Auckland Regional Council
TE RAUHĪTANGA TAIAO

# Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study: Landuse Analysis

December TR 2008/049

Auckland Regional Council
Technical Report No.049 December 2008
ISSN 1179-0504 (Print)
ISSN 1179-0512 (Online)
ISBN 978-1-877483-97-4

Technical Report. First Edition.

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## Recommended Citation:

Parshotam, A; Wadhwa, S; Semadeni-Davies, A; Moores, J. (2008). Southeastern Manukau Harbour / Pahurehure Inlet Harbour Contaminant Study. Landuse Analysis. Prepared by NIWA for Auckland Regional Council. Auckland Regional Council Technical Report 2008/049.

# Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study: Landuse Analysis

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**Prepared for**

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**NIWA Client Report: HAM2008-162**
October 2008

NIWA Project: ARC07137

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# PREFACE

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

The scope of the study entailed:

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

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

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

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

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

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

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

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

The three general stormwater management intervention scenarios evaluated were:

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

**International Peer Review Panel**

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

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

Key Findings of the Study

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

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

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

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

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

### Research and Investigation Questions

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

- Sediment and chemical contaminant dynamics within tidal creeks.

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

- The fate of other contaminants derived from urban sources.

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

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

### Technical reports

The study has produced a series of technical reports:

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

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

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

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

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

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

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

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

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

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

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

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

# 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 preparation of landuse information for the historical period (1940 to 2000), the current time (2001), and the future period (2002 to 2100). This landuse information is required as input to the GLEAMS-SEM model which, in the Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study, is used to hindcast/predict sediment runoff from the rural areas of the catchment surrounding the Southeastern Harbour / Pahurehure Inlet.

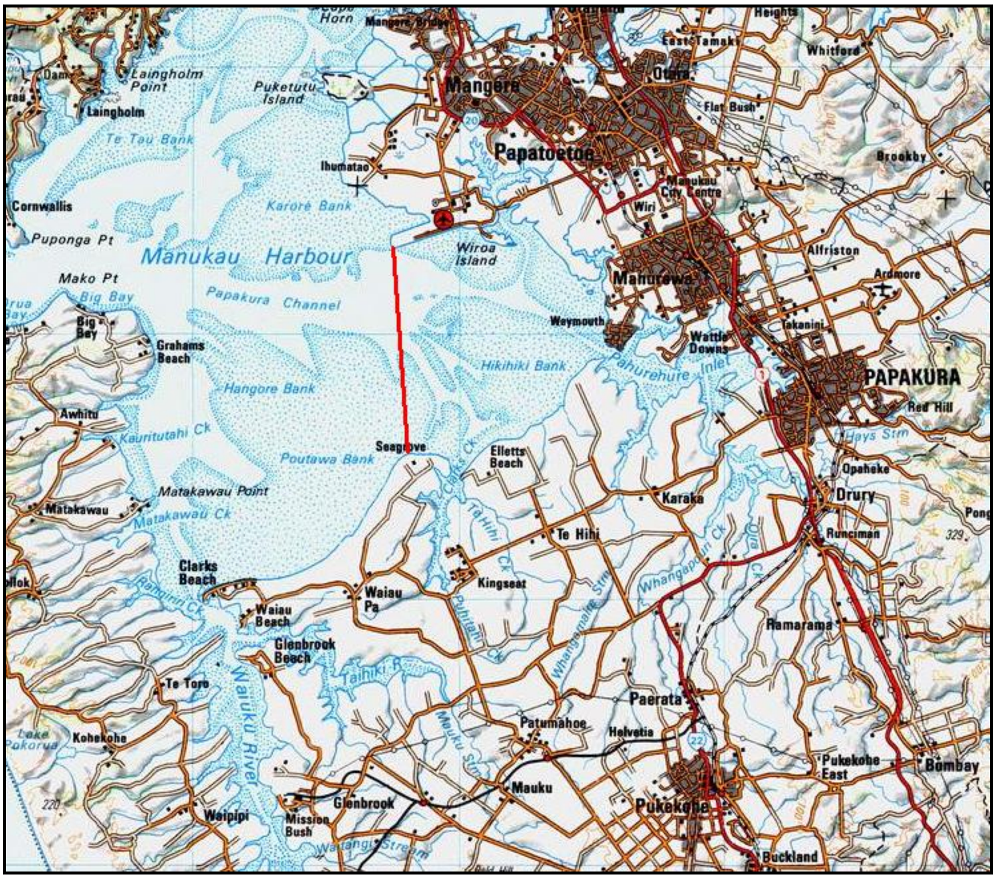
# 2 Introduction

## 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 hydrodynamically 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 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.
- 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.

## 2.4 This report

This report describes the preparation of landuse information for the catchment surrounding the Southeastern Manukau Harbour / Pahurehure Inlet for the historical period (1945 to 2000), the current time (2001), and the future period (2002 to 2100). This landuse information is required as input to the GLEAMS and CLM models. The former is used to hindcast/predict sediment runoff from rural areas of the catchment while the latter is used to hindcast/predict metal and sediment runoff from the urban parts of the catchment. Both models require identification of urban land use in the catchment, although for different reasons. GLEAMS requires information on the rate of change in the historical conversion of rural to urban land, while the CLM requires a breakdown of the different landuse types within the urban area[1]. The CLM also utilises information generated by GLEAMS as inputs, such that the GIS analysis of soils, slope and land cover information produced for use in GLEAMS is also used in the CLM model in less detail. This occurs through the use by the CLM of GLEAMS estimates of greenfield earthworks sediment yields and urban grassland sediment yields in predicting future urban sediment loads (Moores and Timperley, 2008).

Both the GLEAMS and CLM models produce inputs to the USC-3 model (Green, 2008). 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 2002. The predictions are to used in the evaluation of the future catchment development scenarios.

[1] Not only does the CLM require information on areas of residential, commercial, industrial and other types of urban land use, but also the areas of different contaminant 'source areas' within each type of land use, for instance roofs, roads, paved and impervious areas. The estimation of source areas is described in Moores and Timperley (2008).

The reader is referred to Parshotam et al. (2008a), for the GLEAMS model, its setup and implementation; Semadeni-Davies and Parshotam (2009), for the rainfall analysis in the study; Parshotam et al. (2008b), for the GLEAMS evaluation, and Parshotam (2008), for results of the GLEAMS model. The model so implemented is called the "GLEAMS-SEM" model.

# 3 Data sources

Landuse information for the study area is available for the period spanning 1942 to 2006. The maps and databases we drew on include:

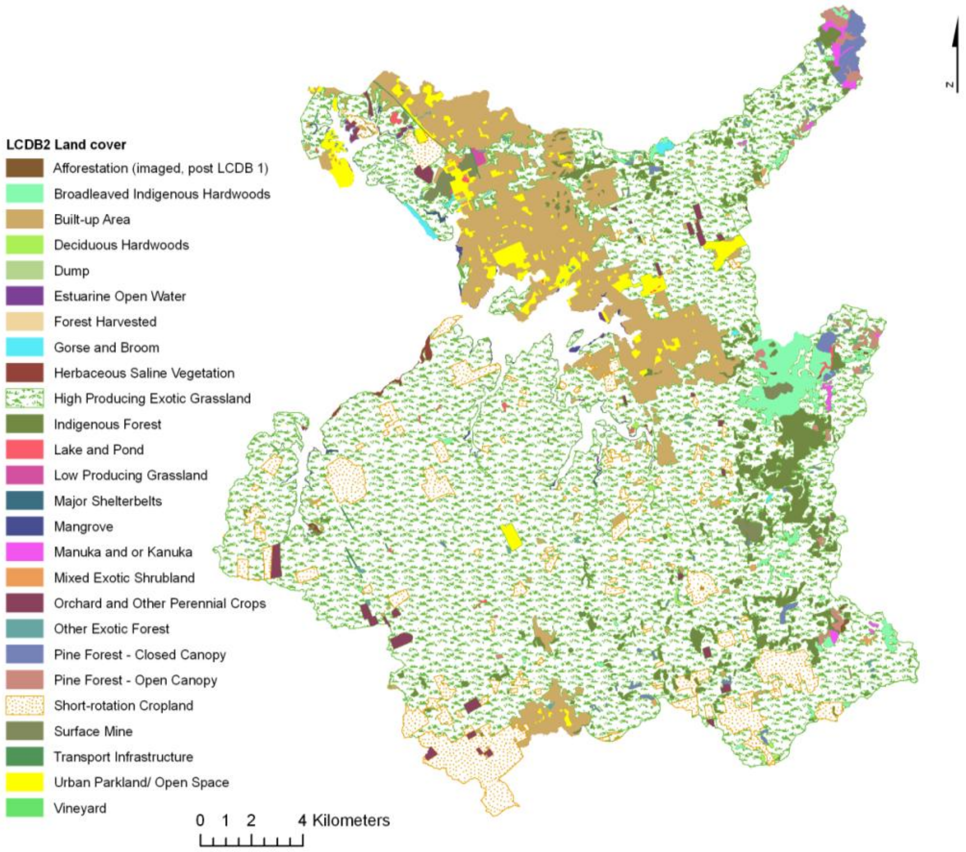
- Urban (built-up area) boundaries
    - Arc-GIS shape files.
    - Years 1945, 1959, 2001.
    - Shows the boundaries of built-up urban land in Auckland and Pukekohe.
    - Data were provided by the Auckland Regional Council (ARC).
- New Zealand Landcover Database 2 (LCDB2)
    - Based on Landsat 7 ETM + satellite imagery (70 land cover classes).
    - Provides a snap-shot of land cover in 2001/02.
- Aerial imagery
    - Manukau City, high resolution geo-referenced aerial photographs for 1959 and 2001.
    - Franklin, 1942 (black and white, provided by Franklin DC).
    - Drury, Pukekohe 1968 (black and white).
    - Urban area 2001 (colour).
    - Whole study area 2003-4 (colour).
    - Urban area, excluding Pukekohe, 2006 (colour).
    - Data were provided by the Auckland Regional Council (ARC, other than Franklin DC where noted above).
    - Aerials from 2001, 2003-4 and 2006 are reported to have been flown over periods of 4-5 months (summer).
- Bare/exposed earth
    - Arc-GIS shape files.
    - Years 2003-2004, 2001, 2006.
    - Data were provided by the Auckland Regional Council (ARC).

# 4 Land cover

## 4.1 Current land cover

Existing (current, 2001) land cover data for the catchment were obtained from New Zealand's Landcover Database 2 (LCDB2). There are 26 LCDB2 land cover classes in the area of study (see Figure 2).

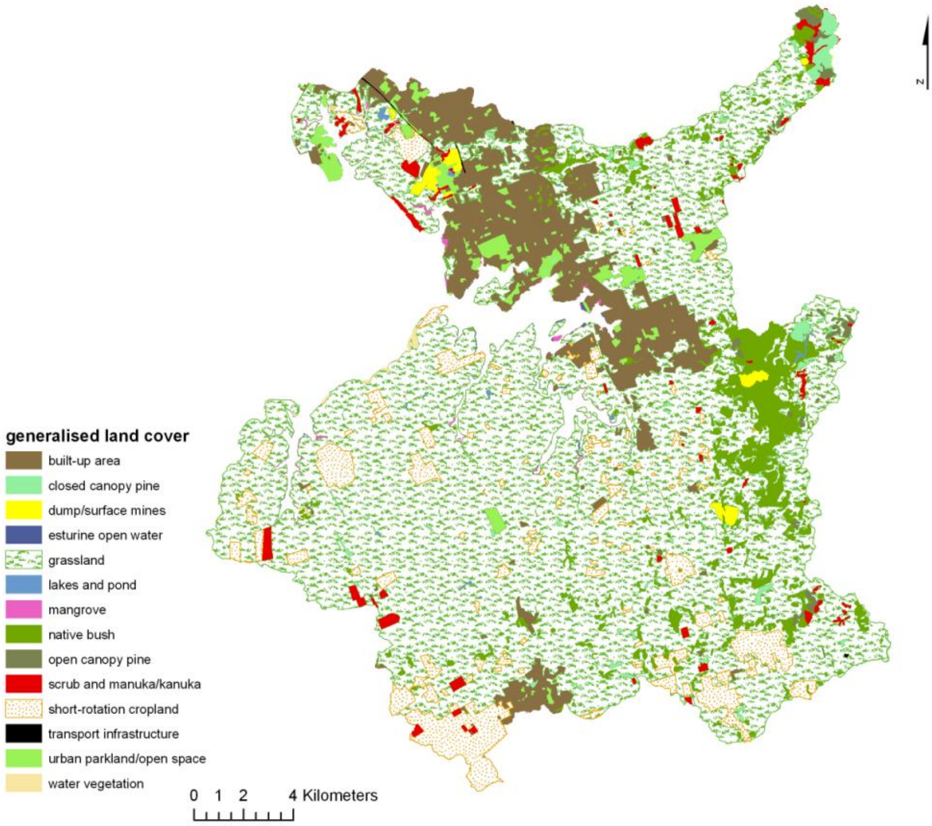
**Figure 2:**
Map of current land cover.




These land cover classes were reclassified into generalised GLEAMS land cover categories (see Figure 3), including special-case, zero-sediment producing classes such as open water, lakes and ponds.

**Figure 3:**

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



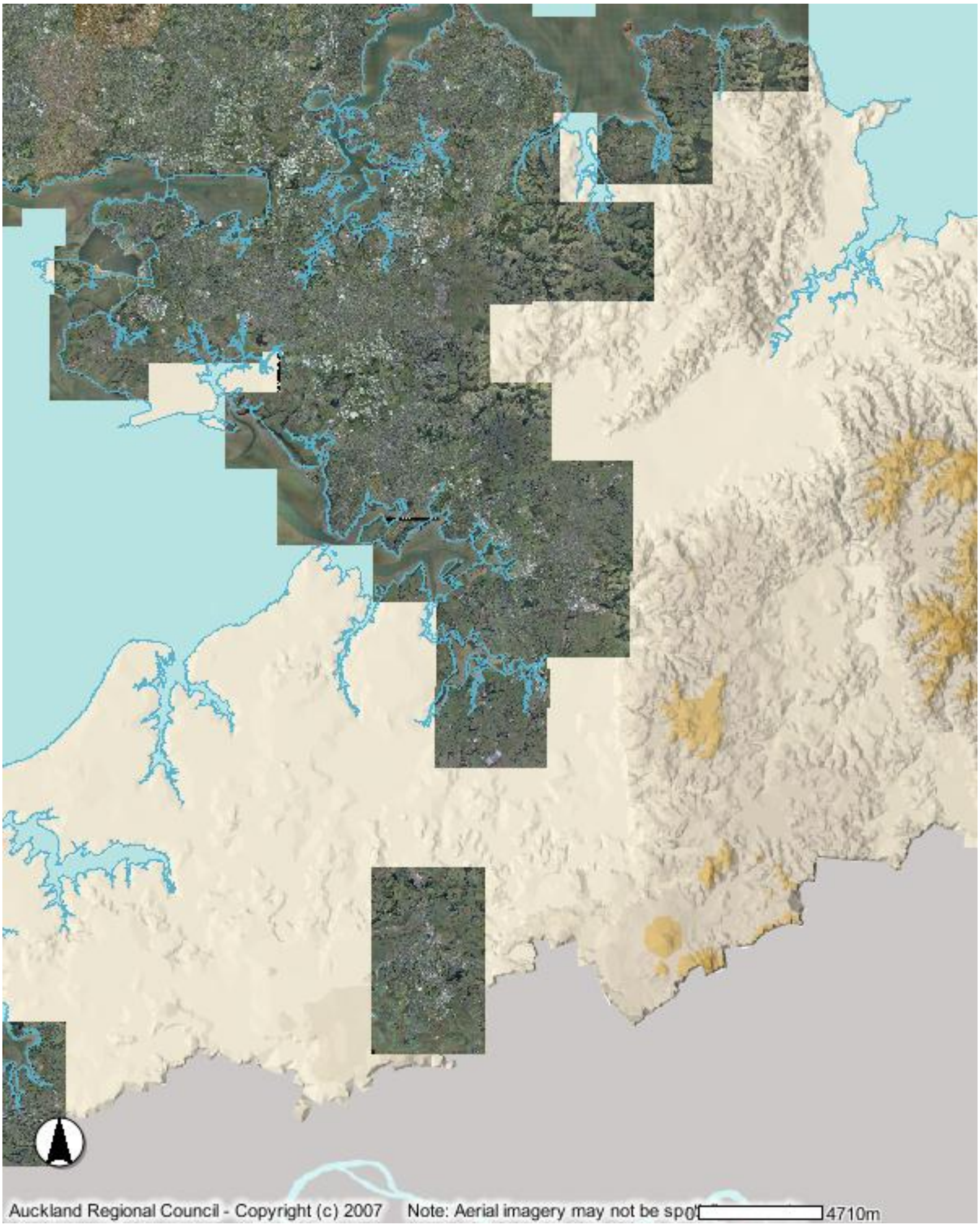

## 4.2 Exposed/bare earth

Sediment loss from exposed or bare earth can be significant and these areas need special consideration.

Figure 4 gives the 2001 aerial coverage used to identify areas of bare/exposed earth. Figure 5 gives the 2003-4 aerial coverage at higher resolution used to identify the areas of bare/exposed earth areas near the Pahurehure Inlet. Figure 6 shows 2006 aerial coverage data used to identify areas of bare/exposed earth. Figures 7, 8 and 9 show a digitization of bare/exposed earth areas for the years 2001, 2003-2004 and 2006 and their breakdown.

**Figure 4:**

2001 aerial coverage**Figure 5:**

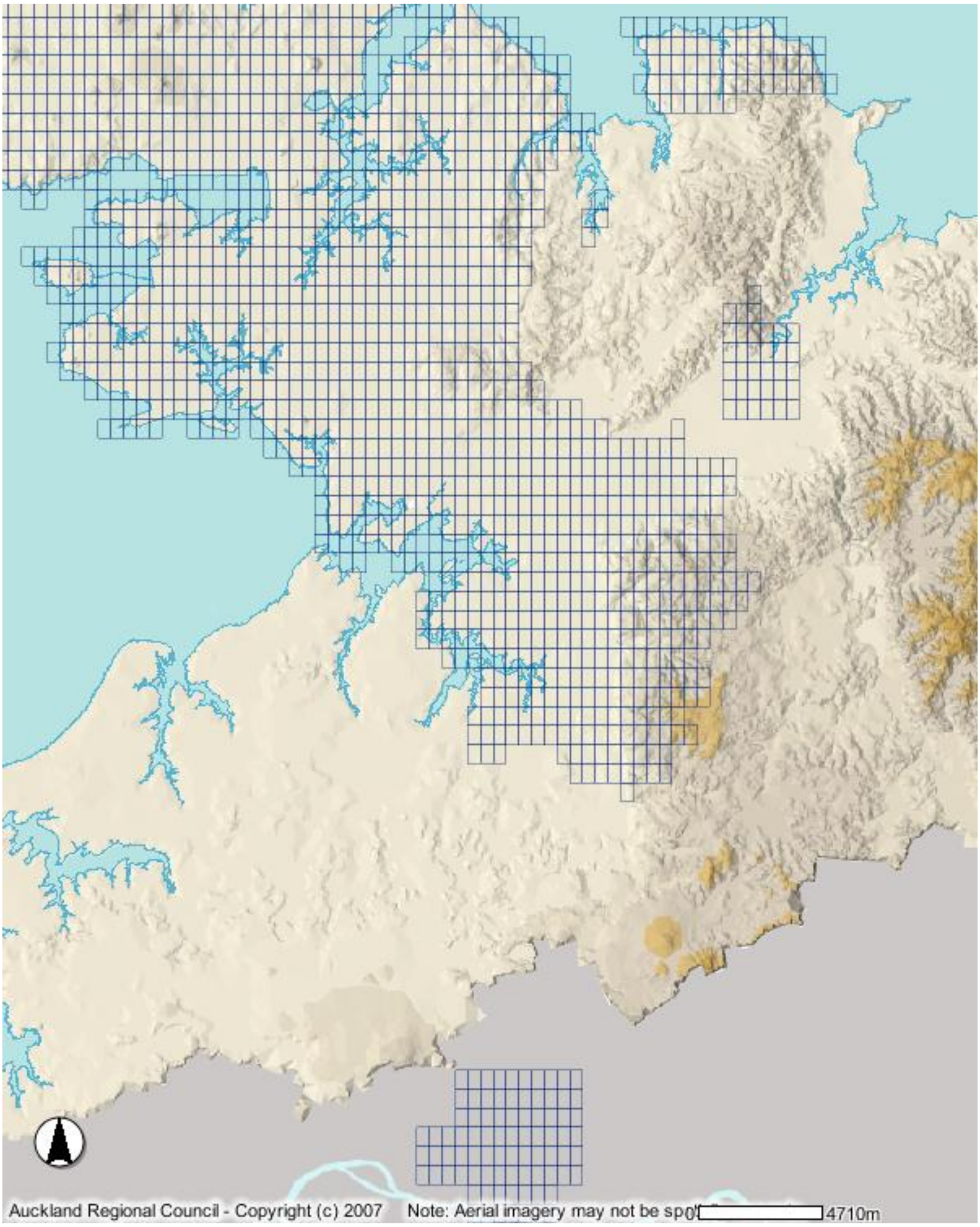



**Note:** Aerial imagery may not be spatially accurate.

2003-2004 aerial coverage.

**Note:** Aerial imagery may not be spatially accurate.

**Figure 6:**
2006 aerial coverage.




**Note:** Aerial imagery may not be spatially accurate.

**Figure 7:**
2001 bare/exposed earth data in and near the study area.

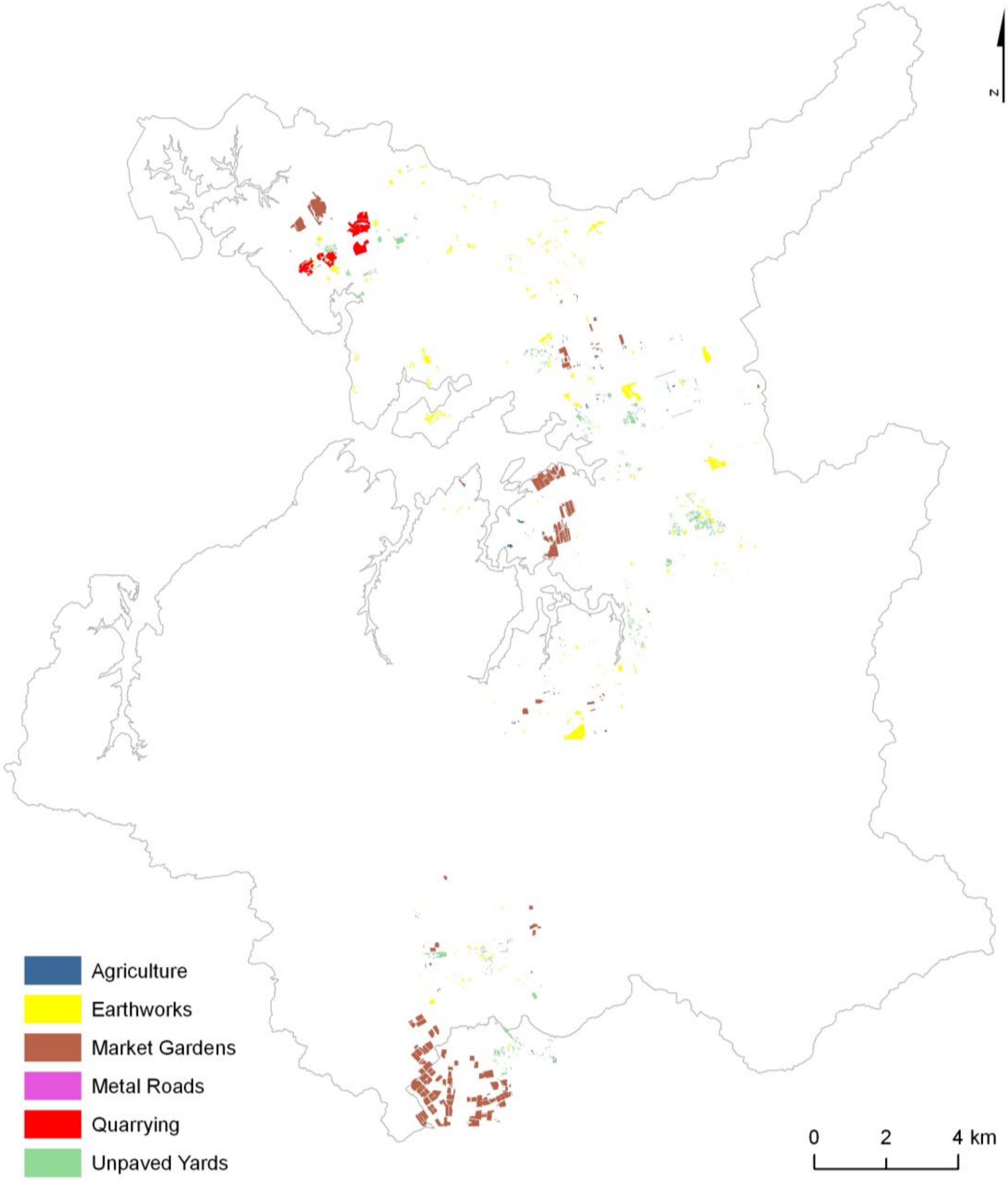


**Figure 8:**

The breakdown of 2003-2004 bare/exposed earth in and near the study area.

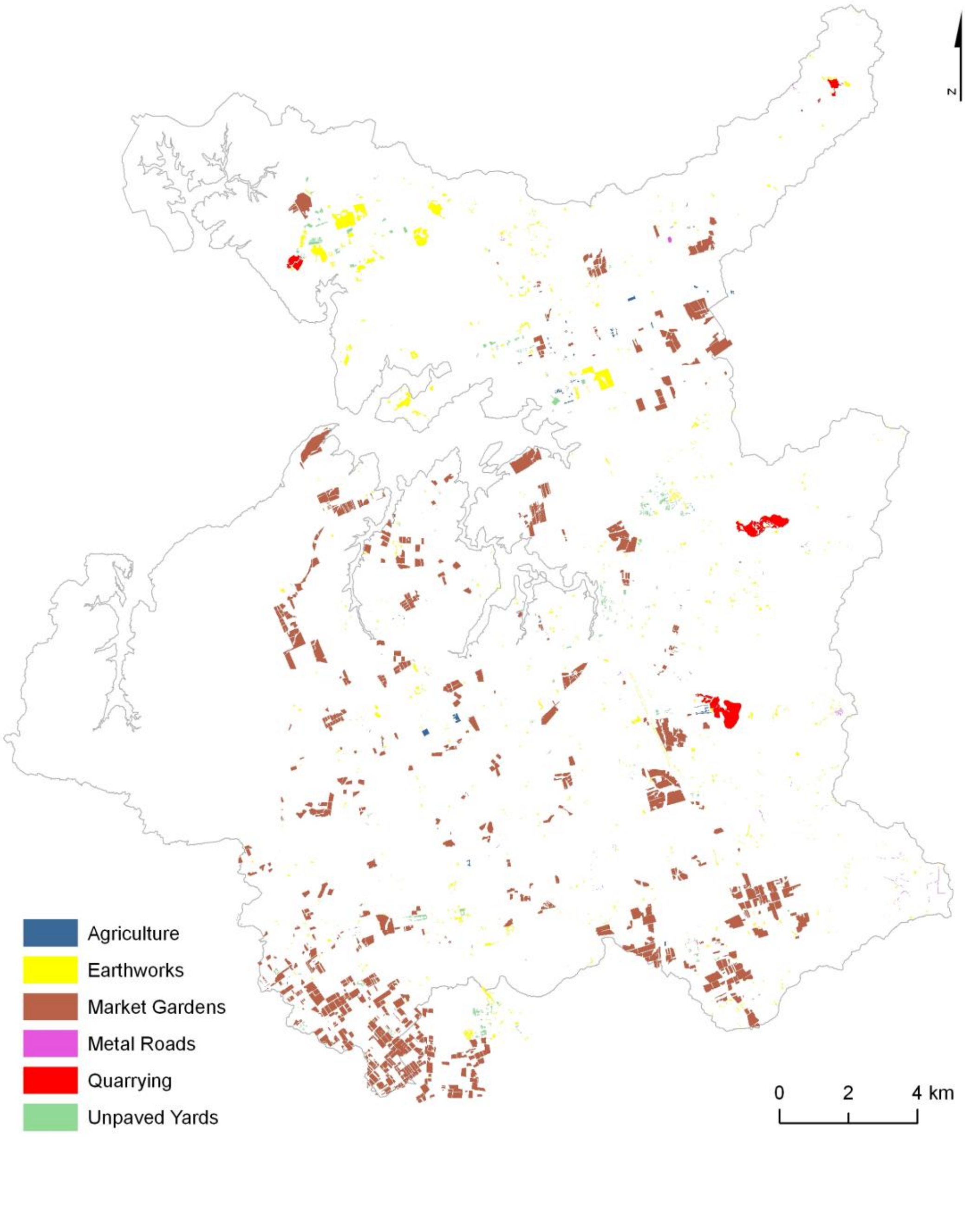
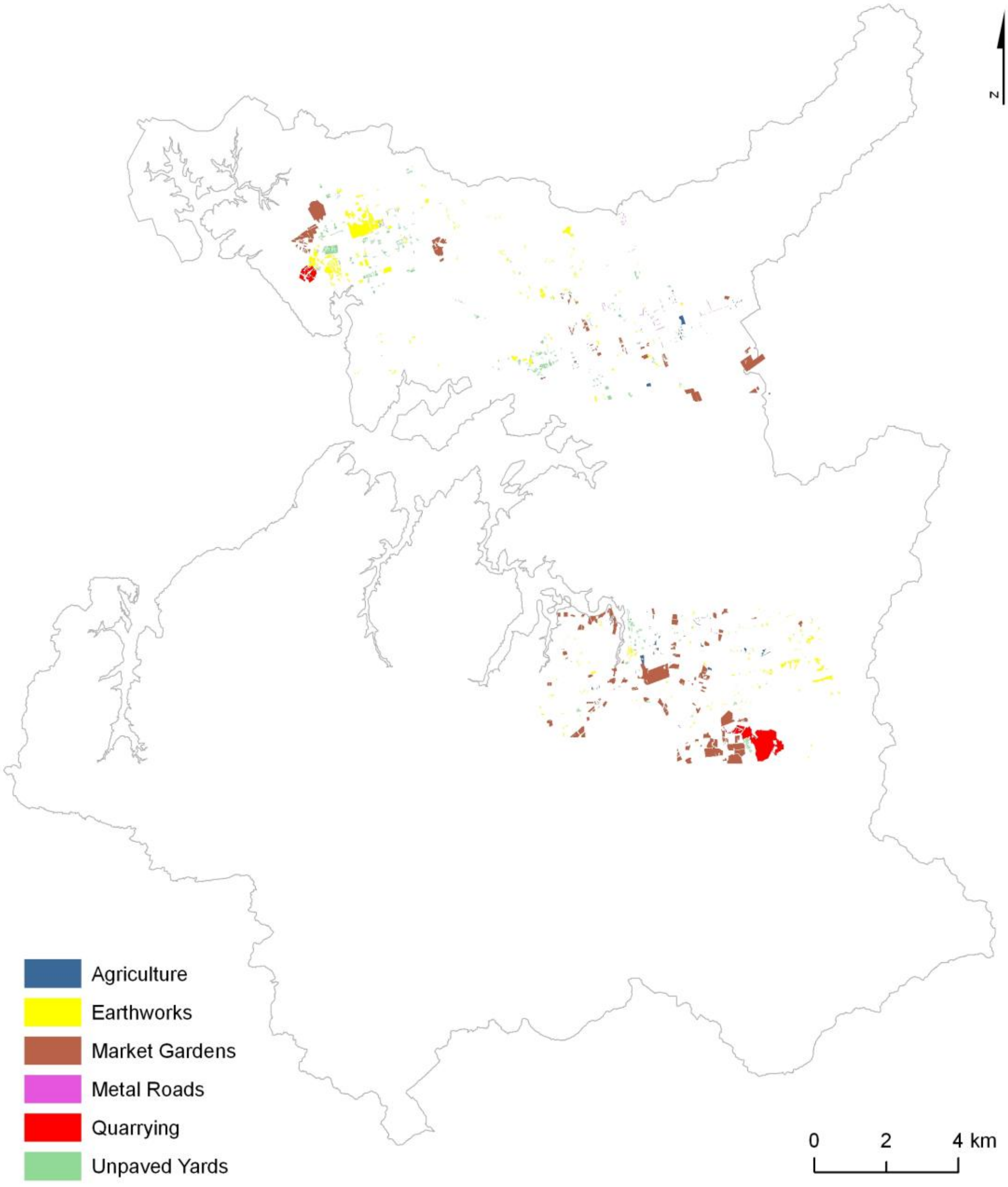


**Figure 9:**
2006 areas of bare/exposed earth in and near the study area.



All digitizations were compared for accuracy. The 2003-2004 digitization was considered to be the most detailed and reliable, and was used for this study.

Generally, the areas of bare/exposed earth by digitization were found to be classified in LCDB2 as the following: digitized current exposed/bare earth areas in areas of market gardens was classified in LCDB2 as short-rotation cropland and low producing grassland; metal roads as high producing exotic grassland; unpaved yards as short-rotation cropland and high producing exotic grassland; quarrying as surface mines and broadleaved indigenous hardwood, agriculture exposed/bare earth as high producing exotic grassland, and earthworks as mostly as high producing exotic grassland, with some indigenous forest, short-rotation cropland, and manuka/kanuka. Areas of earthworks are generally within the Auckland and Pukekohe metropolitan limits and there is very little scattered outside of these areas.

A current landuse scenario was created by overlaying the 2003-2004 bare/exposed earth map (Figure 8) onto the map of generalised GLEAMS-SEM landuse (Figure 3) giving a total of 14 + 6 = 20 landuse classes. This scenario was used as the final current landuse scenario.

## 4.3 Splitting land cover into regions for use in GLEAMS-SEM

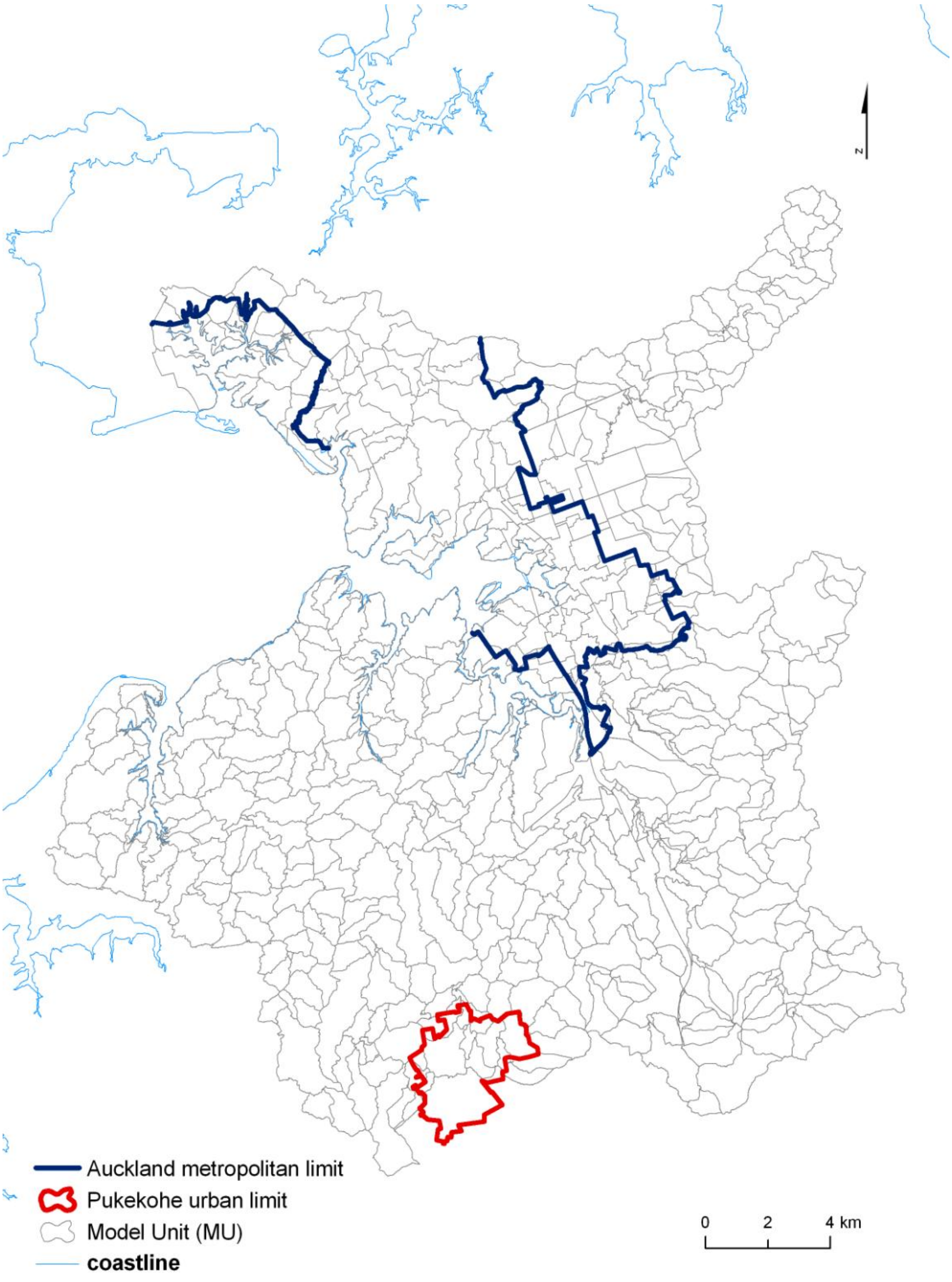
The current land cover data was split into three rural rainfall regions RR1, RR2, and RR3 (see Semadeni-Davies and Parshotam, 2009) and two urban regions (Pukekohe and Auckland metropolitan area), giving a total of five regions. The hydrological model units (MU's) were also split where necessary along the region boundaries. Unique combinations of soil, slope and land cover were created within Arc-GIS for each region.

# 5 Historical and current landuse

## 5.1 Landuse within the current urban limits

For the purpose of GLEAMS and CLM modelling the study area was divided into 580 hydrological model units (MUs) (Parshotam et al. 2008a). These were “clipped” by overlaying the Auckland Metropolitan Urban Limit (MUL) and the boundary of urban zoned land at Pukekohe to identify those units or sections of MUs that fall within these ‘urban limits’ (see Figure 10). The contaminant loads and sediment runoff from units or parts of units lying inside the urban limits were modelled using the CLM model (see Moores and Timperley, 2008). The sediment runoff from selected units or parts of units that fall outside of the urban limits were modelled using the GLEAMS-SEM model.

**Figure 10:**
Model units and urban limits.



Shapefiles of historical landuse lying within the current urban limits were created for years 1945, 1959, 1987 and 2001. The following landuse classes were used: residential, commercial, industrial, open/park, motorways, earthworks, or rural (this is land which is currently zoned for urban purposes but was rural in character in the year in question).

Landuse was digitised for 1959 and 2001 using ARC geo-referenced aerial photographs (see Figure 11 for an example from 2001). The 1959 coverage excluded Pukekohe and Drury and 1968 aerials were used as a proxy for land use in these areas in 1959. Where subdivisions on the 1968 photos were obviously new or being constructed, the landuse was classed as rural in the 1959 landuse map.

No aerial photographs of the study area in 1945 or 1987 were available. Landuse in 1987 and 1945 was therefore estimated by "clipping" the layers for 2001 and 1959 respectively by shapefiles of the 1987 and 1945 boundaries of built-up land provided by the ARC. Landuse falling outside the limits of built-up land was classified as rural. The shapefiles of urban built- up land provided by ARC do not include Pukekohe. However, Franklin District Council was able to provided aerial photography of Pukekohe from 1942 and this was used to map 1945 landuse in that locality. Pukekohe landuse in 1987 was not mapped.

Figure 12 shows the resulting landuse within the current urban limits for 1945, 1959, 1987 and 2001.

Overlays were created between the shapefile of model units lying within the current urban limits and each historical landuse shapefile (1945, 1959, 1987 and 2001). This allowed the estimation of landuse proportions in each model unit. The resulting proportional landuse layers show trends in landuse in each model unit over time. As no data were available for Pukekohe in 1987, the proportions are the same as for 2001.

There was a general increase in the proportion of industrial, residential and commercial landuse over time and an associated decrease in the proportion of rural landuse within each urban MU. Residential landuse proportions for 1945, 1959, 1987 and 2001 are shown in Figure 13 and rural landuse proportions for these years are shown in Figure 14.

**Figure 11:**
Digitising landuse from 2001 ARC aerial photographs showing examples of areas of residential, commercial, industrial and open/park landuse.

**Figure 12:**

Landuse within the area of the SE Manukau Harbour study catchment lying within the current MUL and urban-zoned land at Pukekohe in (a) 1945, (b) 1959, (c) 1987 and (d) 2001.

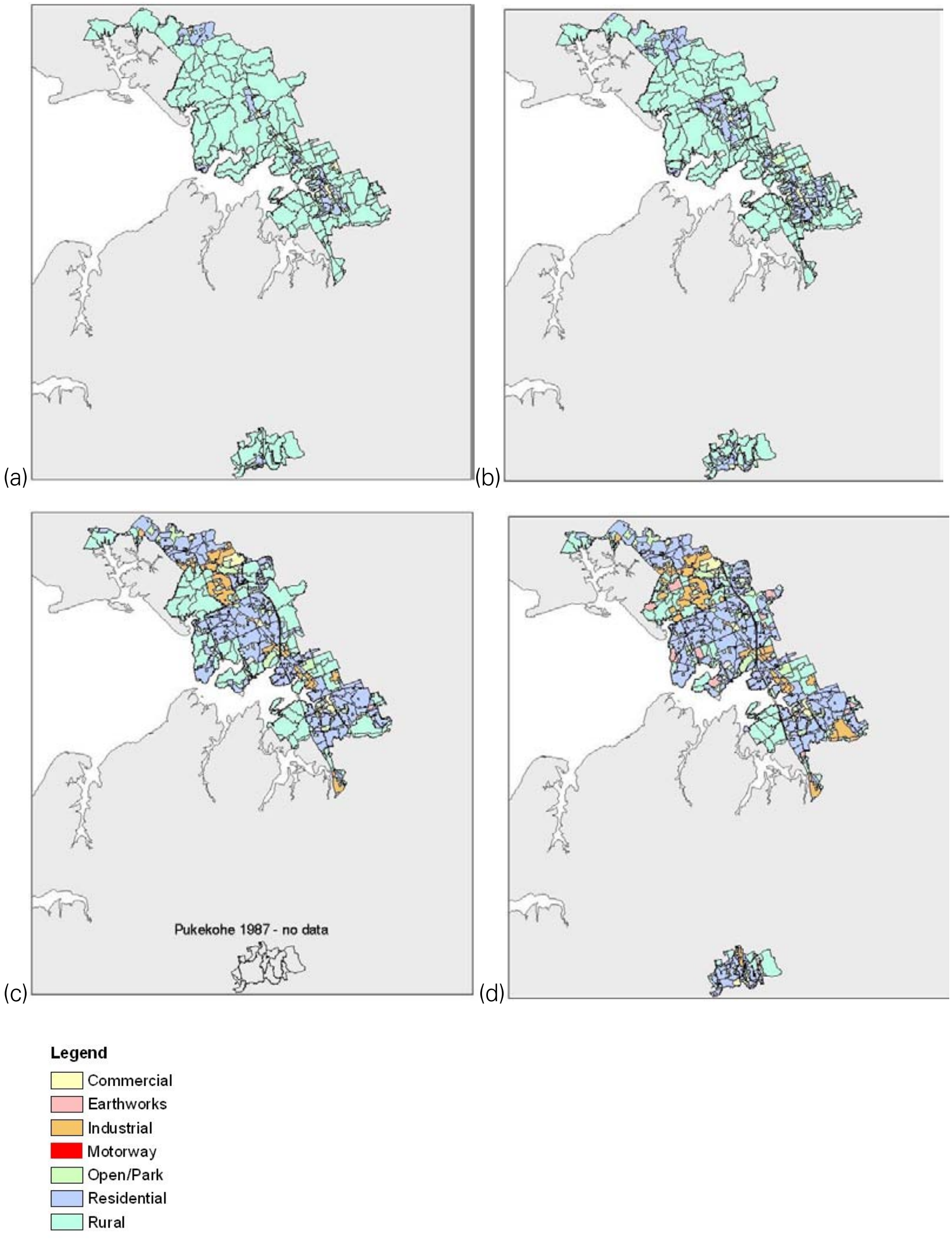


**Figure 13:**
Changing residential landuse proportions over time in urban MUs. Pukekohe proportions in 1987 are taken from 2001 proportions.

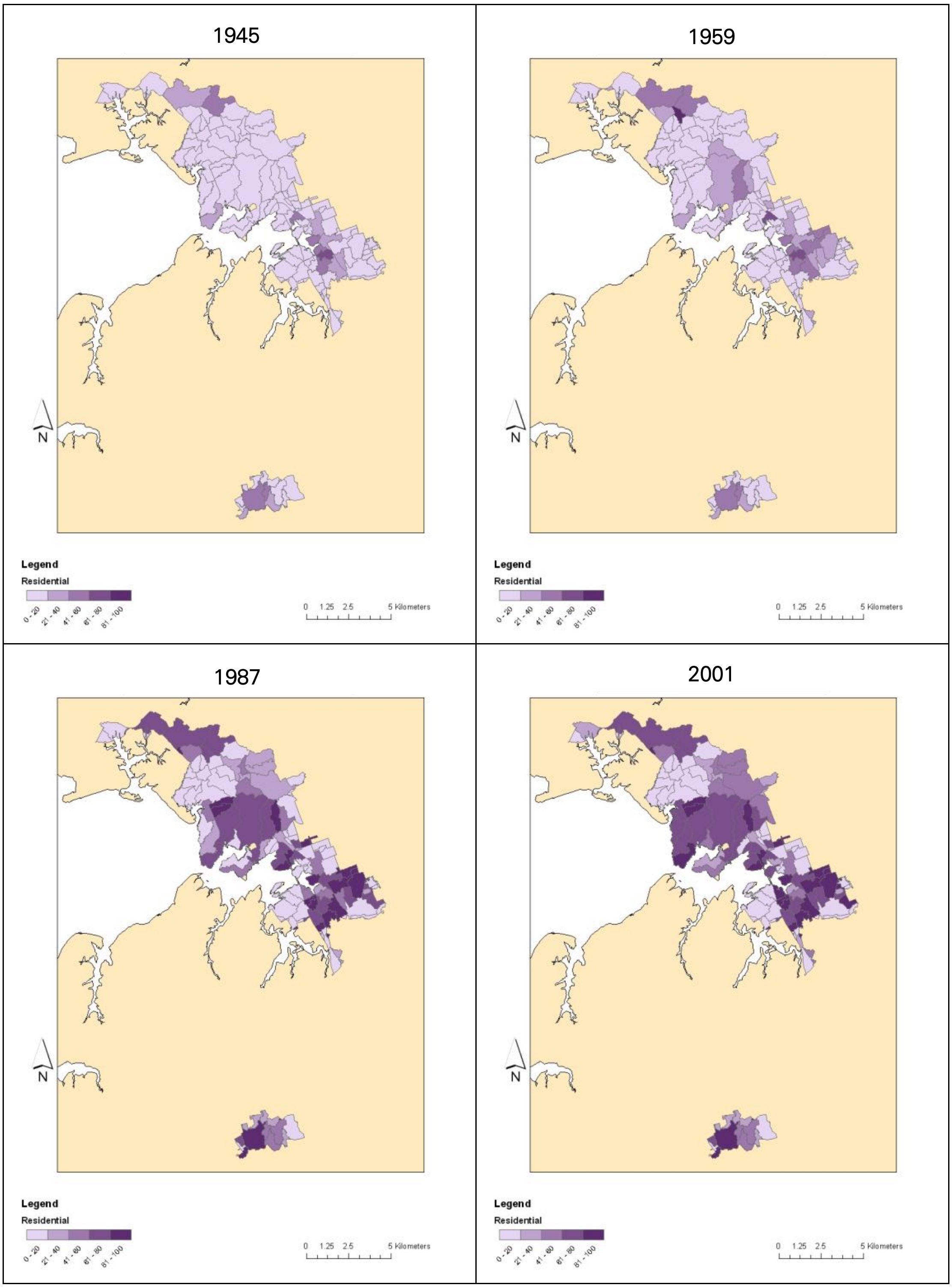
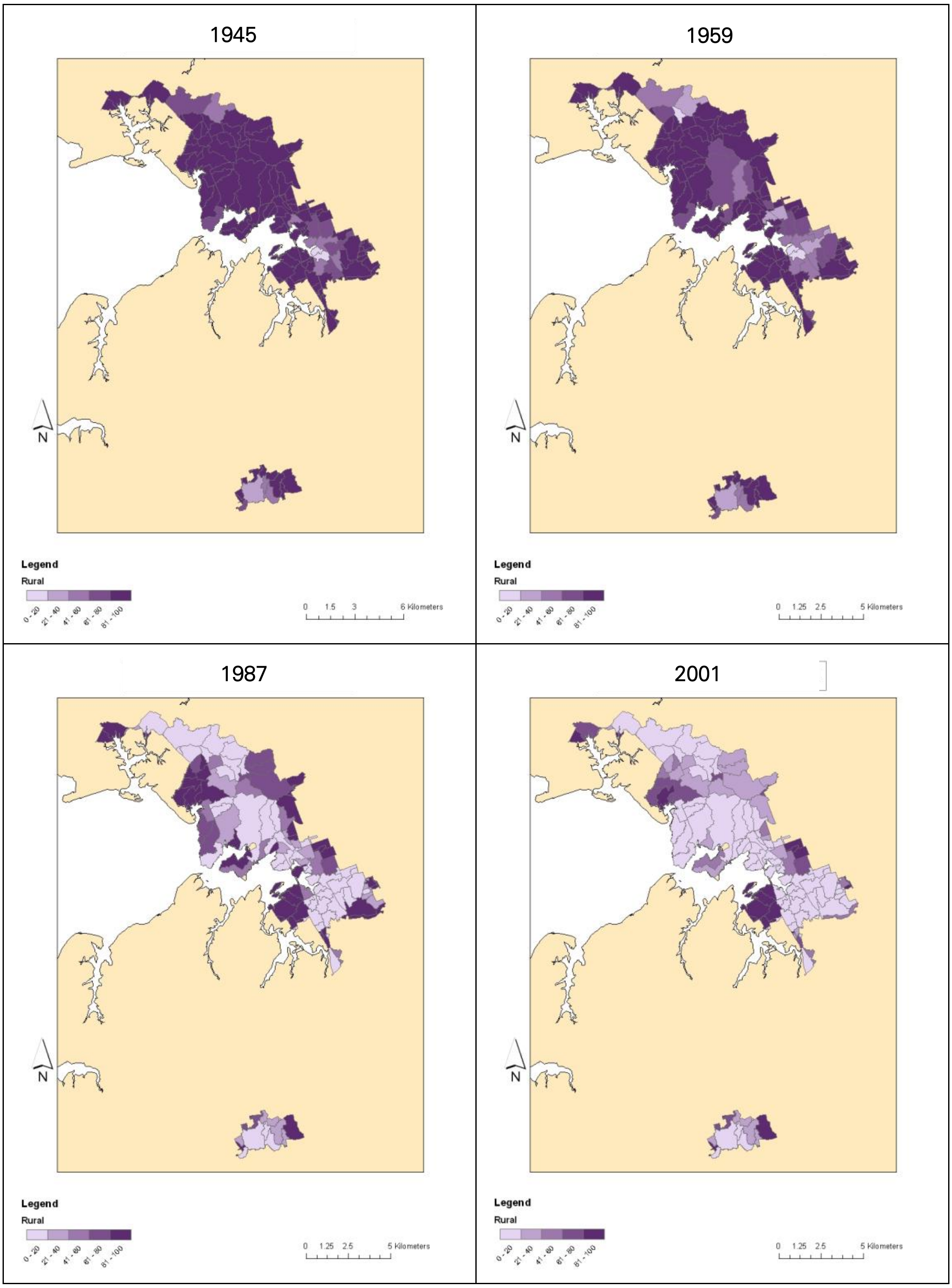


**Figure 14:**
Changing rural landuse proportions over time in urban MUs. Pukekohe proportions in 1987 are taken from 2001 proportions.



The results of this mapping exercise provided the broad scale input data required by the CLM and GLEAMS-SEM models, in other words the area of residential, industrial, commercial, motorway and rural land in each model unit at a selection of time 'snapshots'. Use of the data for the prediction of contaminant loads is described in Moores and Timperley (2008).

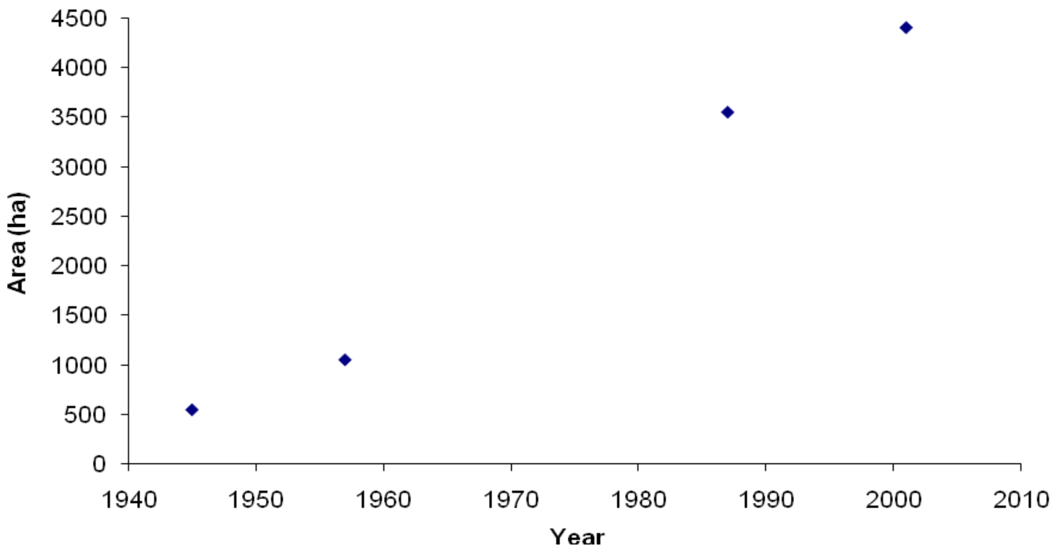
# 6 Landuse Analysis for GLEAMS-SEM modelling

## 6.1 Historical built-up or 'urbanised' areas within the catchment

Historical commercial, industrial and residential areas together comprise the historical "built-up" area. The area of built-up land provides the basis for the estimation of the area of historical earthworks; it gives a more accurate estimate than obtained from the urban boundaries, which includes land with no earthworks such as lakes, ponds, trees, parks, open spaces and the like.

There was an overall linear increase in the built-up area within the urban limits over time (see Figure 15 for the area within the Auckland MUL) but still growing at year 2001. The greatest growth or change in area within the urban boundary was during the 1959–1987 period. For reference, the total area of the study catchment is 45035 ha.

**Figure 15:**
Built-up area (ha) within the Auckland MUL over time.

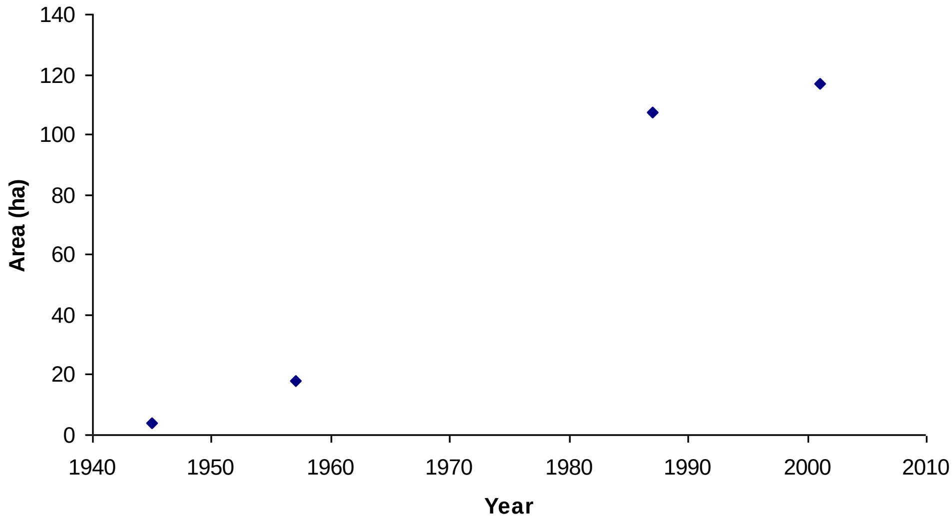



Ideally, it would also be desirable to have an estimate of built-up area in the 1970s, but these data were not available.

### 6.1.1 Built-up area within each Model Unit (MU)

The areas of built up land within individual MUs lying within the urban boundary often increased sigmoidally to approach the value in 2001. Figure 16, for MU 16 within the Auckland metropolitan limit, is such an example. The greatest increases have occurred in those MUs located near the periphery of the urban area.

**Figure 16:**
Expansion of the built-up area within MU 16, located within the Auckland metropolitan limit.




There are 117 MU's lying within the Auckland MUL and Pukekohe urban boundary. Of these, 79 had no built-up area in 1945, 55 had no built-up area in 1957, and 10 had no built-up area in 1987. There is no data for 1987 built-up area within the Pukekohe boundary and this area was estimated from 1959 and 2001 data by linear interpolation.

### 6.1.2 Historical greenfield earthworks area estimates

Greenfield earthworks areas were estimated for the years 1945, 1959, and 1987 in the areas of urban growth within the Auckland MUL and Pukekohe urban area on a model unit (MU) basis. These were generated on the basis of estimated rates of change of built-up areas within each MU using 1) linear regression during periods between 1945 and 2001 when there was observed growth in the 'built-up' area and sufficient data available, and 2) piecewise linear fit when there was insufficient data available. The area of earthworks was only extracted for years when there was urban growth. The earthworks area estimated by this technique was limited by the area of rural grassland available in each MU so as to avoid overestimation of greenfield earthworks areas.

It was assumed that the increase in the area of greenfields earthworks corresponded with a reduction in the area of rural grassland as this became consumed by the expansion of the built-up area.

## 6.2 Rural landuse

As described in Section 5 , all areas outside of the historic ‘built-up’ area, derived either by digitization of historical photographs, or from the 2001 LCDB2 definition, are considered ‘rural’. Comparison of the 1945 and 2001 aerial photographs show that many areas currently under grassland, trees, manuka/kanuka scrub, market gardens and the like were under the same or similar land cover in 1945. Historical landuse shape files for 1945, 1959, and 1987 were therefore created based on LCDB2 (2001) data and classifications overlaid with 2003-4 bare earth areas (as described in Section 4).

It was assumed that 2001 LCDB2 “built-up”, “urban parkland/open space” and “motorways” categories outside the Auckland MUL and Pukekohe urban area were in “low producing grassland” in 1945 and 1959 (i.e., prior to any development), but were in the current landuse for 1987.

## 6.3 Preparing landuse data for use in GLEAMS-SEM

The landuse shapefiles for 1945, 1959, and 1987 were each split into five regions based on urbanised and rural areas, and respective rainfall regions RR1, RR2, and RR3 (see Parshotam et al. 2008a; Semadeni-Davies and Parshotam, 2009). Unique combinations of soil, slope and landuse were created within Arc-GIS for each year and region.

It is worthwhile to note that areas of greenfield earthworks under development, unlike all other landuse classes, were determined as proportional areas of each MU, without specifying their exact locations. The GLEAMS-SEM model was applied to this estimated area on a pro-rata basis according to the proportions of soil and slope combinations within a MU. The GLEAMS-SEM model was also applied to replaced grassland in a similar fashion: greenfield earthworks areas were in grassland (either improved or unimproved) prior to any proposed development, and so an equivalent proportional area of grassland was removed from the model unit.

# 7 Future landuse

In this study, all future urban development is assumed to occur within the current Auckland MUL and urban-zoned land at Pukekohe. The prediction of landuse change within those boundaries, along with consequent changes in sediment generation, is made by the CLM (Moores and Timperley, 2008). GLEAMS predictions of sediment generation in rural parts of the study area are made on the assumption that rural landuse over the future period landuse will remain the same as at present. Current areas of greenfields earthworks is assumed to be 'built-up'.

# 8 References

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