Auckland
Regional Council
TE RAUHĪTANGA TAIAO

Central Waitemata Harbour Contaminant Study

Rainfall Analysis

September TR 2009/109

Auckland Regional Council
Technical Report No.109 September 2009
ISSN 1179-0504 (Print)
ISSN 1179-0512 (Online)
ISBN 978-1-877540-24-0

Technical Report, first edition.

Reviewed by:	Approved for ARC publication by:
	Matthew Davis
Name: Hayden Easton	Name: Matthew Davis
Position: Team Leader Stormwater Action Team	Position: Group Manager Partnerships & Community Programmes
Organisation: Auckland Regional Council	Organisation: Auckland Regional Council
Date: 12 December 2009	Date: 18 December 2009

Recommended Citation:

SEMANDENI-DAVIES, A., 2009. Central Waitemata Harbour Contaminant Study. Rainfall Analysis. Prepared by NIWA Ltd for Auckland Regional Council. Auckland Regional Council Technical Report 2009/109.

Central Waitemata Harbour Contaminant Study. Rainfall Analysis

Annette Semadeni-Davies

Prepared for
Auckland Regional Council

NIWA Client Report: AKL-2009-039
July 2009

NIWA Project: ARC09221

National Institute of Water & Atmospheric Research Ltd
41 Market Place
Auckland Central 1010
Private Bag 99940
Newmarket
Auckland 1149
www.niwa.co.nz

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

Reviewed by:

Georgina Griffiths

Approved for release by:

Ken Becker

1 Executive Summary

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.

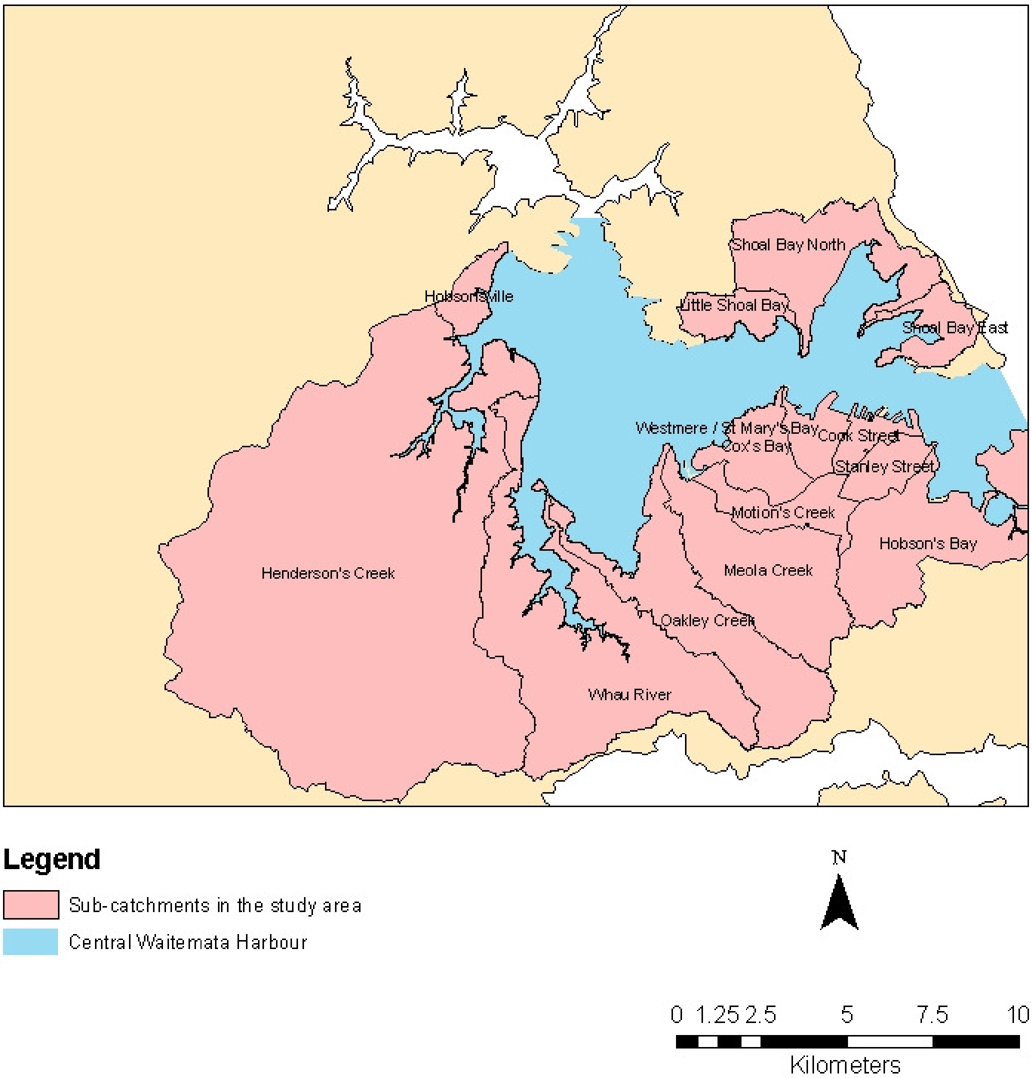
This report describes the choice and derivation of the long-term rainfall record for the study. The main aim was to model contaminant (zinc, copper) and sediment accumulation within the CWH for the purposes of, amongst other things, identifying significant contaminant sources, and testing efficacy of stormwater treatment and contaminant source control.

1.1 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 contaminant source control;
- 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 contaminant source control;
- 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.

Figure 1
Study location showing the Central Waitemata Harbour and stream sub-catchments (split into stormwater management units).



1.2 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. Application of GLEAMS for the Central Waitemata Harbour is described in the ARC Technical Reports (2008c, 2008d and 2008e).

- The CLM contaminant/sediment-generation model, which predicts sediment and contaminant concentrations (including zinc and copper) in stormwater in urban streams, or at end-of-pipe where stormwater discharges into the receiving environment. Application of CLM for the Central Waitemata Harbour is described in ARC Technical Report No. 2008/038 (ARC, 2008f).
- Estuarine sediment-transport models (MIKE3 FM HD hydrodynamic model, MIKE3 FM MT (mud) sediment transport model, and the SWAN model (Holthuijsen *et al.*, 1993), which simulated 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 model outputs underpin the distribution of harbour and inlet suspended sediment and bed deposition used in the USC-3 model. Application of these models for the Central Waitemata Harbour is described in ARC Technical Report No. 2008/037 (ARC, 2008b).
- 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 are the three hydrodynamic models above, which simulate the dispersal of contaminants/sediments by physical processes such as tidal currents and waves. Application of USC-3 for the Central Waitemata Harbour is described in ARC Technical Report No. 2008/042 (ARC, 2008a).

The models were used to hindcast the impacts of historical land use on harbour sediment accumulation and predict future impacts based on a set of land use change scenarios.

1.3 This report

The GLEAMS, hydrodynamic models and USC-3 models all require daily rainfall data as input. This report describes the choice and derivation of the long-term rainfall record (1944-2005) for the models. The report details the derivation of the rainfall record, data handling methods and the application of rainfall in the models listed above.

The rainfall records investigated in this report are from the National Climate Database maintained by NIWA. Of these records, rainfall from the Albany gauge was chosen as representative of the study area.

This report covers the following topics:

- spatial pattern of rainfall over the study area;
- choice of rainfall gauges;
- data handling including reconstruction of missing data and record extension;
- evaluation of rainfall statistics; and
- implementation of rainfall in the model suite.

2 Rainfall Stations and Analysis

2.1 Spatial pattern of annual rainfall

The variation in median annual rainfall across the Auckland region can be seen in Figure 2. This map was interpolated for the period 1971-2000 using a thin-plate smoothing spline (Hutchinson, 1995, 2008), which takes into account the proximity to the climate stations and the spatial pattern of rainfall (Tait *et al.* 2006). The long-term median annual rainfall values are calculated at each station site, and then interpolated onto a 500 m by 500 m grid. The map was then created from these gridded data. The map shows that there is a broad similarity in annual rainfall across the study area (shown in Figure 1). The median annual rainfall ranges from about 1000 mm around the Cox's Bay catchment to nearly 1500 mm in the west of Henderson Creek catchment.

The regional spatial pattern of design rainfalls given in Technical Publication 108 (ARC, 1999) are consistent with that given in Figure 2. By way of example, Figure 3 shows the contours for the 2-year rainfall design storm (ie, the storm event with an average recurrence interval of 2 years).

Taken together, Figures 2 and 3 show that the study area has a medium-to-low annual rainfall with low 24-hour rainfall intensities. The west and north of the study area have higher median annual rainfalls. The 2-year 24-hour design storm intensity ranges from 70 mm/day for central Auckland to 80 mm/day in the west and north.

Figure 2
Interpolated Auckland median annual rainfall for the 30-year period 1971 – 2000. (Map produced by NIWA using the technique described in Tait *et al*. 2006).

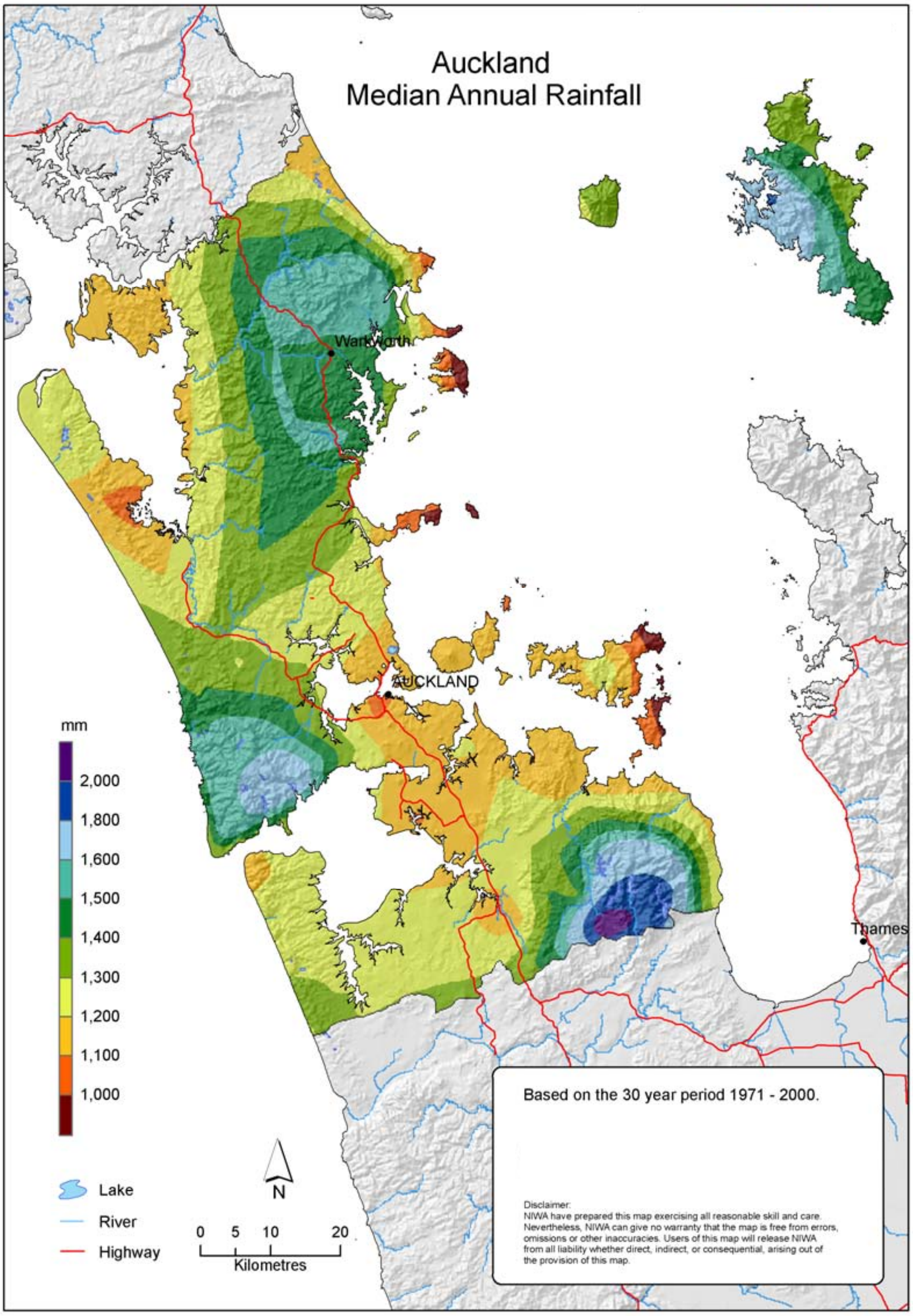
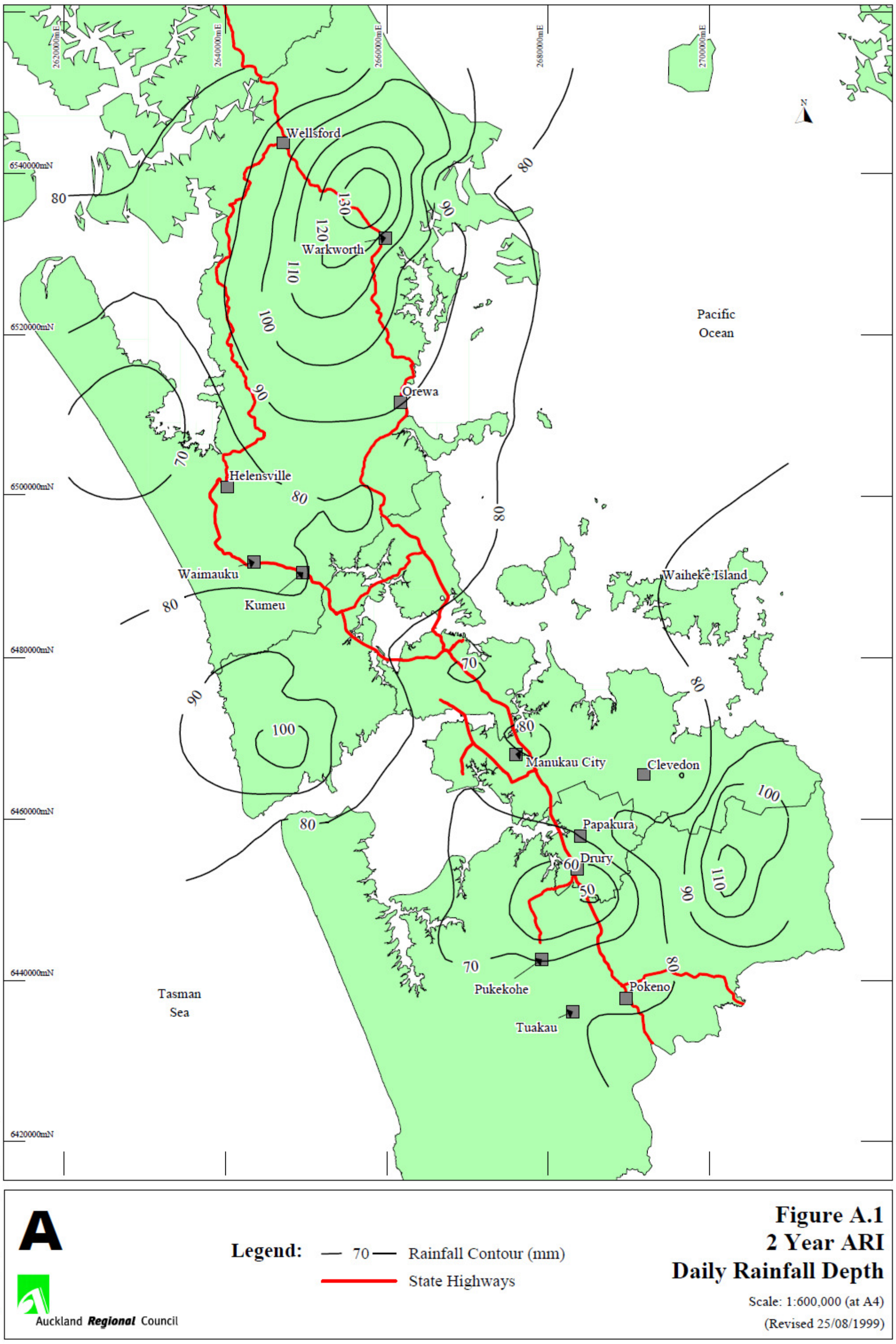


Figure 3

Two-year ARI (average recurrence interval) rainfall depth contours for Auckland – Figure A1 of ARC TP108 (1999).



2.2 Construction of composite records

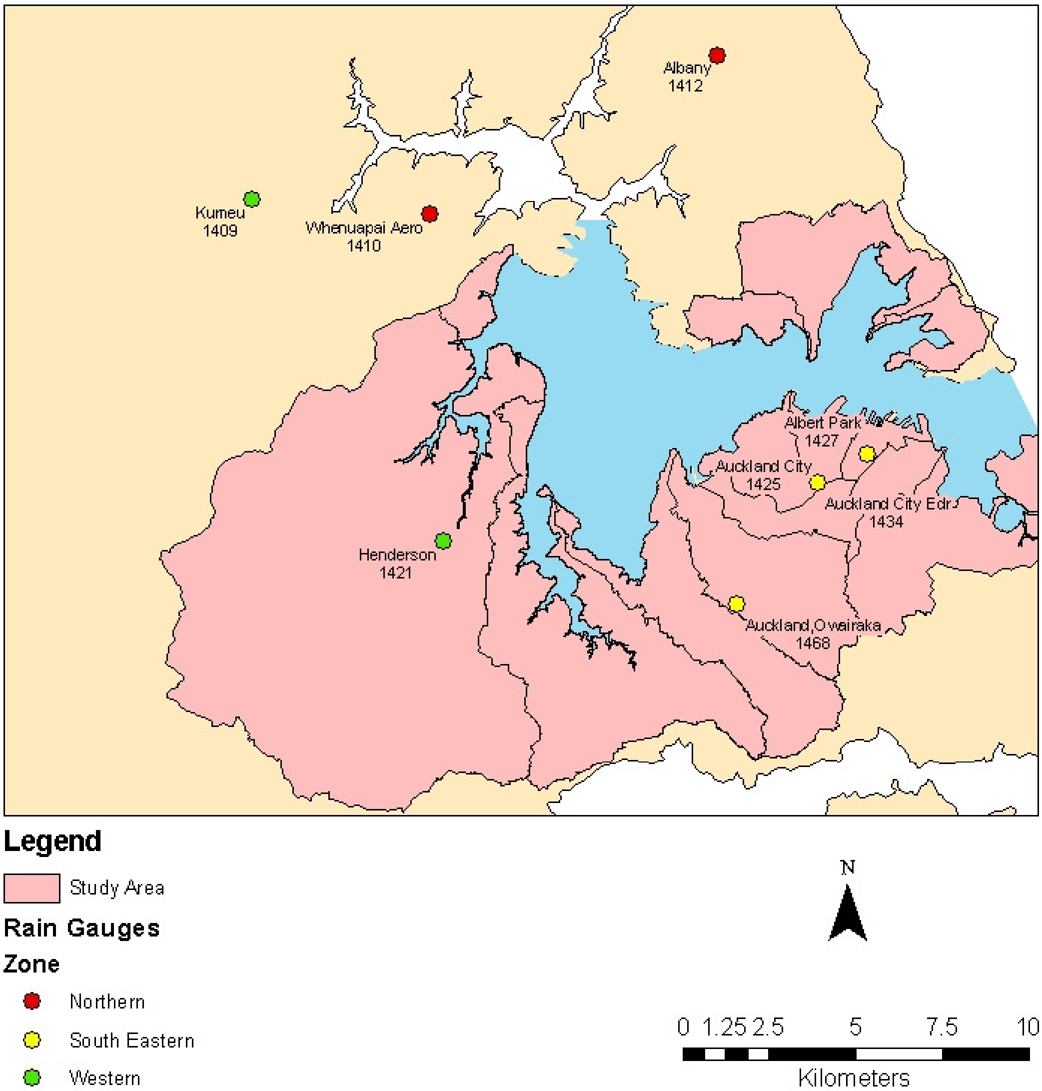
Records from 11 rainfall gauges were initially selected from the National Climate Database maintained by NIWA. The gauges are located in and around the study area (Figure 4) and were grouped into three geographical sectors, Northern, South-eastern and Western. Of the 11, eight gauges were used to develop a composite record for each sector, these were chosen based on location and data availability. The stations used are summarised in Table 1. Note that as the Western sector does not have sufficient data to cover the entire simulation period, the Whenuapai and Owairaka records were used to extend the composite record and fill missing data.

Table 1

Stations used to construct a rainfall record for model input arranged by geographical sector. Main stations for the sectors are shaded.

Agent No	Name	Sector	Start date	End Date	Gauge type
1412	Albany	Northern	1-Jan-66	-	Auto. Daily
1410	Whenuapai Aero	Northern	1-Nov-43	30-Jun-93	Auto. Daily
1434	Auckland City	South-eastern	1-Sep-62	31-Dec-90	Manual 5" Copper
1425	Auckland City Edr	South-eastern	1-Sep-90	19-Nov-1996	Ota Tipping-Bucket
1427	Albert Park	South-eastern	01-Jan-1853	1-Mar-94	Auto. Daily
1468	Owairaka	South-eastern	1-Jan-49	15-May-94	Manual 5" Copper
			16-May-94	-	Auto. Daily
1421	Henderson	Western	1-Jan-24	31-Aug-88	Manual 5" Copper
1409	Kumeu	Western	1-Jul-89	1-Mar-99	Manual 5" Copper

Figure 4
Location of gauges with respect to the study area.



The number of missing days per year of operation is summarised in Table 2. Henderson has substantial periods of missing data from the late 1960s. While Owairaka has some 282 missing days, most of these occur in a single year so that the rest of the record is fairly complete. Auckland City EDR, which replaced the Auckland City gauge in 1990, had 135 missing days in only six years of operation. As a consequence, this record was replaced with the Owairaka record for the composite and was only used for filling missing data. The Northern record can be considered the most reliable as it was constructed from only two gauges, each of which have few missing days (note that the missing days for Whenuapai were all from the final month of operation and are not typical of the record).

Table 2

Summary of missing data for the records used in the construction of composite records.
Main stations for the sectors are shaded.

Year	Northern		South-eastern				Western	
	Albany	Whenuapai	Auckland City	Auckland City EDR	Albert Park	Owairaka	Henderson	Kumeu
1944	-	0	-	-	0	-	2	-
1945	-	0	-	-	0	-	5	-
1946	-	0	-	-	0	-	6	-
1947	-	0	-	-	0	-	3	-
1948	-	0	-	-	0	-	0	-
1949	-	0	-	-	0	0	5	-
1950	-	0	-	-	0	0	29	-
1951	-	0	-	-	0	0	30	-
1952	-	0	-	-	0	0	2	-
1953	-	0	-	-	0	0	12	-
1954	-	0	-	-	0	0	4	-
1955	-	0	-	-	0	0	3	-
1956	-	0	-	-	0	0	0	-
1957	-	0	-	-	0	244	0	-
1958	-	0	-	-	0	32	9	-
1959	-	0	-	-	0	0	0	-
1960	-	0	-	-	0	0	0	-
1961	-	0	-	-	0	0	0	-
1962	-	0	0	-	0	0	10	-
1963	-	0	0	-	0	0	19	-
1964	-	0	0	-	0	0	42	-
1965	-	0	0	-	0	0	19	-
1966	61	0	0	-	0	2	9	-
1967	0	0	0	-	0	0	10	-
1968	31	0	0	-	0	0	57	-
1969	0	0	0	-	0	0	125	-
1970	0	0	0	-	0	0	152	-
1971	0	0	0	-	0	0	159	-
1972	0	0	0	-	0	0	215	-
1973	30	0	0	-	0	0	30	-

Year	Northern		South-eastern				Western	
	Albany	Whenuapai	Auckland City	Auckland City EDR	Albert Park	Owairaka	Henderson	Kumeu
1974	0	0	0	-	0	0	17	-
1975	0	0	0	-	0	0	34	-
1976	0	0	0	-	0	0	66	-
1977	0	0	0	-	0	0	103	-
1978	0	0	0	-	0	0	83	-
1979	0	0	0	-	0	0	121	-
1980	3	0	0	-	0	0	118	-
1981	0	0	0	-	0	0	80	-
1982	0	0	0	-	0	0	84	-
1983	0	0	0	-	0	0	69	-
1984	0	0	0	-	0	0	93	-
1985	0	0	0	-	0	0	83	-
1986	1	0	0	-	0	0	168	-
1987	0	0	0	-	1	1	37	-
1988	0	0	0	-	2	0	-	-
1989	0	0	0	-	3	0	-	0
1990	0	0	0	30	35	0	-	15
1991	0	0	-	77	0	0	-	0
1992	0	0	-	12	0	1	-	18
1993	0	7	-	0	1	2	-	6
1994	0	-	-	16	0	0	-	5
1995	0	-	-	0	-	0	-	43
1996	0	-	-	0	-	0	-	2
1997	0	-	-	-	-	0	-	10
1998	0	-	-	-	-	0	-	1
1999	0	-	-	-	-	0	-	0
2000	0	-	-	-	-	0	-	-
2001	0	-	-	-	-	0	-	-
2002	0	-	-	-	-	0	-	-
2003	0	-	-	-	-	0	-	-
2004	0	-	-	-	-	0	-	-
2005	0	-	-	-	-	0	-	-
Total	126	7	0	135	42	282	2113	100

A composite rainfall record for each sector was made for the period 1944-2005 by first assigning a *main* station (shaded in Table 1), chosen according to location and length of record, and then using the highest quality rain data from the nearest available secondary stations to extend or fill gaps in the record for the main station. Missing data replacement was made using the following formula which normalises the secondary data to the main record:

$$R_1 = \overline{R}_1 + \frac{\overline{R}_1\left(R_2 - \overline{R}_2\right)}{\overline{R}_2} \qquad 1$$

where R_1 is the estimated daily rainfall for the main station, $\overline{R}_1$ is the mean average daily rainfall for the main station, R_2 is the daily rainfall recorded at the secondary station and $\overline{R}_2$ is the mean average daily rainfall for the secondary station.

The composite records were constructed as follows:

Northern

1944 – 1966	Whenuapai normalised to Albany – no missing data.
1966 – 2005	Missing data replaced with Whenuapai normalised to Albany.

South–eastern

1944 – 1962	Albert Park normalised to Auckland City – no missing data.
1962 – 1990	Auckland City – no missing data.
1990 – 2005	Owairaka normalised to Auckland City – missing data replaced with Auckland City EDR.

Western

1944- 1987	Henderson – missing data replaced with Whenuapai normalised to Henderson.
1987 – 1989	Whenuapai normalised to Henderson.
1989 – 1999	Kumeu normalised to Henderson.
1999 – 2005	Owairaka normalised to Henderson.

For each sector, the records from the secondary stations normalised to the primary station were compared to ascertain how well the normalisation is able to capture daily rainfall statistics for inclusion in the composite. For the Northern record (Table 3), the distributions for the Albany and normalised Whenuapai daily rainfalls were compared and showed good agreement. For the Western record (Table 4), there is good agreement between the Henderson rainfall record and the Owairaka record normalised to Henderson. The normalised Whenupai record has fairly good agreement but is slightly drier. No direct comparison could be made between Henderson and Kumeu rainfall normalised to Henderson as Henderson had closed before Kumeu was established. For the South-eastern record (Table 5), the agreement between Auckland City and both the normalised Albert Park and Owairaka rainfall distributions was very good.

Table 3

Summary of rainfall statistics for the records used to construct the Northern composite: rainfall intensity (mm/day) percentiles, mean daily rainfall and total rainfall over the comparison period (March 1966 – July 1993). Days with missing data at either station have been removed from both records.

Percentile	Albany	Whenuapai	Whenuapai normalised
100	162	176	168
99	42	41	39
97	24	23	22
95	18	18	17
90	11	11	10
85	7	7	7
80	5	5	5
Mean daily rainfall (mm)	3.5	3.5	3.4
Total rainfall (mm)	34725	35035	33390

Table 4

Summary of rainfall statistics for the records used to construct the Western composite: rainfall intensity (mm/day) percentiles, mean daily rainfall and total rainfall. Days with missing data at either station have been removed from both records. Note a comparison between Henderson and Kumeu is not possible.

a. Henderson vs. Whenuapai (January 1944 to June 1987).

Percentile	Henderson	Whenuapai	Whenuapai normalised
100	171	260	263
99	40	42	42
97	24	24	24
95	19	18	18
90	11	11	11
85	8	7	7
80	5	5	5
Mean daily rainfall (mm)	3.7	3.5	3.6
Total rainfall (mm)	51225	48691	49275

b. Henderson vs. Owairaka (January 1949 – June 1987).

Percentile	Henderson	Owairaka	Owairaka normalised
100	171	165	172
99	40	43	44
97	30	31	32
95	24	24	25
90	20	21	22
85	18	18	19
80	17	16	16
Mean daily rainfall (mm)	3.7	3.5	3.6
Total rainfall (mm)	42715	40452	42089

Table 5

Summary of rainfall statistics for the records used to construct the South-eastern composite: rainfall intensity (mm/day) percentiles, mean daily rainfall and total rainfall. Days with missing data at either station have been removed from both records.

a. Auckland City vs. Albert Park (Sept 1962 – Nov 1990).

Percentile	Auckland City	Albert Park	Albert Park normalised
100	141	157	143
99	39	39	36
97	22	24	22
95	16	17	16
90	9	10	9
85	6	7	6
80	4	4	4
Mean daily rainfall (mm)	3.0	3.4	3.1
Total rainfall (mm)	31209	34578	31613

b. Auckland City vs. Owairaka (Sept 1962 – Nov 1990).

Percentile	Auckland City	Owairaka	Owairaka normalised
100	141	165	145
99	38	42	37
97	22	24	21
95	16	18	16
90	9	11	9
85	6	7	6
80	4	5	4
Mean daily rainfall (mm)	3.0	3.5	3.1
Total rainfall (mm)	31386	36174	31760

2.3 Comparison of the composite records

Summary statistics for the composite records are given in Table 6, these show that while the number of rain-days are comparable across the study area, the Western record is generally wetter followed by the Northern record. This is also clear from the monthly average rainfalls (Figure 5). The spatial variation in rainfall is consistent with Figures 2 and 3. The rainfall distributions are summarised in Table 7 (percentiles) and Figure 6 (histogram with cumulative probability). These show that the highest intensity 24-hour rainfall was in the Northern record. The Northern and Western records have similar rainfall distributions whereas the South-eastern record has slightly lower rainfall intensities.

Table 6

Summary statistics for the three composite records (1944-2005).

Statistic	Sector		
	South-eastern	Northern	Western
Mean annual (mm/year)	1152	1289	1385
Rain-days (days/year)	181	181	189
Mean daily (mm/day)	3.2	3.5	3.8
Max daily (mm/day)	141.2	247.6	171.4
Std dev (mm/day)	7.7	8.6	8.8

Table 7

Rainfall intensity (mm/day) percentiles for the three composite records (1944-2005).

Percentile	Sector		
	South-eastern	Northern	Western
100	141	248	171
99	37	41	41
97	23	24	25
95	16	18	19
90	10	11	12
85	6	7	8
80	4	5	5
70	2	2	2

Figure 5
Mean monthly rainfall for the three composite records (1944-2005).

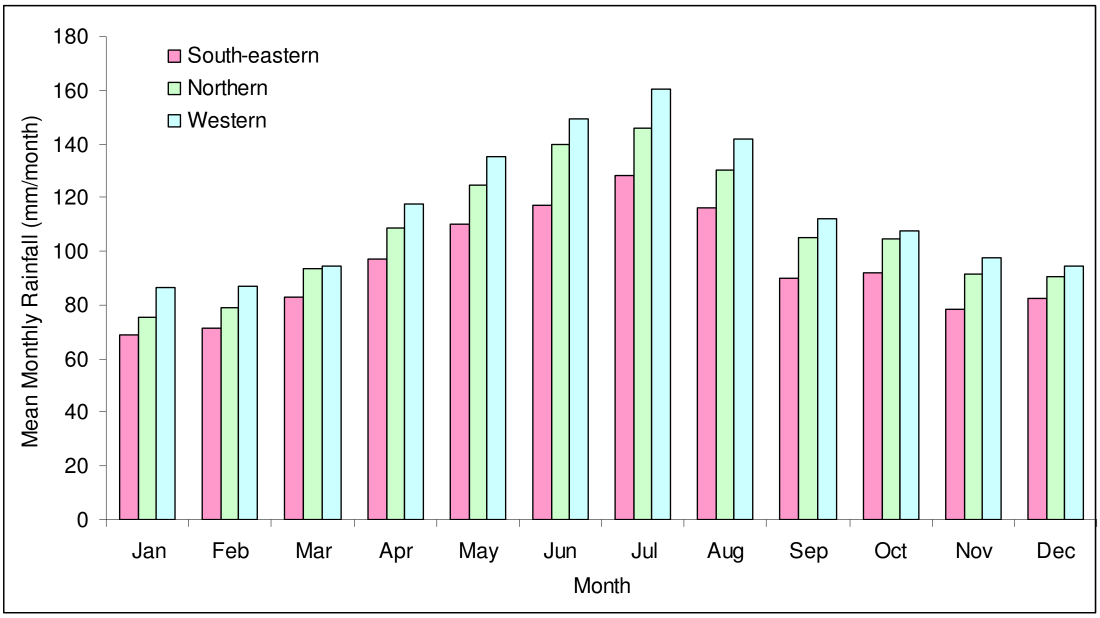
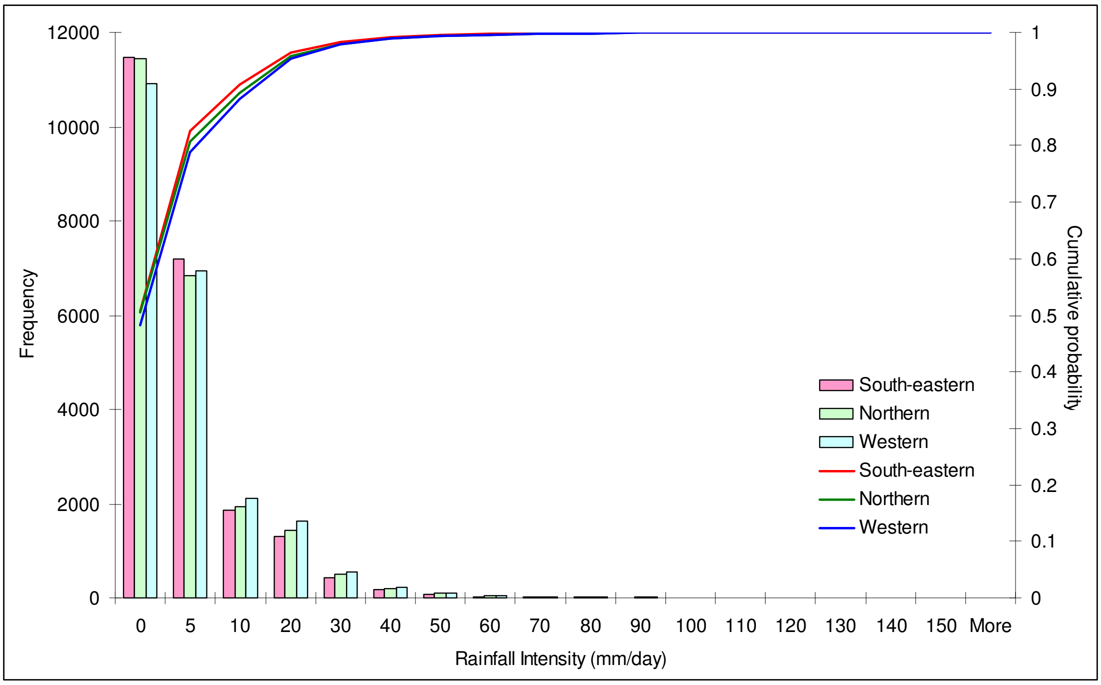


Figure 6
Histogram and cumulative probability of daily rainfall intensities for the three composite records (1944-2005).



3 Rainfall Representation in the Model Suite

The Northern record (composite of Albany and Whenuapai rain gauges) was chosen as model input data as the distribution falls between the South-eastern and Western records making it representative of *average* conditions in the study area for the purposes of modelling. The differences between the records would have a minimal effect on model results. The USC-3 model, for instance, splits rainfall into seven intensity classes ranging from 0.9-4.8 to >100 mm/day. Hence, while there is some difference between the most intense events for the three composite records, these events would be assigned the same intensity class in the USC-3 model.

It was also felt that the Northern Record is most reliable as it is constructed from only two stations with little missing data. In contrast, the more urbanised sites have had problems with site continuity, vandalism and closures. Central Auckland (South-eastern sector), in particular, has suffered from recent rainfall site closures at the national level and now lacks a homogeneous and active record with the exception of Owairaka. The Western record had local data available from 1944 to 1999 (albeit with a large amount of missing data for the Henderson gauge) but was then reconstructed with normalised data from Whenuapai and Owairaka. For modelling purposes, the intensities are comparable across the study area.

3.1 GLEAMS

The application of GLEAMS to the Central Waitemata Harbour Contaminant Study including model calibration is discussed in the ARC Technical Reports (2008c, 2008d and 2008e). GLEAMS provides a daily series of land-derived sediments from rural land use and construction sites (contaminants from urban stream catchments are simulated with CLM) to the USC-3 model. Daily rainfall is a direct input to GLEAMS. It was assumed that rural land is land outside the metropolitan urban limits, which, for this study, is largely restricted to the Henderson Creek catchment. Sediment from urban areas, including Auckland City (ie, South-eastern sector) is modelled using CLM which does not have rainfall as an input.

The model was run using rainfall data (Northern record) from 1945-2005. This record is slightly drier than the Western record, which is nearer to Henderson Creek, but has a very similar distribution of rainfall intensities. Hence, the impact of using the Northern Record instead of the Western Record would be minimal.

Spatial variation in rainfall was not taken into account. Under the assumption that the urban metropolitan limits will not change, future sediment flows will have the same statistical properties as during the historical period. Hence, the historical sediment simulations were disaggregated and reaggregated to create a proxy future sediment record for the USC-3 model (see below) future land use runs (contaminants including sediments from urban areas are simulated using CLM).

3.2 Hydrodynamics Models

The hydrodynamics models (MIKE3 FM, MIKE3 MT and the SWAN wave model) and their calibration for the Central Waitemata harbour are described in ARC Technical Report No. 2008/037 (ARC, 2008b). Rainfall is used as an indirect input to the suite of models, which require inflows of fresh water from streams and estuaries flowing into the harbour. The models were run to provide a set of rules which describe sediment delivery, transport and deposition of land-derived sediments and erosion, and transport and deposition of estuarine sediments. These rules inform the USC-3 model.

The method used to derive the rules was to first calibrate the models and then run them for different tidal and weather scenarios. Two periods were modelled: 10–18 May 2006, and 14–16 June 2006 to calibrate salinity. The first period corresponds to the second wettest week during the 2006 deployment period. Simulating this period provides a good test of the ability of the model to predict harbour-wide mixing of fresh and saline waters.

Three periods in 2006 were chosen for the calibration of suspended sediment transport and deposition: 6-8 May (light winds, small sediment inflows from the catchment); 26-28 May (significant waves, moderate sediment inflows); and 18-21 June (winds averaging 3 m/s, moderated sediment inflows). In combination, these events and sites tested the model's capabilities to simulate the transport of sediment under a range of hydrodynamic conditions and sediment loadings.

Inflows to the harbour were simulated for each catchment draining to the harbour with the method described in TP108 (ARC, 1999), using the Northern rainfall record described above.

Once calibrated, the models were run with a series of discrete scenarios covering combinations of tide (eg, neap to spring), wind speed and direction and flows calculated from rainfall intensity (ie, the USC-3 rainfall intensity bands) to create the rules library. The scenarios and the implementation of the rules library in the USC-3 model are described in ARC Technical Report No. 2008/042 (ARC, 2008a).

3.3 USC-3

The USC-3 model and its implementation in the Central Waitemata Harbour study is described in ARC Technical Report No. 2008/042 (ARC, 2008a). The Northern rainfall record derived for GLEAMS, as described above, was supplied to the USC-3 model along with the GLEAMS sediment loads series so that each day has a matching rainfall and sediment load. The rainfall record is used to select the relevant rule from the rules library derived from the DHI harbour models.

The sediment and rainfall series for past and current land use (ie, up until 2001) were used directly in USC-3. For future land use, the GLEAMS sediment and rainfall series were spliced into 2-year blocks which were then randomly joined in order to create a 100-year series for use in USC-3.

USC-3 also requires urban contaminant loads, which were calculated with CLM (ARC, 2008f). CLM is an annual loads model, hence the model results required temporal disaggregation. For input into USC-3, the annual loads are split proportionally into daily values such that the load for a particular day is proportional to the GLEAMS sediment load for the same day.

The Northern rainfall series is used by USC-3 to determine which rule to apply to a certain day, depending on whether the day has rain (with a threshold of 0.9 mm/day) and, if so, the intensity band in which the rainfall depth falls (these bands, in mm/day, are 0.9–4.8, 4.8–10.3, 10.3–18.8, 18.8–30.0, 30.0–80.0, 80.0-100 and >100.0). Rainfall is used along with tide and wind to query the rules library. The rules then determine how land-derived contaminants are delivered, transported and deposited in the harbour.

4 Summary

This report describes the derivation of a composite rainfall record which was used as input to the Central Waitemata Harbour Contaminant Study. The study uses a suite of models to simulate sediment transport from land surfaces and deposition patterns in the harbour and required daily rainfall as input. The rainfall analysis covers the period 1944 to 2005.

Eleven rainfall gauges from in and around the study area were examined. They were grouped into three geographical sectors; Northern, Western and South-eastern. Of the 11, eight were used to develop composite rainfall records, that is, one for each sector. The composites were derived by selecting the longest rainfall record for the sector and then filling in missing data and extending the record where required using normalised data from the other gauges in the sector.

The three composite records were compared and were shown to have similar daily rainfall distributions for the majority of events (ie, lowest 80 per cent of 24-hour rainfall intensities). The Western record was the wettest and had the highest intensity 24-hour rainfalls while the South-eastern record was driest with lower intensities. The Northern record was chosen as input to the models as it falls in the mid range between the other two composite records and was thought to be a good approximation of rainfall across the study area for modelling purposes.

GLEAMS takes daily rainfall (ie, the Northern composite record) as a direct input. The hydrodynamic models were calibrated using rainfall from the Northern record for three periods in 2006. The models were then used to derive a rules library which governed sediment delivery, transport and deposition of land-derived sediments and erosion, transport and deposition of estuarine sediments. The USC-3 model takes GLEAMS generated sediment loads and daily rainfall as model input. Rainfall intensity is used, along with tide and wind speed and direction, to select the appropriate rule from the rules library derived using the hydrodynamic models.

5 References

Auckland Regional Council, 1999. *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, 2008a. *Central Waitemata Harbour Contaminant Study. USC-3 Model Description, Implementation and Calibration*. Auckland Regional Council Technical Report No. 2008/042. (ARC TR2008/042). Auckland Regional Council.

Auckland Regional Council, 2008b. Central Waitemata Harbour Contaminant Study. Harbour Hydrodynamic, Wave and Sediment-Transport Model Implementation and Calibration. Auckland Regional Council Technical Report No. 2008/037. (ARC TR2008/037). Auckland Regional Council.

Auckland Regional Council, 2008c. *Central Waitemata Harbour Contaminant Study. GLEAMS Model Structure, Set-up and Input Data Requirements*. Auckland Regional Council Technical Report No. 2008/040. (ARC TR2008/040). Auckland Regional Council.

Auckland Regional Council, 2008d. *Central Waitemata Harbour Contaminant Study. Land use scenarios.* Auckland Regional Council Technical Report No. 2008/032. (ARC TR2008/032). Auckland Regional Council.

Auckland Regional Council, 2008e. *Central Waitemata Harbour Contaminant Study. GLEAMS Model Results for Rural and Earthworks Sediment Loads from the Catchment.* Auckland Regional Council Technical Report No. 2008/041. (ARC TR2008/041). Auckland Regional Council.

Auckland Regional Council, 2008f. *Central Waitemata Harbour Contaminant Study. Development of the Contaminant Load Model.* Auckland Regional Council Technical Report 2008/038. (ARC TR2008/038). Auckland Regional Council.

HOLTHUIJSEN, L.H.; BOOIJ, N.; RIS, R.C., 1993. A spectral wave model for the coastal zone, *Proceedings of 2nd International Symposium on Ocean Wave Measurement and Analysis*, New Orleans, USA, pp. 630–641.

HUTCHINSON, M.F., 1995. Interpolating mean rainfall using thin plate smoothing splines. *International Journal of Geographic Information Systems 9*: 385-403.

HUTCHINSON, M.F., 2008. ANUSPLIN, http://cres.anu.edu.au/outputs/anusplin.php (accessed 27 October 2009).

TAIT, A.B.; HENDERSON, R.D.; TURNER, R.W. & ZHENG, X., 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology 26*: 2097-2115.