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TE RAUHĪTANGA TAIAO

Central Waitemata Harbour Contaminant Study

Land Use Scenarios

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Central Waitemata Harbour Contaminant Study. Land Use Scenarios

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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 overall aim of the Central Waitemata Harbour (CWH) Contaminant Study is to model contaminant (zinc, copper) and sediment accumulation within the harbour for the purposes of, amongst other things, identifying significant contaminant sources, and testing efficacy of stormwater treatment and zinc source control of industrial roofs. The objective is to predict (using models) contaminant build-up and movement in the CWH.

This report describes the development of land use information for the catchment of the Central Waitemata Harbour for the historical period (1940 to 2001), the current time (2001), and the future period (2001 to 2100).

The emphasis is on developing land use information required as input to the GLEAMS model which, in the CWH Study, is used to hindcast/predict sediment run-off from the rural parts of the catchment surrounding the Central Waitemata Harbour.

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. .

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 Work plan

There are eight modules in the work plan:

- Module 1 – Implementation of the sediment-generation model.
- Module 2 – Implementation of the contaminant/sediment-generation model.
- Module 3 – Implementation of the contaminant/sediment-accumulation model.
- Module 4 – Calibration and validation of the model suite.
- Module 5 – Depiction of development scenarios, including stormwater treatment and zinc source control of industrial roofs, as required.
- Module 6 – Execution of the model suite to produce predictions of contaminant build-up in bed sediments of the CWH.
- Module 7 – Evaluation of predictions with management.

This may lead to reconsideration of Module 5, and subsequent re-running of Module 6 until an acceptable development scenario can be found.

- Module 8 – Development of desktop application.

2.4 This report

This report describes the development of land use information for the catchment of the Central Waitemata Harbour for the historical period (1940 to 2001), the current time (2001), and the future period (2001 to 2100).

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

Both the CLM contaminant/sediment-generation model and the GLEAMS sediment-generation model require land use information as an input. The ouputs from those two models are used as inputs to the USC-3 model. Earthworks sediment yield data estimated by GLEAMS from areas of greenfield developments is also used as an input to the CLM model (Timperley and Reed, 2008a). Calibration of the USC-3 model is achieved by running the model for the historical period, with sediment and metal inputs from the catchment appropriate to that period, which in turn are hindcast by the GLEAMS and CLM models. Predictions are made for the future period, which starts at the year 2001.

The emphasis in this report is on developing land use information required as input to GLEAMS which, in the CWH Study, is used to hindcast/predict sediment run-off from the rural parts of the catchment only. The CLM model is used to hindcast/predict metal and sediment run-off from the urban parts of the catchment. Hence, this report focuses on land use in rural areas outside of the urban boundary in the catchment of the Central Waitemata Harbour.

The reader is referred to Parshotam and Wadhwa (2008), who describe the implementation of the GLEAMS model for the CWH Study. The model so implemented is called the "GLEAMS-CWH" model.

3 Data sources

Land use information is available for the period spanning 1915 to 2001. The maps and databases drawn on included:

- Urban boundaries
    - Arc-GIS shape files.
    - Years 1915, 1945, 1964, 1975, 1987, 2001.
    - Shows the Metropolitan Urban Limit (MUL).
    - Data were provided by the Auckland Regional Council (ARC).
- New Zealand Landcover Database 1 (LCDB1)
    - Based on SPOT satellite imagery.
    - Provides a snap-shot of land cover from the summer of 1996/97.
    - Data were available from the Ministry for the Environment (MfE).
- New Zealand Landcover Database 2 (LCDB2)
    - Based on Landsat 7 ETM + satellite imagery (70 land cover classes).
    - Provides a snap-shot of land cover in 2001/02.
    - Data were available from the Ministry for the Environment (MfE).
- Aerial imagery
    - High resolution geo-referenced aerial photographs.
    - 1940 (black and white), 1959 (black and white).
    - 2001 (colour), flown February to June, 2001.
    - Data were provided by the Auckland Regional Council (ARC).

As far as possible original definitions of the MfE LCDB2 dataset classes and, where appropriate, LCDB1 definitions, were used.

4 Existing (Current) Land Use

4.1 Current land use

Existing (current, 2001) land cover data for the catchment were obtained from New Zealand's Landcover Database 2 (LCDB2). There are 28 LCDB2 land cover classes in the area of study (see Figure 1).

These land cover classes were reclassified into generalised GLEAMS land cover categories (see Figure 2), including special-case, zero-sediment producing classes.

Areas within the ARC urban boundaries were removed from the GLEAMS-CWH model area (see Figure 3) as the loads from areas within the urban boundary are to be determined separately by the urban CLM model.

Figure 1

Map of current land cover.

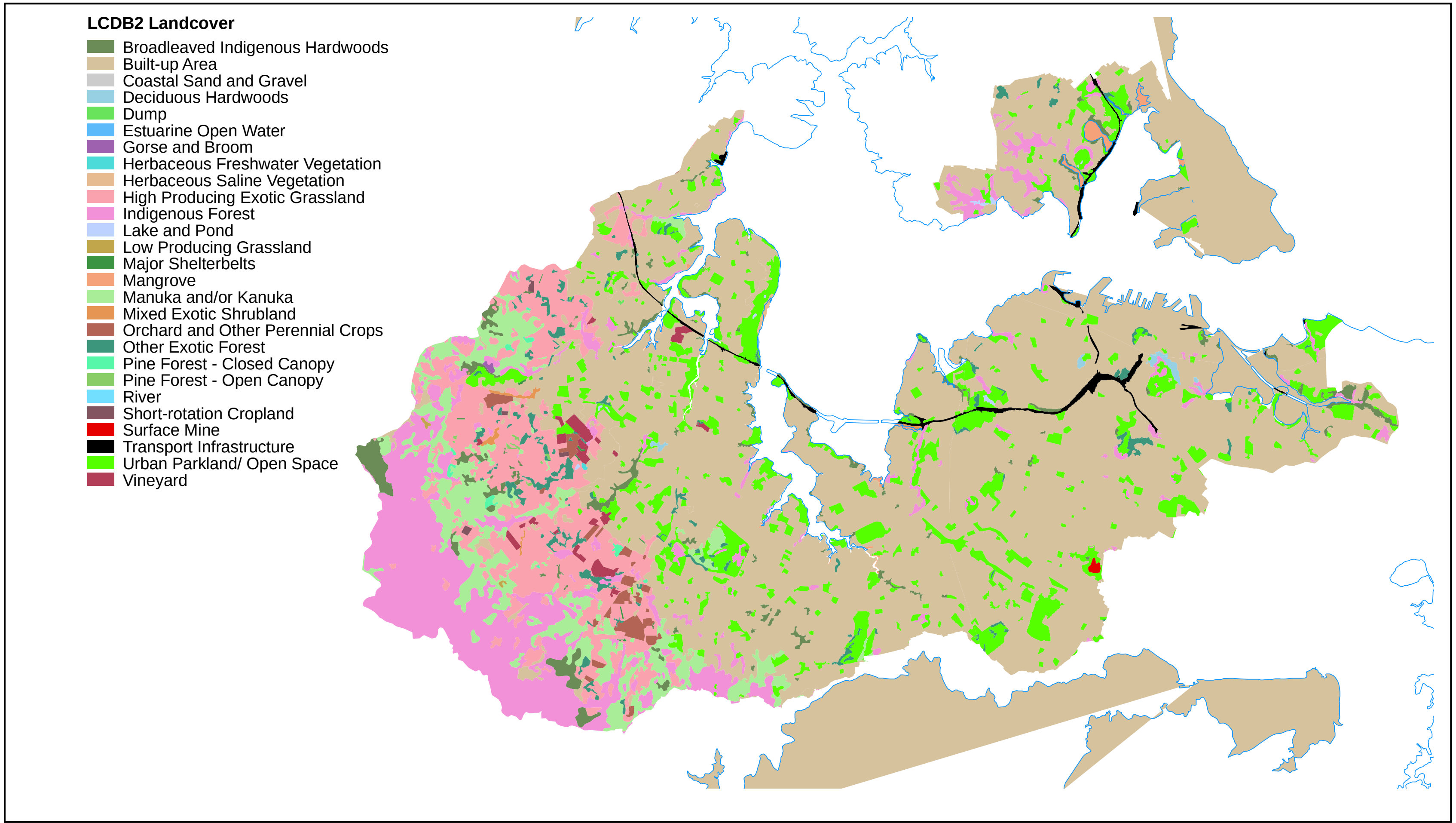


Figure 2

Map of generalised GLEAMS land cover.

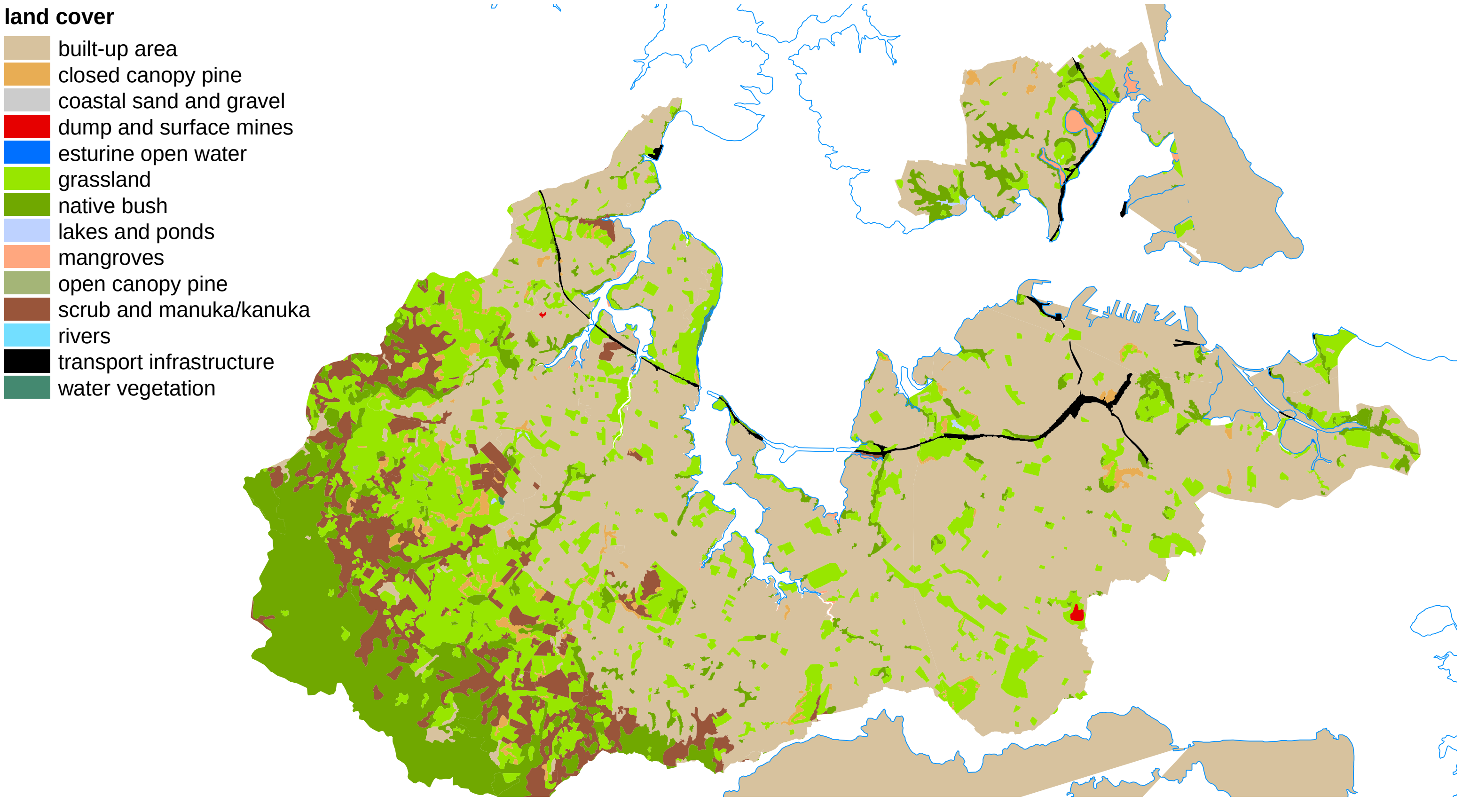
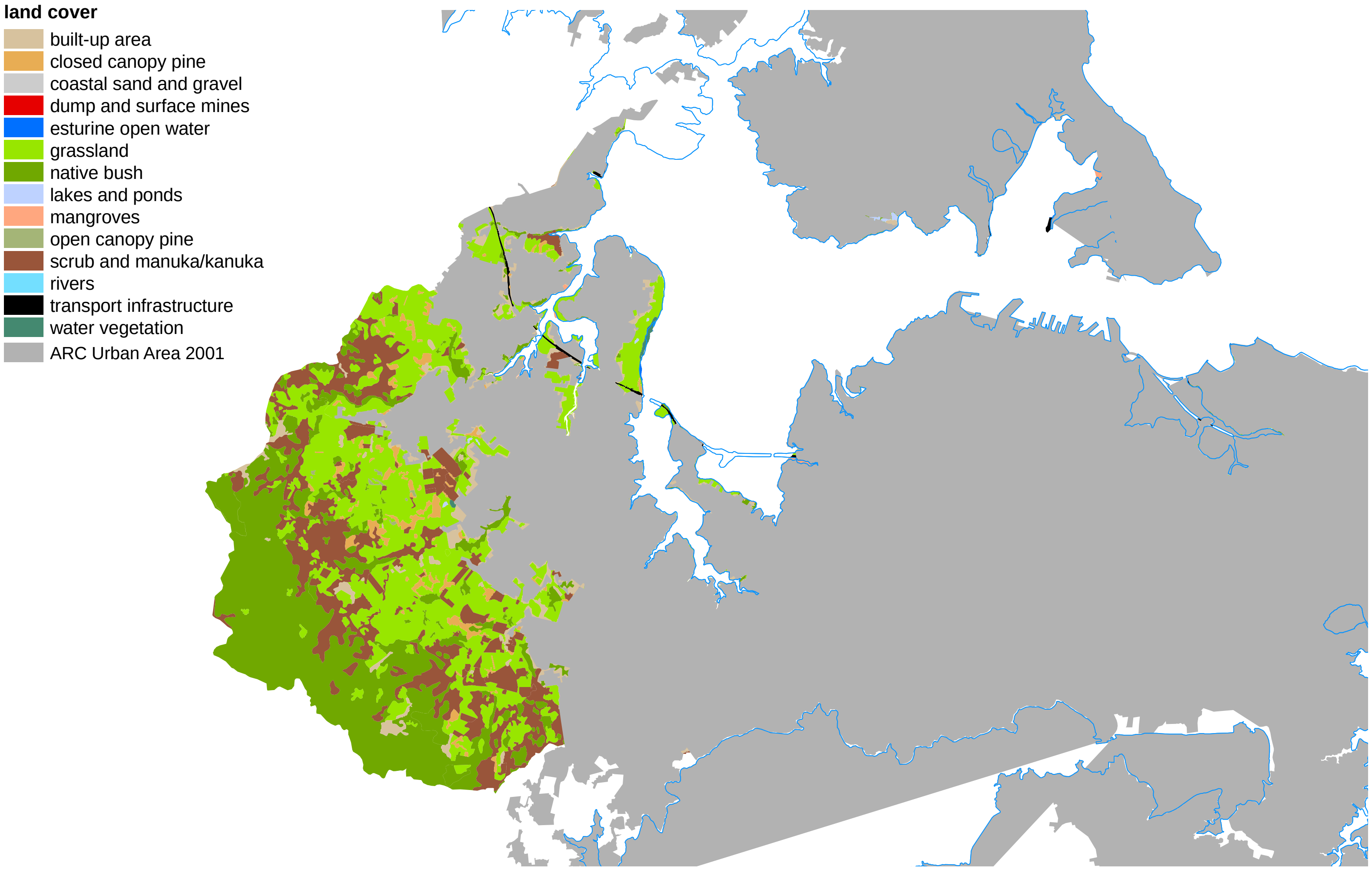


Figure 3

Map of generalised land cover used for the GLEAMS-CWH model.



4.2 Greenfield earthworks areas

Sediment loss as a result of greenfield earthworks from development (located in the rural zone) is always significant.

Areas of greenfield earthworks from development were determined as an area within each SMU (stormwater management unit), without specifying exact locations of the earthworks. These current greenfield earthworks areas from greenfield land were estimated by extrapolating historical rates of change of built-up areas (described later). Greenfield earthworks within the urban boundaries were not considered in any year in GLEAMS-CWH, because sediment from those areas is determined by CLM. However, the CLM model uses greenfield earthworks sediment yield data derived from GLEAMS with the assumption that the whole catchment is 100 % earthworked and results will be apportioned accordingly (Timperley and Reed, 2008a).

5 Historical Land Use

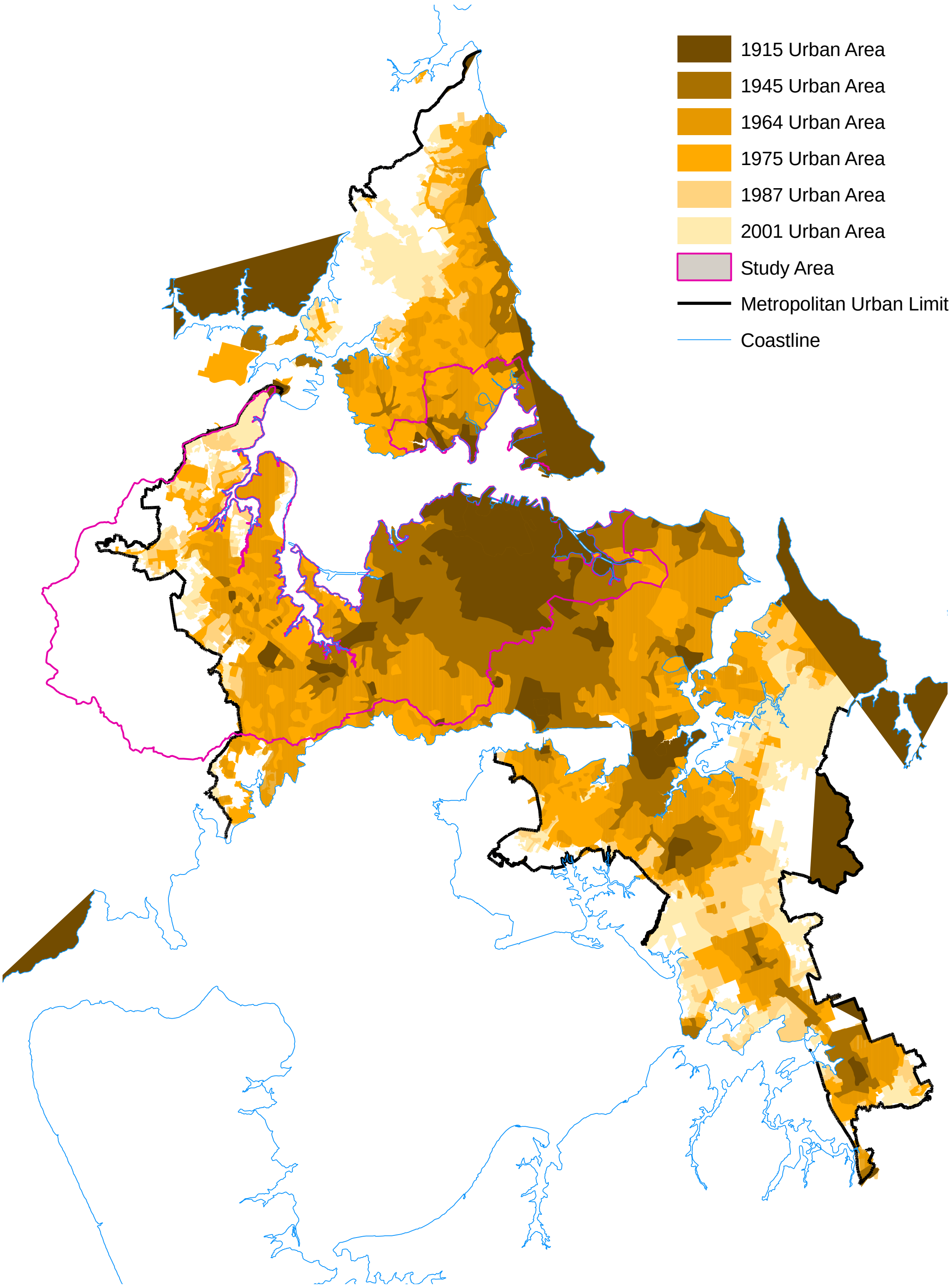
5.1 Land use within the urban boundary

5.1.1 Urban area

Urban areas, that is, areas of the catchment that lie within the urban boundary, were estimated from ARC urban boundary maps for each of the years 1915, 1945, 1964, 1975, 1987 and 2001 (see Figure 4).

Figure 4

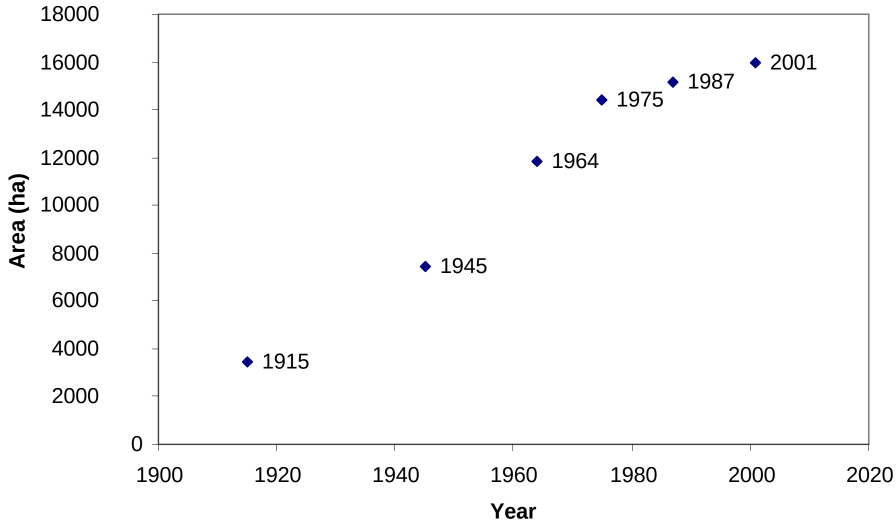
Changing urban boundary over time.



There was an overall sigmoidal-growth increase in the area within the urban boundary over time (see Figure 5). The greatest growth or change in area within the urban boundary was during the 1945–1975 period. For reference, the total area of the study catchment is 22,783 ha.

Figure 5

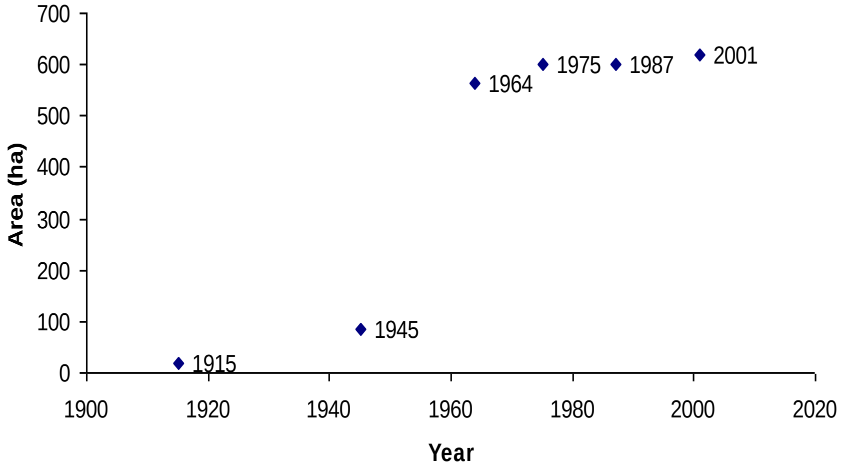
Area of catchment (ha) within the urban boundary over time.



5.1.2 SMU areas

The areas of individual SMUs within the urban boundary increased sigmoidally to approach a maximum. Figure 6, for SMU #67 within the Whau River sub-catchment, which has a total area of 618 ha, shows an example. The greatest increases have occurred near the periphery of the urban boundary.

Figure 6
The expansion of the urban area within SMU #67.



There were SMUs that showed a slight decrease over time in urban area, due perhaps to boundary areas being derived by different methods (aerial photos, reclassification error, etc.). All areas included within the urban boundary in a given year that were not found in subsequent years were therefore removed from the earlier year. The ARC urban boundaries do include lakes, ponds, open spaces, etc. but not some open spaces, ponds, lakes, mangroves, etc. near the periphery of the urban boundary.

5.1.3 Built-up areas within the catchment

Historical commercial, industrial and residential areas are required for use in the contaminant load model (CLM). These were obtained by manual digitization. Together, these comprise the "built-up" area. The built-up area is required in order to estimate the amount of historical earthworks; it gives a more accurate estimate than the urban area, which includes lakes, ponds, trees, parks, open spaces and the like.

Historical built-up areas for 1940 and 1959 were derived from 1940 and 1959 aerial photographs and 1945 and 1964 ARC urban boundaries, respectively. The 1915, 1975 and 1987 ARC urban boundaries were not used in the analysis.

1940 and 1959 rectified aerial photographs provided by ARC were categorised into industrial, residential and commercial regions (see Figures 7 and 8). Areas that were not industrial, residential or commercial in 1940 but that were still within the 1945 ARC urban boundary were categorised as "other". This category includes open spaces, trees and the like. Likewise, areas that were not industrial, residential or commercial in 1959 but that were still within the 1964 ARC urban boundary were categorised as "other". Where aerial maps were not available for some areas (eg, North Shore), the 1959 digitization was applied to 1940.

Figure 7

1940 ARC aerial photograph (excl. North Shore) showing digitised industrial, residential and commercial areas.

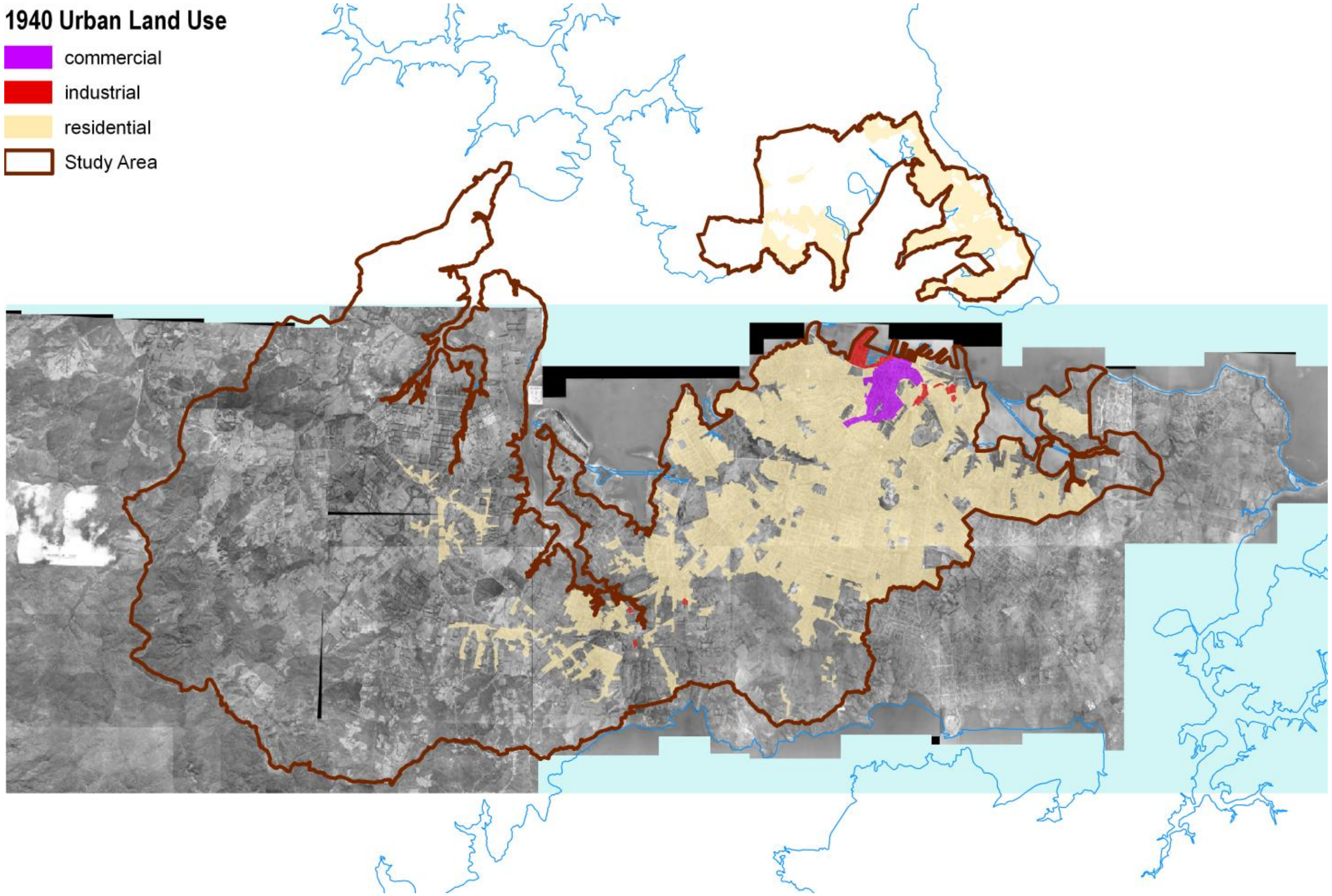
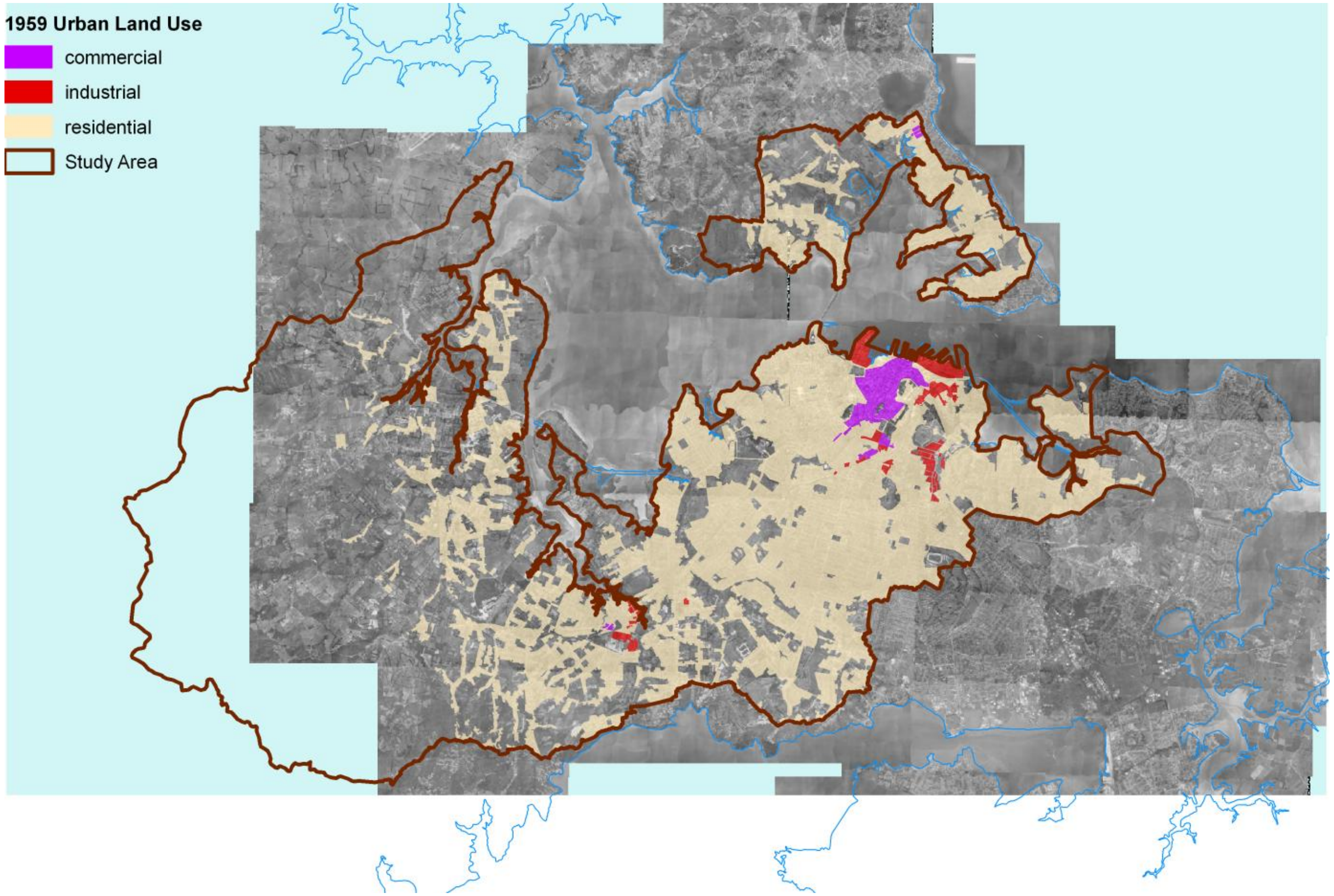


Figure 8

1959 ARC aerial photograph and manual digitization.



There was a general increase in industrial, residential and commercial areas over time in each SMU. Some SMUs, however, showed a decline in area, and this was attributed to digitization error.

The built-up area for each SMU for 1996 was derived from the LCDB1 urban category and included the LCDB2 transport infrastructure category. The built-up area for each SMU for 2001 was obtained from the LCDB2.

Ideally, it would also be desirable to have an estimate of built-up area in the 1970s, but these data were not available.

5.1.4 Built-up areas within SMUs

There are limitations from classification, digitization and urban boundary definitions. This results in built-up areas in some SMUs decreasing in some years. It was not considered justifiable to remove these data from the study. Nonlinear regression of a logistic function (that models resource-limited exponential growth) was used to fit a curve through each SMU's built-up areas for the years 1945, 1964, 1996 and 2001.

Figure 9
Expansion of the built-up area within SMU #2 (located within the Whau River sub-catchment). Nonlinear regression through years 1940, 1959, 1996 and 2001.

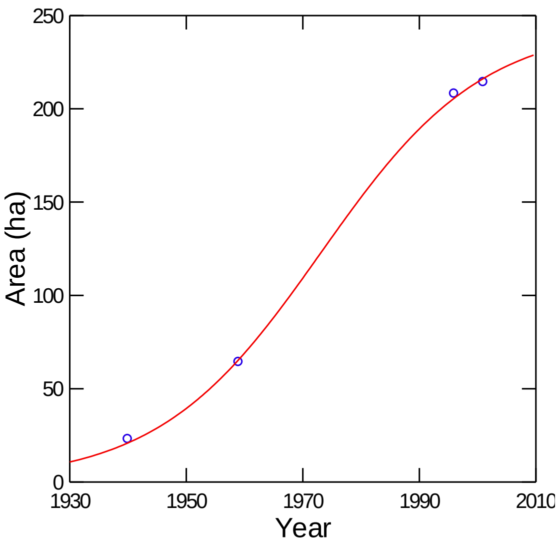
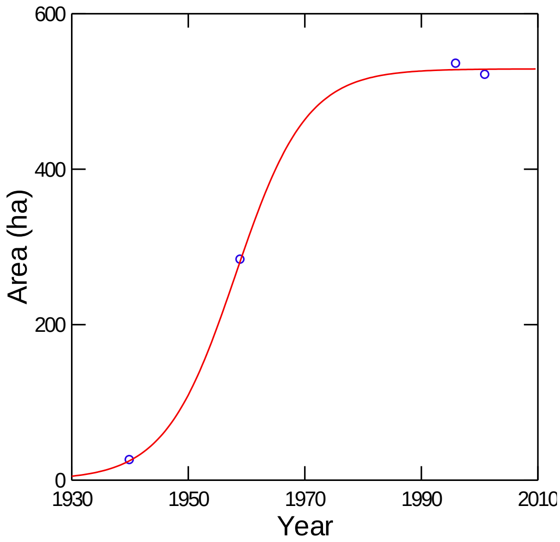


Figure 10
Expansion of the built-up area within SMU #67 (located within Oakley Creek sub-catchment). Nonlinear regression through years 1940, 1959, 1996 and 2001.



5.2 Land use outside the urban boundary

The 2001 and 1940 colour aerial photographs showed that many areas currently under trees, manuka/kanuka scrub and the like were under the same land cover in 1940. Historical land use shape files were re-created based on LCDB2 (2001) classifications and the historical urban boundaries obtained from the ARC. Historical land use outside the urban area was re-created for 1915, 1945, 1964, 1975 and 1987 from LCDB2 (2001) and historical and current ARC urban area boundaries.

The major assumption used was that 2001 "built-up", "urban parkland/open space" and "motorways" categories outside the ARC urban boundary for a given year were considered to have been in "low producing grassland" prior to any development.

Historical land use outside the urban area was recreated for 1996 from LCDB2 and the ARC 2001 urban boundary. Historical land use may also be obtained for 1996 from LCDB1. There were several classification issues between LCDB1 and LCDB2 with LCDB1 data found to be not always reliable for the purpose of this study. The built-up areas decreased in some instances. However, for statistical reasons, it was not considered justifiable to remove LCDB1 data altogether from the study.

5.3 Greenfield earthworks area estimates on an SMU basis

Greenfield earthworks areas were estimated for the years 1945, 1964, 1975, 1987, 1996 and 2001. Historical greenfield earthworks estimates on an SMU basis were generated based on the instantaneous rate of change of built-up areas within each

SMU. It was assumed that prior to 2001 greenfields earthworks corresponded to rural land that was converted to built-up areas by expanding the built-up area. For most SMUs near the outskirts of the urban boundary, the area earthworked per year increased quite rapidly to a maximum during some given period, and would have then decreased to quite low values in 2001. The temporal resolution assumed was sufficient to characterise the temporal progression of greenfield earthworks areas.

Figure 11

Greenfield earthworks estimates for the years 1945, 1964, 1975, 1987, 1996 and 2001 calculated from instantaneous rates of change, for SMU #2 (located within the Whau River sub-catchment).

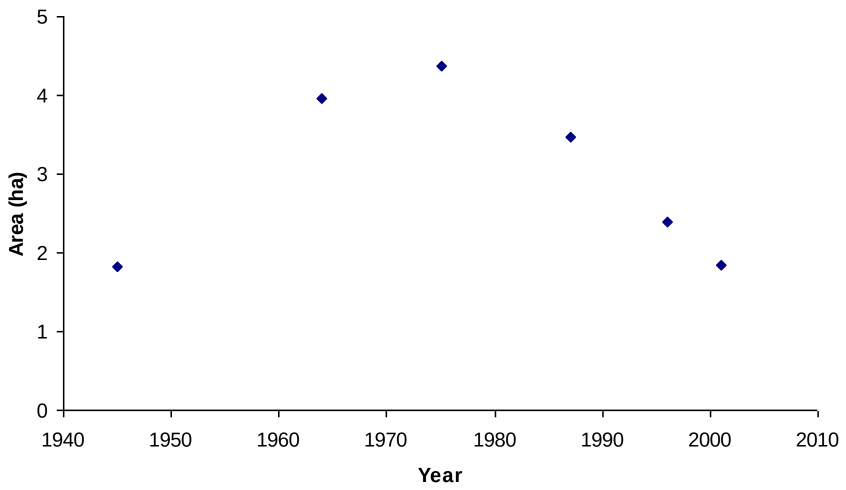
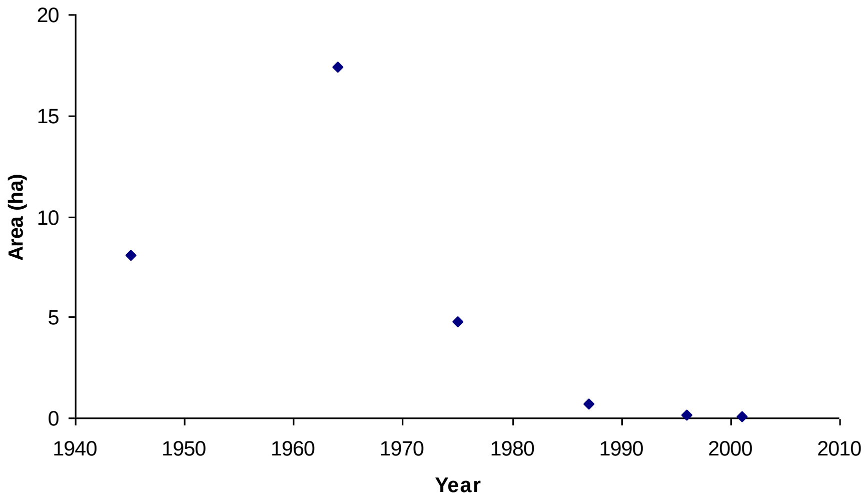


Figure 12

Greenfield earthworks estimates for the years 1945, 1964, 1975, 1987, 1996 and 2001 calculated from instantaneous rates of change. SMU #67 (located within the Whau River sub-catchment).



5.4 Preparing land use data for use in GLEAMS-CWH

Historical greenfield earthworks areas have been individually estimated, but all individual land use areas still need to add up to the total area of the SMU. The major assumption used is that bare earth areas were in grassland (either improved or unimproved) prior to any proposed development and so an equivalent bare earth area was removed from grassland area. In SMUs with very low grassland areas, all grasslands areas were replaced with equivalent bare earth areas but there was no clear justification for removing areas of bush or forests. In this case, bare earth estimates were corrected to equal and replace only grasslands areas. Such errors occurred particularly in later years (1987) when grassland areas in some SMUs became negligible.

6 Future Land Use

For the future, the Metropolitan Urban limit (MUL) (see Figure 4) is assumed to be fixed and would remain the same as at present (Timperley, pers comm.). The GLEAMS-CWH model is applied to areas outside the MUL and the CLM model is applied to areas within the MUL. The future land use outside the MUL. is assumed to remain the same as at present.

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Personal Communication

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