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Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study: Rainfall Analysis

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Southeastern Manukau Harbour / Pahurehure Inlet Contaminant Study: Rainfall Analysis

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Prepared for
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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 choice and derivation of three rainfall data sets for use as input to the models. The rainfall analysis discussed here is for the period 1948 to 2006, however, rainfall from 2007 was used for calibration of GLEAMS and the DHI models with purpose collected data.

The records chosen are considered to be representative of three rainfall zones from the harbour/coastal lowlands to the foothills of the Bombay Hills. As can be expected from topography, the annual rainfall depth increased from the lowlands to the foothills. The rain gauges chosen as representative of these zones are:

Zone 1 – Auckland Airport (harbour/coastal lowlands), median average 1090-1220 mm yr^{-1};

Zone 2 – Ardmore, median average 1220-1344 mm/yr; and

Zone 3 – Ngakaroa (foothills), median average 1344-1685 mm yr^{-1}.

The Ardmore record was available from 1948 to 2006 and has only a few days of missing data. The Auckland Airport record was established in 1962 and has some 194 missing days of data, mostly during 1993 and 1994. The Ngakaroa record began in 1980, but the gauge was replaced and moved to a new location in 1993. There are over 700 days of missing data from Ngakaroa, largely for the original rain gauge, for which around 14% of the 13 year record is missing.

As the Ardmore record has only a few days of missing data and is the longest, it was the logical choice as a base record for reconstructing rainfall at the other sites. Synthetic rainfall records were constructed for both Auckland Airport and Ngakaroa, using regression analyses with the Ardmore record, in order to extend the Auckland Airport and Ngakaroa records to 1948 and to fill in missing data. Although major storms tend to occur across the entire study area, there is a mismatch in timing between gauges for the dates of these events. This is most noticeable between Ngakaroa, which is maintained by the ARC, and Ardmore which is maintained by NIWA. The mismatch is most likely due to differences in the type of gauge (e.g., tipping bucket volume) but could also be affected by local topography. As a consequence, regression analysis of chronological rainfall data between Ardmore and the other two gauges proved to have a weaker relationship than ranked rainfall. There were also differences in the timing of events between Auckland Airport and Ardmore. Thus, the relationships used for constructing the synthetic data were determined from ranked rainfall data. This means that rainfall events in the synthetic records will not correspond to actual events; instead, however, it can be expected that the synthetic records will have the appropriate statistical properties (e.g., probability distribution of events). This point was demonstrated for Auckland Airport, but for Ngakaroa the shortness of the data record combined with the fact that it is a composite record meant the same testing was not possible. In terms of modelling, the important consideration for the Southeastern Manukau Harbour / Pahurehure Inlet study is that the long term transport of sediment from land surfaces to and within the harbour are reasonable.

The rainfall data for the models are summarised in Table 1. GLEAMS and the DHI models require daily rainfall as direct input; the results of these models are used as input to the USC-3 model which predicts sedimentation and accumulation of contaminants in the bed sediments of estuaries on the "planning timescale" (Green, 2008).

The DHI harbour hydrodynamics models were calibrated using rainfall recorded at Auckland Airport for two periods during 2007. This data was used to derive fresh water inflows to the harbour which were simulated with the method laid out in TP108 (ARC, 1999). Once calibrated, the DHI models were used to create a physically-based rules library governing sediment delivery, transport and deposition of land-derived sediments and erosion, transport and deposition of estuarine sediments. These rules inform the USC-3 model and were created for a set of scenarios described in Green (2008).

GLEAMS was run with the three rainfall data sets, representative of the different rainfall zones, in order to create a daily time series of land-derived sediment loads reaching the harbour. Rainfall was distributed across the stream catchments draining to the inlet according to the rainfall zones for the GLEAMS runs. The GLEAMS generated sediment loads and the corresponding daily rainfall from Auckland Airport are supplied as input to the USC-3 model. The latter is used to query the rules library created with the DHI models; the rule that is applied for a particular day depends on that day's rainfall intensity, tide, and wind speed and direction. The GLEAMS future land use change runs were driven using the same rainfall data series. The resulting daily sediment load series and rainfall were spliced and re-aggregated to provide a 100-year future input data series to USC-3. The possible impacts of climate change were not addressed and no changes to the rainfall records were made.

Table 1:

Summary of rainfall data used in the Southeastern Manukau Harbour / Pahurehure Inlet study.

Gauge	Length of record analysed	Number of missing days	Median Annual Rainfall (mm yr^{-1})	Rainfall Zone	Models forced with data	Method used to extend record/replace missing data.
Ardmore	1948-2006	6	1,257	1	GLEAMS	Assumed zero
Auckland Airport	1962-2006	194	1,129	2	GLEAMS and USC-3*	Synthetic rainfall record, derived from the Ardmore record
Ngakaroa	1980-2006	701	1,312	3	GLEAMS	Synthetic rainfall record, derived from the Ardmore record

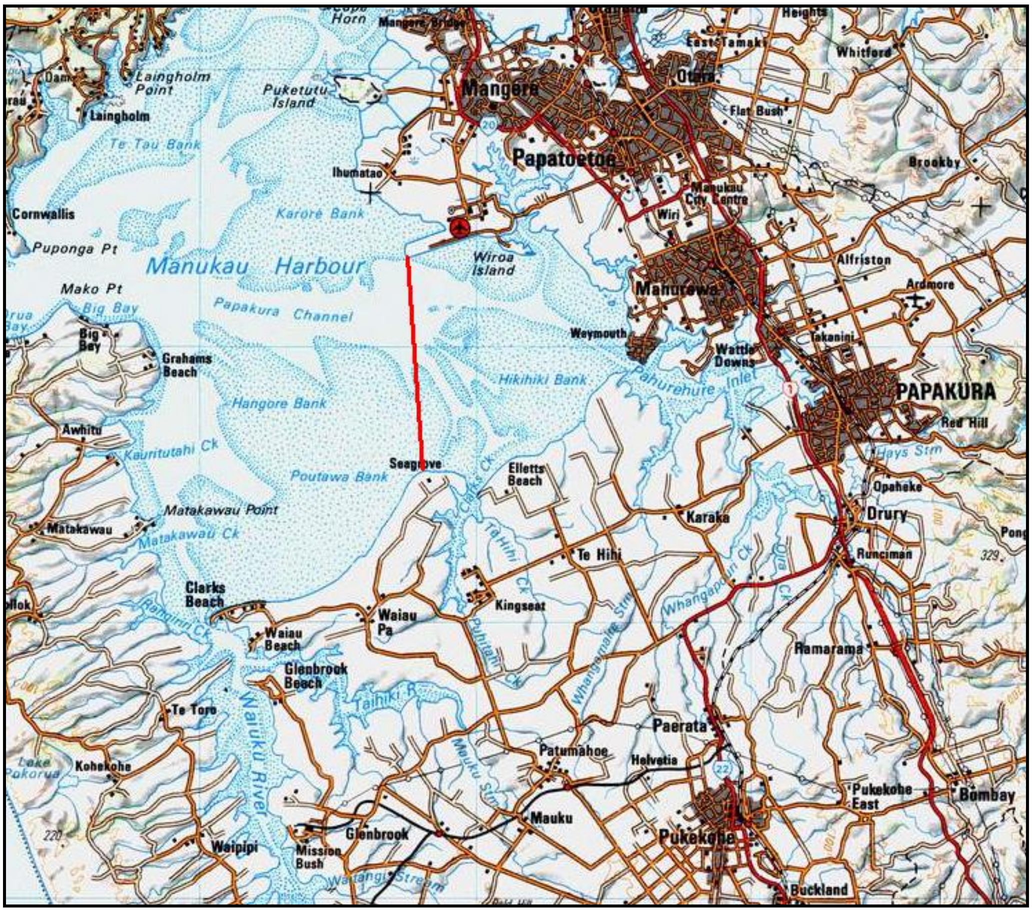
*DHI hydrodynamics models calibrated using data from 2007.

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 multiple catchments. Due to cross-catchment distribution of contaminant sources to the Southeastern Manukau / Pahurehure Inlet, and its hydrodynamically complex nature, ARC requested a single integrated study of contaminant discharge from the catchments and its accumulation in this receiving environment.

2.2 Study aims

The essential requirements of the study are as follows:

- 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 South Eastern Manukau Harbour; and
- to predict the year when sediment-quality guidelines will be exceeded.

2.3 Model suite

The Study centres on the application of a suite of models that are linked to each other:

- The GLEAMS sediment-generation model, which predicts sediment erosion from the land and transport down the stream channel network. Predictions of sediment supply are necessary because, ultimately, sediment eroded from the land dilutes the concentration of contaminants in the bed sediments of the harbour, making them less harmful to biota.
- The Contaminant Load Model (CLM)- a contaminant/sediment-generation model, which predicts sediment and contaminant concentrations (including zinc, copper) in stormwater at a point source, in urban streams, or at end-of-pipe where stormwater discharges into the receiving environment. Note the main distinction between the use of GLEAMS and CLM for estimating sediment generation in this study is that the former is largely used for rural areas and the latter for urban areas. Further details are given in Moores and Timperley (2008).
- The USC-3 (Urban Stormwater Contaminant) contaminant/sediment accumulation model, which predicts sedimentation and accumulation of contaminants (including zinc, copper) in the bed sediments of the estuary. Underlying the USC-3 model is yet another suite of models: the DHI Water and Environment MIKE3 FM HD hydrodynamic model, the DHI MIKE3 FM MT (mud) sediment transport model, and the SWAN wave model (Holthuijsen et al. 1993), which simulate harbour

hydrodynamics and sediment transport. Combined, these three models can be used to simulate tidal propagation, tide- and wind-driven currents, freshwater mixing, waves, and sediment transport and deposition within a harbour.

2.4 This report

The GLEAMS, DHI harbour hydrodynamics and USC-3 models all require daily rainfall data. This report describes the choice, and derivation, of three long-term rainfall series that were used as model inputs.

The rainfall records investigated in this report cover the study area from the coastal lowlands to the foothills of the Bombay Hills south of Auckland. The area was split into three rainfall zones based on examination of annual median rainfalls. Data from rain gauges in each of these zones were analysed to determine which records were most suited to modelling needs. Three rainfall series (Auckland Airport, Ardmore and Ngakaroa) were selected, one for each zone. There are sizable gaps in both the Auckland Airport and Ngakaroa records, hence, synthetic rainfall data were created (for use as surrogate data) from regression analyses with rainfall data from Ardmore, which had the most complete record. Note that the rainfall analysis discussed here was carried out in early 2007 and covers the period 1948 to 2006, however, rainfall from 2007 was used for calibration of both GLEAMS and the DHI models along with purpose collected data from the study area (e.g., salinity, sediment concentrations, wave heights for the DHI models).

This report is arranged such that the subsequent sections describe:

- Analysis of regional rainfall patterns over the study area to establish rainfall zones.
- The rainfall data available and the choice of representative rain gauges for the harbour and catchment.
- Creation of synthetic rainfall data for Auckland Airport and Ngakaroa, to replace missing data and extend the records.

3 Spatial pattern of annual rainfall

The variation in median annual rainfall across the Auckland Region as can be seen in Figure 2. This map was interpolated across the region 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 regional spatial pattern of design rainfalls given in TP 108 (ARC, 1999) are consistent with that given in Figure 2. By way of example, Figure 3 shows the contours for the two year rainfall design storm (i.e., 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 storm intensities.

As can be expected from the topography, in the study area rainfall increases from the coastal lowlands to the foot hills of the Bombay Hills. Figure 4 shows the median annual rainfall detailed for the Southeastern Manukau catchment. This map was produced from the gridded interpolated data discussed above for Figure 2. On the basis of this analysis, the availability of data, the spatial variation of rainfall, and gauge locations and numbers, the study region was split into the following three rainfall zones: Zone 1 1090-1220 mm yr^{-1}; Zone 2 1220-1344 mm yr^{-1} ;and Zone 3 1344-1685 mm yr^{-1} (Figure 5). While more zones could have been added through interpolation of rain data series, this was not considered necessary given the reasonably small increments in rainfall differences between the three zones. The boundaries of the zones were edited manually within GIS, using the spatial pattern of median annual rainfall. The locations of the gauges investigated in this study have also been mapped in Figure 5.

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).

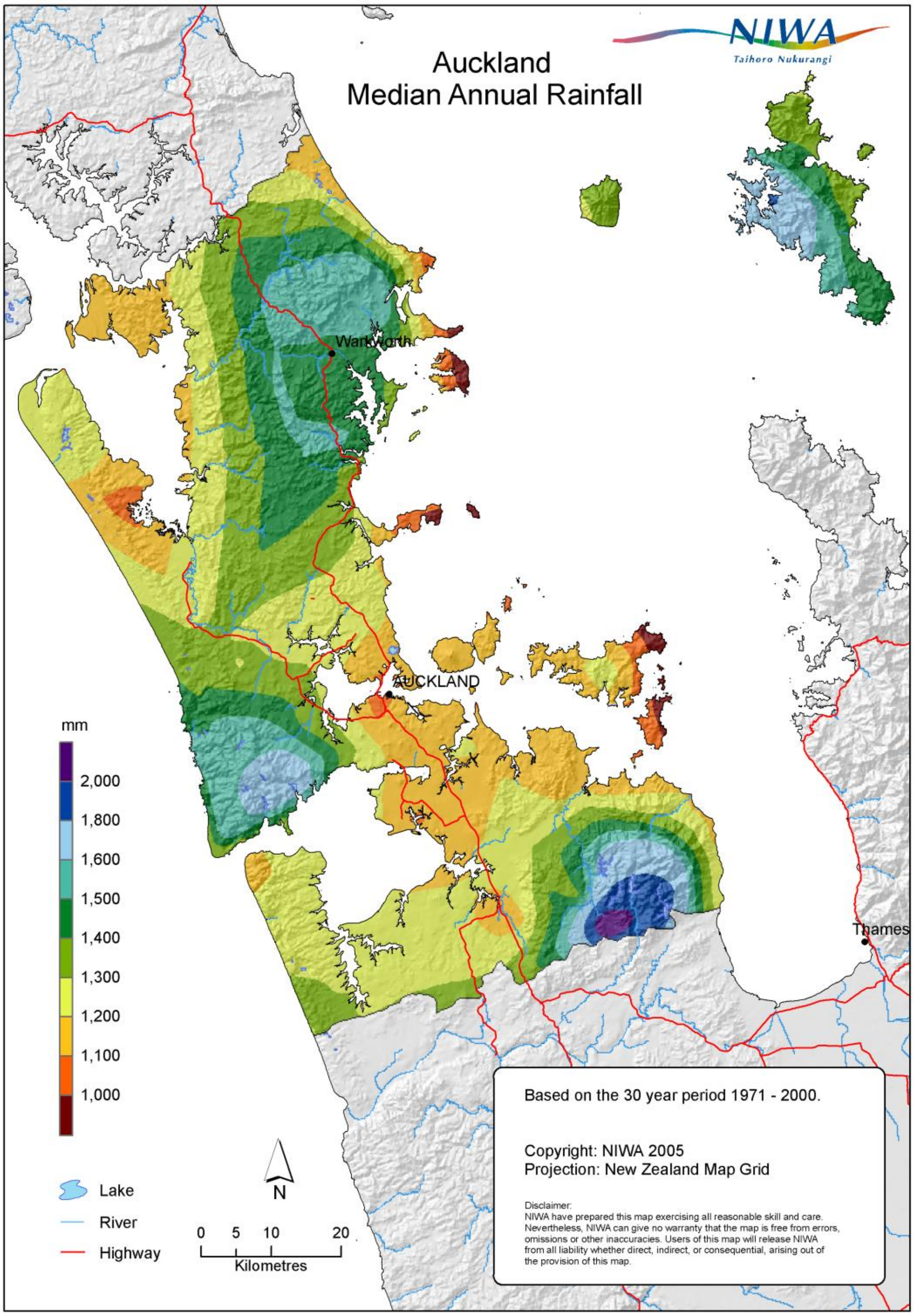


Figure 3:
2-year ARI (average recurrence interval) rainfall depth contours for Auckland - Figure A1 of ARC TP108 (1999).

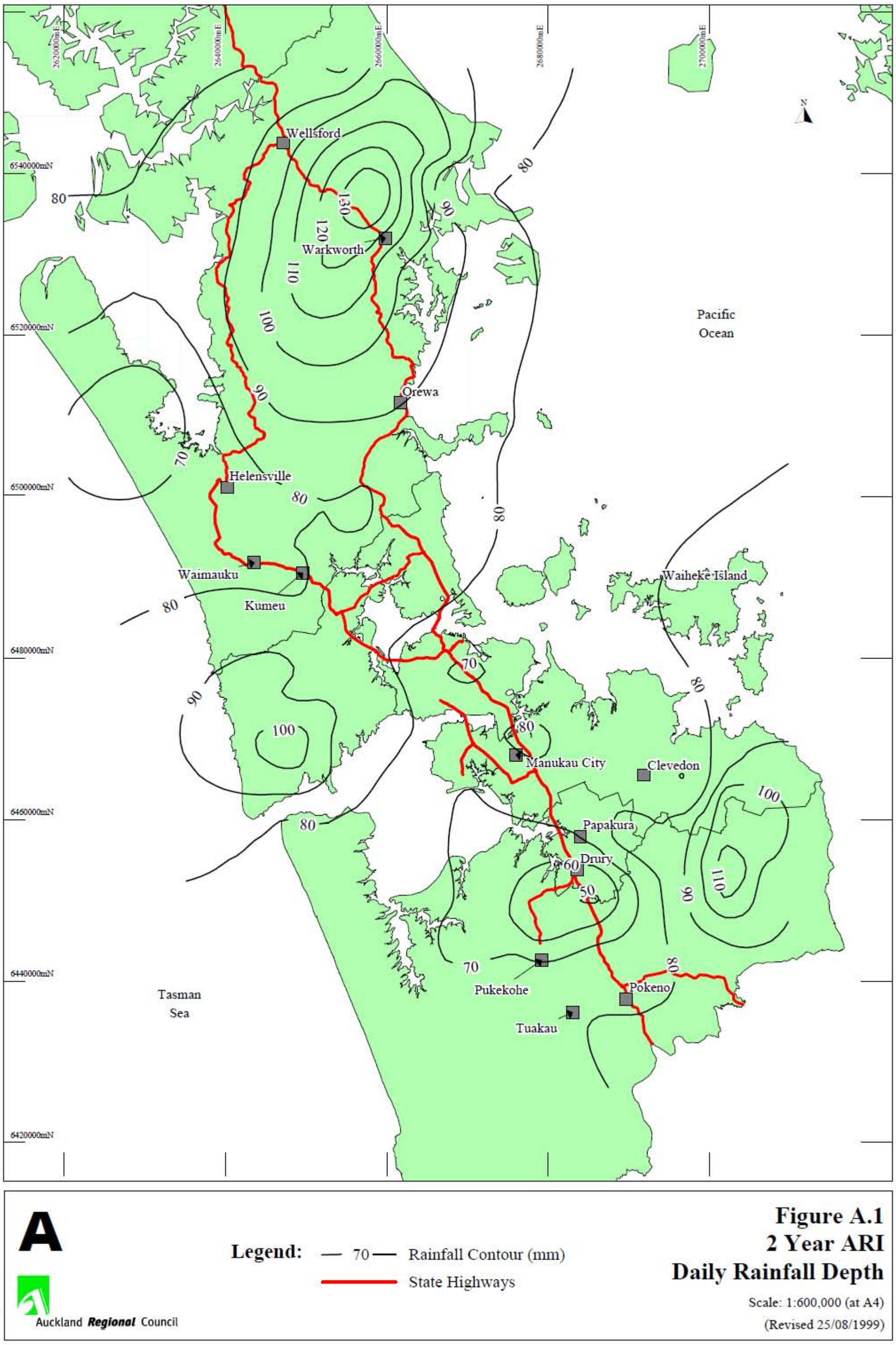


Figure 4:
Median annual rainfall (1971-2000) interpolated for the catchment of the Southeastern Manukau Harbour / Pahurehure Inlet study area.

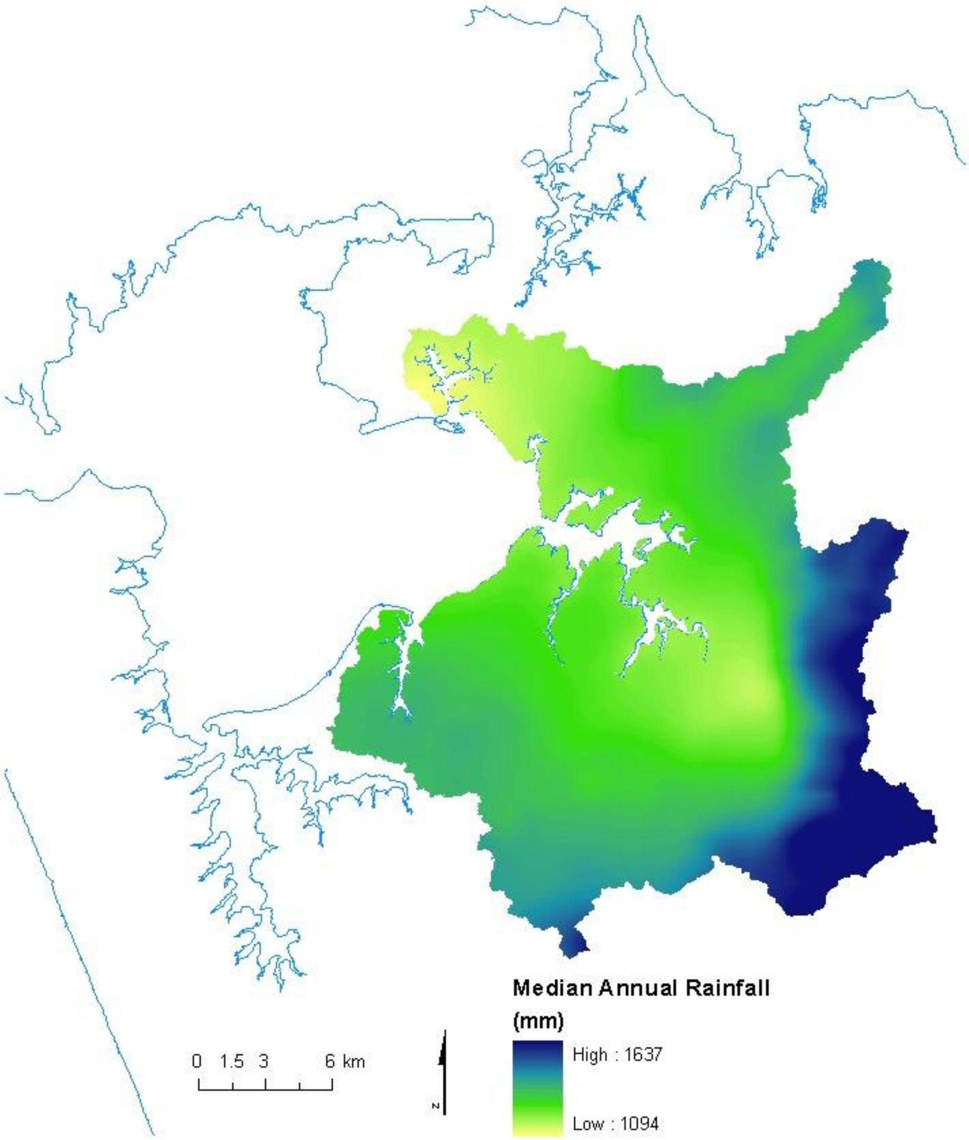
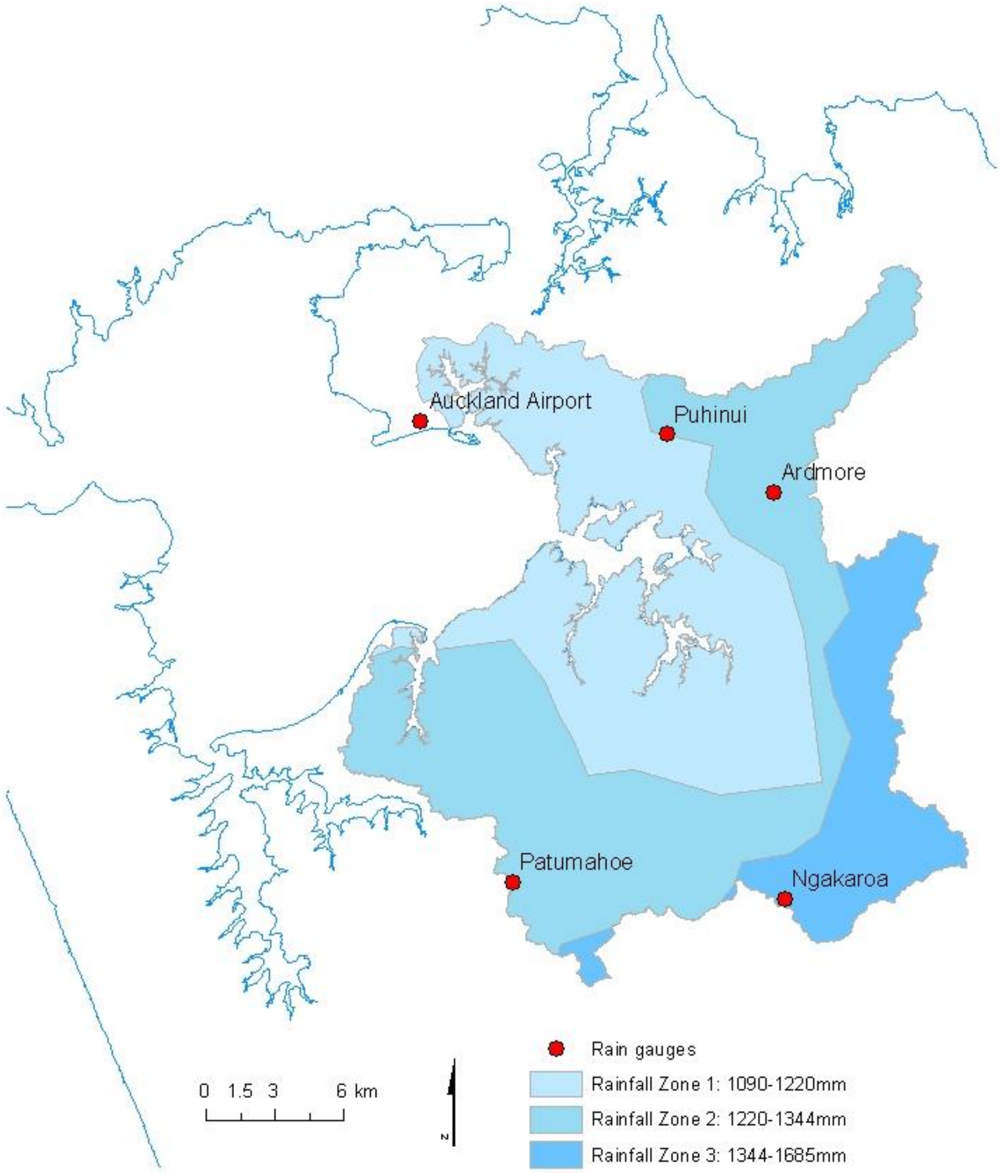


Figure 5:
Rainfall zones for the study area showing location of gauges investigated for use as model input data.



4 Rainfall Stations and Analysis

Data from five rain gauges were available in the ARC or NIWA climate archives for the study area; these were all investigated for use as model input data. The gauges are:

- Auckland Airport (operated by Met Service, data held by NIWA) 1962-present.
  0.2 mm tipping bucket, automatic daily reading at 9 am
- Puhinui, Botanic Gardens (ARC) 1983-present.
  0.5 mm tipping bucket, instantaneous record aggregated to daily record at 9 am
- Ardmore (operated by Met Service, data held by NIWA) 1945-present (regular records started in 1948).
  Manual readings at 9 am from 5 inch copper rain gauge
- Ngakaroa (ARC), composite record from two gauge sites (see Section 4), 1980-present.
  0.5 mm tipping bucket, instantaneous record aggregated to daily record at 9 am
- Patumahoe, Whangamaire Stream (ARC) 1992-present.
  0.5 mm tipping bucket, instantaneous record aggregated to daily record at 9 am

The locations of the rain gauges with respect to the rainfall zones are given in Figure 5. While the Auckland Airport gauge lies outside the study area, its close proximity means that it was considered to be representative of Zone 1. The rainfall statistics for the rain gauges also show that rainfall increases from the coast to the foot hills (Table 2). Table 2 gives the mean and median average rainfall and number of rain-days for the entire record from each gauge (except for years containing more than 10 days missing data), and also a comparison period (1995-2004) when all of the gauges were in operation. All of the gauges have periods with missing data, some for significant periods of time; details are listed in Table 3.

Table 2:

Rainfall statistics for the five rain gauges for their entire recording periods, and also a comparison period (1995-2004). Calculated for full calendar years with no more than 10 days of missing data (see Table 1).

	Zone 1		Zone 2						Zone 3	
Gauge	Airport		Puhinui		Ardmore		Patumahoe		Ngakaroa	
Period	1963-2006	1995-2004	1984-2006	1995-2004	1948-2006	1995-2004	1993-2006	1995-2004	1981-2006	1995-2004
Median (mm)	1,129	1,134	1,240	1,257	1,257	1,329	1,257	1,282	1,312	1,383
Mean (mm)	1,125	1,158	1,202	1,329	1,329	1,343	1,329	1,360	1,333	1,440
Mean rain-days per year	181	189	163	169	169	220	169	172	172	176

Table 3:

Number of missing days per year for the five rain gauges.

Zone 1		Zone 2						Zone 3	
Airport		Puhinui		Ardmore		Patumahoe		Ngakaroa	
Year	Days missing	Year	Days missing	Year	Days missing	Year	Days missing	Year	Days missing
1993	106	1985	36	1948	1	1993	29	1981	60
1994	88	1986	17	1965	1	1999	59	1983	44
		1987	6	1966	2	2001	16	1984	13
		1988	6	1969	1	2006	6	1987	92
				1972	1	1993	29	1988	42
								1989	10
								1990	36
								1991	41
								1992	294
								1994	69
TOTAL	194		65		6		139		701

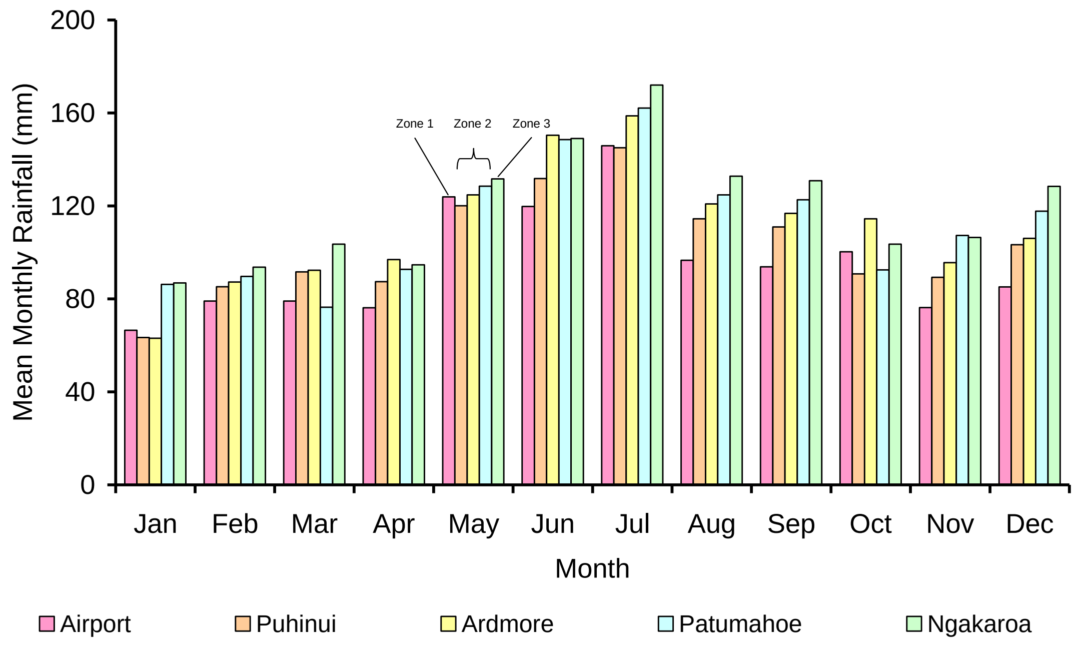
4.1 Rainfall comparison

For the comparison period, Auckland Airport has the lowest average annual rainfall while Ngakaroa has the highest. The median annual rainfalls for both the entire records and the comparison period, shown in Table 2, fall within the ranges associated with the zone boundaries in Figure 5 with the exception of Ngakaroa. The Ngakaroa gauge has a slightly lower median annual rainfall over the entire record period (1981-2006) compared to the comparison period (1995 – 2004).

Mean monthly rainfall was compared for the five sites covering the decade 1995-2004 when all the stations were in operation (Figure 6). It can be seen that the stations have a similar rainfall distribution over the year. Again it is clear that the Airport (Zone 1 - coastal lowland) has less rainfall per month than Ngakaroa (Zone 3 - foothills). Of the Zone 2 gauges, Puhinui (north) generally has the least rainfall while Patamahoe (south) has the most.

Figure 6:

Mean monthly rainfall for all sites during the period 1995-2004.



Daily rainfall, however, shows a difference between sites in the timing and magnitude of rainfall events. This can clearly been seen in Table 4 which ranks the 10 most intense rainfall events at each of the stations.

In general, the comparison between sites of daily rainfall over the period 1995-2004 shows that:

- The timing of storm rainfall events is the same in most cases, however, there are some occasions where specific events are recorded on different days. This is most likely to be an artefact of data collection related to the gauge type.
- All the major storms occurred across the catchment, however, the rank of a storm at one station may not be the same as its rank at another station. That is, the relative intensity of storm events varies spatially.
- The number of rain-days differs across the catchment (as was seen in Table 1). Auckland Airport and Ardmore have the most rain-days, and Puhinui the least. The difference between gauges is most likely due to differences in the gauges used at the sites; for example the ARC gauges have a tipping bucket of 0.5 mm, compared to 0.2 mm at Auckland Airport, which means they are not as sensitive to low intensity rainfalls. Similarly, the manual readings at Ardmore could record minor events not recorded by the automatic gauges. Indeed, if days which have less than 0.5 mm rainfall (i.e., volume of the ARC tipping buckets) are excluded from the calculation of rain-days, the gauges have very similar rain-days (160 - 175 days year^{-1}) for the common period from 1995-2004. Due to missing data in the records and different recording methods, it is difficult to say whether there is a significant difference in rain-days. In any case, the difference is likely to be due to low intensity rainfalls, thus, the effect on sediment transport will be minimal. In other words, the major storms responsible for erosion seem to be catchment wide.

On the basis of the rainfall analysis, and with regard to the length of the rainfall records, the following three rain gauges were finally chosen for this study to represent the three zones identified in Figure 5: Auckland Airport (Rainfall Zone 1); Ardmore (Rainfall Zone 2) and Ngakaroa (Rainfall Zone 3). The Ardmore gauge was chosen in preference to the Puhinui and Patamahoe gauges, which are also in Rainfall Zone 2, as its record is both longer and has fewer missing days.

Table 4:

Top 10 daily rainfalls at the different stations, 1995-2005. Events which appear in the top ten at more than one site have been colour coded for identification (e.g., 28-29 Feb, 2004, cerise, appears in all the gauge records). Note that while some of the storms occur across the catchment, their rank may differ from location to location, possibly reflecting the fact that these events are convective storms and the cells may have been centred on different parts of the catchment.

Rank	AIRPORT		PUHINUI		ARDMORE		NGAKAROA		PATAMAHOE	
1	2/05/2004	84.8	28/02/2004	110.2	29/02/2004	101.3	24/05/1997	142.76	21/01/1999	143.3
2	29/02/2004	81.2	7/03/1999	82.94	8/03/1999	98.5	21/02/1998	120.97	28/02/2004	87.84
3	24/05/1997	81	2/02/2004	82.11	2/05/2004	85.5	21/01/1999	101.79	21/02/1998	74.44
4	22/02/1998	71.6	21/02/1998	81.07	16/06/1995	80	28/02/2004	84.94	1/05/2004	72.34
5	11/08/1998	67.8	1/05/2004	78.33	22/02/1998	74.5	7/03/1999	78.73	2/02/2004	71.35
6	22/05/1996	66.4	2/05/2001	74.43	30/03/1995	72.5	12/07/2002	67.22	21/05/1996	61.36
7	21/07/2000	64.4	4/12/2000	70.35	11/08/1998	72	11/08/1998	65.37	9/07/1998	59.74
8	28/11/1999	63.2	11/03/1998	67.63	3/05/2001	69	9/07/1998	60.32	3/03/1996	58.02
9	11/03/2003	62.8	11/08/1998	62.97	24/05/1997	65.5	2/05/2001	59.59	22/05/1996	56.25
10	30/03/1995	59	14/07/1998	60.78	13/04/2001	63.4	1/05/2004	57.89	17/01/1999	55.16

5 Construction of composite rainfall records

Synthetic rainfall data was constructed for the Auckland Airport and Ngakaroa records, to both extend these rainfall records for the simulation period, and to fill in periods of missing data. Here we use the term 'synthetic' to indicate the process developing a record for one site, based on the data from another site and statistical relationships between the two. The synthetic data were used only as surrogate data to fill in gaps and extend the records. The recorded data, once extended and filled using the synthetic data, is termed the 'composite' record.

The synthetic rainfall data were generated using statistical relationships (i.e., regression analyses) with recorded rainfall from the Ardmore site, which has the longest unbroken record and has very few missing days. The relationships were based on ranked rainfalls ('ranked' regression) rather than rainfalls for matching days ('chronological' regression). While this approach does not preserve the day-to-day variation in rainfall over the period of measurement, it preserves the statistical properties of the most intense rainfalls, which is the key feature of interest for this sediment modelling application.

5.1 Auckland Airport

Rainfall data is available from the Auckland Airport gauge from 1 June 1962. This record has some 194 days missing during 1993 and 1994. To generate synthetic data for use in filling in the gaps and extending the record, a regression analysis was carried out between the daily rainfall recorded at the airport, and the daily rainfall recorded at Ardmore, for the period 1995 – 2006 (Table 5, Figure 7). The linear relationship was weak, and the residuals showed no seasonal pattern. However, when the daily rainfalls were first ranked, the relationship improved (Figure 8); this latter relationship was used to create a synthetic rainfall series from daily data recorded at Ardmore.

Table 5:

Linear relationships between Ardmore and Auckland Airport daily rainfall. The variable x is daily rainfall recorded at Ardmore.

	Relationship	Coefficient of Determination (R^2)
Daily rainfall (chronological)	0.78x	0.73
Daily rainfall (ranked)	0.88x	0.99

As the relationship is between ranked rainfalls, the synthetic rain record does not correspond to actual rainfall at the gauge on specific dates, but rather is intended to mimic the rainfall frequency distribution that can be expected. The synthetic annual total rainfall, mean monthly rainfall and frequency distribution showed fairly good agreement when compared to that of the recorded record for the period 1963 – 1992 (Figure 9 and Figure 10), which adds validity to the method. The small differences in annual rainfall totals will have minimal effect on erosion, which is more responsive to large events than more frequent low intensity events.

Figure 7:

Regression analysis between the chronological daily rainfall for the Ardmore and Auckland Airport gauges, 1995-2006.

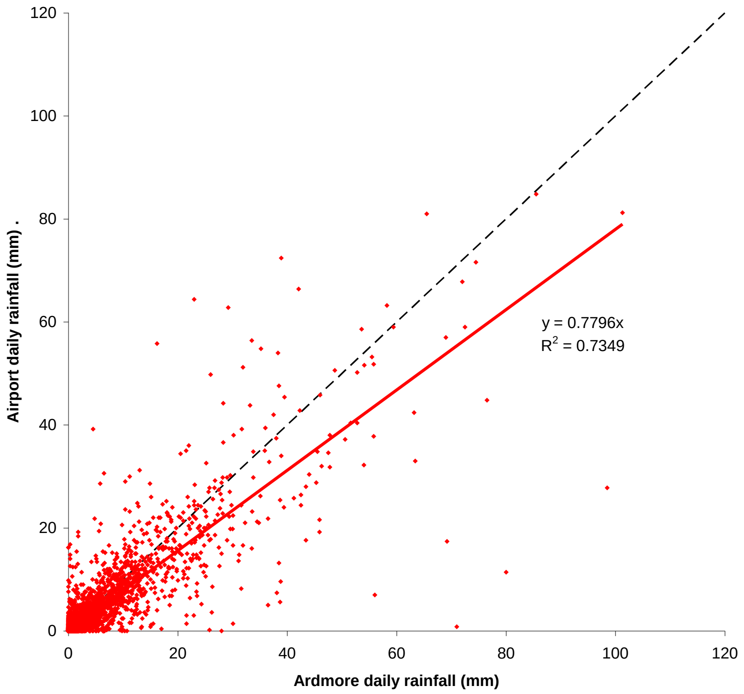


Figure 8:

Regression analysis between the ranked daily rainfall at the Ardmore and Auckland Airport gauges, 1995-2006.

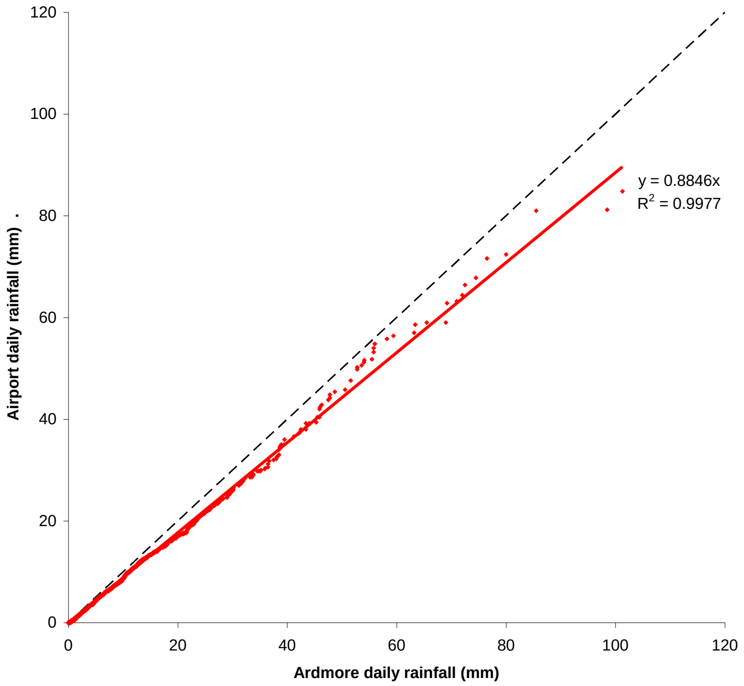
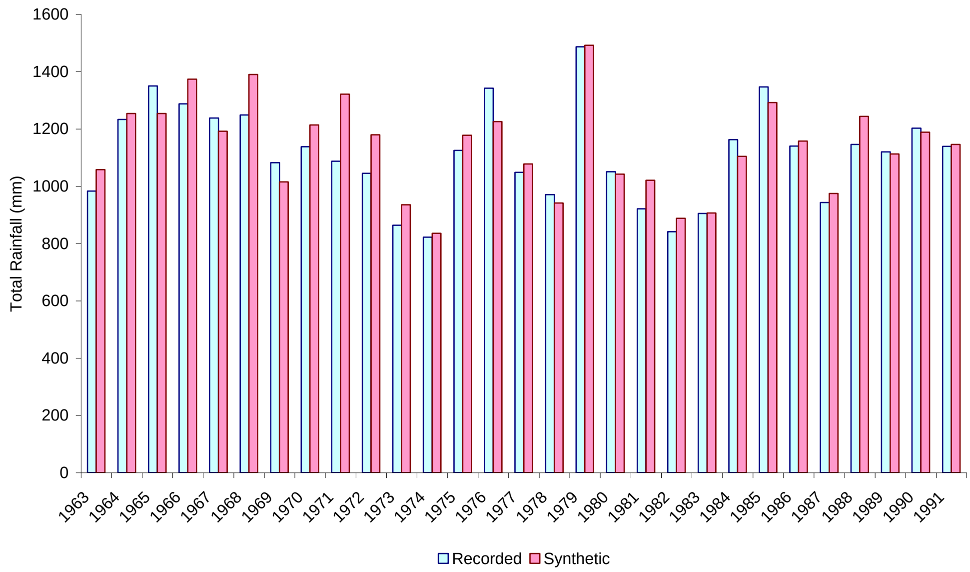


Figure 9:

Comparison of recorded and synthetic rainfall for the Auckland Airport gauge (1963-1991): (a). total annual; rainfall; (b). maximum daily rainfall.

(a)



(b)

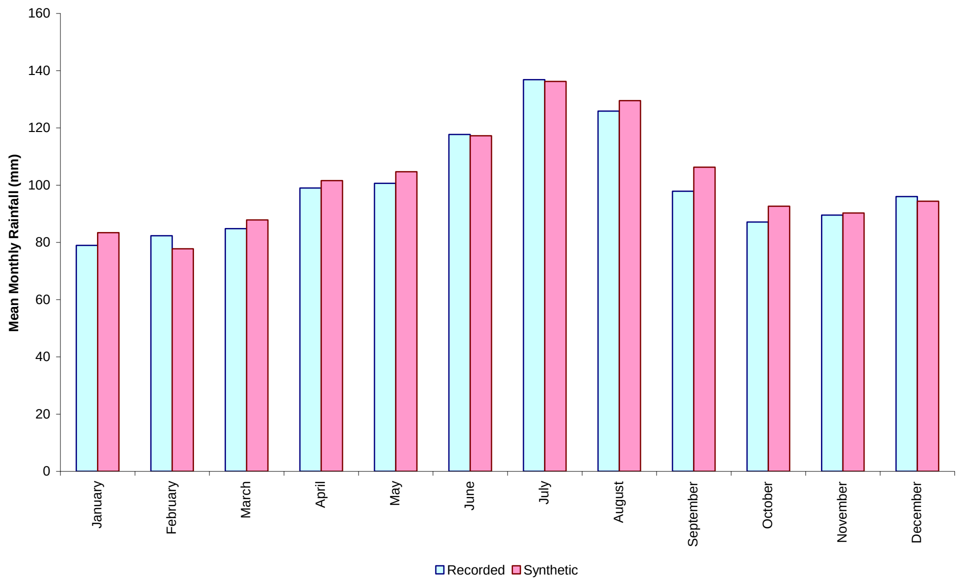
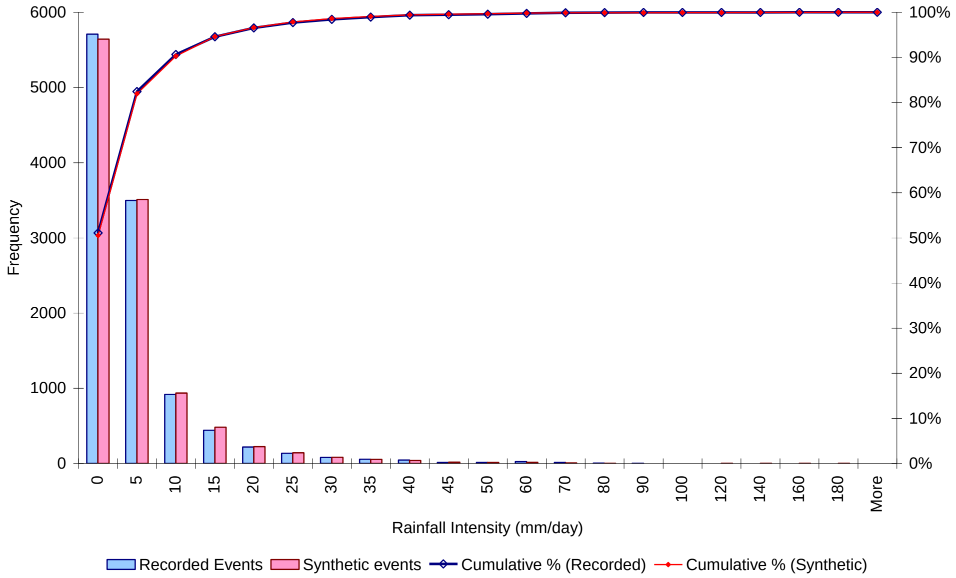


Figure 10:
Histogram and cumulative percentage for recorded and synthetic rainfall at Auckland Airport, 1962-1992, showing the distribution of events by intensity. Note that the size ranges of histogram bins (x axis scale) for rainfall intensity are not even.



5.2 Ngakaroa

The Ngakaroa record is available from 20 October 1980, and is a combination from two gauges at sites around 1.5 km apart: Tilsley's and Donovan's. Tilsley's was the initial site, but the gauge was moved to the Donovan's site in May 1993, so that it was at the same location as a water level monitoring station on Ngakaroa Stream. Tilsley's was a Foxboro paper tape event recorder connected to an OTA tipping bucket rainfall intensity gauge. Donovan's is an OTA tipping bucket intensity gauge connected to a datalogger.

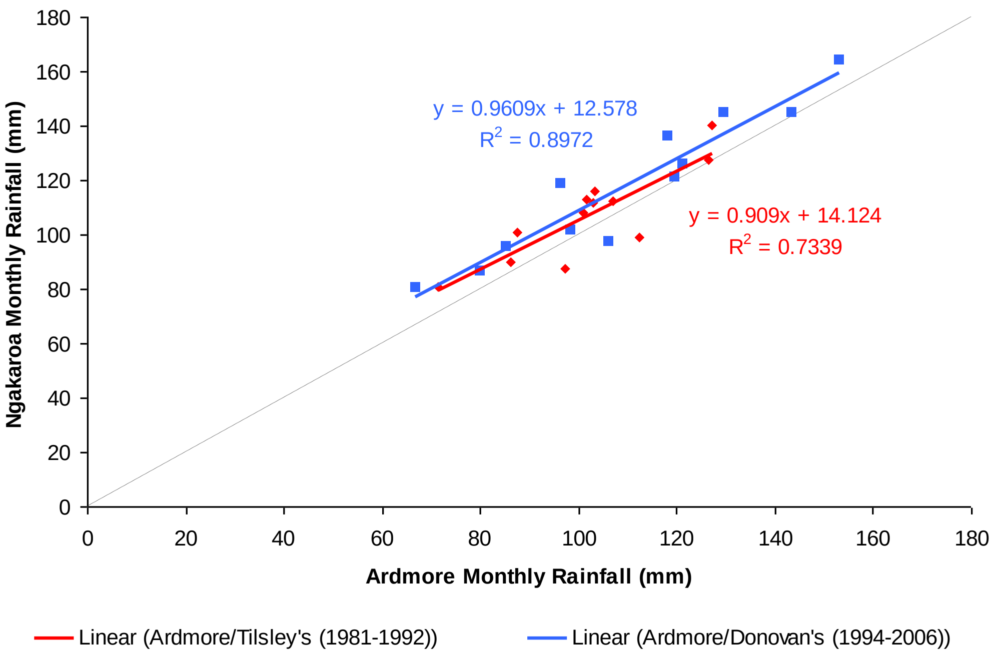
The Tilsley's daily record has a large amount of missing data – 630 days, or around 14% of the 13-year record. The data gaps vary in length, from just a few days to almost all of 1992. The reasons given in the site log range from damage to the paper tape, to gauge malfunction and *unknown*. Some 70 days from October to December 1994 are missing from the Donovan's record.

The first step in creating synthetic data for Ngakaroa was to establish that the two gauge sites are indeed representative of the same data. However, as the latter period was generally wetter than the former, it is not possible to simply compare the rainfall statistics. It was therefore decided to test whether the gauges have a similar statistical relationship with the Ardmore site under the assumption that similarity would imply the two sites are representative of the same regional rainfall pattern.

Figure 11 shows that there is a good relationship between the monthly rainfall recorded at the two Ngakaroa sites and Ardmore, and that these relationships are very similar, hence we are confident that the records from the two gauge sites can be combined to form a singe record. However, to avoid any possible bias, it was decided to base the synthetic data (which fills gaps and extends the data series) on the entire combined record rather than on either the Tilsley's or Donovan's records alone. Therefore it was not possible to validate the record in the same manner as above for Auckland Airport.

Figure 11:

Comparison of mean monthly rainfall. – regression relationship between the sites and Ardmore. Note that the missing data periods have been removed from both Tilsley's and Ardmore for comparison.



The chronological regression between Ardmore and Ngakaroa is weak (Table 6), so once again the ranked regression was used (Figure 12, which contains over 4000 pairs of ranked events). There was scatter in the ranked regression at the highest intensities (over 100 mm day^{-1} at Ngakaroa), which represent the top 12 ranked events. There seems to be two clusters of outliers, one on each side of the regression line (Figure 12). A second order polynomial was fitted that was better able to capture the four highest ranked events (>120 mm day^{-1}) – this gave a comparable coefficient of determination – but did not fit events with an intensity between 70-100 mm day^{-1} (ranked events five to 12) as well as the linear relationship. Both relationships were able to capture events below 70 mm day^{-1} well, as can be seen in Table 6. There is broad similarity in the mean annual rainfall: 1340, 1331 and 1334 for the combined record, the linear synthetic series and the polynomial synthetic series respectively. It was decided to use the linear relationship for this study, as it fits a greater number of events than the polynomial.

Comparisons between the synthetic and measured rainfall series are not made here, due to the lack of a suitable separate independent period of measured rainfall.

Figure 12:

Linear and polynomial fits to the relationship between ranked rainfall at Ardmore and composite Ngakaroa (1980-2006).

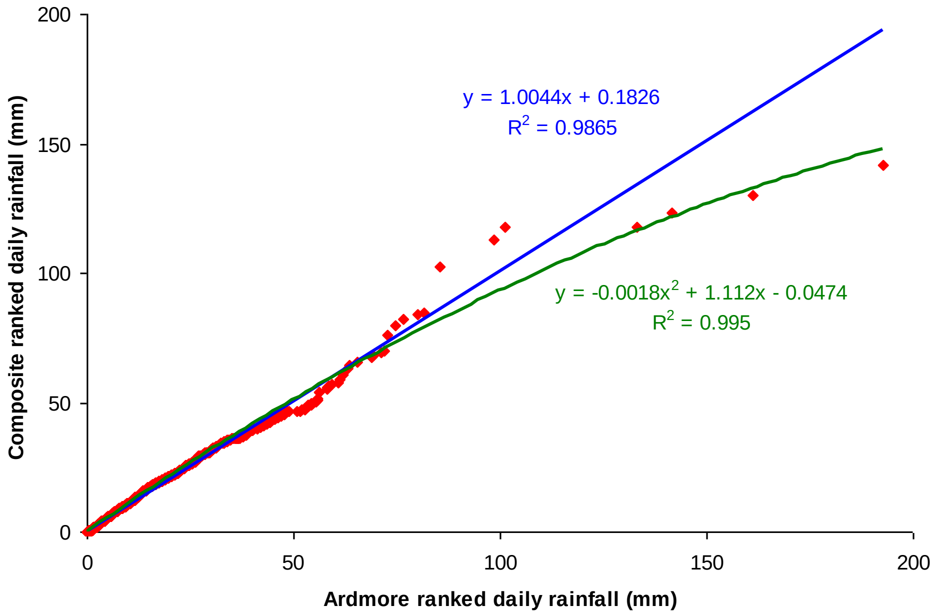


Table 6:

Linear relationships between Ardmore and Ngakaroa daily rainfall. The variable x is daily rainfall recorded at Ardmore.

	Relationship	Coefficient of Determination (R^2)
Daily rainfall (chronological)	0.2968	-0.091
Daily rainfall (ranked) - Linear	$1.0044x + 0.1826$	0.987
Daily rainfall (ranked) - Polynomial	$-0.0018x^2+1.112x-0.0474$	0.995

6 Model representation of rainfall

6.1 GLEAMS

The application of GLEAMS to the Southeasten Manukau Harbour / Pahurehure Inlet study is discussed in Parshotam *et al*. (2008 a,b and c); the model has been used to provide a daily series of land-derived sediments from rural land use (contaminants from urban stream catchments are simulated with CLM). Daily rainfall is a direct input to GLEAMS. The model was calibrated using rainfall data from the three gauges collected in 2007. Sediment simulations were run for the period 1957-2006 (i.e., a 50-year rainfall block) using recorded rainfall where available, or the synthetic rainfall records described above, in order to derive a daily sediment load series to the Southeastern Manukau Harbour for past and current land use. Future land use was simulated using the same 50-year rainfall block without adjustment; that is, the possible impacts of climate change were not assessed. The two 50-year GLEAMS simulated sediment load series (i.e., past/present and future land use) were used as input by the USC-3.

To run GLEAMS, the study area was split into stream catchments and their sub-catchments. These were then intersected by the rainfall zones mapped in Figure 5. The resulting sections were further divided into 30 m x 30 m grid cells which were then re-aggregated into unique combinations of land use, soil type and slope (and *ipso facto* rainfall). Hence, catchments which cover two or more of the rainfall zones will have spatially varying rainfall. GLEAMS was run concurrently for each of the grid-cell aggregations with sediment transport routed down the stream network.

6.2 DHI Harbour Hydrodynamics Models

The DHI Harbour Hydrodynamics Models and their calibration are described in Pritchard *et al*. (2008) Rainfall is used as an indirect input to the DHI suite of models, which require inflows of fresh water from streams and estuaries flowing into the Southeasten Manukau Harbour / Pahurehure Inlet study area. 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. The models were calibrated against purpose collected data collected over two deployment periods in 2007 (15 February - 26 March and 24 April – 29 May). The calibration runs were continuous. Inflows to the harbour over the calibration period were simulated with the method described in TP108 (ARC, 1999), using daily rainfall recorded at Auckland Airport. This record was chosen for the modelling as it is the closest gauge to the harbour. A single gauge was used to reduce model complexity. Once calibrated, the models were run with a series of discrete scenarios covering combinations of tide (e.g., neap to spring), wind speed and direction and flows calculated from rainfall intensity (depth per 24 hours) to create the rules library. The scenarios and the implementation of the rules library in the USC-3 model are decribed in Green (2008).

6.3 USC-3

The USC-3 model is described in Green (2008). The Auckland Airport rainfall record derived for GLEAMS, as described above, is 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 rercord 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 (i.e., up until 2006) were used directly in USC-3. For future land use, the 50-year 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 (Moores and Timperley, 2008). 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 partiular day is proportional to the GLEAMS sediment load for the same day.

The rainfall series from Auckland Airport 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^{-1}) and, if so, the intensity band in which the rainfall depth falls (these bands, in mm day^{-1}, are 0.9–4.8, 4.8–10.6, 10.6–19.2, 19.2–50.0, 50.0–100.0 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. The scenarios and their implementation in the USC-3 model are decribed in Green (2008).

7 Summary

This report describes the choice and derivation of three rainfall records which were used as input to the Southeastern Manukau Harbour / Pahurehure Inlet 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 1948 to 2006, however, rainfall from 2007 was used along with purpose collected data to calibrate the models.

The three rainfall records were chosen as model input for GLEAMS to represent spatial variation in rainfall over the study area. The records were chosen as being representative of three broad rainfall zones from the coastal lowlands (comparatively low rainfall) to the foot of the Bombay Hills (comparatively high rainfall). The rain gauges chosen were Auckland Airport (Zone 1), Ardmore (Zone 2) and Ngakaroa (Zone 3). The sites are summarised in Table 7. As only one of the records (Ardmore) covers the entire simulation period for past and current land use, and records from the other gauges have substantial periods with missing data, synthetic rainfall data were constructed, using regression analyses against the Ardmore data set, with which to extend the data record and fill in gaps. It was noted that high intensity rainfalls occur across the study area with similar timings, but the ranking of these rainfalls can differ between rain gauges. The relationships between daily rainfall at the different gauges are weak, hence relationships used for constructing the synthetic data were determined from ranked rainfall data.

The DHI harbour hydrodynamics models were calibrated using rainfall recorded at Auckland Airport during two periods during 2007. 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 and is informed by the rules on the basis of tide, wind speed and direction and rainfall intensity.

Table 7:

Summary of rainfall data provided as model input for the Southeastern Manukau Harbour / Pahurehure Inlet study. Rainfall zones are shown in Figure 5.

Zone base rainfall site	Rainfall Zone	Models forced with data	Method used to extend record / replace missing data
Ardmore	2	GLEAMS	Assumed zero
Auckland Airport	1	GLEAMS and USC-3	Synthetic rainfall record derived Ardmore record
Ngakaroa (combined)	3	GLEAMS	Synthetic rainfall record derived Ardmore record

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