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TE RAUHĪTANGA TAIAO

Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study: Sediment Load Model Structure, Setup and Input Data

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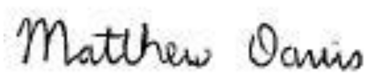

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Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study: Sediment Load Model Structure, Setup and Input Data

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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 Scenarios.

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.

Contents

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.

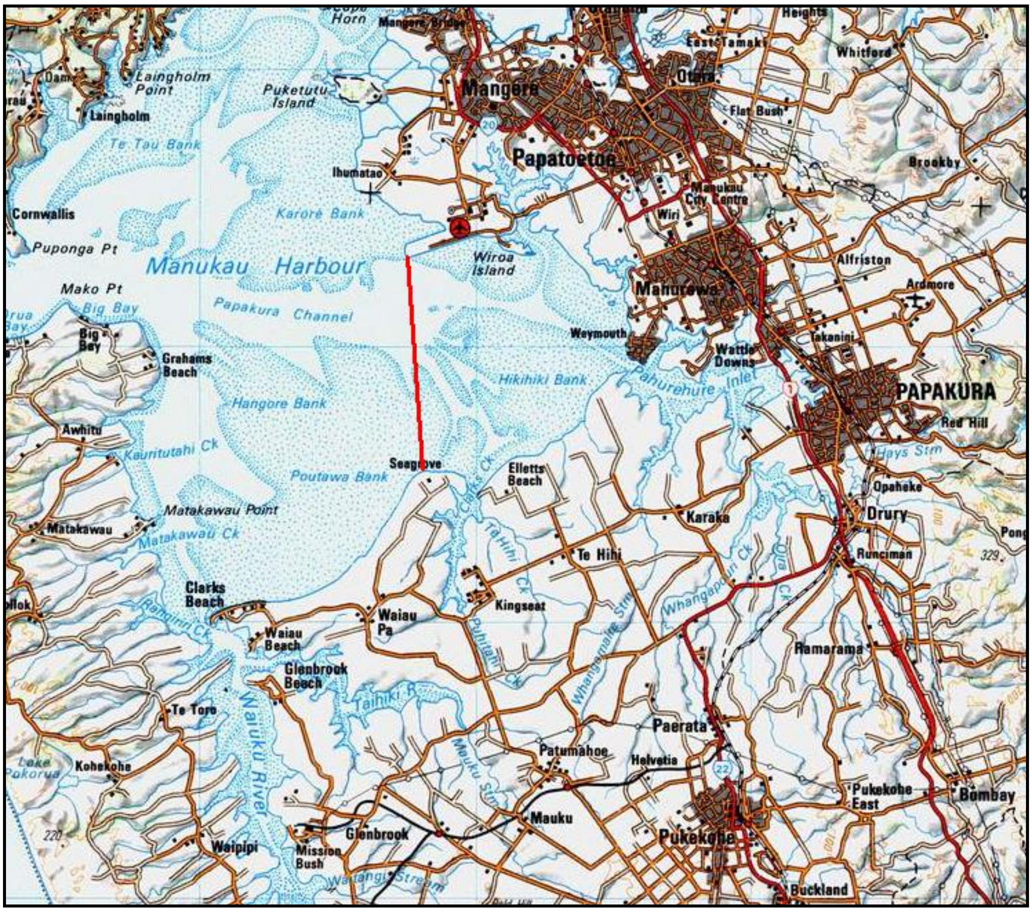
This report describes the implementation and data requirements of the GLEAMS model for simulating sediment generation in rural areas of the catchment of the Southeastern Manukau Harbour / Pahurehure Inlet. The model so implemented is called "GLEAMS-SEM".

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 the model structure, setup and data input requirements of the GLEAMS model for simulating sediment generation in the rural areas of the catchment surrounding the Southeastern Manukau Harbour / Pahurehure Inlet, passing sediment though sedimentation ponds, if and when necessary and routing sediment through the stream network to the estuary. The model so implemented is called "GLEAMS-SEM".

In associated work, the CLM contaminant/sediment-generation model is used to hindcast or predict metal and sediment runoff from the 'built-up' parts of the catchment. Greenfield earthworks sediment yield data as well as urban grassland sediment yield data from GLEAMS-SEM for the whole catchment (urban and rural) is provided as an input to the CLM model, and both the GLEAMS-SEM and CLM models produce inputs to the USC-3 model (see Moores and Timperley, 2008). The GIS maps of soils, slope and landuse data produced for use in GLEAMS-SEM is also used in the CLM model in a simplified and tabulated form. Calibration of the USC-3 model is achieved by running the USC-3 model for the historical period 1940 to 2001, with sediment and metal inputs from the catchment appropriate to that period, which in turn are hindcast by the GLEAMS-SEM and CLM models. The GLEAMS-SEM model is used to predict sediment runoff for the future period 2001 to 2100. The predictions are to be used in the evaluation of future catchment development scenarios.

Earlier GLEAMS-based models, such as BNZ (Basin New Zealand) (Stroud and Cooper, 1997), GLEAMSHELL (Rodda et al. 1997) and WAM-O (Watershed Assessment Model – Okura) (Stroud et al. 1999) have been used to address a variety of water quality issues at scales ranging from small watersheds to larger basins. Some example applications of these GLEAMS-based models in the Auckland region include: studies of sediment loss from vegetable growing fields at Pukekohe (Stroud and Cooper, 1998); identifying sediment sources and potential effects of landuse change in the Mahurangi catchment (Stroud and Cooper, 1997; Oldman et al. 1998; Stroud, 2003); impacts of urban and motorway development on sedimentation in Orewa estuary (Williamson et al. 1998); estimating the effects of urbanisation on sediment loss in the Mangemangeroa catchment (Oldman and Swales, 1999); determining the effects of rural intensification options on sediment loads to the Okura estuary (Stroud, et al.

1999; Stroud and Cooper, 1999), and contaminant accumulation in the Upper Waitemata Harbour (Green et al. 2004) and the Central Waitemata Harbour (Parshotam et al. 2007 a, b, c).

GLEAMS-SEM has been validated and updated against monitoring data. 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. Information from previous catchment modelling, the literature (e.g., Basher et al. 1997; Basher and Ross, 2002) and monitoring data within and near the study area was used to establish parameter values. The parameters were established based on previous experience and on guidelines contained in the GLEAMS manuals. Model validation against measured sediment loss was conducted to confirm that these parameters are appropriate. This validation is described in a companion report (Parshotam et al. 2008b).

A key benefit of a modelling approach is its predictive ability and allowing 'what if' scenarios to be carried out. These predictions can be an important aid in decision making. Models such as these can and have been used to provide guidelines to protect estuaries; evaluate impacts of development and urbanisation; understand watershed hydrology–stages, flows and loads in the stream network; identify sediment loading "hotspots"; determine the effectiveness of urban and agricultural detention ponds; evaluate the impacts of changing landuse management; predict sediment accumulation and runoff from impervious surfaces; and evaluate erosion and deposition in streams, lakes and reservoirs.

3 Model description

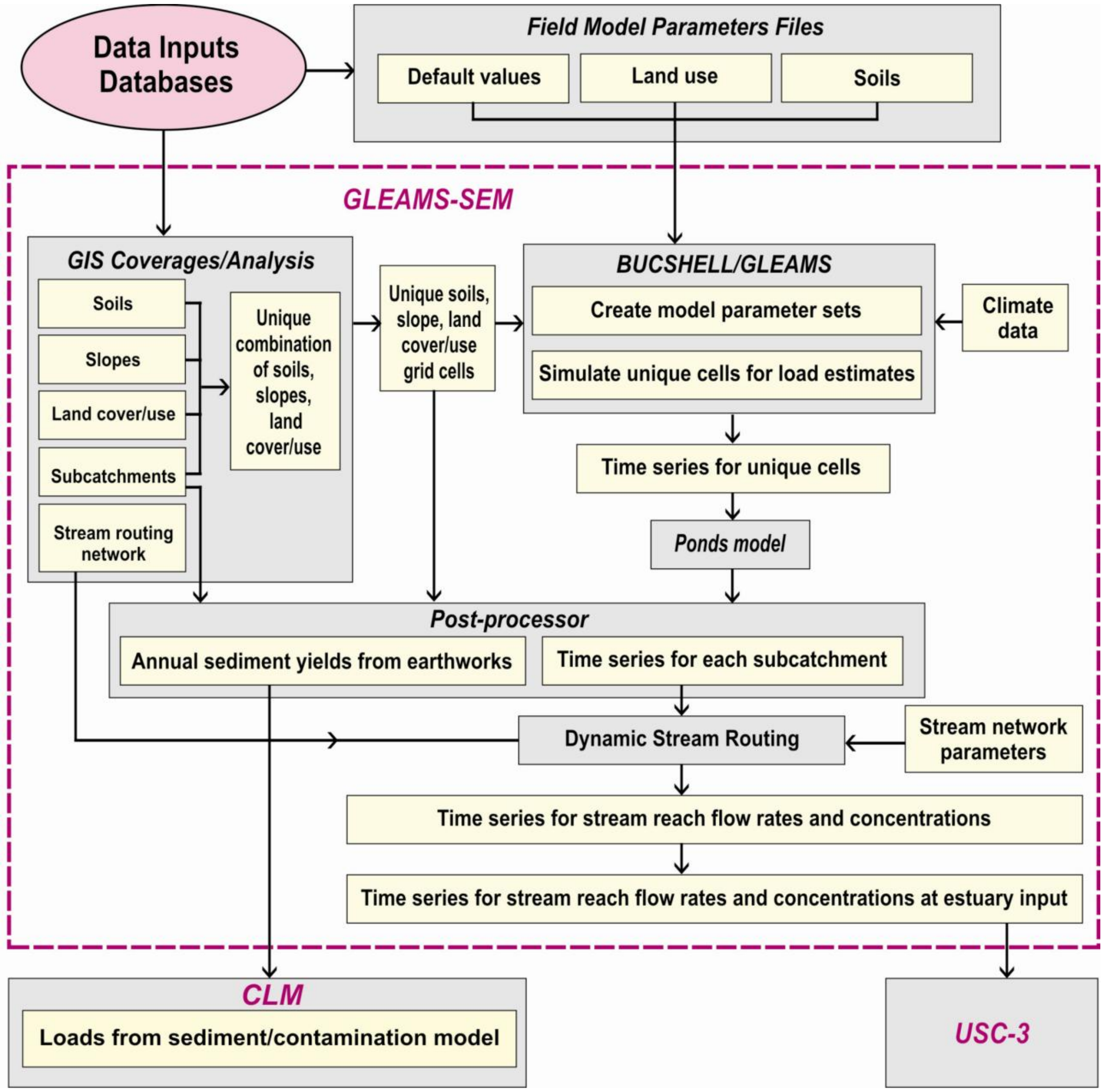
3.1 GLEAMS-SEM model description

The procedure for deriving catchment sediment loads involves dividing a catchment into uniform grid cells of user-defined size. Predictions are made of the daily runoff of water and sediment from the grid cells using the field-scale, physics-based mathematical model GLEAMS (Knisel and Davis, 2000) as its core model. The primary information requirements are catchment characteristics, including climate, topography, soils, landuse, and the stream characteristics including linkages. A GIS interface is used to manage the spatial information required as input (e.g., soil patterns, landuse, and topography). Model simulations are conducted for unique combinations of soil, slope and land cover. The results are aggregated by Model Unit and routed through the stream network (sediment routing), via connected reaches, to the catchment outlet.

The version of the GLEAMS-based models modified and adapted for our purposes is known here as the GLEAMS-SEM model. The Basin Unique Cell Shell (BUCSHELL) model within GLEAMS-SEM generates input parameter files and determines which submodel to use by comparing landuse and/or soil codes. GLEAMS-SEM (see Figure 2) is similar in concept to GLEAMS-CWH (Parshotam and Wadhwa, 2007a), except that GLEAMS-SEM includes stream processes.

The GLEAMS-SEM model uses soils and landuse data for each cell, together with long-term (this study used a 50-year record) climate data (rainfall, temperature and solar radiation) to calculate a daily water balance for each cell. Incoming rainfall is proportioned between surface runoff, storage in the soil profile, evapotranspiration and percolation beneath the root zone. Predictions of surface runoff are coupled with soil, vegetation and slope properties to calculate particle detachment and hillslope sediment transport and deposition. Note that processes of sheetwash and rill erosion are represented in the model, but soil loss from mass movement (e.g., landslips) is not. The load from a grid cell may also be passed through a sediment control pond if and when necessary. The predicted surface runoff, subsurface runoff and sediment generated from each grid cell is aggregated on a subcatchment scale and routed through the stream network, via connected reaches, to the catchment outlet.

Figure 2:
GLEAMS-SEM model structure.



3.2 Setting up the GLEAMS-SEM model

Digitised soil, topographical and landuse data are pre-processed within GIS to input to GLEAMS-SEM. Associated divisions or working units within the subcatchments (known as model units (MU's)), some derived from SMU's (Stormwater Management Units) from respective councils are used to manage the whole catchment.

GLEAMS-SEM has been established using a 30 m x 30 m grid (i.e., 498,639 grid cells for the 45,035 ha catchment), providing the scale necessary to adequately represent the terrain and soils, and any site developments and rural intensification. Note the extent of the modelled catchment (Figure 3).

The following steps are required to estimate sediment generation in the South Eastern Manukau Harbour using GLEAMS-SEM:

1. Create files of unique combinations of soils, slope and land cover classes using pre-processing.
2. Set up soils and landuse parameter files.
3. Set up the daily rainfall, monthly temperature and monthly solar radiation files.
4. Run the GLEAMS model for each unique combination of soil, slope and land cover.
5. Run sediment pond model where appropriate.
6. For each MU:
    a. Derive the number of cells for each combination of soil, slope, and land cover.
    b. Combine results from GLEAMS runs to give daily outputs of sediment loads and rainfall runoff for the MU.
7. Combine loads from MUs to give a daily time series of loads from all subcatchments.
8. Pass loads and rainfall runoff from MUs through the stream network, to obtain stream reach flow rates and concentrations.
9. Pass stream sediment concentrations at the estuary input in the appropriate form and data format to the USC-3 model.
10. To identify the contribution of a particular Integrated Catchment Management Plan (ICMP) area to the estuary, switch off the load from MU's associated with other ICMP's and repeat the procedure from 4.

3.3 Generation of unique cells

GLEAMS-SEM uses standard ArcGIS functions to create a file of "unique combinations" of landuse, soils and slope classes. This pre-processing is required by GLEAMS to produce individual text files of daily outputs from individual cells from previously delineated subcatchments.

3.4 The GLEAMS model

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) (Knisel and Davis, 2000) is the core model used in GLEAMS-SEM. GLEAMS is a physics-based, continuous-simulation, field-scale model, which was developed as an extension of the Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980). GLEAMS consists of four major components: hydrology, erosion/sediment yield, pesticide transport, and nutrients. GLEAMS estimates surface runoff and sediment losses from the field and assumes that a cell has homogeneous landuse, soils, and precipitation. A full description of how the GLEAMS model works is given in Knisel (1993).

The latest version of GLEAMS, i.e., GLEAMSv3.0 (Knisel and Davis, 2000) was used. Computer parameter data files required by GLEAMSv3.0 were prepared. This includes incorporating any proposed earthworks within the model.

3.5 Earthworks

For earthworked areas, topsoils are removed to reflect earthworks practices. Seasonal restrictions for bare earth/earthworks practices were assumed as in previous studies (Parshotam and Wadhwa, 2007 a) limiting them to between 1st October and 30th April inclusive, with stabilisation in the off-season. Sediment control ponds may also be applied, as described in the next section.

For historical periods, the amount of earthworks is given only as an area or fraction of a MU, and not at a specific location. In that case, earthworks are distributed on all possible soil and slope combinations. Also, equivalent areas of a other land cover were removed to account for the area of earthworks.

3.6 Sediment control ponds

In this study, the pond model used in GLEAMS-SEM was configured to allow the following:

- Up to 10 sediment size classes, which settle independently in the pond (well-mixed settling during storms, and quiescent settling between storms).
- Transient concentrations in the pond as the concentration in the pond adjusts to a new inflow.
- Decanting of the pond water during quiescent settling between storm events, followed by quiescent settling between runoff events.
- Flow varying through a storm event (of 1 day duration). This was achieved by: calculating an effective curve number for the event (based on GLEAMS output runoff); distributing the event rain over time using the design storm hyetograph as in TP108 (ARC, 1999b); applying this rainfall and the SCS curve number equation to calculate excess rainfall through the event; translating this to the pond with no lag or attenuation (justified on the basis of the small catchments leading to a sediment control pond); distributing the daily sediment load (from GLEAMS) over time using a power sediment rating curve. Note that sedimentation pond

performance is not very sensitive to the details of the timing of inflows, as there is storage/buffering in the pond.

- Summing the pond outlet flux over time (including during the decant phase) to give the outlet sediment load for the event.
- Applying the pond model for each event in the GLEAMS output file, to derive a time-series of event loads after ponds.

The dimensions of the ponds were set to match those in the ARC TP90 guidelines on sediment control ponds (ARC 1999a). The decant rate was set at 4 $ls^{-1}ha^{-1}$, the mean pond depth was set at 1.5 m, and the dead storage was 30% of the total pond volume (at the outlet level).

For standard sediment retention ponds, the median settling velocity was adjusted so that the long-term average sediment removal achieved by '2%' ponds was 70%. This removal efficiency is commonly accepted as a representative value for sediment control ponds with silty-clay soils in the Auckland area (Bannister, pers comm.). The median settling velocity was 0.4 m day^{-1}, corresponding to spherical sand particles with a diameter of 4 µm, and the log_{10}-s.d. of particle sizes was set at 1.5, consistent with measurements of particle sizes in urban runoff (Hicks, 1994). The removal efficiency is less for larger storms, as in larger storms the main pond discharge operates and the residence time of the water is less.

3.7 Post-processing

The daily sediment loads from each unit cell are input to an MS-Access database and aggregated to produce daily sediment loads from each MU, which are subsequently passed through a stream network. The sediment loads, broken down by particle size class, are passed directly to the USC-3 estuary model as a time series of daily sediment loads at each outlet point for the full period of model runs. (Green, 2008b,c). Exactly how these loads are incorporated into the USC-3 model is explained by Green (2008a).

Results from the GIS analysis (subcatchment areas, soils, slopes and landuse information) are also passed to the CLM model in a simplified and tabulated form. Predictions of losses from earthworks and grassland across the whole study area are passed to the CLM model as annual average yields for each MU. Exactly how these are used in the CLM model is explained by Moores and Timperley (2008).

3.8 Sediment routing

A sediment routing model has been developed for use within GLEAMS-SEM. The model reads in daily water and sediment discharge time series from GLEAMS subcatchments, and also reads information describing the river network, and how the subcatchments link to the network. The drainage network is comprised of a number of reaches. A reach is the length of stream between junctions in the stream network, or, at the top of the catchment, a reach is the length of stream from the headwaters to the first junction. Each reach has a local catchment associated with it. On each day, the sediment and water from the subcatchments are fed into the relevant reaches, and the sediment is routed down the network. The results for all reaches and for all timesteps are saved in a model output file which can be used for further analysis or as input to the estuary model.

In each day in each reach, the sediment deposition is calculated using a steady-state approach for that day. Sediment and flows enters the reach from the upstream reaches and the local catchment. The sediment discharge is obtained by calculating the input of sediment from upstream reaches, and removing daily sediment deposition in each reach. The model simulates the routing of multiple particle sizes or classes (e.g., sand, silt and clay). Deposition of the sediment in a size class is calculated using a fall velocity with an assumed steady-state flow (the peak flow), with well-mixed conditions in the water column in each reach, a user-defined particle size and density with Stokes' settling, and a plan area for settling based on a hydraulic geometry relation. The flow rate for these calculations is a peak flow based on distributing the daily discharge over a triangular hydrograph with a duration of twice the time of concentration (Tc, in minutes, calculated using TP108 (ARC, 1999b)). The triangular unit hydrograph is a standard engineering hydrology approach used for example with the SCS curve number method (see Maidment, 1993). This approximation of the hydrograph was used to represent the response of the catchment to a sharp pulse in rainfall, which will be associated with the bulk of the sediment load. The method is applicable for subcatchments with time of concentration much less than the timestep of the GLEAMS model (one day), which is applicable to this site. This method gives an approximate estimate of sediment deposition.

The input files required in the routing model are:

1) Control File: This defines the number of days, MUs, reaches, and particle size classes in the simulation.

2) Subcatchment Data File: The daily time series of subcatchment flows and sediment discharges produced by the GLEAMS model.

3) Particle Data File: The density and radius of each sediment size class.

4) River Network Data File: The properties of the river network, such as reach-to-reach linkages, subcatchment-to-reach linkages, reach slopes and lengths, etc.

The routing model produces a time series for all reaches, on all days, by particle size with the following information: peak flow, sediment (concentration, input, output, storage), both as total sediment and by particle size class.

There is uncertainty with the delivery processes and it is difficult to fully characterise this. The issue of erosion and subsequent transport by later larger floods is not addressed in the model and the bed of the stream network is assumed to be purely depositional, based on our prior knowledge that considerable deposition occurs in the catchment (Basher and Ross 2002). Representation of the stream process remains an uncertain component in the catchment model.

Note that in the current study, stream erosion associated with urbanisation is treated separately in the associated CLM contaminant/sediment generation model.

4 Model input information

4.1 Subcatchments, outlets and hydrological Model Units (MU's)

The study area was divided into 580 Hydrological MUs (Model Units) nested within 15 defined outfall subcatchment areas, given identifiers 101 to 115 (Figure 3), associated with an outlet with an identical identifier ID. The MU boundaries were delineated using inputs from a LIDAR 2 m DEM (digital elevation model) provided by ARC, and GIS shapefiles of the boundaries of Integrated Catchment Management Plan (ICMP) areas and Stormwater Management Units (SMUs) provided by Papakura District Council and Manukau City Council.

Drainage basins were delineated from 2 m DEM using hydrological modelling functions available in ArcGIS Spatial Analyst and applying a threshold value to limit their size. The drainage basins were used as a guide to create all MUs in the study area of a systematic size. If SMU data were not available, the watersheds were used as MUs. If SMU data was provided by respective councils and of an appropriate size, the SMU boundaries were used to define MUs boundaries. If the SMUs were too small, then they were aggregated into larger MUs. If SMU were too large, then these SMUs were subdivided into smaller MUs according to the watershed boundaries. Also, the MU boundaries were adjusted where necessary to align with ICMP boundaries, so that allocation of contaminant loads to ICMP areas could be done by extracting the loads from the relevant MU's. During the DEM analysis, some coastal areas not associated with a stream were omitted. These areas were added back as separate MU's.

Each subcatchment is assigned an outlet point into the harbour. This is assumed to be a single point source of input from a subcatchment to the estuary (see Figure 3). The number and location of the outlet points were determined based on considerations of estuarine modelling requirements and in conjunction with the ARC.

A map of MUs with unique identifiers used in this study is given in Figure 4.

Figure 3:

Map of subcatchments and corresponding outlet points.

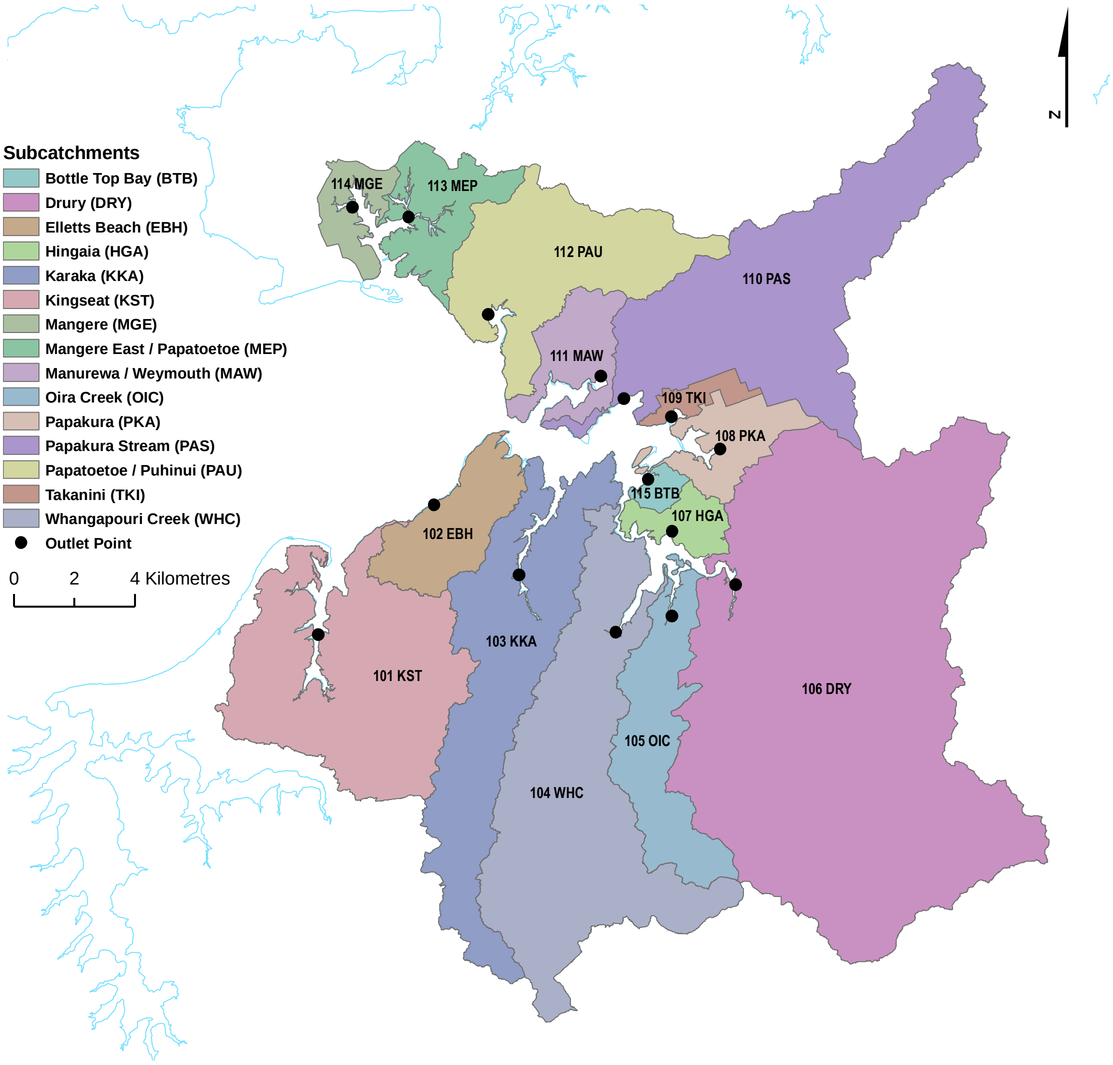
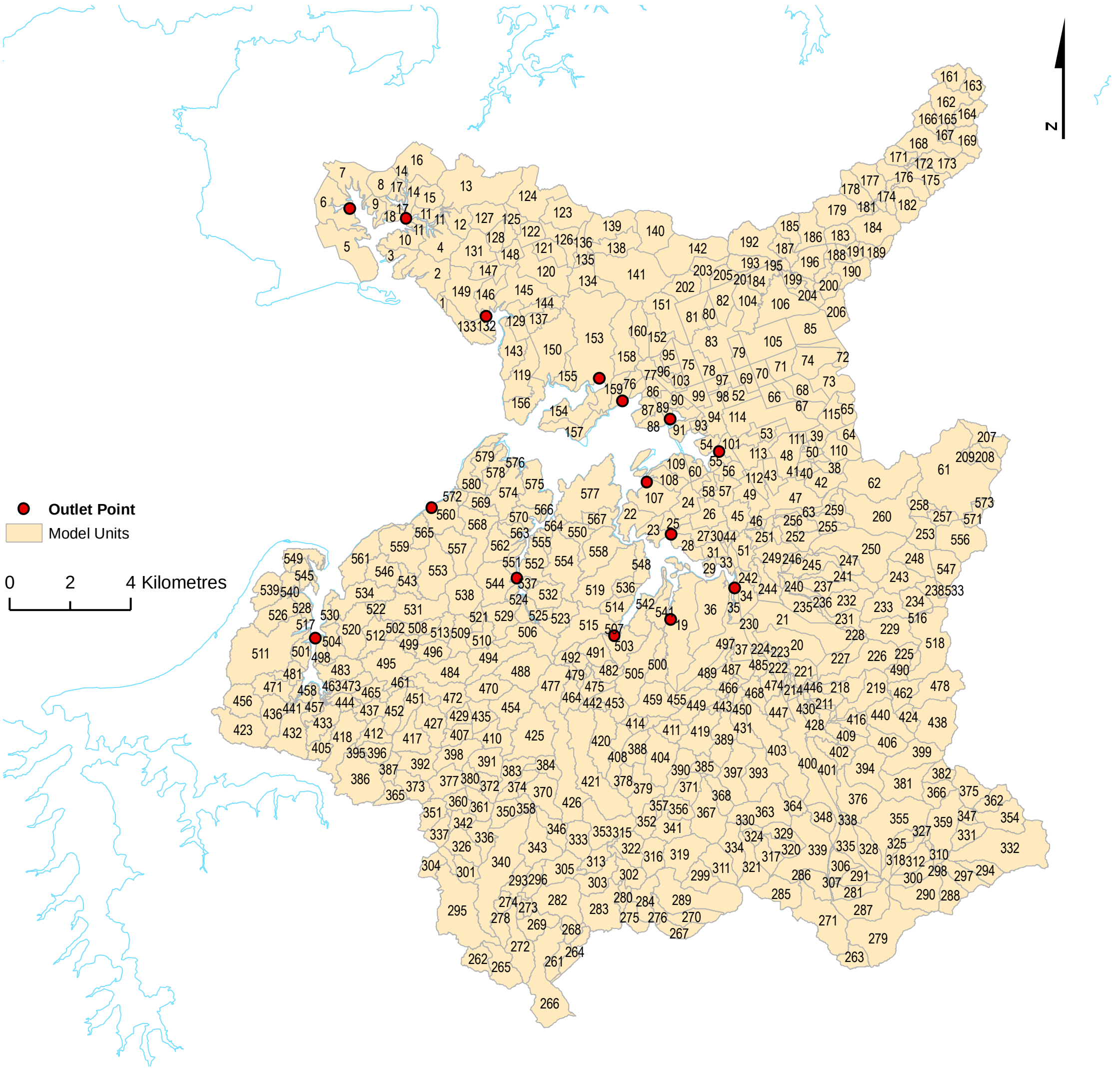


Figure 4:

Map of hydrological model units (MU's), including unique identifiers used in this study.



The subcatchment names, outlet ID’s, codes and areas (in ha) are given in Table 1 for reference.

Table 1:

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

Subcatchment name	Outlet ID	Code	Area (ha)
Kingseat	101	KST	4,614
Elletts Beach	102	EBH	1,321
Karaka	103	KKA	4,114
Whangapouri Creek	104	WHC	5,691
Oira Creek	105	OIC	1,984
Drury	106	DRY	14,264
Hingaia	107	HGA	500
Papakura	108	PKA	912
Takanini	109	TKI	287
Papakura Stream	110	PAS	5,513
Manurewa / Weymouth	111	MAW	946
Papatoetoe / Puhinui	112	PAU	2,962
Mangere East / Papatoetoe	113	MEP	1,176
Mangere	114	MGE	570
Bottle Top Bay	115	BTB	181
Total catchment			45,035

4.2 Climate

This section summarises the climate data used in the GLEAMS-SEM model and accounts for the spatial distribution of climate in the region, the climate stations chosen for the study including model evaluation, and major rainfall regions chosen for the study. All details on the choice and derivation of the rainfall data sets for use as model input are discussed in Semadeni-Davies and Parshotam (2009).

Climate: spatial distribution

The median annual rainfall map, based on the period 1971-2000, was generated from data collected at climate stations for the Auckland region (see Figure 5). The interpolation scheme used is a thin-plate smoothing spline (Hutchinson, 1995, 2008), which takes into account the proximity to the climate stations and the spatial pattern of rainfall derived from an expert-derived rainfall climatology (Tait et al. 2006). The long-term median annual rainfall values are calculated at each station site and these values are interpolated onto a 500 m by 500 m grid. The map is then created from these gridded data.

In our study, the distribution of long-term median annual rainfall and temperature are obtained from NIWA's climate grids, which are interpolated from observation stations using ANUSPLINE (Tait et al. 2006). See Figures 6 and 7 for the distribution of median annual temperature and median annual rainfall, respectively, used in our study.

Figure 5:
Auckland median annual rainfall based on the 30 year period 1971 – 2000.

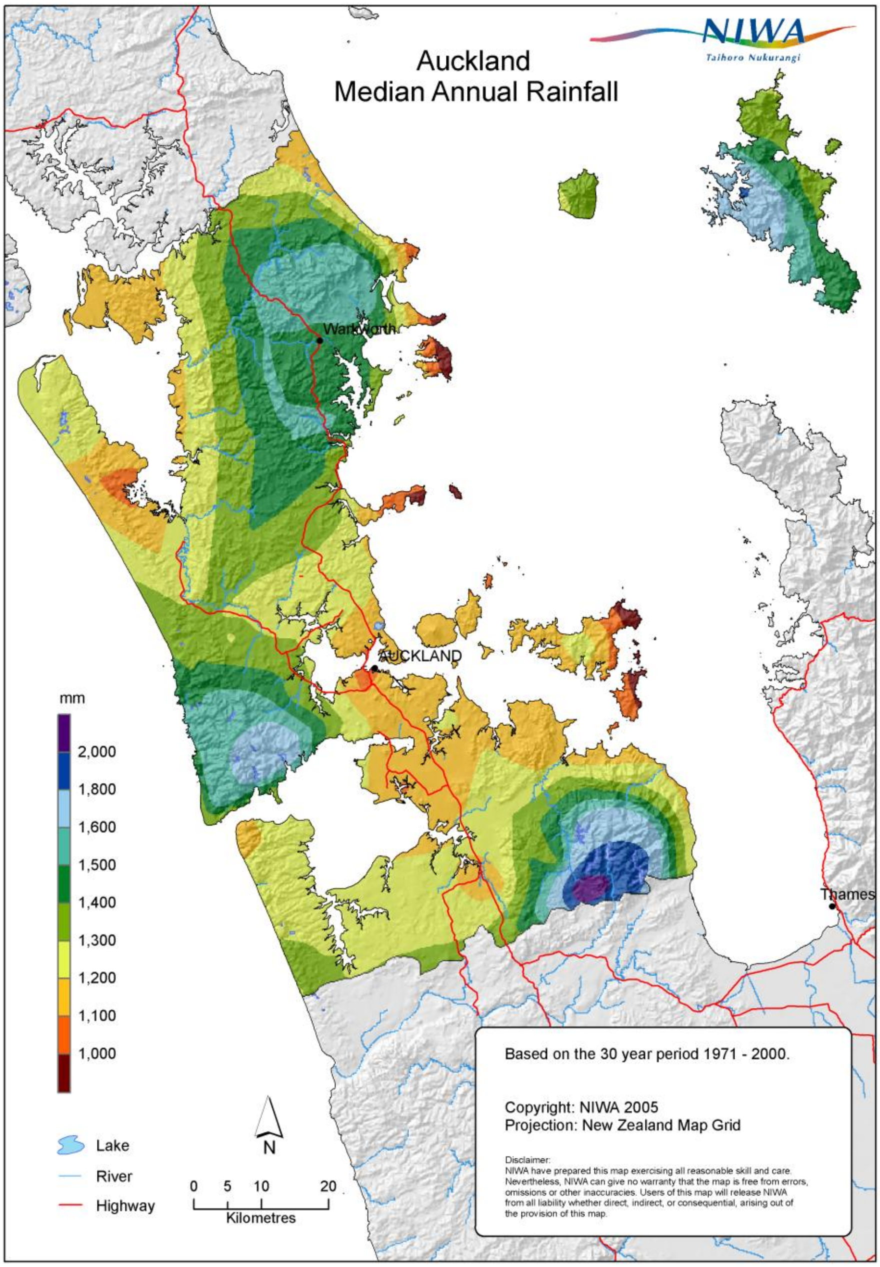


Figure 6:
Map of median annual temperature.

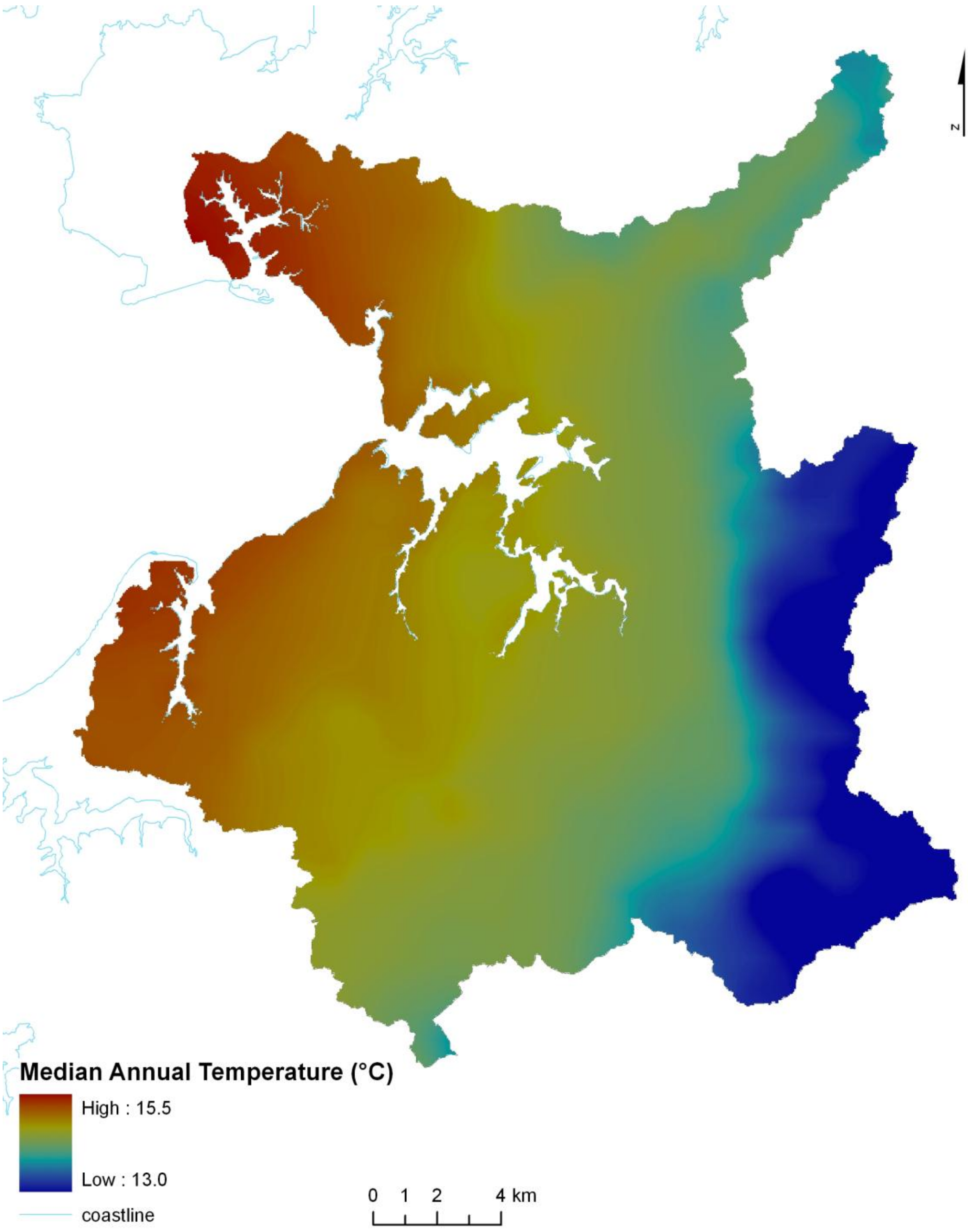
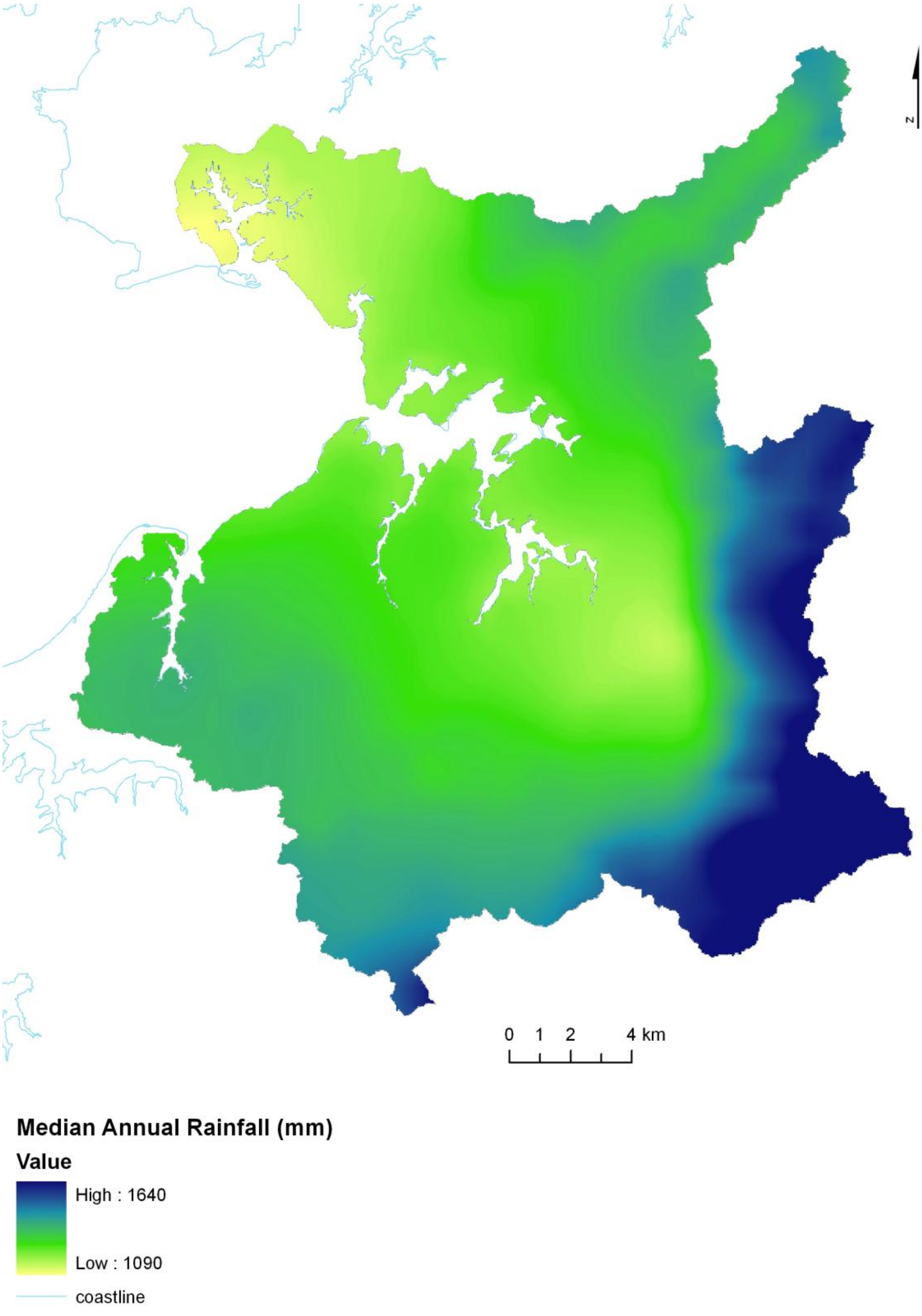


Figure 7:
Map of median annual rainfall.



The GLEAMS model requires daily and monthly meteorological data. These data were obtained from six ARC and NIWA climate stations from across the study area. The reason for this was that 1) no single site held a complete, unbroken record, and 2) some sites may better represent the different climate conditions in the study area.

The data records were collated, analyzed and merged (if necessary to fill gaps). GLEAMS climate input files were compiled based on 50 years of rainfall, temperature and solar radiation data. Data from some sites were not available for the entire study period, in which case data from neighbouring stations were used to complete the record based on regression analysis. The raingauge locations (see Figure 8) are:

1 Auckland Airport (Met Service – data held by NIWA) 1962-present.

2 Puhinui, Botanic Gardens (ARC) 1987-2005.

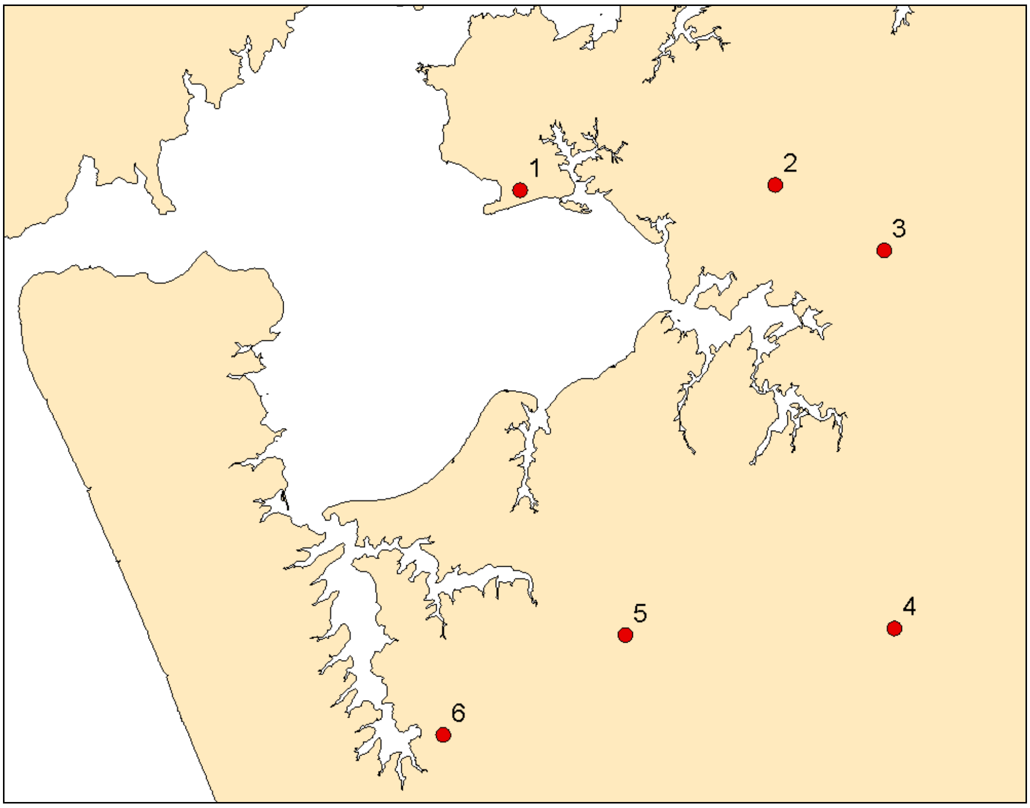
3 Ardmore (Met Service – data held by NIWA) 1940-present, missing data.

4 Ngakaroa, Donovans (ARC) 1980-present.

5 Patumahoe, Whangamaire Stream (ARC) 1992-present.

6 Waitangi, Diver Rd (ARC) 1968-present.

Figure 8:
Location of rain gauge sites.



After analysing the data, it was decided to split the study area into three rainfall regions and use corresponding rainfall data from Auckland Airport, Ardmore and Ngakaroa (see Semadeni-Davies and Parshotam, 2009).

Monthly climate data for GLEAMS-SEM (1948-2006)

The data requirements for the potential evapotranspiration (PET) component of the GLEAMS model for the period 1948 to 2006 are monthly averages of: (1) daily maximum/minimum air temperature and dew point temperature (°C); (2) daily average solar radiation. All data comes from Auckland Airport (station 1962). Data from 1948 to 1966 (when data are available) for all variables are climate normals, i.e., 30 year averages. Normals are also used for solar radiation until 1968 and to fill in missing data gaps.

The raw data sets are used to determine mean monthly values or normals for the entire data set (1968-2006 for solar radiation, 1966-2006 for all other data series). Gaps in the daily data sets are identified. There are large blocks of data missing from the temperature and radiation series, e.g., 1994. Missing daily data are replaced by the normal value.

The daily data for each year are averaged to give mean monthly values for that year.

Statistics (mean, median and standard deviation) are given for each climate variable on a per month basis to ascertain the spread of the monthly data from year to year.

Each climate variable is mapped along with the mean and standard deviation. All the series are fairly conservative with little year to year variation in monthly mean values.

As there does not seem to be much spread in the climate data, the years 1948 – 1965 (1967 for solar radiation) were assigned monthly normals. The full data set for 1948 – 2006 is constructed from the normals and observed data.

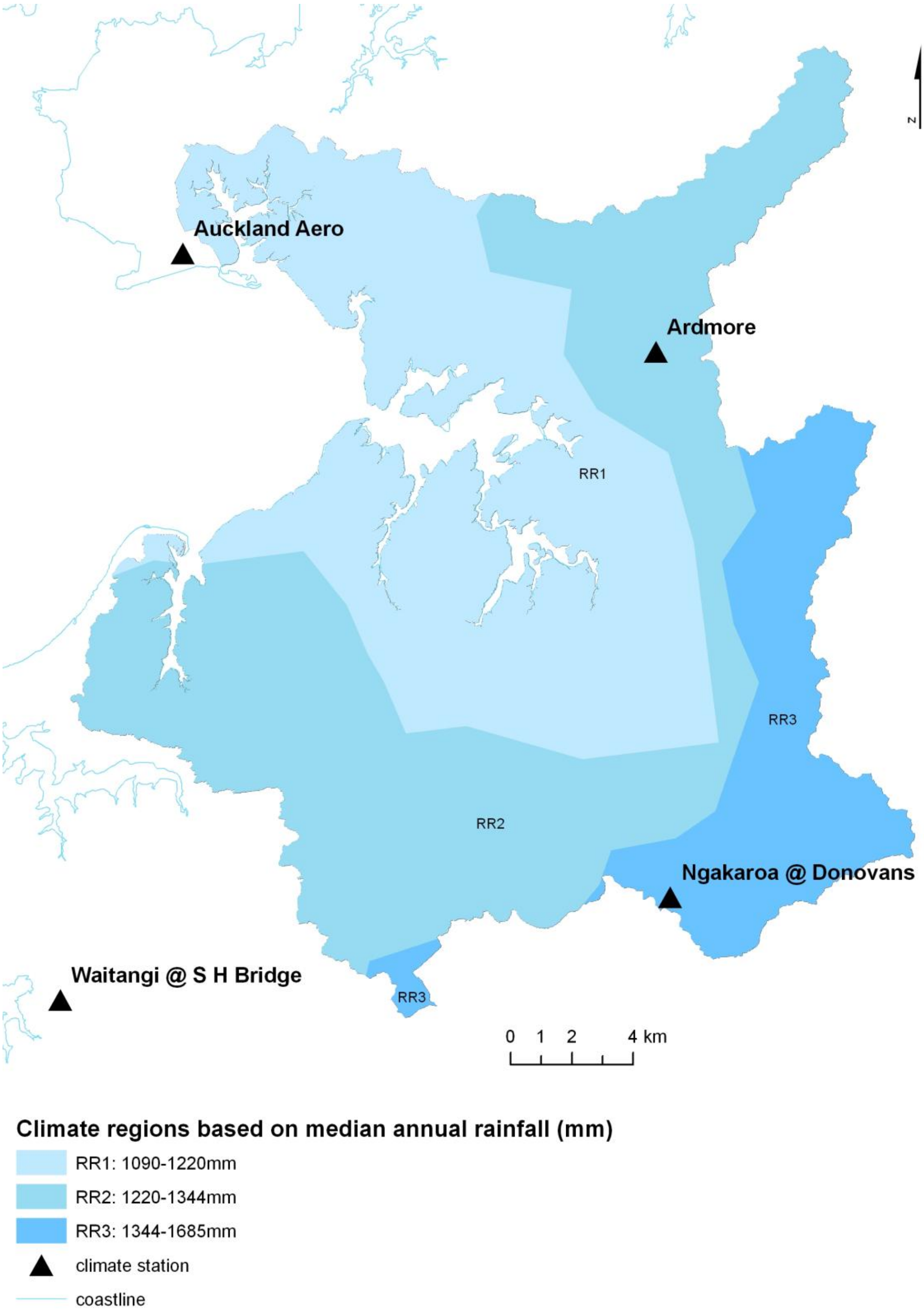
Climate regions

As noted above, the study area is divided into three major climate regions based on rainfall, referred to as RR1, RR2 and RR3 (see Figure 9). The boundaries were determined within GIS and were based on annual median rainfalls from station data and their spatial distribution (Figure 7). The GLEAMS-SEM model was run with different weather inputs for each of these three rainfall regions to predict sediment runoff.

Daily rainfall for RR1 is taken from long-term composite data at Auckland Aero AWS. Daily rainfall for RR2 is taken from long-term composite data at Ardmore. Daily rainfall for RR3 is taken from long-term composite data at Ngakaroa. The positions of the 3 climate stations are shown in Figure 9. All other data (minimum/maximum temperature, solar radiation) used in PET calculations were assumed to be identical across the study area.

The rainfall regions are shown in Figure 9. The details of the corresponding rainfall data from Auckland Airport, Ardmore and Ngakaroa is discussed in Semadeni-Davies and Parshotam (2009). Also included in Figure 9 is the new Waitangi station just outside of the study area, used in this study for model evaluation (Parshotam et al. 2008b).

Figure 9:
Map of rainfall regions based on median annual rainfall.



4.3 Soils

Soil classes, properties and maps (see Figure 10) for the study area were obtained from the National Soils Database (NSD) held by Landcare Research and, where required, interpreted for use in the model by Malcolm McLeod (Soil Scientist, Landcare Research). Further useful information on these soils and soils in the Auckland region was derived from published data and reports. These soils were combined into a smaller number of major soils types (Figure 11).The spatial pattern of soil types was used as an input GIS overlay to GLEAMS-SEM. Soil input files were set up to include the nine major soil classes (including landfill), with bare earth classes being the respective soil classes with their topsoils removed to reflect earthworks practice.

Figure 10:
Soil types in the study area from the National Soils Database (NSD).

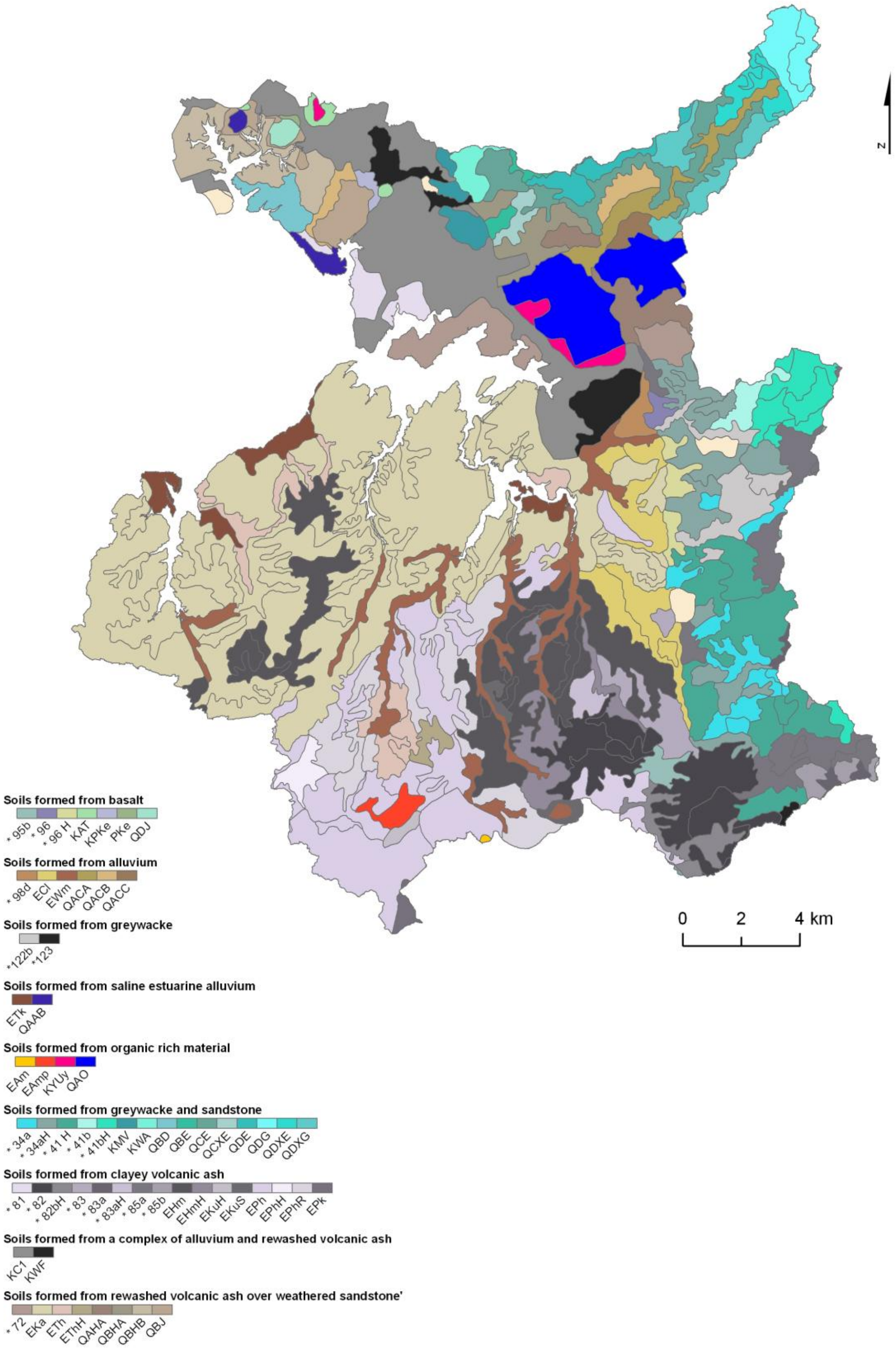
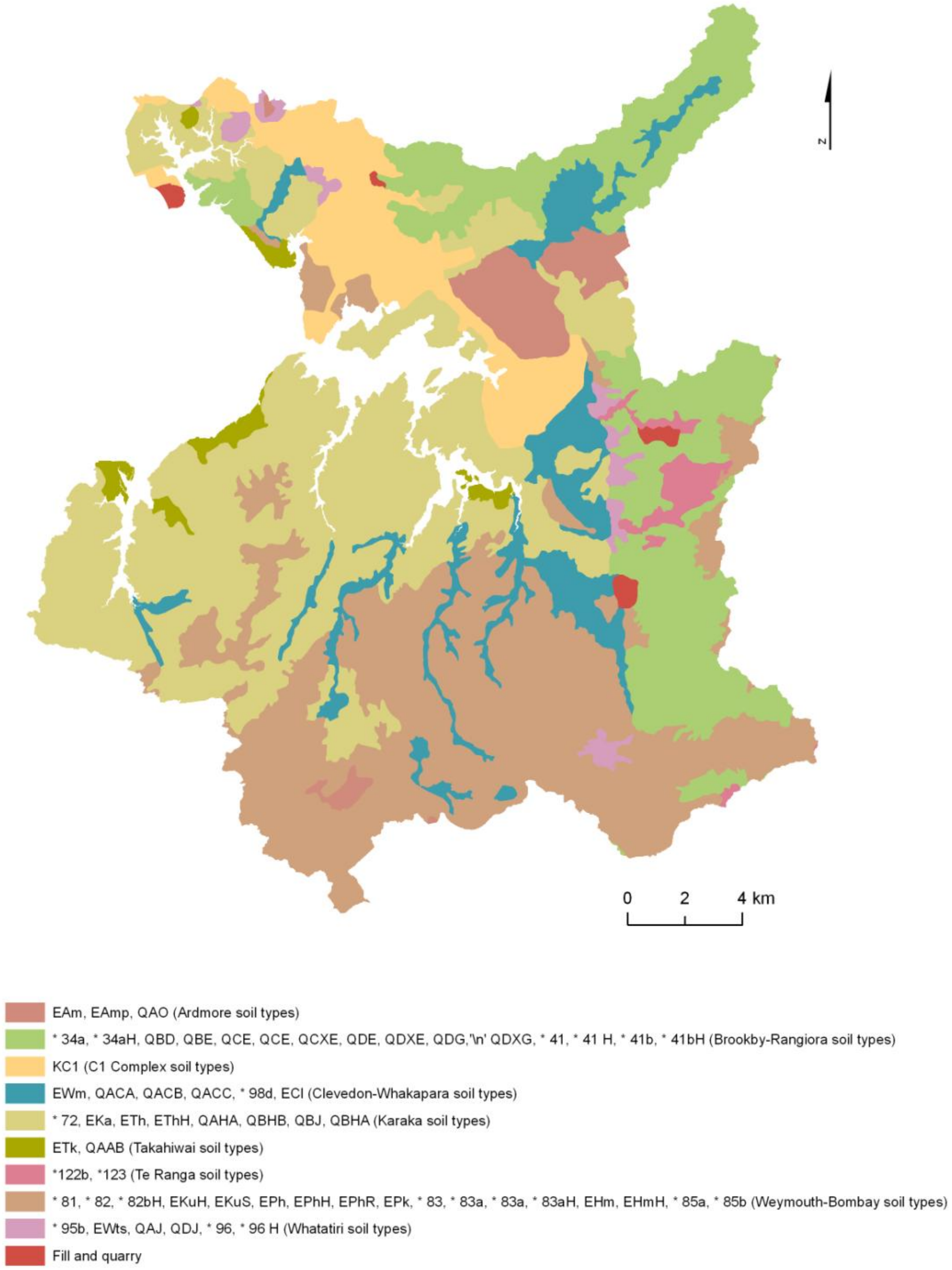


Figure 11:
Major soil types in the study area derived from the National Soils Database (NSD).



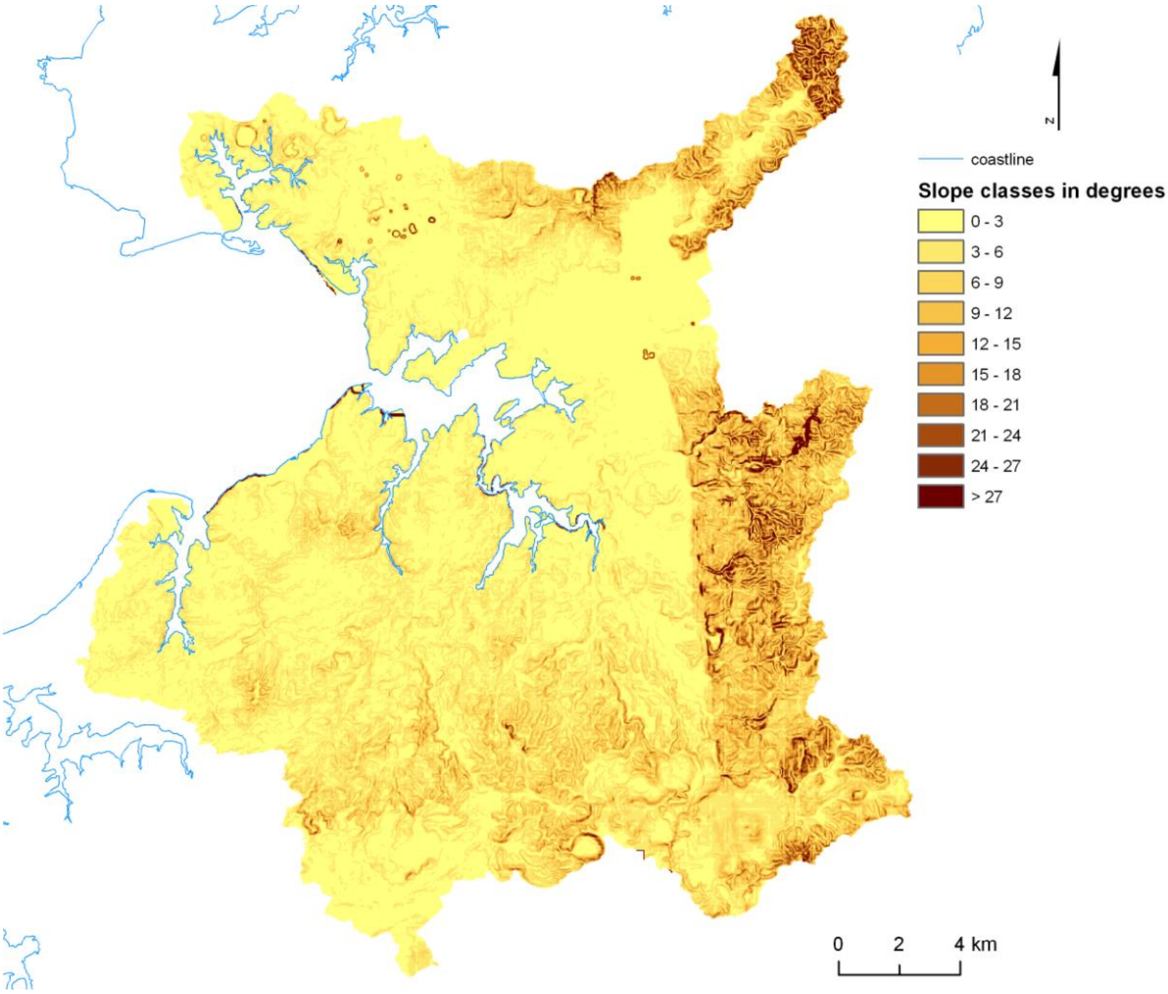
During the earthworks phase of site development, topsoil is generally removed exposing clay-dominated subsoil and this practice was simulated in the modelling. Because subsoil clay has little organic matter associated with it, it is easily detached from the soil surface and entrained within the surface runoff but generally less erosion occurs for higher clay content, which counters the effect of reduced organic matter.

Details on methods for calculating parameters, such as soil erodibility factors, vegetative cover coefficients, Manning's roughness coefficients used in our modelling exercise are given in Knisel (1993).

4.4 Topography

GLEAMS-SEM slope classes were based on 2 m digital elevation model (DEM) provided by ARC. From the DEM, the mean slope angle for each 2 m 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 12). Slope angle classes ranged from 3 to over 27degrees and these values were used in the model simulations. 49%, 23%, 11% and 6.6% of land within the study area falls within the 0-3, 3-6, 6-9 and 9-12 degree slope categories, respectively.

Figure 12:
Slope angle classes in the South-East Manukau Harbour catchment.



4.5 Landuse

The preparation of landuse information for the historical period (1940 to 2000), the current time (2001), and the future period (2002 to 2100) to be used in the GLEAMS-SEM model are discussed in the companion report by Parshotam et al. (2008a).

4.6 Unique combinations of soil, slope and land cover

GIS techniques for overlaying South Eastern Manukau Harbour soils, land cover and slope information produced unique combinations of soils, land cover, and slope within each rainfall region, RR1, RR2, and RR3.

4.7 Treatment of land with the use of sediment ponds

4.7.1 Urban development

The use of sediment retention ponds and their sizes have changed over time in relation to urban land development in the Auckland area:

- The Auckland Regional Water Board's Urban Earthworks Guideline for Erosion and Sediment Control (1978) did not require ponds but recommended that they be used. Ponds were sized at 1% of the disturbed portions of the catchment (for example, a 1 ha pond for 100 ha of disturbed land) and 0.5% for vegetated portions. The widespread use of ponds had occurred by the later 1980's.
- In 1990 the Auckland Regional Water Board published Erosion and Sediment Control Guidelines for Earthworks (Auckland Regional Water Board, 1990). Sediment control was required by this time and ponds were sized at 1% of catchment area on slopes less than 10% and 2% for slopes greater than that. Floating decants were detailed in the design guide.
- The most recent sediment control guidelines were issued in 1999 (ARC, 1999a). Implementation was widespread by that time and ponds became larger. Flocculation came into use around 2002 with widespread implementation by 2005.

In the current study, it is assumed that ponds are applied only within the Auckland metropolitan limits with seasonal restrictions to 0% of earthworks before 1980, 40% from 1981 to 1990, 90% from 1991 to 2000 and 100% after 2000. Pond sizes were sized at 1% of the catchment area for the 1980s and 1990s and 2% after 2000. For the future prediction of urban sediment loads, all treatment of runoff with sediment control ponds is done within the CLM model.

4.7.2 Market gardening (commercial vegetable growing)

A three-year multi-stakeholder Franklin Sustainability Project was established in 1997 to identify and promote best management practices amongst Franklin vegetable growers to protect water and soil resources. A number of good practices have been identified, trialled and compiled into a set of guidelines called *Doing it Right*, which was officially launched in October 2000. Field representatives promoted and encouraged adoption of practices outlined in the *Doing it Right* guidelines, and facilitated discussion and greater awareness of resource management issues amongst growers in the district and beyond.

The use of sediment treatment ponds to reduce soil loss from market gardens (commercial vegetable growing) in the Pukekohe area have been encouraged with positive results; however, the practice is not yet widespread. In the current study, there are no sediment ponds applied in modelling sediment runoff from market gardens.

GLEAMS market gardens/short-rotation crop parameters were obtained from Pukekohe farm data prepared in earlier studies by Stroud and Cooper (1998). Onions being the most common crops were chosen as the representative crops in this study because it and potatoes in rotation, are the dominant crops in the Pukekohe area. Information on onion cropping data was taken from earlier studies and included planting and harvesting regimes, leaf area index (LAI) and ground cover distributions over the season, crop yields, dry matter yield ratios, fertiliser application and rates (by month).

4.8 Input data for stream routing

A stream network for the study area was delineated from the 2 m digital elevation model (DEM) using:

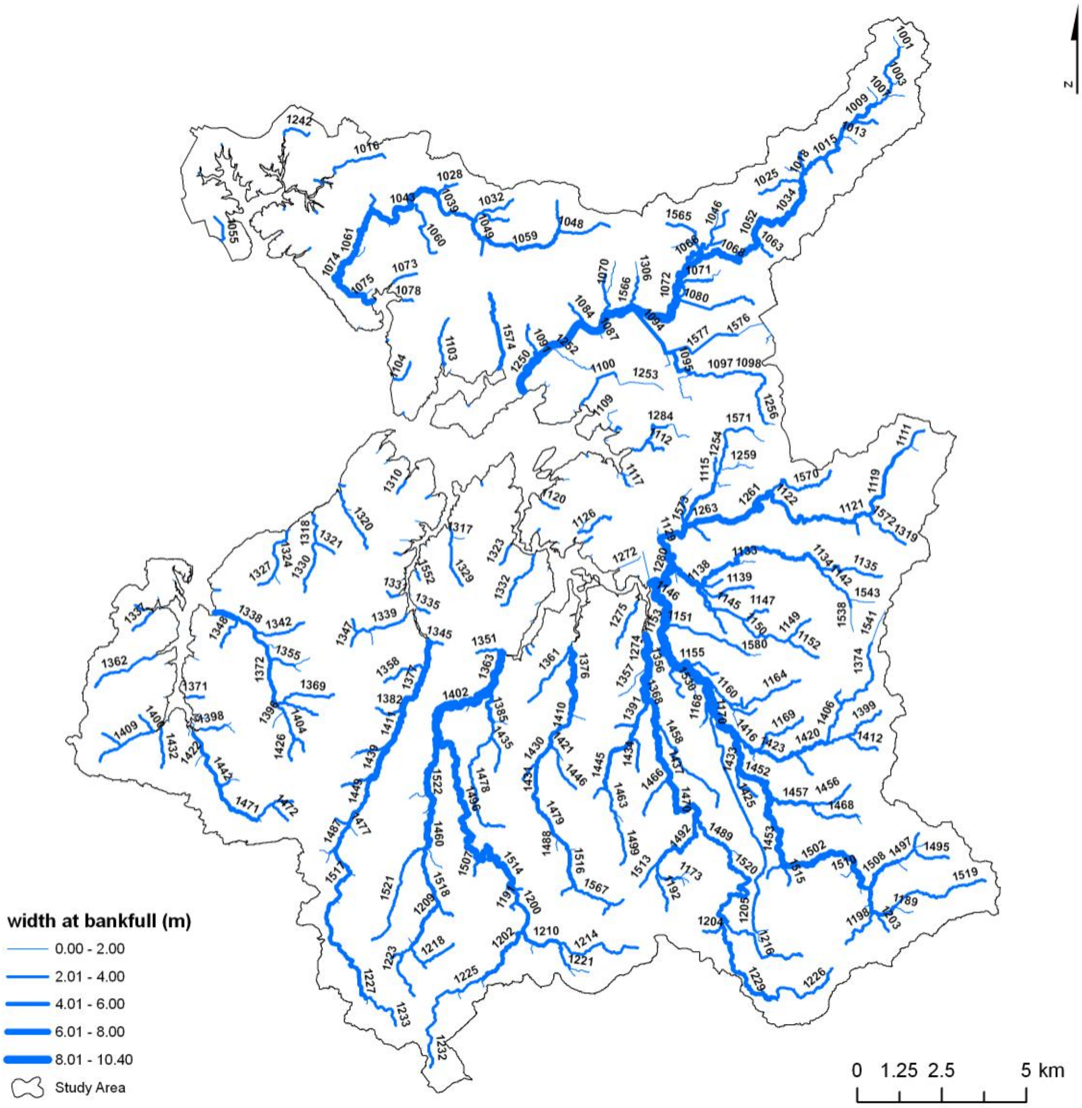
1. the flow accumulation function within ArcGIS to calculate the number of upslope cells flowing to a location with a threshold value applied to limit the number of cells;
2. stream ordering within ArcGIS to assign a numeric order to links in the stream network;
3. the stream link function within ArcGIS to assign unique values to each of the links in a raster (pixel-based) linear network;
4. the stream to feature tool within ArcGIS to convert a raster representing a linear network to features representing the linear network with "to" and "from" nodes.

A map of the stream network in the study area is given in Figure 13.

The average curve number (CN), average slope (by the equal area method), and maximum reach length are required to compute time of concentration using the empirical formula derived from a regression analysis of Auckland catchments given in TP108 (ARC, 1999b). For all model units (MUs), the time of concentration was much less than the timestep of the GLEAMS model (one day). The average curve number (CN), average slope, and maximum reach length are derived from the entire subcatchment draining to each reach in the river network, i.e., aggregated upstream. A weighted runoff curve number was calculated using the TP108 (ARC, 1999b) method from an intersection of model units (MUs), characteristic land cover descriptions, and a reclassification of soil types into their hydrological soil groups. The zonal statistics tool within ArcGIS was used to calculate average slopes for each MU which was in turn used to calculate average slopes by the equal area method. Reach lengths were calculated using a simple field calculator within ArcGIS. Subcatchments-to-reach linkages were identified by using the spatial join tool within ArcGIS. The channelisation factor, allowing for the effects of urbanisation on runoff velocities was taken as 0.6 for all urban reaches, and 0.7 for reaches in the urban and rural zone. These factors were applied to all current, historical and future urban and rural areas, accordingly. The stream channel width at bankfull, shown in Figure 13, was derived from empirical relationships of stream channel width and catchment area for the Waikato, given by

Davies-Colley and Quinn (1998). The flow at bankfull was derived from empirical relationships of flow at bankfull and catchment area (McKerchar and Pearson, 1989).

Figure 13:
Map of the stream network in the study area.



A river network data file was created from the above properties containing information on reach IDs, subcatchment IDs, reach-to-reach linkages, subcatchment-to-reach linkages, catchment areas, slopes and lengths, reach slopes and lengths, roughness, channelisation factors, width and flow at bankfull, and weighted curve numbers.

A control file was created with the number of subcatchments (580), number of reaches (580), number of daily times steps (18,262, corresponding to 50 years), and number of sediment classes (3).

A subcatchment data file was created with a daily time series of subcatchment flows and sediment discharges produced by the GLEAMS-SEM model.

A particle data file was created with properties of particles in three sediment classes: clay (<4 μm diameter), silt (4 to 63 μm) and sand (>63 μm). A density of 1,400kg m^{-3}, 1,550 kg m^{-3} and 1,800 kg m^{-3} was assumed for clay, silt and sand respectively, using information on soil physical properties in the area (McLeod, Landcare Research, pers comm.). The stream routing model is quite sensitive to the assumed particle size distribution. The GLEAMS model produces fractions of total sediment, and a mix of quantity of aggregates and particles of 5 particle types of eroded sediment in runoff: 1) clay, 2) silt, 3) small aggregates, 4) large aggregates, and 5) sand. Individual mixes of particle and aggregate size fractions were obtained from separate GLEAMS runs with the dominant soils in the subcatchment. These fractions were grouped into three classes of sand, clay and silt, based on particle and aggregate sizes. These fractions, based on GLEAMS outputs of eroded sediment in runoff were used as inputs to the stream routing model.

The routing model produces a time series for all reaches, on all days by particle size with the following information: peak flow, sediment (concentration, input, output, storage), both as total sediment, and by particle size class. All loads were added at the terminal reaches within a subcatchment.

5 Model outputs

Sediment loads from rural areas are passed to the estuary model (USC) as daily sediment loads at each outlet point for the full period of model runs (50 years). The outputs from GLEAMS-SEM are given in Parshotam (2008).

Sediment loads from earthworks and urban grasslands are passed to the contaminant load model (CLM) as annual average yields for each MU. This data is used by the CLM in the estimation of future urban sediment loads (Moores and Timperley, 2008). The loads from GLEAMS-SEM and the CLM are passed to the estuary model (USC) and manipulated to give a total load for a subcatchment, from both the rural and the urbanised area. Green (2008a) describes this process in detail.

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