Collaborations

Subject: **Erosion Risk Mapping for Te-Awarua-o-Porirua and Te-Whanganui-a-Tara**

Attention: Barry Loe

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1 Introduction

Collaborations have developed spatial erosion risk layers to support Greater Wellington Regional Council's (GWRC) Plan Change 1 (PC1) and implementation of Te-Awarua-o-Porirua and Te-Whanganui-a-Tara Whaitua Implementation Plans (WIPs). The layers are designed to map erosion risk and enable prioritisation of sediment mitigations to achieve target sediment load reductions. This technical memorandum documents the erosion risk layer development methodology and briefly summarises the results.

1.1 Background

Erosion risk mapping, focussed on hillslope erosion (surficial erosion and shallow landslides), was originally carried out by Collaborations to support the GWRC land management team to identify erosion Critical Source Areas (CSAs) in the Takapu and Pouewe part Freshwater Management Units (part-FMUs) (Collaborations, 2023a)[1]. This mapping was then updated and assessed for its relevance and applications to potential PC1 policies (Collaborations, 2023b)[2].

At the request of GWRC, the erosion risk mapping has been expanded to cover all of Te-Awarua-o-Porirua (TAoP) and Te-Whanganui-a-Tara (TWT) Whaitua FMUs and processed to map:

1. The 'highest-risk' land currently in pasture defined as the most erodible 10% by area, and 'high risk' land in pasture defined as the most erodible 30% by area, within each Whaitua.
2. The 'highest-risk' land currently in forestry, defined as the most erodible 10% by area within each Whaitua.

[1] Collaborations, 2023. Sediment Reduction Implementation Plan for Pouewe and Takapu – Deliverable 1. Prepared for Greater Wellington Regional Council. 06 April 2023.
[2] Collaborations, 2023. Erosion Risk Mapping for Plan Change 1 – Takapū and Pouewe Rural Property Analysis. Prepared for Greater Wellington Regional Council. 31 May 2023.

This has necessitated some changes in the erosion risk mapping from the previous two technical memos to meet the project aims, namely:

- Analysis at 5-metre resolution (rather than 1-metre resolution),
- Spatial consideration of rainfall erosivity,
- Fundamental Soil Layer (FSL) information used to fill gaps in S-map coverage, and
- Combination of landslide and surficial erosion risk to produce a single hillslope erosion risk layer.

The erosion risk mapping methodology is described in Section 2. Results are presented in Section 3 and discussed alongside limitations in Section 4. A3 Whaitua erosion risk maps and summary tables are included in the Appendices.

2 Methodology

The erosion risk mapping methodology follows that established for the dSedNet sediment modelling for the Porirua Whaitua (Jacobs, 2019), modified and updated with more recent approaches and datasets to spatially identify erosion risk.

The three primary erosion types identified in the project catchments are surficial erosion, shallow landslides, and streambank erosion. Collectively, shallow landslides and surficial erosion are termed hillslope erosion which is predicted to account for the majority of sediment loading in the two Whaitua and is the focus of the erosion risk maps.

Methods for risk layer development for each erosion type are outlined in the following sub-sections.

2.1 Hillslope erosion risk

Hillslope erosion risk accounts for surficial and shallow landslide risk in a combined layer. This approach has been undertaken to provide a single risk layer that is easier to understand and disseminate than two separate layers. An aggregated hillslope risk layer also provides flexibility of mitigation options for potential treatment, i.e. retirement, pole planting, or sediment bunds will all reduce sediment losses from the mapped risk area to varying degrees. By contrast, consideration of surficial and landslide erosion processes separately necessitates separate consideration of mitigations, e.g. pole planting at typical densities is generally assumed to reduce landslide risk but not surficial erosion rates.

2.1.1 Surficial erosion

A 5-metre resolution Revised Universal Soil Loss Equation (RUSLE) model has been developed spatially (in GIS) to predict surficial erosion vulnerability and loads. The RUSLE (Renard et al. 1997) predicts surficial erosion according to:

$$\boldsymbol{E} = \boldsymbol{R} \times \boldsymbol{K} \times \boldsymbol{LS} \times \boldsymbol{C} \times \boldsymbol{P}$$

Equation 1

Where: $\boldsymbol{E}$ is the soil erosion per unit area (t ha^{-1} year^{-1});
$\boldsymbol{R}$ is the rainfall erosivity (MJ mm ha $^{-1}$ h^{-1} year^{-1});
$\boldsymbol{K}$ is the soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1});
$\boldsymbol{LS}$ is the slope length and steepness factor (dimensionless);
$\boldsymbol{C}$ is the cover management factor (dimensionless); and
$\boldsymbol{P}$ is the practice factor (conservation measures) (dimensionless).

The R, K, LS, and C factors have been calculated as spatial grids based on the methodologies in the following subsections. The P factor is related to farm management practices (contouring, terracing etc.) and is assumed to be equal to 1.

2.1.1.1 R factor

We have adopted an R factor based on mean annual rainfall following Dymond at al. (2016). Mean annual rainfall has been taken from the New Zealand Environmental Data Stack spatial mean annual rainfall layer (McCarthy et al., 2021)[3].

2.1.1.2 K factor

Following Dymond (2010), and consistent with the previous dSedNet modelling, the K-factor has been differentiated based on soil texture:

- Sand: 0.05
- Silt: 0.35
- Clay: 0.20
- Loam: 0.25

The K-factor values above have been applied to the Smap spatial layer (2022 update) provided by GWRC. Where Smap did not have coverage the New Zealand Fundamental Soils Layer (FSL) was used. In areas where neither Smap nor the FSL had coverage, loam was assumed. Following Renard et al. (1997), the K factor values above have been converted to SI units (multiplied by 0.1317).

2.1.1.3 LS factor

The LS factor encompasses the slope length (L) and slope steepness (S) factors. We have adopted the spatial approach of Moore & Burch (1986) and Moore & Wilson (1992) which accounts for flow accumulation within the landscape:

$$\boldsymbol{LS} = \left(\frac{\boldsymbol{A_S}}{\mathbf{22.13}}\right)^{\mathbf{0.4}} \times \left(\frac{\sin\boldsymbol{\theta}}{\mathbf{0.0896}}\right)^{\mathbf{1.3}}$$

Equation 2

Where: $\boldsymbol{LS}$ is the combined length and slope factors,

[3] https://datastore.landcareresearch.co.nz/ne/dataset/nzenvds

A_s is the specific catchment area,
θ is the slope angle.

The LS factor has been calculated using a 5-m resolution DEM derived from the Wellington Region LiDAR data[4].

2.1.1.4 C factor

C factor values have been adapted from SedNetNZ, which applies the following (Dymond et al. 2016):

- 0.005 for plantation forest, native forest, and scrub;
- 0.01 for pasture and urban areas;
- 1.0 for bare earth.

The C factor values above have been mapped to the Land Cover Database (LCDB) version 5.0[5] (mapped summer 2018/19).

2.1.2 Landslide erosion

Landslides are thought to be a significant contributor to sediment loading in Te-Awarua-o-Porirua and Te-Whanganui-a-Tara Whaitua, however they are difficult to predict and highly variable (spatially and temporally). Work in New Zealand shows that landslides are generally confined to steep slopes greater than 26 degrees (DeRose 2013; Dymond et al. 2016), and the highest number of landslides per area occur in pastureland (Glade, 1998). It is recognised that geology is an important risk-factor for shallow landslides however project timelines have precluded explicit consideration of underlying rock-type.

We have followed the previous approach used for the Porirua Whaitua dSedNet modelling to define at-risk hillsides as steep land (>26 degrees) without woody vegetation cover, mapped using a 5-m resolution DEM derived from the Wellington region LiDAR information and the LCDB (High- and Low-producing grassland categories).

2.1.3 Hillslope risk aggregation

Hillslope erosion risk has been estimated as an intersection of the developed surficial and landslide erosion risk layers. Risk categories are based on area-quantiles calculated from the modelled surficial erosion loss rates: ‘Highest risk’ is the most erodible 10%, ‘Very high risk’ is the most erodible 20%, and ‘High risk’ is the most erodible 30%. By definition, ‘High risk' includes all ‘Very high risk’ and ‘Highest risk’ land, and ‘Very high risk’ includes all ‘Highest risk’ land.

[4] https://data.linz.govt.nz/layer/53621-wellington-lidar-1m-dem-2013-2014/
[5] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

For example, the highest risk pastoral land is calculated as the 10% of pasture area with the highest surficial erosion loss rates, that is also at risk of landslides (on slopes above 26°). Processing to calculate quantiles and map erosion risk has been carried out in ArcGIS Pro[6].

2.1.3.1 Pasture Erosion Risk

Pasture erosion risk has been calculated for each Whaitua within the area defined by the LCDB as "High-producing grassland" and "Low-producing grassland". Risk quantiles were calculated first, then any pixels not at risk of shallow landslides removed.

2.1.3.2 Forestry Erosion Risk

Forestry erosion risk is based on potential erosion risk on land currently in forestry should that land be converted to pasture. Forestry area is derived from the LCDB categorisation of "Exotic Forest" and "Forest – Harvested". The layer does not account for the harvest status or tree-age profile of forestry land, nor does it account for or attempt to model forestry harvest or harvest activities. As for pasture, risk quantiles were calculated first, then any pixels not at risk of shallow landslides removed.

2.2 Streambank erosion

In the Porirua Whaitua dSednet modelling, Streambank erosion rates were calibrated to annual loads as estimated following the methodology in Dymond et al. (2016), largely relying on default values due to a lack of local information. The approach developed in Dymond et al. (2016) has since been updated and refined in Smith & Betts (2021). The published spatial index of streambank erosion susceptibility[7] has been summarised for the project catchments to identify the most erodible stream reaches.

The streambank erosion susceptibility index is based on stream power, channel sinuosity, soil erodibility, valley confinement, and proportional extent of riparian vegetation. The index is linked to the River Environments Classification (REC) version 2.5, with other data inputs estimated from measured relationships in NZ and national scale datasets such as the Fundamental Soils Layer, National 15m DEM, and EcoSat Woody.

We have summarised the streambank erosion susceptibility index within each FMU and part-FMU to rank each REC reach from most to least susceptible.

3 Results

A map series showing the erosion risk layers for each Whaitua is included in Appendix B. Additional outputs have been provided to GWRC separate to this technical memo:

- Summary statistics of pasture and forestry hillslope erosion risk.

[6] ArcGIS Pro Version 3.1.1. ESRI Inc.
[7] https://data.mfe.govt.nz/layer/105771-streambank-erosion-susceptibility-index/

- Map series' summarising pasture and forestry hillslope erosion risk.
- Spatial layers of pasture and forestry hillslope erosion risk.

The following subsections briefly describe and summarise the developed layers.

3.1 Hillslope Erosion risk

3.1.1 Surficial erosion risk

A 5-metre scale raster layer estimating annual surficial erosion rate (t/ha/year) has been produced, which may be visualised and summarised in various ways to identify CSAs at different scales or areas of interest. Figure 1 shows the 'raw' surficial erosion rate raster. In general, topography is the largest contributing factor to high erosion rates. The steep slopes and high rainfall in the Tararua and Remutaka ranges contribute to high predicted erosion rates even with extensive native woody vegetation cover. Elsewhere, high erosion rates are predicted for pastoral land in the Pouewe and Parangarehu part-FMUs.

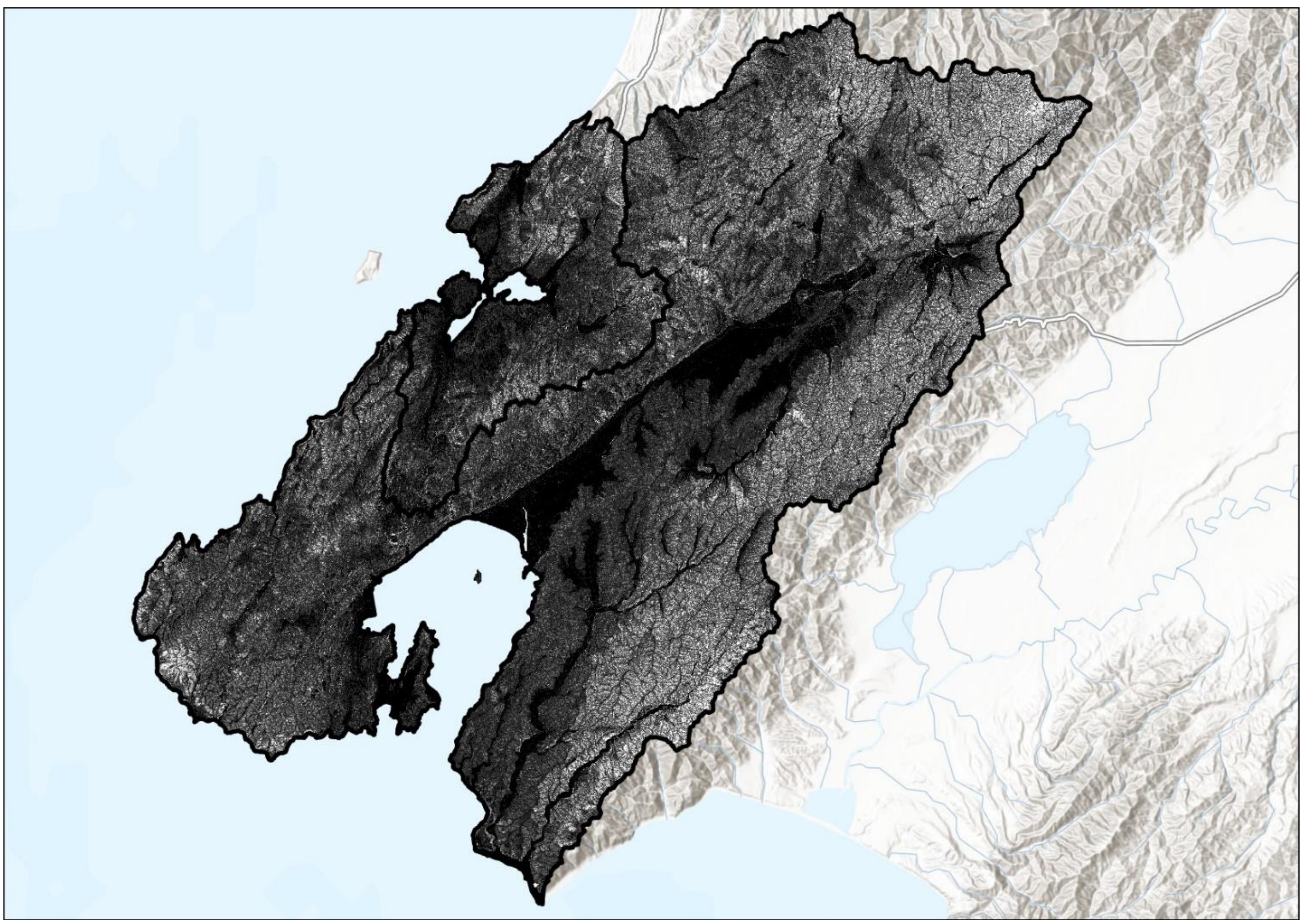

Figure 1 RUSLE modelled surficial erosion layer. Relative surficial erosion rate is visualised from low (black) to high (white).

3.1.2 Landslide erosion risk

As for surficial erosion, a 5-metre scale raster layer of landslide erosion susceptibility has been produced (Figure 2). The landslide erosion risk areas show a high degree of overlap with surficial erosion CSAs across steep pasture land as both methodologies are influenced by slope angle and land cover.

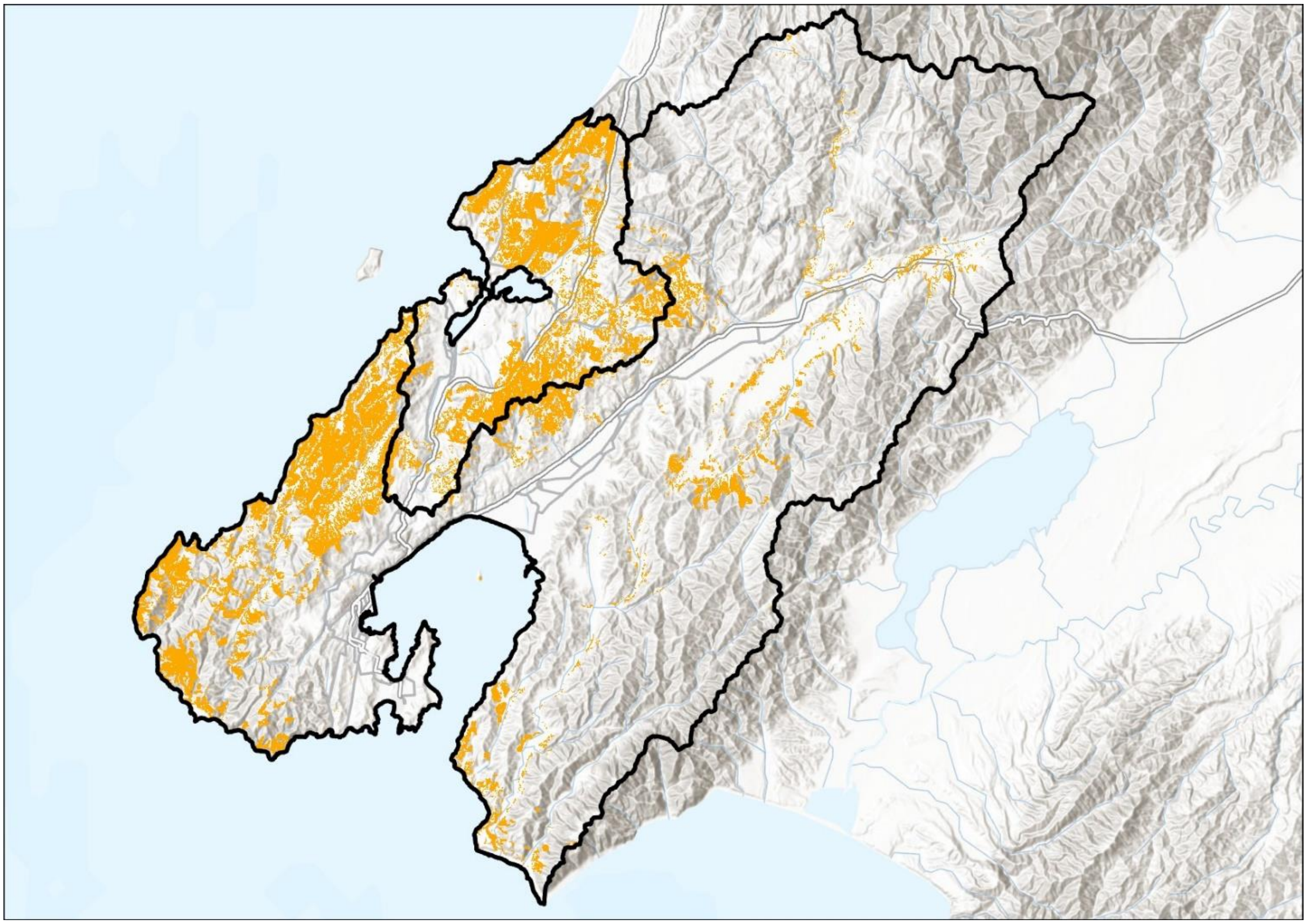

Figure 2 Landslide risk extent in yellow

3.1.3 Combined hillslope erosion risk

The hillslope erosion risk (combined surficial and landslide risk) is mapped in Appendix B. Table 1 and Table 2 summarise the risk areas for Pasture and Forestry for each Whaitua, respectively. Table 3 and Table 4 in Appendix A summarise the risk areas for Pasture and Forestry at the part-FMU scale. The highest risk areas are predicted to be in the Parangarehu (TWT) and Pouewe (TAoP) part-FMUs, which each account for more than half of the mapped hillslope risk area in their respective Whaitua.

In general, high surficial erosion risk and shallow-landslide risk are spatially correlated on pastoral land. However in some places high surficial erosion rates are estimated for pixels that are not deemed to be at risk of land sliding, for example where there is high flow accumulation at the base of gullies. These pixels are precluded from the hillslope erosion risk layer which is why the risk mapping summary tables cover an area slightly smaller than the areal quantile value (e.g. 8% of pasture is in the 'highest' risk category instead of 10%).

Table 1 Hillslope erosion risk - Pasture

Area	Statistic	Te Awarua-o-Porirua	Te Whanganui-a-Tara
FMU	Area (ha)	20,121	116,007
	Area in Pasture	8,562	16,973
High risk - Pasture	Area (ha)	1,771	3,385
	Proportion of Pasture in FMU	21%	20%
Very high risk - Pasture	Area (ha)	1,252	2,468
	Proportion of Pasture in FMU	15%	15%
Highest risk - Pasture	Area (ha)	646	1,325
	Proportion of Pasture in FMU	8%	8%

Table 2 Hillslope erosion risk - Forestry

Area	Statistic	Te Awarua-o-Porirua	Te Whanganui-a-Tara
FMU	Area (ha)	20,121	116,007
	Area in Forestry (ha)	2,733	9,138
Highest risk - Forestry	Area (ha)	220	771
	Proportion of Forestry in FMU	8%	8%

3.2 Streambank erosion risk

Streambank erosion risk was ranked by the erosion susceptibility index and is included in the erosion risk maps in Appendix B. Stream lengths predicted to be the most erodible are generally found in the lower reaches of the largest catchments in each Whaitua (e.g. Hutt River and Porirua stream), likely due to the influence of high flow rates, lack of riparian vegetation, and reduced valley confinement.

4 Discussion and limitations

4.1 Erosion risk layers

4.1.1 Hillslope erosion

The hillslope erosion risk layer is based on the RUSLE modelled surficial erosion rate, intersected with the landslide risk layer. The risk layer accounts for erosion risk factors including land cover, slope steepness, flow accumulation, soil type, and rainfall, and allows for spatial targeting of mitigations at multiple scales (e.g. paddock, property, and catchment). The layer development methodology improves on previous methods by using updated input data such as LiDAR, Smap, and the latest LCDB information. Visual analysis indicates a good agreement with national scale erosion layers (e.g. NZEEM), with improvements in resolution and detail.

The methodology to identify landslide risk is simple in comparison to the multi-factor methods for surficial and streambank erosion due to the lack of local information and general difficulty in predicting landslides. Improvements may be made by accounting for underlying geology in the risk layer, or by mapping active landslides (e.g. through imagery classification methods) to build risk-associations with other factors, such as slope aspect and soil attributes. Due to its simplicity, we expect that the landslide risk layer is relatively conservative, that is it predicts an area larger than if additional risk-factors were included.

Further improvements to the hillslope risk layers may be made by using aerial or satellite imagery to map land cover more precisely, in particular small pockets of vegetation and areas of bare earth not captured in the LCDB. Other limitations of the methodology are the lack of explicit consideration of sediment loading from forestry harvest and harvest activities, or accounting for currently- implemented erosion control measures such as pole planting on erodible pasture.

4.1.2 Streambank erosion

In general, streambank erosion risk is predicted to be highest where flows are highest correlating with the largest catchments within each FMU (Hutt river and Porirua stream) and the lower reaches within each catchment (i.e. higher-order streams). There are several limitations associated with the streambank erosion susceptibility index which should be considered when using the mapped streambank CSAs to target mitigations. In particular, riparian fencing is not accounted for in the index, and the extent of riparian vegetation is based on the EcoSat Woody land use classification[8], which is approximately 20 years old and relatively coarse (15m resolution). Further mapping of current riparian fencing and established riparian vegetation will allow GWRC to preclude some identified high-risk reaches and better target streambank erosion mitigations. Furthermore, the application of the index to lower order streams is uncertain due to a lack of calibration information, resulting in low index values due to lower estimated flow and greater levels of valley confinement. Further limitations of the layer are outlined in Smith & Betts (2021).

4.2 Mitigations

It is expected that PC1 will require sediment mitigations on the identified erosion risk areas. Appropriate mitigation type and extent will vary depending on physical factors such as slope, aspect, site access and pest-control, and non-physical factors such as cost and landowner cooperation. The produced maps are intended to guide general mitigation placement but do not preclude site specific assessment.

For surficial erosion, mitigations may include directly targeting erodible terrain through measures such as land use change or intercepting eroded sediment before reaching waterways through measures such as wetland or bund construction. For landslides, mitigations are generally limited to those that can stabilise slopes (e.g. re-vegetation or pole planting). Streambank erosion mitigations are likely to include fencing and revegetation, with possible bank engineering works. Mitigations targeting hillslope

[8] https://lris.scinfo.org.nz/layer/48183-ecosat-woody-north-island/

erosion such as retirement or re-vegetation will also reduce streambank erosion risk as the establishment of woody vegetation (once mature) will reduce runoff rates. Within the mapped risk areas, site specific assessment is likely to be necessary to inform mitigation choice and placement – for example bund placement on flow paths or pole planting on steeper slopes.

4.3 Limitations

The erosion risk layers are designed to spatially identify erosion risk and enable prioritisation of sediment mitigations to achieve target sediment load reductions. There are several assumptions and limitations associated with the layers:

- The accuracy of the risk layers relies on various information sources and data sets, each with their own sources of error. Any error in those data sets will also be present in the erosion risk layers. For example, the LCDB land use mapping does not identify small pockets of vegetation or open earth that may influence local erosion risk.
- The risk layers are based on surficial erosion rate, intersected with the landslide risk layer. There remain erosion risks outside of the mapped at-risk areas (for example, where surficial erosion rates are high, but not deemed to be at-risk of landslides). The layers do not purport to map all sources of sediment within the project area. The risk area quantiles (i.e. highest risk, very high risk, and high risk) represent relative risk and have been calculated at the FMU scale. They may need to be re-assessed for risk area mapping at part-FMU or sub-catchment scales, particularly when considering implementation at a smaller scale.
- Erosion risk maps do not account for sediment delivery processes such as interception or deposition or assess connectivity to the stream network.
- Earthworks, forestry harvest, or other land-disturbing activities are not considered. Similarly, already-implemented erosion control measures such as established pole planting or sediment retention bunds are not accounted for in the current iteration of the risk layers.
- The mapped risk areas should not be used exclusively as the basis for management and investment decisions. They are intended to identify high erosion risk areas but do not replace the need for site specific field assessment and expert advice.

5 Summary

A spatial layer of hillslope erosion risk was developed and a national streambank erosion risk layer was summarised for Te Whanganui-a-Tara and Te Awarua-o-Porirua Whaitua. The hillslope erosion risk layer accounts for landslide risk and surficial erosion rate calculated using the RUSLE. Data inputs include LiDAR information and a range of national datasets that account for soil type, slope, rainfall and land cover. Analysis of the hillslope erosion risk layer was undertaken for pastoral and exotic forestry land identifying the highest (10^{th} percentile), and high (30^{th} percentile) erosion risk areas within each FMU.

6 References

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Appendix A Hillslope Erosion Risk Tables

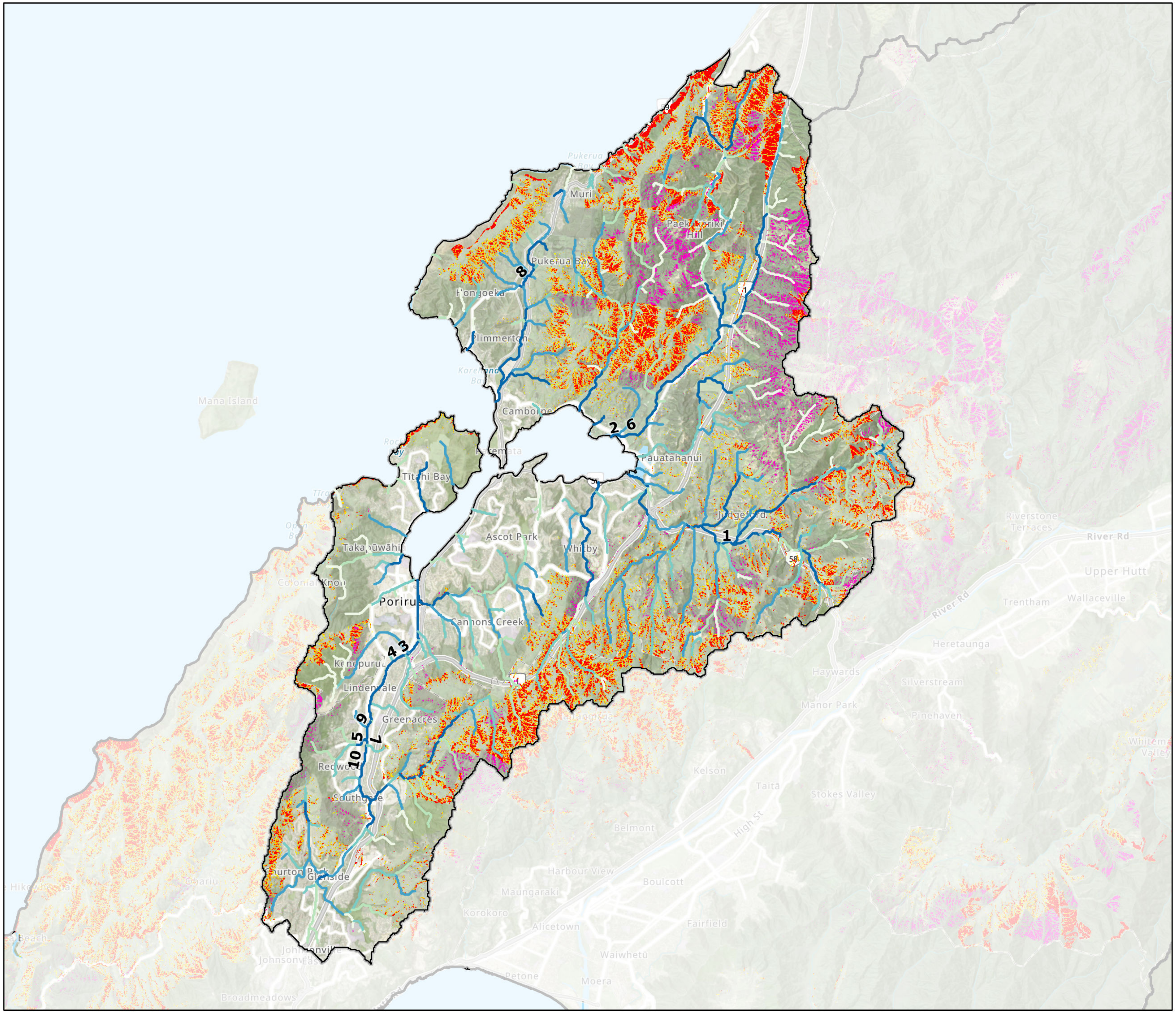
Table 3 Hillslope erosion risk - Te Awarua-o-Porirua

Part-FMU	Area (ha)	Area in Pasture (ha)	High risk (30th) percentile erosion - Pasture			Very high risk (20th) percentile erosion - Pasture			Highest risk (10th) percentile erosion - Pasture			Area in Forestry (ha)	Highest Risk (10th) percentile erosion - Forestry		
			Area (ha)	% of Pasture in part-FMU	% of FMU risk area	Area (ha)	% of Pasture in part-FMU	% of FMU risk area	Area (ha)	% of Pasture in part-FMU	% of FMU risk area		Area (ha)	% of Forestry in part-FMU	% of FMU risk area
Pouewe	6,146	2,922	801	27%	45%	597	20%	48%	337	12%	52%	1,462	156	11%	71%
Taupo	1,138	787	96	12%	5%	56	7%	5%	20	3%	3%	40	0	1%	0%
Duck Creek	1,032	486	160	33%	9%	116	24%	9%	59	12%	9%	104	3	3%	1%
Takapu	5,247	3,050	551	18%	31%	380	12%	30%	188	6%	29%	706	51	7%	23%
Te Rio o Porirua and Rangituhi	6,558	1,316	163	12%	9%	102	8%	8%	42	3%	7%	421	9	2%	4%
Total	**20,121**	**8,562**	**1,771**	**21%**	**100%**	**1,252**	**15%**	**100%**	**646**	**8%**	**100%**	**2,733**	**220**	**8%**	**100%**

Table 4 Hillslope erosion risk - Te Whanganui-a-Tara

Part-FMU	Area (ha)	Area in Pasture (ha)	High risk (30th) percentile erosion - Pasture			Very high risk (20th) percentile erosion - Pasture			Highest risk (10th) percentile erosion - Pasture			Area in Forestry (ha)	Highest Risk (10th) percentile erosion - Forestry		
			Area (ha)	% of Pasture in part-FMU	% of FMU risk area	Area (ha)	% of Pasture in part-FMU	% of FMU risk area	Area (ha)	% of Pasture in part-FMU	% of FMU risk area		Area (ha)	% of Forestry in part-FMU	% of FMU risk area
Kaiwharawhara Stream	1,665	59	20	34%	1%	15	26%	1%	8	14%	1%	70	1	2%	0%
Korokoro Stream	1,668	249	64	26%	2%	46	19%	2%	22	9%	2%	190	8	4%	1%
Makara Estuary	9	1	0	15%	0%	0	8%	0%	0	4%	0%	0	0	0%	0%
Te Awa Kairangi lower mainstem	171	7	0	2%	0%	0	1%	0%	0	0%	0%	0	0	0%	0%
Te Awa Kairangi urban streams	11,895	1,361	220	16%	6%	164	12%	7%	79	6%	6%	1,188	59	5%	8%
Wai Tai (south-western coast)	14	7	1	18%	0%	1	15%	0%	1	10%	0%	0	0	0%	0%
Wainuiomata rural streams	7,076	1,112	82	7%	2%	55	5%	2%	22	2%	2%	375	8	2%	1%
Wainuiomata urban streams	1,533	130	2	1%	0%	1	1%	0%	1	0%	0%	22	0	2%	0%
Wellington urban	10,110	406	132	32%	4%	102	25%	4%	56	14%	4%	390	13	3%	2%
Parangarehu catchment streams and South-west coast rural streams	17,346	8,376	2,387	28%	71%	1,713	20%	69%	911	11%	69%	633	14	2%	2%
Te Awa Kairangi and Wainuiomata small forested, Te Awa Kairangi forested mainstems and Orongorongo	55,986	1,462	241	17%	7%	192	13%	8%	119	8%	9%	4,949	536	11%	70%
Te Awa Kairangi rural streams and rural mainstems	8,533	3,803	235	6%	7%	177	5%	7%	107	3%	8%	1,319	132	10%	17%
Total	**116,007**	**16,973**	**3,385**	**20%**	**100%**	**2,468**	**15%**	**100%**	**1,325**	**8%**	**100%**	**9,138**	**771**	**8%**	**100%**

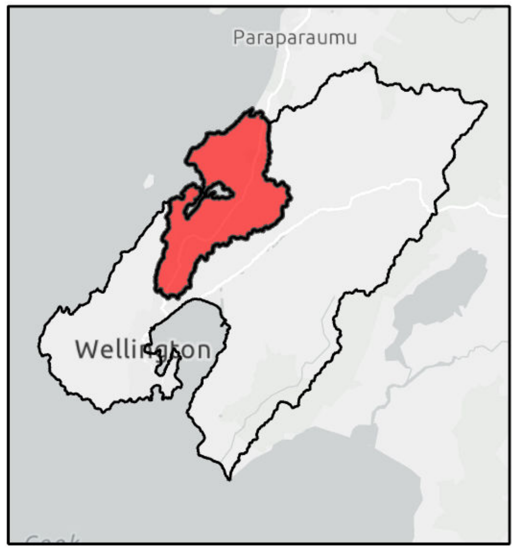
Appendix B Catchment erosion risk maps (A3 size)



Hillslope erosion risk
- Highest erosion risk - Forestry
- Highest erosion risk - Pasture
- Very High erosion risk - Pasture
- High erosion risk - Pasture

Streambank Erosion Risk quantiles

Top 10 reaches labelled
- Lowest risk
- Low risk
- Medium risk
- High risk
- Highest risk
- FMU Boundary



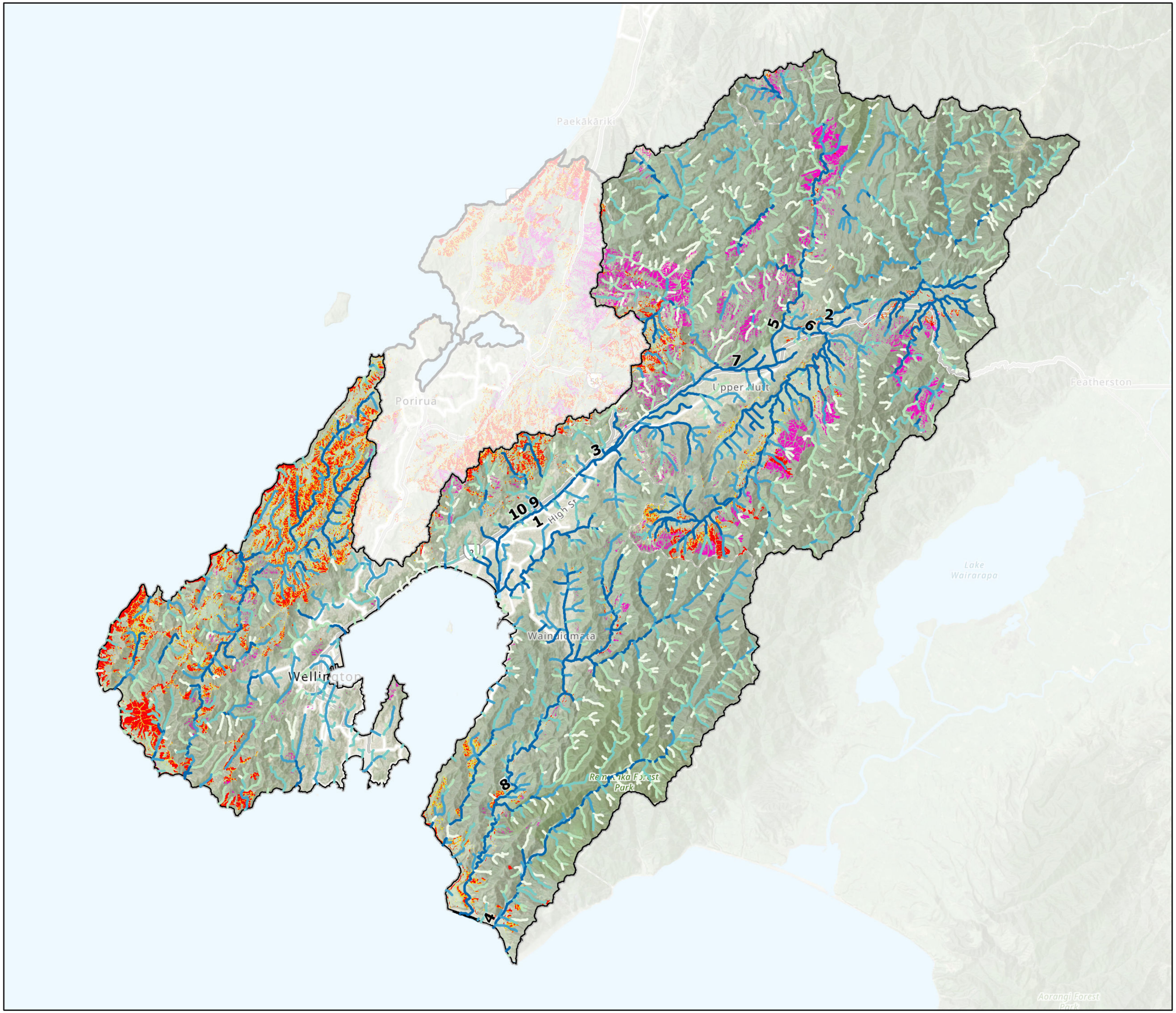
N

0 2,500 5,000 Metres

Erosion Risk
Te Awarua-o-Porirua

Project:	Sediment Assessment	Author	SE & TN
Client:	GWRC	Date	August 2023
Ref:	001	Size	A3

Collaborations



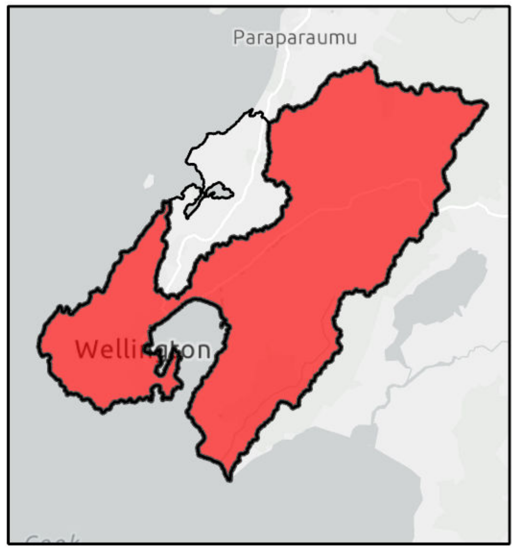
Hillslope erosion risk

- Highest erosion risk - Forestry
- Highest erosion risk - Pasture
- Very High erosion risk - Pasture
- High erosion risk - Pasture

Streambank Erosion Risk quantiles

Top 10 reaches labelled

- Lowest risk
- Low risk
- Medium risk
- High risk
- Highest risk
- FMU Boundary



N

0 5,000 10,000 Metres

Erosion Risk Te Whanganui-a-Tara

Project:	Sediment Assessment	Author	SE & TN
Client:	GWRC	Date	August 2023
Ref:	002	Size	A3

Collaborations