greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Te Awarua-o-Porirua Harbour and catchment sediment modelling

Development and application of the CLUES and Source-to-Sink models

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Executive summary

Te Awarua-o-Porirua Harbour (Porirua Harbour) is a regionally significant estuarine habitat that has experienced substantial environmental degradation over the last century. In recognition of the present and ongoing environmental pressures facing the harbour, the Porirua Harbour and Catchment Strategy and Action Plan aspires to a 50% reduction in sediment inputs to the harbour by 2021 and a target areal sedimentation rate of 1 mm/yr by 2031 (PCC 2012).

The CLUES (Catchment Land Use for Environmental Sustainability) model has been used to estimate the present-day sediment load entering the harbour from the surrounding catchments. Concurrently, a 'Source-to-Sink' (S2S) model was developed to estimate where in the harbour incoming sediment would deposit and the subsequent rates of sedimentation.

This report details the inner workings of the CLUES and S2S models as they were modified and developed for estimating catchment sediment inputs to and sediment distribution within, Porirua Harbour. It is anticipated that, with validation and further refinement, the CLUES and S2S models will ultimately be used as a tool to manage catchment sediment inputs and achieve the sedimentation targets envisioned by the Porirua Harbour and Catchment Strategy.

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1. Introduction and background

Te Awarua-o-Porirua Harbour (Porirua Harbour) is a significant estuarine habitat in the Wellington region. The harbour is composed of two largely distinct estuaries: the Pauatahanui Arm (380 ha) to the east, which drains a predominantly rural catchment and the Onepoto Arm (529 ha) to the south-west draining a more urban-dominated catchment (Figure 1.1). Porirua Harbour, as with all estuaries, fulfils important ecosystem functions such as flood protection, nutrient cycling and sediment entrainment and provides valuable habitat for numerous birds, fish and invertebrate communities.

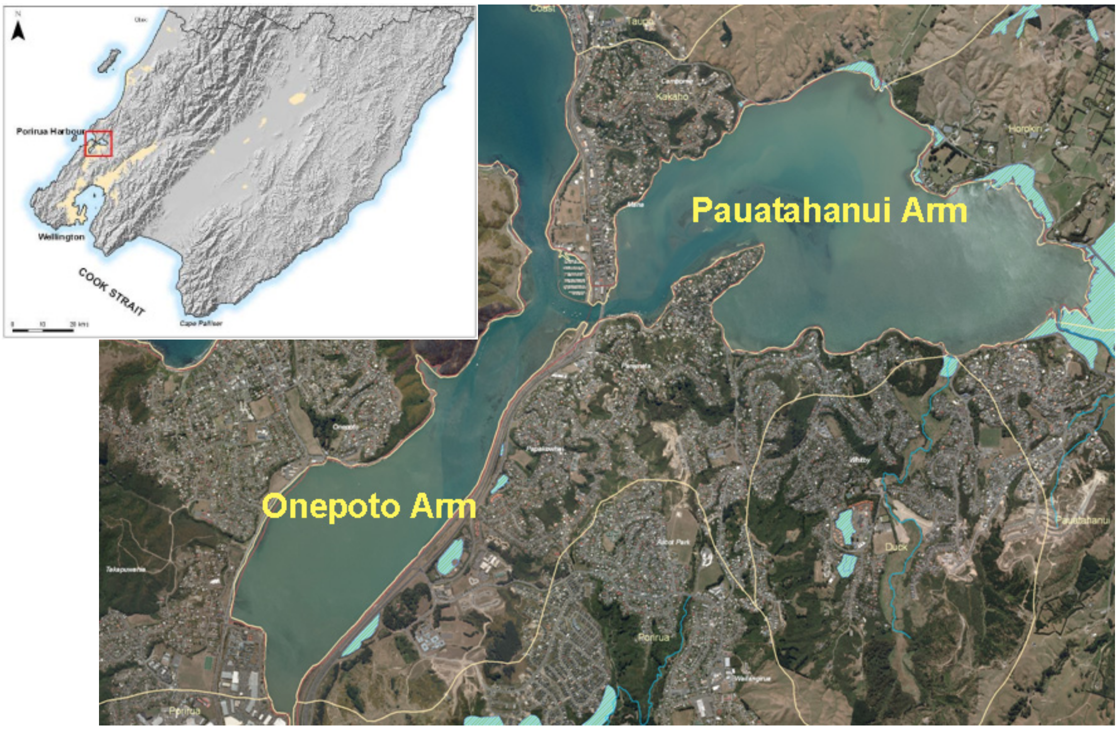

Figure 1.1: Te Awarua-o-Porirua Harbour is a regionally significant estuarine system located in the Wellington region

Porirua Harbour has undergone significant environmental change in the last century, including larges areas of reclamation to accommodate road and rail networks and the Porirua CBD, as well as widespread catchment deforestation to make way for farmland and urban development. A direct result of urban development and deforestation has been excessive sedimentation within the harbour. Numerous studies have shown that sedimentation rates throughout the harbour have increased since European settlement and that the increase has accelerated over the past 25 years. Swales et al. (2005), using data from isotopic analysis and pollen dating of sediment cores, calculated an average sedimentation rate for the Pauatahanui Arm of the harbour over the past 2,000 years as 0.7 mm/year, rising to 2.0–2.4 mm/year (post 1850), 3.1–3.7 mm/year (post 1950) and 4.6 mm/year (post 1985). Gibb and Cox (2009), using data from sequential bathymetric surveys, calculated average sedimentation rates for the Pauatahanui and Onepoto arms between 1974 and 2009 of 9.1 and 5.6 mm/year, respectively.

Such high rates of sedimentation are linked with rapid infilling of valuable estuary habitats, smothering of habitat forming species such as seagrass, reduced water clarity, increased muddiness, sediment anoxia and loss of biodiversity. Furthermore, many contaminants such as heavy metals adhere to the fine mud particles and can accumulate, often to toxic concentrations, in the depositional basins.

In recognition of the present and ongoing environmental pressures facing the harbour, the Porirua Harbour and Catchment Strategy and Action Plan was launched in early 2012 in an effort to improve the health of the harbour and waterways. The strategy aspires to a 50% reduction in sediment inputs to the harbour by 2021 and a target areal sedimentation rate of 1 mm/yr by 2031 (PCC 2012).

To achieve the proposed sedimentation targets and prioritise science needs for the harbour and its catchment, Greater Wellington Regional Council (GWRC) has convened three Porirua Harbour science workshops. These workshops have been multi-agency and multi-disciplinary, with a primary focus on determining how much sediment is coming into the harbour and where it is coming from. For this task a mathematical model, specifically the CLUES (Catchment Land Use for Environmental Sustainability) model, has been used to estimate the amount of sediment entering the harbour from the surrounding catchments. Concurrently, a 'Source-to-Sink' (S2S) model was developed to estimate where in the harbour incoming sediment would deposit and the subsequent rates of sedimentation. It is anticipated that the S2S model will ultimately be used as a tool to manage catchment sediment inputs and achieve the sedimentation targets envisioned by the Porirua Harbour and Catchment Strategy.

1.1 Scope and outline of this report

This report details the inner workings of the CLUES and S2S models as they were modified and developed, respectively, for estimating catchment sediment inputs to and sediment distribution within, Porirua Harbour.

The report comprises two primary sections:

- Section 2, authored by Leigh Stevens of Wriggle Coastal Management Ltd, details the iterative process of estimating catchment sediment yields. The CLUES model was used initially to generate estimates of catchment sediment loads and Excel spreadsheet models were subsequently developed to incorporate additional land disturbance activities and modified sediment loadings that better characterise the Porirua Harbour catchment. The model outputs provide an estimate of present-day sediment inputs to the harbour, an indication of how various options for mitigation might alter those inputs, and sediment loads that could be incorporated into the S2S sediment transport model.

- Section 3, authored by Mal Green of NIWA, outlines the S2S sediment transport model developed to distribute catchment-derived sediment within the harbour and estimate the subsequent sedimentation rates.

2. Estimating catchment sediment loads using CLUES

2.1 Background

The primary method used to assess catchment sediment loads to Porirua Harbour was the Catchment Land Use for Environmental Sustainability (CLUES) model (version 3.1), developed by NIWA in collaboration with Lincoln Ventures, Harris Consulting, AgResearch, HortResearch, Crop and Food Research, and Landcare Research for the Ministry of Agriculture and Forestry (MAF) and the Ministry for the Environment (MfE).

CLUES is a GIS-based modelling system for predicting long-term annual average loads of sediment and *Escherichia coli*, and loads, concentrations and yields of total nitrogen and phosphorus generated by different land use classes. It is principally designed for assessing broad scale rural catchments, and the effects of changes to land use, at a minimum scale of sub-catchments (~10 km^2 and above). The land use classes included in CLUES are derived from the 2001 Land Cover Database 2 (LCDB2) – a GIS output produced by Landcare Research based on satellite imagery and aerial photography for all of New Zealand from summer 2001/02 (see Figure 2.1 for Porirua catchment summary).

The land use classes are combined with several specific models nested within the CLUES model (eg, Overseer, Spasmo, Sparrow, EnSus – Appendix 1) that use physical features including slope, geology, soil type, drainage and rainfall, to make catchment-specific predictions based on dominant land use classes. These model predictions have been compared to data from representative locations throughout New Zealand to validate model outputs.

CLUES permits the likely source and magnitude of existing catchment loads to be quickly and cost effectively assessed without the collection of new data. It also allows land use classes to be changed, or mitigation options to be applied to specific land uses, to compare how changes may alter predicted catchment inputs. This in turn, can be used to highlight the likely source of inputs, the type of reductions possible, and the catchments and sub-catchments best suited to different management options.

2.2 Limitations of the CLUES model

In relation to sediment, the CLUES model is limited in that it does not account well for the following:

- Bare land – sediment inputs from bare land exposed during earthwork activities are often very high but are not specifically addressed within CLUES;

- Exotic forestry – sediment inputs from forest harvesting and the construction of forestry infrastructure (eg, haul/skid sites and roading) are not included within CLUES, which estimates losses assuming a stable forest cover;

- Urban land use – because CLUES was designed primarily for broad rural catchments, it does not discriminate between different types of land use within urban catchment areas;

- In-stream erosion (this includes stream-bank erosion);
- Site-specific projects – large development projects, such as predicted inputs from the Transmission Gully Motorway (TGM) road development, are not included within CLUES;
- Recent information – studies undertaken since CLUES was developed (eg, Wellington City Council, Greater Wellington Regional Council, Auckland Regional Council data) have improved knowledge of estimated yields from some land use classes and provide better resolution than currently possible within CLUES; and
- CLUES does not provide sediment load estimates for each land use class within sub-catchments (a key output in assessing land use changes and mitigation options).

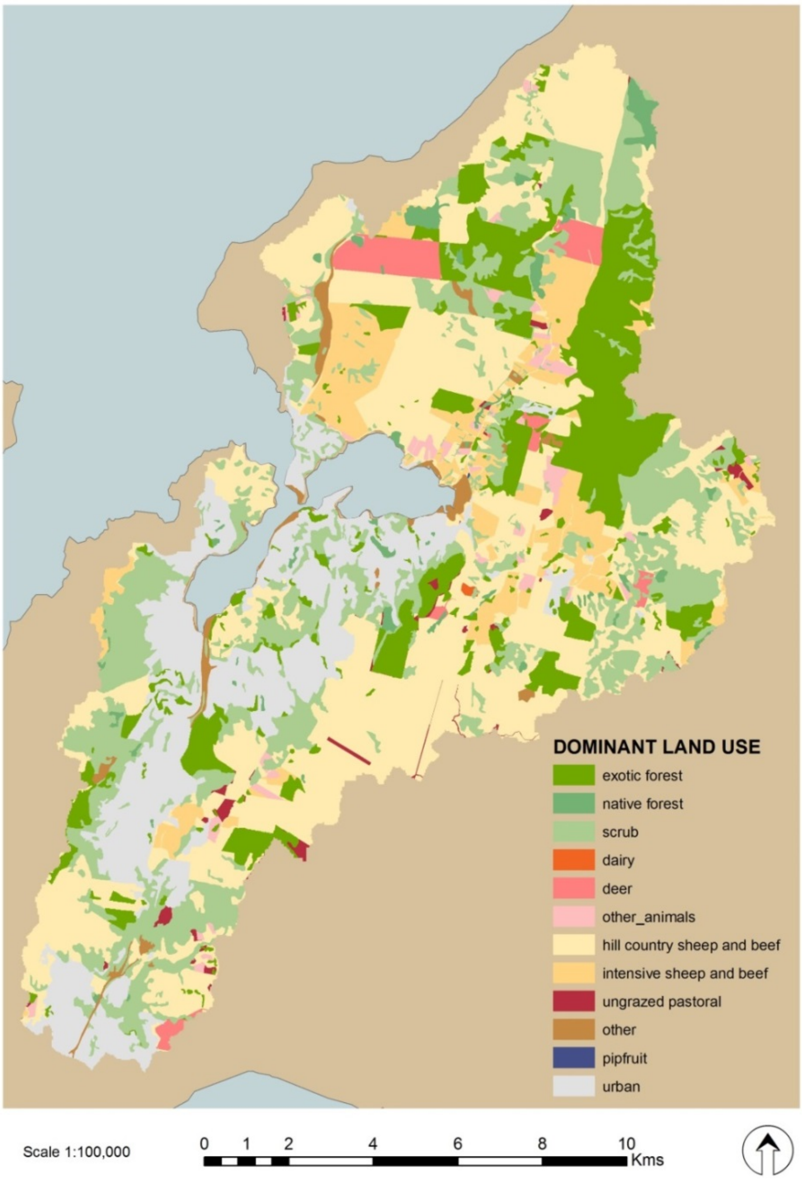

Figure 2.1: Dominant land use (LCDB2) in default CLUES for catchments draining into Porirua Harbour

To account for the limitations of CLUES in estimating local land use sediment loads, an Excel spreadsheet addendum has been used to modify CLUES outputs to incorporate sediment inputs from sources relevant to Porirua Harbour, and to facilitate comparison of land use changes. The process undertaken to generate the modified CLUES output was staged as follows:

- Run CLUES (v3.1) in default mode to derive predicted sediment loads from each sub-catchment of Porirua Harbour (Table 2.1, Figures 2.2 and 2.3). Default mode bases outputs on the 'current' catchment land use, which is the most up-to-date LCDB cover included within CLUES (in this case 2001 land cover from the LCDB2[1]);

- Incorporate specific land cover not addressed by CLUES (eg, bare land, forest harvesting or forest roading) and add to CLUES default outputs via spreadsheet by multiplying selected yields by the area of land in relevant land use classes (eg, bare land area x bare land yield);

- Determine average yields used by CLUES for each land use class by manually interrogating CLUES in subcatchments where cover is exclusive to a single land use class and compare CLUES estimated sediment yields for each land use class to sediment yields derived from other sources to determine whether CLUES values need altering;

- Proportionally adjust CLUES outputs where appropriate by scaling CLUES default outputs. For example, if default CLUES exotic forest yield = 1 t/ha/yr, and the likely yield is 2 t/ha/yr, multiply CLUES default exotic forest output by 2. A risk of this approach is that slope, attenuation and other naturally occurring stream processes are overlooked. The CLUES model considers these processes and may confer some sediment output reductions; and

- Apply modified outputs to scenarios run through the spreadsheet-modified CLUES (eg, conversion of pasture to native forest, or load reductions expected from the implementation of Best Management Practices (BMPs) to key land uses such as pasture). This is to highlight the likely alterations to sediment loads required to reduce sediment inputs to Porirua Harbour by ~50%.

In the following sections four main outputs are presented of predicted catchment sediment loads. Three of these use the CLUES model outputs, in some cases incorporating loads predicted from land use yields, whereas the fourth uses loads predicted entirely from relevant land use yields.

- **CLUES default results (Section 2.3)**: Summary of initial default CLUES outputs (the unmodified outputs underestimate sediment loads).

- **CLUES modified results 2012 (Section 2.4)**: Modified CLUES outputs presented at the 15 March 2012 workshop, incorporating additional

[1] CLUES was updated in 2014 (v10.2.2) to include LCDB3 but the modelling documented in this report was carried out prior to this update being available.

sediment inputs based on predicted yields from specified land uses (eg, forestry, urban and bare land), and a range of mitigation scenarios.

- **CLUES modified results 2013 (Section 2.5)**: Modified CLUES outputs presented at the 26 March 2013 workshop, incorporating revised sediment inputs based on predicted yields from specified land uses (Transmission Gully Motorway (TGM) construction, forestry roading estimates, validated estimates of bare land) and revised mitigation scenarios.

- **Predicted loads based on land use yields 2013 (Section 2.6)**: Sediment load outputs presented at the 26 March 2013 workshop, incorporating revised sediment inputs based on predicted yields from specified land uses.

2.3 CLUES default results

Figure 2.2 shows the catchment detail used in the CLUES model. Table 2.1 and Figures 2.3 and 2.4 present the default outputs from CLUES prepared for the 15 March 2012 Porirua Harbour and Catchment science workshop. These values underestimate expected sediment loads and yields for the following reasons:

- They do not include inputs from key sources of bare land (urban development), forest harvesting and road construction, or the TGM construction; and
- Higher yields are expected from some specific land uses (eg, urban, exotic forest) than those currently applied within the CLUES model.

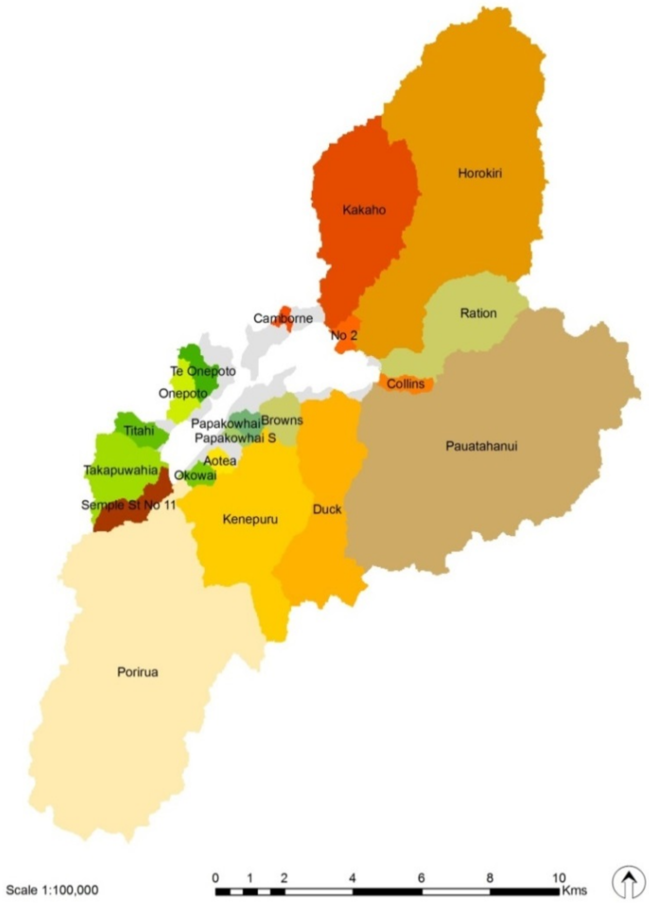

Figure 2.2: Location of CLUES subcatchments draining into Porirua Harbour

Table 2.1: Estimated sediment loads (kt/yr) and calculated yields (t/ha/yr) by subcatchment for the Porirua Harbour catchment (based on unmodified CLUES default output) and resulting mean annual areal sedimentation rates (mm/yr)

Subcatchment	Area (ha)	Sediment load (kt/yr)	Calculated yield (t/ha/yr)
Camborne Stream	25	0.014	0.56
Kakaho Stream	1,246	2.320	1.86
No 2 Stream	39	0.038	0.97
Horokiri Stream	3,306	6.880	2.08
Ration Stream	680	0.442	0.65
Collins Stream	63	0.030	0.48
Pauatahanui Stream	4,168	5.519	1.32
Duck Creek	1,030	1.354	1.32
Browns Stream	135	0.051	0.38
Subtotal Pauatahanui	*10,692*	*16.648*	*1.56*
Papakowhai north	63	0.025	0.40
Papakowhai south	28	0.013	0.47
Aotea Lagoon	42	0.022	0.52
Okowai Road	52	0.036	0.70
Kenepuru Stream	1,266	1.089	0.86
Porirua Stream	4,108	4.164	1.01
Semple Street Stream	160	0.064	0.40
Takapuwahia Stream	347	0.205	0.59
No 13 Stream ‘Titahi’	101	0.034	0.34
No 14 Stream ‘Onepoto’	111	0.023	0.21
No 15 Stream ‘Te Onepoto’	98	0.061	0.62
Subtotal Onepoto	*6,376*	*5.735*	*0.90*
OVERALL TOTAL (ha)	**17,068**	**22.383**	**1.31**

Pauatahanui Arm Mean Areal Sedimentation Rate	(mm/yr)	2.6
Onepoto Arm Mean Areal Sedimentation Rate	(mm/yr)	1.7
Total Mean Areal Sedimentation Rate*	(mm/yr)	2.3

*Total mean (annual) areal sedimentation rate is the average depth sediment would increase by in the estuary if all inputs were 7spread evenly over the estuary area.

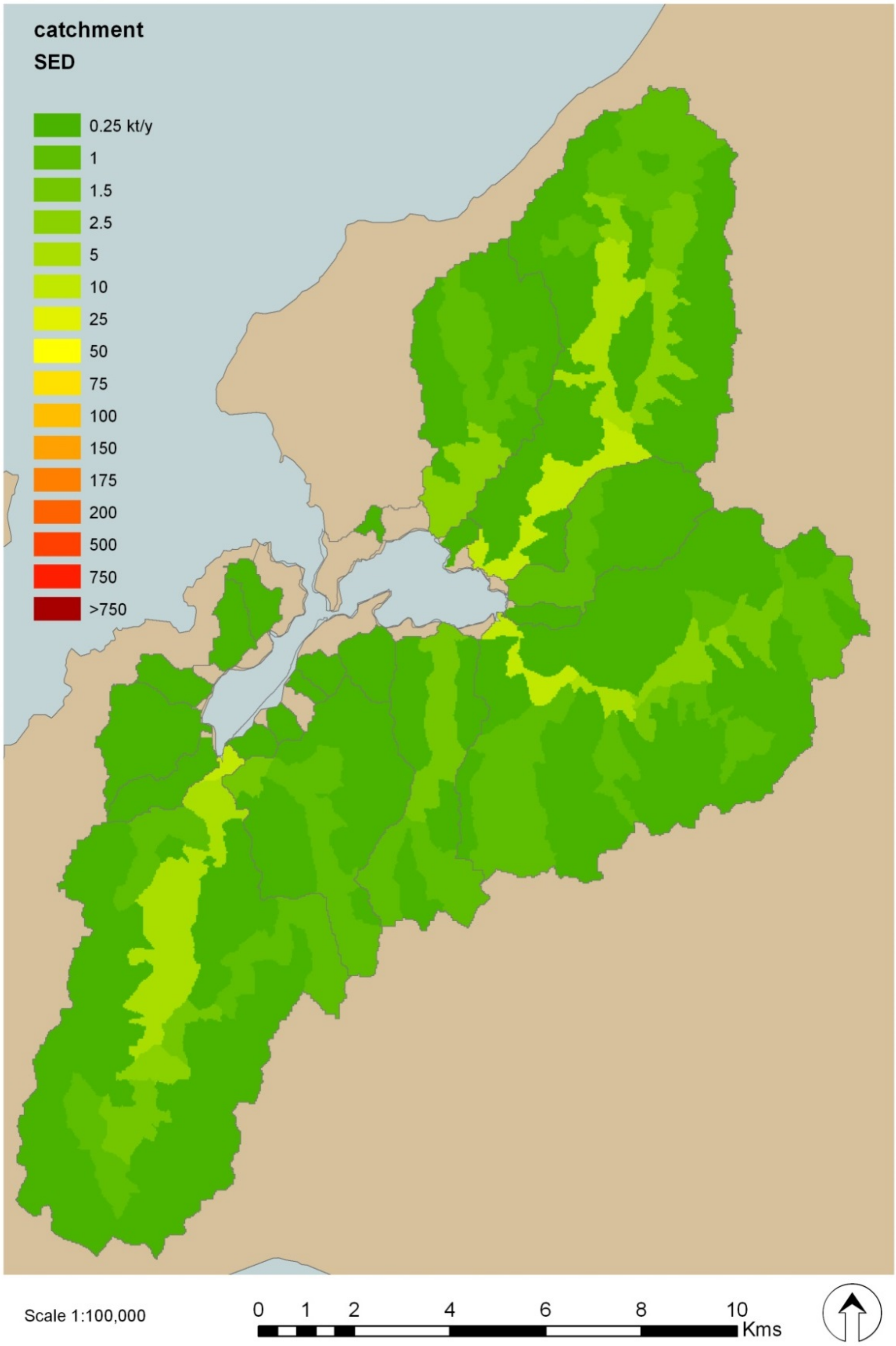

Figure 2.3: Estimated sediment loads (kt/yr) for the Porirua Harbour catchment (based on unmodified CLUES default output)

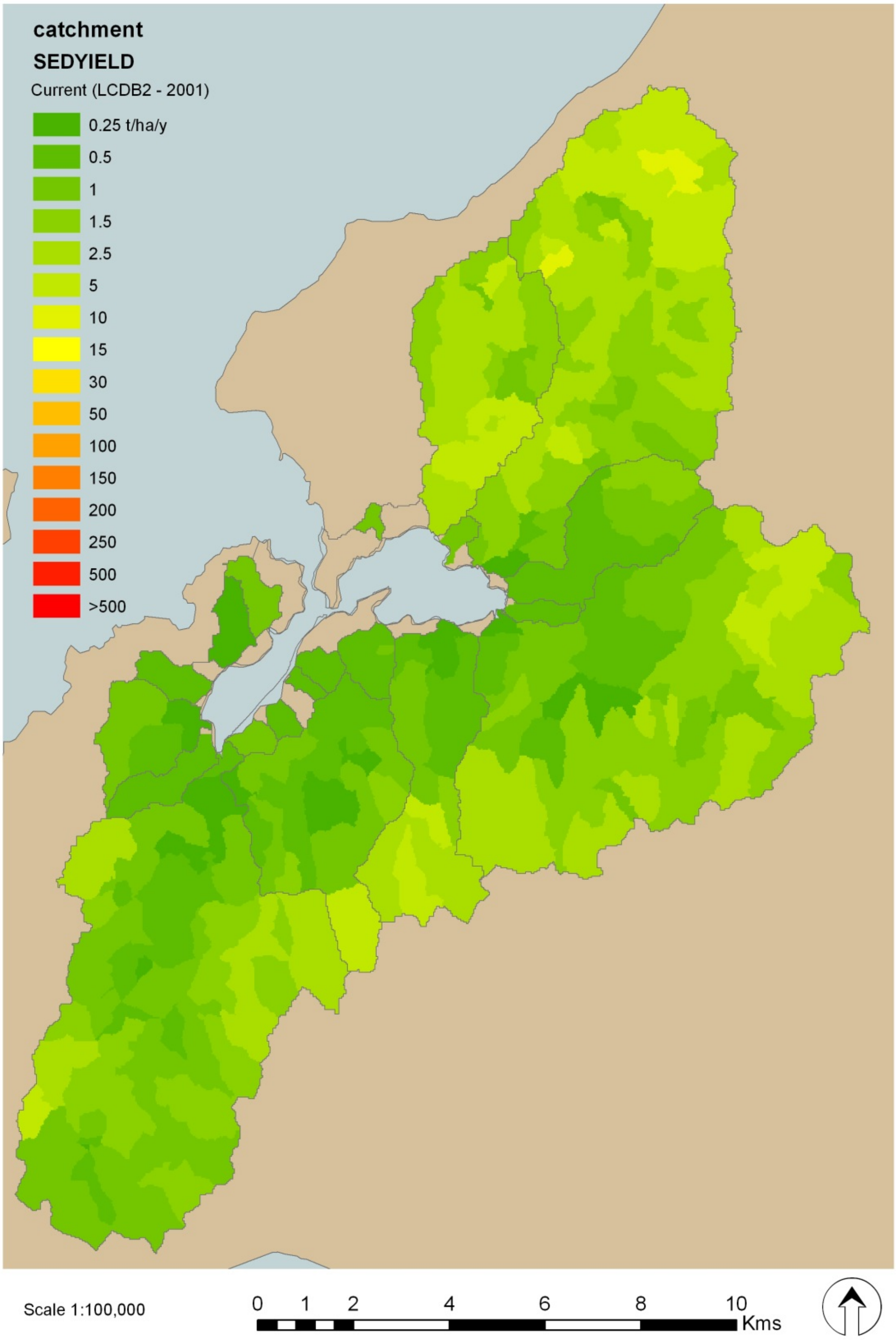

Figure 2.4: Estimated sediment yields (t/ha/yr) for the Porirua Harbour catchment (based on unmodified CLUES default output)

2.4 CLUES modified results 2012

To account for the limitations of the default CLUES assumptions (eg, exclusion of bare land or forestry roading estimates) spreadsheet modifications were made to the CLUES default output to include contributions expected from exotic forestry, urban areas and bare land developments above those predicted by CLUES). These estimates were presented at the initial 15 March 2012 Porirua Harbour and Catchment science workshop. Table 2.2 shows the yields used in the spreadsheet addendum to modify CLUES default outputs.

Table 2.2: CLUES default yields for dominant land use in the Porirua Harbour catchment and modified values applied in a spreadsheet addendum to calculate predicted sediment loads

Sediment yield (t/ha/yr)	Pasture	Native forest	Exotic forest	Urban	Other	Bare land
CLUES default	2.1	1	1	0.3	0.3	0
Modified CLUES	2.1	1	2	2	0.3	130

The spreadsheet addendum results were then applied to a range of mitigation options to highlight the likely alterations to sediment loads that could be achieved through various broad scale changes in land use, mitigation of current land uses, or a combination of the two. The CLUES-modified 2012 outputs are summarised in Table 2.3 with catchment detail presented in Table 2.4.

Table 2.3: Estimated total sediment loads and yields for the Porirua Harbour catchment (based on CLUES modified 2012 outputs) under a range of mitigation scenarios

<table>
<tr><th colspan="7" rowspan="2">Mitigation option</th><th colspan="3">Sediment load</th><th rowspan="2">Mean areal rate (mm/yr)</th></tr>
<tr><th>Load (kt/yr)</th><th>Yield (t/ha/yr)</th><th>% Change</th></tr>
<tr><td colspan="7">Pre-European[1]</td><td>1.7</td><td>0.1</td><td>-96%</td><td>0.2</td></tr>
<tr><td rowspan="2">Modified CLUES yields (t/ha/yr)</td><td>Pasture</td><td>Native Forest</td><td>Exotic Forest[2]</td><td>Urban[3]</td><td>Other</td><td>Bare land[3]</td><td rowspan="2">48.5</td><td rowspan="2">2.8</td><td rowspan="2">0%</td><td rowspan="2">5.0</td></tr>
<tr><td>2.1</td><td>1</td><td>2</td><td>2</td><td>0.3</td><td>130</td></tr>
<tr><td colspan="7">1. Steep Pasture to Native Forest</td><td>37.7</td><td>2.2</td><td>-22%</td><td>3.9</td></tr>
<tr><td colspan="7">2. Pasture with 25%[4] BMP (Best Management Practices)</td><td>44.9</td><td>2.6</td><td>-7%</td><td>4.6</td></tr>
<tr><td colspan="7">3. Pasture with 75%[5] BMP</td><td>37.7</td><td>2.2</td><td>-22%</td><td>3.9</td></tr>
<tr><td colspan="7">4. Steep Pasture to Native + 25% BMP on Remaining Pasture</td><td>36.8</td><td>2.2</td><td>-24%</td><td>3.8</td></tr>
<tr><td colspan="7">5. All Pasture to Native Forest</td><td>36.0</td><td>2.1</td><td>-26%</td><td>3.7</td></tr>
<tr><td colspan="7">6. All Pasture to Exotic Forest</td><td>45.1</td><td>2.6</td><td>-7%</td><td>4.7</td></tr>
<tr><td colspan="7">7. Urban with 75% BMP</td><td>45.5</td><td>2.7</td><td>-6%</td><td>4.7</td></tr>
<tr><td colspan="7">8. Bare land with 75% BMP</td><td>33.9</td><td>2.0</td><td>-30%</td><td>3.5</td></tr>
<tr><td colspan="7">9. Urban and bare land with 75% BMP</td><td>30.9</td><td>1.8</td><td>-36%</td><td>3.2</td></tr>
<tr><td colspan="7">10. 90% reduction in bare land area</td><td>31.0</td><td>1.7</td><td>-36%</td><td>3.2</td></tr>
<tr><td colspan="7">11. 90% reduction in bare land area + 75% BMP on bare land</td><td>29.5</td><td>0.7</td><td>-39%</td><td>3.0</td></tr>
<tr><td colspan="7">12. 90% reduction in bare land area + 75% BMP on urban & bare land</td><td>26.5</td><td>1.6</td><td>-45%</td><td>2.7</td></tr>
<tr><td colspan="7">13. 90% bare land reduction +75% BMP on pasture & urban & bare land</td><td>15.7</td><td>0.9</td><td>-68%</td><td>1.6</td></tr>
<tr><td colspan="7">14. 90% bare land reduction +75% BMP on pasture & urban & bare land & exotic forest</td><td>11.8</td><td>0.7</td><td>-76%</td><td>1.2</td></tr>
</table>

1 Pre-European is 20% of CLUES native forest load (to account for expected high natural wetland and saltmarsh filtering).
2 Exotic forest is 2 x CLUES native forest loads (to incorporate a moderate increase from forestry disturbance).
3 Urban and bare land inputs added to CLUES outputs based on predicted yields allocated (see Table 2.2).
4 This refers to a 25% reduction in sediment run-off with application of BMP.
5 This refers to a 75% reduction in sediment run off with application of BMP.

The modified CLUES 2012 loads reflect the addition of load estimates from CLUES (v3.1) run in default mode to loads calculated by multiplying land use yield by area where changes were considered appropriate. To do this the yields produced by CLUES were estimated by averaging the CLUES yields from multiple subcatchments containing land use of only one type (eg, exotic forest). The difference between the CLUES default yield and the yield being applied in the modified CLUES was then determined (see Table 2.2). For example, the exotic forest yield for Porirua Harbour in default CLUES was 1 t/ha/yr, compared to a yield of 2 t/ha/yr that was identified as a more representative value for the Porirua Harbour catchment. The additional load used in modified CLUES was calculated by multiplying the area of land in exotic forest by 1 t/ha/yr. This was then added to the default CLUES load to effectively double the load. This process was repeated for each major land use where changes were needed.

The mitigation options were derived in the same way. Firstly, key changes were made within CLUES, eg, Scenario 1 – the conversion of steep pasture to native forest was undertaken within CLUES by converting all steep pasture to native forest, and running CLUES. The outputs were then added via spreadsheet addendum to incorporate the modified yield changes to highlight likely changes possible with different land use change scenarios. These are summarised in Table 2.3 and detailed in Table 2.4.

Table 2.4: Estimated sediment loads for the Porirua Harbour catchment (based on modified CLUES 2012 outputs) under a range of mitigation scenarios

Modified CLUES 2012 sediment load (kt/yr)	**Pre European**	**Modified CLUES (no mitigation)**	**1. Steep Pasture to Native Forest**	**2. Pasture with 25% BMP**	**3. Pasture with 75% BMP**	**4. Steep to Native & Pasture 25% BMP**	**5. all Pasture to Native Forest**	**6. all Pasture to Exotic Forest**
Camborne Stream	0.001	0.019	0.013	0.017	0.014	0.012	0.012	0.018
Kakaho Stream	0.159	2.504	1.248	2.020	1.053	1.147	0.973	1.683
No 2 Stream	0.002	0.041	0.025	0.036	0.027	0.022	0.019	0.032
Horokiri Stream	0.596	8.382	5.168	7.333	5.242	4.851	4.645	7.644
Ration Stream	0.047	2.754	2.609	2.708	2.616	2.596	2.568	2.802
Collins Stream	0.002	0.036	0.022	0.031	0.020	0.019	0.015	0.020
Pauatahanui Stream	0.407	10.803	8.042	9.800	7.794	7.734	7.462	9.413
Duck Creek	0.075	3.775	2.920	3.491	2.922	2.863	2.860	3.248
Browns Stream	0.005	0.965	0.965	0.965	0.965	0.965	0.965	1.016
Subtotal Pauatahanui	*1.293*	*29.268*	*21.009*	*26.396*	*20.650*	*20.206*	*19.516*	*25.872*
Papakowhai north	0.002	0.106	0.106	0.106	0.106	0.106	0.106	0.131
Papakowhai south	0.001	0.052	0.051	0.052	0.052	0.052	0.052	0.065
Aotea Lagoon	0.002	0.431	0.419	0.429	0.424	0.421	0.421	0.431
Okowai Road	0.002	0.171	0.152	0.166	0.157	0.152	0.151	0.164
Kenepuru Stream	0.067	3.297	2.746	3.131	2.797	2.726	2.712	3.177
Porirua Stream	0.294	14.291	12.435	13.767	12.720	12.315	12.257	14.250
Semple Street	0.006	0.196	0.195	0.196	0.196	0.196	0.196	0.260
Takapuwahia Stream	0.020	0.368	0.305	0.345	0.299	0.295	0.294	0.420
Titahi Stream	0.003	0.095	0.090	0.093	0.090	0.089	0.088	0.114
Onepoto Stream	0.002	0.182	0.181	0.182	0.182	0.180	0.180	0.201
Te Onepoto Stream	0.004	0.069	0.036	0.061	0.045	0.032	0.031	0.049
Subtotal Onepoto	*0.421*	*19.258*	*16.726*	*18.529*	*17.069*	*16.565*	*16.489*	*19.262*
OVERALL TOTAL	**1.714**	**48.526**	**37.736**	**44.926**	**37.719**	**36.771**	**36.005**	**45.134**
Percentage change from current loads	-96%	0%	-22%	-7%	-22%	-24%	-26%	-7%

Total catchment SS yield t/ha/yr	0.1	2.8	2.2	2.6	2.2	2.2	2.1	2.6
Pauatahanui Arm mean areal sed rate (mm/yr)	0.2	4.7	3.3	4.2	3.3	3.2	3.1	4.1
Onepoto Arm mean areal sed rate (mm/yr)	0.5	14.3	11.1	13.2	11.1	10.8	10.6	13.3
Total mean areal sed rate (mm/yr)	0.2	5.0	3.9	4.6	3.9	3.8	3.7	4.7

Table 2.4 (*cont.*): Estimated sediment loads for the Porirua Harbour catchment (based on modified CLUES 2012 outputs) under a range of mitigation scenarios

Modified CLUES 2012 sediment load (kt/yr)					90% reduction in bare land area		90% bare land red. +75% pasture BMP	
	7. Urban with 75% BMP	8. Bare land with 75% BMP	9. Urban and bare land with 75% BMP	10. 90% reduction in bare land area	11. 75% bare land BMP	12. 75% urban and bare land BMP	13. 75% urban and bare land BMP	14. 75% urban/bare BMP and 75% forest BMP
Camborne Stream	0.016	0.019	0.016	0.019	0.019	0.016	0.011	0.009
Kakaho Stream	2.504	2.504	2.504	2.504	2.504	2.504	1.053	0.777
No 2 Stream	0.039	0.041	0.039	0.041	0.041	0.039	0.025	0.025
Horokiri Stream	8.382	7.895	7.895	7.797	7.749	7.749	4.609	3.330
Ration Stream	2.750	1.291	1.287	0.999	0.853	0.849	0.711	0.176
Collins Stream	0.032	0.036	0.032	0.036	0.036	0.032	0.016	0.016
Pauatahanui Stream	10.716	7.391	7.304	6.708	6.367	6.280	3.271	2.344
Duck Creek	3.529	2.312	2.066	2.020	1.873	1.627	0.774	0.560
Browns Stream	0.871	0.380	0.286	0.263	0.204	0.110	0.110	0.098
Subtotal Pauatahanui	*28.833*	*21.858*	*21.423*	*20.376*	*19.635*	*19.200*	*10.582*	*7.330*
Papakowhai north	0.046	0.106	0.046	0.106	0.106	0.046	0.046	0.044
Papakowhai south	0.023	0.052	0.023	0.052	0.052	0.023	0.023	0.022
Aotea Lagoon	0.422	0.138	0.130	0.080	0.050	0.042	0.035	0.024
Okowai Road	0.171	0.073	0.073	0.054	0.044	0.044	0.030	0.023
Kenepuru Stream	2.646	2.322	1.671	2.127	2.030	1.379	0.879	0.818
Porirua Stream	12.838	8.441	6.988	7.271	6.686	5.233	3.662	3.078
Semple Street	0.098	0.196	0.098	0.196	0.196	0.098	0.098	0.096
Takapuwahia Stream	0.246	0.368	0.246	0.368	0.368	0.246	0.177	0.177
Titahi Stream	0.053	0.095	0.053	0.095	0.095	0.053	0.048	0.041
Onepoto Stream	0.064	0.182	0.064	0.182	0.182	0.064	0.064	0.061
Te Onepoto Stream	0.063	0.069	0.063	0.069	0.069	0.063	0.039	0.039
Subtotal Onepoto	*16.670*	*12.043*	*9.455*	*10.600*	*9.878*	*7.290*	*5.101*	*4.423*
OVERALL TOTAL	**45.503**	**33.901**	**30.878**	**30.976**	**29.513**	**26.491**	**15.684**	**11.753**
Percentage change from current loads	-6%	-30%	-36%	-36%	-39%	-45%	-68%	-76%

Total catchment SS yield t/ha/yr	2.7	2.0	1.8	1.7	0.7	1.6	0.9	0.7
Pauatahanui Arm mean areal sed rate (mm/yr)	4.6	3.5	3.4	3.2	3.1	3.1	1.7	1.2
Onepoto Arm mean areal sed rate (mm/yr)	13.4	10.0	9.1	9.1	8.7	7.8	4.6	3.5
Total Mean areal sed rate (mm/yr)	4.7	3.5	3.2	3.2	3.0	2.7	1.6	1.2

2.5 CLUES modified results 2013

Following the 15 March 2012 Porirua Harbour and Catchment science workshop, it was recognised that key sediment inputs from bare land development, forestry harvesting and associated road construction, and the TGM construction needed to be better characterised. Additional detail was subsequently sought from Auckland Council (AC), Sinclair Knight Merz (SKM), Porirua City Council (PCC), Wellington City Council (WCC), Greater Wellington Regional Council (GWRC) and Wriggle Coastal Management on:

- Estimated sediment yields from detailed studies in the Auckland region for different land uses (forestry, urban and bare land);
- Land cover and sediment load estimates used in the TGM construction assessments; and
- Actual areas of bare land (bulk earthworks) in the Porirua Harbour catchment from PCC and WCC consents data (and any available loading information).

CLUES sediment yield data were subsequently updated for the whole Porirua Harbour catchment following collation of this information, and presented at a second workshop on 26 March 2013. The key changes made, and assumptions and rationale for each change, are presented in the following sections.

(a) Estimated yields from different land uses

Detailed studies undertaken by the AC on sediment yields from different land uses (included in their 2011 Contaminant Load Model – (CLM)) are expected to be the best currently available estimates of forest, urban, and bare land loadings. These are summarised in Table 2.5.

For each land use, a decision was made regarding whether to use or alter the default CLUES yield in the spreadsheet addendum and to determine the yields to apply for land uses not covered by CLUES. Table 2.5 presents the AC CLM (2011) values, estimated default CLUES yields for Porirua Harbour catchments, and the yields selected for use in the latest load estimates, along with brief rationale for each change. Yields used are summarised in Table 2.6.

Table 2.5: Estimated suspended sediment yields (t/ha/yr) based on the AC Contaminant Load Model (2011 Version), CLUES model predicted yields and Porirua catchment yields chosen for use in this report

	AC CLM (2011)			**Default CLUES**	**Modified CLUES**	**Rationale**
SEDIMENT YIELD (T/ha/yr)	**Slope (Degrees)**					
LAND USE	**<10**	**10–20**	**>20**	**Est. yields**	**Est. yields**	
Stable Bush	0.14	0.42	0.83	1	0.8	Most remaining bush confined to steeper parts of catchment
Exotic Production Forestry	0.35	1.04	2.08	1	2.1	Most exotic forest located in steeper parts of catchment
Retired Pasture	0.21	0.63	1.25	2.1		
Farmed Pasture	1.52	4.56	9.23	2.1	2.1	AC values are higher but may not be applicable to Porirua.
Horticulture	1					
Urban Residential	0.32			0.3	0.75	Urban input assumed to fall within the middle of the estimates based on high vehicle numbers, and the presence of steep urban grassland.
Urban Grasslands	0.45	0.92	1.85			
Commercial	0.32					
Industrial	0.22					
Roads (5,000–20,000 vehicles/day)	0.53					
Roads (>100,000 vehicles/day)	2.34					
Construction sites: Slope (Degrees)	<5	5–10	>10			
Bare land – Open 2 mths/yr	4	9	18	0		
Bare land – Open 6 mths/yr	13	28	53		53	Assume bare land on steeper slopes, and open for 6 mths
Bare land – Open 12 mths/yr	25	56	106		106	Assume forest roads on steeper slopes, and open for 12 mths

(b) Transmission Gully Motorway (TGM) inputs

The predicted sediment inputs generated by the construction of the TGM were incorporated directly from estimates provided in the Transmission Gully Project Technical Report 15, Assessment of Water Quality Effects (Keating et al. 2011), and in subsequent communications with SKM.

The output from a coupled hydrodynamic, wave and sediment transport model provided an indication of the cumulative effects of sediment deposition in the harbour over the full construction period. Results were extracted after running the model for 10 years and 20 years. In the long term simulation, an additional 3,000 tonnes of sediment is estimated to enter the harbour as a result of all the construction activities (over a 6-year period). This represents around 2% of the total terrestrial sediment load entering the harbour over a 10-year period (Keating et al. 2011; Appendix 2).

Once construction is completed, SKM predict no further increase in inputs because of mitigation actions (eg, wetland construction) in the motorway affected catchments that have a combined effect of reducing suspended sediment (SS) yields to less than what they were prior to motorway construction. Estimates indicate that the total predicted improvement in SS loads to Porirua Harbour as a result of these mitigation actions amounts to 457 t/yr once the motorway is fully operational.

SKM (pers comm. letter 8 May 2012, Appendix 3) also recently provided a more detailed estimate of the maximum annual SS load during construction of 2,468 t/yr from all catchments (they also provided a breakdown for each sub-catchment).

(c) Bare land area estimates

A detailed assessment of bare land (bulk earthworks from aerial photography) was provided by WCC covering several years (2002, 2004, 2006, 2009, 2010) and indicated that, in relative terms, the catchment wide estimates of bare land used in the initial calculations (ie, March 2012 calculations) were representative of the likely level of disturbance. Other estimates provided by PCC, while very helpful, were not comprehensive enough to allow a catchment wide estimate to be derived. As a consequence, this report uses the initial estimates for bare land as supported by WCC results. That is, the extent of bare land comprised 150 ha based on a visual assessment of 2009 aerial photographs.

(d) Forestry roading inputs

A review of available information indicated a range of values for forest road density and so mean annual forestry roading inputs were incorporated based on the following assumptions:

- Forest roading density of 83 m/ha (=1 km road for every 12 ha forest) was used based on the higher of:
  - Forest roading density of 83 m/ha reported in "Roger Dickie NZ Forestry Conference 2011 – (summary sheet" (http://rogerdickie.co.nz)
  - Forest roading density of 28 m/ha (Neilson D. 2012. Building better roads using better technology. NZIF Conference Proceedings 2012. (http://www.treesandstars.com/euan/NZIF2012/8Neilson.pdf)
- Each km of road was assumed to be 10 m wide (therefore each km represents 1 ha of disturbed land);
- The forest is harvested on a 30-year cycle;
- Forest roads are predominantly on slopes >10 degrees and remain open (unsealed) for 12 months; and
- Sediment yield from forest roads was assumed to equate to 106 t/yr (ie, the yield estimated for a construction site open for 12 months/yr and >10 degree slope (AC CLM 2011).

The area affected by each of the above changes was defined and incorporated into the over-arching land use classes, with the revised results presented in Tables 2.6 to 2.8. The forestry road extent used was 1/30th of the total to estimate an annual average for an assumed 30-year harvesting cycle. Clearly, harvesting is not evenly spread across the 30 years and there will be peak periods of disturbance where annual sediment loads are likely to be higher than the average values indicate.

Pasture was not modified as it was considered that CLUES would appropriately predict likely average sediment inputs from pasture. However the AC CLM (2011) (Table 2.5) indicates yields from steep pasture are likely to be higher than CLUES predicts. At present, CLUES does not allow yields for specific land uses to be directly extracted to assess their relative contribution from within subcatchments. Ideally the next update of this work should separate pasture into slope class yields so they can be compared to CLUES.

Table 2.6 shows the yields applied in the spreadsheet addendum used to modify CLUES default outputs for the 26 March 2013 science workshop.

Table 2.6: CLUES default yields for dominant land uses in the Porirua Harbour catchment and modified values applied in a spreadsheet addendum to calculate predicted sediment loads

Sediment yield (t/ha/yr)	Pasture	Native forest	Exotic forest	Urban	Other	Bare land	Forest roads
Default clues	2.1	1	1	0.3	0.3	0	-
Modified clues (March 2012)	2.1	1	2	2	0.3	130	-
Modified clues (March 2013)	2.1	0.8	2.1	0.75	0.3	53	106

The spreadsheet addendum results were again applied to a range of mitigation options to highlight the likely alterations to sediment loads that could be achieved through various broad scale changes in land use, mitigation of current land uses, or a combination of the two. The outputs are summarised in Table 2.7 and presented at a subcatchment scale in Table 2.8. These estimates do not incorporate the predicted inputs associated with the proposed TGM development. These estimates are incorporated later in Tables 2.10 and 2.11.

Table 2.7: Estimated total sediment loads and yields for the Porirua Harbour catchment (based on modified CLUES outputs) under a range of mitigation scenarios

<table>
<tr><th colspan="7" rowspan="2">Mitigation option</th><th colspan="3">Sediment load</th><th rowspan="2">Mean areal rate (mm/yr)</th></tr>
<tr><th>Load (kt/yr)</th><th>Yield t/ha/yr)</th><th>% Change</th></tr>
<tr><td colspan="7">Pre-European[1]</td><td>1.7</td><td>0.1</td><td>-96%</td><td>0.2</td></tr>
<tr><td rowspan="2">Modified CLUES yields (t/ha/yr)</td><td>Pasture</td><td>Native forest</td><td>Exotic forest[2]</td><td>Urban[3]</td><td>Other</td><td>Bare land[3]</td><td rowspan="2">34.2</td><td rowspan="2">2.0</td><td rowspan="2">0%</td><td rowspan="2">3.5</td></tr>
<tr><td>2.1</td><td>1</td><td>2</td><td>2</td><td>0.3</td><td>130</td></tr>
<tr><td colspan="7">1. Steep (>20° slope) Pasture to Native Forest</td><td>23.4</td><td>1.4</td><td>-32%</td><td>2.4</td></tr>
<tr><td colspan="7">2. Pasture with 25% BMP (Best Management Practices)</td><td>30.6</td><td>1.8</td><td>-11%</td><td>3.2</td></tr>
<tr><td colspan="7">3. Pasture with 75% BMP</td><td>23.4</td><td>1.4</td><td>-32%</td><td>2.4</td></tr>
<tr><td colspan="7">4. Steep Pasture to Native + 25% BMP on Remaining Pasture</td><td>22.5</td><td>1.3</td><td>-34%</td><td>2.3</td></tr>
<tr><td colspan="7">5. All Pasture to Native Forest</td><td>21.7</td><td>1.3</td><td>-37%</td><td>2.2</td></tr>
<tr><td colspan="7">6. All Pasture to Exotic Forest</td><td>32.6</td><td>1.9</td><td>-5%</td><td>3.4</td></tr>
<tr><td colspan="7">7. Urban with 75% BMP</td><td>33.4</td><td>2.0</td><td>-2%</td><td>3.5</td></tr>
<tr><td colspan="7">8. Bare land with 75% BMP</td><td>28.3</td><td>1.7</td><td>-17%</td><td>2.9</td></tr>
<tr><td colspan="7">9. Urban and bare land with 75% BMP</td><td>27.5</td><td>1.6</td><td>-20%</td><td>2.8</td></tr>
<tr><td colspan="7">10. 90% reduction in bare land area</td><td>27.1</td><td>1.6</td><td>-21%</td><td>2.8</td></tr>
<tr><td colspan="7">11. 90% reduction in bare land area + 75% BMP on bare land</td><td>26.5</td><td>1.6</td><td>-23%</td><td>2.7</td></tr>
<tr><td colspan="7">12. 90% reduction in bare land area + 75% BMP on urban & bare land</td><td>25.7</td><td>1.5</td><td>-25%</td><td>2.7</td></tr>
<tr><td colspan="7">13. 90% bare land red. +75% BMP on pasture & urban & bare land</td><td>14.9</td><td>0.9</td><td>-57%</td><td>1.5</td></tr>
<tr><td colspan="7">14. 90% bare land red. +75% BMP on pasture & urban & bare land & exotic forest</td><td>10.6</td><td>0.6</td><td>-69%</td><td>1.1</td></tr>
</table>

[1] Pre-European is 20% of CLUES native forest load (to account for expected high natural wetland and saltmarsh filtering).
[2] Exotic forest is 2 x CLUES native forest loads (to incorporate a moderate increase from forestry disturbance).
[3] Urban and bare land inputs added to CLUES outputs based on predicted yields allocated (see Table 2.2).

Table 2.8: Estimated sediment loads for Porirua Harbour subcatchments (based on modified CLUES 2013 outputs) under a range of mitigation scenarios

Modified CLUES 2013 sediment load (kt/yr)					90% reduction in bare land area		90% bare land red. + 75% pasture BMP	
	Pre European	Modified CLUES (no mitigation)	1. Steep Pasture to Native Forest	2. Pasture with 25% BMP	3. Pasture with 75% BMP	4. Steep to Native & Pasture 25% BMP	5. all Pasture to Native Forest	6. all Pasture to Exotic Forest
Camborne Stream	0.001	0.015	0.010	0.013	0.010	0.008	0.008	0.016
Kakaho Stream	0.159	2.527	1.271	2.042	1.076	1.170	0.996	1.863
No 2 Stream	0.002	0.038	0.023	0.033	0.024	0.019	0.016	0.034
Horokiri Stream	0.596	8.162	4.948	7.112	5.022	4.631	4.425	7.883
Ration Stream	0.047	1.728	1.584	1.682	1.590	1.570	1.542	1.824
Collins Stream	0.002	0.032	0.017	0.027	0.016	0.015	0.011	0.020
Pauatahanui Stream	0.407	8.066	5.305	7.063	5.057	4.997	4.725	7.121
Duck Creek	0.075	2.401	1.546	2.117	1.548	1.489	1.486	1.969
Browns Stream	0.005	0.405	0.405	0.405	0.405	0.405	0.405	0.461
Subtotal Pauatahanui	*1.293*	*23.366*	*15.108*	*20.495*	*14.748*	*14.304*	*13.614*	*21.191*
Papakowhai north	0.002	0.045	0.045	0.045	0.045	0.045	0.045	0.073
Papakowhai south	0.001	0.024	0.023	0.024	0.024	0.024	0.024	0.038
Aotea Lagoon	0.002	0.193	0.182	0.191	0.186	0.183	0.183	0.196
Okowai Road	0.002	0.094	0.076	0.089	0.080	0.075	0.074	0.092
Kenepuru Stream	0.067	1.845	1.294	1.679	1.345	1.274	1.260	1.815
Porirua Stream	0.294	8.206	6.350	7.682	6.635	6.230	6.172	8.515
Semple Street	0.006	0.085	0.085	0.085	0.085	0.085	0.085	0.155
Takapuwahia Stream	0.020	0.209	0.146	0.186	0.140	0.136	0.135	0.279
Titahi Stream	0.003	0.046	0.040	0.044	0.041	0.040	0.039	0.069
Onepoto Stream	0.002	0.066	0.065	0.066	0.066	0.064	0.064	0.087
Te Onepoto Stream	0.004	0.056	0.023	0.048	0.032	0.019	0.018	0.044
Subtotal Onepoto	*0.421*	*10.869*	*8.337*	*10.140*	*8.680*	*8.176*	*8.100*	*11.363*
OVERALL TOTAL	**1.71**	**34.24**	**23.44**	**30.63**	**23.43**	**22.48**	**21.71**	**32.55**
Percentage change from current loads	-95%	0%	-32%	-11%	-32%	-34%	-37%	-5%

Total catchment SS yield t/ha/yr	0.1	2.0	1.4	1.8	1.4	1.3	1.3	1.9
Pauatahanui Arm mean areal sed rate (mm/yr)	0.2	3.7	2.4	3.3	2.3	2.3	2.2	3.4
Onepoto Arm mean areal sed rate (mm/yr)	0.5	10.1	6.9	9.0	6.9	6.6	6.4	9.6
Total mean areal sed rate (mm/yr)	0.2	3.5	2.4	3.2	2.4	2.3	2.2	3.4

Table 2.8 (*cont.*): Estimated sediment loads for the Porirua Harbour catchment (based on modified CLUES 2013 outputs) under a range of mitigation scenarios

Modified CLUES 2013 sediment load (kt/yr)	7. Urban with 75% BMP	8. Bare land with 75% BMP	9. Urban and bare land with 75% BMP	10. 90% reduction in bare land area	90% reduction in bare land area: 11. 75% bare land BMP	90% reduction in bare land area: 12. 75% urban and bare land BMP	90% bare land red. +75% pasture BMP: 13. 75% urban and bare land BMP	90% bare land red. +75% pasture BMP: 14. 75% urban/bare BMP and 75% forest BMP
Camborne Stream	0.015	0.015	0.015	0.015	0.015	0.015	0.010	0.008
Kakaho Stream	2.527	2.527	2.527	2.527	2.527	2.527	1.076	0.772
No 2 Stream	0.038	0.038	0.038	0.038	0.038	0.038	0.024	0.024
Horokiri Stream	8.162	7.963	7.963	7.924	7.904	7.904	4.764	3.358
Ration Stream	1.727	1.132	1.131	1.013	0.953	0.952	0.814	0.226
Collins Stream	0.030	0.032	0.030	0.032	0.032	0.030	0.014	0.014
Pauatahanui Stream	8.043	6.675	6.652	6.397	6.257	6.234	3.225	2.206
Duck Creek	2.336	1.805	1.740	1.685	1.626	1.561	0.708	0.472
Browns Stream	0.380	0.166	0.141	0.119	0.095	0.070	0.070	0.056
Subtotal Pauatahanui	*23.250*	*20.345*	*20.229*	*19.741*	*19.439*	*19.322*	*10.704*	*7.135*
Papakowhai north	0.029	0.045	0.029	0.045	0.045	0.029	0.029	0.027
Papakowhai south	0.016	0.024	0.016	0.024	0.024	0.016	0.016	0.015
Aotea Lagoon	0.191	0.074	0.072	0.050	0.038	0.036	0.029	0.017
Okowai Road	0.094	0.054	0.054	0.046	0.042	0.042	0.028	0.021
Kenepuru Stream	1.673	1.448	1.276	1.368	1.329	1.156	0.656	0.589
Porirua Stream	7.821	5.821	5.436	5.344	5.105	4.721	3.150	2.507
Semple Street	0.059	0.085	0.059	0.085	0.085	0.059	0.059	0.057
Takapuwahia Stream	0.177	0.209	0.177	0.209	0.209	0.177	0.108	0.108
Titahi Stream	0.035	0.046	0.035	0.046	0.046	0.035	0.030	0.021
Onepoto Stream	0.035	0.066	0.035	0.066	0.066	0.035	0.035	0.031
Te Onepoto Stream	0.055	0.056	0.055	0.056	0.056	0.055	0.031	0.031
Subtotal Onepoto	*10.184*	*7.927*	*7.242*	*7.339*	*7.045*	*6.360*	*4.171*	*3.425*
OVERALL TOTAL	**33.43**	**28.27**	**27.47**	**27.08**	**26.48**	**25.68**	**14.88**	**10.56**
Percentage change from current loads	-2%	-17%	-20%	-21%	-23%	-25%	-57%	-69%

Total catchment SS yield t/ha/yr	2.0	1.7	1.6	1.6	1.6	1.5	0.9	0.6
Pauatahanui Arm mean areal sed rate (mm/yr)	3.7	3.2	3.2	3.1	3.1	3.1	1.7	1.1
Onepoto Arm mean areal sed rate (mm/yr)	9.8	8.3	8.1	8.0	7.8	7.6	4.4	3.1
Total mean areal sed rate (mm/yr)	3.5	2.9	2.8	2.8	2.7	2.7	1.5	1.1

2.6 Predicted loads based on land use yields 2013

To facilitate rapid assessments for specific land use classes (an option not currently available within CLUES) and activities like the TGM development, a spreadsheet calculation was also undertaken independently of CLUES based on multiplying the area in each land use class (Table 2.9) by predicted yields to obtain sediment totals for each land use class (Table 2.10). While calculated independently of CLUES, the spreadsheet predictions show strong concordance with the modified CLUES outputs, with total predicted sediment loads (excluding TGM inputs) as follows:

- 34.2 kt/yr from spreadsheet calculations (Table 3.11) and
- 34.4 kt/yr from modified CLUES (Table 2.7).

The spreadsheet results presented in Tables 2.9 and 2.10 include predicted inputs associated with the proposed TGM development that are based on the predicted maximum annual load during construction (as supplied by SKM, Appendix 3) assuming a 10-year annual return interval (ARI) storm event and the adherence to proposed earthworks mitigation measures.

Table 2.9: Land use in catchments draining into Porirua Harbour based on LCDB2, with changes made to incorporate estimated areas of bare land (based on urban earthworks evident in 2009 aerial photos), forestry roading*, and proposed peak year TGM changes)

	Catchment land use (ha and %)								
Catchment	**Pasture**	**Native forest**	**Exotic forest**	**Urban**	**Other**	**Bare (2009)**	**Forest roads***	**TMG**	**Total**
Camborne Stream	10 (39%)	5 (20%)	1 (4%)	2 (9%)	7 (27%)	0 (0%)	0 (0%)	0 (0%)	25
Kakaho Stream	790 (63%)	251 (20%)	184 (15%)	0 (0%)	20 (2%)	0 (0%)	1 (0%)	0 (0%)	1246
No 2 Stream	24 (63%)	2 (5%)	0 (0%)	2 (4%)	11 (28%)	0 (0%)	0 (0%)	0 (0%)	38
Horokiri Stream	1,427 (43%)	855 (26%)	852 (26%)	0 (0%)	146 (4%)	5 (0%)	2 (0%)	23 (1%)	3310
Ration Stream	199 (29%)	32 (5%)	356 (52%)	3 (0%)	51 (7%)	15 (2%)	1 (0%)	24 (4%)	681
Collins Stream	44 (70%)	1 (1%)	0 (0%)	4 (6%)	11 (18%)	0 (0%)	0 (0%)	3 (5%)	63
Pauatahanui Stream	2,271 (55%)	991 (24%)	611 (15%)	68 (2%)	173 (4%)	35 (1%)	2 (0%)	14 (0%)	4,165
Duck Creek	488 (47%)	169 (16%)	143 (14%)	193 (19%)	7 (1%)	15 (1%)	0 (0%)	14 (1%)	1,029
Browns Stream	0 (0%)	46 (34%)	8 (6%)	74 (55%)	1 (0%)	6 (4%)	0 (0%)	0 (0%)	135
Subtotal Pauatahanui	*5,252 (49%)*	*2,352 (22%)*	*2,156 (20%)*	*346 (3%)*	*427 (4%)*	*76 (1%)*	*6 (0%)*	*78 (1%)*	*1,0692*
Papakowhai north	0 (0%)	13 (21%)	1 (2%)	47 (75%)	1 (2%)	0 (0%)	0 (0%)	0 (0%)	63
Papakowhai south	1 (3%)	2 (7%)	1 (2%)	23 (81%)	2 (7%)	0 (0%)	0 (0%)	0 (0%)	28
Aotea Lagoon	18 (42%)	5 (11%)	7 (17%)	7 (16%)	3 (8%)	3 (7%)	0 (0%)	0 (0%)	43
Okowai Road	28 (56%)	7 (13%)	5 (9%)	0 (0%)	10 (20%)	1 (2%)	0 (0%)	0 (0%)	51
Kenepuru Stream	381 (30%)	295 (23%)	40 (3%)	510 (40%)	14 (1%)	10 (1%)	0 (0%)	16 (1%)	1266
Porirua Stream	1,369 (33%)	956 (23%)	381 (9%)	1,136 (28%)	184 (4%)	60 (1%)	1 (0%)	14 (0%)	4100
Semple Street Stream	0 (0%)	78 (49%)	2 (1%)	76 (48%)	2 (1%)	0 (0%)	0 (0%)	0 (0%)	158
Takapuwahia Stream	55 (16%)	194 (56%)	0 (0%)	96 (28%)	1 (0%)	0 (0%)	0 (0%)	0 (0%)	346
No 13 Stream "Titahi"	10 (10%)	50 (50%)	5 (5%)	33 (33%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	100
No 14 Stream "Onepoto"	7 (6%)	8 (7%)	2 (2%)	92 (84%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	110
No 15 Stream "Te Onepoto"	54 (55%)	34 (35%)	0 (0%)	5 (5%)	5 (5%)	0 (0%)	0 (0%)	0 (0%)	98
Subtotal Onepoto	*1,922 (30%)*	*1,642 (26%)*	*443 (7%)*	*2,026 (32%)*	*225 (4%)*	*74 (1%)*	*1 (0%)*	*29 (0%)*	*6363*
TOTAL AREA (ha)	7,174 (42%)	3,994 (23%)	2,599 (15%)	2,372 (14%)	652 (4%)	150 (1%)	7 (0%)	107 (1%)	1,7055
Area by land use (%)	42	23	15	14	4	1	0	1	100

*Forest roads based on 1km/12ha of forest divided by 30-year harvest period to estimate annual contribution.

Table 2.10 utilises average annual sediment yields (t/ha/yr) for specified land uses, multiplied by the area within each land use category. These land use categories have been modified to incorporate estimates for bare land earthworks, forestry roads and the predicted TGM development. Each load is calculated by multiplying the area in each land use class in each subcatchment (Table 2.9), by the predicted sediment yield for the land use class (specific yield calculated as per Table 2.6 and summarised at the top of Table 2.10).

For example: *Camborne Stream pasture area (10 ha) x yield (2.1 t/ha/yr) = predicted sediment load (20 t/yr)*

Table 2.10: Updated TSS loadings from catchments and additional areas draining into Porirua Harbour. Data are for a peak construction year from TGM assuming a 10-year ARI

Catchment load (TSS/yr)	Pasture	Native forest	Exotic forest	Urban	Other	Bare (2009)	Forest roads*	TMG	Total
Sediment yield (t/ha/yr)**	2.1	0.8	2.1	0.75	0.3	53	106	23	–
Camborne Stream	20	4	2	2	2	0	0	0	30
Kakaho Stream	1,658	201	387	0	6	0	54	0	2,306
No 2 Stream	50	2	0	1	3	0	0	0	56
Horokiri Stream	2,997	684	1,790	0	44	265	251	1,101	7,131
Ration Stream	418	26	748	2	15	795	105	557	2,666
Collins Stream	92	1	0	3	3	0	0	13	112
Pauatahanui Stream	4,769	793	1,283	51	52	1,855	180	269	9,252
Duck Creek	1025	135	300	145	2	795	42	251	2694
Browns Stream	0	37	18	55	0	318	2	0	431
Subtotal Pauatahanui	*11,030*	*1,881*	*4,527*	*259*	*128*	*4,028*	*635*	*2,190*	*24,678*
Papakowhai north	0	11	3	35	0	0	0	0	49
Papakowhai south	2	2	1	17	1	0	0	0	22
Aotea Lagoon	37	4	15	5	1	159	2	0	223
Okowai Road	59	5	10	0	3	53	1	0	132
Kenepuru Stream	800	236	84	383	4	530	12	208	2,257
Porirua Stream	2,874	765	800	852	55	3,180	112	70	8,709
Semple Street Stream	0	62	3	57	0	0	0	0	124
Takapuwahia Stream	115	155	0	72	0	0	0	0	343
No 13 Stream "Titahi"	21	40	11	25	0	0	1	0	99
No 14 Stream "Onepoto"	14	6	5	69	0	0	1	0	95
No 15 Stream "Te Onepoto"	113	27	0	4	1	0	0	0	146
Subtotal Onepoto	*4,036*	*1,314*	*931*	*1,520*	*68*	*3,922*	*131*	*278*	*12,199*
TOTAL load (TSS/yr)	15,066	3,195	5,458	1,779	196	7,950	765	2,468	36,877
Load by land use (%)	41	9	15	5	1	22	2	7	100

* Maximum annual load during construction (as supplied by SKM 2012) assuming a 10 year ARI (Annual Return Interval) storm event, and the meeting of proposed earthworks mitigation.

** the CLUES TSS yield for pasture (mean 2.1 t/ha/yr) may significantly underestimate actual loads if "pasture" was divided into "steep pasture" and "other pasture" and the appropriate AC CLM (2011) yields were applied for each of these land uses. This will translate into increased benefits (potentially up to 30% based on preliminary estimates) in terms of sediment reduction if mitigation of pasture is undertaken (eg, conversion of steep pasture to native forest).

The spreadsheet assessment values have been used to predict sediment loads for four specific scenarios as follows:

- Existing situation (based on modified CLUES);
- Existing situation plus TGM (peak loading during construction – 1 year only);
- Existing situation plus TGM (average loading during the 6-year construction period); and
- Predicted future land use changes, including the reduced loadings expected from TGM mitigation, based on a broad judgement of what the long term situation would be if there were moderate incentives for land use change (Handford, pers. comm.). A map layer was used to identify areas of land use change and calculate sediment yield based on average land use yield figures for the catchment.

Results are summarised in Table 2.11 with key findings presented Section 2.7.

Table 2.11: Porirua Harbour estimated sediment loads (t/yr) calculated from average yields for specified scenarios

LAND COVER	Pasture	Native forest	Exotic forest	Urban	Other	Bare	Forest roads	TMG	Total load (t/yr)	Mean areal sed rate (mm/yr)	Catchment TSS yield (t/ha/yr
Catchment area – 17,055 ha (derived from CLUES)	7,251	4,004	2,620	2,400	650	150	0	0			
1. MARCH 2013 REVISED PORIRUA CATCHMENT ESTIMATES (modified LCDB2) (existing situation)											
Area (ha)	7,251	4,004	2,613	2,400	650	150	7	0	34,628	3.6	2.0
Yield (t/ha/yr)	2.1	0.8	2.1	0.75	0.3	53	106	0			
Load (t/yr)	15,227	3,203	5,487	1,800	195	7,950	765	0			
% contribution	44	9	16	5	1	23	2	0			
2. EXISTING SITUATION plus Transmission Gully peak (1 year only) construction loading											
Area (ha)	7,173	3,995	2,597	2,396	622	150	7	107	36,877	3.8	2.2
Yield (t/ha/yr)	2.1	0.8	2.1	0.75	0.3	53	106	23			
Load (t/yr)	15,066	3,195	5,458	1,779	196	7,950	765	2,468			
% contribution	41	9	15	5	1	22	2	7			
3. EXISTING SITUATION plus Transmission Gully Average loading over 6-yr construction period											
Area (ha)	7,173	3,995	2,597	2,396	622	150	7	107	34,615	3.6	2.0
Yield (t/ha/yr)	2.1	0.8	2.1	0.75	0.3	53	106	1.9			
Load (t/yr)	15,063	3,196	5,454	1,797	187	7,950	765	203			
% contribution	44	9	16	5	1	23	2	1			
4. PREDICTED FUTURE PORIRUA CATCHMENT ESTIMATES (based on Peter Handford's estimated land use changes* and reduced Transmission Gully loads as a result of mitigation)											
Area (ha)	5,394	4,237	2,681	4,486	28	150	7	107	32,522	3.4	1.9
Yield (t/ha/yr)	2.1	0.8	2.1	0.75	0.3	53	106	1			
Load (t/yr)	11,327	3,389	5,631	3,365	11	7,950	742	107			
% contribution	35	10	17	10	0	24	2	0.3			

* Peter Handford's estimated land use changes (with allowance made for TGM) are as follows: Pasture decreases from 7,174ha to 5,394ha, exotic forest increases from 2,599 ha to 2,681ha, native forest increases from 3,994 to 4,237ha, urban increases from 2,372ha to 4,486ha. Subsequent estimates of reduction in sediment yield with land use change have used CLUES to model yield changes by area, rather than use averages. This estimates a significantly greater reduction with land use change as this activity is targeted to the high yield areas (Handford & Cosslett 2014).

2.7 Key findings

The outputs from the CLUES model indicate that under existing land use the dominant sediment sources in the Porirua Harbour catchment are pasture (44%), bare land (23%) and exotic forest (16%). The dominant sources of sediment under future land use scenarios, including during peak construction of the Transmission Gully Motorway (TGM), are predicted to be pasture (41%), bare land (22%), exotic forest (15%) and TGM construction (7%).

The CLUES model pinpointed the three largest subcatchments of Horokiri, Pauatahanui and Porirua Stream as the greatest contributors of sediment to the harbour and estimates that overall, sediment inputs from pasture, exotic forest, urban, forest roads and bare land would need to be reduced by 50–60% to achieve the targeted sedimentation rate of 1mm/year aspired to in the Porirua Harbour and Catchment Strategy (PCC 2012).

The maximum expected annual load in the first six years of TGM construction is estimated to be ~2,500 t/yr. In the long-term, however, once the motorway is established and all proposed mitigation in place, the sediment load from the catchments affected by TGM is expected to be 450 t/yr less than prior to the motorway being established.

2.8 Recommendations

The sediment load and yield estimates for the Porirua Harbour catchment could be improved as follows:

- Determine sediment yields from pasture separated into slope class yields for comparison with CLUES;
- Determine sediment yields from steep pasture areas to determine whether potential mitigation from retirement of steep pasture is greater than currently predicted;
- Validate model estimates for key drivers of sediment load, in particular, sediment loads in each of major stream inputs;
- Update sediment load estimates for all catchments using latest land cover estimates (ie, run with LCDB3 once it is fully functional in CLUES); and
- Refine management options to reduce major sediment load inputs using the Source-2-Sink model outputs.

3. Estimating sedimentation rates in the Pauatahanui Arm using the S2S model

3.1 Background

The purpose of building a Source-2-Sink (S2S) model was to develop a sediment budget for Porirua Harbour that could be used to support planning and decision-making. This was achieved by drawing on the principles of a source-to-sea model. The source-to-sea model aims to predict the fate of contaminants, such as sediment, in the coastal marine area that are generated in the catchment and transported downstream by freshwater.

3.2 Overview of approach

Depending on both the temporal and spatial scales of the problem being addressed, different approaches may be taken to source-to-sink model building. For example, it may be feasible to build a single model that simulates the generation, transport and ultimate fate of contaminants when both the temporal and spatial scales of interest are very small. More commonly, individual models for generation, transport and fate are coupled by the passing between the models of water, contaminants and, sometimes, momentum. For problems at the planning timescale, which is decades or longer, certain abstractions are typically required. Green (2008) described a source-to-sea model of this type that predicts rates and locations of estuarine sedimentation on a decadal timescale. Green's (2008) planning-scale source-to-sea model uses information from two separate models: a catchment sediment model and an estuarine hydrodynamics / sediment-transport model. The catchment sediment model is typically formulated at a daily timescale and the estuarine hydrodynamics / sediment-transport model is typically formulated at an event scale (tides, wind events, rain events).

The preparation for running Green's (2008) planning-scale source-to-sea model is as follows. A time series of daily weather, which includes rainfall and wind, is created for the simulation period by referring back to past observations and making suitable allowances for climate change, and a time series of tides is also created for the simulation period by using a standard tide forecaster. The estuary model is used to evaluate estuarine sediment transport under different tides, winds and freshwater runoff, each combination of which is called an "event", and a "library" of event sediment-transport patterns is created. Finally, the catchment sediment model is used to predict daily sediment loads over the simulation period, taking as input the daily rainfall.

For each day in the simulation period, the source-to-sea model looks up in the library the patterns of sediment transport according to the rainfall, wind and tide for the day in question, and then applies those patterns to both distribute the daily catchment sediment load (which would be zero when there was no rainfall) and also to "redistribute" estuarine sediment that is transported on a daily basis by waves and currents. The source-to-sea model builds up the predictions over the simulation period, tracking the fate of sediment from each source region (or "subcatchment").

A key prediction of the source-to-sea model is the change in bed-sediment level over the simulation period in each of a number of sinks ("subestuaries") into which the estuary may be divided. Dividing the difference between the bed-sediment level at the end of the simulation period and the bed-sediment level at the start of the simulation period by the duration, in years, of the simulation, yields an annual-average sedimentation rate for each subestuary. Since the model keeps track of the origin of every particle of sediment, the set of annual-average sedimentation rates (one rate for each subestuary) can be further decomposed into the so-called "total-sediment fate matrix" $F_{c,e}$. This shows how catchment sediment loads are distributed, on average over the simulation period, amongst different depositional environments in the estuary at the base of the catchment. Specifically, $F_{c,e}$ is the fraction of the total (sum of all grainsizes) sediment load from subcatchment c that is deposited in subestuary e over the simulation period, where $0 < F_{c,e} < 1$ for all (c, e).

The annual-average total-sediment budget may now be stated as:

$$D_e = \sum_{c=1}^{C} L_c F_{c,e} \qquad (1)$$

where D_e is the mass of sediment deposited in subestuary *e* during the time period Γ, L_c is the total (sum of all sediment grainsizes) mass load of sediment that derives from subcatchment *c*, and there are *C* subcatchments. In each subestuary the sedimentation rate S_e is related to D_e, and hence the source loads, by:

$$\sum_{c=1}^{C} L_c F_{c,e} = S_e \rho A_e \Gamma \qquad (2)$$

where S_e is a vertical rate of accretion with units length per time, ρ is the density of the deposited sediment, and A_e is the area over which deposition occurs in subestuary *e*. More generally, *e* may be thought of as any sink, and *c* may be thought of as any source, which can include the adjacent coastal ocean.

3.3 Application to the Pauatahanui Arm

The Onepoto Arm was not included in the analysis since, compared to Pauatahanui Arm, it is a relatively simple system. Specifically, only one major freshwater source discharges into the Onepoto Arm (ie, the Porirua Stream) and the arrangement of depositional basins is rather simple, with essentially just the once subtidal region. A sediment budget for the Onepoto Arm will be prepared at another time.

An annual-average total sediment budget in the form of equations (1) and (2) was constructed for the Pauatahanui Arm of Porirua Harbour. Green (2013) showed how a sediment budget so formulated can be used to calculate catchment sediment load limits for achieving estuary sedimentation targets, which in turn can be set to achieve a range of objectives for the estuary.

For this project, instead of deriving a sediment-fate matrix by analysing the outputs of a computational source-to-sea model, as described above, a sediment-fate matrix was specified.

Specifically, the constituent-particle sediment fate matrix $F_{c,e,p}$ was specified, where p is the sediment size-fraction, $F_{c,e,p}$ is the fraction of sediment mass of size fraction p from subcatchment c that deposits in subestuary e, and there are P size fractions. The constituent-particle fate matrix $F_{c,e,p}$ was tested by applying it to predictions of catchment sediment load to predict sedimentation in the harbour, and then comparing the predictions to observed sedimentation rates. Finally, the total-sediment fate matrix was calculated from the constituent-particle fate matrix, which then could be used to formulate the annual-average total-sediment budget in the form of equations (1) and (2). Amongst other things, the budget so formulated can be used to evaluate catchment sediment load limits, as described by Green (2013).

3.4 Estimation of a sediment budget for the Pauatahanui Arm

The detailed procedure for estimating the sediment budget for the Pauatahanui Arm (Pauatahanui Inlet) is described in this section. All of the estuarine depositional environments landward of the flood-tide delta are thought to be dominated by catchment-sourced sediment, and the flood-tide delta is thought to be dominated by marine-sourced sediment (Gibb & Cox 2009). This analysis focuses on establishing a sediment budget for the estuarine depositional environments landward of the flood-tide delta, which are intended to be managed by managing catchment sediment runoff. A different strategy may be required to control any sedimentation issues on the flood-tide delta (eg, dredging).

The catchment was divided into the six main subcatchments identified by Page et al. (2004) (Figure 3.1). Following Gibb and Cox (2009) and Gibb (2011) the inlet was divided into seven subestuaries (Figure 3.2). A further subestuary representing the coastal ocean was added to receive sediment that may be lost seawards from the inlet.

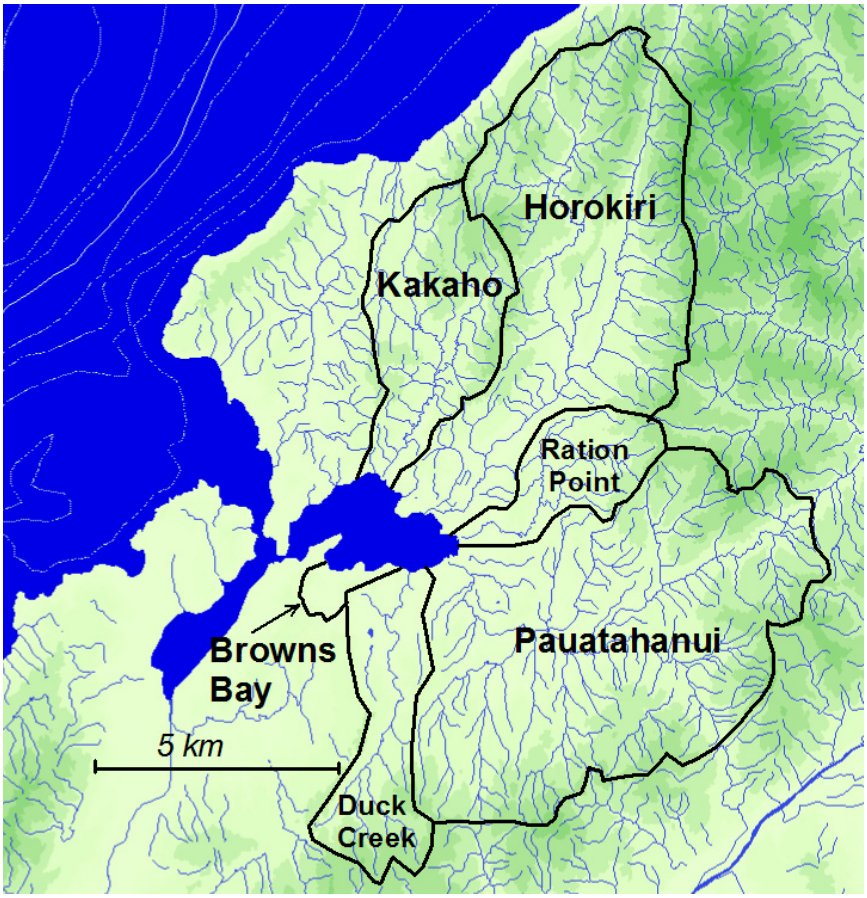

Figure 3.1: Pauatahanui Inlet and subcatchments
(Base map: TUMONZ, Vision Software for Management & Technology Systems Ltd)

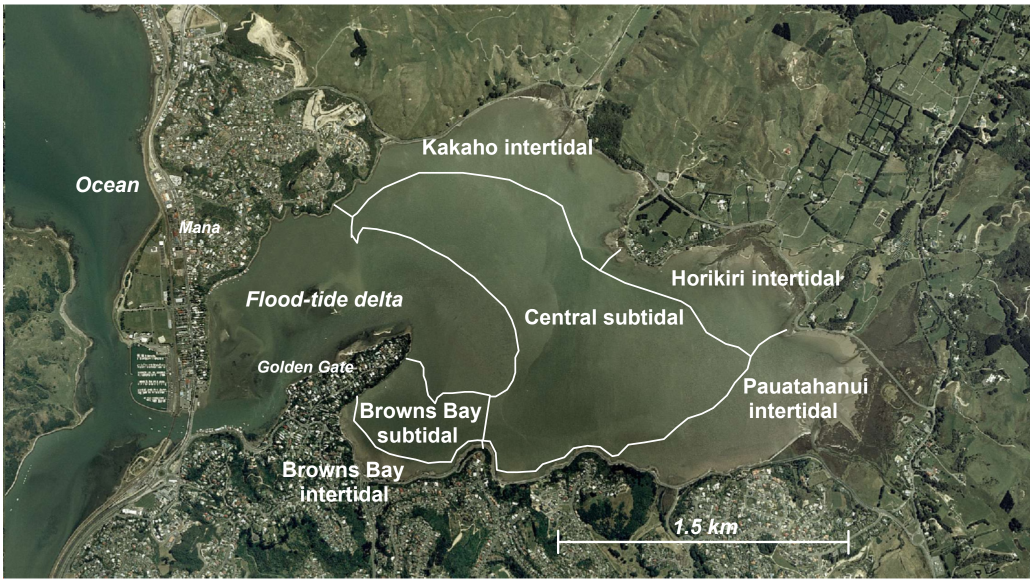

Figure 3.2: Location of subestuaries in Pauatahanui Inlet

Table 3.1 shows the constituent-particle fate matrix $F_{c,e,p}$, for which two size fractions, coarse (particle sizes >125 μm) and fine (particle sizes <125 μm), were used (P=2); this allows coarse and fine sediment to be dispersed differently from one another throughout the estuary. Figure 3.3 shows a visualisation of the coarse-sediment fate matrix and Figure 3.4 shows a visualisation of the fine-sediment fate matrix. The timescale is annual; hence, the set of terms $F_{c,e,p}$ represents annual-average sediment dispersal patterns. The constituent-particle fate matrix was contrived to prevent any deposition of catchment-sourced sediment on the flood-tide delta and, following Healy (1980), to export 20% of the fine-sediment runoff from every subcatchment to the coastal ocean (from where it cannot return).

Coarse sediment from each subcatchment deposits primarily in the subestuary at the base of the respective subcatchment, but with allowance for some longshore transport into adjacent embayments. Along the eastern and southern shorelines, coarse sediments are driven alongshore into Browns Bay, which is presumed to occur on the back of a net clockwise circulation driven by dominant northwesterly winds. The bulk (50–70%) of fine sediment from each subcatchment is deposited in the central subtidal basin on the premise that, even if initially deposited on an intertidal flat, wind waves will eventually resuspend the fines and initiate offshore transport and ultimate deposition in the more quiescent subtidal basin (Swales et al. 2005). The same presumed wind-driven clockwise circulation along the eastern and southern shorelines is also allowed to drive fine sediment into Browns Bay. The transport and accumulation of fine sediment into Browns Bay in this way is more effective than that of coarse sediment, which is less mobile than fine sediment.

Table 3.1: The constituent-particle fate matrix $F_{c,e,p}$. This represents annual-average sediment dispersal patterns for Pauatahanui Inlet. Subcatchments (c) are listed down the left and subestuaries (e) along the top. Sediment-size fraction p=1 is coarse sediment and sediment-size fraction p=2 is fine sediment

	Flood-tide delta	Central subtidal	Kakaho intertidal	Horokiri intertidal	Pauatahanui intertidal	Browns Bay intertidal	Browns Bay subtidal	Ocean
	Coarse							
Kakaho	0.00	0.05	0.95	0.00	0.00	0.00	0.00	0.00
Horokiri	0.00	0.10	0.15	0.60	0.15	0.00	0.00	0.00
Ration Point	0.00	0.10	0.15	0.25	0.50	0.00	0.00	0.00
Pauatahanui	0.00	0.10	0.05	0.15	0.60	0.10	0.00	0.00
Duck Creek	0.00	0.10	0.05	0.50	0.65	0.10	0.05	0.00
Browns Bay	0.00	0.00	0.00	0.00	0.00	0.70	0.30	0.00
	Fine							
Kakaho	0.00	0.65	0.70	0.00	0.00	0.00	0.08	0.20
Horokiri	0.00	0.70	0.00	0.02	0.00	0.00	0.08	0.20
Ration Point	0.00	0.61	0.00	0.01	0.03	0.00	0.16	0.20
Pauatahanui	0.00	0.58	0.00	0.01	0.03	0.03	0.16	0.20
Duck Creek	0.00	0.55	0.00	0.00	0.02	0.07	0.16	0.20
Browns Bay	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.20

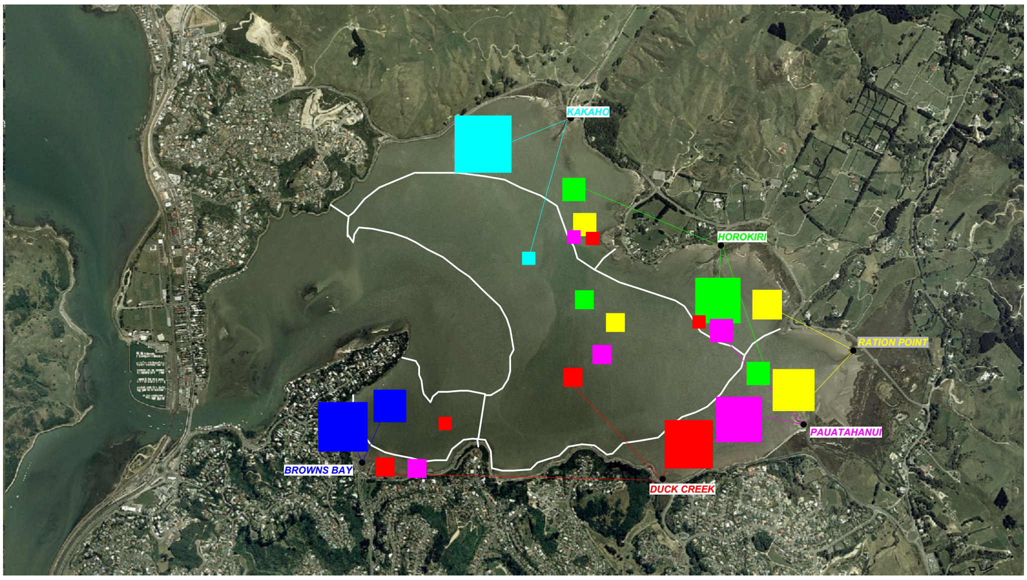

Figure 3.3: Visualisation of the coarse-sediment fate matrix for Pauatahanui Inlet. The coloured squares correspond to the subcatchment of the same colour and the area of each square is proportional to $F_{c,e,p}$

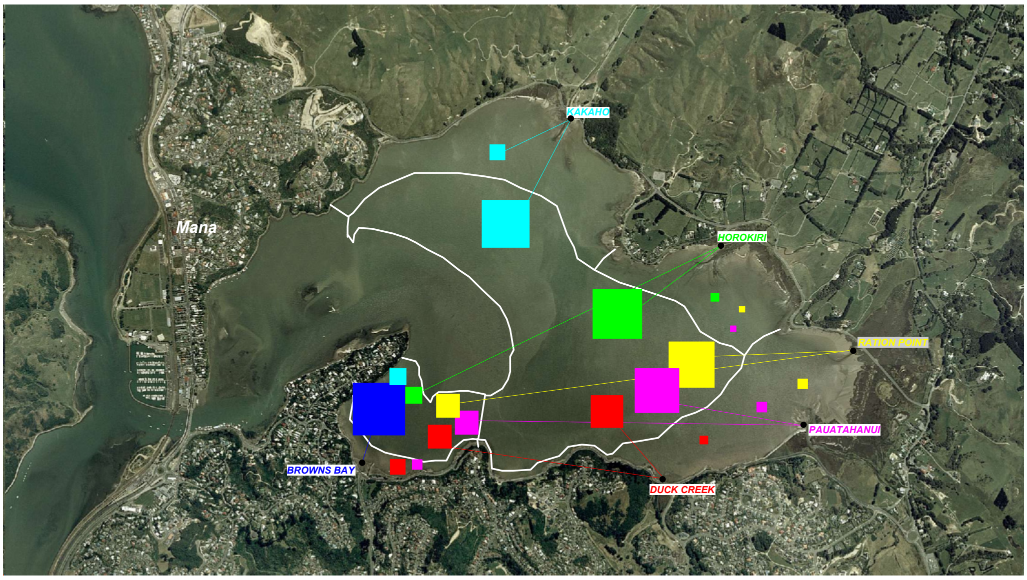

Figure 3.4: Visualisation of the fine-sediment fate matrix for Pauatahanui Inlet. The coloured squares correspond to the subcatchment of the same colour and the area of each square is proportional to $F_{c,e,p}$

To test the constituent-particle fate matrix, the constituent-particle sedimentation rate $S_{e,p}$ for each subestuary was hindcast by:

$$S_{e,p} = \frac{\sum_{c=1}^{C} L_{c,p} F_{c,e,p}}{\rho A_e \Gamma} \qquad (3)$$

and the total (sum of all particle sizes) sedimentation rate S_e for each subestuary was calculated as:

$$S_e = \sum_{p=1}^{P} S_{e,p} \qquad (4)$$

Here, $L_{c,p}$ is the mass load of sediment of grainsize fraction p deriving from subcatchment c. The density of the deposited sediment ρ was taken as 1,200 kg/m^3. Because the timescale of the analysis is annual, Γ is 1 year, and S_e, $S_{e,p}$ and L_c are all annual averages.

Equations (3) and (4) only account for the dispersal and deposition of catchment-sourced sediment. As described in Section 2, the CLUES catchment sediment model (Semadeni-Davies et al. 2011) was used to predict the annual-average total (sum of all grain sizes) sediment runoff L_c at the base of each subcatchment under the present-day catchment land use (Table 3.2).

Table 3.2 shows the partitioning of the sediment runoff between the coarse and fine sediment fractions to give $L_{c,p}$. The partitioning was derived by reference to Malcolm (2011), who calculated a particle size distribution for sediment loads discharged into the estuary based on samples taken from the catchment.

Table 3.3 shows, for each subestuary, the total area and the fraction of the total area over which catchment-sourced sediment was allowed to deposit. Area fractions ranged between 0.5 and 0.75.

Table 3.2: CLUES predictions for Pauatahanui Inlet of the annual-average total (sum of all grain sizes) sediment load* at the base of each subcatchment under present-day land use, and partitioning of the total sediment load between the two sediment size fractions

Sub-catchment	Annual-average total sediment load (Kt)	Coarse fraction	Fine fraction
Kakaho	2.279	0.2	0.8
Horokiri	5.950	0.2	0.8
Ration	2.102	0.2	0.8
Pauatahanui	8.921	0.3	0.7
Duck Creek	2.453	0.35	0.65
Browns Bay	0.429	0.4	0.6

*There has been further refinement of these estimated loads since they were incorporated into this model.

Table 3.3: Pauatahanui Inlet subestuary total area and area over which catchment-sourced sediment was allowed to deposit

Subestuary	Area (m²)	Fraction of area deposition allowed
Flood-tide delta	1,171,437	0
Central subtidal	1,746,993	0.7
Kakaho intertidal	482,226	0.5
Horokiri intertidal	317,345	0.75
Pauatahanui intertidal	520,382	0.75
Browns Bay intertidal	104,575	0.5
Browns Bay subtidal	264,806	0.7
Ocean	–	

The predicted total (sum of all particle sizes) sedimentation rates S_e are compared in Table 3.4 to total sedimentation rates calculated by Gibb (2011) by taking the difference between the 1974 and 2009 bathymetric surveys. (Note that the predictions of sedimentation rate are actually ‘backward-looking’ and so are probably more accurately understood as ‘hindcasts’. The sedimentation rate predictions are, therefore, referred to as sedimentation rate hindcasts.) Gibb’s rates are corrected for a sea-level rise of 1.95 mm/year in the period 1974–2009 and are subestuary averages. Also shown in Table 3.4 are hindcasts of the constituent-particle sedimentation rates $S_{e,p}$ and Gibb’s measured total rates broken down into constituent-particle rates by multiplying by subestuary-average bed-sediment composition (percentage coarse / percentage fine) derived from Malcolm (2011).

Table 3.4: Pauatahanui Inlet hindcast and observed total (sum of all particle sizes) and constituent–particle (total multiplied by bed-sediment composition) annual-average sedimentation rates (mm/year). ‘Ratio’ is the ratio of hindcast to observed

	Flood-tide delta	Central subtidal	Kakaho intertidal	Horokiri intertidal	Pauatahanui intertidal	Browns Bay intertidal	Browns Bay subtidal	Ocean
	Coarse							
Predicted	–	0.4	2.9	4.4	5.4	7.5	0.4	–
Observed	–	0.5	7.3	7.5	7.3	7.1	0.8	–
Ratio	–	0.68	0.40	0.59	0.75	1.06	0.56	–
	Fine							
Predicted	–	6.9	0.4	0.4	0.5	4.8	10.1	–
Observed	–	10.2	0.6	0.6	0.6	7.1	14.4	–
Ratio	–	0.67	0.70	0.63	0.76	0.67	0.70	–
	Total							
Predicted	–	7.2	3.4	4.8	5.9	12.3	10.6	–
Observed	–	10.7	7.9	8.1	7.9	14.2	15.2	–
Ratio	–	0.68	0.43	0.60	0.75	0.87	0.70	–

Referring to Table 3.4, the hindcast values for fine-sediment $S_{e,p}$ are about 60–70% of those measured by Gibb (2011). The agreement between hindcast and measured values for the coarse-sediment $S_{e,p}$ is more variable, with hindcast values being about 40–100% of those measured by Gibb (2011). Hindcast total-sediment sedimentation rates S_e are between 43–87% of the measured values. The low value is Kakaho intertidal; removing that subestuary from consideration, the hindcast total-sediment sedimentation rates are between 60–87% of the measured values.

The total-sediment fate matrix was calculated from the constituent-particle fate matrix as:

$$F_{c,e} = \frac{\sum_{p=1}^{P} F_{c,e,p} L_{c,p}}{L_c} \qquad (5)$$

and Table 3.5 shows the total-sediment fate matrix so calculated.

Table 3.5: The total-sediment fate matrix $F_{c,e}$ calculated from the constituent-particle fate matrix and subcatchment sediment load. This represents annual-average sediment dispersal patterns in Pauatahanui Inlet. Subcatchments (c) are listed down the left and subestuaries (e) along the top

	Flood-tide delta	Central subtidal	Kakaho intertidal	Horokiri intertidal	Pauatahanui intertidal	Browns Bay intertidal	Browns Bay subtidal	Ocean
Kakaho	0.00	0.53	0.25	0.00	0.00	0.00	0.06	0.16
Horokiri	0.00	0.58	0.03	0.13	0.03	0.00	0.06	0.16
Ration	0.00	0.51	0.03	0.05	0.12	0.00	0.13	0.16
Pauatahanui	0.00	0.44	0.02	0.05	0.20	0.05	0.11	0.14
Duck Creek	0.00	0.40	0.02	0.02	0.24	0.08	0.12	0.13
Browns Bay	0.00	0.00	0.00	0.00	0.00	0.28	0.60	0.12

As a matter of interest, and to provide an 'intuitive' check on the results, Table 3.6 shows the total-sediment 'source matrix' $O_{c,e}$, which was calculated by:

$$O_{c,e} = \frac{\sum_{p=1}^{P} F_{c,e,p} L_{c,p}}{\sum_{c=1}^{C} \sum_{p=1}^{P} F_{c,e,p} L_{c,p}} \qquad (6)$$

The source matrix shows the annual-average origin of sediment that deposits in each subestuary. For example, reading down the third column of Table 3.6 shows that 57% of the sediment that deposits on the Kakaho intertidal flats originates from the Kakaho subcatchment, 18% comes from the Horokiri subcatchment, and so on. For any particular subcatchment to contribute significantly to the sedimentation in any particular subestuary, there has to be a 'strong' sediment-transport pathway between the two (ie, $F_{c,e}$ has to be large) and sediment runoff from the subcatchment in question must be large relative to the other sources that deposit in the subestuary. For instance, reading across the table reveals that neither Ration nor Browns Bay subcatchments contribute more than a few percent to sedimentation in any part of Pauatahanui Inlet.

Table 3.6: The total-sediment source matrix $O_{c,e}$ calculated from the fate matrix and subcatchment sediment load. This shows the annual-average origin of sediment that deposits in each subestuary of Pauatahanui Inlet. Subcatchments (c) are listed down the left and subestuaries (e) along the top

	Flood-tide delta	Central subtidal	Kakaho intertidal	Horokiri intertidal	Pauatahanui intertidal	Browns Bay intertidal	Browns Bay subtidal	Ocean
Kakaho	0.00	0.11	0.57	0.00	0.00	0.00	0.06	0.11
Horokiri	0.00	0.33	0.18	0.57	0.06	0.00	0.16	0.29
Ration	0.00	0.10	0.06	0.08	0.09	0.00	0.11	0.10
Pauatahanui	0.00	0.37	0.14	0.31	0.63	0.59	0.43	0.38
Duck Creek	0.00	0.09	0.04	0.03	0.21	0.26	0.13	0.10
Browns Bay	0.00	0.00	0.00	0.00	0.00	0.16	0.11	0.02

3.5 Applications

The annual-average sediment budget (Table 3.5) relates sediment load from each subcatchment to sedimentation rate in each subestuary. It can be used in both ‘forwards’ and ‘backwards’ senses, meaning that it can be used to predict how sedimentation will change in response to some change in sediment load (the ‘forwards’ sense), and it can be used to calculate what change in sediment load is required to achieve some given change in sedimentation (the ‘backwards’ sense).

An example of the forwards use of the sediment budget is given in Figure 3.5a, which shows the relationship between sediment load from Kakaho subcatchment and sedimentation in every subestuary, and in Figure 3.5b, which shows the relationship between sediment load from Browns Bay subcatchment and sedimentation in every subestuary. In these figures, a 70% (for instance) reduction in sediment load means the new load is 30% of the original load. The same meaning applies to a reduction in sedimentation rate. Note, of course, that a zero percent reduction in sediment load results in zero percent reduction in sedimentation in every subestuary. Figure 3.5a shows that Kakaho intertidal subestuary is most responsive to reductions in sediment load from Kakaho subcatchment; here, 100% reduction in sediment load (ie, to zero) results in a reduction in sedimentation of about 65%. In contrast, sedimentation in the Horikiri intertidal, Pauatahanui intertidal and Browns Bay intertidal subestuaries is virtually completely unaffected by reductions in sediment load from Kakaho subcatchment. In contrast, Figure 3.5b shows that sediment originating from Browns Bay subcatchment has virtually no effect on sedimentation in any part of the harbour. The reason is that Browns Bay provides a very small source of sediment to the harbour relative to the other subcatchments (Table 3.2).

A simple example of backwards use of the sediment budget is given in Figure 3.6, which provides precise guidance on how sediment loads from the Pauatahanui and Duck Creek subcatchments need to be reduced in order to achieve various sedimentation targets in the central subtidal mud basin. Each coloured line on the graph represents a particular percent reduction in sedimentation, and the coloured lines are drawn such that every combination of Pauatahanui and Duck Creek sediment loads that fall on a line will result in the percent reduction in sedimentation denoted by that line. For example, the blue line represents a 10% reduction in sedimentation rate. Just as one example, the particular combination of 40% reduction in Duck Creek sediment load and 27% reduction in Pauatahanui sediment load will deliver a 10% reduction in sedimentation rate, since that combination falls on the blue line. There are many other combinations of load reductions that will result in the same reduction in sedimentation rate. Note that the point corresponding to zero sediment load from both Pauatahanui and Duck Creek falls to the left of the orange line (30% reduction in sedimentation) which indicates that the maximum possible reduction in sedimentation that can be achieved is between 30 and 40%. Finally, note that the coloured lines are inclined to the x-axis at an angle of greater than 45 degrees, which indicates that sedimentation in the central subtidal mud basin is more responsive to changes in sediment load from Pauatahanui than it is to changes in sediment load from Duck Creek.

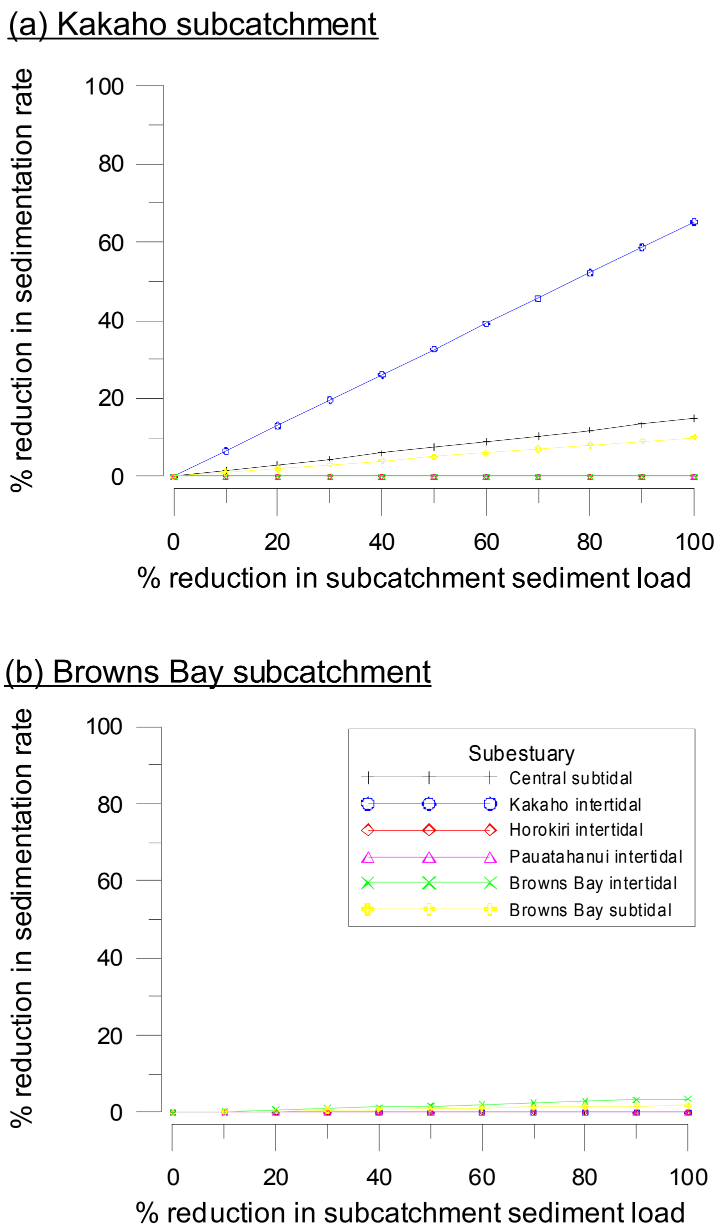

Figure 3.5: An example of how the sediment budget can be used in the 'forwards' sense: relationship between catchment sediment load from (a) Kakaho and (b) Browns Bay subcatchments and sedimentation in every subestuary of Porirua Harbour

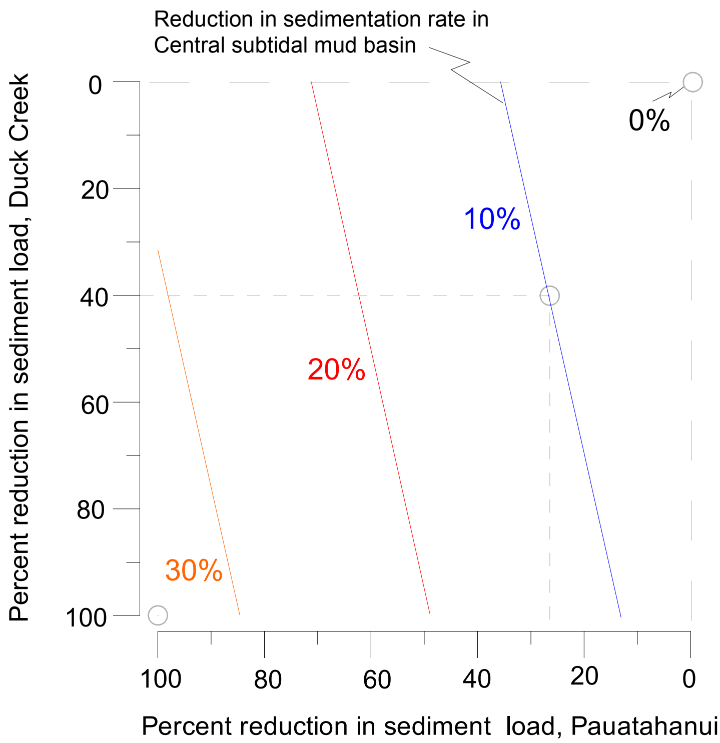

Figure 3.6: A simple example of how the sediment budget can be used in the 'backwards' sense: precise guidance on how sediment loads from the Pauatahanui and Duck Creek subcatchments need to be reduced in order to achieve various sedimentation targets in the Central subtidal mud basin

A more complex example of backwards use of the sediment budget is given in Figure 3.7. This is reproduced from Green (2013), which the reader is referred to for more information.

Finally, the sediment budget can be used to develop strategies for sediment load offsetting. Consider, for example, a strategy that centres on determining how development in the Duck Creek subcatchment that is expected to result in an increase in sediment runoff can be offset by mitigation in other subcatchments with the goal of maintaining the status quo sedimentation rate in the central subtidal mud basin. Figure 3.8 shows one possible approach to load offsetting, which involves reducing the sediment load from just the Pauatahanui subcatchment in order to offset the anticipated increase in sediment from Duck Creek. Every combination of sediment loads that falls on the black line will deliver the present-day sedimentation rate in the central subtidal mud basin. Hence, a 300% increase (say) in the sediment load from Duck Creek as a result of development could be offset by an approximately 45% reduction in sediment runoff from Pauatahanui with the result that sedimentation in the central basin would be unchanged.

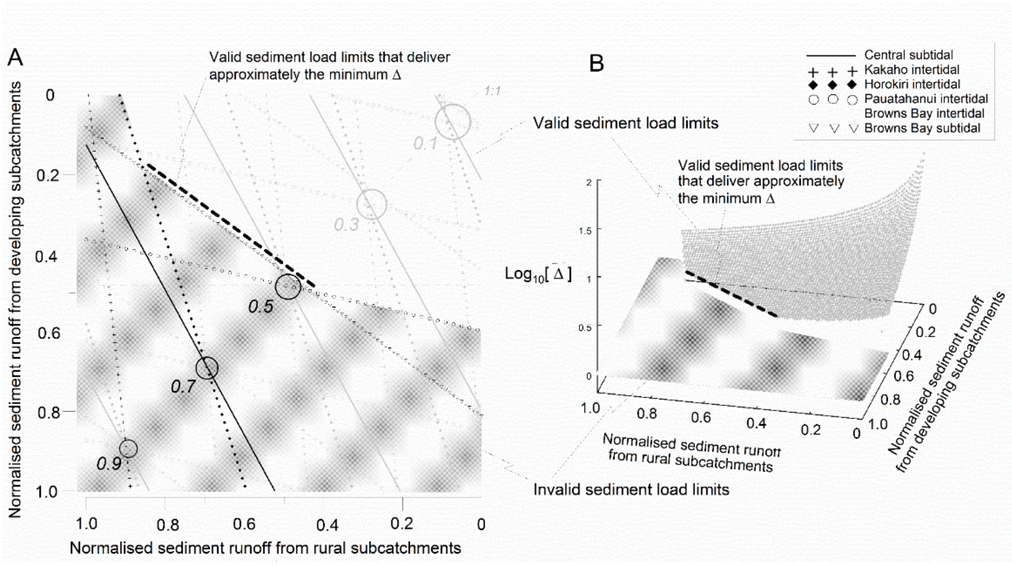

Figure 3.7: A more complex example of 'backwards' use of the sediment budget, reproduced from Green (2013)

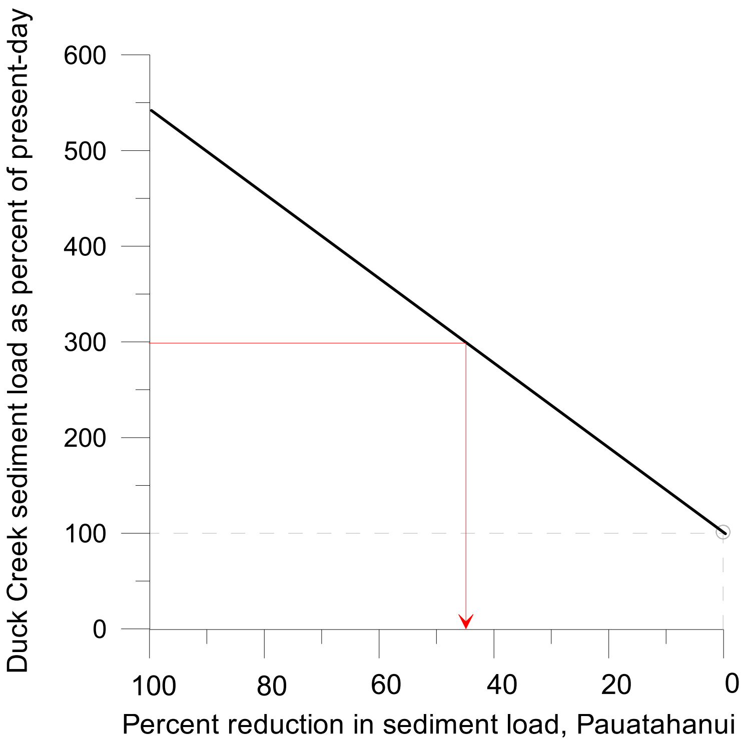

Figure 3.8: An example of the use of the sediment budget to assist in planning sediment load offsetting

3.6 Use of the sediment budget in managing sediment issues in the harbour

Fundamentally, Figures 3.5 to 3.8 relating to application of the sediment budget to management issues are predictions. The manipulation of the sediment budget that lies behind these kinds of predictions is mathematically straightforward and defendable from a conceptual point of view as a basis for management.

However, like all predictions, the predictions embodied in the likes of Figures 3.5 to 3.8 are uncertain since, amongst other things, there are uncertainties in basic assumptions and data used to construct the sediment budget. For example, there are obviously uncertainties in the sediment fate matrix and the amount of sediment specified as being lost to sea (data used to implement the model). The model only approximately reproduces Gibb's (2011) measured inlet-average sedimentation rates and the sediment fate matrix may change as the estuary infills with sediment, or the density of the deposited sediment may change over time if the seabed consolidates (basic model assumptions). Furthermore, the uncertainty associated with the management predictions will typically be unquantifiable. The appropriate response by management is to monitor to determine if the sedimentation predictions are accurate. This will need to be matched with monitoring of catchment sediment runoff to check that catchment sediment load limits are actually being achieved. Furthermore – and just as importantly – monitoring will be required to confirm the larger assumptions of any management scheme, which is that the desired environmental objectives are actually being achieved. With monitoring intended to confirm specific predictions and assumptions, and information gained from monitoring being used to improve predictions (by refining any component of the sediment budget model, for instance) and thereby adjust management methods (changing sediment load limits, for instance), this approach has the attributes to properly qualify as 'adaptive management' as defined by, for example, Stankey et al. (2005).

3.7 Recommendations

Confidence in the sediment budget could be improved as follows:

- A computational source-to-sea model of Porirua Harbour and its catchment could be developed and applied to confirm and refine the sediment fate matrix. Particular attention should be paid to using the model to confirm the proportion of each subcatchment sediment load that is lost to the coastal ocean and to confirm that the definition of the subestuaries is sensible.
- The sediment fate matrix could also be refined and tested against the results of a sediment source-tracking experiment using, for example, compound-specific stable isotopes.
- Annual-average sedimentation rates used to test the sediment fate matrix could continue to be refined and updated by conducting repeat bathymetric surveys and maintaining GWRC's existing network of harbour sedimentation plates.
- The CLUES model used to estimate subcatchment sediment runoff could be validated against sediment runoff monitoring data, and any changes to the model as a result should then be propagated through to changes in the sediment budget.
- Monitoring of freshwater sediment loads could provide information on the particle-size distribution which could then be used to validate the partitioning of the sediment load between the coarse and fine sediment fractions that was applied in the development of the sediment budget.

Acknowledgements

The modelling documented in this report was jointly funded by GWRC's Environmental Science and Biodiversity departments.

The authors would like to gratefully acknowledge the time taken by Bill Stevens (Wellington City Council) and Matt Trlin (Porirua City Council) to collate estimates of bare land across multiple years within their respective council boundaries. Thanks also to Shyam Morar (GWRC) for collating estimates of large areas (>0.3 ha) of bare land administered under regional council consents.

The following people and organisations provided additional information on sediment yields and land use changes: Michelle Sands (Jacobs[2]), Peter Handford (Groundtruth), and Dr Barry Robertson (Wriggle Coastal Management).

Juliet Milne and Dr John Drewry (GWRC) provided valuable peer review comments on draft versions of this report.

[2] Formerly known as SKM.

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Appendix 1

Overview of the models nested within CLUES.

Model	Purpose
OVERSEER®	OVERSEER® Nutrient Budgets is an agricultural management tool which assists farmers and their advisers to examine nutrient use and movements within a farm to optimise production and environmental outcomes. The computer model calculates and estimates the nutrient flows in a productive farming system and identifies risk for environmental impacts through nutrient loss, including run off and leaching, and greenhouse gas emissions. www.overseer.org.nz
SPASMO	The Soil Plant Atmosphere System Model (SPASMO) models the transport of water, microbes and solutes through soils integrating variables such as climate, soil, water uptake by plants in relation to farm and orchard practices, and any other factors affecting environmental process and plant production. SPASMO is currently used by six regional councils for allocation of irrigation water.
SPARROW	SPARROW is a modelling tool for the regional interpretation of water-quality monitoring data. The model relates in-stream water-quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and aquatic transport. SPARROW empirically estimates the origin and fate of contaminants in river networks and quantifies uncertainties in model predictions. http://water.usgs.gov/nawqa/sparrow
EnSus	Soil Vulnerability Modelling, formerly known as EnSus, defines soil zones of similar vulnerability profile for nutrient and microbial contamination to waterways to provide a basis for: 1) setting nutrient load limits across a catchment 2) target management of non-point-source discharges 3) setting aside vegetated buffer zones to trap contaminants in overland flow.

Appendix 2

Taken from the Keating et al. (2011).

12.6 Long Term Assessment

In addition to the event-based simulations, the harbour model was also utilised to predict the longer term impacts of the Transmission Gully Projects. A 20-year model run was undertaken with and without the Project constructed to quantify the effects. For these scenarios historical rainfall and wind data was used. The generation of the sediment inputs into the harbour are discussed in Section 12. The likely 6-year staging programme for the entire project, predicted by MacDonald International was combined with historical rainfall data and used to predict the long term changes in sediment loads into the harbour. Table 15.49 summarises the predicted difference in sediment loads at various intervals in the 20-year simulation.

Table 15.49: Predicted sediment loads into Porirua Harbour during the 20-year of simulation data

	Total Sediment Load after 6 Years at completion of construction (tonnes)	Total Sediment Load after 10 Years (tonnes)	Total Sediment Load after 20 Years (tonnes)
No Construction Scenario	99200	143600	244700
During Construction Scenario	102200	146600	247700
Difference	3000	3000	3000
% Difference	3.0%	2.1%	1.2%

To achieve realistic run times a simplified model mesh was used. The following should be noted for the long term simulations:

- A 20-year time series for wind was produced by taking the available five years of scaled Mana Island wind data and repeating this four times.
- A 20-year time series for the open ocean tidal boundary condition was produced by carrying out a harmonic analysis for one year of water level data from Mana Marina. The harmonic analysis calculated the phase and amplitude for 32 tidal constituents from which a twenty year time series of water level was generated.
- Only the fate of cohesive mud has been predicted with the long term simulations, which is approximately 80% of terrestrial sediments which enter into harbour. The model was not appropriate to predict the long term fate of non-cohesive sand, since the sediment transport model does not include bed load transport (the predominant method of transport for sand within the harbour). Sand would build up close to sediment inflows, obscuring the findings of long term simulations, when in reality it would be distributed to the local beaches. This approach is still considered appropriate for the long term modelling and assessment of effects of the Transmission Gully Project which is predicted to contribute largely finer material from the catchment.

- A 20-year time series for daily averaged inflow hydrographs and associated TSS concentrations for cohesive mud for the 23 catchments surrounding Porirua Harbour was used as inputs.
- All model parameters are the same for the coarse model compared with higher resolution model used in the event based simulation.

Appendix 3

Peter Ward
NZTA - Transmission Gully
PO Box 5084
Lambton Quay
Wellington 6011

8 May 2012

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Dear Peter

Sediment Yield and Landuse in Porirua Habour Catchments- Porirua City Council Data Request.

This letter summarises sediment yield and land use data for the Porirua Harbour catchments, this data is to be supplied to Porirua City Council (PCC), in response to a data request. Following discussion with Leigh Stevens, of Wriggle Coastal Management, we determined that the data summarised in this letter would provide useful starting point. More detailed data may be extracted and analysed in the future if required.

Sediment Yield

Table 1 summarises the existing sediment yield (kg/ha/yr) for each of the catchments that drain to Porirua Harbour. See figure 1.

Table 2 summarises the treated sediment yield (kg/ha/yr) from the assumed annual construction stage, within each catchment in the peak construction year for that catchment.

The construction areas are not active earthworks areas. They are annual staging areas, within which active earthworks and progressive stabilization will occur. The maximum unstabilized areas are described in the proposed consent condition E1.

The yields presented in table 2, represent the average annual yield for the annual construction stage, rather than an active earthworks yield. More detailed analysis to calculate sediment yields for active earthworks areas specifically, is documented in the SKM report: *Transmission Gully Project, Revised USLE Analysis, January 2012.*

The sediment yield assumes erosion and sediment control measures, consistent with those outlined in proposed consent conditions. The values presented in Table 2, are average annual sediment yields. It is assumed that sediment retention measures will remove 70% of sediment and that erosion control measures will remove 75% of sediment.

- **Table 1 Existing Sediment Yield Estimate**

Catchment	**Catchment Area**	**Existing Sediment Yield**
	Ha	**Kg/ha/yr**
Duck	1030	1111
Horokiri	3306	1602
Kenepuru	1266	653
Pauatahanui*	4168	818
Porirua	4108	966
Ration	680	1166
Browns Catchment	135	552
Collins Stream Catchment	64	261
Kakaho Catchment	1246	1162
Takapuwahia Catchment	346	270
a	64	314
b	29	347
c	41	399
d	45	1341
e	58	775
f	98	193
g	111	210
h	101	193
i	159	372
j	40	507
k	25	471
l	25	457
m	25	442

* (SSYE)

The sediment yields provided are calculated using SKM's sediment yield model (SYM), which is based on Universal Soil Loss Equation (USLE) factors scaled to the NIWA Suspended Sediment Yield Estimator (SSYE). The USLE factors were adjusted for future landuse and construction scenarios. However, the yields provided for the Pauatahanui catchment are based on the SSYE baseline and SKM SYM construction estimate. The Kenepuru is based on the SKM SYM baseline estimate and SKM USLE Revised Analysis for the construction estimate.

- **Table 2 Sediment Yield Estimates – Peak Construction, Annual Staging Areas**

Catchment	Ha Annual Construction staging area (Ha)	Sediment Yield (Tonnes/yr)	Treated Sediment Yield per annual construction staging area
			Kg/ha/yr
Kenepuru	15.8	104*	6582
Duck	14.3	169	11811
Pauatahanui	13.5	131	9694
Ration	24	292	12161
Horokiri	22.5	793	35253
Porirua	17	70	4118
Collins	3	13	4333

* USLE Revised Analysis

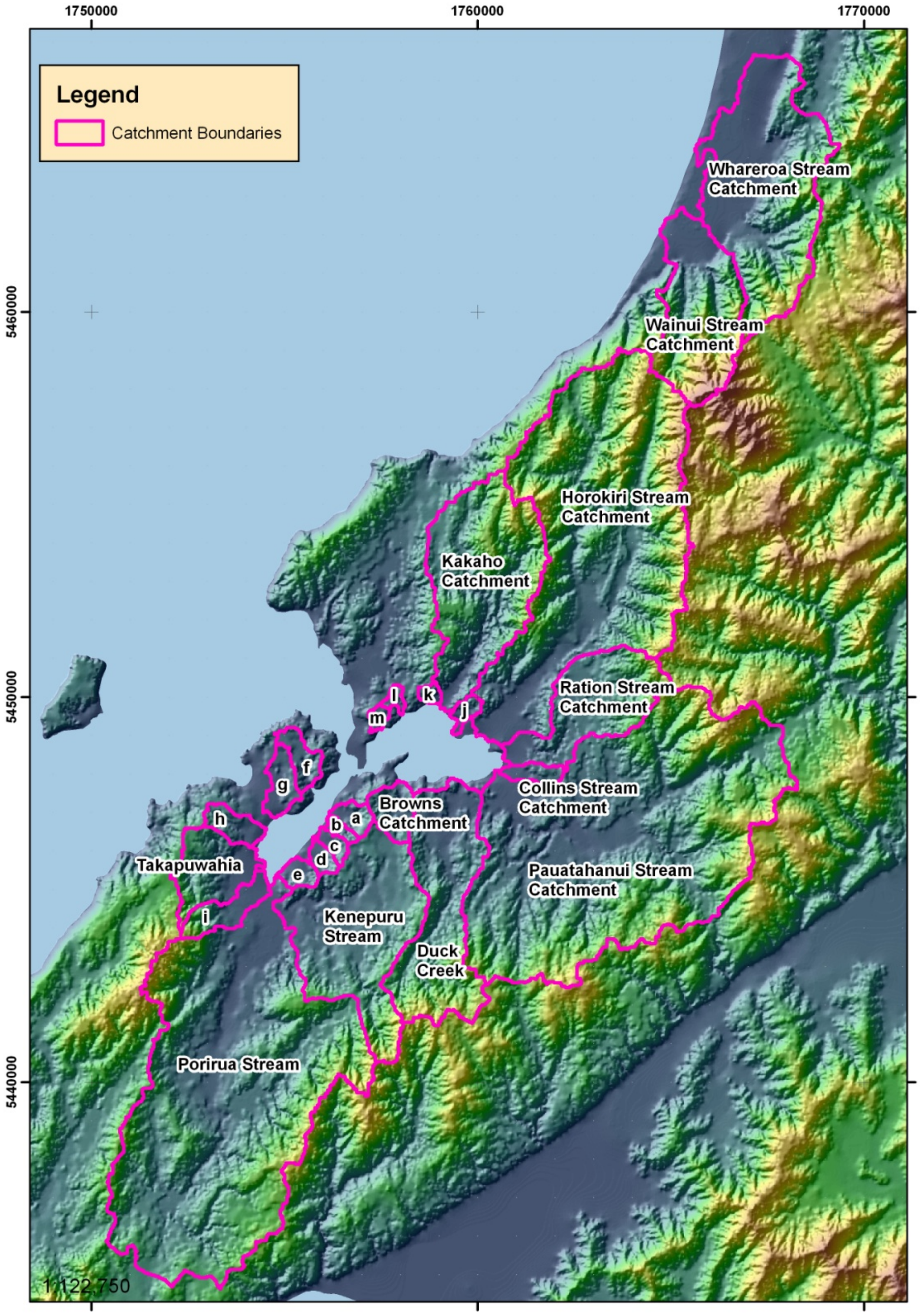
Table 3, is taken from The SKM report: *Transmission Gully Project Revised USLE analysis, January 2012*. It summarises sediment yields from active earthworks and areas subject to erosion control, but excludes stabilised areas within the annual construction stage area. This analysis is more detailed than the SKM SYM method, and accounts for ground conditions at depth, road geometry and a more accurate construction footprint. The sediment yield estimates generated using this method are comparable to the SKM SYM method.

- **Table 3 USLE Revised Analysis – Sediment Yield Estimates**

Catchment		Road	Fill sites	Stream Works
Kenepuru	Area	12.1	2.2	0.1
	Untreated kg/ha	68035	22756	11225
	Treated kg/ha	7266	6827	7858
Duck	Area	7.9		0.4
	Untreated kg/ha	54645	n/a	4371
	Treated kg/ha	10164		3060
Pauatahanui	Area	8.8		0.6
	Untreated kg/ha	83492	n/a	2229
	Treated kg/ha	15529		1560
Ration	Area	18.9		0.6
	Untreated kg/ha	86271	n/a	7523
	Treated kg/ha	13861		5266
Horokiri	Area	17.2		1.6
	Untreated kg/ha	80638	n/a	2951
	Treated kg/ha	17811		885
Te Puka	Area	14.8		2.4
	Untreated kg/ha	109570	n/a	7169
	Treated kg/ha	24201		5018

The construction estimates summarised in table 2 and 3, are consistent with those used as part of the assessment of effects, however, the harbour modelling was based on the 2 year, 10 year and 50 year ARI event loads for coincident earthworks in the Harbour catchments as a whole, and therefore does not relate directly to the average annual sediment yields summarised in this letter, which are provided on an individual catchment basis.

Figure 1 Porirua Harbour Catchments



Landuse

The Landuse for the existing situation was classified based on the Land Cover Database 2 (LCDB2). The 'with project' scenario is based in 2020, and includes the assumed landuse at that time projected from permitted and consented landuse change and population projections at that time, as well as the proposed Transmission Gully project, assumed construction staging, highlighted in yellow.

The USLE *'C Factor'* for each landuse class is described within the tables. The '*C Factor'* ranges from 1 for bare earth to 0 for water.

Duck, C Factor	AREA Ha
pasture/grassland 0.02	489.7
parkland/gardens 0.02	52
plantation forest 0.02	135
bush 0.01	177
urban 0.009	155
urban 0.0124	1
pasture/grassland, converted to Transmission Gully 1	14.3
water 0	4
wetland 0	2

Horokiri, C Factor	AREA Ha
pasture/grassland 0.02	1555.9
plantation forest 0.02	853.8
bush 0.01	859.7
pasture/grassland, converted to Transmission Gully 1	22.5
crops 0.02	8.2
water 0	0.2
bare 1	1.7
wetland 0	4.2

Kenepuru, C Factor	AREA Ha
bush 0.01	303.8
plantation forest 0.02	27.8
parkland/gardens 0.02	71.1
urban 0.009	315.6
pasture/grassland 0.02	392.05
bush, converted to Transmission Gully 1	3.5
transport infrastructure 0	3.4
bush 0.5	3.8
parkland/gardens 0.5	0.0002
pasture/grassland, converted to Transmission Gully 1	11.85
plantation forest, converted to Transmission Gully 1	0.4
urban 0.0056	1.8
urban 0.007	129.7
pasture/grassland 0.5	0.5
plantation forest 0.5	0.7

Pauatahanui, C Factor	AREA Ha
plantation forest 0.02	371.7
pasture/grassland 0.02	2429.2
bush 0.01	1203.1
fallow 0.02	30.4
parkland/gardens 0.02	35.5
urban 0.02	3.3
bare 1	9
urban 0.0056	9.4
urban 0.0124	26.5
pasture/grassland, converted to Transmission Gully 1	6
plantation forest, converted to Transmission Gully 1	6.8
urban 0.009	28.7
bush, converted to Transmission Gully 1	0.7
plantation forest 0.5	0.2
water 0	0.5
wetland 0	7.3

Porirua	AREA Ha
pasture/grassland 0.02	1466.76
bush 0.01	1167.38
urban 0.02	4.22
plantation forest 0.02	141.62
bare 1	24.49
parkland/gardens 0.02	86.08
transport infrastructure 0	50.79
pasture/grassland 0.009	0.46
pasture/grassland 0.0056	0.12
urban 0.009	661.37
urban 0.0056	156.25
bush 0.0045	1.25
urban 0.0124	28.42
parkland/gardens 0.009	0.7
bush 0.0028	1
parkland/gardens 0.0056	0.25
urban 0.007	226.1
pasture/grassland 0.5	13.39
bush 0.5	28.76
plantation forest 0.5	0.08
parkland/gardens 0.5	0.47
urban, converted to Transmission Gully 1	3.7
urban 0.5	0.16
bush, converted to Transmission Gully 1	2.15
parkland/gardens, converted to Transmission Gully 1	0.1
plantation forest 0.009	0.08
plantation forest, converted to Transmission Gully 1	7.55
water 0	0.02
urban 0.003	33.98
parkland/gardens 0.003	0.08
bush 0.0015	0.02

Ration, C Factor	AREA Ha
pasture/grassland 0.02	224.5
plantation forest 0.02	344.4
pasture/grassland converted to Transmission Gully 1	19
bush 0.01	37.8
parkland/gardens 0.02	17.1
crops 0.02	9.1
bare 1	0.2
plantation forest, converted to Transmission Gully 1	1.2
parkland/gardens, converted to Transmission Gully 1	0.7
bush, converted to Transmission Gully 1	2.8
crops, converted to Transmission Gully 1	0.6
fallow 0.02	6.2
water 0	0.3
wetland 0	16
urban 0.0124	0.4
pasture/grassland 0.5	0.00003

Collins, C Factor	AREA Ha
pasture/grassland 0.02	47.56
water 0	0.22
wetland 0	8.09
bush 0.01	0.42
urban 0.0124	4.05
pasture/grassland, converted to Transmission Gully 1	3.2
bush converted to Transmission Gully 1	0.01

Browns, C Factor	AREA Ha
water 0	0.3
bush 0.01	47.8
parkland/gardens 0.02	7
plantation forest 0.02	7.1
urban 0.007	14
urban 0.0124	0.2
urban 0.009	58.6

A, C Factor	AREA Ha
water 0	0.1
transport infrastructure 0	1.1
bush 0.01	13.9
plantation forest 0.02	1.2
parkland/gardens 0.02	4.7
urban 0.007	43.1

B, C Factor	AREA Ha
water 0	0
transport infrastructure 0	1.7
bush 0.01	2.1
pasture/grassland 0.02	0.9
plantation forest 0.02	0.7
urban 0.007	23.5
urban 0.0056	0.1

C, C Factor	AREA Ha
water 0	1.8
transport infrastructure 0	0.8
parkland/gardens 0.02	1
plantation forest 0.02	1
pasture/grassland 0.02	12.5
bush 0.01	9.7
urban 0.007	3
urban 0.0056	10.9

D, C Factor	AREA Ha
transport infrastructure 0	0.1
parkland/gardens 0.02	0.3
water 0	1.3
bush 0.01	6.5
pasture/grassland 0.02	20.6
plantation forest 0.02	6.3
urban 0.0056	10.1

E, C Factor	AREA Ha
water 0	2.6
transport infrastructure 0	5.7
pasture/grassland 0.02	35.6
bush 0.01	8.4
plantation forest 0.02	4.5
urban 0.0056	1

F, C Factor	AREA Ha
water 0	0.02
pasture/grassland 0.02	57.2
bush 0.01	34.6
urban 0.0124	5.9
pasture/grassland 0.5	0.5

G, C Factor	AREA Ha
water 0	0.008
pasture/grassland 0.02	6.7
plantation forest 0.02	2.5
parkland/gardens 0.02	7
bush 0.01	8.3
urban 0.0124	71
urban 0.009	15.3
bush 0.5	0.4

H, C Factor	AREA Ha
water 0	0.0003
pasture/grassland 0.02	12.2
fallow 0.02	3.4
plantation forest 0.02	1.5
bush 0.01	50.8
urban 0.02	0.05
parkland/gardens 0.02	0.02
urban 0.009	32.3
bush 0.0045	0.04
parkland/gardens 0.009	0.003
bush 0.5	0.2

I, C Factor	AREA Ha
water 0	0.2
pasture/grassland 0.02	2.2
bush 0.01	67.6
urban 0.02	0.5
parkland/gardens 0.02	15.9
bush 0.0045	0
urban 0.009	0.2
urban 0.003	57.1
urban 0.0056	2.7
parkland/gardens 0.003	0.2
bush 0.0015	0.1
bush 0.0028	0.04
parkland/gardens 0.0056	0.0047
bush 0.5	12.6

J, C Factor	AREA Ha
pasture/grassland 0.02	35.9
water 0	0.4
bush 0.01	2.2
urban 0.0124	1.8

K, C Factor	AREA Ha
pasture/grassland 0.02	23
bush 0.01	1.2
water 0	0.6

L, C Factor	AREA Ha
pasture/grassland 0.02	14.4
bush 0.01	4.9
plantation forest 0.02	0.9
water 0	0.1
parkland/gardens 0.02	1.7
urban 0.007	1.3
pasture/grassland 0.5	1.4
plantation forest 0.5	0.001

M, C Factor	AREA Ha
water 0	0.1
parkland/gardens 0.02	0.2
bush 0.01	4
urban 0.007	19.5
bush 0.5	1.3
urban 0.5	0.0002

Kakaho, C Factor	AREA Ha
pasture/grassland 0.02	795
plantation forest 0.02	183
bush 0.01	252
wetland 0	16
water 0	0.05

Takapuwahia, C Factor	AREA Ha
water 0	0.4
pasture/grassland 0.02	54.1
bush 0.01	189
urban 0.02	0.5
parkland/gardens 0.02	12.1
bush 0.0045	0.1
urban 0.0056	5.4
urban 0.009	60.9
urban 0.003	18.4
parkland/gardens 0.009	0.1
parkland/gardens 0.003	0.04
parkland/gardens 0.0056	0.1
bush 0.5	5.4

I am happy to discuss the data contained within this letter and to discuss how the data-sets developed as part of the Transmission Gully Project may be best utilised for land use planning in the Porirua Harbour Catchments.

Yours sincerely

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