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TE RAUHĪTANGA TAIAO

Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study: Sediment Load Model Results

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Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study: Sediment Load Model Results

Aroon Parshotam

Prepared for
Auckland Regional Council

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PREFACE

The Manukau Harbour is comprised of tidal creeks, embayments and the central basin. The harbour receives sediment and stormwater chemical contaminant run-off from urban and rural land from a number of subcatchments, which can adversely affect the ecology. State of the environment monitoring in the Pahurehure Inlet showed increasing levels of sediment and stormwater chemical contaminant build up. However, previously little was known about the expected long-term accumulation of sediment and stormwater chemical contaminants in the inlet or adjacent portion of the Manukau Harbour. The South Eastern Manukau Harbour / Pahurehure Inlet Contaminant Study was commissioned to improve understanding of these issues. This study is part of the 10-year Stormwater Action Plan to increase knowledge and improve stormwater management outcomes in the region. The work was undertaken by the National Institute of Water and Atmospheric Research (NIWA).

The scope of the study entailed:

1. field investigation,
2. development of a suite of computer models for
    a. urban and rural catchment sediment and chemical contaminant loads,
    b. harbour hydrodynamics, and
    c. harbour sediment and contaminant dispersion and accumulation,
3. application of the suite of computer models to project the likely fate of sediment, copper and zinc discharged into the central harbour over the 100-year period 2001 to 2100, and
4. conversion of the suite of computer models into a desktop tool that can be readily used to further assess the effects of different stormwater management interventions on sediment and stormwater chemical contaminant accumulation in the central harbour over the 100-year period.

The study is limited to assessment of long-term accumulation of sediment, copper and zinc in large-scale harbour depositional zones. The potential for adverse ecological effects from copper and zinc in the harbour sediments was assessed against sediment quality guidelines for chemical contaminants.

The study and tools developed address large-scale and long timeframes and consequently cannot be used to assess changes and impacts from small subcatchments or landuse developments, for example. Furthermore, the study does not assess ecological effects of discrete storm events or long-term chronic or sub-lethal ecological effects arising from the cocktail of urban contaminants and sediment.

The range of factors and contaminants influencing the ecology means that adverse ecological effects may occur at levels below contaminant guideline values for individual chemical contaminants (i.e., additive effects due to exposure to multiple contaminants may be occurring).

Existing data and data collected for the study were used to calibrate the individual computer models. The combined suite of models was calibrated against historic sediment and copper and zinc accumulation rates, derived from sediment cores collected from the harbour.

Four scenarios were modelled: a baseline scenario and three general stormwater management intervention scenarios.

The baseline scenario assumed current projections (at the time of the study) of

- future population growth,
- future landuse changes,
- expected changes in building roof materials,
- projected vehicle use, and
- existing stormwater treatment.

The three general stormwater management intervention scenarios evaluated were:

1. source control of zinc from industrial areas by painting existing unpainted and poorly painted galvanised steel industrial building roofs;
2. additional stormwater treatment, including:
    - raingardens on roads carrying more than 20,000 vehicles per day and on paved industrial sites,
    - silt fences and hay bales for residential infill building sites and
    - pond / wetland trains treating twenty per cent of catchment area; and
3. combinations of the two previous scenarios.

International Peer Review Panel

The study was subject to internal officer and international peer review. The review was undertaken in stages during the study, which allowed incorporation of feedback and completion of a robust study. The review found:

- a state-of-the-art study on par with similar international studies,
- uncertainties that remain about the sediment and contaminant dynamics within tidal creeks / estuaries, and
- inherent uncertainties when projecting out 100 years.

Key Findings of the Study

Several key findings can be ascertained from the results and consideration of the study within the context of the wider Stormwater Action Plan aim to improve stormwater outcomes:

- The inner tidal creeks and estuary branches of the Pahurehure Inlet continue to accumulate sediment and contaminants, in particular in the eastern estuary of Pahurehure Inlet (east of the motorway).

- The outer Pahurehure Inlet/Southeastern Manukau bed sediment concentrations of copper and zinc are not expected to reach toxic levels based on current assumptions of future trends in landuse and activities.

- Zinc source control targeting industrial building roofs produced limited reduction of zinc accumulation rates in the harbour because industrial areas cover only a small proportion of the catchment area and most unpainted galvanised steel roofs are expected to be replaced with other materials within the next 25 to 50 years.

- Given that the modelling approach used large-scale depositional zones and long timeframes, differences can be expected from the modelling projections and stormwater management interventions contained within these reports versus consideration of smaller depositional areas and local interventions. As a consequence, these local situations may merit further investigation and assessment to determine the best manner in which to intervene and make improvements in the short and long terms.

Research and Investigation Questions

From consideration of the study and results, the following issues have been identified that require further research and investigation:

- Sediment and chemical contaminant dynamics within tidal creeks.

- The magnitude and particular locations of stormwater management interventions required to arrest sediment, copper and zinc accumulation in tidal creeks and embayments, including possible remediation / restoration opportunities.

- The fate of other contaminants derived from urban sources.

- The chronic / sub-lethal effects of marine animal exposure to the cocktail of urban contaminants and other stressors such sediment deposition, changing sediment particle size distribution and elevated suspended sediment loads.

- Ecosystem health and connectivity issues between tidal creeks and the central basin of the harbour, and the wider Manukau Harbour.

Technical reports

The study has produced a series of technical reports:

Technical Report TR2008/049
Southeastern Manukau Harbour / Pahurehure Inlet Harbour Contaminant Study. Landuse Analysis.

Technical Report TR2008/050
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Sediment Load Model Structure, Setup and Input Data.

Technical Report TR2008/051
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Sediment Load Model Evaluation.

Technical Report TR2008/052
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Sediment Load Model Results.

Technical Report TR2008/053
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Predictions of Stormwater Contaminant Loads.

Technical Report TR2008/054
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Harbour Sediments.

Technical Report TR2008/055
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Harbour Hydrodynamics and Sediment Transport Fieldwork.

Technical Report TR2008/056
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Hydrodynamic Wave and Sediment Transport Model Implementation and Calibration.

Technical Report TR2008/057
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Implementation and Calibration of the USC-3 Model.

Technical Report TR2008/058
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Predictions of Sediment, Zinc and Copper Accumulation under Future Development Scenario 1.

Technical Report TR2008/059
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Predictions of Sediment, Zinc and Copper Accumulation under Future Development Scenarios 2, 3 and 4.

Technical Report TR2009/110
Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study. Rainfall Analysis.

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1 Executive Summary

The main aim of the Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study is to model contaminant (zinc, copper) and sediment accumulation for the purposes of, amongst other things, identifying significant contaminant sources, and testing efficacy of stormwater treatment options.

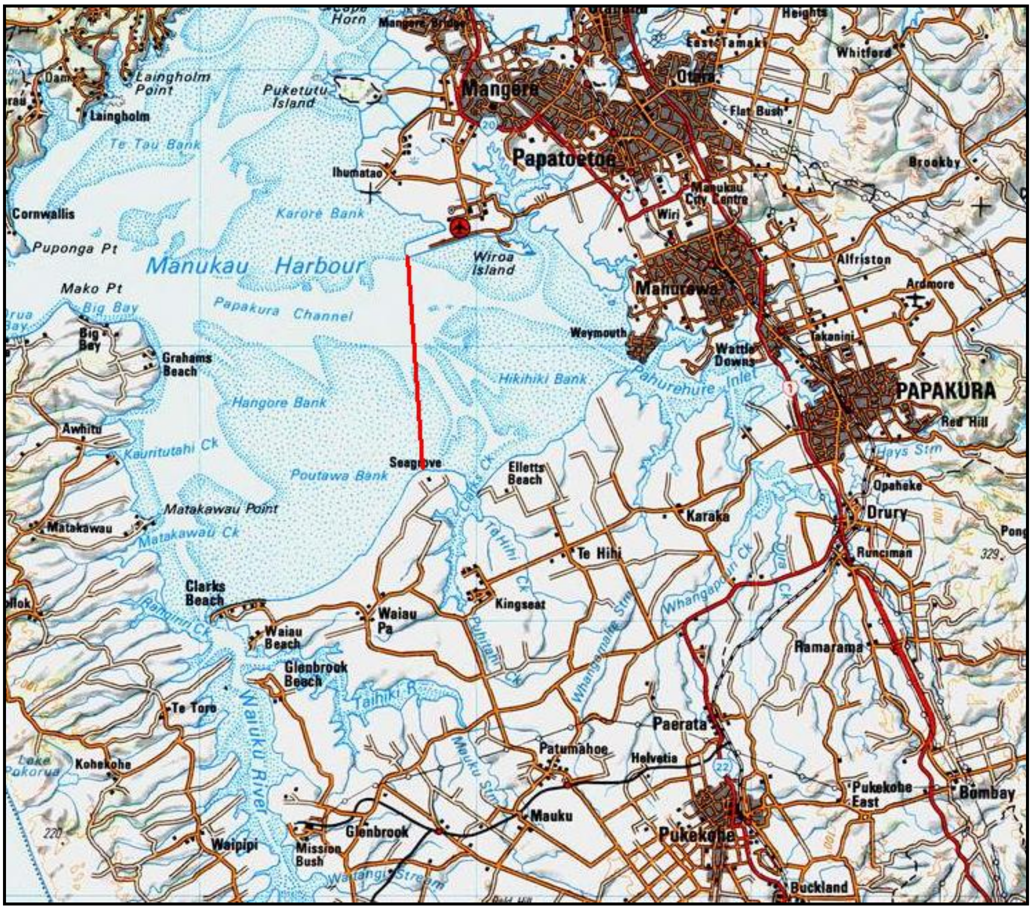
This report describes model results for the 'historical' period (1945 to 2000, the 'current time' (2001), and the 'future' period (2002 to 2100) to hindcast/predict sediment runoff from the rural areas of the catchment surrounding the Southeastern Manukau Harbour / Pahurehure Inlet. The results presented here are provided to both the CLM model as an input for the estimation of urban contaminant loads and the USC-3 model as an input for the hindcasting and prediction of sediment and contaminant accumulation in Harbour subestuaries.

2 Introduction

2.1 Background

The main aim of the Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study is to model contaminant (zinc, copper) and sediment accumulation for the purposes of, amongst other things, identifying significant contaminant sources, and testing efficacy of stormwater treatment options. The study area extends westward from Pahurehure Inlet to a line running approximately south from the western end of Auckland Airport (see Figure 1).

Figure 1:
Manukau Harbour, showing the study area to the east of the red line extending south from Auckland International Airport.



This part of the Manukau Harbour receives discharges from all or part of three separate territorial authorities (TAs): Manukau City Council (MCC), Papakura District Council (PDC) and Franklin District Council (FDC). Each of these TAs is currently planning or in the process of preparing Integrated Catchment Management Plans (ICMPs) to support stormwater network discharge consent applications. The ICMP process requires TAs to undertake an evaluation of the effects of contaminant delivery to receiving marine environments.

However, as a consequence of the cross-boundary distribution of contaminant sources to the Southeastern Manukau Harbour / Pahurehure Inlet and its hydrodyamically complex nature, ARC has commissioned a single integrated study of contaminant accumulation in this receiving environment. The scope of the project is set out in the ARC's request for proposals and the contractual agreement between ARC and NIWA.

2.2 Study aims

The essential requirements of the project are:

- for each 'inlet compartment' (or sub-estuary) of the study area, to predict trends over the period 1950 to 2100 of sediment deposition and copper and zinc concentrations for probable future population growth and urban development consistent with the Regional Growth Strategy, without either zinc source control of industrial areas or additional stormwater treatment;
- to predict trends in the accumulation of these contaminants with various combinations of zinc source control of industrial areas and stormwater treatment;
- to estimate the mass load contributions of sediment, copper and zinc from each sub-catchment draining into the Southeastern Manukau Harbour / Pahurehure Inlet; and
- to predict the year when sediment-quality guidelines will be exceeded.

2.3 Model suite

The Study centres on the application of a suite of models that are linked to each other:

- The GLEAMS sediment-generation model, which predicts sediment erosion from the land and transport down the stream channel network. Predictions of sediment supply are necessary because, ultimately, sediment eroded from the land dilutes the concentration of contaminants in the bed sediments of the harbour, making them less harmful to biota.
- The Contaminant Load Model (CLM)- a contaminant/sediment-generation model, which predicts sediment and contaminant concentrations (including zinc, copper) in stormwater at a point source, in urban streams, or at end-of-pipe where stormwater discharges into the receiving environment. Note the main distinction between the use of GLEAMS and CLM for estimating sediment generation in this study is that the

former is largely used for rural areas and the latter for urban areas. Further details are given in Moores and Timperley (2008).

- The USC-3 (Urban Stormwater Contaminant) contaminant/sediment accumulation model, which predicts sedimentation and accumulation of contaminants (including zinc, copper) in the bed sediments of the estuary. Underlying the USC-3 model is yet another suite of models: the DHI Water and Environment MIKE3 FM HD hydrodynamic model, the DHI MIKE3 FM MT (mud) sediment transport model, and the SWAN wave model (Holthuijsen et al. 1993), which simulate harbour hydrodynamics and sediment transport. Combined, these three models can be used to simulate tidal propagation, tide- and wind-driven currents, freshwater mixing, waves, and sediment transport and deposition within a harbour."

2.4 This report

This report describes model results for the historical period (1945, 1959 and 1987), the current time (2001), and the future period (2002 to 2100) to hindcast/predict sediment runoff from the rural areas of the catchment surrounding the Southeastern Manukau Harbour / Pahurehure Inlet. These results are produced by GLEAMS-SEM (as we have termed the implementation of GLEAMS for this study) before and after application of a stream routing subroutine employed to simulate conveyance of sediment to harbour outfalls.

Both the USC-3 model and CLM contaminant generation model use outputs from the GLEAMS sediment-generation model. Calibration of the USC-3 model is achieved by running the model for the historical period, with sediment and metal inputs from the catchment appropriate to that period, which in turn are hindcast by the GLEAMS and CLM models (Green, 2008). Predictions are made for the future period, which starts at the year 2002, again with sediment and contaminant load inputs provided by GLEAMS and CLM. The CLM requires GLEAMS estimates of bare earth sediment yields as inputs in order to derive sediment load estimates associated with urban development by infill development (historical and future periods) and development of vacant land (future period only) (Moores and Timperley, 2008). In the historical period, the estimation of sediment loads associated with the development of vacant land at the margins of the built up area occurs directly through GLEAMS.

In summary, the results presented here comprise:

- for the historical period, sediment yields and loads from land beyond the margins of the urban built up area, including both rural and vacant urban fringe land;
- for the future period, sediment yields and loads solely from rural land beyond the Auckland Metropolitan Limit (MUL) and boundary of urban-zoned land at Pukekohe (the only significant urban area outside the MUL); and
- sediment yields for areas of bare earth lying within the MUL and urban zoned land at Pukekohe.

The reader is referred to Parshotam et al. (2008a) for a description of the GLEAMS-SEM model, its setup and implementation; Semadeni-Davies and Parshotam (2009) for the rainfall analysis; Parshotam et al. (2008b) for the landuse analysis and Parshotam et al. (2008c) for the evaluation of GLEAMS-SEM for this particular study.

The predicted sediment runoff is presented as (1) annual sediment yields (i.e., total loads per area per year), averaged over the rural area for every hydrological model unit (MU[1]), and (2) daily sediment loads in selected subcatchments routed through the stream network to the estuary as a function of rainfall. Total daily sediment loads generated from a subcatchment are related to daily precipitation from the dominant rainfall region in the subcatchment. This report also describes variations in bare earth sediment yields, data provided to the CLM for the estimation of sediment loads associated with development of urban infill and vacant land.

[1] The study area was divided into 580 Hydrological MUs (Model Units) nested within 15 defined outfall subcatchment areas, given identifiers 101 to 115, associated with an outlet.

3 Current scenario

This section presents results for the 'current' scenario, which is largely based on the landuse existing in 2001.

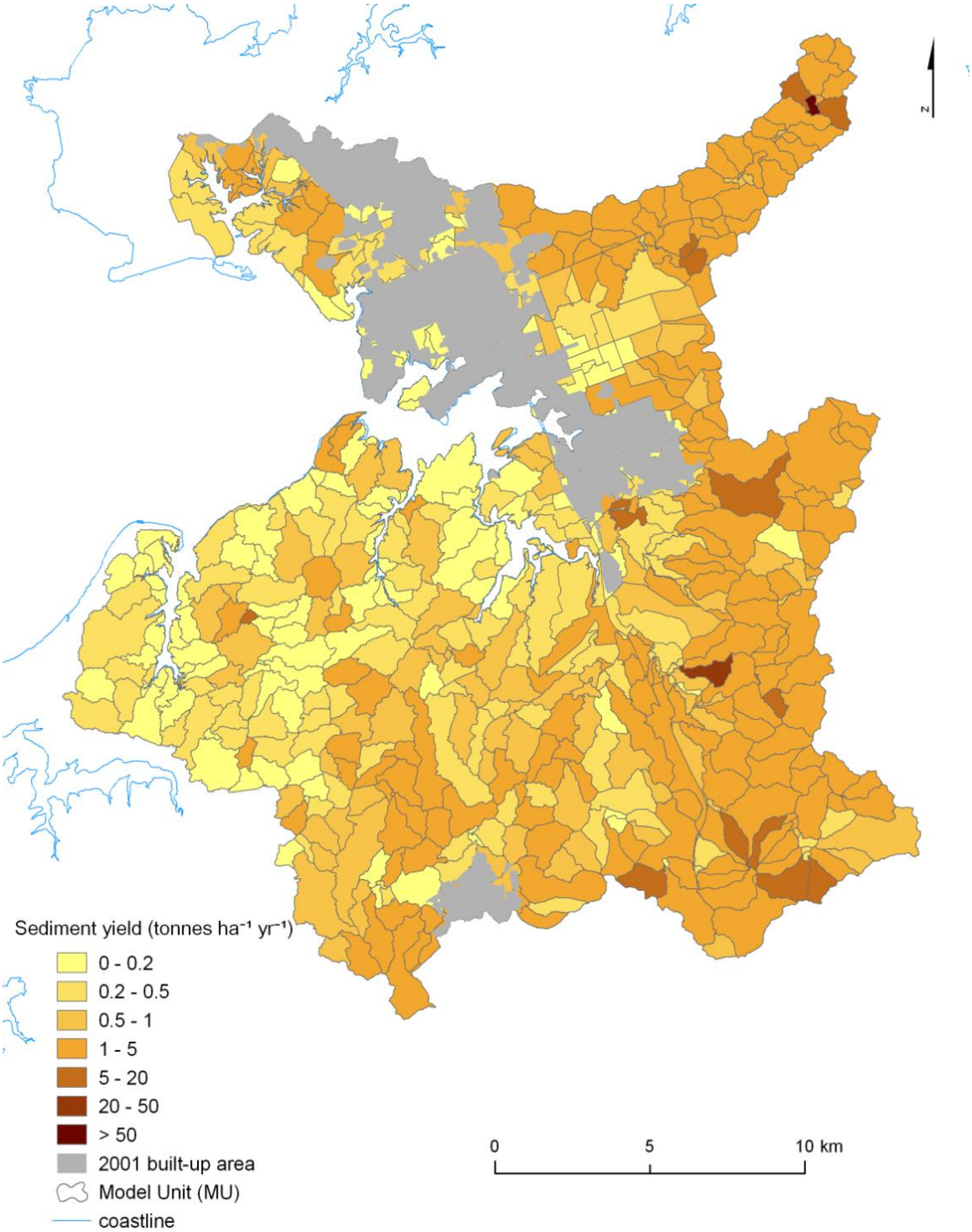
3.1 Sediment yields by Model Unit (MU)

Figure 2 shows current (2001 LCDB2 landuse data with 2003-2004 bare/exposed earth) sediment yields averaged over the rural part of each MU (i.e., land lying beyond the margins of the built-up area). These are yields at source, in other words the mean annual sediment load per unit catchment area before considering the effects of routing through the stream network (but after hillslope delivery processes).

Differences in sediment yields between the subcatchments are attributed to variations in landuse, soil type and slope angle. Given the same soil and slope, the predicted sediment yields increase in the following sequence: native forest < pine forest < scrub, manuka/kanuka < grassland < market gardens < earthworks. The estimates are consistent with those reported by previous studies, including measured yields (Senior et al. 2003; Collins, 2003).

Generated yields for a given landuse and slope increase according to soil types from lowest to highest in the following order: 1) Te Ranga soil types (formed from greywacke), 2) Whatatiri soil types (formed from basalt), 3) Weymouth-Bombay soil types (formed from clayey volcanic ash, 4) Ardmore soil types (formed from organic rich material), 5) Takahiwai soil types (formed from saline esturine alluvium), 6) Brookby-Rangiora soil types (formed from greywacke and sandstone), 7) C1 Complex soil types (formed from a complex of alluvium and rewashed volcanic ash), 8) Karaka soil types (formed from rewashed volcanic ash over weathered sandstone), and 9) Clevedon-Whakapara soil types (formed from alluvium).

Figure 2:
Current (2001) generated sediment yields from rural areas (tonnes $ha^{-1} yr^{-1}$). The yield for each MU is calculated based on the rural area in that MU.



3.2 Relationship between daily rainfall and sediment loads

There is generally a well-defined relationship between total daily rainfall and modelled daily sediment loads from a subcatchment. For the purpose of illustrating this relationship, the rainfall from the dominant rainfall region in each subcatchment is used. The dominant rainfall region in a subcatchment is defined from the proportion of the rural part of the MU lying in each of rainfall regions, RR1, RR2, and RR3 (see Table 1). Outlying values in the relations reflect in part the influence of rainfall events in non-dominant rainfall regions generating a higher sediment load than would be predicted from the rainfall falling in the dominant rainfall region on that day. As described by Semadeni-Davies and Parshotam (2009), total daily rainfall in rainfall regions RR1, RR2, and RR3 do not correlate well against each other on any given day (although they do once the data are ranked). The degree of scatter of data in the total daily rainfall and modelled daily sediment load figures is also reflected by the influence of daily rainfall from the different rainfall regions assumed in the model.

Most of the current built-up area lying within the Auckland MUL lies within rainfall region RR1 and most of the current built-up area lying within the Pukekohe urban area lies within rainfall region, RR2 (see Figure 9 of Parshotam, et al. 2008a and Figure 3 of Parshotam et al. 2008b).

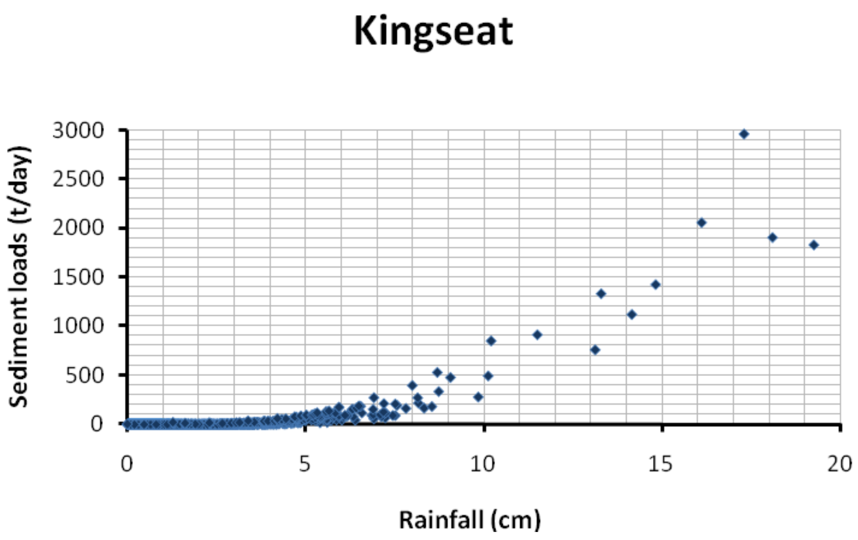
Table 1:

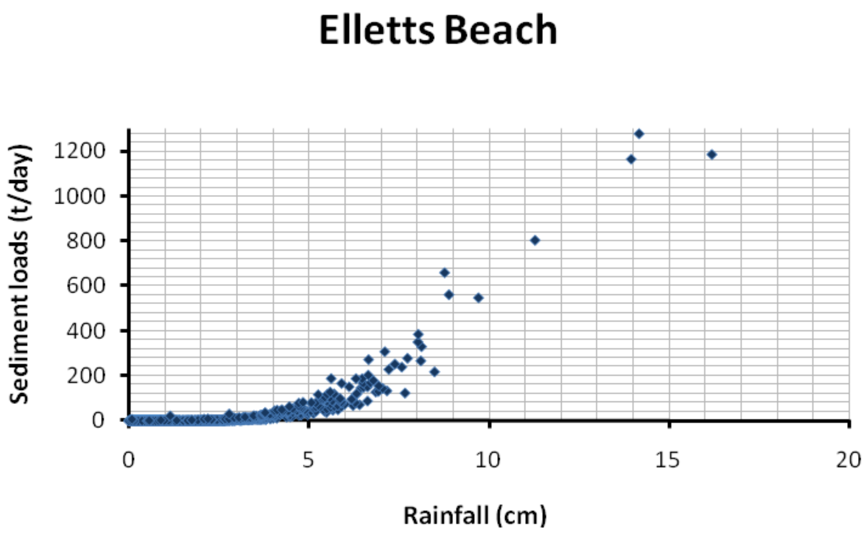
Subcatchments and approximate proportion of rural areas lying in rainfall regions, RR1, RR2 and RR3 with dominant rainfall region underlined.

Subcatchment (identifier)	RR1 (%)	RR2 (%)	RR3(%)
Kingseat (101)	90	10	-
Elletts Bay (102)	10	90	-
Karaka (103)	45	50	5
Whangapouri (104)	5	60	35
Oira Creek (105)	55	45	-
Drury (106)	20	30	50
Hingaia (107)	100	0	0
Papakura (108)	55	45	-
Takanini (109)	60	40	-
Papakura Stream (110)	30	70	-
Manurewa/Weymouth (111)	100	-	-
Papatoetoe/Puhinui (112)	70	30	-
Mangere East/Papatoetoe (113)	100	-	-
Mangere (114)	100	-	-
Bottle Top Bay (115)	100	-	-

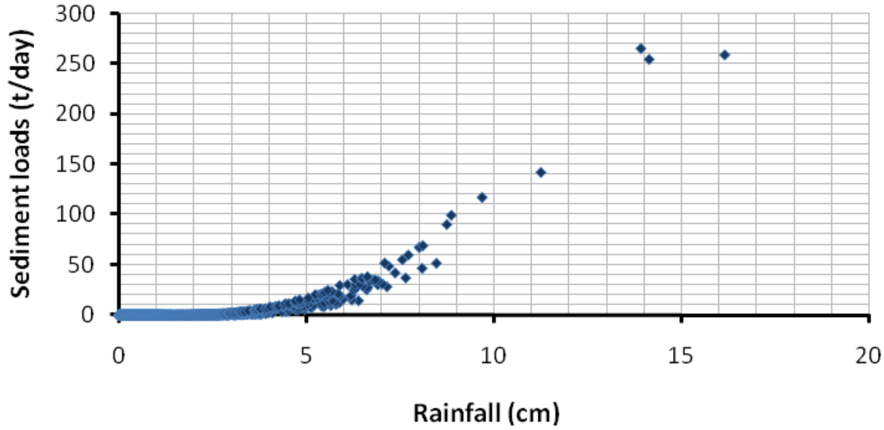
Figure 3 shows predicted sediment loads for 2001 from the rural area of each subcatchment and routed through the stream network as a function of total daily rainfall (cm) from the dominant rainfall region in that subcatchment. The data illustrate that individual rainfall events can generate substantial sediment loads and that an increased rainfall generally increases sediment load, although there is variability arising from soil types, slopes, landuse, management practices, prior rainfall events, and stream network properties. Figure 3 shows the trend in sediment loads in the various subcatchments with total daily rainfall event sizes.

Figure 3:
Model predictions of 2001 routed sediment loads (t day^{-1}) from the rural area of a subcatchment, as a function of total daily rainfall (cm) from the dominant rainfall region in that subcatchment (continued onto the next four pages). The loads reported are for a 50 year period and assume that the landuse is fixed at the 2001 scenario.

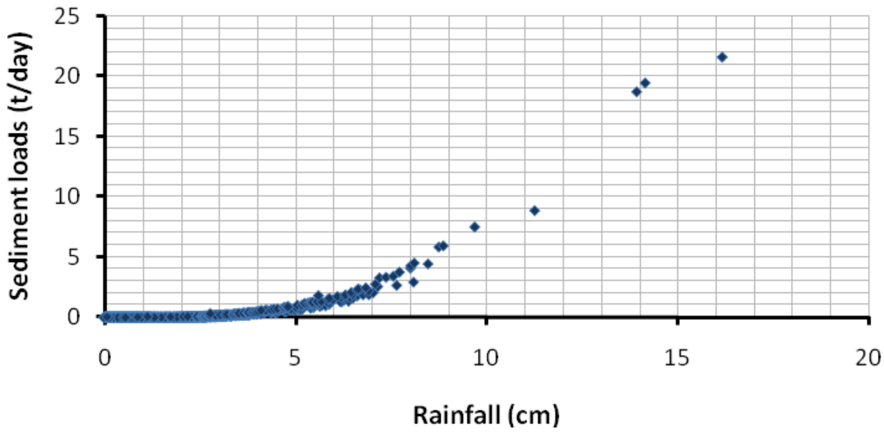




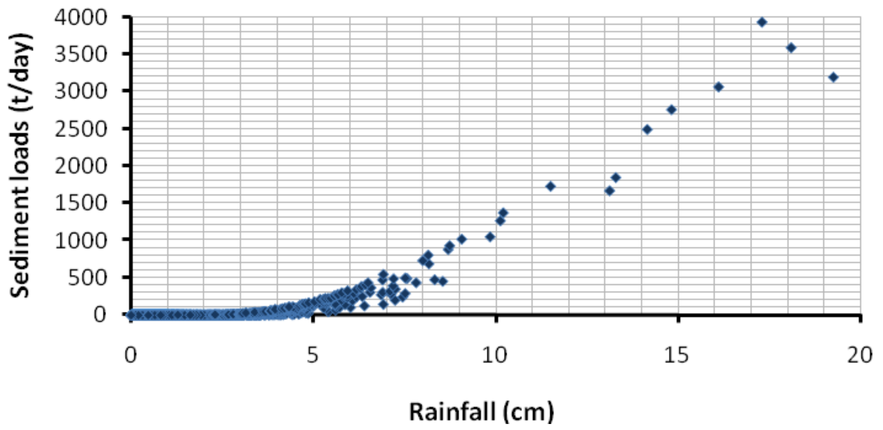
Hingaia



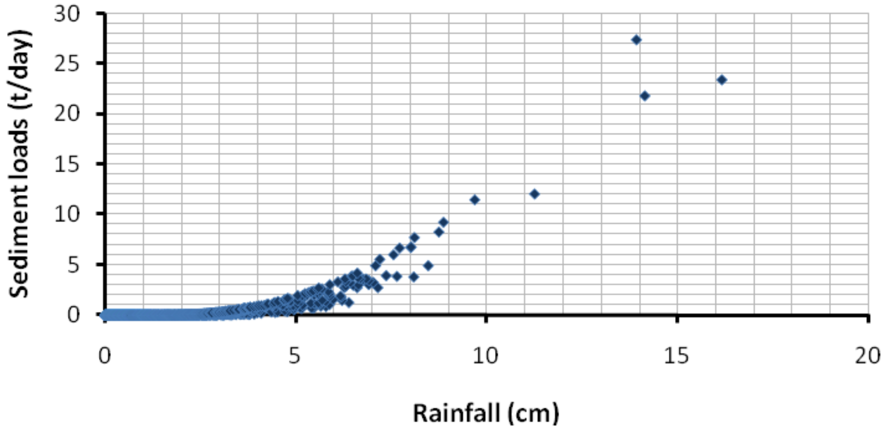
Takanini



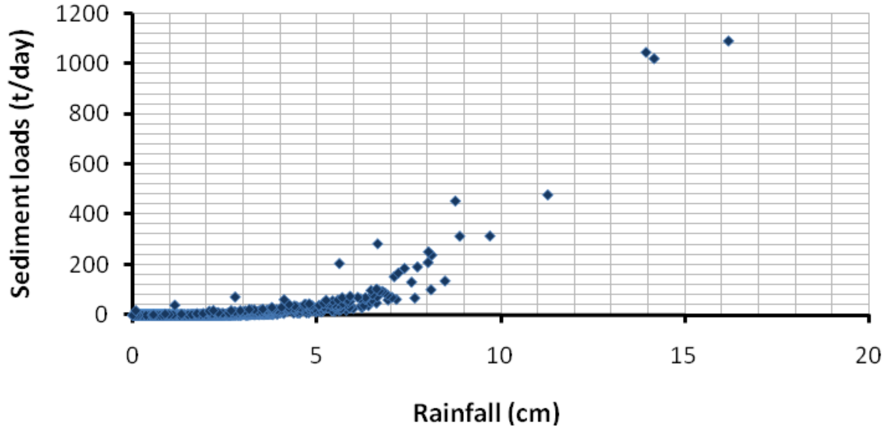
Papakura Stream



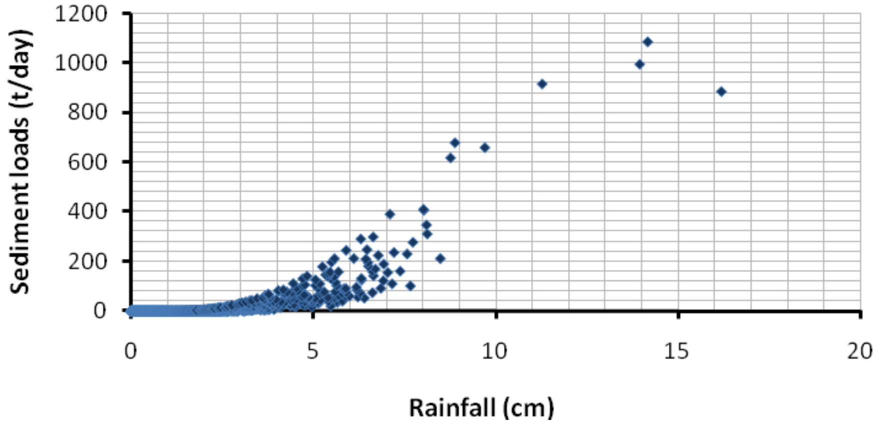
Manurewa/Weymouth

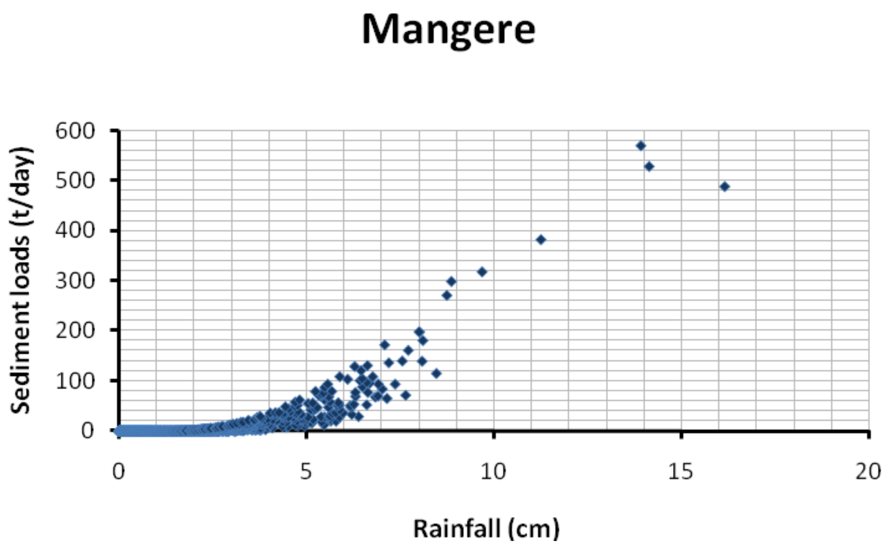


Papatoetoe/Puhinui



Mangere East/Papatoetoe





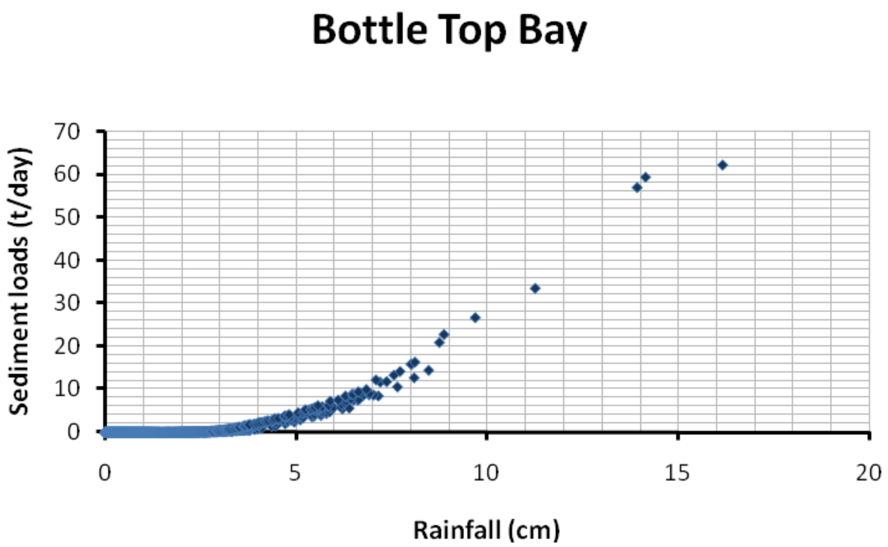


Figure 4 shows a time series (1956–2005) of predicted sediment loads from the Papakura stream subcatchment. The 50 years of data illustrate that individual rainfall events generate substantial sediment loads. The highest rainfall event of 19.3 cm on 17 February, 1985 contributed the third highest load (3188 t) in the Papakura Stream subcatchment. This amounts to 5% of the total load of 62 620 t from this subcatchment over 50 years (see Figure 5). Most sediment delivery is therefore delivered in large-sized events, and this is also true of the other subcatchments under both existing and historical landuse. The loads reported are for a 50 yr period assuming that landuse is fixed at the 2001 scenario.

There is no sediment runoff generated in the Papakura Stream subcatchment below the threshold of 0.7 cm of rainfall. The size of rainfall at which sediment loads begin to increase substantially is about 5 cm in the Papakura Stream subcatchments (see Figure 5) and it is generally about 5cm for all subcatchments.

Figure 4:
Time series of rainfall (cm) from rainfall region, RR2 used in this study (blue line) and time series of predicted sediment loads (tonnes day-1) from the rural part of the Papakura Stream subcatchment. The highest rainfall in rainfall region, RR2 is 19.27 cm on 17 February, 1985.

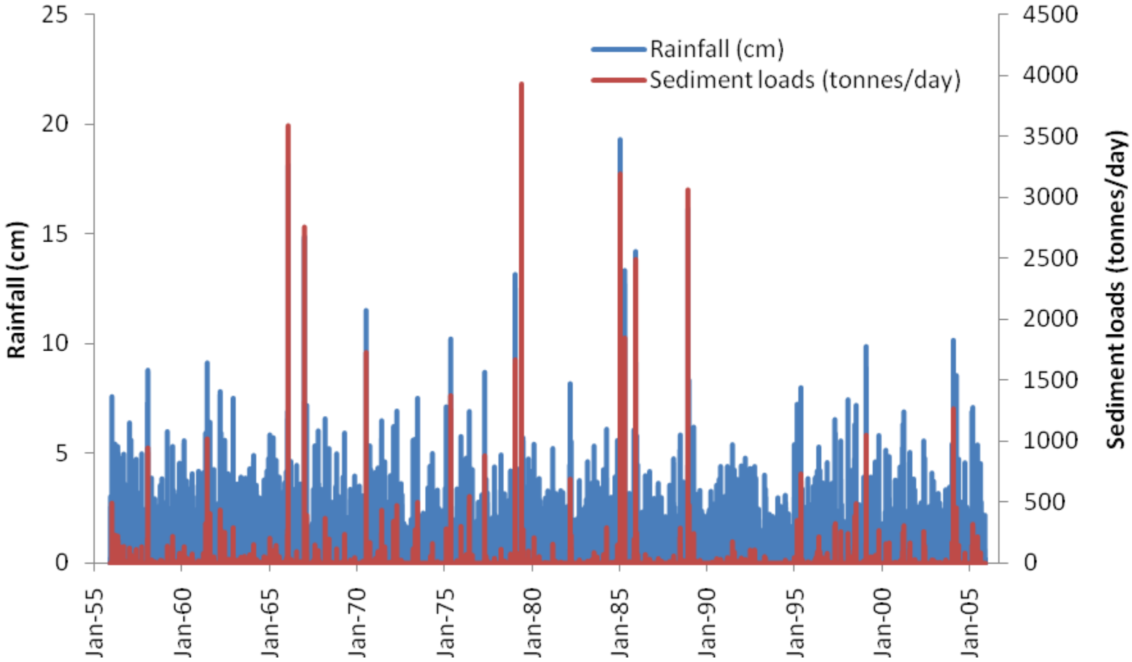
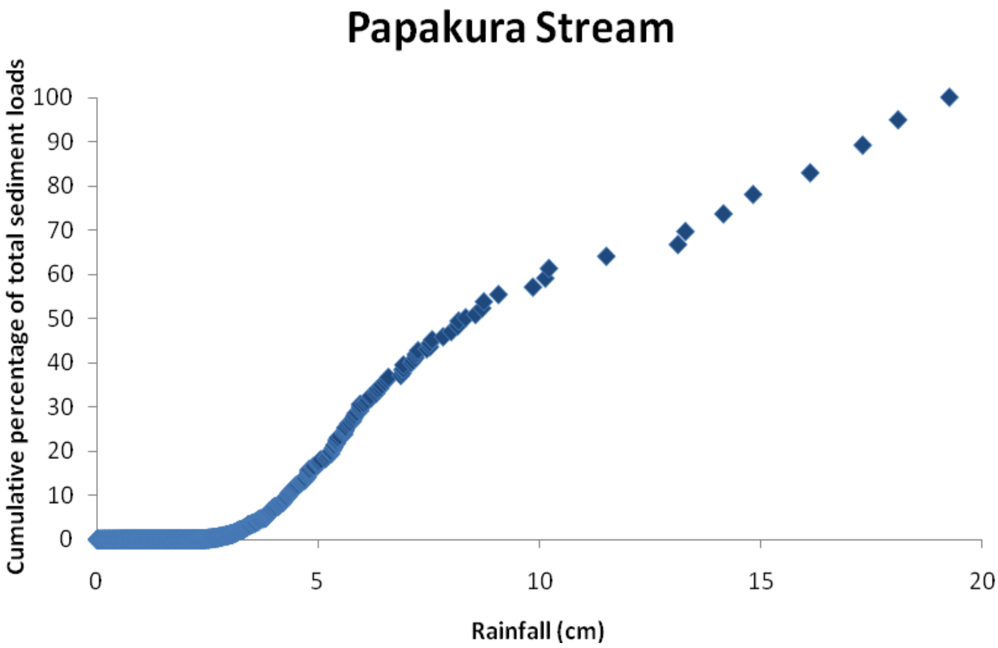


Figure 5:
Cumulative percentage of total daily sediment loads from the rural part of the Papakura Stream subcatchment as a function of rainfall on that day, derived by sorting daily sediment loads by daily rainfall. The loads reported are for a 50 year period and assume that the landuse is fixed at the 2001 scenario.

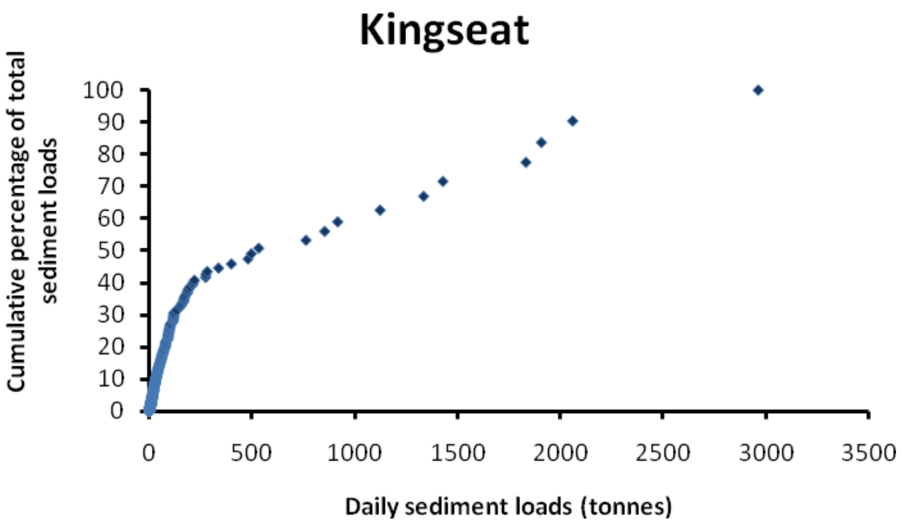


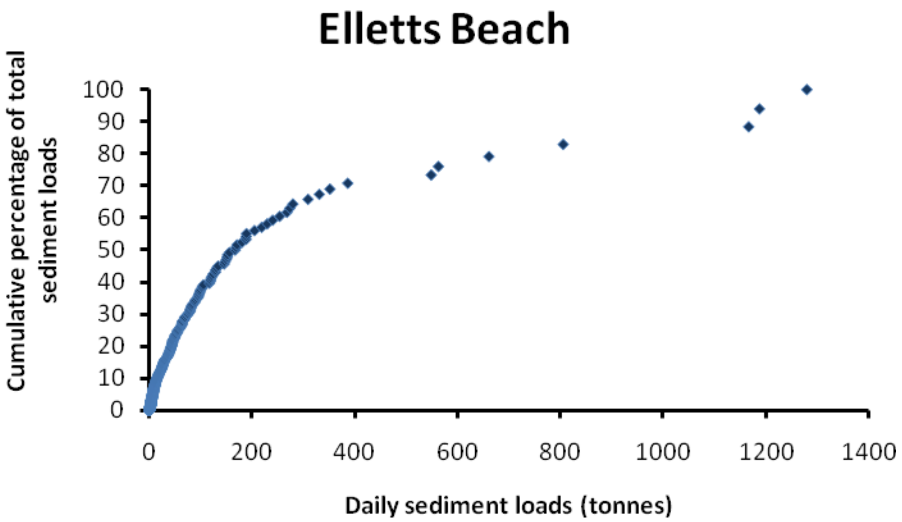
The effect of stream routing on subcatchment loads is described further in Section 3.4.

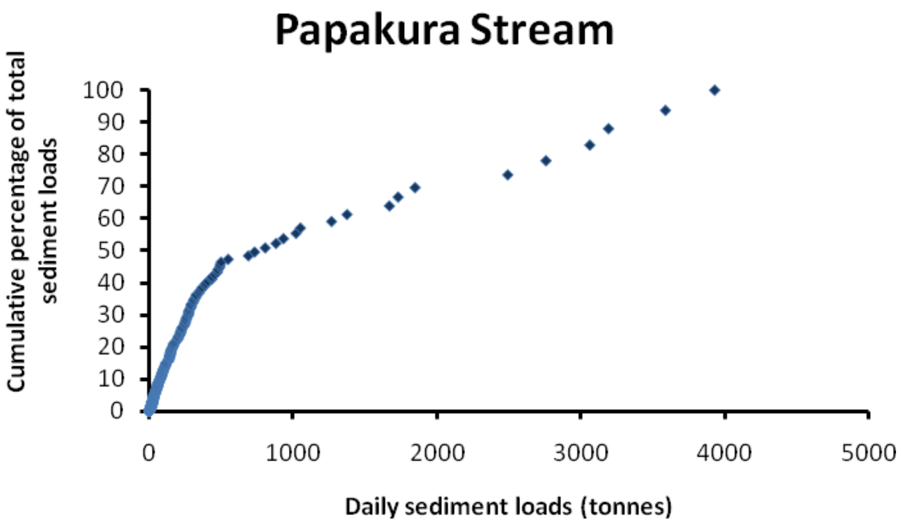
Sediment is generated between 5.5 and 14.2 % of the days over the 50 year simulation period (depending on the subcatchment). In each subcatchment, the mean annual sediment load (after routing) is comparable to the load generated by a single rainfall event of between 9 cm and 10 cm.

Figure 6 shows the statistical distribution, for selected subcatchments, of the probability of a daily sediment load equal to or less than a given value. For example, events loads of 1500 tonnes or less make up 70% of the total load for the Kingseat subcatchment. Most sediment delivery occurs during a small number of large sized events. On its own, the highest single daily sediment load in a subcatchment contributes between 3.6% and 9.6% of the total 50 year load (see Table 2). The highest three daily sediment loads contribute approximately 20% of the total 50 year load (see Figure 6). Figure 7 shows a histogram and cumulative percentage showing a frequency distribution of loads at the Papakura Stream subcatchment.

Figure 6:
Cumulative percentage of total daily sediment loads from the rural part of selected subcatchments equal to or less than a given daily load (continued onto the next page). The loads reported are for a 50 year period and assume that the landuse is fixed at the 2001 scenario.






Papakura Stream
Cumulative percentage of total sediment loads
Daily sediment loads (tonnes)
100
90
80
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000

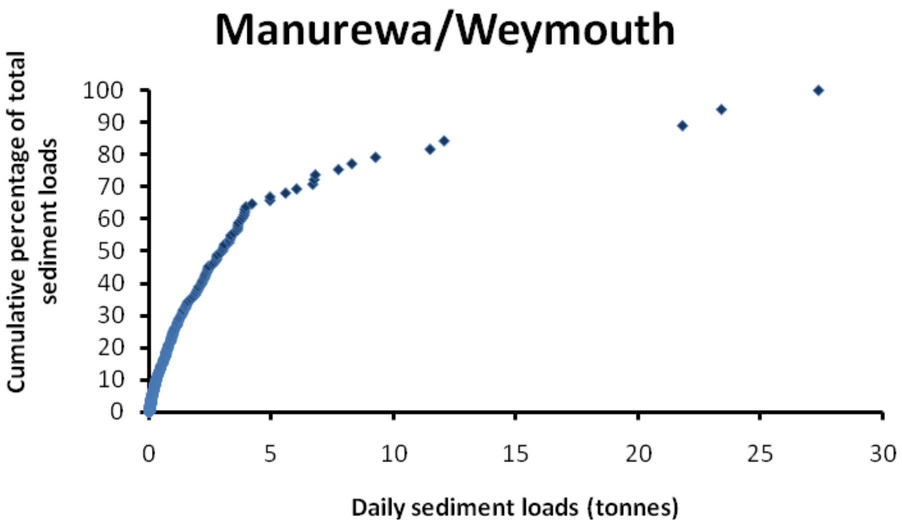

Manurewa/Weymouth
Cumulative percentage of total sediment loads
Daily sediment loads (tonnes)
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30

Figure 7:
Histograms and cumulative percentage of loads at the Papakura Stream subcatchment showing a frequency distribution of loads (tonnes day^{-1}). The first bin corresponds to sediment loads of between 0 and 50 tonnes day^{-1}.

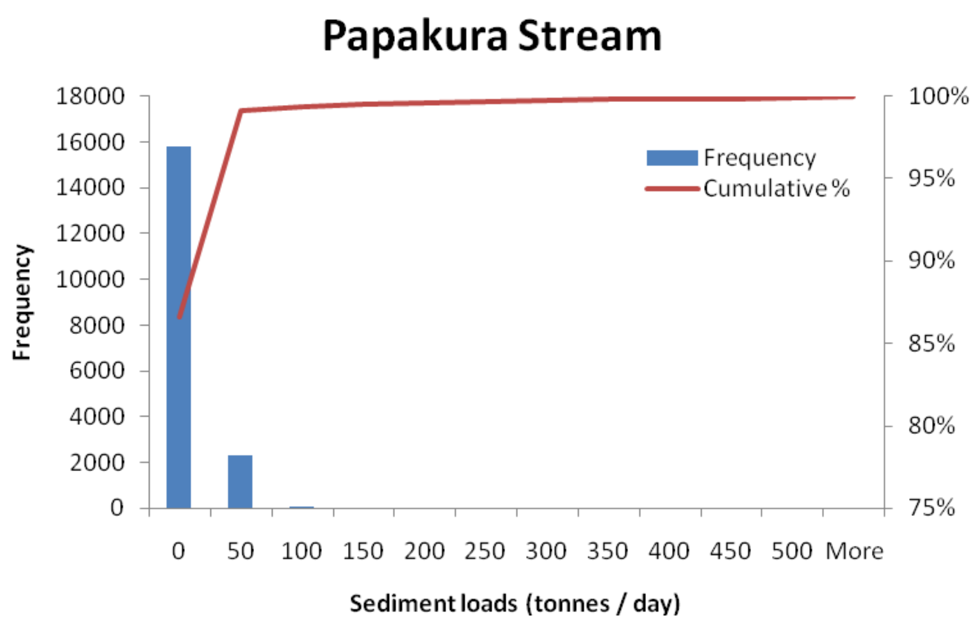


Table 2 summarises several characteristics of subcatchment sediment loads. For reference, the subcatchment names, outlet IDs, codes and areas are included in Table 3, and they are also given in Parshotam et al. (2008a).

The largest loads (before and after routing) are from the Drury subcatchment (subcatchment 106), which has by far the largest area and is predominantly rural. The Papakura Stream subcatchment (subcatchment 110) also has a relatively high rural area and is the second largest generator of sediment. In contrast, the smallest loads are from subcatchments Takanini (subcatchment 109), and Manurewa / Weymouth (subcatchment 111) which are predominantly urban.

Subcatchment loads for historical and future scenarios, as well as the overall catchment load, are presented in Section 6.

Table 2:

Mean annual loads of sediment from rural areas over 50 years (current landuse scenario), before and after routing; percentage of total number of days that sediment is generated; and highest sediment load (routed) in a single day for each subcatchment.

Subcatchment name	Outlet ID	Mean annual loads, before routing (tonnes y^{-1})	Mean annual loads, after routing (tonnes y^{-1})	Percentage of days sediment is generated (over 50 y, routed)	Highest load in a single day (% of total load over 50 y, routed)	Rural area (ha)
Kingseat	101	1550	616	9	9.6	4614
Elletts Beach	102	686	426	7.8	6	1321
Karaka	103	2509	551	8	7	4114
Whangapouri Creek	104	5324	697	13.8	6.9	5102
Oira Creek	105	1574	239	8.4	6.1	1983
Drury	106	33409	3073	10.2	7.6	13514
Hingaia	107	145	88	5.8	6.1	294
Papakura	108	856	419	13.3	3.6	147
Takanini	109	11	6	6.5	7	10
Papakura Stream	110	10794	1252	13.4	6.3	4659
Manurewa / Weymouth	111	12	9	14.2	5.9	50
Papatoetoe / Puhinui	112	1327	289	11.7	7.5	693
Mangere East / Papatoetoe	113	581	520	8.7	4.2	715
Mangere	114	270	255	8.7	4.5	417
Bottle Top Bay	115	39	23	5.5	5.3	4
Total catchment		59087	8464	17.5	6.1	37637

Table 3:

Subcatchment names, outlet ID's, codes and area.

Subcatchment name	Outlet ID	Code	Area (ha)
Kingseat	101	KST	4614
Elletts Beach	102	EBH	1321
Karaka	103	KKA	4114
Whangapouri Creek	104	WHC	5691
Oira Creek	105	OIC	1984
Drury	106	DRY	14264
Hingaia	107	HGA	500
Papakura	108	PKA	912
Takanini	109	TKI	287
Papakura Stream	110	PAS	5513
Manurewa / Weymouth	111	MAW	946
Papatoetoe / Puhinui	112	PAU	2962
Mangere East / Papatoetoe	113	MEP	1176
Mangere	114	MGE	570
Bottle Top Bay	115	BTB	181
Total catchment			45035

3.3 Sediment load delivery ratios

The sediment delivery ratio (SDR) is the load of sediment exiting the subcatchment after stream routing divided by the load entering the stream network. The SDR values are summarised in Table 4.

The sediment delivery ratio (SDR) is affected by many highly variable physical characteristics of a subcatchment including the drainage area, slope, maximum length of a subcatchment expressed as a relief-length (R/L) ratio, runoff-rainfall factors, landuse/land cover and sediment particle size.

In this study, the predominantly urban, smaller subcatchment areas close to the harbour generally have a high delivery ratio. These include Elletts beach (subcatchment 102), Hingaia (subcatchment 107), Papakura (subcatchment 108), Takanini (subcatchment 109), Manurewa/Weymouth (subcatchment 111), Mangere East / Papatoetoe (subcatchment 113), Mangere (subcatchment 114), and Bottle Top Bay (subcatchment 115) The predominantly rural, larger and longer subcatchments generally have a low delivery ratio. These include Karaka (subcatchment 103), Whangapouri Creek (subcatchment 104), Oira Creek (subcatchment 105), Drury (subcatchment 106) and Papakura Stream (subcatchment 110).

Table 4.

Sediment delivery ratio (SDR) of each subcatchment.

Subcatchment (identifier)	SDR (%)
Kingseat (101)	39.8
Elletts Beach (102)	62.1
Karaka (103)	21.9
Whangapouri (104)	13.1
Oira Creek (105)	15.2
Drury (106)	9.2
Hingaia (107)	60.2
Papakura (108)	48.9
Takanini (109)	57.1
Papakura Stream (110)	11.6
Manurewa/Weymouth (111)	74.9
Papatoetoe/Puhinui (112)	21.8
Mangare East/Papatoetoe (113)	89.5
Mangere (114)	94.4
Bottle Top Bay (115)	59.9
Whole catchment	14.3

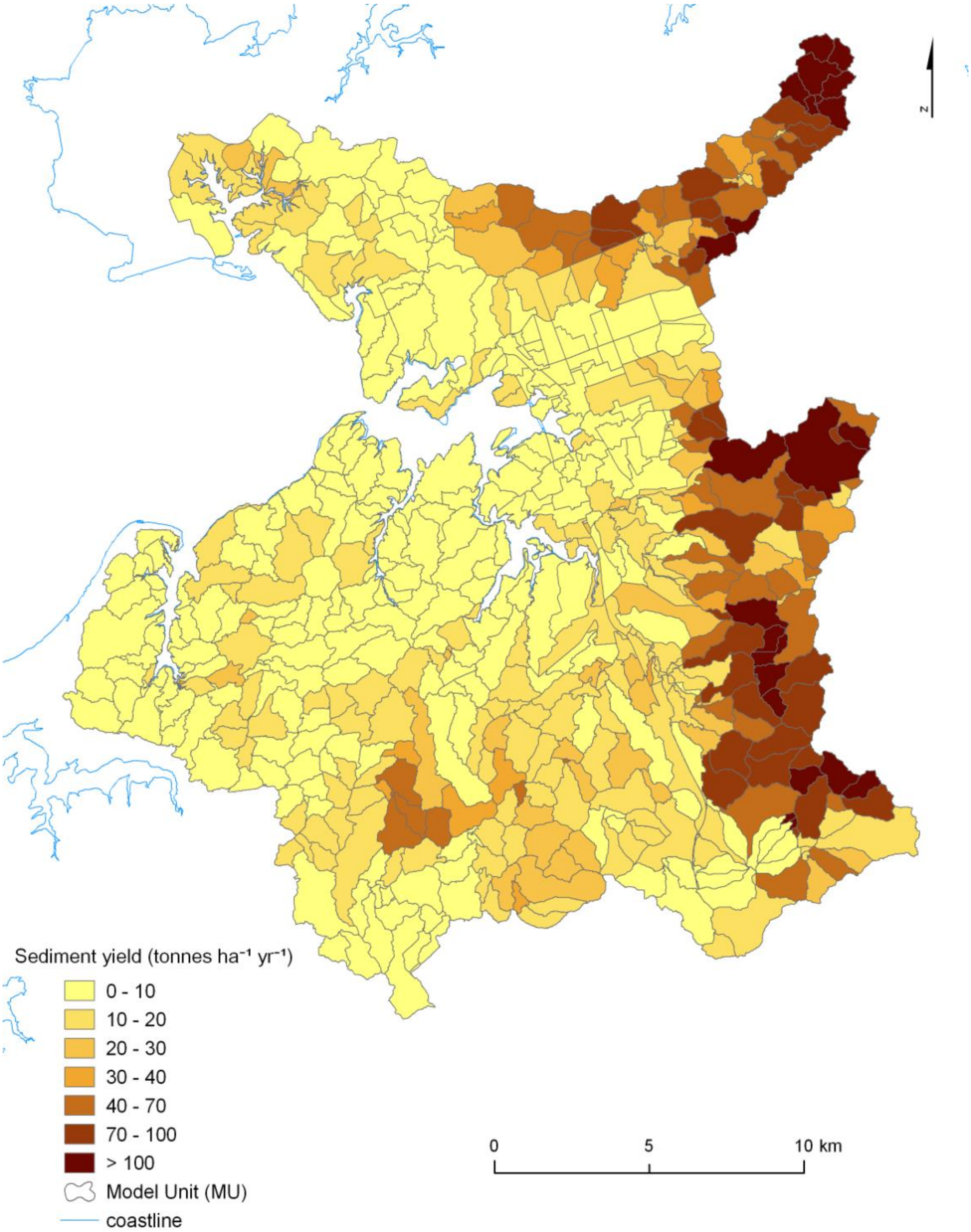
3.4 Sediment yields from greenfield earthworks areas

The CLM model requires estimates of the sediment yield from bare earth in each model unit (Moores and Timperley, 2008). These data are derived from GLEAMS. Since the particular location of bare earth within a model unit (MU) is not known, an average yield of bare earth is used. The average yield for bare earth is calculated by assuming that the whole MU is bare earth. There is no treatment of land by sediment ponds assumed for this scenario, since such treatment is taken care of within the CLM model (Moores and Timperley, 2008).

Sediment yields for bare earth for each MU are given in Figure 8. The variation between MUs is largely dependent on soil types and slope angles. Note the relatively low sediment yields from areas which are within the current urban boundaries, a result of the relatively low slopes and rainfall in those areas

The results lie within the range reported by Ng and Buckeridge, (2000) in a review of sediment yields from construction sites within the Auckland region. Yields have also been prepared for urban grassland for use in the CLM model for estimating sediment loads from open spaces within the urban area.

Figure 8:
Average sediment yields (tonnes ha^{-1} yr^{-1}) for bare earth for each MU of the study area.



4 Historical scenarios

This section presents results for the years 1945, 1959 and 1987 based on the patterns of landuse and earthworks described in Parshotam et al. (2008a). The results are only for the land up to the margin of the urban built-up area that existed in each of these years; loads generated from within the urban built-up area (including infill development) are estimated by the CLM model (Moores and Timperley, 2008) and are not included in this report

Changes in the load estimates over the historical period largely occur in those catchments experiencing urban growth. This reflects the development of vacant land and loss of grassland at the urban fringe. In rural subcatchments, there are annual variations in loads (reflecting year to year variations in rainfall), but no long term trends since rural landuse is assumed to have remained largely the same over the historical period (although see comments below in relation to bare earth).

4.1 Sediment generation. Year 1945

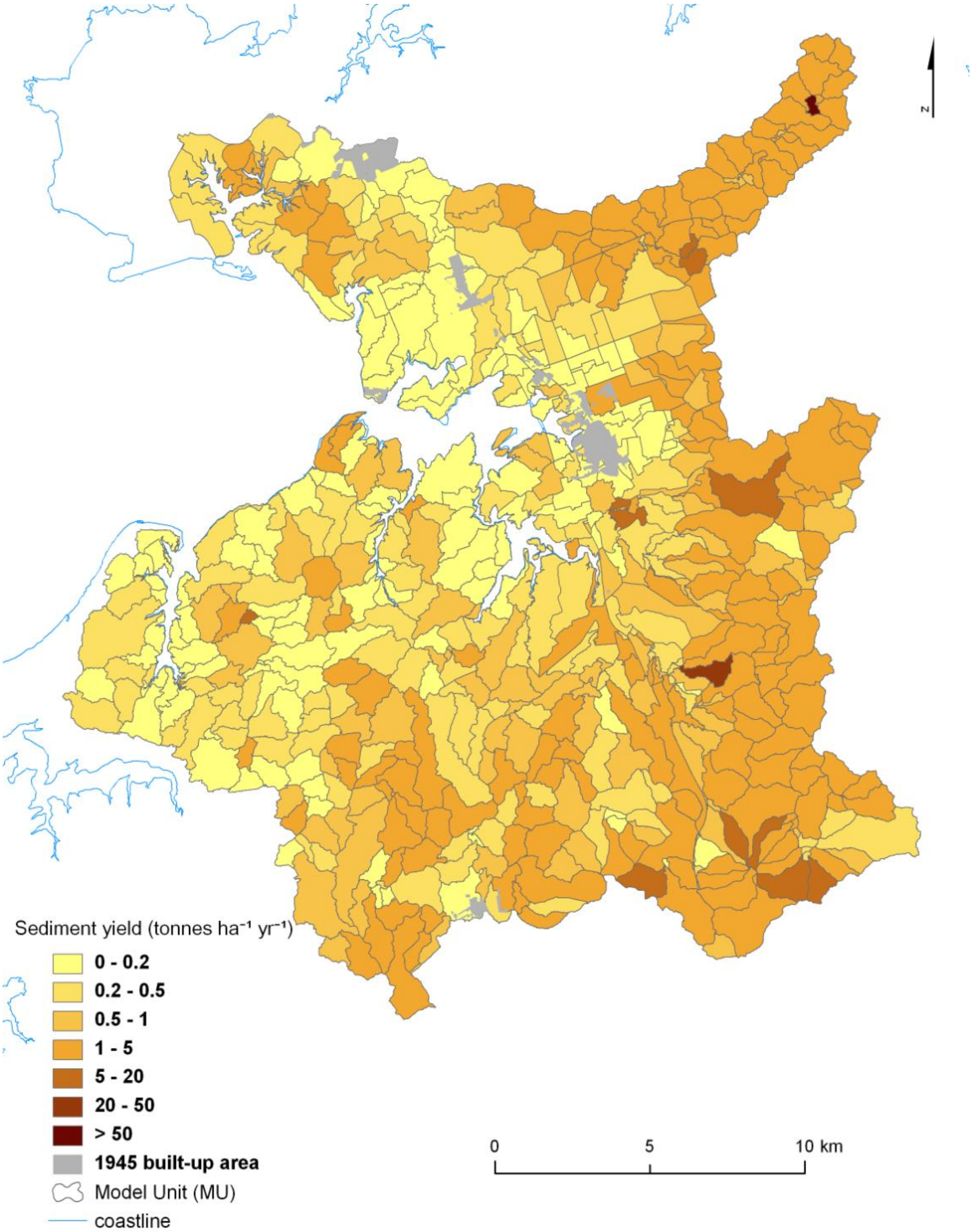
4.1.1 Sediment generation yields by Model Unit (MU)

Figure 9 shows sediment yields from land beyond the periphery of the 1945 built-up area. These are average yields over the rural part of each MU. The yield estimates in some MUs are lower than those estimated for the current scenario (Figure 2). This is at least partly a reflection of the more comprehensive landuse information available for the estimation of bare earth in 2001 compared to the historical landuse scenarios. In the historical (1945, 1959 and 1987) scenarios, areas of bare earth are derived from the LCDB2 database and some additional areas from the digitized 2003-4 aerial photography. These additional bare earth areas include quarries, unpaved yards, metal roads, agriculture, and market gardens which were likely to be to be present in 1945, 1959 and 1987.

However, areas of bare earth associated with urban earthworks in 2003-4 (see Figure 10 of Parshotam et al. 2008b) were excluded from the 1945, 1959, and 1987 coverages. Bare earth associated with earthworks in these years was estimated from the rate of change of built-up area. Bare earth associated with earthworks in 2001 was also estimated in this fashion but included additional areas shown in the 2003-4 aerials in rural locations beyond the urban fringe (see Figure 8 of Parshotam et al. 2008b).

Figure 9:

1945 generated sediment yields from rural areas (tonnes ha^{-1} yr^{-1}). The yield for each MU is calculated based on the rural area in that MU.



4.2 Sediment generation. Year 1959.

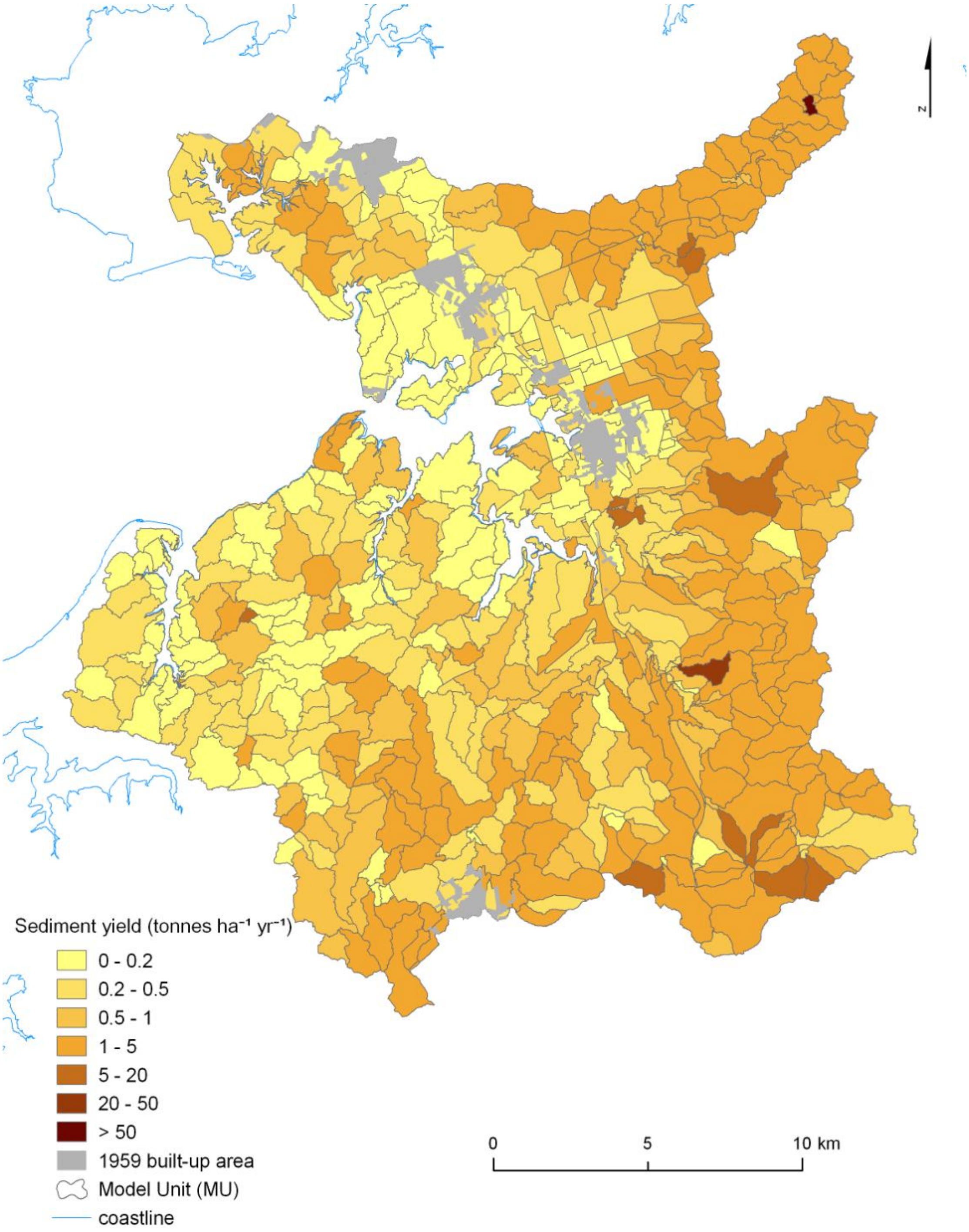
4.2.1 Sediment generation yields by Model Unit (MU)

Figure 10 shows sediment yields from land beyond the periphery of the 1959 built-up area. These are average yields over the rural part of each MU.

Note that yield estimates in some MUs are lower than those estimated for the current 2001 scenario (Figure 2) for the reasons described in Section 4.1.1.

There are no noticeable differences in the 1959 yield estimates and the 1945 yield estimates given in Figure 9 because of similar landuse scenarios assumed in 1945 and 1959 for the rural areas. There is a slight increase in yields for MUs from increased earthworks activity as a result of urbanisation, such as around Pukekohe. In some MUs there is a slight decrease in yields where urbanisation has consumed the higher sediment producing parts of the MU.

Figure 10:
1959 generated sediment yields from rural areas (tonnes ha^{-1} yr^{-1}). The yield for each MU is calculated based on the rural area in that MU.



4.3 Sediment generation. Year 1987.

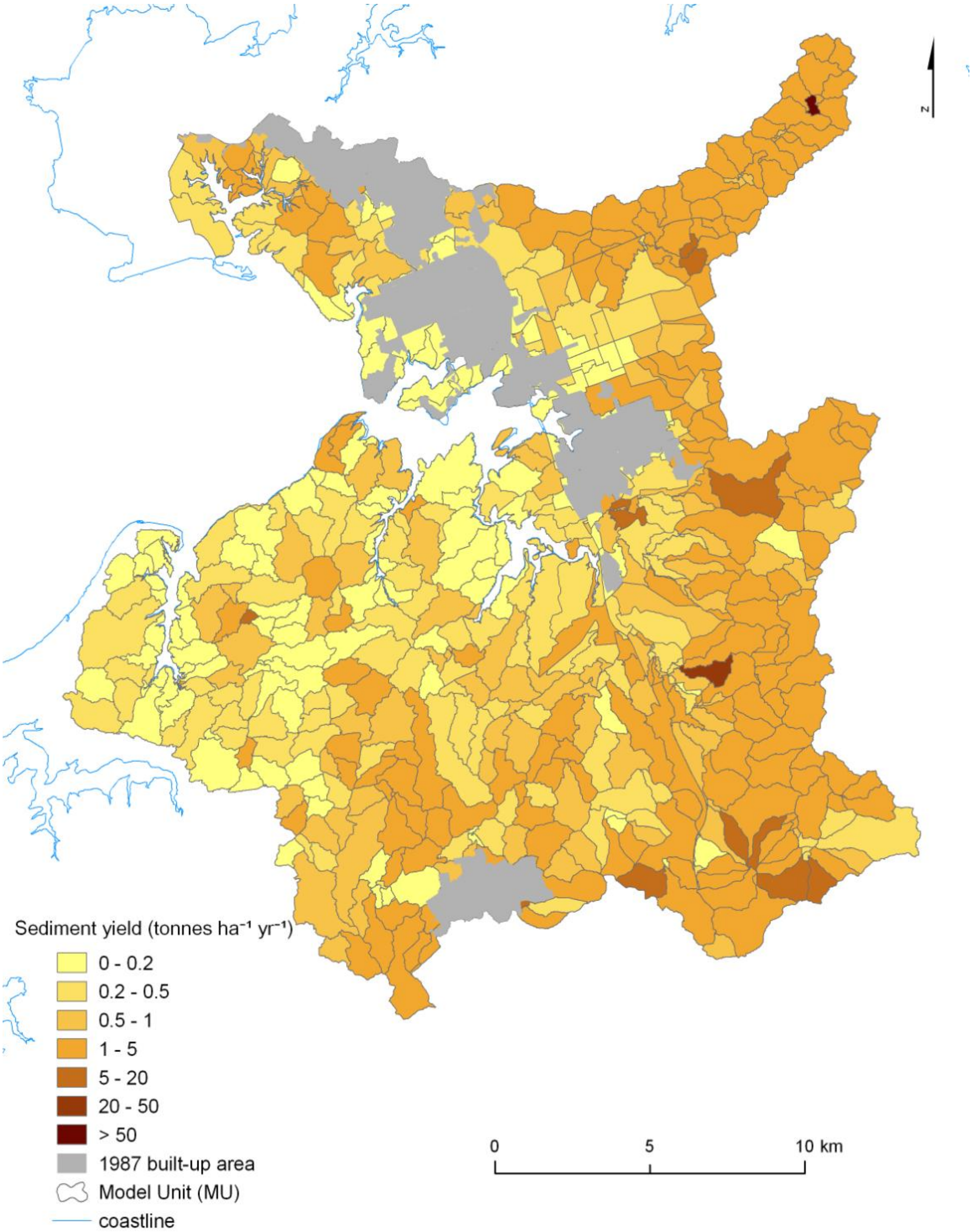
4.3.1 Sediment generation yields by Model Unit (MU)

Figure 11 shows sediment yields from land beyond the periphery of the 1987 built-up area. These are average yields over the rural part of each MU. Note that the yield estimates in some MUs are lower than those estimated for the current scenario (Figure 2) for the reasons described in Section 4.1.1.

There are no noticeable differences in the 1987 yield estimates given in Figure 11 and 1959 yield estimates given in Figure 10 because of similar landuse scenarios assumed in 1959 and 1987 for the rural areas.

There are some increases in yields as a result of urbanisation, around Pukekohe and within the Auckland MUL. In some MUs there is a slight decrease in yields where urbanisation has consumed the higher sediment producing parts of the MU.

Figure 11:
1987 generated sediment yields from rural areas (tonnes ha^{-1} yr^{-1}). The yield for each MU is calculated based on the rural area in that MU.



5 Future scenario

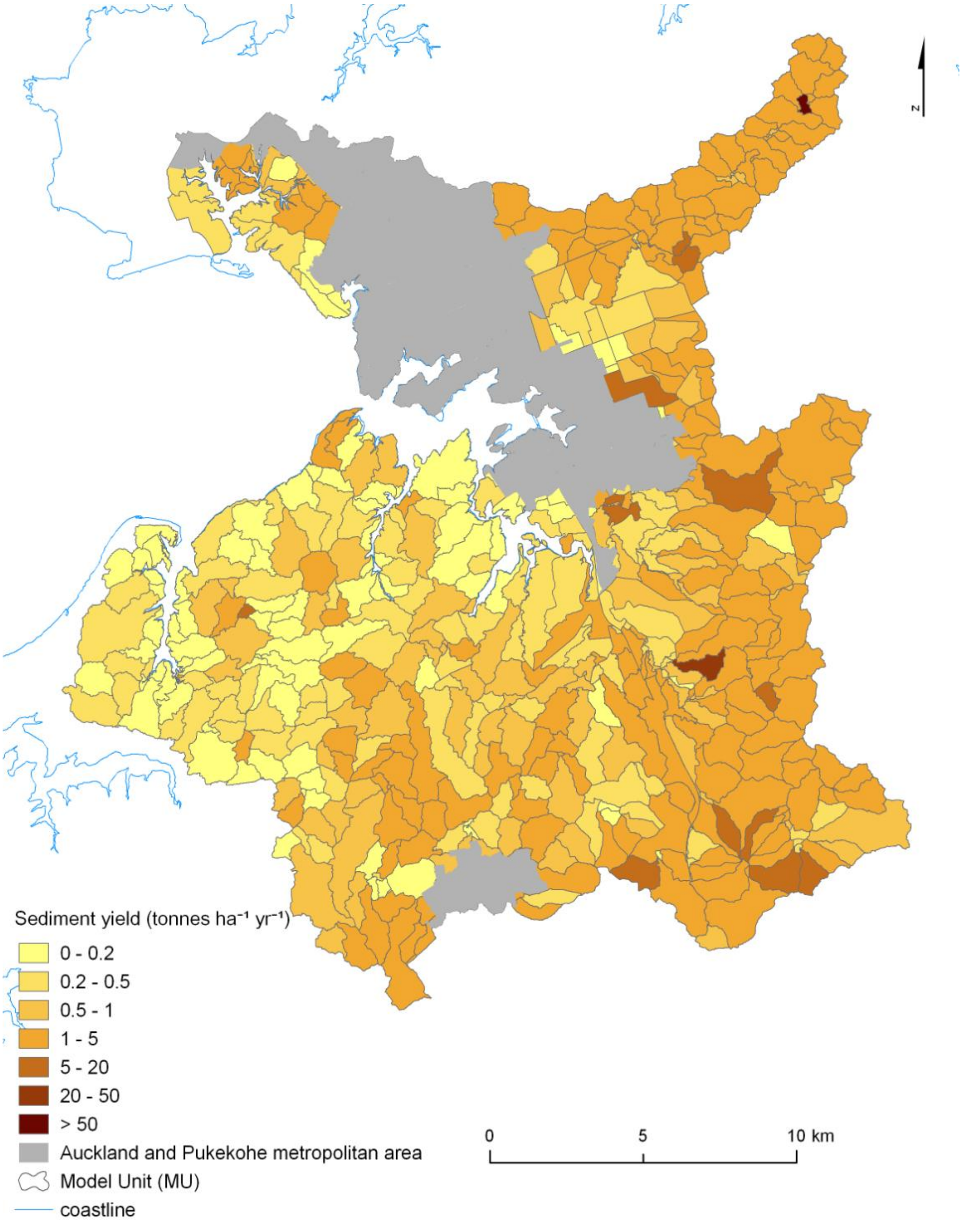
This section presents results of GLEAMS modelling for the future scenario, arbitrarily assigned the date 2050. Model predictions are based on the assumption that the Auckland MUL and boundaries of urban zoned land at Pukekohe are fixed (Parshotam et al. 2008b) and that rural landuse outside these limits remains the same as at present. Note that while the results are used by the USC model to generate a 100 year time series of future sediment loads, the GLEAMS model runs reported here are for a 50 year period, assuming land use is fixed at the 2050 land use scenario. The USC model samples from this 50 year time series to generate multiple 100 year input time series (Green, 2008).

For the future period, sediment loads from areas outside the MUL and urban zoned land at Pukekohe were modelled by GLEAMS-SEM and sediment loads from areas within these urban boundaries were modelled by CLM (reported in Moores and Timperley, 2008).

5.1 Sediment yields by MU

Figure 12 shows current sediment yields from land lying outside the MUL and urban zoned land at Pukekohe. These yields are averaged over each MU (excluding any part of an MU that is within the urban area).

Figure 12:
Future (2050) generated sediment yields from rural areas (tonnes ha^{-1} yr^{-1}). The yield for each MU is calculated based on the rural area in that MU.



5.2 Sediment delivery ratios

Future sediment delivery ratios (SDR) of each subcatchment are generally similar to current delivery ratios (Table 4) but show a reduction in delivery ratios in Papakura, Takanini, Papatoetoe/Puhunui, and Bottle Top Bay subcatchments as a result of the fact that areas of the subcatchment near the harbour have become urbanised (and thus the routing function was only applied to sediment originating from the more distant parts of these subcatchments). In contrast, the delivery ratio in Hingaia has increased because on that subcatchment it is the urban land which is located further from the harbour edge. Routing to simulate load reduction along the stream network has the greatest effect on sediments derived from those parts of each subcatchment located furthest from the harbour edge.

6 Changes in sediment loads over time

Figure 13 shows the total annual sediment loads from the rural part of the South Eastern Manukau Harbour, as estimated by GLEAMS-SEM. The values are the mean annual sediment load for the scenario. Key points to note are:

- a fairly constant sediment load over time;
- the slight reduction in loads between 1945 and 1987 associated with the expansion of the urban area and corresponding reduction in the size of the rural area;
- the slight increase in loads between 1987 and 2001 resulting from the inclusion of all additional 2003/2004 bare earth data from earthworks development in the 2001 scenario, but only part of it in the 1945, 1959 and 1987 scenarios; and
- the slight reduction in loads between 2001 and future scenario resulting from the fact that the future scenario GLEAMS estimates are restricted to land lying outside the MUL and urban zoned land at Pukekohe.
- The SDR for the catchment as a whole is between 14.1 and 14.9 % (depending on the year). While many of the subcatchments have a larger SDR, the load is dominated by catchments which have a relatively small SDR.

Figure 13:
Total annual sediment generation from the rural area of the South Eastern Manukau Harbour catchment (before and after routing through the stream network to the estuary). The loads reported are for a 50year period and assume that the landuse is fixed at the 1945, 1959, 1987, 2001 and future (2050) scenario.

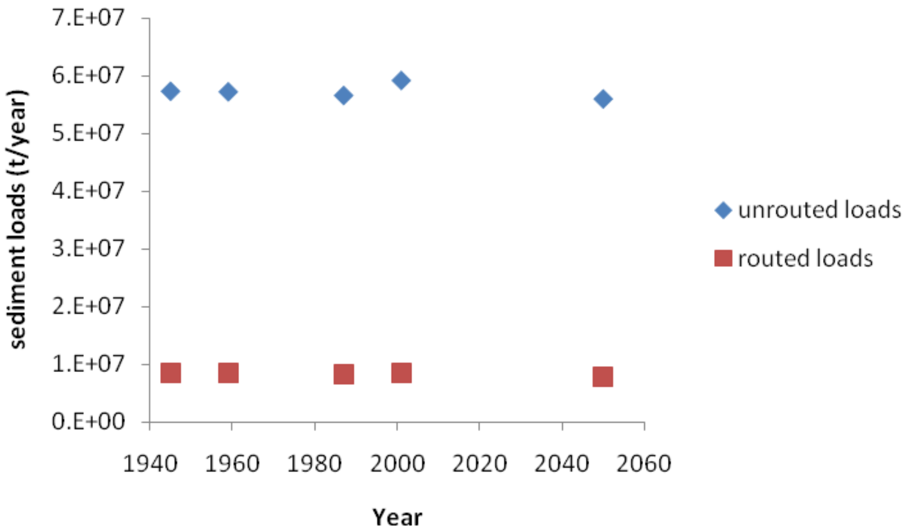


Table 5 summarises these total loads (before and after routing), and SDR by subcatchment. Table 6 shows the corresponding change in rural area over time. Some points to note are as follows:

- No change in mean annual load and sediment delivery ratio in subcatchments 101 (Kingseat), 102 (Elletts Beach) and 103 (Karaka) in years 1945, 1959, 1987, and the future because the rural area has not changed in those subcatchments. Loads in 2001 are slightly elevated because of the additional areas of 2003/4 bare earth data in that landuse scenario.
- Little change in mean annual load and sediment delivery ratio in years 1945, 1959, and 1987 in subcatchments 104 (Whangapouri Creek), 105 (Oira Creek) and 106 (Drury) and a slight increase in 2001, resulting from the inclusion of additional 2003/2004 bare earth data from earthworks development in the 2001 scenario.
- A decrease in sediment loads in subcatchments 107 (Hingaia), 108 (Papakura), 111 (Manurewa/Weymouth), 112 (Papatoetoe/Puhinui), 113 (Mangare East/Papatoetoe), 114 (Mangere) and 115 (Bottle Top Bay) in years 1945, 1959, 1987, 2001 and into the future. These are predominantly urban subcatchments where the area of rural catchment has decreased.
- A steady decrease in sediment loads in subcatchments 110 (Papakura Stream) in years 1945, 1959, 1987, but a slight increase in 2001 resulting from the inclusion of additional 2003/2004 bare earth data from earthworks development in the 2001 scenario, but not in the 1945, 1959 and 1987 scenarios.
- Little difference in sediment delivery ratios within all subcatchments in years 1945, 1987, and 2001. In subcatchments 107 (Hingaia), 108 (Papakura), 111 (Manurewa/Weymouth), 112 (Papatoetoe/Puhinui), 114 (Mangere) and 115 (Bottle Top Bay) there are differences between SDRs for the historical and future scenarios as a result of differences in the extent of each subcatchment for which sediment loads were estimated using GLEAMS and routed to the harbour.

Overall, there is a constancy of sediment load over time and a constancy of SDR. This is related to the constancy of the rural area for many subcatchments, and the constancy of urbanisation rate assumed in the most part in the model and the method for estimating this rate (see Parshotam et al. 2008b). Routing to simulate load reduction along the stream network has the greatest effect on sediments derived from those parts of each subcatchment located furthest from the harbour edge. The decrease in loads predicted in the future scenario reflects the reduction in the extent of the area modelled by GLEAMS-SEM with all future sediment loads within the urban limits estimated by the CLM.

Table 5:

Mean annual loads estimated under each landuse scenario over a period of 50years, before and after routing, with sediment delivery ratios (SDR) for each subcatchment (WC=whole catchment). Key to subcatchments is under Table 6.

	Subcatchment identifier	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	WC
1945 land use	Mean annual loads, before routing (t y^{-1})	1550	684	2470	5281	1589	31456	153	904	40	9948	105	2084	630	278	40	57214
	Mean annual loads, after routing (t y^{-1})	616	425	542	708	242	2871	96	464	23	1181	68	413	560	263	24	8498
	SDR (%)	39.8	62.2	21.9	13.4	15.2	9.1	62.6	51.3	56.9	11.9	64.5	19.8	88.9	94.6	60.4	14.9
1959 land use	Mean annual loads, before routing (t y^{-1})	1550	684	2470	5264	1589	31451	153	898	35	9926	89	2069	625	277	40	57118
	Mean annual loads, after routing (t y^{-1})	616	425	542	700	242	2879	96	455	20	1176	56	408	555	262	24	8457
	SDR (%)	39.8	62.2	21.9	13.3	15.2	9.2	62.6	50.7	57.1	11.9	63.4	19.7	88.9	94.6	60.4	14.8
1987 land use	Mean annual loads, before routing (t y^{-1})	1550	684	2470	5283	1530	31368	148	863	12	9840	28	1796	595	273	40	56479
	Mean annual loads, after routing (t y^{-1})	616	425	542	697	234	2902	90	425	6	1168	20	305	527	258	24	8238
	SDR (%)	39.8	62.2	21.9	13.2	15.3	9.3	60.9	49.3	48.3	11.9	69.6	17.0	88.7	94.5	60.4	14.6
2001 land use	Mean annual loads, before routing (t y^{-1})	1550	686	2509	5324	1574	33409	145	856	11	10794	12	1327	581	270	39	59087
	Mean annual loads, after routing (t y^{-1})	616	426	551	697	239	3073	88	419	6	1252	9	289	520	255	23	8464
	SDR (%)	39.8	62.1	21.9	13.1	15.2	9.2	60.3	48.9	57.1	11.6	74.9	21.8	89.5	94.5	59.9	14.3
Future land use	Mean annual loads, before routing (t y^{-1})	1550	684	2470	4917	1529	32536	58	788	0.41	9761	0	788	565	229	0.10	55877
	Mean annual loads, after routing (t y^{-1})	616	426	549	657	236	3003	50	357	0.18	1156	0	95	510	215	0.03	7870
	SDR (%)	39.8	62.3	22.2	13.4	15.4	9.2	84.9	45.4	45.1	11.8	-	12.0	90.1	93.6	27.4	14.1

Table 6.

Rural area over time (in ha) and total area of a subcatchment.

Land use scenario	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	WC
1945 land use (rural area)	4614	1321	4114	5645	1984	14214	500	698	266	5481	876	2868	1060	570	181	44391
1959 land use (rural area)	4614	1321	4114	5521	1984	14148	500	634	230	5398	747	2748	1019	563	181	43719
1987 land use (rural area)	4614	1321	4114	5076	1983	13770	427	388	134	4958	292	1779	757	546	181	40348
2001 land use (rural area)	4614	1321	4114	5102	1983	13514	294	147	10	4659	50	693	715	417	4	37638
Future land use (rural area)	4614	1321	4114	5076	1983	13488	294	147	10	4631	0	585	715	417	4	37400
TOTAL AREA	4614	1321	4114	5691	1984	14264	500	912	287	5513	946	2962	1176	570	181	45035

Key to Tables 5 and 6.

Subcatchment (identifier)	
Kingseat (101)	Takanini (109)
Elletts Beach (102)	Papakura Stream (110)
Karaka (103)	Manurewa/Weymouth (111)
Whangapouri (104)	Papatoetoe/Puhinui (112)
Oira Creek (105)	Mangare East/Papatoetoe (113)
Drury (106)	Mangere (114)
Hingaia (107)	Bottle Top Bay (115)
Papakura (108)	Whole catchment (WC)

7 Conclusions

The model results have been presented for the current, historical and future generation and transport of sediment to the Southeastern Manukau Harbour / Pahurehure Inlet (excluding sediment from urban areas). Some key findings are:

- Overall, there is a constancy of sediment load over time and a constancy of sediment delivery ratio.
- There are fairly small yields from areas of urban earthworks, due to the low slopes.
- Loads to the harbour are dominated by rural land uses.
- The largest subcatchments generally have the largest loads. The largest contributors are the Drury subcatchment (36% of the total load) and the Papakura Stream subcatchment (15% of the total load).
- Loads have fallen over time where rural land has been converted to urban land uses.
- The sediment delivery ratio is generally smaller for those parts of each subcatchment located furthest from the harbour edge.

These model results are used as inputs in the urban CLM model (Moores and Timperley, 2008), and the USC-3 estuary model (Green, 2008).

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