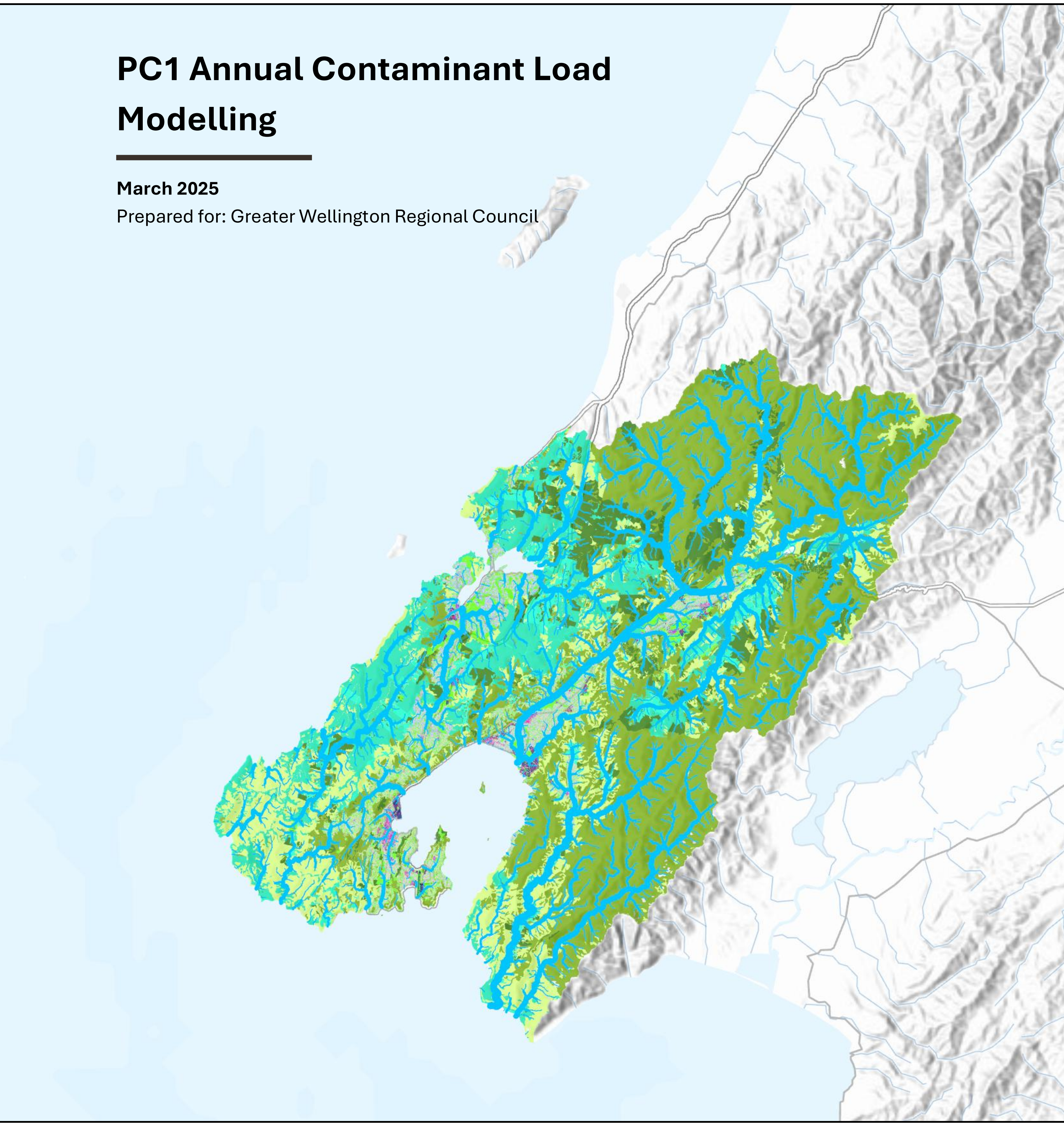
PC1 Annual Contaminant Load Modelling

March 2025

Prepared for: Greater Wellington Regional Council



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Collaborations

Summary

An annual load model has been developed for copper, zinc, and sediment for catchments in the Proposed Change 1 (PC1) area to assess the PC1 provisions and their effectiveness, which have not been explicitly modelled to date.

Annual average contaminant loads have been estimated based on literature and methods established during the Te Awarua-o-Porirua and Te Whanganui-a-Tara Whaitua processes. Two existing contaminant load model spatial layers covering the two whaitua were amalgamated to cover all of the PC1 area. The baseline model is an approximation of contaminant loads at 2012, approximately aligned with the water quality objective setting period. A notified PC1 future development state (PC1-FDS) scenario was then developed to account for urban growth from 2012 to 2024 and projected urban growth to 2053 based on the most recent regional predictions. Provisions in PC1 were represented in the PC1-FDS scenario using load reduction factors based on published literature.

Modelled loads are compared at the target attribute state sites and Porirua Harbour catchments to predict the relative (%) reduction that could be anticipated should the provisions be in full effect. Results show a reduction in contaminant loads for zinc, copper, and sediment in the PC1-FDS scenario. This is due to a combination of modelled factors such as land-use change (e.g. development or roof replacement) and Load Reduction Factors (LRF) and mitigations related to PC1 provisions.

While the developed annual load models do not predict changes in concentrations due to the lack of hydrological consideration, they provide an overview of changes in water quality by accounting for drivers of contaminant load increase (development) and decrease (mitigations). In addition, the model provides the ability to rapidly test the potential effectiveness of revised provisions or other scenarios.

Contents

1 Introduction

Greater Wellington Regional Council (GWRC) are currently undertaking Proposed Change 1 (PC1, also referred to as 'Plan Change 1') to the Natural Resources Plan (NRP). The water quality objectives of PC1 give effect to the National Policy Statement for Freshwater Management 2020 (NPS-FM) by managing key activities to control their impacts on water quality and ecological health within Te Awarua-o-Porirua (TAoP) and Te Whanganui-a-Tara (TWT) Whaitua (the PC1 area). Collaborations have been engaged to develop an annual load model for copper, zinc, and sediment for catchments in the PC1 area to inform and test current and potential provisions for PC1.

1.1 Background

Water quality objectives have been set through the TAoP and TWT Whaitua processes. Extensive modelling has been undertaken and, for TWT Whaitua, an expert panel of scientists were used to assess hydrology and water quality states for a range of contaminants relevant to the NPS-FM attribute tables. Modelling included the development of a daily hydrological and water quality model (eWater 'Source' model) which was used to model the current state 'baseline', and for TAoP Whaitua to test three future scenarios. The scenarios incorporated future growth and development and tested different levels of water sensitive urban design (WSUD) in urban environments and enhanced mitigations in rural environments to reduce contaminant loading. The three scenarios (business as usual, improved and water sensitive) provided an indication to the Whaitua Committee on the level of effort required to achieve a water quality attribute state (i.e. shifting nitrate-N concentrations from a B attribute state to an A state), which helped guide the setting of Target Attribute States (TAS) in various catchments.

However, the scenarios assessed in the Whaitua processes do not precisely reflect the PC1 provisions, which were drafted after the completion of both Whaitua. PC1 provisions reflect specific rules and policies seeking to achieve the TAS, and while a S32 analysis was undertaken to predict what the provisions may achieve (Greer 2023), they have not been modelled or assessed by an expert panel.

Updating of the Source Model was not possible in the timeframe available, as this would require building and calibrating a Source Model with water quality (sediment, metals, and nutrients) sub-models for TWT Whaitua. In addition, Source modelling is complex and time-intensive to design and run scenarios, reducing the ability to simulate provisions in short timeframes should they change.

Collaborations have subsequently been engaged to develop an annual average load model for copper (Cu), zinc (Zn), and sediment for catchments in the PC1 area to inform and test current and potential provisions for PC1 to help advise GWRC and S42a authors.

The modelling is intended to align with the previous Source daily-time step modelling undertaken for the Porirua whaitua to provide additional support to the analysis undertaken by Dr. Greer to predict what the provisions may achieve (Greer 2023), and to understand potential contaminant load changes that may occur with more recent information regarding future development, for example in the Porirua Northern Growth Area in the Taupo Stream catchment.

A CLM approach was adopted for metals as existing CLM spatial mapping has previously been undertaken for both Whaitua and extensive customisation was carried out for the TAoP Whaitua to tailor the CLM contaminant yields to the Wellington region (Moores et al., 2017). For sediment, a custom annual load model has been developed, adapted from erosion risk mapping undertaken by Collaborations (Collaborations, 2023) while seeking to align with the TAoP Whaitua daily SedNet (dSedNet) modelling (Jacobs, 2019).

This report documents the data sources and methodology used to map the Whaitua land use and land cover (Section 2) and develop customised annual load models for metals (Zn & Cu) and sediment (Section 3.3). The methodology and parameters used for the development of a future scenario which includes proposed PC1 provisions are presented in Section 4. Results including comparisons between the current state (baseline) and the future PC1 scenario are briefly summarised in Section 5. It is expected that further scenarios are developed and/or additional metrics reported as the PC1 hearing process progresses.

1.2 Modelling overview

Metals have been modelled using the customised CLM that was developed for TAoP Whaitua (Moores et al., 2017) and applied in TWT Whaitua (Easton and Hopkinson, 2022). Sediment has been modelled using a bespoke annual load model. Sediment losses have been estimated using the CLM for urban land uses and for surficial, landslide, and streambank erosion processes for rural land following the methods described in Section 3.3.

The modelling approach estimates annual average contaminant loads based on diffuse annual loss rates ('yields') mapped to detailed land use and land cover categories. Point sources such as wastewater overflows have not been modelled. Results may be aggregated to various scales (e.g. by catchment, FMU, or land use category). Outputs aid identification of contaminant critical source areas and can test the effectiveness of mitigations and impact of land use change (e.g. urban development). However, as there is no hydrological component to the modelling, water quality concentrations or changes in concentrations due to interventions are not predicted (e.g. annual median or 95th percentile concentrations).

The developed models are intended to test and inform potential provisions during the PC1 process. Two scenarios are briefly summarised in this report, a baseline representative of land use at 2012, and a future PC1 scenario which accounts for PC1 provisions and development to the year 2053.

2 Land use mapping

2.1 Baseline mapping

The baseline mapping process combined the previously developed TAoP (Jacobs, 2019) and TWT (Easton & Hopkinson, 2020) Whaitua land use maps (see respective reports for data and methods). Limitations associated with the accuracy of the land use mapping are discussed in Easton & Hopkinson (2020). For the TAoP CLM, the rural zone was unavailable in the existing data and was re-mapped using the Land Cover Database (LCDB) dataset for 2012 to maintain alignment with the original TAoP mapping and modelling. Additionally, TAoP rural roads were incorporated into the mapping by buffering LINZ centrelines[1], following the methodology used in the original CLM mapping process.

The baseline land use map is shown in **Appendix A**. The mapping is representative of the land use configuration at approximately 2012.

3 Baseline contaminant modelling

3.1 Overview

The baseline metals and sediment models cover the PC1 area (TAoP and TWT Whaitua together) based on the mapping described in Section 2. The models have been developed to align with previous Whaitua models in regard to input data and parameterisation despite being annual average load models (rather than the daily time-step Source Model and dSedNet sub-model).

3.2 Metals

Urban annual contaminant loss rates for different land uses and surfaces have been derived from the customised CLM developed for TAoP Whaitua (Moores et al., 2017), applied to the mapped land use categories (Section 2) to estimate annual average loads. The contaminant loss rates are predominantly derived from New Zealand stormwater runoff studies originating from Auckland Council, assessed and updated with local information, including Kāpiti Coast District Council (KCDC) stormwater monitoring, Wellington region soil testing, and Wellington region roof material information. Load Reduction Factors (LRFs) simulating stormwater treatment devices (such as bio-retention or raingardens as defined in provisions) have been applied to various land covers in the modelled future scenario (see Section 4.3). LRFs have not been applied in the baseline scenario due to a lack of information.

Rural zinc and copper loss rates have been estimated using soil metal concentrations, consistent with the TAoP Whaitua CLM customisation. Values of 52.5 mg kg^{-1} and 9 mg kg^{-1} have been adopted as representative background concentrations of zinc and copper, respectively. These concentrations are median values from soil sampling across the Wellington region (URS, 2003) and are discussed in Moores et al. (2017). Soil metal concentrations have been applied to the modelled sediment load (Section 3.3).

[1] https://data.linz.govt.nz/layer/50329-nz-road-centrelines-topo-150k/

3.2.1 Limitations

The CLM methodology provides a robust, literature-based approach to estimating annual average total metal loads. Metals yields are based on limited data however, and subject to various sources of uncertainty; they may not be representative of the range activities that occur on or within a given land cover type. Further limitations and uncertainties associated with the contaminant yields are discussed in ARC (2010) and Moores et al. (2017). Additionally, stormwater treatment devices have not been accounted for in the baseline model which may result in an over-estimation of baseline loads where they are installed.

3.3 Sediment

A customised annual sediment load model has been developed based on the erosion risk mapping undertaken by Collaborations for GWRC PC1 (Collaborations, 2023[2]), TAoP and TWT dSedNet modelling (Jacobs, 2019a; Jacobs, 2020), and the customised CLM developed for TAoP Whaitua (Moores et al., 2017). The sediment load model has been designed to maintain consistency with previous Whaitua dSedNet modelling while allowing for land use change and mitigations associated with PC1 provisions to be tested using an average-annual approach. Sediment loads have been calibrated to the three sites in TAoP Harbour catchment sediment monitoring programme for the period of 2012-2016 to align with the dSedNet baseline period (Jacobs, 2019).

Sediment loads from urban land uses have been estimated following the CLM (Moores et al., 2017). For rural land uses, loads have been estimated for surficial, landslide, and streambank processes, consistent with the processes modelled using dSedNet for the TAoP and TWT Whaitua.

3.3.1 Surficial erosion

Surficial erosion is estimated using the Revised Universal Soil Loss Equation (RUSLE) mapped spatially at 5m scale for GWRC (Collaborations, 2023). A Sediment Delivery Ratio (SDR) of 0.5 has been applied to estimate the proportion of eroded sediment delivered to the stream network (Dymond et al., 2016). 0.5 is consistent with the TWT dSedNet modelling and provides utility for reporting on non-hydrological catchments or areas (e.g. part-FMUs), that would otherwise not be practicable using a catchment-size based method.

3.3.2 Shallow landslide erosion

Following the dSedNet methodology (Jacobs, 2019), and consistent with the erosion risk mapping (Collaborations, 2023), landslide-susceptible land has been mapped as steep land (above 26 degrees) without woody vegetation cover. Where woody vegetation cover is present on steep land, landslide risk is deemed present, however, reduced by 90% following Dymond et al. (2016) and Basher et al. (2018). This provides consistency with mitigation testing for future scenarios, where landslide-associated sediment loads have been reduced by 90% following the maturation of native retirement.

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[2] https://www.gw.govt.nz/assets/Documents/2023/10/Easton-Nation-and-Blyth-2023.-Erosion-risk-mapping-for-TAoP-Whaitua-and-Whaitua-TWT.pdf

The alignment of the model calibration period (2012-2016) with the TAoP dSedNet modelling allows for annual sediment loads to be associated with the mapped landslide-susceptible land based on the load estimated by dSedNet (see Jacobs 2019a). In dSedNet, shallow landslide events were estimated to occur on steep land without woody vegetation cover based on the modelled quickflow run-off rate during each event, with event loads modelled to occur once the average rainfall in the preceding three days had exceeded 30 mm. In the average annual model described here, the estimated proportion of total load attributed to landslides in dSedNet has been applied to the mapped landslide-susceptible area. The consideration of rainfall and runoff in the model developed here is therefore not explicit.

In general, the adopted landslide modelling approach is simplistic, however landslides are difficult to predict with confidence due to their complex range of influencing factors (including geology, soil, land cover, and seismic activity) and localised nature of triggering rainfall-events (as outlined in Phillips *et al*., 2024). Landslides can occur on a wide-range of slope angles, with risk generally increasing with angle until a stabilisation point is reached (see Betts et al., 2017). It is recognised that the slope threshold for national highly erodible land mapping for hill country un-weathered to moderately-weathered greywacke is 28 degrees in Dymond & Shepherd (2023). However, Wellington greywacke is highly varied in terms of weathering and geomechanical properties (Brideau et al., 2020) and consistency with the previous dSednet modelling has been maintained here. This is supported by recent statistical modelling that predicts landslide susceptibility at lower slope thresholds and for slopes under woody vegetation (Smith et al., 2021). It is likely that the mapped landslide-susceptible area is conservative and refinement with updated information will likely reduce the mapped area.

3.3.3 Streambank erosion

Following the TWT dSedNet model (Jacobs, 2019), streambank erosion has been predicted following the methodology in SedNetNZ (Dymond et al., 2016), applied to River Environments Classification (REC) stream lengths:

$$Bj = \rho \; Mj \; Hj \; Lj$$

Equation 1

where *Bj* is the total mass of soil eroded by bank erosion in the *j*th stream link (t yr),
ρ is the bulk density of soil (t m^{-3}),
Mj is the bank migration rate of the *j*th stream link (m yr),
Hj is the mean bank height of the *j*th stream link (m), and
Lj is the length of the *j*th stream link (m).

Soil bulk density is estimated as 1.5 t/m^3 following Mueller & Dymond (2015). The bank migration rate is estimated from an empirical relationship with the mean annual flood (Dymond et al., 2016; Mueller & Dymond, 2015). Estimates of bank height are also derived from a relationship to modelled discharge developed from bank height field observations following Dymond et al. (2016). Discharge has been estimated using a relationship between median flow derived from national modelling (Booker & Woods, 2014)[3] and mean annual flood derived from the Porirua Whaitua Source hydrological model outputs (Jacobs, 2019). Stream length is calculated as the sum of second order or higher REC 2 stream length represented by each model link.

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[3] Accessed using NIWA rivermaps *https://shiny.niwa.co.nz/nzrivermaps/*

Where streambanks are deemed to be vegetated and exclude animal access, an 80% reduction in streambank load has been adopted following SedNetNZ (Dymond et al., 2016, also reported in Neverman et al. 2019). As there is no readily available fencing or riparian vegetation information for the project catchments, a spatial data intersect was undertaken between the REC stream reaches and LCDB information with stock exclusion assumed to occur on vegetated land covers in the baseline and scenario models (i.e. non-pastoral and urban land uses). Scenario assessment of additional stock exclusion related to PC1 provisions has been based on mapping provided by GWRC.

3.3.4 Sediment load calibration

Sediment loads have been calibrated to the three sites in TAoP Harbour catchment sediment monitoring programme: Pāuatahanui Stream at Gorge, Porirua Stream at Town Centre, and Horokiri Stream at Snodgrass (GWRC, 2023). Calibration involved matching the modelled annual load and observed annual average load at the three monitoring catchments (together) for the period of 2012-2016 (Table 1) to align with the dSedNet baseline period (Jacobs, 2019). Calibrated parameters were manipulated to maintain the proportionality of sediment load attributed to surficial, landslide, and streambank erosion as estimated by dSedNet for the three calibration catchments (Table 2). Calibration was to the total load for the three catchments combined to achieve a single set of parameter values able to be applied globally within the model (i.e. to catchments outside of the TAoP Harbour catchment sediment monitoring programme).

Table 1. TAoP Harbour catchment sediment loads for 2012 - 2016 (adapted from GWRC, 2023).

Monitoring Site	Monitoring Days	Total Load (t)	Daily Load (t/day)	Average Annual Load (t/year)	Total Average Annual Load (t/year)
Pauatahanui Stream at Gorge	1271.7	16,264	12.8	4,671	12,321
Porirua at Town Centre	1565.2	18,139	11.6	4,233	
Horokiri Stream at Snodgrass	1471.7	13,769	9.4	3,417	

Table 2. Erosion type proportionality as estimated by dSedNet for Pāuatahanui Stream at Gorge, Porirua Stream at Town Centre, and Horokiri Stream at Snodgrass (combined).

Erosion Process	Proportion of Total Load
Surficial (including Urban)	47%
Shallow Landslide	36%
Streambank	16%

For the surficial erosion component, a load scaling factor was applied to match the modelled RUSLE surficial load to the estimated annual surficial load tied to observed monitoring data and modelling proportions (47% of 12,321 t based on Table 1 and Table 2). The streambank erosion component was calibrated by adjusting the net fraction of gross load to match the estimated proportion of the observed load attributed to streambank erosion. A net-fraction of 0.4 has been adopted, comparable to 0.2 as reported in Dymond et al. (2016) based on measurements for the Waipaoa River. For the shallow landslide component, 1,574 ha of land susceptible to land-sliding were mapped within the calibration catchments (Section 3.3.2), resulting in an average yield of

2.82 t/ha/year of sediment delivered to the stream network based on the estimated landslide-attributed proportionality of total load.

Note that this calibration process does not prescribe the proportionality of the three modelled erosion processes to other catchments as each erosion process is spatially modelled according to the methods described in Sections 3.3.1 to 3.3.3. The proportionality of the erosion processes is also based on modelled rather than observed information and is uncertain. Final calibrated model loads are shown in Table 3.

Table 3. Calibrated annual sediment loads.

Monitoring Site	Total Modelled Load (t/year)	Modelled Erosion Process (t/yr, proportion in parentheses)		
		Surficial & Urban	Shallow Landslide	Streambank
Pauatahanui Stream at Gorge	3853	1643 (43%)	1675 (43%)	535 (14%)
Porirua Stream at Town Centre	4443	2534 (57%)	1107 (25%)	801 (18%)
Horokiri Stream at Snodgrass	3925	1558 (40%)	1655 (42%)	713 (18%)
Total	12220	5735 (47%)	4436 (36%)	2049 (17%)

3.3.5 Discussion and limitations

The developed annual average sediment load model is intended to provide estimates of annual average loads and assess change following interventions within the PC1 catchments. The model seeks to align previous dSedNet modelling methods with static GIS erosion prone land risk mapping that has been used by GWRC to inform policies and rules.

It is recognised that improved data and methods have been developed since the TAoP dSedNet modelling, for example updated RUSLE factors in Donovan (2022), updated streambank and landslide erosion consideration in SedNetNZ (Smith et al., 2019; Betts et al., 2017), and improved landcover mapping held by GWRC. However, the methodology utilised for the TAoP and TWT Whaitua modelling has been followed where practicable to maintain consistency between load predictions, alignment with Whaitua scenarios, and in-stream targets set by the Whaitua Committee based on the dSedNet results. Furthermore, the dSedNet modelling demonstrated satisfactory calibration and validation performance when evaluated against continuous monitoring data, confirming the suitability of the modelling methodology.

In addition to those previously mentioned, there are several assumptions and limitations associated with the sediment model:

- Annual loads have been calibrated to three catchments in Porirua; model estimates of annual load are uncertain outside of the calibration catchments.
- It is recognised that annual sediment load predictions may be underreported due gaps in the sediment load monitoring, for example during extreme events owing to equipment failure (GWRC, 2023).

- The proportionality of the different erosion processes is based on previous modelling and not validated by observation or sediment source tracking methods.
- While sediment delivery processes such as interception or deposition are broadly accounted for to estimate total in-stream loads, the erosion model does not account for spatial variability of sediment delivery processes that influence connectivity to the stream network of eroded sediments.
- The model is calibrated to annual average loads and does not attempt to model specific event loads. During extreme events it is expected that total loads are far greater than predicted in this model which is calibrated to average annual loads over a 5-year period of relatively mild climate. Over longer time-scales the proportion of sediment load from landslide and streambank erosion processes is expected to increase.
- Earthworks, forestry harvest, or other land-disturbing activities are not modelled. Similarly, already-implemented erosion control measures such as established pole planting, sediment retention bunds, or adoption of best management practices are not accounted for in the model baseline or scenarios.

4 Scenario modelling

This section documents the development of a 'PC1 Future Development scenario' (PC1-FDS), which represents a future date of approximately 2053 and assesses PC1 draft provisions (as at December 2024).

4.1 Recent development

Future development has been modelled for scenarios (see Section 4.2). Additional mapping has also been undertaken to account for the development period between the original CLM mapping (2012 base-year) and the present. This mapping used a process where new greenfield and infill developments were identified based on changes in the LINZ building outline dataset[4] and professional judgement. Within the identified development areas, the 2012 mapped land use was updated using the urban configurations given in Table 5. In addition to urban developments, the Transmission Gully expressway (TG) has also been mapped and included in the PC1-FDS scenario.

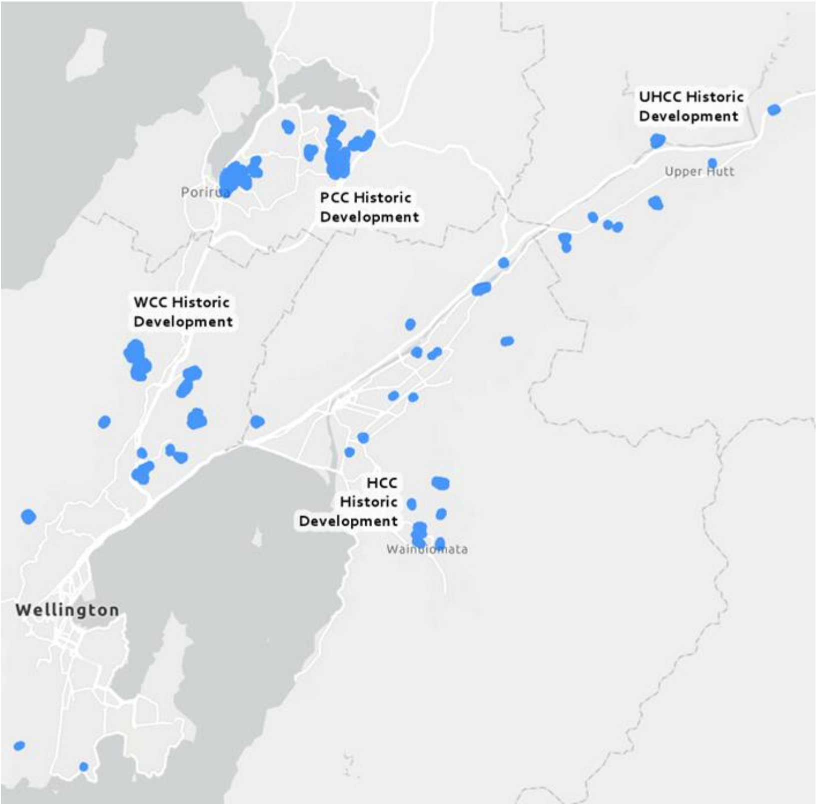

Figure 1. Recent development areas (blue) making up the 12-year development period from the 2012 CLM (updated to 2024).

[4] https://data.linz.govt.nz/layer/101290-nz-building-outlines/

4.2 Future urban development

Future residential urban development has been estimated based on information supplied by GWRC[5]. Development estimates are derived from the Future Development Strategy 2024 (WRLC, 2024) which predicted where urban growth is likely to occur across the region based on existing policies, central government direction and trends at the time. Table 4 summarises the additional dwellings modelled within the PC1 area (totalling 78,288) across three categorisations; Medium Density Residential Standards (MDRS) infill, planned infill, and greenfield. Only residential development has been modelled due to a lack of information regarding commercial or industrial development.

Table 4. Greenfield and infill modelled dwellings.

Territorial Authority	MDRS Infill	Planned Infill	Greenfield
Porirua	8360	3500	7330
Wellington	19500	19000	-
Lower Hutt	9384	3500	-
Upper Hutt	6254	860	600

For planned infill and greenfield developments, the geographic areas were digitised in GIS using the best available data (Appendix B), then modelled using estimated lot sizes and configurations of roads, roofs, paved surfaces, and urban greenspace. Urban configurations were derived from the Kapiti Whaitua CLM assessments (Collaborations, 2022) and corroborated via assessment of the baseline CLM mapping within the PC1 area. The configurations account for high, medium, and low-density developments and are summarised in Table 5.

Development types have been applied to the mapped areas for planned infill and greenfield based on the estimated number of dwellings and the development size. Figure 2 maps the future development areas. For future MDRS Infill which is not able to be accurately predicted and mapped, additional dwellings have been applied proportionally across the existing residential urban zone: 10-17% of each territorial authority's existing residential urban area has been 'infilled' based on the estimated number of dwellings (Table 4), dwellings per hectare (Table 5), and available area. Infilling has been spread across all residential land covers: residential roofs, paved surfaces other than roads, and urban grasslands and trees. At a catchment scale, infilling results in a reduction in the area of urban grasslands and trees and an increase in the area of roofs and paved surfaces other than roads.

Table 5. Future development configuration.

Development types	Dwellings/ha	Roads	Roofs**	Paved Residential	Urban Grasslands and Trees
Greenfield	15	16%	25%	14%	45%
Infill (Planned and MDRS)	27	0%*	50%	30%	20%
Infill (High-Density Apartments)	197	0%*	63%	20%	17%

* Infill types are modelled to use the existing road network with increased traffic as described in Section 4.3.
**All future development roofs are modelled as low-yielding Colorsteel.

[5] 'Developments for Preferred Scenarios' spreadsheet provided by GWRC in September 2024

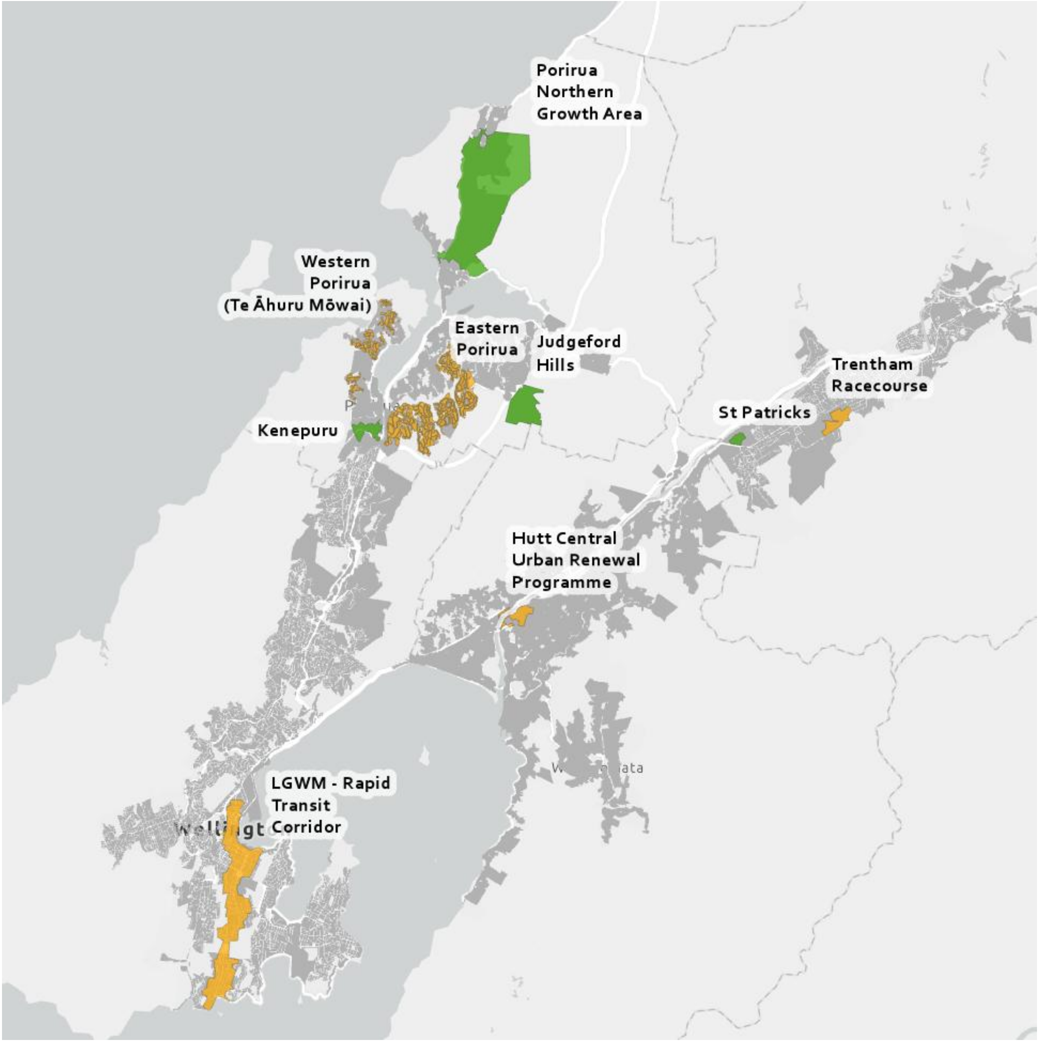

Figure 2. Future development: greenfield (green), planned infill (orange) and where a proportion of MDRS infill is applied (grey).

4.3 Non-development future change

The following bullets summarise other changes modelled in the PC1-FDS scenario not directly related to urban development or PC1 provisions:

- Roof replacement: 50% of existing roofs (residential, industrial and commercial) have been estimated to be replaced by low-zinc yielding Colorsteel[6]. This is consistent with the Porirua Whaitua Improved Scenario (Jacobs, 2019b).
- Traffic increase: Road yields of metals have been increased by 15%, consistent with the medium population growth scenario for Porirua City, Upper Hutt City, Lower Hutt City and Wellington City from 2018 to 2048[7].
- Transmission Gully (TG) offset retirement area: A 275-ha area is modelled as retired in the headwaters of the Kenepuru Stream and Duck Creek.

[6] Colorsteel roofs represented in the PC1-FDS scenario have substantially lower yields than the baseline roof yields, with relative reductions of residential roof zinc and copper yields of ~96% and 20%, respectively.
[7] StatsNZ 2024 Subnational population projections. https://www.stats.govt.nz/information-releases/subnational-population-estimates-at-30-june-2024-2018-base/

- TG expressway operational: TG road mapped and a LRF of 70% has been applied to TG contaminant yields to simulate the adoption of stormwater treatment devices based on Islam & Summerhays (2017). Note that traffic changes resulting from traffic moving off other roads (e.g. ex-State Highway 1) due to TG has not been accounted for.

4.4 PC1 provisions

This section summarises the model changes undertaken to simulate the adoption of PC1 provisions for the PC1-FDS scenario. The modelled provisions and their representation in the model were developed in collaboration with GWRC. The provision summaries here are simplified to allow for representation in the modelling framework and not all PC1 provisions have been modelled, for example specific provisions related to earthworks or forestry harvest activities are not represented.

4.4.1 Urban provisions

Table 6 summarises the urban provisions modelled in PC1-FDS scenario. The provisions were modelled using a LRF of 76.5% applied to greenfield, planned infill, and MDRS infill impervious surface metal and sediment yields. The LRF is equivalent to 85% of the runoff volume treated to 90% efficiency. No treatment was considered on existing impervious surfaces or roads, except for the TG expressway (see Section 4.3).

Table 6. Modelled urban Provisions.

Effects	Provision
Stormwater management	New infill and urban developments carried out under Rule P.R6 and Rule P.R7 generally required to treat stormwater with the equivalent of a bioretention device.
	Some infill and urban developments >0.3 ha carried out under Rule P.R10 required to provide treatment and hydrological controls through consent conditions (Policy P.P10 and Policy P.P13).

4.4.2 Rural provisions

Table 7 summarises the rural provisions modelled in PC1-FDS scenario. The proceeding bullets describe the modelling methodology for each effects type.

Table 7. Modelled rural provisions.

Effects	Whaitua	Provision
Rural Retirement	Porirua	Encompasses BAU retirement which are required by existing resource consents.
	Porirua	Rule P.R26(b) and Schedule 36(B)&(E) require retirement of all highest erosion risk land on farms >20 ha by 2040 (50% by 2023).
	Wellington	WH.R27(b) and Schedule 36(B)&(E) require retirement of all highest erosion risk land on farms >20 ha by 2040 (50% by 2023).
Space Planting	Porirua	Rule P.R26(b) and Schedule 36 (E)(3)(c) require appropriate soil conservation treatment (assumed to be space planting) on all high erosion risk land on farms >20 ha.

	Wellington	Rule WH.R27(b) and Schedule 36 (E)(3)(c) require appropriate soil conservation treatment (assumed to be space planting) of all high erosion risk land on farms >20 ha
Livestock Exclusion	Porirua	The ERTPs required under Rule P.R26(b) should result in the exclusion of livestock in rivers running through highest erosion risk land on farms >20 ha.
	Wellington	The ERTPs required under Rule WH.R27(b) should result in the exclusion of livestock in rivers running through highest erosion risk land on farms >20 ha.
	Wellington	Rule WH.R28 requires livestock exclusion on all rivers >1m wide in the Makara and Mangaroa River Catchment unless resource consent is obtained (Rule WH.R29) or a small stream riparian programme is developed and cattle/deer/pig crossings are supervised to a maximum of 2x per month (Rule WH.R28(b) and Schedule 36(F)).
	Wellington	Rule R98(b)&(c) of the NRP requires livestock exclusion on all Category 2 surface water bodies unless resource consent is obtained (Rule R99).
Riparian Management	Porirua	The ERTPs required under Rule P.R26(b) require riparian planting of rivers running through highest erosion risk land on farms >20 ha.
	Wellington	The ERTPs required under Rule WH.R27(b) requires riparian planting of rivers running through highest erosion risk land on farms >20 ha.

- Rural retirement
  - Land use change to established woody vegetation on highest erosion risk land (top 10th percentile) on pasture for properties >20ha based on previous Collaborations mapping for PC1 (Collaborations, 2023).
  - Where land use change to retirement occurs, surficial erosion is reduced by 50% and landslide erosion reduced by 90% based on Dymond et al. (2016).
  - While Dymond et al. (2016) estimate retirement to be 90% effective on total hillslope erosion (surficial and landslide), a 50% reduction in surficial erosion maintains internal model consistency as it is equivalent of the change in RUSLE C-factor from 0.01 (pasture) to 0.005 (woody vegetation) and is consistent with TAoP dSedNet modelling (Jacobs, 2019b).

- Space planting
  - Established space planting modelled on high erosion risk land (top 30th percentile) on pasture for properties >20ha based on previous Collaborations mapping for PC1 (Collaborations, 2023).
  - Landslide erosion reduced by 70% where space planting is modelled based on Dymond et al. (2016). No reduction in surficial erosion has been modelled.
  - It is recognised that Dymond et al. (2016) estimate space planting to be 70% effective on total hillslope erosion (surficial and landslide) however no effect on surficial erosion has been modelled as a conservative measure to ensure a lower effectiveness than retirement and reflect the difficulty in establishing space-planting in the PC1 area[8].

[8] GWRC land management, personal communication, 5/12/2024.

- Livestock exclusion & riparian management
  - Streambank erosion reduced by 80% for mapped reaches (provided by GWRC) based on Dymond et al. (2016).
  - Surficial erosion is reduced by 50% within a 5m buffer of mapped retired reaches (as for retirement).
  - Note that streambank erosion is modelled only for 2nd order or greater streams. Provisions may be applicable to 1st order streams however they have not been explicitly modelled or summarised in Table 8 or Table 10.
  - National regulations pertaining to livestock exclusion from streams on low-slope land were initially modelled, however, have been removed here after those regulations were repealed. Table 10

A summary of the modelled provisions is provided in Table 8, Table 9, and Table 10.

Table 8. Rural provision summary.

Metric	Unit	Te Awarua-o-Porirua	Te Whanganui-a-Tara	Total
Area in Pasture	ha	8,503	17,325	25,828
Retirement	ha	730	1,186	1,916
	% of pasture	9%	7%	7%
Space Planting	ha	791	1814	2605
	% of pasture	9%	11%	10%
Stream Length through Pasture (total)	Order 2+ (km)	49	191	240
Stream Length Fenced & Planted	Order 2+ (km)	8	95	103
	% of stream length through pasture	16%	50%	43%

Table 9. Rural retirement and space planting provision summary (TASS catchments).

TASS catchment	Area in Pasture	Retirement		Space Planting	
	ha	ha	% of pasture	ha	% of pasture
Hutt River at Boulcott	6358	247	4%	300	5%
Hutt River at Te Marua Intake	891	11	1%	10	1%
Korokoro Stream at Cornish St Bridge	286	27	9%	26	9%
Mangaroa River at Te Marua	3071	126	4%	117	4%
Taupo Stream at Plimmerton Domain	772	11	1%	44	6%
Duck Creek at Tradewinds Drive Bridge	499	234	47%	55	11%
Horokiri Stream at Snodgrass	1169	136	12%	172	15%
Pauatahanui Stream at Elmwood Bridge	2289	95	4%	179	8%
Porirua Stream at Milk Depot	1187	44	4%	87	7%
Whakatikei River at Riverstone	516	36	7%	44	9%
Makara Stream at Kennels	4558	269	6%	702	15%
Hulls Creek adjacent Reynolds Bach Drive	105	0	0%	0	0%
Wainuiomata River Downstream of White Bridge	1054	9	1%	27	3%
Waiwhetu at Whites Line East	0	0	-	0	-
Karori Stream at Makara Peak Mountain Bike Park	13	0	2%	0	4%
Black Creek at Rowe End Parade	118	0	0%	0	0%
Kaiwharawhara Stream at Ngaio Gorge	85	0	0%	0	0%

Table 10. Rural riparian provision summary (TASS catchments).

TASS catchment	Stream length through Pasture	Stream Length Fenced & Planted	% of stream length through pasture
	Order 2+ (km)	Order 2+ (km)	
Hutt River at Boulcott	91	38.3	42%
Hutt River at Te Marua Intake	14.9	2.1	14%
Korokoro Stream at Cornish St Bridge	1.0	0.1	12%
Mangaroa River at Te Marua	51.0	26.9	53%
Taupo Stream at Plimmerton Domain	0.7	0.0	0%
Duck Creek at Tradewinds Drive Bridge	2.5	2.4	97%
Horokiri Stream at Snodgrass	13.1	1.3	10%
Pauatahanui Stream at Elmwood Bridge	16.3	0.3	2%
Porirua Stream at Milk Depot	4.8	0.0	0%
Whakatikei River at Riverstone	3.3	1.3	38%
Makara Stream at Kennels	47.1	45.1	96%
Hulls Creek adjacent Reynolds Bach Drive	3.0	1.8	61%
Wainuiomata River Downstream of White Bridge	25.9	3.1	12%
Waiwhetu at Whites Line East	0.0	0.0	-
Karori Stream at Makara Peak Mountain Bike Park	0.0	0.0	-
Black Creek at Rowe End Parade	1.2	0.0	0%
Kaiwharawhara Stream at Ngaio Gorge	0.0	0.0	-

4.5 Scenario limitations

Alongside model architecture limitations discussed in Sections 3.2.1 and 3.3.5, there are several limitations associated with the representation of future land use and PC1 provisions.

Future land use is based on the Future Development Strategy 2024, which represents the most up-to-date information regarding likely future development in the PC1 area. However, urban development form and location may change due to economic, regulatory, or natural hazard related factors not able to be accounted for in the modelling architecture. Climate change is not modelled, nor are future commercial and industrial developments considered, both of which may result in increased contaminant loads. No treatment has been assumed on existing residential, commercial or industrial land uses, and treatment equivalent to bioretention devices has been applied in all areas of infill and greenfield, which may not reflect all developments where practicalities of available space constrain treatment options. Similarly, no treatment of road runoff outside of the TG expressway has been modelled.

Increasing loads of the existing roading footprint by a nominal 15% to account for population growth may not reflect traffic increases due to localised development driven by land values or territorial authority plan policies, rules, and development contributions. However, infill growth is unable to be predicted with certainty and the modelled approach is a generalisation of spreading load across the mapped road network. These roads are not treated, with further load reductions expected where treatment is applied.

PC1 provisions are represented in the model and are discussed in Section 4.4. However, due to a lack of relevant information, some provisions that are expected to reduce contaminant loads are not represented in the models such as those pertaining to earthworks, woody vegetation clearance and forestry harvest and management. Subsequently, there may be greater reductions in sediment load than predicted.

Modelled provisions are assumed to be in full effect and at 100% compliant when applied in the PC1-FDS scenario. Provision representation does not account for the time taken to establish poles or retire and plant land to then reach maturity to stabilise soil, nor the practicalities of establishing the modelled mitigations. It is recognised that provisions are subject to change as the PC1 process develops or national regulations change; readers are referred to the PC1 documentation available from GWRC[9].

[9] https://www.gw.govt.nz/your-region/plans-policies-and-bylaws/updating-our-regional-policy-statement-and-natural-resources-plan/regional-policy-statement-change-1/

5 Results

Baseline and PC1-FDS scenario annual loads and relative (percentage) change are given for Target Attribute State (TAS) catchments for metals in Table 11 and sediment in Table 12. Change in annual sediment load for the Porirua Harbour is given in Table 13.

Results show a reduction in contaminant loads for zinc, copper, and sediment in the PC1-FDS scenario. This is due to a combination of modelled factors such as land-use change (e.g. development or roof replacement) and LRFs and mitigations related to PC1 provisions.

For copper and zinc, urban catchments show a reduction in load primarily due to the installation of treatment devices in urban developments and widespread roof-replacement with low-yielding Colorsteel (50% of all roofs), which is particularly effective in reducing zinc loads. This demonstrates that with extensive treatment of run-off, urban intensification may result in a net-benefit in catchment contaminant loading. In rural catchments, reductions in zinc and copper load are primarily driven by sediment load reductions achieved through the modelled PC1 provisions.

Sediment loads are predicted to reduce for most catchments with the largest reductions estimated for rural catchments where widespread retirement, space-planting, and livestock exclusion and riparian management has been applied (e.g. Duck Creek, Makara). Some small increases in load are predicted for urbanised catchments (e.g. Black Creek) driven by urban development which serves to increase the area of urban grasslands and trees which is not modelled to be treated by stormwater devices as for impervious surfaces.

As previously discussed, the models are bound by limitations that may limit the accuracy of the results; they should be viewed as a general indication of change rather than relied on to provide precise annual loads. Load reduction predictions may not correlate linearly with in-stream concentrations, which would require complex hydrological and water quality modelling to predict with greater accuracy.

Table 11. Metals results for TAS catchments.

TAS Catchment*	Zinc			Copper		
	Baseline	PC1-FDS	Scenario Change in Load	Baseline	PC1-FDS	Scenario Change in Load
	kg/year	kg/year	% change from baseline	kg/year	kg/year	% change from baseline
Hutt River at Boulcott	9615	7389	-23%	1117	1033	-8%
Hutt River at Te Marua Intake	1180	1152	-2%	203	198	-2%
Korokoro Stream at Cornish St Bridge	275	207	-25%	28	27	-3%
Mangaroa River at Te Marua	758	528	-30%	118	85	-27%
Taupo Stream at Plimmerton Domain	357	262	-27%	44	39	-11%
Duck Creek at Tradewinds Drive Bridge	291	204	-30%	28	26	-9%
Horokiri Stream at Snodgrass	207	177	-14%	35	31	-12%
Pauatahanui Stream at Elmwood Bridge	241	196	-18%	40	32	-18%
Porirua Stream at Milk Depot	2683	1863	-31%	252	233	-8%
Whakatikei River at Riverstone	416	391	-6%	69	66	-4%
Makara Stream at Kennels	555	336	-40%	85	53	-37%
Hulls Creek adjacent Reynolds Bach Drive	481	307	-36%	36	32	-11%
Wainuiomata River Downstream of White Bridge	1879	1345	-28%	199	176	-12%
Waiwhetu at Whites Line East	1222	766	-37%	74	71	-5%
Karori Stream at Makara Peak Mountain Bike Park	510	279	-45%	22	20	-9%
Black Creek at Rowe End Parade	897	582	-35%	60	58	-3%
Kaiwharawhara Stream at Ngaio Gorge	842	485	-42%	43	41	-5%

*TAS catchments are nested, e.g. the Hutt River at Boulcott includes Hutt River at Te Marua Intake, Mangaroa River at Te Marua, and Whakatikei River at Riverstone sites.

Table 12. Sediment results for TAS catchments.

TAS Catchment*	Sediment		
	Baseline	PC1-FDS	Scenario Change in Load
	t/year	t/year	% change from baseline
Hutt River at Boulcott	80712	76013	-6%
Hutt River at Te Marua Intake	21973	21680	-1%
Korokoro Stream at Cornish St Bridge	1395	1282	-8%
Mangaroa River at Te Marua	11850	9500	-20%
Taupo Stream at Plimmerton Domain	1135	949	-16%
Duck Creek at Tradewinds Drive Bridge	1386	809	-42%
Horokiri Stream at Snodgrass	3926	3113	-21%
Pauatahanui Stream at Elmwood Bridge	3898	3199	-18%
Porirua Stream at Milk Depot	4358	3994	-8%
Whakatikei River at Riverstone	7486	7161	-4%
Makara Stream at Kennels	9374	5854	-38%
Hulls Creek adjacent Reynolds Bach Drive	784	729	-7%
Wainuiomata River Downstream of White Bridge	15230	14630	-4%
Waiwhetu at Whites Line East	799	801	0%
Karori Stream at Makara Peak Mountain Bike Park	538	536	0%
Black Creek at Rowe End Parade	822	824	0%
Kaiwharawhara Stream at Ngaio Gorge	1293	1294	0%

*TAS catchments are nested, e.g. the Hutt River at Boulcott includes Hutt River at Te Marua Intake, Mangaroa River at Te Marua, and Whakatikei River at Riverstone sites.

Table 13. Sediment results for Porirua Harbour catchments.

Porirua Harbour Catchment	Porirua Harbour Arm	Baseline	PC1-FDS	Scenario Change in Load
		t/year	t/year	% change from baseline
Whitireia at Mouth	Onepoto	81	81	0%
Onepoto Fringe at Elsdon		63	62	-1%
Hukatai Stream at Mouth		49	42	-15%
Porirua at Mouth		6180	5315	-14%
Direct to Onepoto mid		97	91	-6%
Direct to Onepoto North		80	76	-6%
Direct to Onepoto South		74	34	-54%
Kahotea Stream (Onepoto Park)		82	66	-19%
Next to Mahinawa		42	35	-16%
Total - Onepoto		**6748**	**5803**	**-14%**
Horokiri and Motukaraka at Mouth	Pauatahanui	4452	3545	-20%
Kakaho at Mouth		1956	1295	-34%
Ration at Mouth		363	355	-2%
Motukaraka		35	34	-3%
Pauatahanui at Mouth		4207	3503	-17%
Pauatahanui village		18	17	-1%
Browns Bay		175	170	-3%
Direct to Pautahanui (mid)		30	32	9%
Lower Duck Creek at Mouth		1470	892	-39%
Total - Pauatahanui		**12704**	**9843**	**-23%**
Total - Porirua Harbour		**19452**	**15649**	**-20%**

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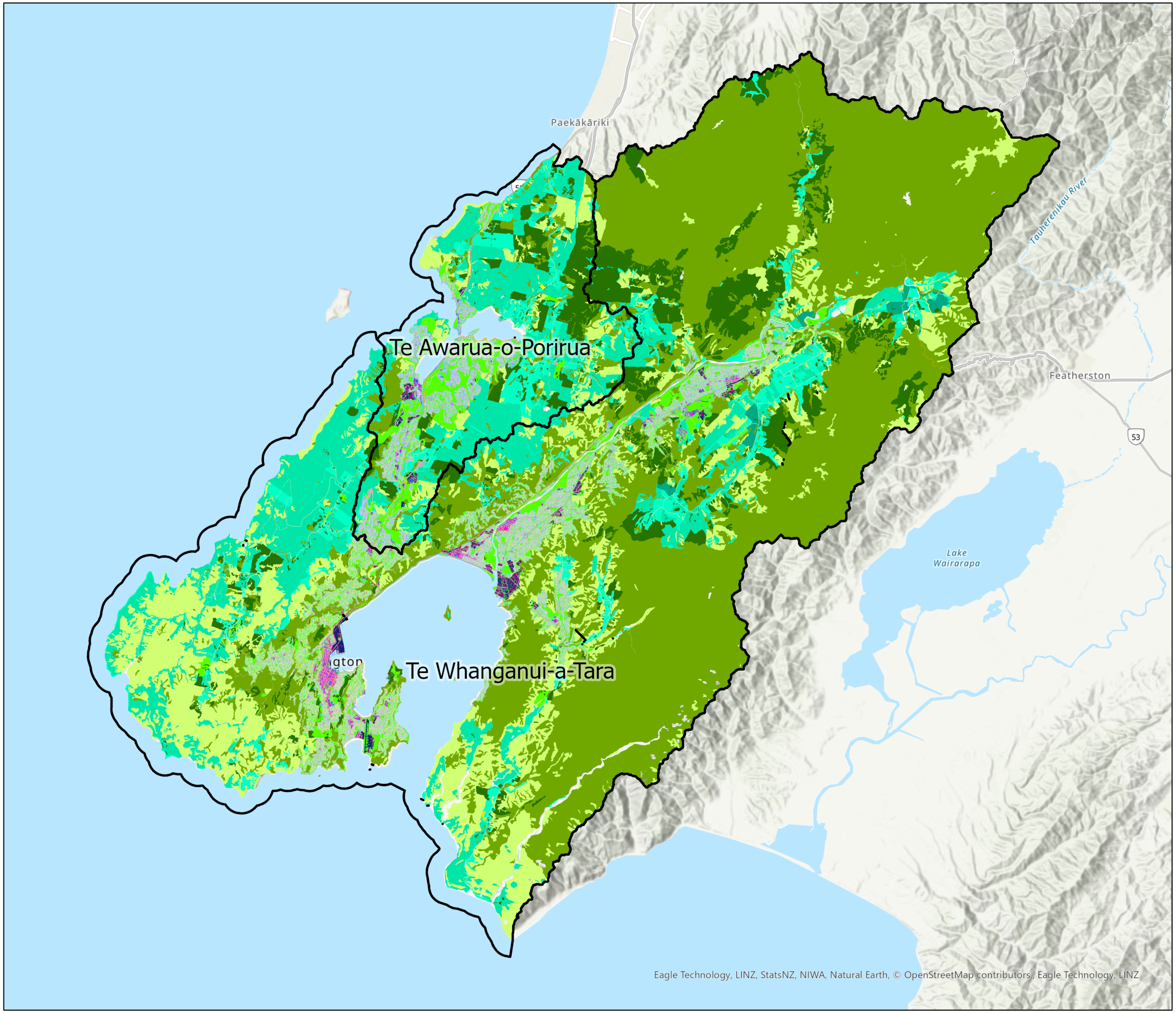
Appendix A Baseline land use



CLM Land Use

- Farmed Pasture,Dairy
- Farmed Pasture,Sheep and Beef
- Farmed Pasture,Lifestyle and Other Animals
- Exotic Production Forest
- Horticulture,Cropping
- Horticulture,Perennial
- Retired Pasture & Scrub
- Stable Forest incl. Natives
- Paved surfaces other than roads,Industrial
- Paved surfaces other than roads,Commercial
- Paved surfaces other than roads,Residential
- Road Surface,> 100000
- Road Surface,50000 - 100000
- Road Surface,20000 - 50000
- Road Surface,5000 - 20000
- Road Surface,1000 - 5000
- Road Surface,< 1000
- Roof,Industrial
- Roof,Commercial
- Roof,Residential
- Urban grasslands and trees
- Urban grasslands and trees,Parks
- Urban (Other)
- Other
- FMUs

N

0 5,000 10,000 Metres

CLM Baseline Land Use

PC1 CLM Modelling Project

Project:	PC1	Author	SE
Client:	GWRC	Date	2025
Ref:	001	Size	A3

Collaborations

Appendix B Future development data sources

- **Porirua – Judgeford Hills Greenfield** – Based on the PCC 'Judgeford Hills Zone' planning layer
- **Porirua** – **Kenepuru Greenfield** – Based on a development stage plan available on the Kenepuru Landing website https://www.kenepurulanding.co.nz/development
- **Porirua - Northern Growth Area Greenfield –** Based on the 'Specified Development Project - Northern Growth Area' boundary available via the PCC website https://poriruacity.govt.nz/your-council/city-planning-and-reporting/district-plan/responding-to-growth/specified-development-project-northern-growth-area/
- **Porirua – Eastern Porirua Planned Infill –** Based on the Te Rā Nui, Eastern Porirua Development Spatial Plan available here https://teranuidevelopment.co.nz/public/assets/PDF-Factsheets/Spatial-Plan.pdf
- **Porirua - Western Porirua (Te Āhuru Mōwai) Planned Infill –** Based on the Isthmus masterplan webpage accessed here https://isthmus.co.nz/project/te-ahuru-mowai/
- **Upper Hutt** – **St Patricks Greenfield** – Based on data supplied by GWRC and UHCC. Area matches the District Plan Precincts 'Development Area – St Patrick's' overlay in the UHCC Operative District Plan
- **Upper Hutt - Trentham Racecourse Planned Infill -** Based on data supplied by GWRC and UHCC. Area matches the District Plan Precincts 'Wallaceville Living B' overlay in the UHCC Operative District Plan
- **Lower Hutt - Hutt Central Urban Renewal Programme Planned Infill** – Based on figure 11.1 in the 'Central City Transformation Plan' accessed here https://www.huttcity.govt.nz/environment-and-sustainability/urban-planning/central-city-transformation-plan
- **Wellington City – LGWM Rapid Transit Corridor Planned Infill** – Based on the preferred option (option 1) and associated MRT walkable catchment found here https://www.transport.govt.nz/assets/Uploads/Lets-Get-Wellington-Moving-Transformational-Prog.._-markedup_Redacted-watermark.pdf
- **WCC, PCC, HCC & UHCC Historic Development –** Based on the difference between the 2012 CLM roof data and the LINZ Building footprints from 2024.