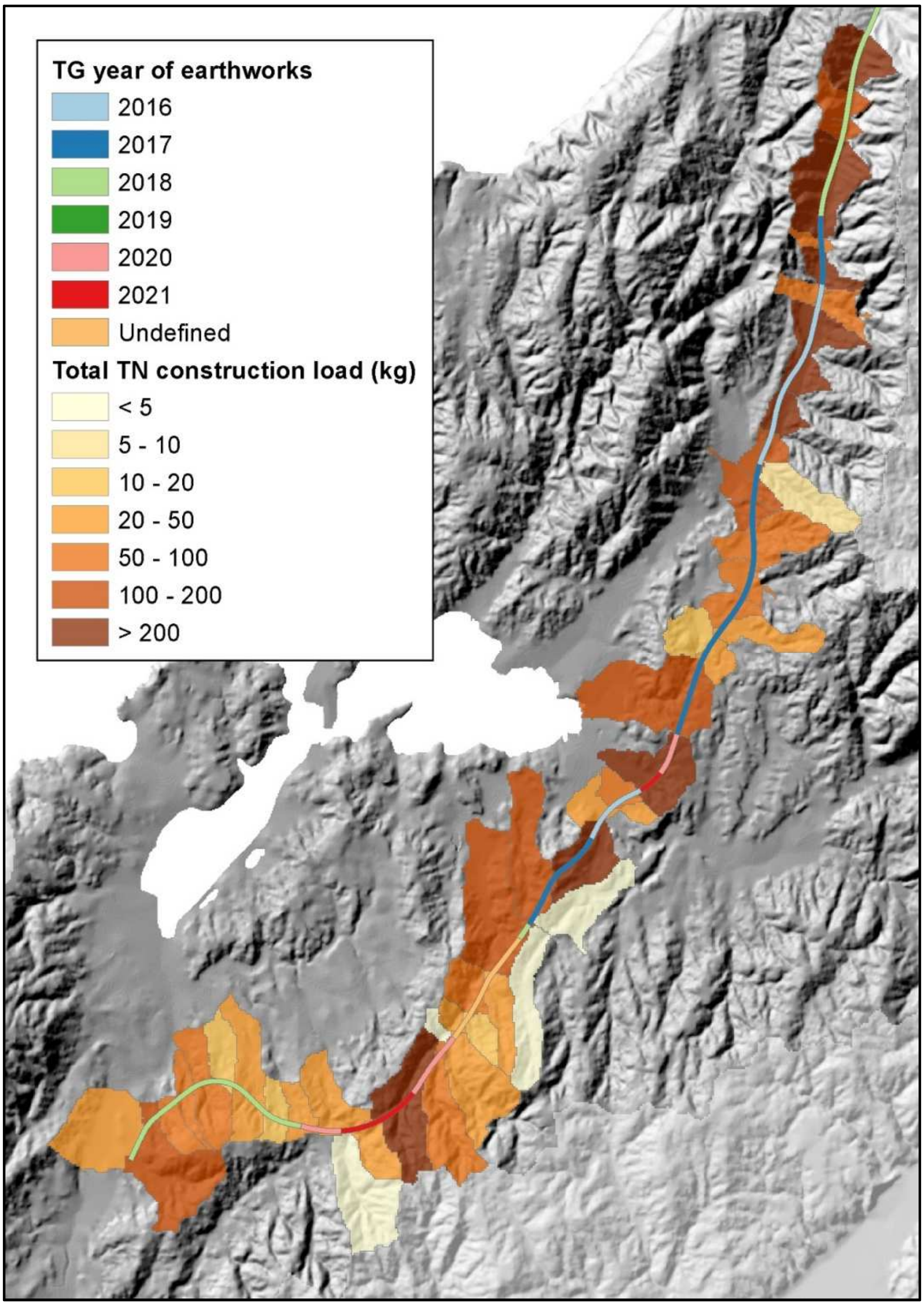

Figure 4-2: Earthworks predicted year and sub-catchment TN load (all years).

4.4 TN, TP & *E. coli* loads from vegetated land covers and roads within the TG corridor during the operational phase

4.4.1 Vegetated land covers

For the TG study, CLM models were developed at catchment scale (SKM, 2011). The models assume the current land use is maintained along the TG alignment border. Much of the bordering land use is rural (farmland, forestry etc.), for which yields of TN, TP, and *E. coli* have not been developed in the CLM customisation, and which are likely to vary significantly from urban yields. Furthermore, the TG study used the 2006 version of the CLM, which has since been updated, including changes to contaminant yields for vegetated land covers and changes to slope categories.

We therefore propose that TN, TP, and *E. coli* loads from vegetated land covers within the TG corridor (i.e. the strip of pervious land cover between the edge of the sealed motorway surface and the boundary of the motorway corridor) will be modelled as part of the adjacent land area; in work brief 1 task B for the TG corridor within the urban limits (using the updated, customised CLM), and work brief 1 task C for the TG corridor outside the urban limits (using CLUES). It is not expected that this will increase processing time for these tasks, assuming that land use that borders the motorway does not change significantly following motorway construction, as a land use GIS layer has already been developed.

4.4.2 Roads

TN, TP, and *E. coli* loads from the road surface of the TG motorway have been derived from the road surface area in the original TG modelling[8] and the relevant yields developed in the CLM customisation, summarised in Table 4-3. The lower value of 18,000 *E .coli* m^{-2} a^{-1} has been adopted as wastewater contamination is not predicted to be present along the TG motorway.

Table 4-3: TP, TN, and *E. coli* yields used for TG road surface during operational phase.

VPD Category	TP (g $m^{-2}a^{-1}$)	TN (g $m^{-2}a^{-1}$)	E.coli (no. $m^{-2}a^{-1}$)
<1000	0.15	1.5	18000
1000-5000	0.15	1.5	18000
5000-20000	0.15	1.5	18000
20000-50000	0.15	1.5	18000

TN, TP, and *E. coli* loads produced here will be conservative because the original TG modelling generally over-estimates the road surface area. Following the TG methodology, road widths are determined using the original CLM default widths (17m for a two-lane road), with an adjustment to account for the underestimation of the number of lanes for the TG motorway that results from the assumed number of lanes per vpd class in the CLM (Table 4-4). The length of the road with 5,000 to 20,000 vehicles per day and four lanes (i.e. the TG motorway) has been duplicated in the <1000 vehicles per day category (to achieve 4 lanes for the road width for this length). Similarly, for the length of road with 20,000 to 50,000 vehicles per day and six lanes – the road length has been duplicated in the <1000 vehicles per day category.

The original modelling methodology has been used here to maintain consistency with the original TG modelling results and with other contaminant loads to be derived from the original TG modelling for work brief 1 task B (annual Zn and Cu loads and annual and event sediment loads).

The TG catchment scale CLMs have been replicated for the TG road surface (only) for each REC sub-catchment intersected by the TG alignment polyline used in the original modelling exercise. This polyline accounts for the TG motorway and associated link roads (however may not represent the later alterations to the road design). Loads assume run-off filters are in place following the original TG modelling. TN, TP, and *E. coli* loads for each catchment and REC sub-catchment are summarised in Appendix C. While loads are conservative, they are expected to account for an insignificant fraction of total catchment load given the relatively small TG road footprint, and have relatively low yields compared to other land uses.

Table 4-4: Original CLM assumed relationship between traffic volume and number of lanes.

Vehicles per day	Number of lanes
<1000	2
1000-5000	2
5000-20000	2
20,000-50,000	3
50,000-100,000	4
> 100,000	6

5 Summary

5.1 Customisation of CLM yields

Table 5-1 presents the proposed set of contaminant yields to be adopted in implementing the CLM for the Porirua whaitua. Customised yields of TSS, zinc and copper have been developed for urban grassland and trees and construction sites. Customised yields of zinc have also been developed for highly-trafficked roads and commercial paved surfaces while customised yields of copper have been developed for all classes of roads. Yields of TN, TP and *E. coli* have been developed for all land cover types.

We recognise that the yields developed here are subject to various sources of uncertainty and that there may be value in considering their further revision as part of model implementation and sensitivity testing. Such testing forms part of the implementation of the CLM and its use to model the "business as usual" (BAU) land cover and stormwater management characteristics, the details of which have yet to be specified. However, in considering any further revision of the yields it will be important to take account of the potential influence of urban diffuse sources of each contaminant on the environmental and socio-economic attributes of interest to the Whaitua Committee. Where their influence is small relative to other contaminant sources (rural and/or point sources), it may be difficult to justify pursuing any further refinement.

5.2 Estimation of loads excluded from core models

Contaminant loads have estimated from the following sources excluded from the core Te Awarua-o-Porirua models:

- TSS, Zn, and Cu loads from roads outside urban limits;
- TN and TP loads during the earthworks phase of Transmission Gully (TG); and
- TN, TP and *E. coli* loads from roads within the TG corridor during the operational phase.

These loads have been estimated at the REC sub-catchment scale to allow aggregation with loads estimated by the core models.

Further contaminant sources excluded from the core whaitua models are loads of Cu and Zn from pervious land covers outside the urban limits. These are to be delivered later, as they will be derived from estimates of sediment loads produced during dSedNet modelling for task B of work brief 1.

Table 5-1: Proposed set of contaminant yields for use in the CLM modelling, Porirua Whaitua. Yields shown in yellow have been customised**.**

Source	Source Type	Yields ($g/m^2/a$, except *E. coli* – No./m^2/a)					
		TSS	Zinc	Copper	TP	TN	*E. coli**
Roofs	Galvanised steel unpainted	5	2.24	0.0003	0.07	1.5	80,000
	Galvanised steel poorly painted	5	1.34	0.0003	0.07	1.5	80,000
	Galvanised steel well painted	5	0.2	0.0003	0.07	1.5	80,000
	Galvanised steel coated(Decramastic)	12	0.28	0.0017	0.07	1.5	80,000
	Zinc/aluminium unpainted (Zincalume)	5	0.2	0.0009	0.07	1.5	80,000
	Zinc/aluminium coated (Colorsteel/Colorcote)	5	0.02	0.0016	0.07	1.5	80,000
	Concrete	16	0.02	0.0033	0.07	1.5	80,000
	Copper	5	0	2.12	0.07	1.5	80,000
	Other materials	10	0.02	0.002	0.07	1.5	80,000
Roads (vpd)	<1000	21	0.0044	0.00088	0.15	1.5	80,000
	1000-5000	28	0.0266	0.00532	0.15	1.5	80,000
	5000-20000	53	0.1296	0.02593	0.15	1.5	80,000
	20000-50000	96	0.3012	0.06023	0.15	1.5	80,000
	50000-100000	158	0.5512	0.11024	0.15	1.5	80,000
	>100000	234	0.8534	0.17068	0.15	1.5	80,000
Paved surfaces other than roads	Residential	32	0.195	0.036	0.18	1.5	80,000
	Industrial	22	0.59	0.107	0.15	1.5	80,000
	Commercial	32	0.162	0.0294	0.18	1.5	80,000
Urban grasslands and trees	Slope < 5	37	0.0019	0.0003	0.19	1.5	80,000
	5 < Slope < 10	108	0.0057	0.0010	0.32	1.5	80,000
	Slope > 10	260	0.0137	0.0023	0.49	1.5	80,000
Construction site open for 12 months/year	Slope < 5	2800	0.1470	0.0252	1.1	4.5	-
	5 < Slope < 10	8291	0.4353	0.0746	3.3	13.3	-
	Slope > 10	19305	1.0135	0.1737	7.7	30.9	-

*Assuming stormwater is contaminated with wastewater from cross-connections etc. Where wastewater contamination is absent, a lower *E.coli* yield of 18,000 m^2/a is proposed.

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7 Glossary of abbreviations and terms

BAU	Business as usual
CLM	Contaminant Load Model
CLUES model	Catchment Land Use for Environmental Sustainability model
CMP	Collaborative Modelling Project
CSO	Combined Sewer Overflow
Cu	Copper
DEM	Digital Elevation Model
E.coli	*Escherichia coli*
GLEAMS model	Groundwater Loading Effects of Agricultural Management Systems model
International BMP Database	International Best Management Practice Database
LCDB	Land Cover Database
MLG	Modelling Leadership Group
NZLRI	New Zealand Land Resources Inventory
REC	River Environment Classification
RSS model	Road Stormwater Screening model
RUSLE	Revised Universal Soil Loss Equation
TG motorway	Transmission Gully motorway
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
URQIS	Urban Runoff Quality Information System
US NSQD	United States National Stormwater Quality Database
VCSN	Virtual Climate Station Network
VPD	Vehicles per day
Zn	Zinc

Appendix A Overview of tasks in Porirua CMP work brief 1

The following diagrams are revised versions of those provided in Porirua CMP work brief 1

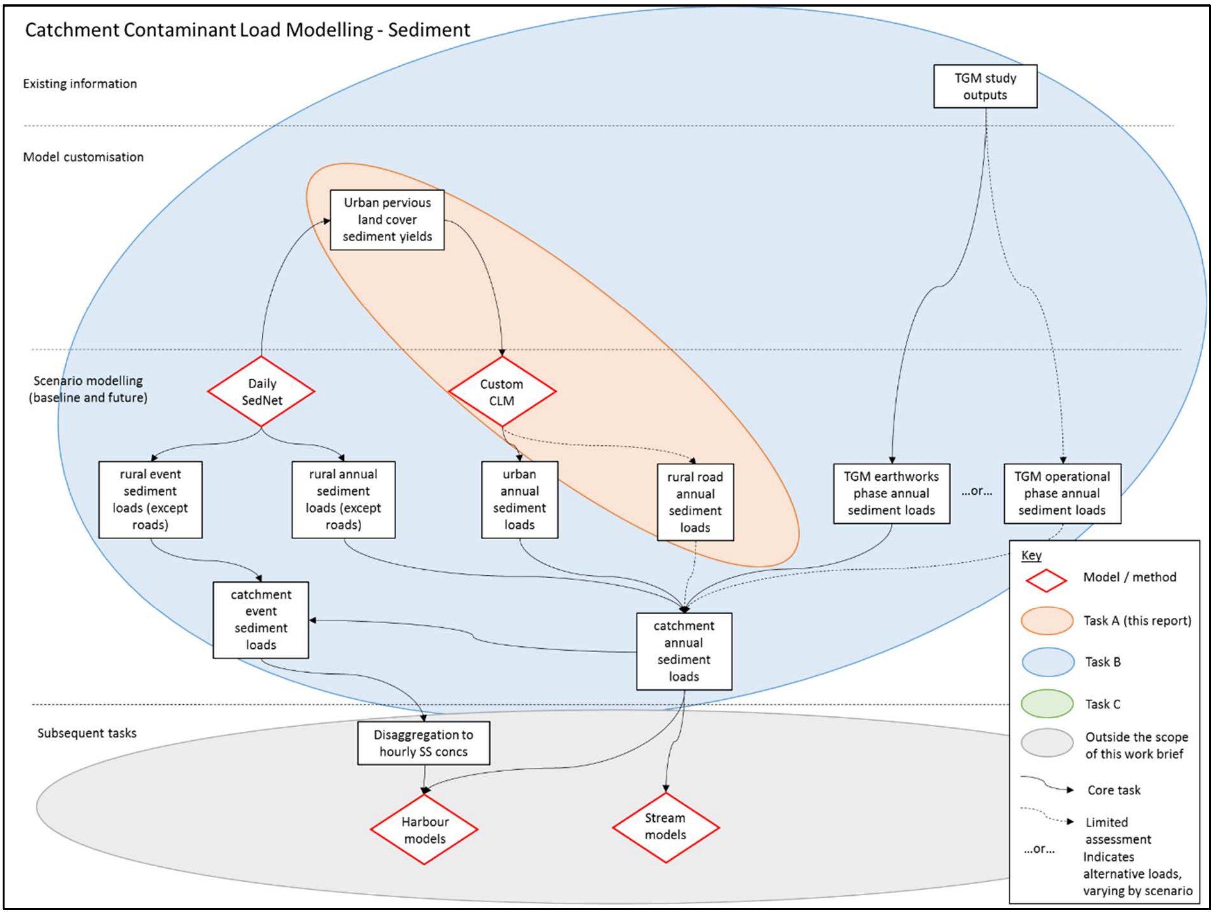

Figure A-1: Tasks involved in modelling catchment sediment loads, Porirua CMP work brief 1.

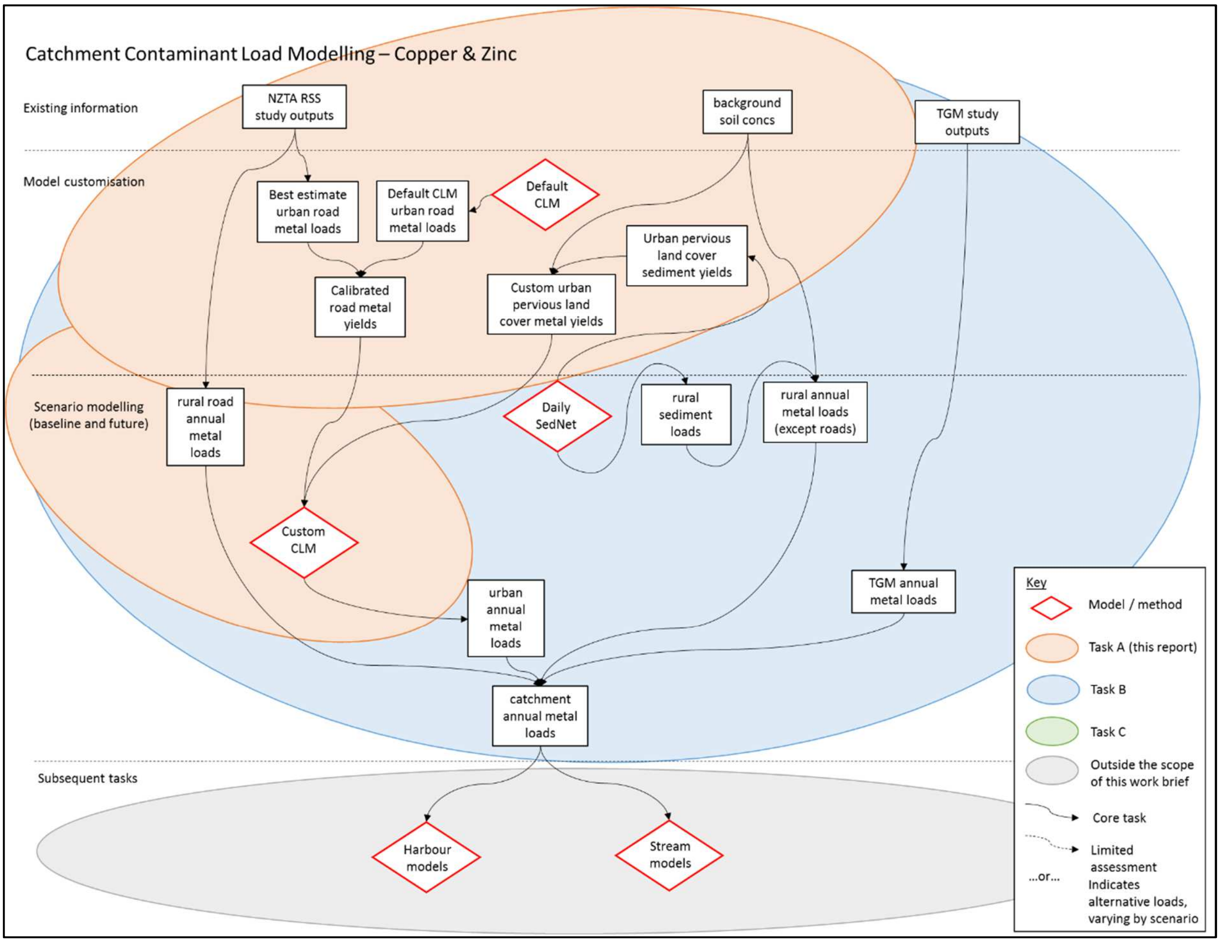

Figure A-2: Tasks involved in modelling catchment copper and zinc loads, Porirua CMP work brief 1.

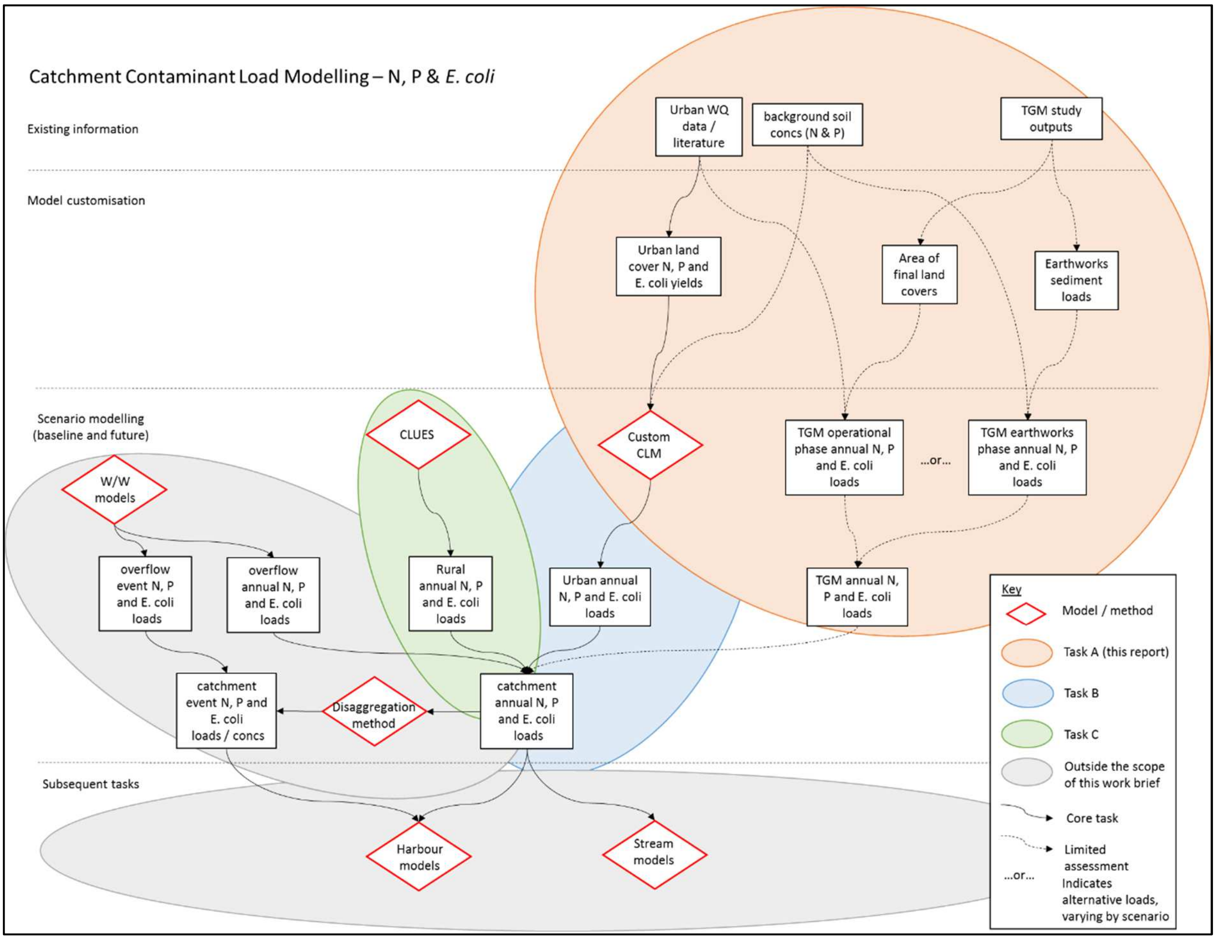

Figure A-3: Tasks involved in modelling catchment N, P and *E.coli* loads, Porirua CMP work brief 1.

Appendix B TG construction loads per catchment per year

Year, catchment, constituent REC sub-catchment	TP load (kg)	TN load (kg)
2016	**372.0**	**1488.2**
Duck	**22.3**	**89.3**
259974	22.0	88.0
260132	0.3	1.3
Horokiri	**296.1**	**1184.4**
258117	2.1	8.5
258241	20.7	82.7
258322	64.9	259.6
258323	15.5	61.9
258494	73.2	292.8
258676	64.1	256.6
258808	46.3	185.0
258875	8.8	35.3
258876	0.5	2.0
Pauatahanui	**53.6**	**214.5**
259948	13.4	53.7
259949	1.2	5.0
259967	6.9	27.6
260133	31.8	127.3
260361	0.2	0.9
2017	**395.8**	**1583.2**
Duck	**26.8**	**107.2**
259974	22.5	89.9
260132	4.3	17.4
Horokiri	**201.8**	**807.2**
257717	33.9	135.6
258060	18.7	74.7
258117	52.5	209.9
258875	22.1	88.5
258876	1.1	4.4
258896	32.2	128.9
259010	41.3	165.3
Pauatahanui	**46.7**	**186.7**
259949	22.8	91.2
260133	23.5	93.9
260361	0.4	1.6
Ration	**120.5**	**482.0**
259112	19.8	79.3
259240	18.6	74.2

Year, catchment, constituent REC sub-catchment	TP load (kg)	TN load (kg)
259388	15.5	61.9
259399	3.6	14.2
259472	11.2	44.9
259556	11.0	44.1
259625	40.9	163.5
2018	**394.6**	**1578.5**
Duck	**8.7**	**34.6**
260132	8.7	34.6
Horokiri	**288.4**	**1153.6**
257419	91.2	364.8
257543	45.0	179.9
257648	31.3	125.3
257717	120.9	483.5
Kenepuru	**18.5**	**73.8**
260769	7.8	31.4
260778	3.3	13.1
261038	4.8	19.3
261039	2.5	10.1
Pauatahanui	**0.0**	**0.1**
260603	0.0	0.1
Porirua	**79.1**	**316.3**
260856	15.2	60.7
260916	14.9	59.7
261063	7.0	28.1
261112	29.5	117.8
261113	12.5	50.0
2020	**102.8**	**411.3**
Duck	**58.2**	**233.0**
260844	0.0	0.1
260845	5.9	23.5
260870	38.1	152.6
260871	14.2	56.8
Kenepuru	**15.3**	**61.3**
260905	8.0	32.0
261039	2.9	11.6
261226	0.3	1.1
261227	4.1	16.5
Pauatahanui	**28.8**	**115.0**
259949	28.8	115.0
Ration	**0.5**	**2.1**
259625	0.5	2.1

Year, catchment, constituent REC sub-catchment	TP load (kg)	TN load (kg)
2021	**41.3**	**165.3**
Duck	**22.8**	**91.0**
260870	22.8	91.0
Kenepuru	**7.5**	**30.2**
260905	3.1	12.6
261226	0.3	1.1
261227	4.1	16.5
Pauatahanui	**11.0**	**44.1**
259949	11.0	44.1
Undefined	**60.0**	**240.2**
Duck	**60.0**	**240.2**
260132	21.7	86.8
260678	15.0	59.9
260679	8.8	35.4
260787	5.7	22.7
260788	4.9	19.7
260845	3.9	15.6

Appendix C TG operational contaminant loads

Catchment, constituent REC sub-catchment	TP load (g/year)	TN load (g/year)	*E.coli* load (n/year)
Duck	**24621**	**246207**	**2954488489**
259974	6341	63411	760933222
260110	1841	18407	220885284
260132	7661	76614	919366057
260678	1412	14121	169448871
260679	775	7751	93013196
260787	520	5200	62404209
260788	398	3975	47701879
260845	934	9342	112109874
260870	3334	33336	400036312
260871	1405	14049	168589583
Horokiri	**32604**	**326041**	**3912489455**
257419	3706	37064	444768398
257543	1871	18711	224526739
257648	1356	13561	162736445
257717	6382	63816	765792168
258060	792	7922	95069546
258117	2245	22450	269398874
258241	938	9375	112500284
258322	2725	27250	327003424
258323	540	5403	64834732
258494	3058	30577	366921839
258676	2604	26044	312532553
258808	1982	19819	237826944
258875	1358	13576	162906226
258896	1325	13255	159059908
259010	1722	17218	206611374
Kenepuru	**13211**	**132108**	**1585293525**
260425	1464	14640	175674575
260769	2724	27242	326898811
260778	1151	11506	138068490
260905	2904	29042	348509831
261038	1684	16838	202053746
261039	1959	19589	235067166
261227	1325	13252	159020905
Pauatahanui	**24205**	**242051**	**2904608724**
259948	6714	67144	805731922

259949	5046	50457	605484409
259967	3847	38467	461606953
260133	6968	69677	836119717
260167	1243	12435	149216937
260361	387	3871	46448785
Porirua	**13877**	**138774**	**1665289357**
260856	1716	17159	205902878
260915	1044	10438	125253516
260916	2423	24226	290710188
261030	1212	12118	145412577
261112	3217	32172	386068081
261113	4266	42662	511942116
Ration	**13599**	**135991**	**1631895324**
259112	2242	22423	269080393
259240	2079	20786	249429042
259388	1791	17912	214946303
259399	326	3256	39067117
259472	1308	13083	157000119
259556	1311	13109	157302073
259625	4542	45423	545070276
Total	**122117**	**1221172**	**14654064873**