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

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

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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 Data Requirements.

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.

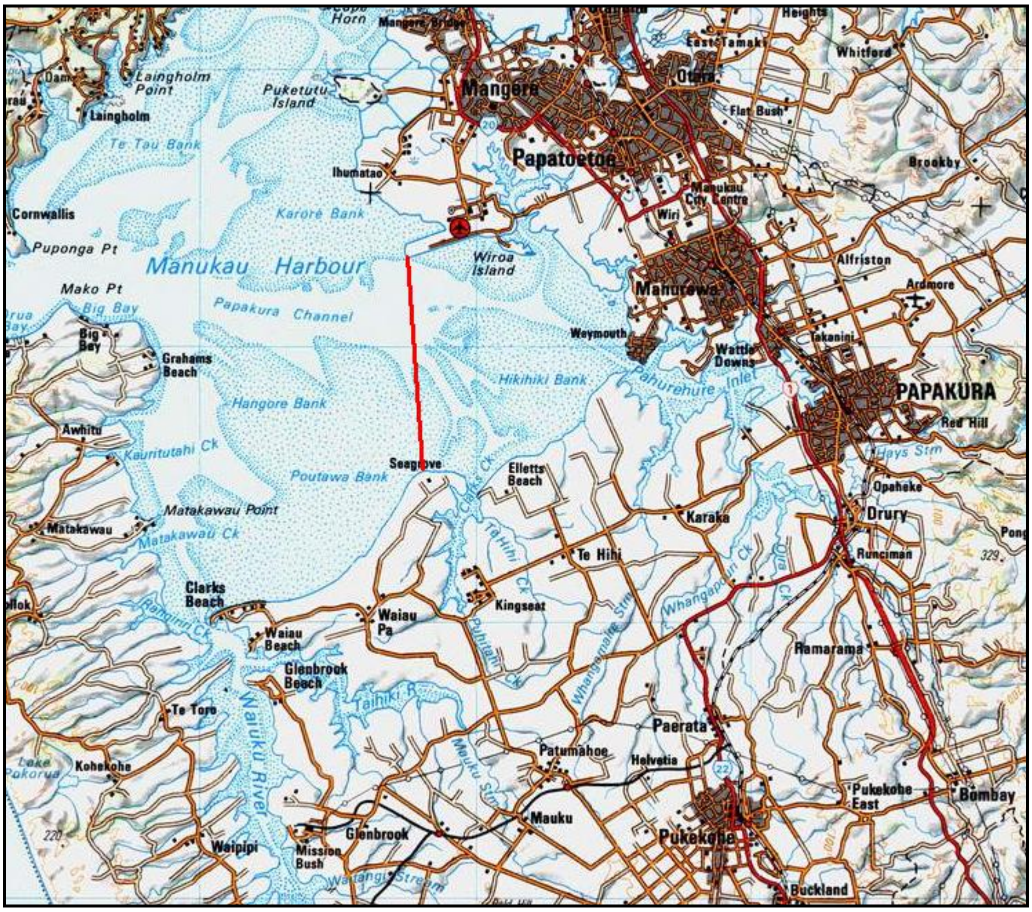
This report describes the evaluation of the outputs of the sediment load model, GLEAMS-SEM. As part of this study we have developed a routing procedure to simulate conveyance of sediment to harbour outfalls. This report describes the evaluation of the ability of the combined models (GLEAMS and the routing function) to predict sediment loads discharged to the Harbour.

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 evaluation of the GLEAMS-SEM model developed for the Southeastern Manukau / Pahurehure Inlet study. This model is used to hindcast/predict sediment runoff from the rural land of the catchment, and from urban earthworks.

As part of this study a routing procedure was developed to simulate conveyance of sediment to harbour outfalls. This report describes the evaluation of the ability of the combined models (GLEAMS and the routing function) to predict sediment loads discharged to the Harbour. The modelled loads are compared with estimates derived from measurement of flow, turbidity and total suspended solids (TSS) in the Waitangi Stream catchment near the study area, and the Papakura Stream catchment, within the study area.

The reader is referred to Parshotam et al. (2008a) for the GLEAMS-SEM model setup, Parshotam et al. (2008b), for landuse analyses used in GLEAMS-SEM, Semadeni-Davies and Parshotam (2009) for climate analyses used in the study, and Parshotam (2008) for GLEAMS-SEM model results.

3 Data for Model Evaluation

3.1 Introduction

In order to evaluate the routed GLEAMS-SEM sediment loads it was decided to independently estimate loads from measured data and compare the two. A monitoring programme was put in place to measure flow and collect water samples, the results of which provided for the estimation of sediment loads. Monitoring was conducted at existing flow recorder sites in order to allow extrapolation of load estimates over the period of the historical flow record. An important criteria for the selection of monitoring sites was that they be located close to a catchment outlet, in order that loads estimated from stream sampling could be compared with loads from GLEAMS-SEM that had been fully routed through the stream network. Sites which met these criteria were on the Papakura Stream, in the north of the catchment, and on the Waitangi Stream, which lies to the west of the study catchment boundary. Although this latter site lies outside of the study area, it has similar landuse, topography and soils as the largely rural southern half of the catchment. While it was therefore a valid selection for the evaluation of GLEAMS-SEM loads, its use for this purpose necessitated the setting up and running of GLEAMS-SEM for a substantial additional area. This section describes the characteristics and instrumentation of the monitoring sites along with the additional data inputs required in order to run GLEAMS-SEM for the Waitangi catchment.

3.2 Monitoring sites

This section describes the selection and instrumentation of stream monitoring sites. The sites were used for collection of data to allow evaluation of the GLEAMS-SEM sediment load model.

Previous variants of GLEAMS-based models applied in the Auckland area have been validated and calibrated to monitoring data from the Auckland area (e.g., Okura, Mahurangi and Whitford (Senior et al. 2003)), as discussed in Parshotam et al. (2007).

New monitoring data used in this study were collected from two existing stream flow monitoring sites. (see Figure 2 for these sites in relation to the boundary of the study and catchments areas): Papakura Stream at Great South Rd (see Figure 3) and Waitangi Stream at Glenbrook-Waiuku Rd (see Figure 4). These sites are operated by ARC and NIWA respectively and both have stream flow records going back to the 1960s. They were selected on the basis of their location close to their catchment outlets and for their representativeness of the north-eastern and southern parts of the study area respectively. Papakura Stream drains a mixed rural/urban catchment of predominantly recent alluvial deposits. The Waitangi Stream catchment is of mixed rural landuse (pastoral and market gardening) and comprises areas of both volcanic and alluvial geology.

In addition to the existing water level recorders, automatic water samplers were installed at each site. Water samples were collected during periods of high water level following significant rainfall and stored in dark, refrigerated conditions until a sufficient number had been collected to cover a range of flow conditions. A selection of samples was taken to cover a representative range of flow conditions. This selection occurred in two separate batches over the period of monitoring (June to October 2007). The selected samples were for analysed for TSS concentration. A small number were also analysed for volatile suspended solids (VSS) concentration in order to determine the organic/inorganic proportions of TSS. Analyses were performed at NIWA's water quality laboratory in Hamilton.

Flow at each of the two sites was recorded as part of site routine operation. This provided for the estimation of sediment loads from the sampled TSS concentrations.

Optical turbidity probes (configured for the range of 0-3000 NTU) were also installed at each site with the aim of investigating relationships between TSS, turbidity and flow, which would potentially allow extrapolation of TSS concentrations from the sample measurements. There were some difficulties in the measurement of turbidity at the Papakura Stream site to the extent that turbidity data collected at that site has been deemed too unreliable for further use (see Section 4.2) due to frequent fouling by weeds / algae.

The results of monitoring and the estimation of sediment loads from these data are described in Section 4.

3.3 Model input data for the Waitangi Stream

All information on landuse, soil, and slope properties for the Papakura Stream catchment is given in Parshotam et al. (2008a). This section concentrates on the input data obtained to run GLEAMS for the Waitangi Stream catchment, which is not part of the South Eastern Manukau catchment. However, the soils and landuse for the Waitangi catchment are assumed to be representative of the southern, largely rural, parts of the study area.

Figure 2:
Locations of water level recorder sites in the Papakura and Waitangi Stream catchments. The boundary of the South East Manukau Harbour Study area is shown.

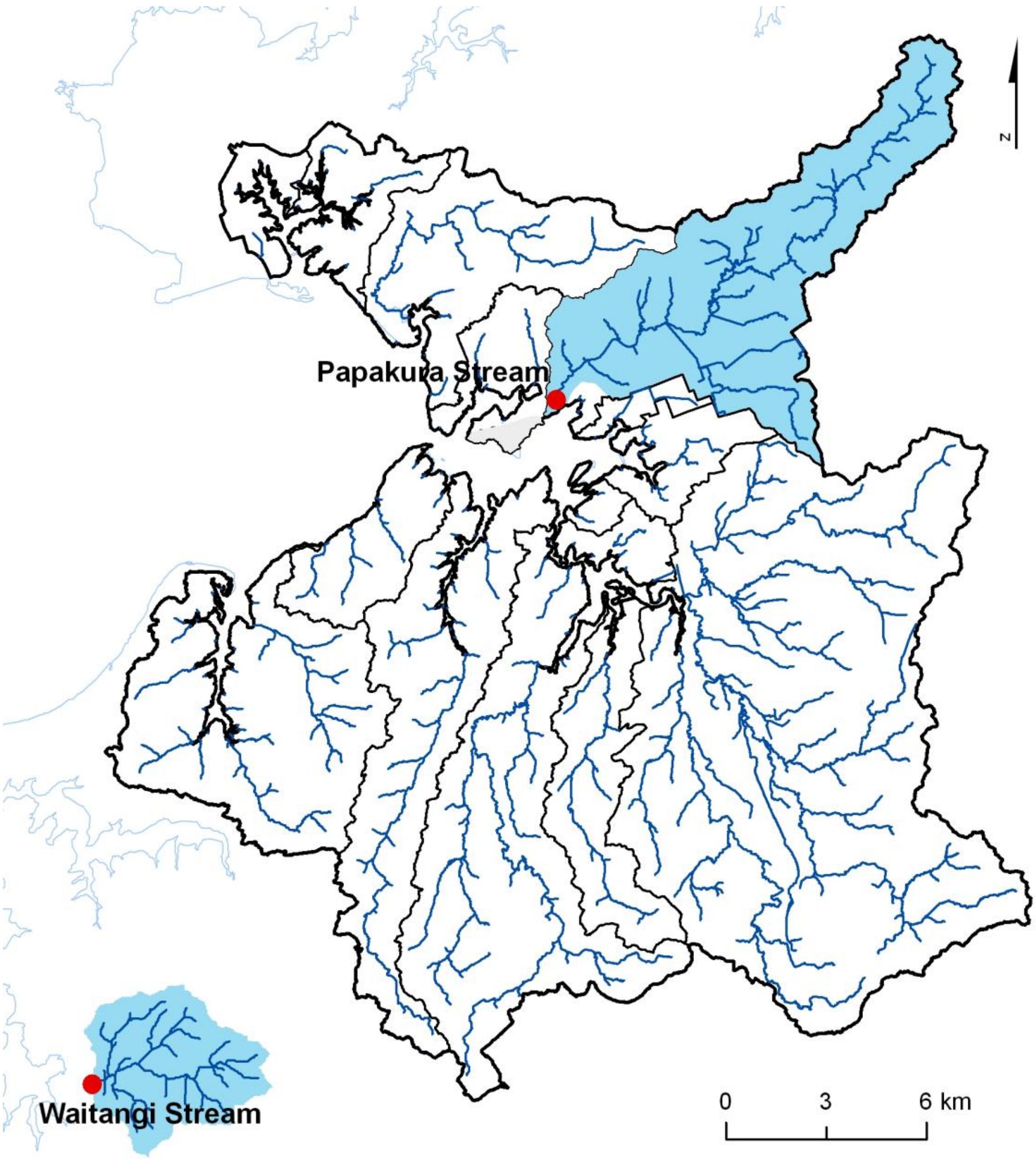
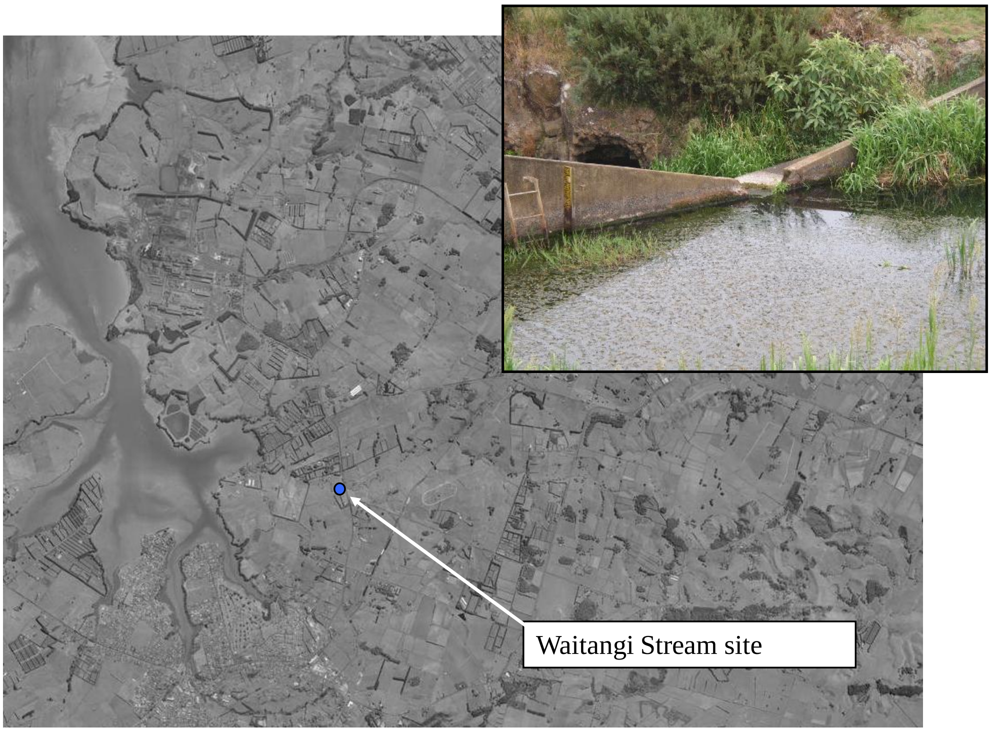


Figure 3:
Aerial and site photographs showing the Papakura Stream monitoring site.

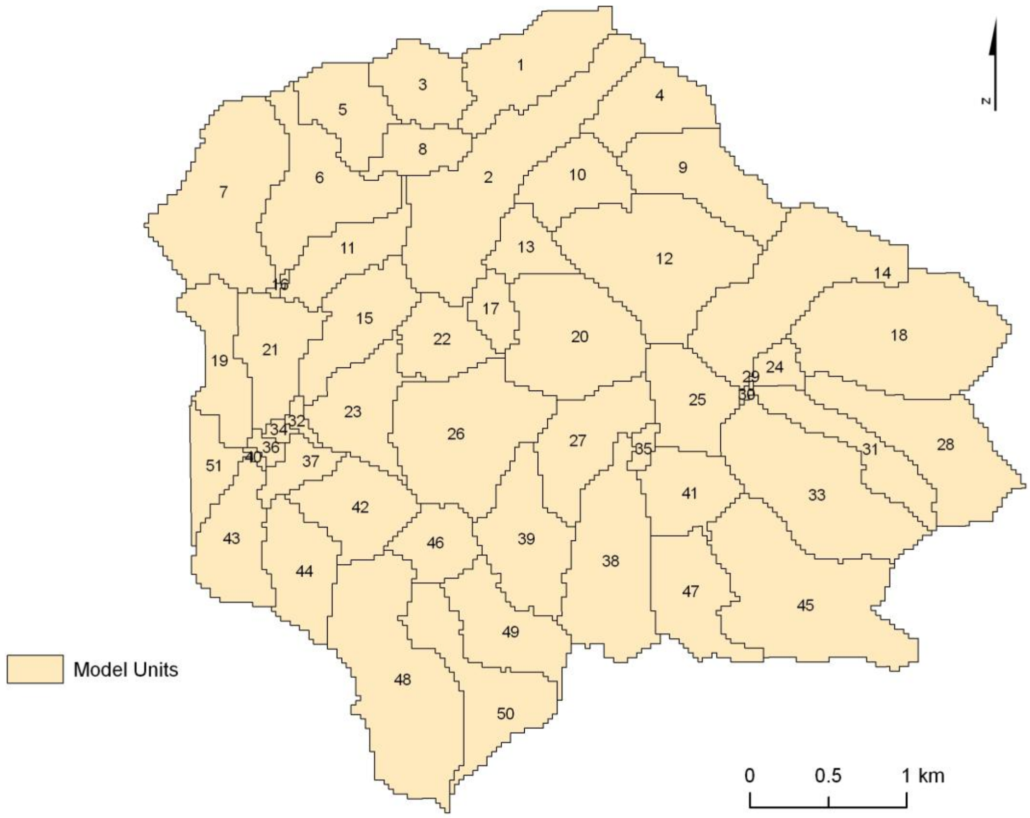
Figure 4:
Aerial and site photographs showing the Waitangi Stream monitoring site.



3.3.1 Catchment and Model Units (MUs)

The Waitangi catchment study area was broken into 51 hydrological model units (MUs), and given unique identifiers (see Figure 5). These were created from watersheds from NIWA's River Environment Classification (REC) network.

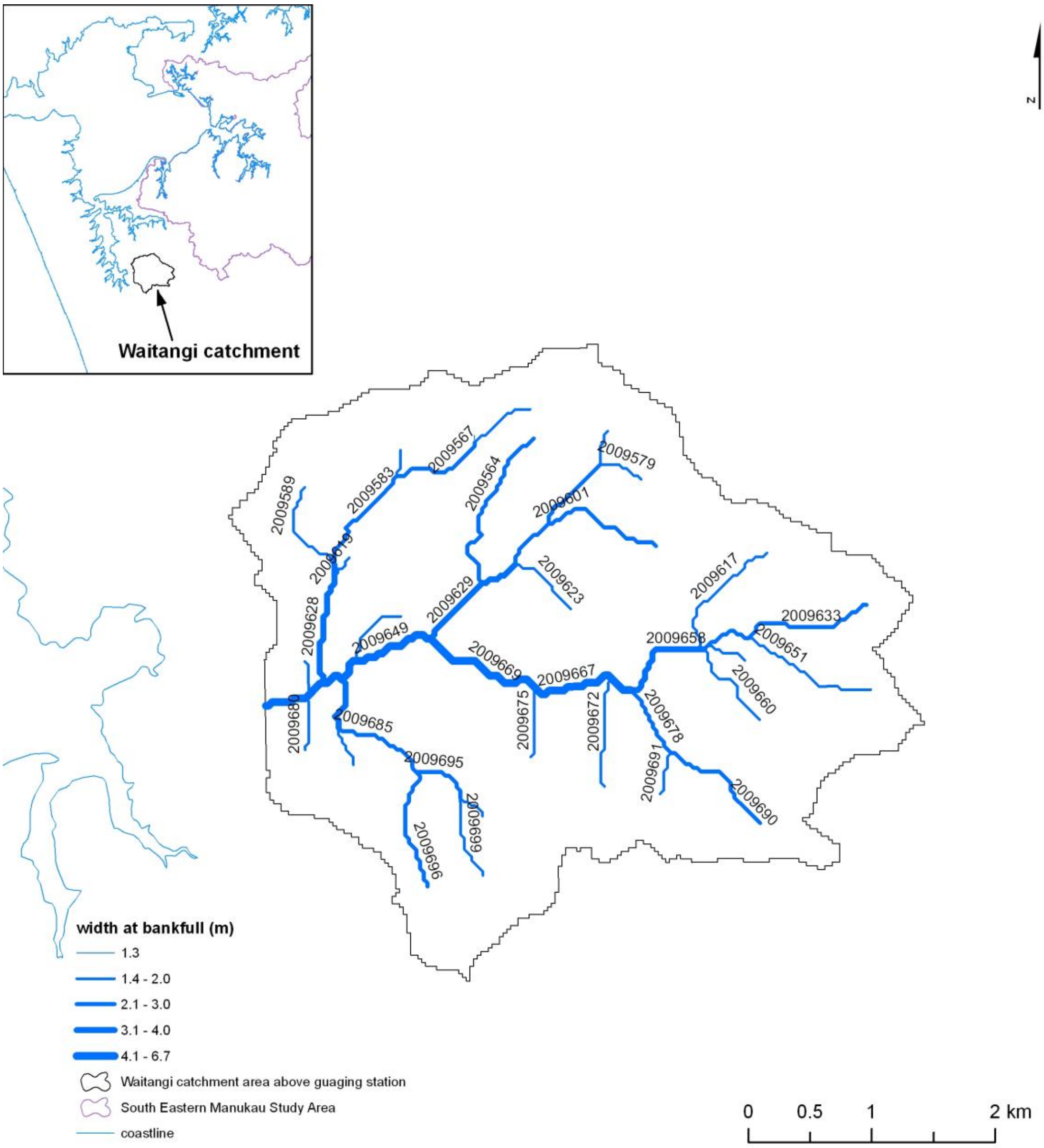
Figure 5:
Map of Hydrological Model units (MU's), including unique identifiers.



3.3.2 Stream network and outlet point

A stream network was created for the catchment study area with reach IDs from NIWA's River Environment Classification (REC) network (see Figure 6, which includes the Waitangi catchment in relation to the study area).

Figure 6:
Map of stream network, showing estimated width at bankfull flow.



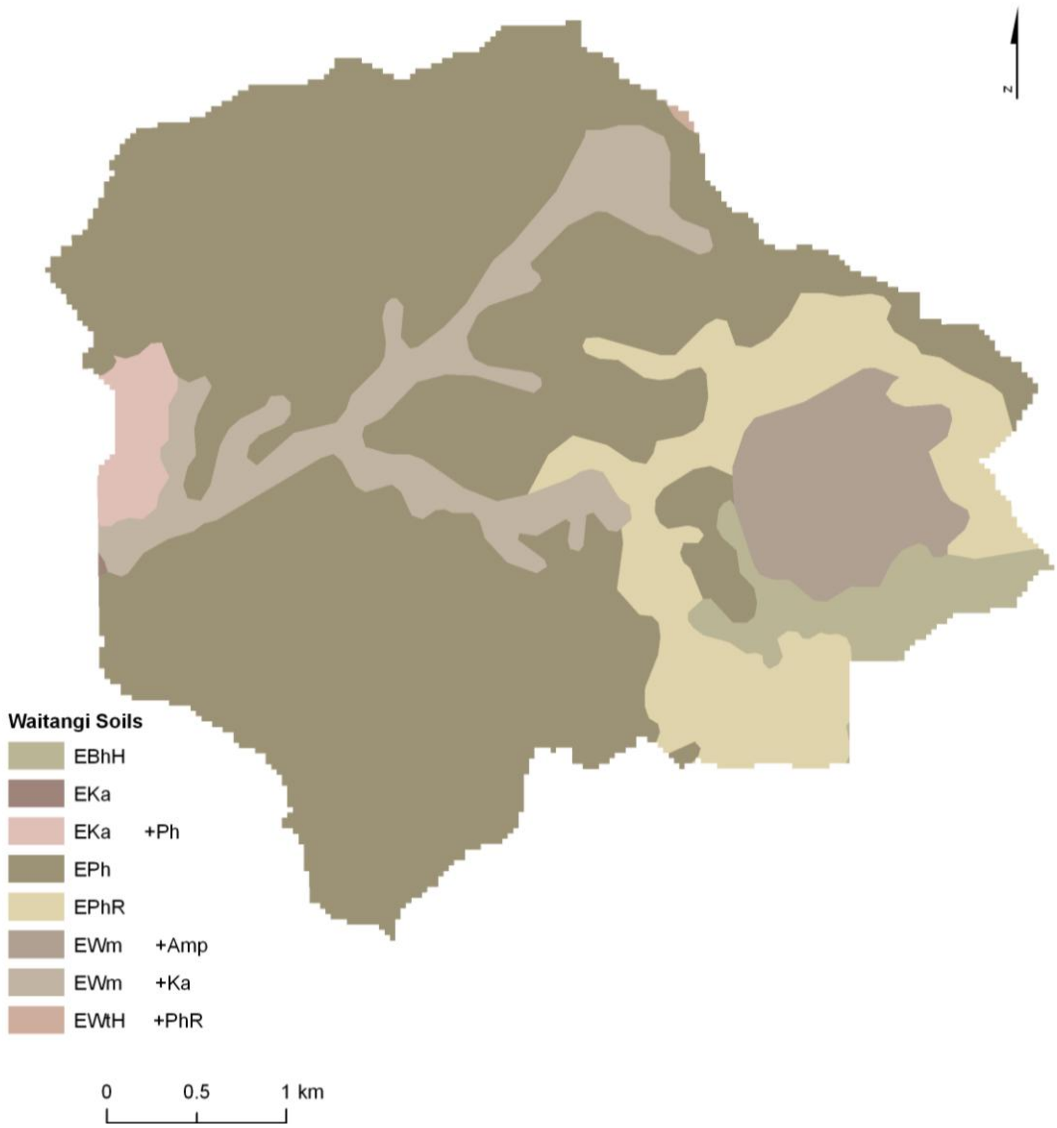
3.3.3 Climate

Rainfall data for the year 2007 are from the Waitangi at SH Bridge station (located adjacent to the flow recorder site shown in Figure 4). Temperature and solar radiation data are taken from the main catchment study area.

3.3.4 Soils

Soil classes, properties and maps for the study area were obtained from the New Zealand Land Resources Inventory (NZLRI) (see Figure 7) and grouped into four major soils classes, all of which are found in the main catchment study area and given in Parshotam et al. (2008a).

Figure 7:
Major soils in the Waitangi study area from the NZLRI.

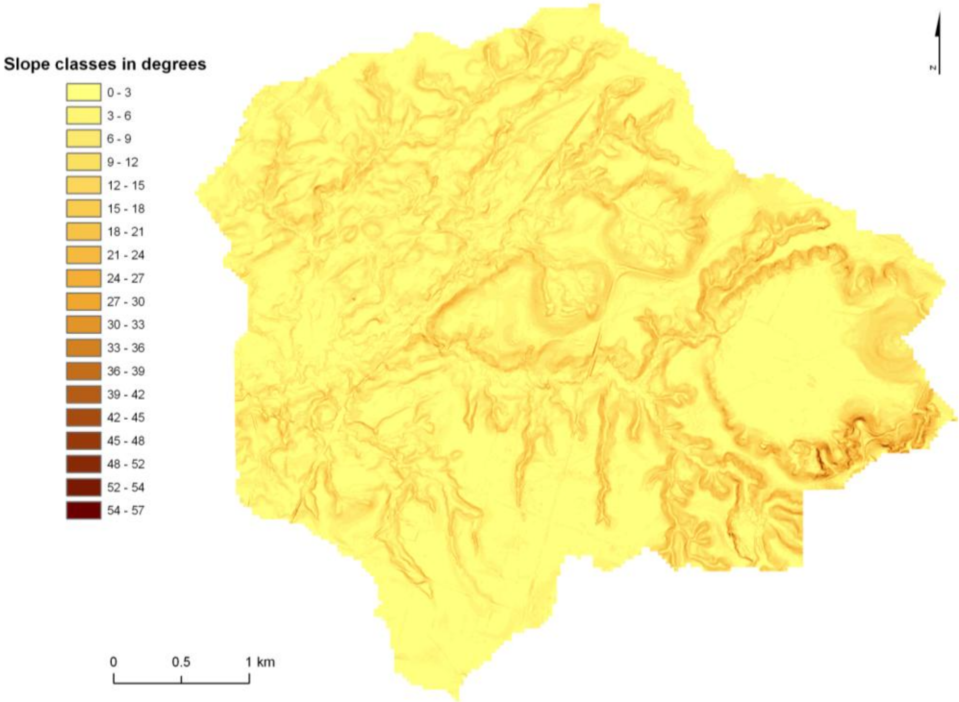


3.3.5 Topography

Slope classes were based on 2 m digital elevation model (DEM) provided by ARC. From the DEM, the mean slope angle for each cell was determined. The slope raster was resampled to 30 m cell size for input to GLEAMS-SEM. The cell slopes were grouped in intervals of 3 degrees and the spatial distribution of these groups used as input to GLEAMS-SEM (see Figure 8). Slope angle classes ranged from 3 to 57 degrees and these values were used in the model simulations. 40%, 23.4%, 13.7% and 9.3% of the land area falls within the 0-3, 3-6, 6-9 and 9-12 degree slope categories, respectively.

Figure 8:

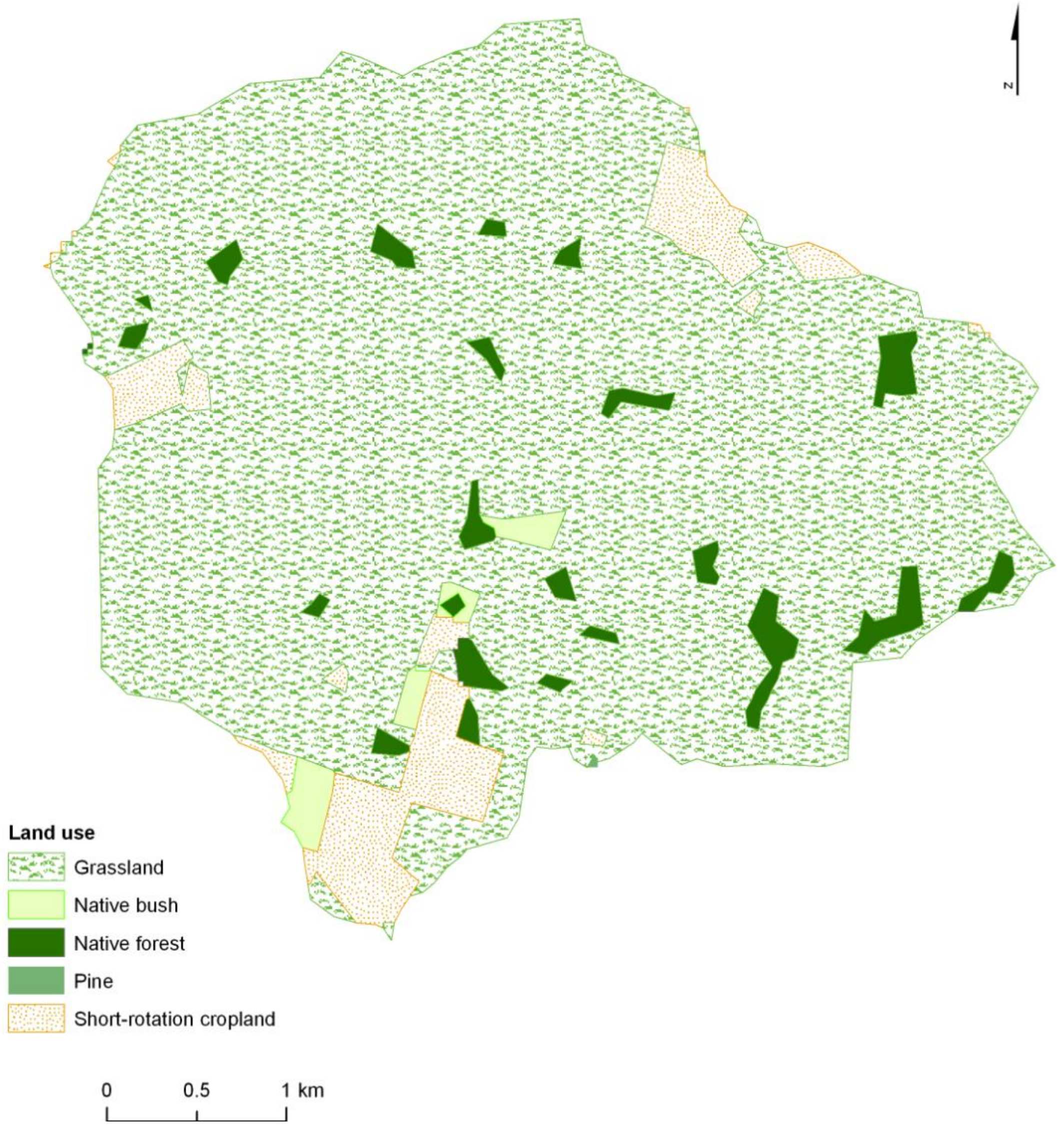
Slope angle classes in the Waitangi catchment.



3.3.6 Landuse

The landuse data for the study area is from the LCDB2 and uses the same classifications as in the GLEAMS-SEM model discussed by Parshotam et al. (2008b) (See Figure 9). 88%, 6.9%, 3.8%, 1.3%, and 0.015% of the land area was grassland, short-rotation cropland, native forest, native bush, and pine forest, respectively.

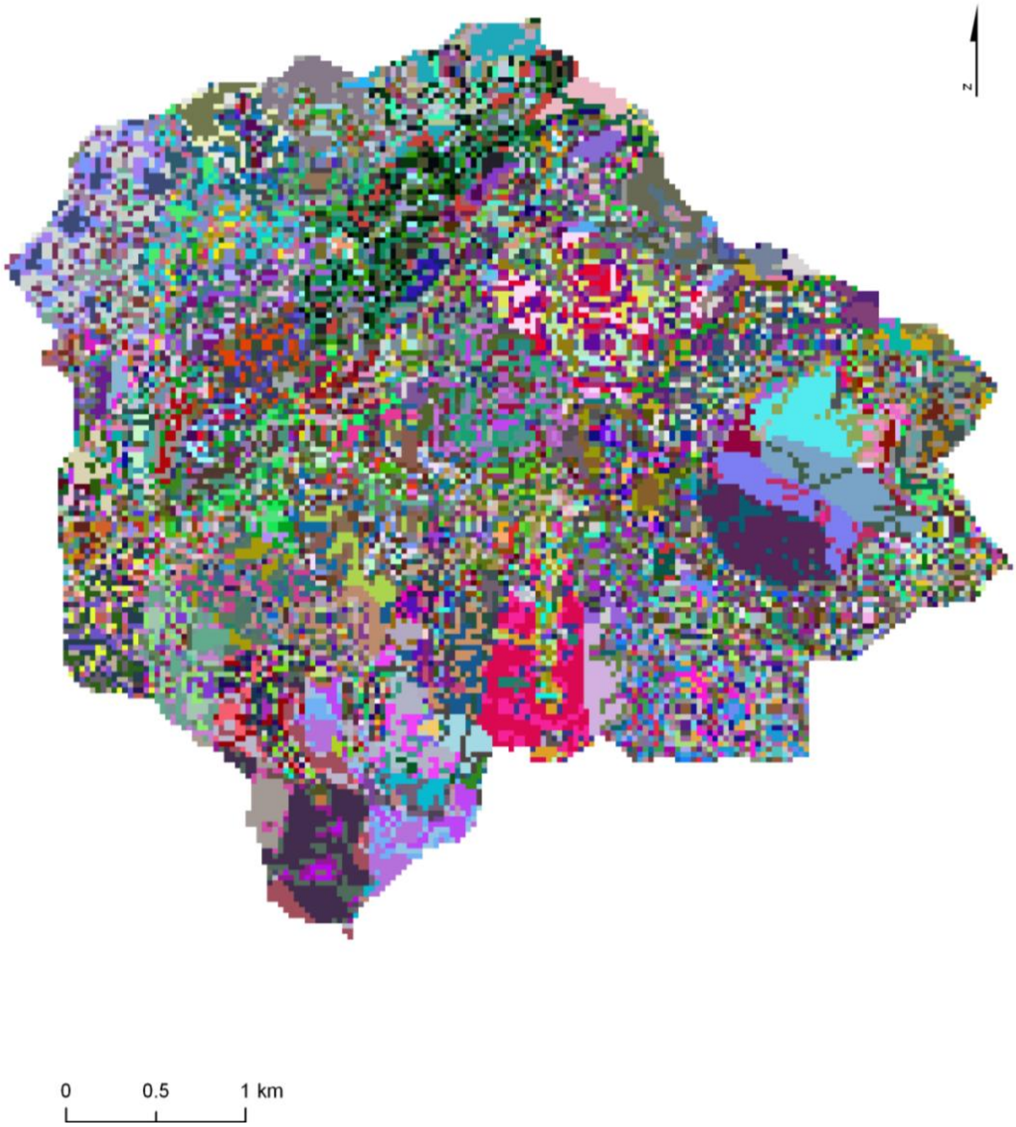
Figure 9:
Map of generalised land cover used for the GLEAMS-SEM model.



3.3.7 Unique combinations of soil, slope and land cover

GIS techniques for overlaying Waitangi soils, land cover and slope information produced unique combinations of soils, land cover and slope (see Figure 10).

Figure 10:
Map showing unique combinations of soils, slopes and land cover for use in GLEAMS-SEM with unique colours denoting the unique combinations.



3.3.8 Stream routing

All stream network and routing parameters are derived using the methodology given in Parshotam et al. (2008a).

4 Estimation of Loads from Monitoring Data

4.1 Overview

The section describes the manipulation of results of monitoring and water sampling at the sites on the Papakura and Waitangi Streams along with the these data to provide long-term time series of estimated daily sediment loads for comparison with those from the GLEAMS-SEM sediment load model.

4.2 Monitoring Results

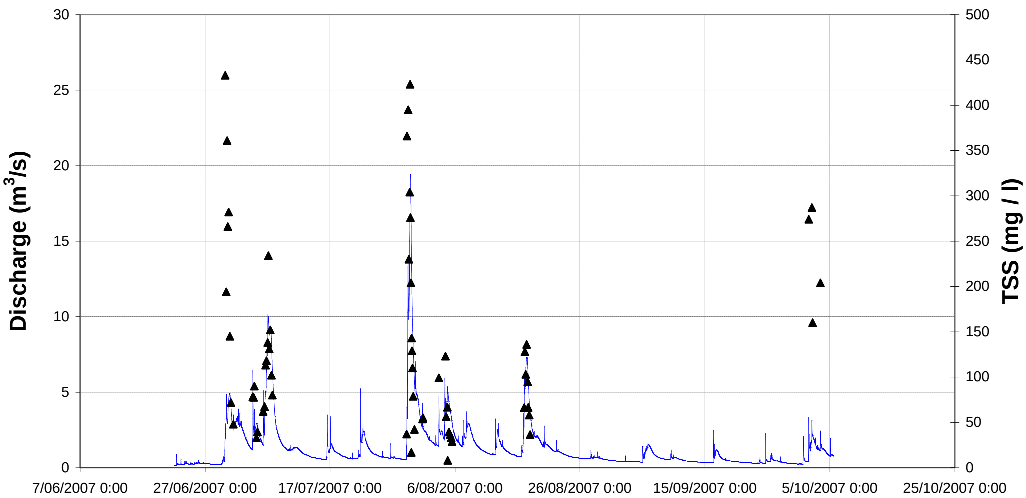
Of the 137 water samples collected from the Papakura Stream over the period July-October 2007, 61 were analysed for TSS concentration and 6 for VSS concentration. Of the 79 samples collected over the period July-Sep 2007 from Waitangi Stream 39 were analysed for TSS concentration and 6 for VSS concentration. Mean and maximum TSS concentrations of around 140 mg l^{-1} and 450 mg l^{-1} respectively were recorded at both sites (Figure 11). The VSS analysis indicates that typically 80% of TSS is inorganic matter, again similar at both sites.

Mean and maximum flows recorded over the period of sampling were 1.3 m^3 s^{-1} and 19.4 m^3 s^{-1}, respectively, at Papakura and 0.4 m^3 s^{-1} and 17.0 m^3 s^{-1}, respectively, at Waitangi.

Mean and maximum measurements of turbidity recorded over the period of sampling were 95 NTU and 604 NTU, respectively, at Papakura and 16 NTU and 407 NTU, respectively, at Waitangi. However, the turbidity record from Papakura Stream is considered unreliable due to repeated drifting, most likely due to fouling of the turbidity probe (see Figure 12). Despite frequent clearance, this site suffered from regular deposition of weed matter washed from upstream which appears to have interfered with the instrument operation.

Figure 11:
Discharge (blue line) and TSS (black triangles): (a) Papakura Stream and (b) Waitangi Stream.

(a)



(b)

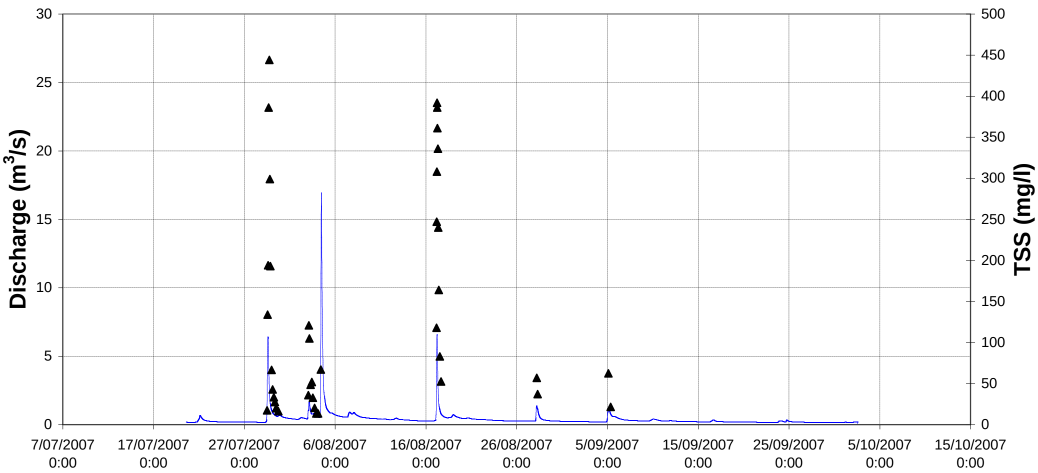
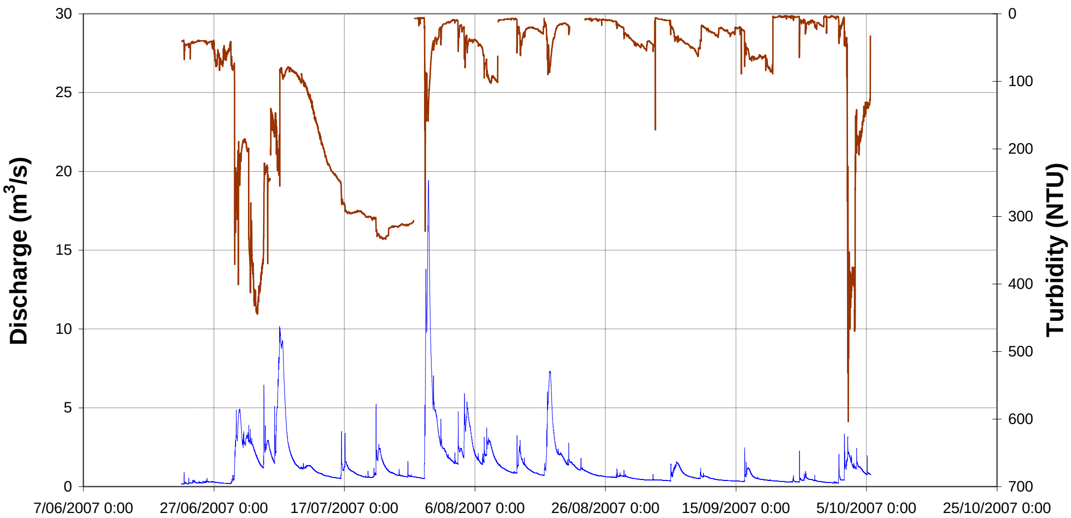


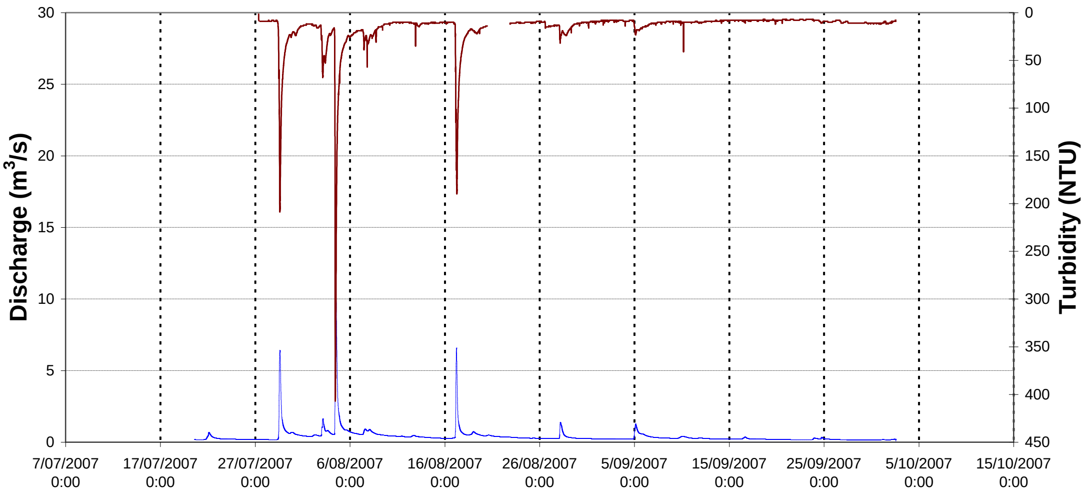
Figure 12:

Discharge (blue line) and turbidity (brown line): (a) Papakura Stream and (b) Waitangi Stream.

(a)



(b)



4.3 Estimation of Daily Sediment Loads

Event and daily sediment loads were estimated from TSS concentrations and concurrent flows for each event from which samples had been analysed. Loads between each pair of successive samples were calculated from the mean of the two sample TSS concentrations and the volume of flow in the intervening period. These loads were aggregated to give total event and daily sediment loads. The estimated daily sediment loads varied in the ranges 306 – 219,034 kg (Papakura Stream) and 1,524 - 30,755 kg (Waitangi Stream).

In addition, time series of upper and lower bound estimates of daily sediment loads over the entire period of flow record were estimated by the methods below.

4.3.1 Papakura Stream

The TSS-discharge relationship was investigated and lower and upper bounds fitted by eye to provide an envelope around most of the data points (see Figure 13). These bounds excluded a number of data points with relatively high TSS concentrations at low flows (samples taken 30 June to 1 July and 1-3 October). This was a pragmatic decision made on the basis of the dissimilarity of these results with those from the majority of sampling events. Inclusion of these data points would result in a very wide (and almost meaningless) range between the lower and upper bound sediment load estimates. It is worthwhile to note that both of the events during which these samples were collected followed relatively long periods of generally stable or receding flows (3 and 1.5 months, respectively). The peak flows and flow volumes during both sampling events were also relatively low compared to other events over the period of monitoring. The high TSS concentrations may therefore reflect a combination of:

- the accumulation and subsequent washing-off of relatively large quantities of sediments on impervious surfaces in urban parts of the catchment; and
- the relatively limited dilution of urban-derived runoff by stream flow originating from other parts of the catchment.

Upper and lower bound mean daily TSS concentrations were estimated from mean daily discharge over the period of record (1969 to date) and the relationships shown in Figure 13. Upper and lower bound daily sediment loads were then estimated for the period of record from these mean daily TSS concentrations and mean daily discharge. As an example, the estimated upper and lower bound loads over the period of sampling are shown in Figure 14.

Figure 13:

Relationship between sample TSS concentrations and discharge, Papakura Stream.

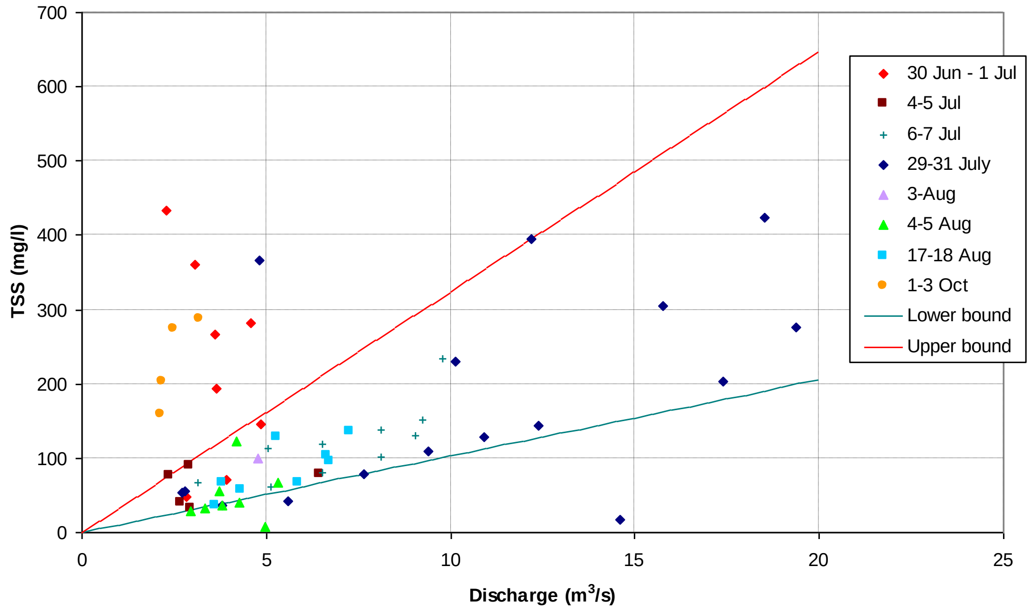
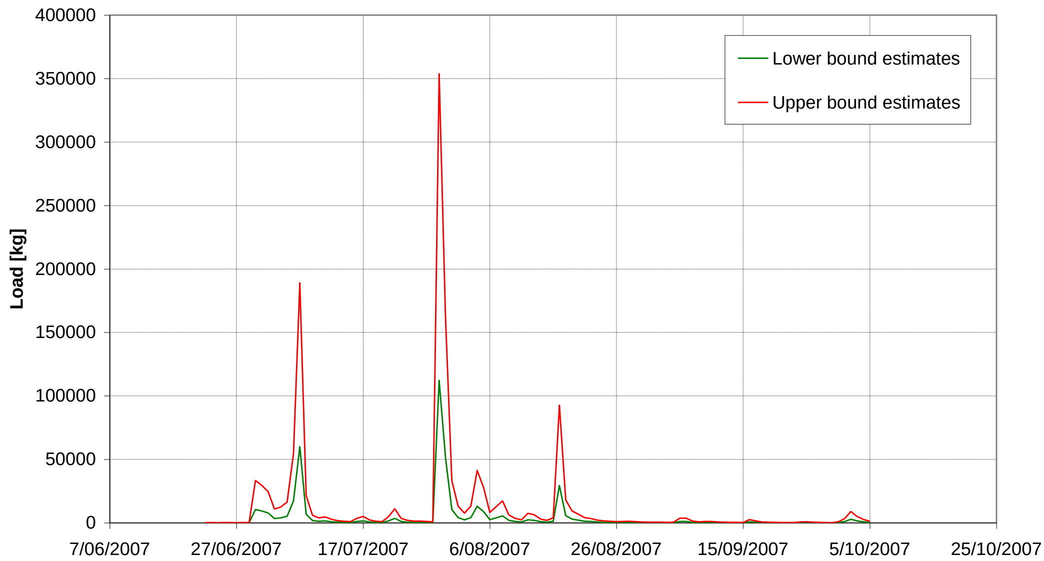


Figure 14:

Example of upper and lower bound estimates of daily sediment load, Papakura Stream.

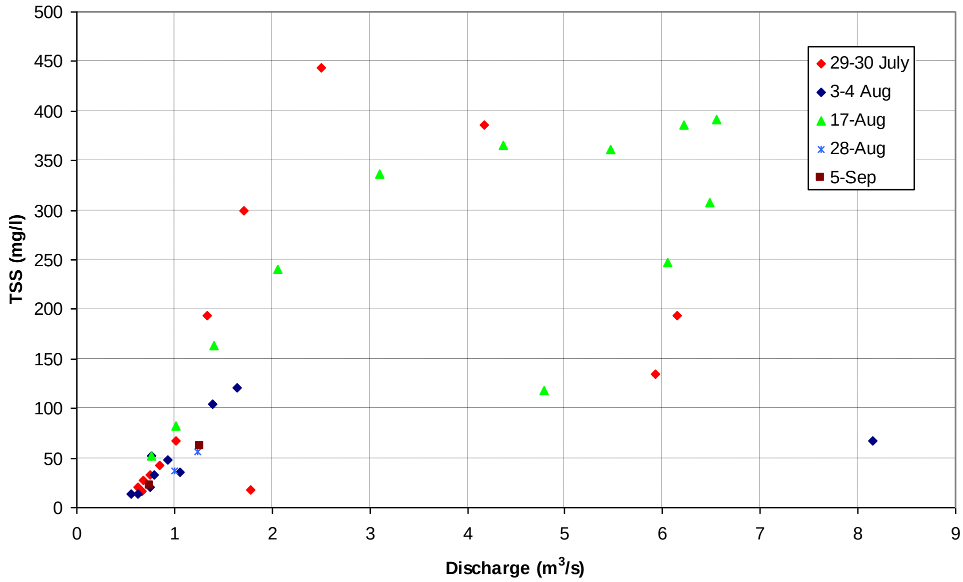


4.3.2 Waitangi Stream

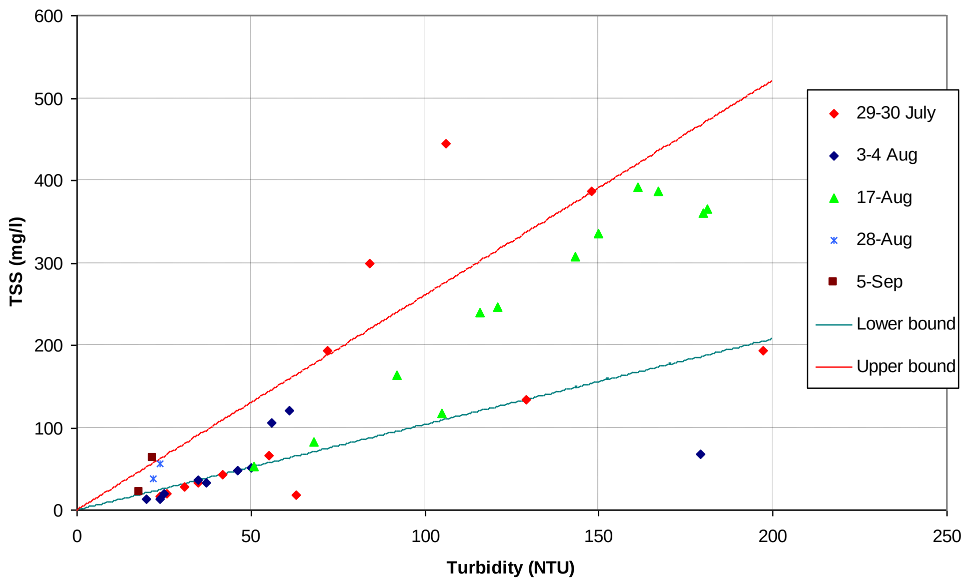
Both the TSS-discharge and TSS-turbidity relationships were investigated (see Figures 15a and 15b). The latter appeared to be the more clearly defined relationship, with evidence of hysterisis in the relationship between TSS and discharge. Consequently, further analysis focused on the TSS-turbidity relationship with lower and upper bounds were fitted by eye to provide an envelope around most of the data points.

Figure 15:
Relationship between (a) sample TSS concentrations and discharge, and (b) sample TSS concentrations and turbidity, Waitangi Stream.

(a)



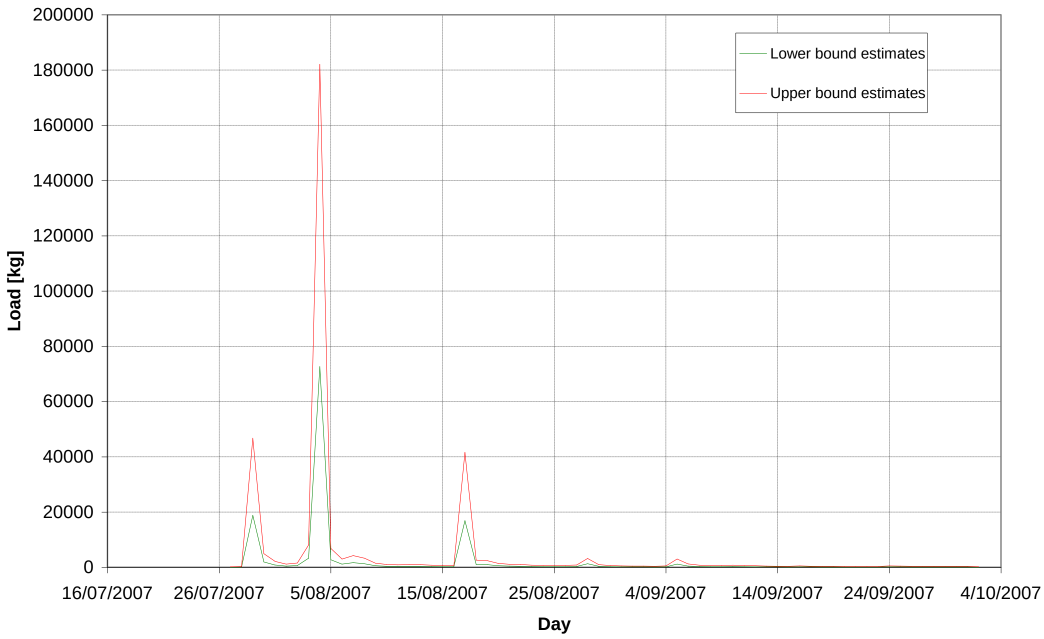
(b)



From these relationships, upper and lower TSS concentrations at 15 minute intervals (the logging interval for turbidity measurements) were estimated over the period of the turbidity record (July-Sep 2007). Upper and lower bound 15 minute sediment loads were calculated from these TSS estimates and concurrent flows. These were aggregated to give estimated upper and lower bound daily sediment loads over the period Jul-Sep 2007.

Curves were then fitted to describe the relationship between mean daily discharge and the estimated upper and lower bound daily sediment loads over the period Jul-Sep 2007. Lower and upper bound daily sediment loads over the period of record (1966 to date) were then estimated from these relationships and mean daily discharge. As an example, the estimated upper and lower bound loads over the period of sampling are shown in Figure 16.

Figure 16:
Example of upper and lower bound estimates of daily sediment load, Waitangi Stream.



5 Evaluation of Model Predictions

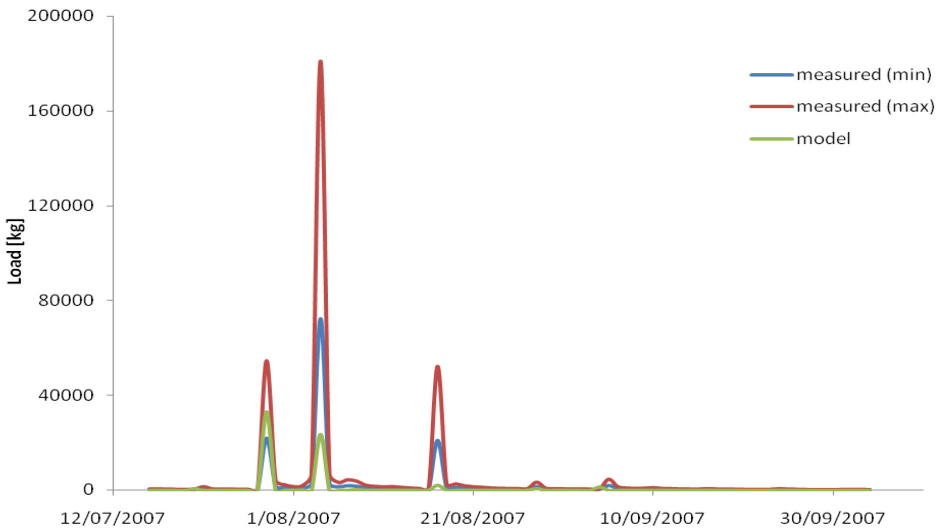
This section describes the comparison of measured sediment load estimates (Section 4) with GLEAMS-SEM model results (Parshotam 2008).

Table 1 presents a comparison of measured and predicted long-term yields (t km^{-2} y^{-1}) over 50 years. The GLEAMS-SEM sediment load model predictions (with stream routing) lie within the estimated upper and lower bound sediment loads for the Papakura Stream subcatchment.

The Waitangi Stream subcatchment GLEAMS prediction (42.1 t km^{-2} y^{-1}) is within the estimated lower (17.6 t km^{-2} y^{-1}) and upper (44.0 t km^{-2} y^{-1}) sediment load bounds derived from sediment sampling and gives confidence to results from the GLEAMS-SEM model. As shown in Table 1, our model estimates for the Waitangi subcatchment with 88% grassland are only slightly lower than estimates from market gardening (49 t km^{-2} y^{-1} (3 years of record)) given by Hicks (1994).

While the long-term sediment loads are predicted adequately, the event-to-event predictions are not as reliable (Figure 17). The model over-predicts some events while it under-predicts others. This is typical for sediment transport models, where there is considerable un-explained variability in the short-term response of the catchment. However, what is more important from the estuarine deposition perspective is the probability distribution of different events. There were not sufficient monitored events in this study to assess the ability of the model to predict the probability distribution of events: such an assessment would require a considerably longer monitoring period.

Figure 17:
Time series of measured and modelled sediment loads at Waitangi.



Also included in Table 1 for further comparison are data reported for the Whangapouri basin subcatchment (Hicks 1994; Basher et al. 1997; Basher and Ross 2002) from studies of market gardens in the Pukekohe area and Hick's (pers comm.) based on an analysis of historical data using the software 'SedRate' (NIWA Christchurch). The Whangapouri subcatchment (MU#266 in Figure 4 of Parshotam et al. 2008a) is located within the study area and is dominated by market gardening. Hicks (1994) notes that the yield of sediment from the market gardening basin was much lower than expected, being the same as the yield of a nearby pasture basin at Manukau. Hicks (1994) also concludes that sediment yields from catchments undergoing urban development are an order of magnitude greater than from any other landuses, including market gardening. The model over-predicts the sediment loss from the Whangapouri Basin (73.1 t $km^{-2} y^{-1}$ predicted versus 49 t $km^{-2} y^{-1}$ measured).

Table 1 also shows net erosion measured from market garden hillslope in the upper Whangapouri catchment using ^{137} Cs techniques (Basher and Ross 2002). The predicted net erosion is less than the measured, for comparable slopes. However, as noted above, the loss at the catchment outlet, which is of more relevance to impacts on the estuary, is slightly over-predicted.

The Sediment Delivery Ratio (SDR) is, effectively, an index of sediment transport efficiency and is determined in this work from the ratio of sediment loads entering the stream network to the load exported from the stream network after routing. The sediment delivery ratio (SDR) is affected by many highly variable physical characteristics of a watershed and varies with the drainage area, slope, maximum length of a watershed expressed as a relief-length (R/L) ratio, runoff-rainfall factors, landuse/land cover and sediment particle size, etc. Empirical equations relating SDR with one or more factors are often useful tools to estimate SDR. The delivery ratio of Waitangi (36.8%) agrees reasonably well with estimates from empirical relationships of the transportation of sediment by water (e.g., an estimate of 33% is obtained by using a relationship given by Vanoni, 1975 using data from 300 watersheds throughout the world). The net erosion rate from the Whangapouri hillslopes is much higher than measured from at the catchment outlet (Basher and Ross 2002), with a delivery ratio of approximately 4%, an unusually small value which may be attributable to the particularly stable aggregates from the soils in the area. There is evidence of silting up of streams in the area (Basher et al. 1997). The modelled SDR for that catchment was larger (26%). The difference may relate to under-estimating the settling of the sediment, but may also relate to inaccuracies in the 4% estimate (it was based on comparing a the loss from a small number of paddock to the catchment outlet which included a large number of different paddocks with different characteristics. Regardless, the prediction at the catchment outlet for Whangapouri agreed reasonably well with the measured load, so the deposition or source parameters were not adjusted.

Table 1:

Comparison of modelled and estimated upper and lower bound long-term sediment loads (t km^{-2} y^{-1}). Also included is the delivery ratio (%) and area (km^2) for reference.

	Papakura	Waitangi	Whangapouri	Whangapouri hillslope
Lower bound estimate	17.8	17.6		
Upper bound estimate	56.1	44.0		
Model prediction	22.7	42.1	73.1	323†
Delivery ratio (%)	11.6	34.2	26.0	
Area (km^2)	55.13	17.97	2.56	
Hicks (pers comm.)		16.3		
Hicks (1994)			49	
Basher & Ross (2002)				1100*

† soil loss from the hillslope, before entering streams.

* From the hillslope at 5 °. Average from three hillslopes of various slopes was 1400 t km^{-2} y^{-1}.

6 Conclusions

The predictions of the combined GLEAMS-SEM model and routing function have been compared with sediment load estimates derived from monitoring data at Waitangi and Papakura Streams and relevant data reported in the literature. The modelled loads compare well with these other data, giving confidence in the application of the sediment load model, and results from the model given in Parshotam (2008) for the Southeastern Manukau Harbour / Pahurehure Inlet contaminant study.

7 References

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