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Central Waitemata Harbour Contaminant Study

GLEAMS Model Structure, Set-up and Data Requirements

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Central Waitemata Harbour Contaminant Study. GLEAMS Model Structure, Set-up and Input Data Requirements

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Prepared for
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Preface

The Waitemata 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. An earlier study examined long-term accumulation of sediment and stormwater chemical contaminants in the Upper Waitemata Harbour. However, previously little was known about the existing and long-term accumulation of sediment and stormwater chemical contaminants in the central harbour. The Central Waitemata Harbour 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 sedimentation 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 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:

- Henderson Creek (which drains the largest subcatchment and with the largest urban area, as well as substantial areas of rural land) contributes the largest loads of sediment, copper and zinc to the Central Waitemata Harbour. The second largest loads come from the Upper Waitemata Harbour.

- Substantial proportions of the subcatchment sediment, copper and zinc loads are accumulating in the Henderson, Whau, Meola and Motions tidal creeks and in the Shoal Bay, Hobson Bay and Waterview embayments.

- Central Waitemata Harbour bed sediment concentrations of copper and zinc are not expected to reach toxic levels based on current assumptions of future trends in urban 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. (For example, whereas the study addresses the Whau River as a whole, differences exist within parts of the Whau River that may merit a different magnitude or type of intervention than may be inferred from considering the Whau River and its long-term contaminant trends as a whole.) 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 Hauraki Gulf.

Technical reports

The study has produced a series of technical reports:

Technical Report TR2008/032
Central Waitemata Harbour Contaminant Study. Landuse Scenarios.

Technical Report TR2008/033
Central Waitemata Harbour Contaminant Study. Background Metal Concentrations in Soils: Methods and Results.

Technical Report TR2008/034
Central Waitemata Harbour Contaminant Study. Harbour Sediments.

Technical Report TR2008/035
Central Waitemata Harbour Contaminant Study. Trace Metal Concentrations in Harbour Sediments.

Technical Report TR2008/036
Central Waitemata Harbour Contaminant Study. Hydrodynamics and Sediment Transport Fieldwork.

Technical Report TR2008/037
Central Waitemata Harbour Contaminant Study. Harbour Hydrodynamics, Wave and Sediment Transport Model Implementation and Calibration.

Technical Report TR2008/038
Central Waitemata Harbour Contaminant Study. Development of the Contaminant Load Model.

Technical Report TR2008/039
Central Waitemata Harbour Contaminant Study. Predictions of Stormwater Contaminant Loads.

Technical Report TR2008/040
Central Waitemata Harbour Contaminant Study. GLEAMS Model Structure, Setup and Data Requirements.

Technical Report TR2008/041
Central Waitemata Harbour Contaminant Study. GLEAMS Model Results for Rural and Earthworks Sediment Loads.

Technical Report TR2008/042
Central Waitemata Harbour Contaminant Study. USC-3 Model Description, Implementation and Calibration.

Technical Report TR2008/043
Central Waitemata Harbour Contaminant Study. Predictions of Sediment, Zinc and Copper Accumulation under Future Development Scenario 1.

Technical Report TR2008/044
Central Waitemata Harbour Contaminant Study. Predictions of Sediment, Zinc and Copper Accumulation under Future Development Scenarios 2, 3 and 4.

Technical Report TR2009/109
Central Waitemata Harbour Contaminant Study. Rainfall Analysis.

Contents

1 Executive Summary

The main aim of the Central Waitemata Harbour (CWH) Contaminant Study is to model contaminant (zinc, copper) and sediment accumulation within the CWH for the purposes of, amongst other things, identifying significant contaminant sources, and testing efficacy of stormwater treatment and zinc source control of industrial roofs.

This report describes the implementation of the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model for simulating sediment generation in the rural parts of the catchment of the Central Waitemata Harbour. The model so implemented is called "GLEAMS-CWH".

The GLEAMS-CWH model is to be used to hindcast sediment run-off for the historical period 1940 to 2001 and to predict sediment run-off for the future period 2001 to 2100. The hindcast data are to be used to calibrate the USC-3 model. The predictions are to be used in the evaluation of future catchment development scenarios.

GLEAMS-CWH is a field-scale physics-based mathematical model for predicting daily run-off of water and sediment. The primary information required by the model is the catchment characteristics, including climate, topography, soils and land use. A GIS interface is used to manage the spatial information required as input (eg, soil patterns, land use and topography).

Predictions of surface run-off are coupled with soil, vegetation and slope properties to calculate particle detachment and hillslope sediment transport and deposition. The model predictions are of hillslope sediment loss and do not incorporate in-stream sediment dynamics. Processes of sheetwash and rill erosion are represented in the model, but soil loss from mass movement (eg, landslips) is not. The load from a grid cell may also be passed through a sediment control pond. These loads are aggregated on a catchment scale or routed to the stream network.

In previous applications of GLEAMS-based models in Auckland, a simple model for sediment control ponds was used. The pond model has been extended for this study.

Although GLEAMS-CWH is a physics-based model that does not require calibration strength of the model), extensive tests of the model's ability to predict sediment loss from earthworks activity were conducted. Confidence in the model for other land uses is derived from its application in a number of other studies in the Auckland region.

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2 Introduction

Modelling and empirical data indicate that stormwater contaminants are rapidly accumulating in the highly urbanised side branches of the Central Waitemata Harbour (CWH). However, there is no clear understanding of the fate of contaminants exported from these side branches into the main body of the harbour, or that of contaminants discharged directly into the harbour.

The main aim of the study is to model contaminant (zinc, copper) and sediment accumulation within the CWH for the purposes of, amongst other things, identifying significant contaminant sources, and testing efficacy of stormwater treatment and zinc source control of industrial roofs.

2.1 Study aims

The study aims to:

- predict contaminant loads based on past, present and future land use and population growth for each sub-catchment discharging into the CWH, allowing for stormwater treatment and zinc source control of industrial roofs;
- predict dispersal and accumulation (or loss) of sediment and stormwater contaminants in the CWH;
- calibrate and validate the dispersal/accumulation model;
- apply the various models to predict catchment contaminant loads and accumulation of copper, zinc and sediment in the CWH under specific scenarios that depict various combinations of projected land use/population growth, stormwater treatment efficiency, and zinc source control of industrial roofs;
- determine from the model predictions the relative contributions of sediment and contaminant from individual sub-catchments and local authorities;
- provide an assessment of the environmental consequences of model outputs;
- provide technical reports on each component of the work; and
- provide a desktop application suitable for use by ARC personnel.

2.2 Model suite

The study centres on the application of three models that are linked to each other in a single suite:

- 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[1].

- The CLM 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.
- 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 model: an estuarine sediment-transport model, which simulates the dispersal of contaminants/sediments by physical processes such as tidal currents and waves.

2.3 This report

This report describes the implementation of the GLEAMS model for simulating sediment generation in the rural parts of the catchment of the Central Waitemata Harbour. The model so implemented is called "GLEAMS-CWH".

A GIS analysis of soils, slope and land use information is used in GLEAMS. The same analysis is also used in the CLM model in coarser detail. (The CLM model is used to simulate sediment and contaminant generation from urban parts of the catchment.) Greenfield earthworks sediment yield data from GLEAMS for the whole catchment (urban and rural) is provided as an input to the CLM model (Timperley and Reed, 2008).

The GLEAMS-CWH model was used to hindcast sediment run-off from the catchment of the Central Waitemata Harbour for the historical period 1940 to 2001 and to predict sediment run-off for the future period 2001 to 2100. The hindcast data were used to calibrate the USC-3 model, which is described by Green (2008). The predictions were used in the evaluation of future catchment development scenarios.

Earlier variants of the GLEAMS-CWH model, such as BNZ (Basin New Zealand) (Stroud and Cooper, 1997), GLEAMSHELL (Rodda et al., 1997) and WAM-O (Watershed Asessment 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 land use 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,

[1] We use the term "contaminant" herein to mean chemical contaminants such as zinc and copper, and we refer to "sediments" separately.

et al., 1999; Stroud and Cooper, 1999); and contaminant accumulation in the Upper Waitemata Harbour (Green et al., 2004).

A key benefit of this 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 land use management; predict sediment accumulation and run-off from impervious surfaces; and evaluate erosion and deposition in streams, lakes and reservoirs.

3 Model Description

3.1 GLEAMS-CWH 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 run-off 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 requirement is the catchment characteristics, including climate, topography, soils and land use. A GIS interface is used to manage the spatial information required as input (eg, soil patterns, land use and topography). Model simulations are conducted for unique combinations of soil, slope and land cover. The version of the GLEAMS model modified and adapted for the purposes of this study is known here as the GLEAMS-CWH model. The Basin Unique Cell Shell (BUCSHELL) model within GLEAMS-CWH generates input parameter files and determines which submodel to use by comparing land use and/or soil codes.

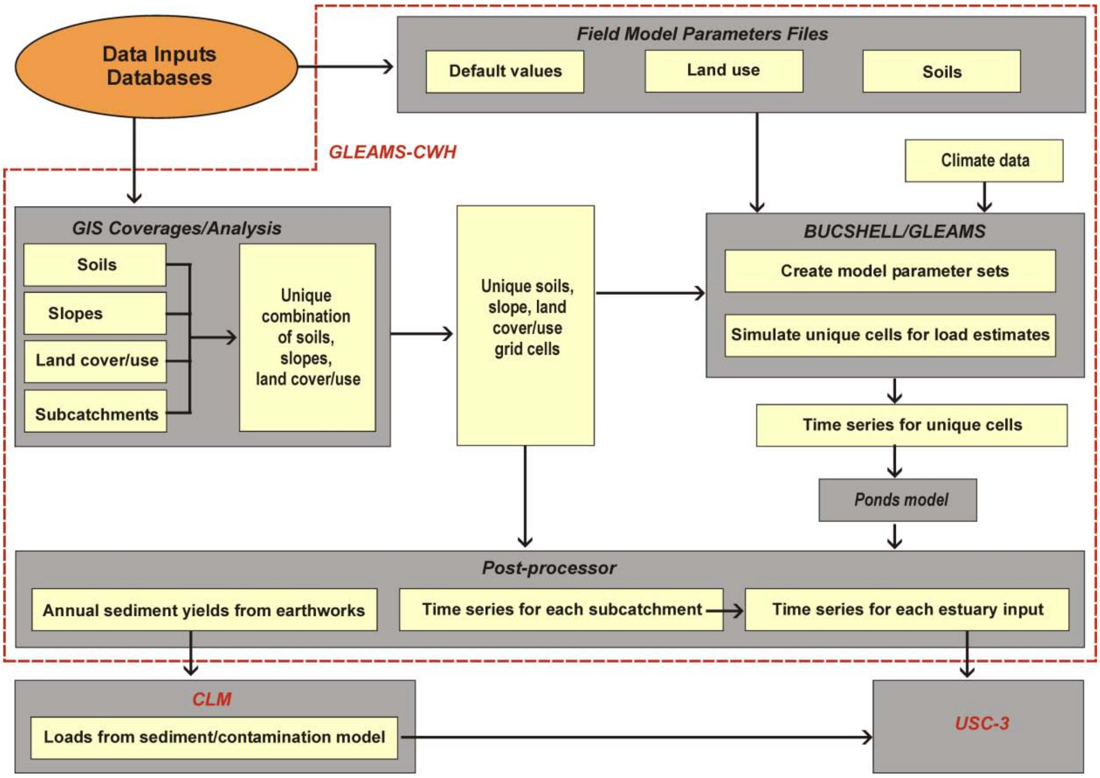
GLEAMS-CWH (see Figure 1) is similar in concept to the Watershed Assessment Model (WAM) (Botcher, 1998), which is a GIS-based, watershed-scale model developed by Soil and Water Technologies (SWET), Inc., except that GLEAMS-CWH does not include stream processes. WAM is an upgraded version of the initial Basin-New Zealand model developed by Cooper and Botcher (1993).

The GLEAMS model uses soils and land use data for each cell, together with long-term (this study used a 50-year record) climate data (rainfall, temperature, and radiation) to calculate a daily water balance for each cell. Incoming rainfall is proportioned between surface run-off, storage in the soil profile, evapotranspiration and percolation beneath the root zone. Predictions of surface run-off are coupled with soil, vegetation and slope properties to calculate particle detachment and hillslope sediment transport and deposition. The model predictions are of hillslope sediment loss and do not incorporate in-stream sediment dynamics. Note that processes of sheetwash and rill erosion are represented in the model, but soil loss from mass movement (eg, landslips) is not. The load from a grid cell may also be passed through a sediment control pond. These loads are aggregated on a catchment scale or routed to the stream network.

GLEAMS has been validated and updated against monitoring data. Information from previous catchment modelling (particularly the Upper Waitemata Harbour [UWH] contaminant study), and the literature was used to establish suitable parameter values for this study.

The predicted surface run-off, subsurface run-off and sediment generated from each grid cell may be routed through the stream network, via connected reaches, to the catchment outlet. In the current work, as in the previous UWH study, model results from the grid cells are simply aggregated to a catchment scale and no sedimentation or erosion in the stream channels was simulated. This assumption was used after noting that there is limited opportunity for sediment deposition in this relatively steep catchment. Moreover, any stream erosion sources are either not significant or are already implicity embodied within the parameters derived in previous calibration/validation work in the Auckland region. Also, note that in the current study, stream erosion associated with urbanisation is treated separately in the associated CLM contaminant/sediment generation model.

Figure 1
GLEAMS-CWH model structure.



3.2 Setting up the GLEAMS-CWH model

Rasterised soil, topographical and land use data are pre-processed within a GIS to input to GLEAMS-CWH. Associated sub-catchments (known as SMUs or Stormwater Management Units) are used to manage the whole catchment.

GLEAMS-CWH has been established using a 30 m x 30 m grid (ie, 253,144 grid cells for the 22,783 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 2). In particular, the catchment of the Upper Waitemata Harbour was not modelled as this area had been covered in earlier studies.

The following steps are required to estimate sediment generation in the Central Waitemata Harbour using GLEAMS-CWH:

1. Create files of unique combinations of soils, slope and land cover classes using pre-processing.
2. Set up soils and land use parameter files.
3. Run the GLEAMS model for each unique combination of soil, slope and land cover.
4. Run sediment pond model where appropriate.
5. For each SMU:
    a. Derive fraction of each land cover type for the year.
    b. Derive number of each soil–slope–land cover combinations.
    c. Combine results from GLEAMS runs to give daily load for the SMU.
6. Combine yields from SMUs to give a time series of loads from all sub-catchments associated with an outlet into the harbour.
7. Pass sub-catchment sediment loads in the appropriate form and data format to the CLM and USC models.

3.3 Generation of unique cells

GLEAMS-CWH uses ArcGIS functions to create a computer text-file list of "unique combinations" of land use, 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 sub-catchments.

3.4 The GLEAMS model

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) (Knisel and Davis, 2000) is the core model used in GLEAMS-CWH. GLEAMS is a physics-based, continuous-simulation, field-scale model, which was developed as an extension of the Chemicals, Run-off 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 run-off and sediment losses from the field and assumes that a field has homogeneous land use, soils, and precipitation. A full description of how the GLEAMS model works is given in Knisel (1993).

In the current work, the latest version of GLEAMS, ie, 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.

One of the factors responsible for variation in sediment losses is the variation in rainfall. If rainfall were low during the period of earthworks then measured sediment losses would be less than if major rainfall events occurred. As field studies are typically short-term, the data they generate may not take into account this source of variability (Stroud et al., 1999). This is particularly relevant when predictions are to be made of the consequences of future earthworks activity, where a risk-based approach that includes some representation of rainfall variability must be used. This is where the strength of a simulation modelling approach becomes particularly apparent because it synthesises a record of sediment run-off using long-term rainfall data (50 years in this case) that can be used to examine risks of certain values being exceeded.

Although GLEAMS-CWH is a physics-based model that does not require calibration (a strength of the model), extensive tests of the model's ability to predict sediment loss from earthworks activity have been conducted. Predictions from the model have consequently been compared to monitoring data. Confidence in the modelling approach for other land uses is derived from its success in predicting sediment loss from pasture, pine and mixed land use catchments of the Mahurangi esturay (Stroud and Cooper, 1997; Stroud et al., 1999), Okura (Stroud and Cooper, 1999) and Whitford (Senior et al., 2003). The study at Okura (Stroud and Cooper, 1999) examined sediment in the Alexandra stream during the earthworks phase of catchment development. The study at Whitford examined earthworks associated with individual site developments and road construction during rural intensification. These studies and others contain soils and slopes that are representative of the CWH catchment. Parameter values are generally taken from previous catchment modelling (particularly the Upper Waitemata Harbour) studies.

3.5 Bare earth treatment

Techniques were developed for incorporating the spatial and temporal pattern of any earthworks within the model, if given only as an area or fraction of an SMU, and not at a specific location. Bare earth cover is treated as another land cover and this is distributed on all possible soil and slope combinations. Techniques were also developed for removing an equivalent area of a given land cover. Soils are reclassified with their topsoils removed reflecting earthworks practices. Seasonal restrictions for earthworks practices were assumed as in previous studies (Collins, 2003) limiting them to between 1 October and 30 April inclusive, with earthworks stabilisation in the off-season. Sediment control ponds

3.6 Sediment control ponds

In previous applications of GLEAMS-based models in Auckland, a simple model for sediment control ponds was used. In this study, the pond model was extended to allow the following:

- 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 run-off events.
- Flow varying through a storm event (of one-day duration). This was achieved by: calculating an effective curve number for the event (based on GLEAMS output run-off); 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 sediment 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 volume of the ponds is discussed in a later section. The decant rate was set at 4 L s^{-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. The median settling velocity was 0.4 m day^{-1}, corresponding to spherical quartz 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 run-off (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 corresponding to each outlet from fractions of each land use type and numbers of soil–slope–land use combinations. Sediment loads from rural areas 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. Exactly how these loads are incorporated into the USC-3 model is explained by Green (2008).

Results from the GIS analysis (catchment areas, soils, slopes and land use information) are also passed to the CLM model in a coarse and tabulated form. Predictions of losses from earthworks in the urban areas are passed to the CLM model as annual average yields for each SMU. Exactly how these are used in the CLM model is explained in Timperley and Reed (2008).

4 Model Input Information

4.1 Catchments, outlets and Stormwater Management Units (SMUs)

The study area was broken into 72 SMUs (Stormwater Management Units) nested within 14 outfall sub-catchment areas. The SMU data were provided by respective councils. Each of these sub-catchments has been assigned an outlet into the harbour (see Figure 2). Further details on the outfall locations are given in the report on the implementation of the USC-3 model for the Central Waitemata Harbour (Green, 2008). The catchment excludes the earlier Upper Waitemata Harbour catchment.

Figure 2

Map of sub-catchments and corresponding outlet points.

A map of corresponding Stormwater Management Units (SMUs) is given in Figure 3.

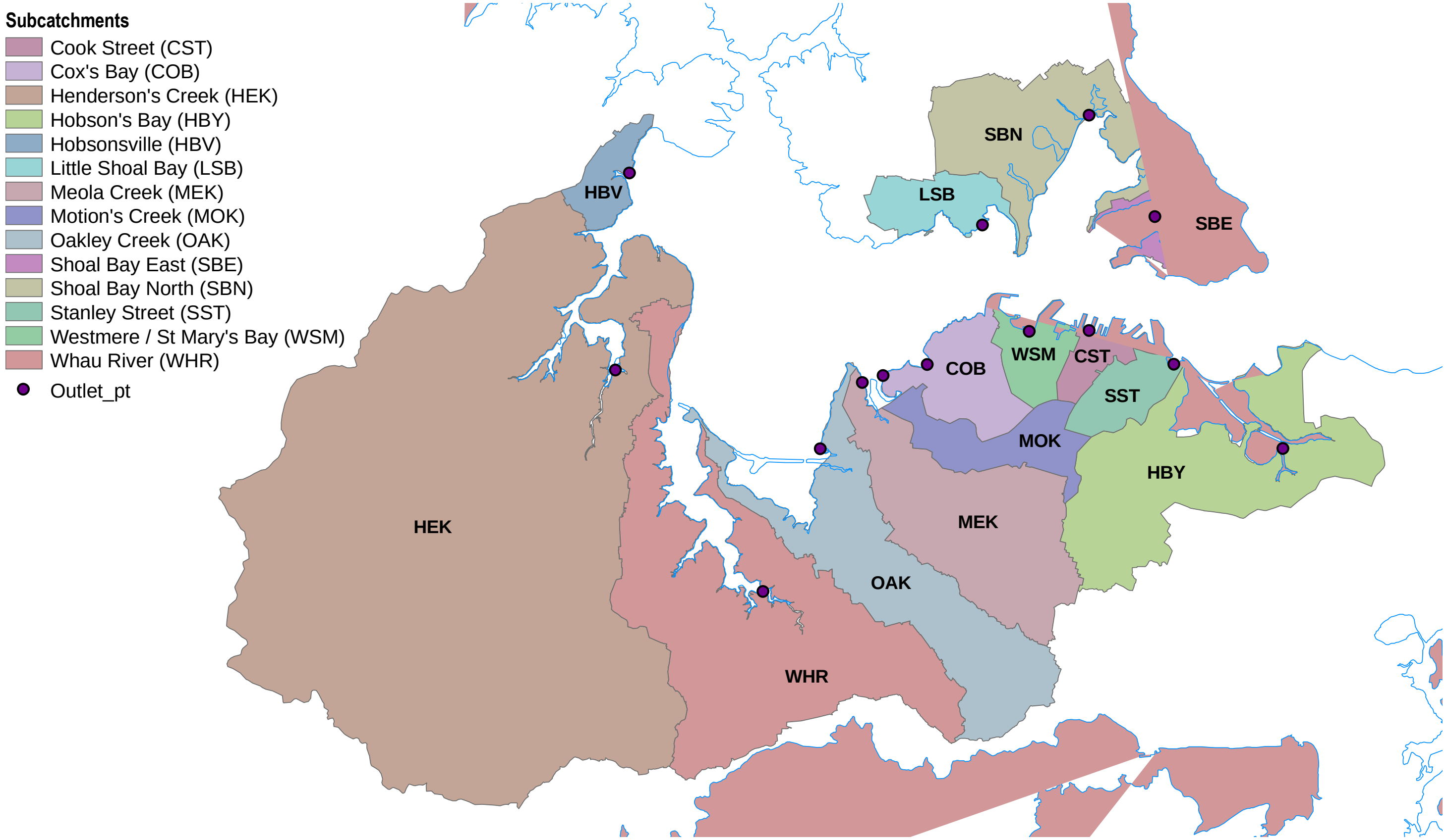
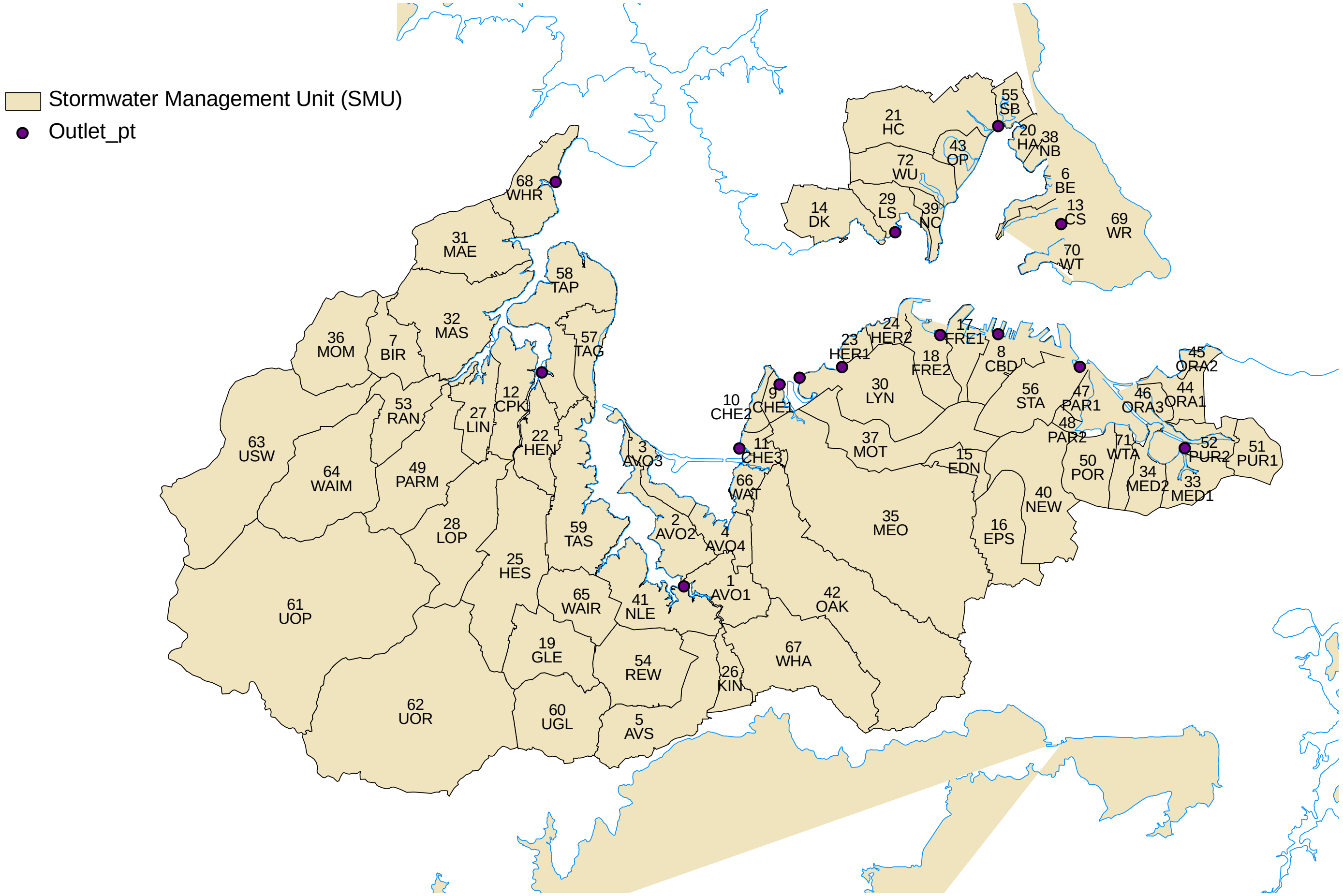


Figure 3

Map of Stormwater Management Units (SMUs) including unique identifiers used in this study.



4.2 Climate

The GLEAMS model requires daily and monthly meteorological data. These data were obtained from numerous sites because no single site held a complete, unbroken record.

Climate data were obtained from NIWA's climate database, CliFlo, from various stations throughout the region. The specific rainfall gauges used are well described in CliFlo. These records were collated, analyzed and merged. GLEAMS climate input files were compiled based on 50 years of rainfall data, temperature and radiation. Some data were not available for a long period of record at a single station, in which case a few stations were used to fill the gaps with corrections based on ratios of annual averages.

Rainfall data from 11 stations around the Waitemata Harbour were examined. These stations were grouped into Western, Northern and South-eastern stations and charts of cumulative percentiles versus rainfall (mm day^{-1}) were compared. These showed very little differences in the probability distribution of rainfall between these sites. A final selection of daily rainfall data representative of the region was taken from the Northern station 1412 (Albany) for the period 1966 to 2005 with station 1410 (Whenuapai Aero) used to fill gaps. Station 1412 (Albany) commenced in 1966 and station 1410 (Whenuapai Aero) was used to extend the record from 1954 to 1966.

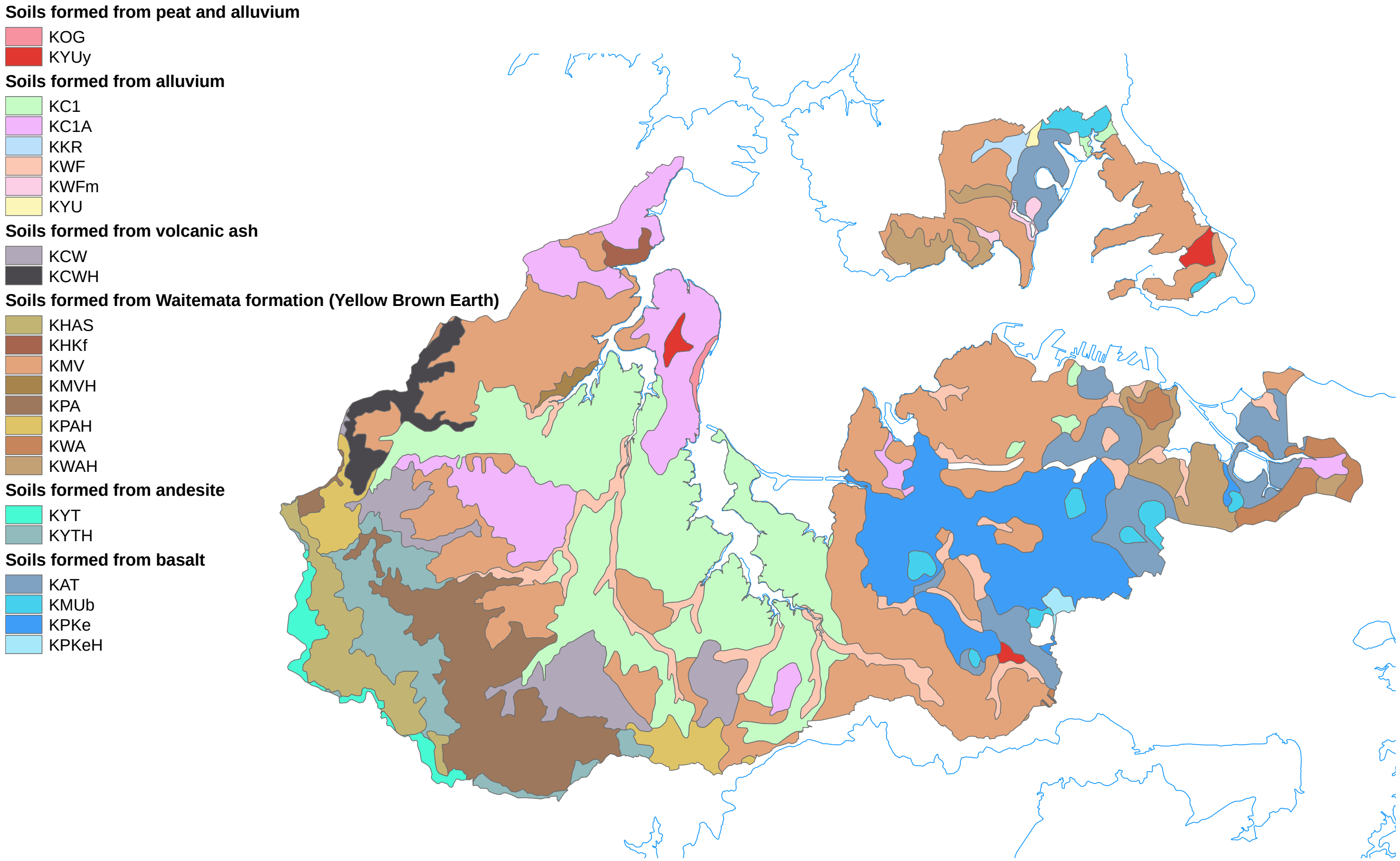
The data requirements for the potential evapotranspiration (PET) component of the GLEAMS model for the period 1954 to 2005 are monthly averages for: 1) daily maximum air temperature and daily minimum air temperature (most data are from Station 1468 – Auckland, Owairaka); 2) daily average solar radiation. Most data are from Station 1410 (Whenuapai Aero) and a high proportion of data is calculated based on differences from annual averages.

4.3 Soils

Soil classes, properties and maps (see Figure 4) 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).

Figure 4

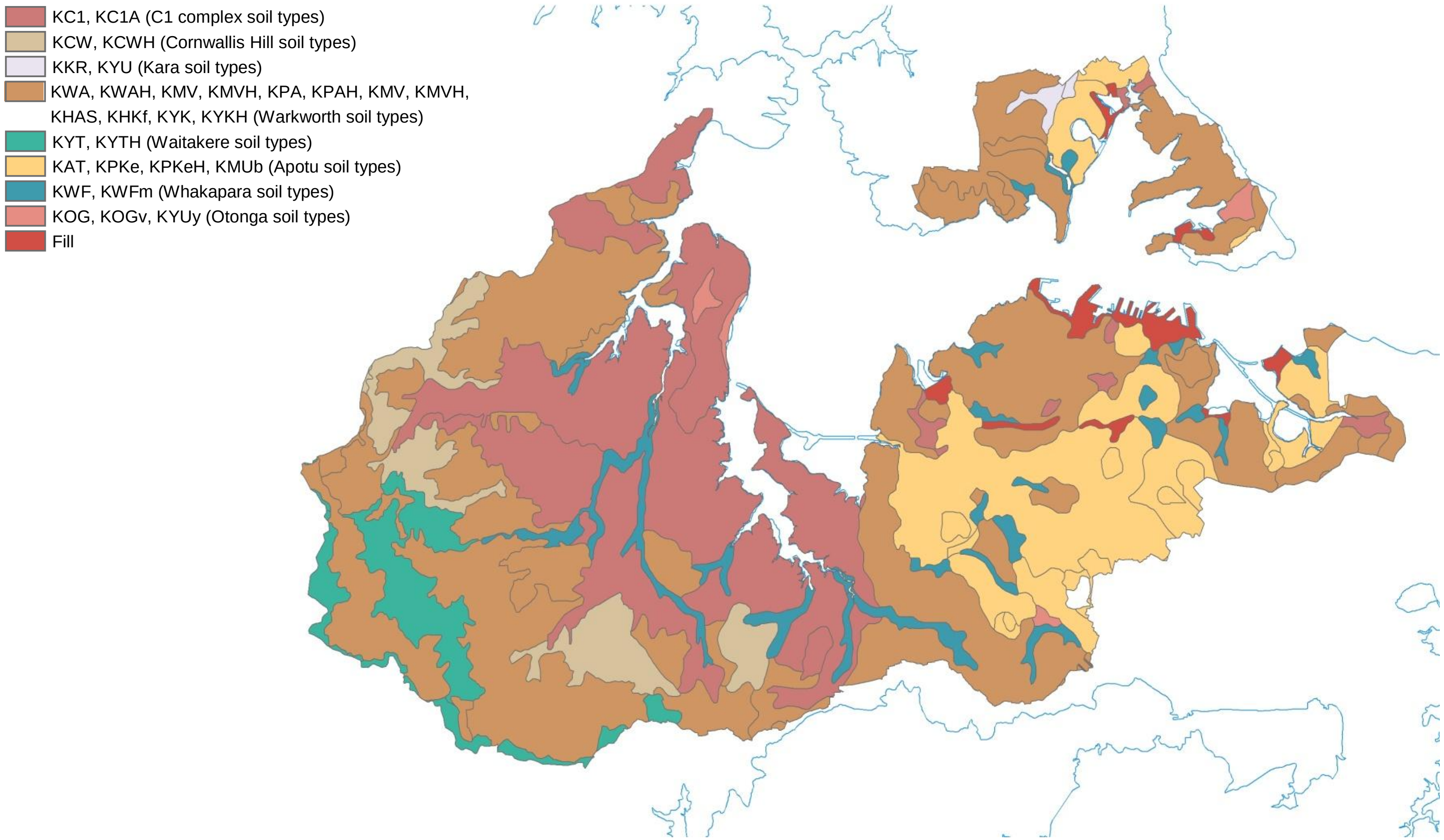
Major soils in the Auckland region from the National Soils Database (NSD).



These soil types were combined into a smaller number of major soil types (Figure 5). The spatial pattern of soil types was used as an input GIS overlay to GLEAMS-CWH. 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 5

Major soil types in the Auckland region from the National Soils Database (NSD).



Further useful information on these soils and soils in the Auckland region was derived from published data and reports (Harmsworth, 1996; Jessen, 1983; Stroud and Cooper, 1997; ARC, 2001).

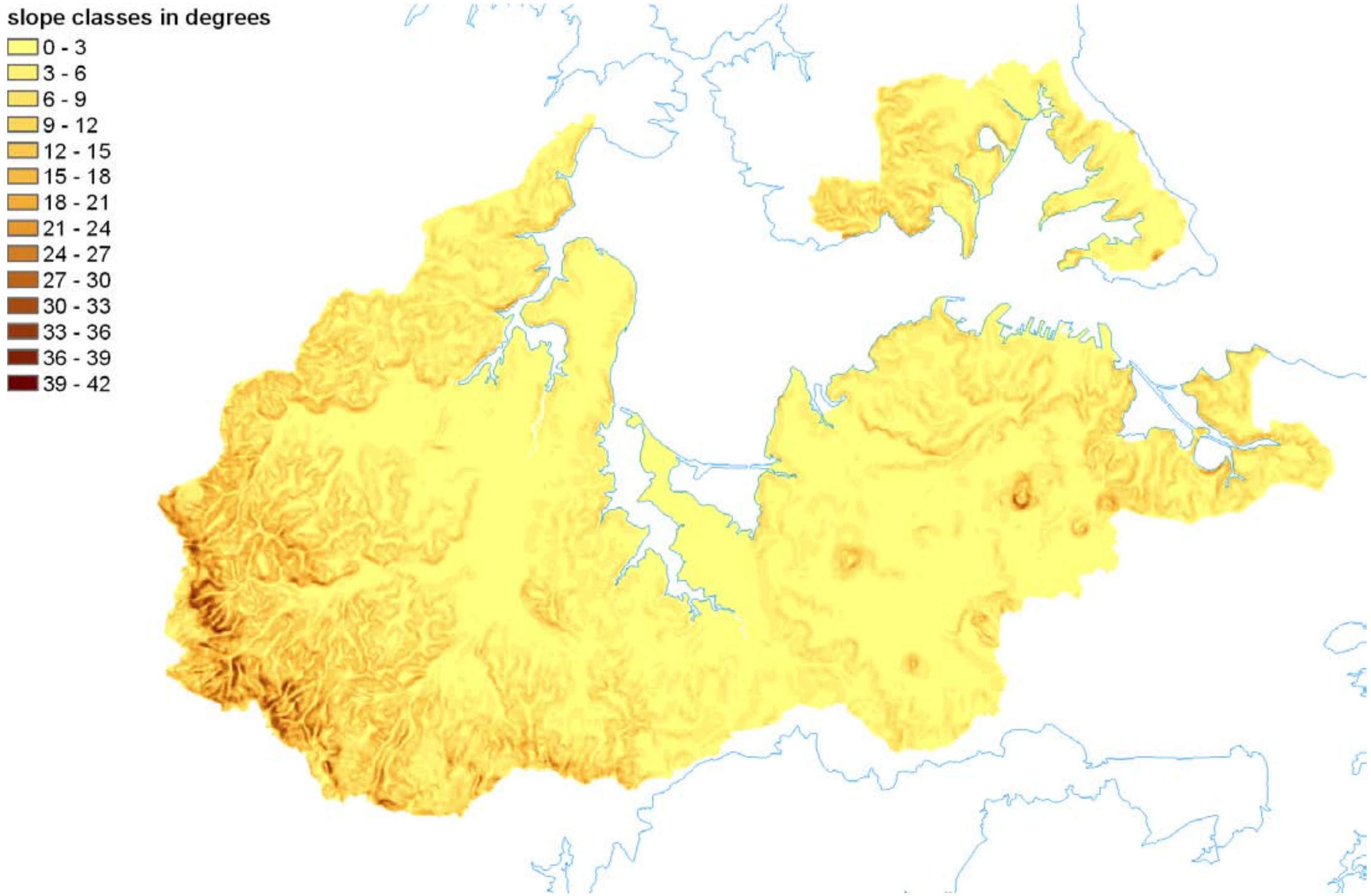
During the earthworks phase of site development, topsoil is generally removed, thus exposing clay-dominated subsoils. This practice was simulated in the modelling. Because subsoil clay has little organic matter associated with it, it is easily detached from the soil surface and entrained within the surface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

Details on methods used for calculating parameters, such as soil erodibility factors, vegetative cover coefficients and Manning's roughness coefficients are given in the reports on earlier studes (referenced above).

4.4 Topography

GLEAMS slope classes were based on 20-m contour data. Arc-GIS was used to derive a digital elevation model (DEM). From the DEM, the mean slope angle for each cell was determined. The cell slopes were grouped in intervals of 3 degrees and the spatial distribution of these groups used as input to GLEAMS-CWH (see Figure 6).

Figure 6
Slope angle classes in the Central Waitemata Harbour catchment.



Slope angle classes ranged from 3 to 42 degrees and these values were used in the model simulations. 45%, 25% and 13% of land within the study area falls within the 0–3, 3–6 and 6–9 slope categories, respectively.

4.5 Land use

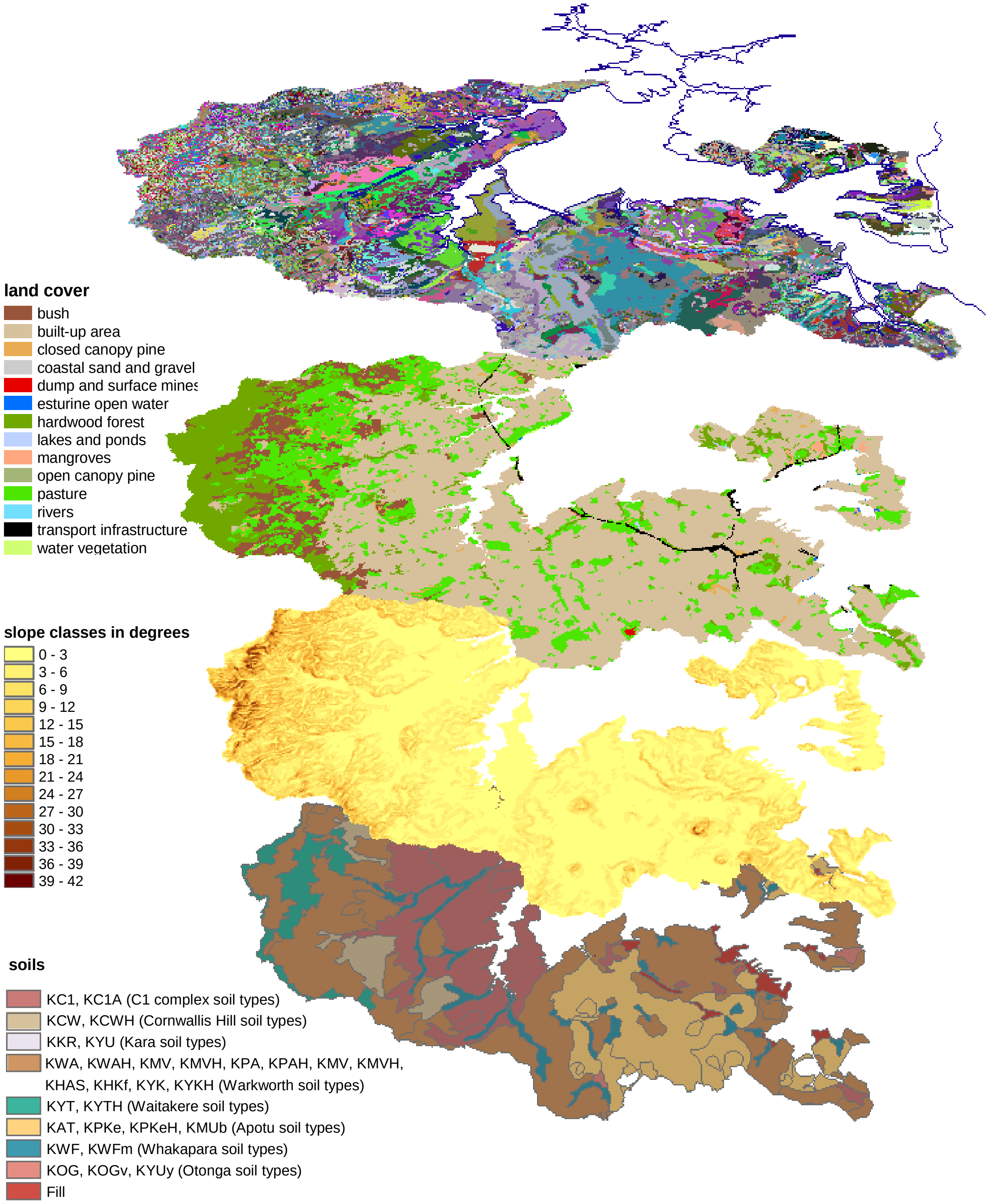
The land use data for use in the GLEAMS-CWH model are discussed in the report by Parshotam and Wadhwa (2007).

4.6 Unique combinations of soil, slope and land cover

GIS techniques for overlaying CWH soils, land cover and slope information produced unique combinations of soils, land cover and slope (see Figure 7)

Figure 7

Map showing unique combinations of soils, slopes and land cover.



4.7 Estimates of bare earth

Estimates for bare earth used in the GLEAMS-CWH model are discussed in the report by Parshotam and Wadhwa (2007).

4.8 Treatment of land with the use of sediment ponds

The use of detention ponds and their sizes have changed over time:

- 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 catchments and ½% for vegetated portions. Widespread use of ponds had occurred by the late 1980s.
- 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, 1999). Implementation was widespread by that time and ponds became larger. Flocculation came into use around 2002 with widespread implementation by 2005

In our GLEAMS-CWH modelling work, it is assumed that ponds are applied, 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, all treatment of run-off with sediment control ponds is done within the CLM model.

4.9 Sediment particle size distribution data

Sediment particle-size distribution data in streams were obtained from Alexandra, an urbanising basin on the North Shore (Hicks,1994), and from recent sampling from Waitangi and Papakura streams (see Figures 8, 9 and 10). This information is to be used in the USC-3 model, as explained in detail by Green (2008).

Figure 8

Particle-size distributions of suspended sediment sampled at the Waitangi stream.

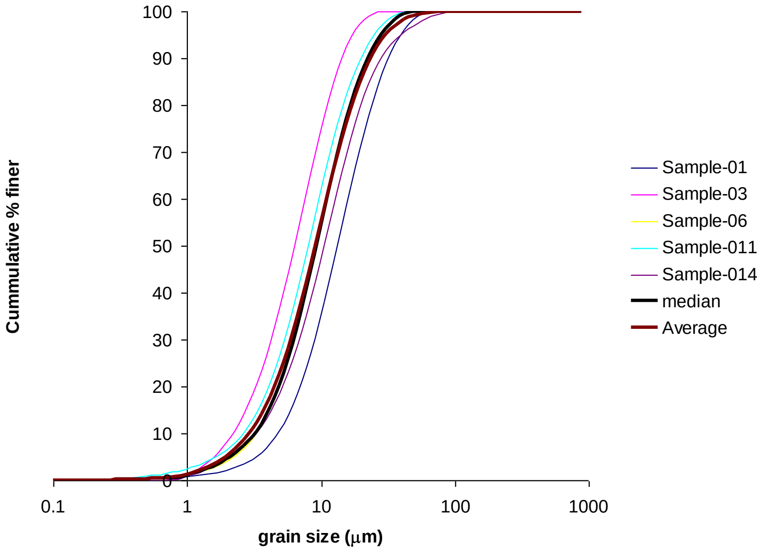


Figure 9

Particle-size distributions of suspended sediment sampled at the Papakura stream.

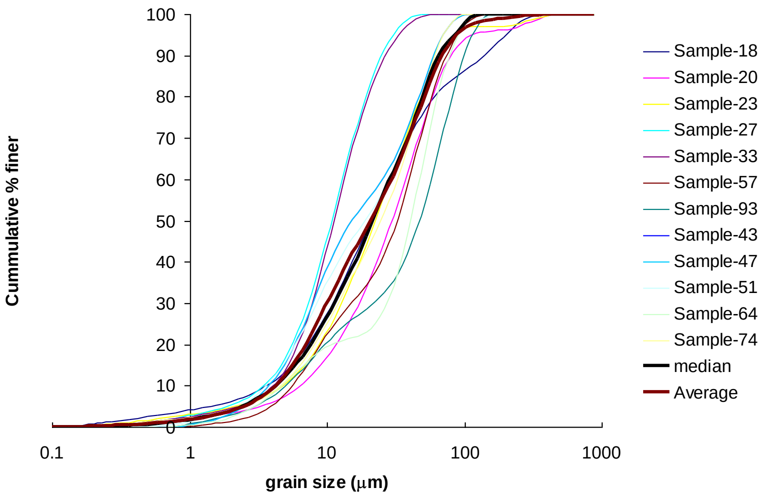
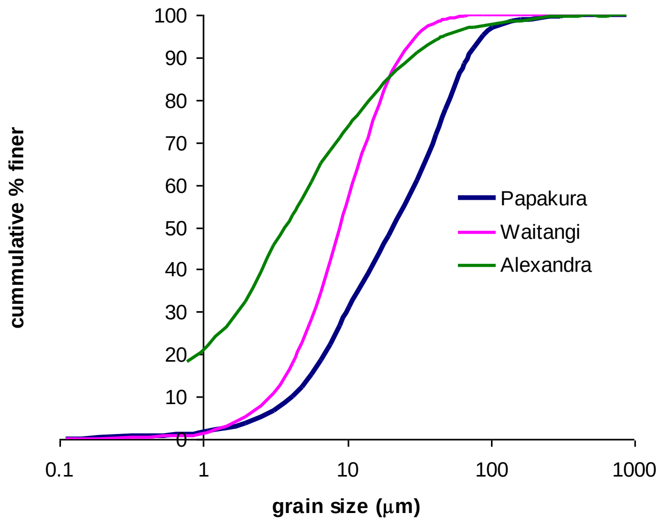


Figure 10

Averages of particle-size distributions of suspended sediment sampled at the Alexandra, Waitangi and Papakura streams.



5 References

AUCKLAND REGIONAL WATER BOARD, 1990. *Erosion and Sediment Control Guidelines for Earthworks*. Series Technical publication (Auckland Regional Water Board); No. 97. 38 p.

AUCKLAND REGIONAL COUNCIL, 1999a. *Erosion and Sediment Control Guidelines for Land Disturbing Activities in the Auckland Region*. Auckland Regional Council Technical Publication No. 90. Auckland Regional Council.

AUCKLAND REGIONAL COUNCIL, 1999b. *Guidelines for stormwater run-off modelling in the Auckland region.* Auckland Regional Council Technical Publication No. 108. (ARC TP108). Auckland Regional Council.

AUCKLAND REGIONAL COUNCIL, 2001. *Background concentrations of inorganic elements in soils from the Auckland region.* Auckland Regional Council Technical Publication No. 153. Auckland Regional Council.

AUCKLAND REGIONAL WATER BOARD, 1978. *Earthworks - A Guideline for Erosion and Sediment Control.*

BOTCHER, A.B.; HISCOCK, J.G.; PICKERING, N.B. & JACOBSEN, B.M., 1998. WAM: Watershed Assessment Model for agricultural and urban landscapes, In: Proceedings of the *7th International conference of Computers in Agriculture*, Orlando, ASAE Publication 13-98, St Joseph, Michigan. ISBN 0-929355-99-7, pp 257-268.

COLLINS, R., 2003. *Predicting sediment loss under proposed development in the Waiarohia catchment.* NIWA Client Report HAM2003-063. National Institute of Water and Atmospheric Research, Hamilton.

COOPER, A.B. & BOTCHER, A.B., 1993. Basin scale modelling as a tool for water resource planning. *Journal of Water Resources Planning and Management 119*: 303-323.

GREEN, M.; TIMPERLEY, M.; COLLINS, R.; SENIOR, A.; ADAMS, R. & SWALES, A., 2004. *Prediction of Contaminant accumulation in the Upper Waitemata Harbour – Methods*. NIWA Client Report HAM2003-087/1.

GREEN, M., 2008. Central Waitemata Harbour Contaminant Study. USC-3 Model Description, Implementation and Calibration. Prepared by NIWA Ltd for Auckland Regional Council. Auckland Regional Council Technical Report 2008/042.

HARMSWORTH, G.R., 1996. *Land Use capability classification of the Northland region*, Landcare Research Science Series No. 9.

HICKS, D.M., 1994. *Storm sediment yields from basins with various land uses in Auckland area.* Auckland Regional Council Technical Publication No. 54. Auckland Regional Council.

JESSEN, M., 1983. *Land resources of the Upper Waitemata Harbour catchment.* Auckland Regional Authority UWHCS Specialist Report.

KNISEL, W.G. (ed.), 1980. *CREAMS: A Field Scale Model for Chemicals, Run-off, and Erosion from Agricultural Management Systems.* U.S. Department of Agriculture, Conservation Report No. 26, 640 pp.

KNISEL, W.G. (ed.), 1993. *GLEAMS Groundwater Loading Effects of Agricultural Management Systems,* Version 2.10. Dept. Publication No. 5, Biological & Agricultural Engineering Department, University of Georgia-Coastal Plain Experiment Station, Tifton. 260 pp.

KNISEL, W.G.; DAVIS, F.M., 2000. *Groundwater Loading Effects of Agricultural Management Systems*. Version 3.0. Publication No. SEWRL-WGK/FMD-050199, revised 081500, Washington.

OLDMAN, J.; STROUD, M.J.; CUMMINGS, V.J.; COOPER, A.B., 1998. *Mahurangi land use scenario modelling*. Client Report ARC70216/2, National Institute of Water and Atmosphere, Hamilton.

OLDMAN, J.W.; SWALES, A., 1999. *Mangemangeroa estuary numerical modelling and sedimentation.* NIWA Client Report ARC70224. National Institute of Water and Atmospheric Research, Hamilton.

PARSHOTAM, A.; WADHWA, S., 2007. *Central Waitemata Harbour Contaminant Study. Land use scenarios* .Prepared by NIWA Ltd for Auckland Regional Council. Auckland Regional Council Technical Report 2008/032

RODDA, H.; SHANKAR, U.; THORROLD, B., 1997. *The Development of Decision Support Tools for Managing Water Quality in Agricultural Landscapes: Year 2*. NIWA Consultancy Report MAF7021. National Institute of Water and Atmospheric Research, Hamilton.

SENIOR, A.; OLDMAN, J.; GREEN, M.O.; NORKKO, A.; HEWITT, J.; COLLINS, R.P.; STROUD, M.J.; COOPER, A.B.; THRUSH, S., 2003. *Risks to estuarine biota under proposed development in the Whitford catchment*. ARC01264;

ARC01265; ARC01266. Hamilton, NIWA Client Report HAM2003-016. National Institute of Water and Atmospheric Research, Hamilton.

STROUD, M.J.; COOPER, A.B., 1997. *Modelling sediment loads to the Mahurangi Estuary*. Unpublished NIWA client report ARC60211.

STROUD, M.J.; COOPER, A.B., 1998. *Predicting soil loss under outdoor vegetable production at Pukekohe.* NIWA Client Report ARC60202. National Institute of Water and Atmospheric Research, Hamilton.

STROUD, M.J.; COOPER, A.B., 1999. *Assessment of sediment impacts on Okura estuary associated with catchment developments. Effects of sediment controls.* NIWA Client Report ARC00202. National Institute of Water and Atmospheric Research, Hamilton.

STROUD, M.J.; COOPER, A.B.; BOTCHER, A.B.; HISCOCK, J.G., PICKERING, N.B., 1999. *Sediment run-off from the catchment of Okura estuary.* NIWA Client Report ARC90241/1. National Institute of Water and Atmospheric Research, Hamilton.

STROUD, M.J., 2003. *Modelling long-term daily sediment loads to the Mahurangi Estuary.* NIWA Client Report HAM2003-144. National Institute of Water and Atmospheric Research, Hamilton.

TIMPERLEY, M., REED, J. 2008. *Central Waitemata Harbour Contaminant Study. Development of the Contaminant Load Model..* Prepared by NIWA Ltd for Auckland Regional Council. Auckland Regional Council Technical Report 2008/038.

WILLIAMSON, R.B.; GREEN, M.O.; STROUD, M.J.; HUME, T.M.; PRIDMORE, R.D., 1998. *Sedimentation in Orewa estuary: impacts of further urban and motorway development.* 45p. Report prepared for Auckland Regional Council. Report and project number ARC80234. National Institute of Water and Atmospheric Research, Hamilton.