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Flood hydrology of the Mangaroa River

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Contents

Summary

This investigation into the flood hydrology of the Mangaroa River includes rainfall analyses for the Mangaroa catchment, calibration and validation of a rainfall runoff model, modelling of design rainfall events and flood frequency analyses using at-site and regional methods.

The rainfall runoff model for the catchment, calibrated using observed flood events at Mangaroa River at Te Marua (29830), produced good results when tested on five validation events. The model can be used with confidence to model flood flows in the catchment, but model performance should be continually assessed as floods occur.

The recommended flood frequency estimates for the Mangaroa River at Te Marua (29830) are those derived by pooling the at-site and rainfall runoff model derived results, which had an average difference of 2.5%. The at-site and rainfall runoff model results were considerably higher than the regional results derived using the method of McKerchar & Pearson (1989). As the at-site and rainfall runoff modelled results were so similar, and there is a decent length of good flood data, there is no need to incorporate the regional results into the final flood frequency estimates. The final estimates (Table 1) are on average 13% higher than the previous flood frequency estimates for the Mangaroa River at Te Marua (29830).

Table 1: Final flood frequency estimates for the Mangaroa River at Te Marua (29830)

	Flow (m^3/s)	Standard error (m^3/s)
Q2	150	14
Q5	198	21
Q10	237	29
Q20	276	37
Q50	329	48
Q100	372	57
Q200	410	65
PMF	1864	n/a

1. Introduction

This report presents an analysis of the flood hydrology of the Mangaroa River catchment. The aim of the report is to produce design flood estimates for use in a flood hazard assessment of the catchment.

The specific output required from this report was:

1. A review of hydrological data availability for the Mangaroa catchment.

2. Rainfall depth-duration-frequency analysis and derivation of the design storms and probable maximum precipitation.

3. Calibration and validation of a rainfall runoff model, which is then used to produce design flood hydrographs for the catchment.

4. At-site and regional flood frequency analysis.

5. Recommended design flood frequency estimates to be used in the flood hazard assessment.

A previous flood hydrology assessment of all subcatchments of the Hutt River was completed in 1990 (Pearson, 1990) and later updated (Pearson, 1999). However, this report provides results from a rainfall runoff model calibrated specifically for the Mangaroa catchment, and a flood frequency analysis based on a considerably longer at-site flood record.

2. Catchment description

The Mangaroa River is a tributary of the Hutt River, entering the Hutt River at Te Marua. The Mangaroa catchment lies on the eastern side of the Hutt catchment and borders the Wainuiomata and Orongorongo catchments to the south and the Pakuratahi catchment to the northeast (Figure 1). The Mangaroa River flows in a northerly direction before turning west to converge with the Hutt River.

The Mangaroa catchment has a total area of 104 km^2 and rises to an elevation of 860 m in the vicinity of Mount Climie on the Rimutaka range. The Mangaroa River is about 18 km long, and its main tributaries listed here are shown in Figure 2:

- Johnsons Road Stream
- Fifty-eight Valley Stream
- Narrow Neck Stream
- Huia Stream
- Cooleys Stream
- Colletts Stream
- Mahers Stream
- Blaikie Stream
- Collins Stream
- Black Stream.

The majority of the Mangaroa catchment is covered in scrub and pasture for rural and semi-rural landuse, but there are isolated areas of indigeneous and exotic forest stands. Much of the catchment is old swamp remnants formed about 18,000 years ago (Wellington Regional Council, 1995).

Figure 1: Mangaroa and adjacent major catchments

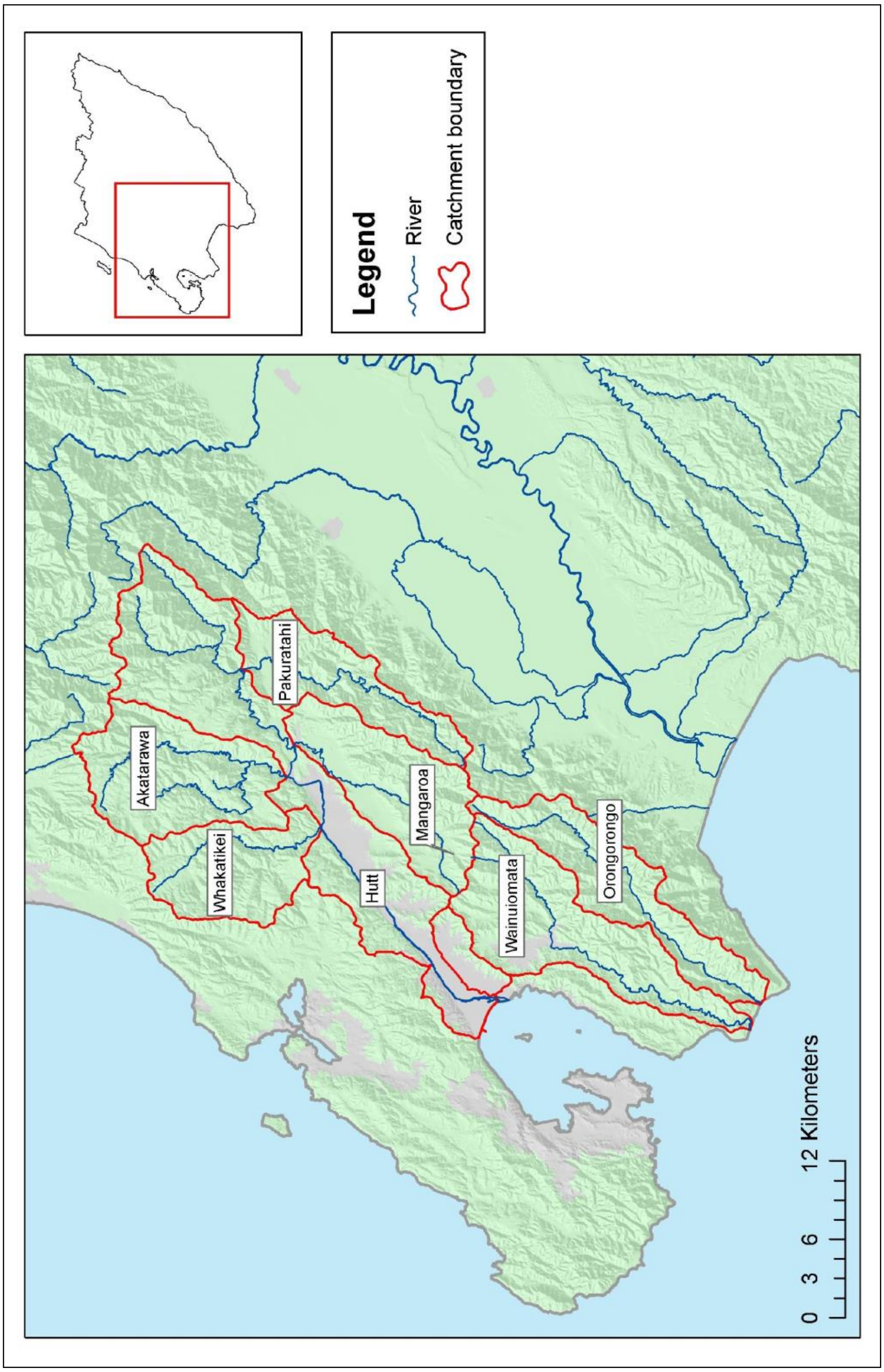
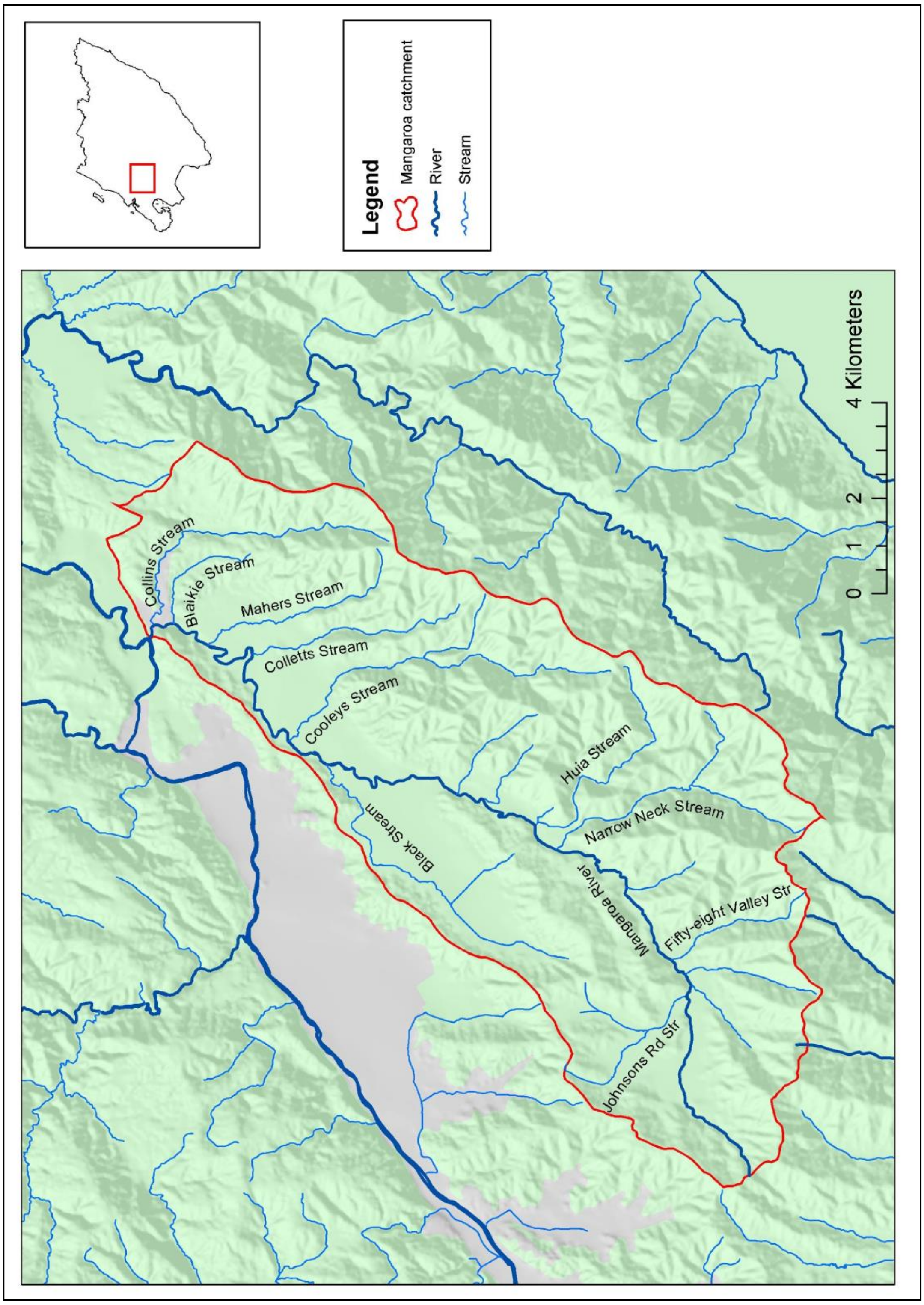


Figure 2: Tributaries of the Mangaroa River



3. Data availability and quality

Rainfall and river flow data used in this report are taken from the Greater Wellington and NIWA databases.

3.1 Rainfall data

Official rainfall records for the Mangaroa catchment (as on the Greater Wellington hydrological database and the NIWA climate database) are relatively short. The first records were collected at Mangaroa Valley (E15114) from 1978; there may be some limited records from Whitemans Valley (E15200) collected between 1915 and 1921, but these are not available on the climate database.

Table 2 shows the rainfall data that is available for the Mangaroa catchment. The only rainfall station currently in operation is Tasman Vaccine Limited (E15204), and this site now provides the longest record for the catchment. However, there are several automatic stations near the boundary of the Mangaroa catchment (Figure 3). Of particular interest to the Mangaroa catchment is Centre Ridge (E15122), which is at a higher altitude than Tasman Vaccine Limited (E15204) and therefore a better indicator of rainfall in the upper parts of the catchment.

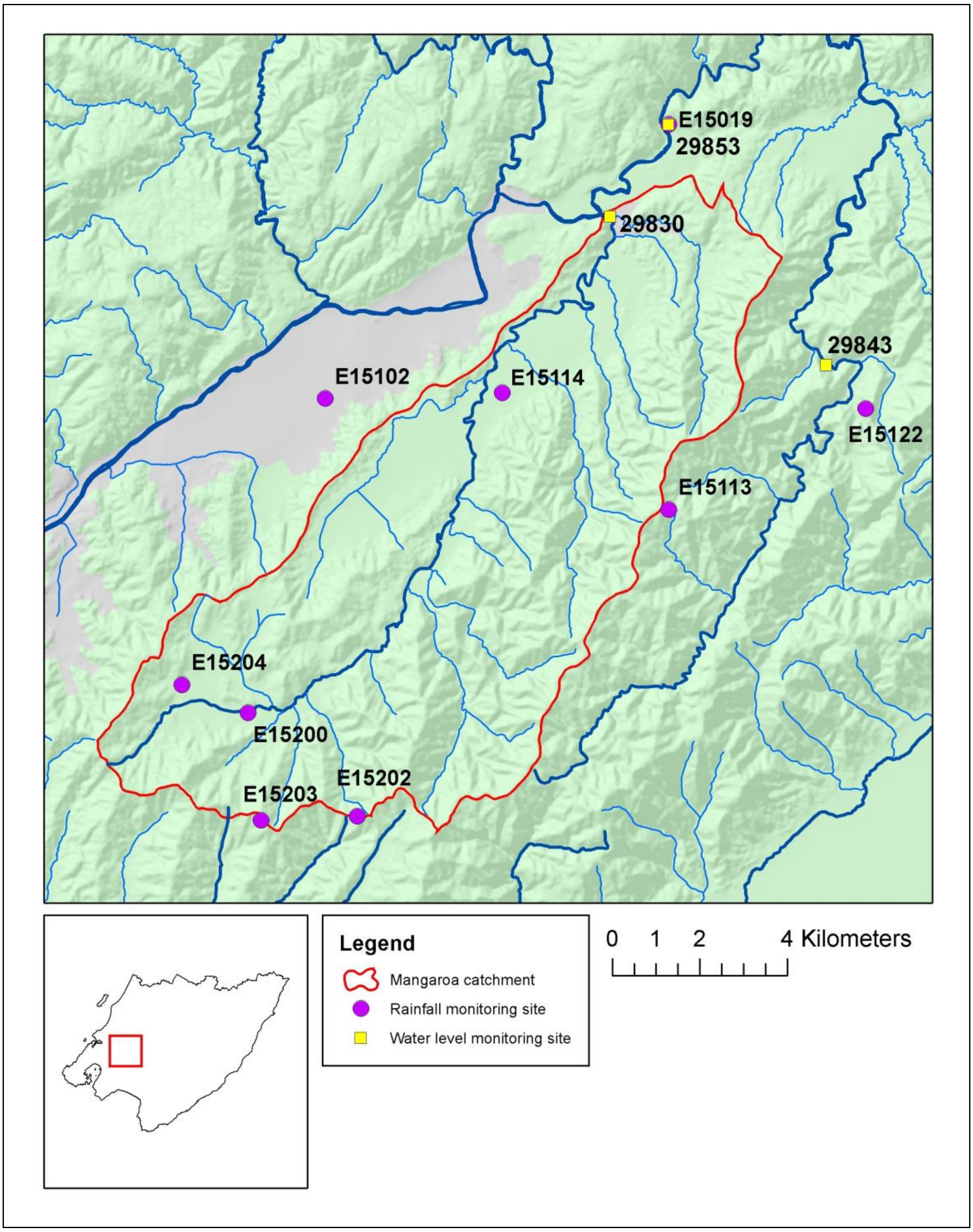
Table 2: Rainfall stations in and around the Mangaroa catchment

Station	Met No.	Recording authority	Altitude (m)	Recorder type	Period	Catchment
Te Marua	E15019	GW	150	Automatic	1993-	Hutt
Wallaceville	E15102	NIWA	56	Automatic	1939-	Hutt
Climie	E15113	GW	845	Storage	1989-1998	Mangaroa
Mangaroa Valley	E15114	NIWA	183	Storage	1978-1989	Mangaroa
Centre Ridge	E15122	GW	510	Automatic	1984 -	Pakuratahi
Whitemans Valley	E15200	NIWA	220	Storage	1915-1921	Mangaroa
Misty	E15202	GW	545	Storage	1989-1998	Mangaroa
Devine	E15203	GW	610	Storage	1989-1998	Wainuiomata
Tasman Vaccine Limited	E15204	GW	229	Automatic[1]	1980 -	Mangaroa

Data collected at the Greater Wellington rainfall stations is collected and archived in accordance with the Resource Information Quality Procedures, which meet the ISO: 9002 Standard. All rainfall data is audited on an annual basis by a TELARC registered auditor. The continuity of the data record from Tasman Vaccine Limited (E15204) is good; apart from 3.5 months of missing data in 1983 there are relatively few gaps in the record.

[1] Also operated as a storage rainfall station between 1968 and 1979

Figure 3: Environmental monitoring sites in and around the Mangaroa catchment



3.2 Water level and flow data

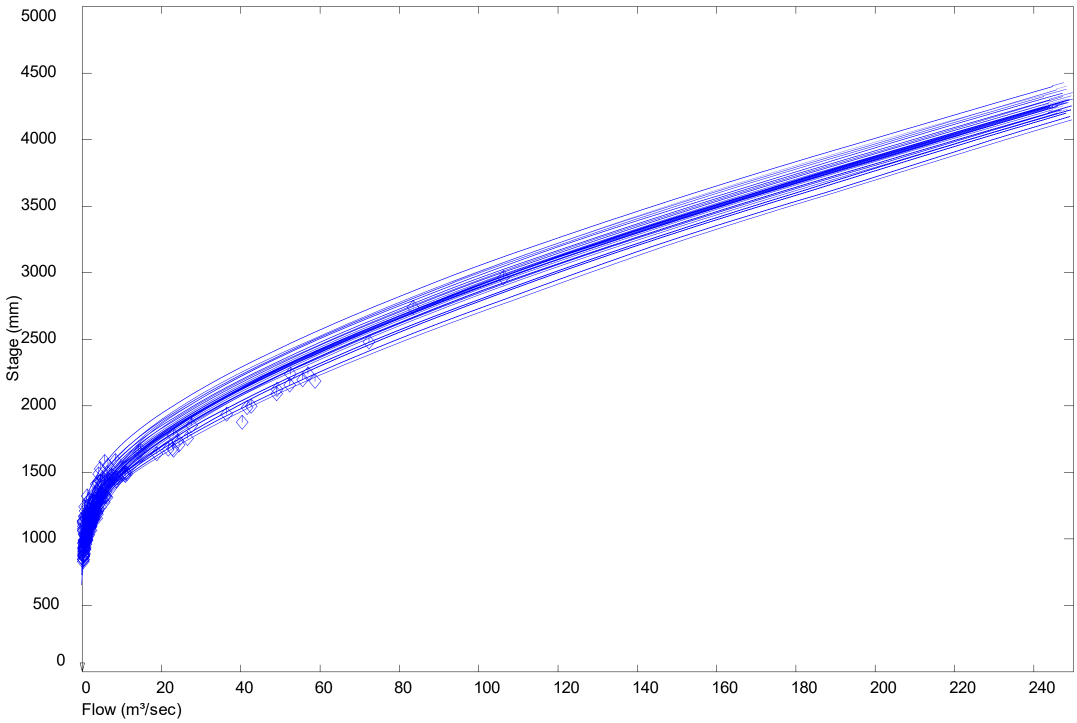
Water level data for the Mangaroa River has been recorded by Greater Wellington on a continuous basis at Mangaroa River at Te Marua (29830) (Figure 3) since May 1977. Data for the site is collected in accordance with the Resource Information Quality Procedures, which meet the ISO: 9002 Standard, and the data are audited on an annual basis by a TELARC registered auditor. A second water level site operated at Mangaroa at Black Swamp (29842) between 1977 and 1978, but as the data have not been archived and no rating exists, this report will use data from Mangaroa River at Te Marua (29830) only.

Nearby water level recorders are found at Pakuratahi River at Truss Bridge (29843) and Hutt River at Te Marua (29853).

3.2.1 Rating curve

The current rating curves for Mangaroa River at Te Marua (29830) are shown in Figure 4. A previous assessment of the rating curve found that high stage flows would not be greatly changed by converting to type curves and that the rating was perfectly acceptable (Pearson, 1990). High flow gaugings should be a priority for the site; the highest gauged flow is currently about 42% of highest recorded flow.

Figure 4: Mangaroa River at Te Marua (29830) rating curves



3.2.2 Record continuity and annual maxima

Mangaroa River at Te Marua (29830) has operated continuously since 1977. Between May 1977 and February 2005 there are about 320 days of missing record. Cross-checking with nearby sites (Pakuratahi River at Truss Bridge (29843) and Hutt River at Te Marua (29853)) was carried out to ensure that no annual maximum occurred during a gap in the record. The check confirmed that all annual maxima since 1977 have been recorded (Table 3).

Table 3: Mangaroa River at Te Marua (29830) annual maximum series

Year	Date of occurrence	Annual maximum (m^3/s)
1977	22 November	123

1978	21 April	68
1979	13 October	73
1980	20 January	207
1981	21 May	246
1982	11 December	192
1983	05 November	99
1984	18 October	161
1985	19 August	186
1986	24 August	74
1987	10 April	62
1988	03 September	77
1989	23 November	60
1990	13 March	134
1991	07 August	156
1992	16 October	77
1993	21 November	45
1994	08 November	194
1995	15 October	98
1996	19 February	96
1997	04 October	227
1998	28 October	239
1999	15 May	48
2000	02 October	189
2001	09 December	76
2002	18 June	133
2003	03 October	231
2004	16 February	252
2005	06 January	247

The highest annual maxima recorded at Mangaroa River at Te Marua (29830) tend to be of a similar magnitude (maxima from 1981, 1997, 1998, 2003, 2004 and 2005), which could indicate that the largest flood(s) have been under predicted. However, the Pakuratahi River at Truss Bridge (29843) annual maxima display the same phenomenon, therefore under-prediction of floods at the high end of the rating curve for Mangaroa River at Te Marua (29830) is not a concern.

4. Rainfall analysis

The rainfall analyses required were:

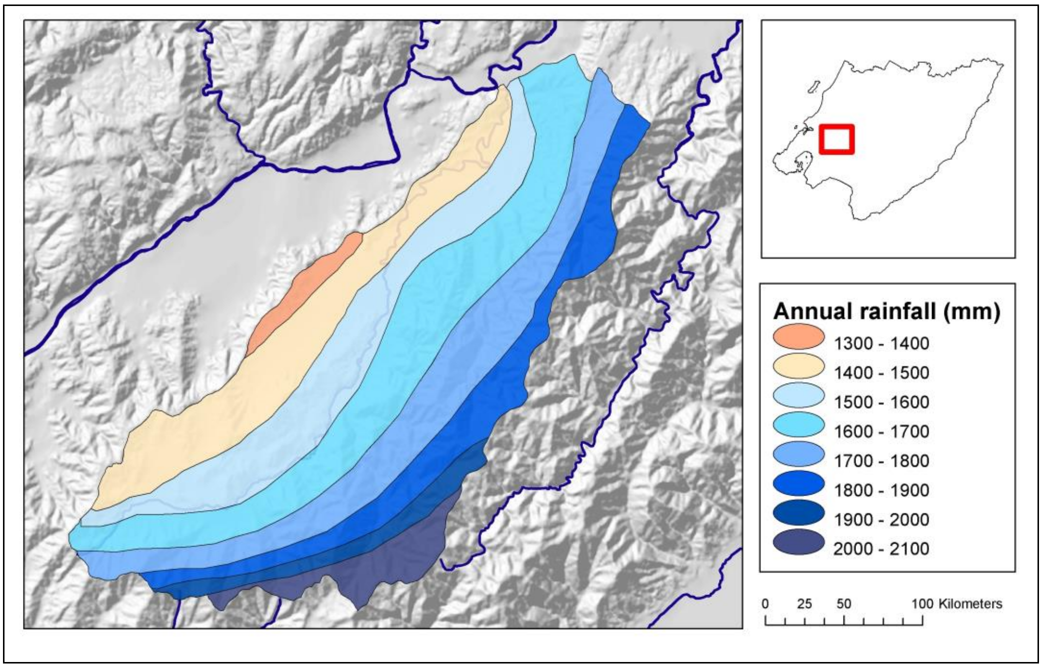
- Assessment of spatial variation in rainfall over the Mangaroa catchment;
- Estimation of the 2, 5, 10, 20, 50, 100 and 200 year return period rainfall depths of durations 1 hour to 24 hours;
- Estimation of the probable maximum precipitation for the Mangaroa catchment;
- Derivation of design storms.

4.1 Rainfall spatial variation

Knowledge of how rainfall varies across the Mangaroa catchment is important for accurately estimating rainfall depths in the rainfall runoff model. Annual rainfall isohyets for the Hutt catchment were presented by Wellington Regional Council (1995), but these do not provide great detail for the Mangaroa catchment.

Annual rainfall isohyets for Mangaroa were derived as part of this study (Figure 5), using rainfall data from all stations listed in Table 1. Annual rainfall varies from about 1300 mm in the west to about 2100 mm in the higher altitude parts of the catchment.

Figure 5: Mean annual rainfall in the Mangaroa catchment



4.2 Rainfall depth-duration-frequency

Depth-duration-frequency analysis of rainfall data is necessary to derive the design rainfall depths for modelling purposes. An analysis was carried out on the only automatic rainfall data for the Mangaroa catchment, Tasman Vaccine Limited (E15204), and for the nearby high-altitude rainfall station Centre Ridge (E15122). The rainfall depths of 2 to 200 year return periods were derived by fitting an EV1 distribution to the annual maximum series using the L-moments method. Although other frequency distributions were trialled, the EV1 was found to provide the best fit for both data sets. The resulting depth-duration-frequency estimates are shown in Tables 4 and 5.

Table 4: Tasman Vaccine Limited (E15204) rainfall depth duration frequencies (mm), 1980 -2005

Return period	Duration:					
	1 hour	2 hours	4 hours	6 hours	12 hours	24 hours
2 years	21	30	43	52	68	89
5 years	28	39	54	66	88	117
10 years	33	44	62	75	101	136
20 years	38	49	70	84	114	154
50 years	44	46	79	95	130	177
100 years	49	61	87	103	142	194
200 years	53	66	94	112	154	212

Table 5: Centre Ridge (E15122) rainfall depth duration frequencies (mm), 1984 - 2005

Return period	Duration:					
	1 hour	2 hours	4 hours	6 hours	12 hours	24 hours
2 years	19	28	44	54	74	98
5 years	24	34	53	64	91	126
10 years	27	38	58	71	101	143
20 years	30	42	64	78	110	159
50 years	34	47	71	86	123	180
100 years	37	51	77	93	132	195
200 years	40	55	82	99	141	211

The rainfall depths for Centre Ridge (E15122) tend to be lower that those for the lower altitude site of Tasman Vaccine Limited (E15204), particularly for the high return periods. This result was also apparent in a previous high rainfall intensity analysis (Wellington Regional Council, 1995), and is surprising because the annual rainfall is higher at Centre Ridge (E15122). As a check, annual maximum flood event rainfall totals for the two stations were compared. Centre Ridge (E15122) received between 70% and 130% of the rainfall at Tasman Vaccine Limited (E15204), and the rainfall at Centre Ridge (E15122) was sometimes more and sometimes less intense. Thus, seeing as there is no consistent relationship between rainfall intensity at the two sites and the depth-duration-frequency analysis is based on a good length of data, the results in Tables 4 and 5 are accepted.

Design rainfall depths are also needed for the lower part of the Mangaroa catchment, which is represented by the nearby Te Marua (E15019) rainfall station. However, the data record from Te Marua (E15019) is not long enough for a reliable depth-duration-frequency analysis. Rainfall depths for the site are therefore estimated using HIRDSv2 (NIWA, 2002) (Table 6).

Table 6: Te Marua (E15019) rainfall depth duration frequencies (mm), derived using HIRDS

Return period	Duration:					
	1 hour	2 hours	4 hours[2]	6 hours	12 hours	24 hours
2 years	20	29	42	50	72	102
5 years	25	36	52	63	90	128
10 years	28	40	58	70	100	142
20 years	32	46	66	80	115	164
50 years	39	56	81	98	140	200
100 years	46	65	95	115	165	236
200 years[3]	52	70	105	125	190	255

The depths estimated using HIRDS are up to 10% higher than the Tasman Vaccine Limited (E15204) depths, except for the 12 and 24 hour durations and the 200-year return period depths which are greater than 10% higher. It is to be expected that the Te Marua (E15019) rainfall depths will be slightly higher, because the mean annual rainfall is approximately 10% higher at Te Marua. In addition, an analysis of recent storm events found Te Marua (E15019) tends to receive 5 to 10% more rainfall, although of course the difference will be dependent on storm direction.

4.3 Probable maximum precipitation

Probable maximum precipitation (PMP) is theoretically the greatest depth of rainfall that is meteorologically possible over a given duration at a particular time of the year (World Meteorological Organization, 1986). The return period of the PMP is considered to be about 10,000 years. An estimate of the PMP for the Mangaroa catchment is required so that the probable maximum flood (PMF) can be modelled.

Thompson & Tomlinson (1993) determined a method for estimating the PMP for small areas (less than 1000 km^2) in New Zealand for durations up to six hours. Their method was used to determine the PMP for the Mangaroa catchment (Table 7). The 6:1 hour ratio of 3.5 was chosen because this is close to the ratio of 3.62 observed during the December 1976 storm in the Hutt Valley (Wellington Regional Water Board, 1977).

[2] Rainfall depths for 4 hours are interpolated from the 3 and 6 hour rainfall depths
[3] Extrapolated

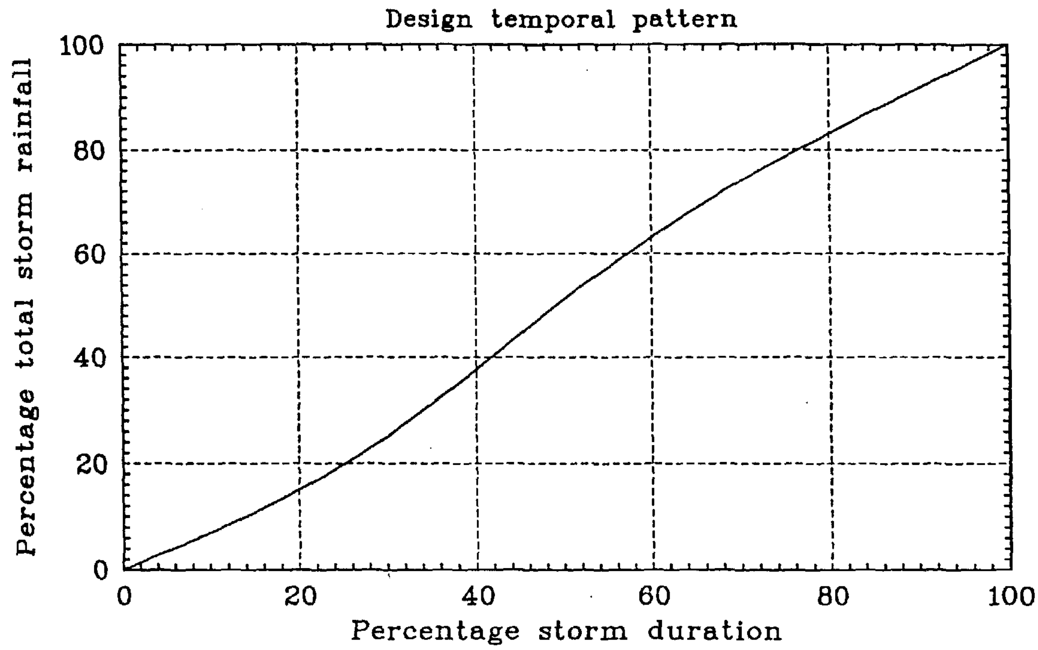
Table 7: Calculation of probable maximum precipitation for the Mangaroa catchment

Step	Description of step	Results					
1	Catchment details • Area • Maximum altitude	104 km² 860 m					
2	Reference 1 hour PMP	146 mm					
3	Adjustment for location	87.5%					
4	Adjustment for altitude	N/A					
5	Catchment average 1 hour PMP	128 mm					
	Duration (hours)	**1**	**2**	**3**	**4**	**5**	**6**
6	Percentage adjustments	100	162	215	263	307	350
7	Catchment average PMP (mm)	128	207	275	337	393	448

4.4 Design storm temporal distribution

The PMP estimates and the 2 to 200 year return period rainfall depths for Tasman Vaccine Limited (E15204), Centre Ridge (E15122) and Te Marua (E15019) need to be distributed temporally into design storms for use in the rainfall runoff model. Pilgrim & Cordery (1975) proposed that design storms can be derived according to a pattern of average variability, as shown in Figure 6. The temporal distribution graph (Figure 6) was applied to the rainfall depths in Tables 4 to 6 to obtain the design storms (Appendix 1). Note that the rainfall percentages for each hour were equally apportioned to gain 15 minute rainfall depths.

Figure 6: Temporal pattern of rainfall within a design storm (from Pilgrim & Cordery, 1975)



5. Rainfall runoff modelling

To determine design hydrographs for the Mangaroa River a rainfall runoff model was developed. The process involved:

- Building a network model to represent the catchment;
- Calibrating the hydrologic parameters of the model using observed flood events;
- Validating the calibrated model using observed flood events; and
- Running the design rainfall events through the model to produce design flood hydrographs.

5.1 Model description

Greater Wellington Regional Council uses the rainfall runoff model TimeStudio (version 4.0.4.2) developed by Hydstra. TimeStudio is a storage routing model for estimating the flood hydrograph and was previously known as Hydrol.

Storage routing models consist of two steps. The first step is a loss function, which estimates how much rainfall becomes rainfall excess. TimeStudio provides three different types of loss functions: the Australian Water Balance Model (AWBM), an Initial-Continuing Loss Model, and a Proportional Runoff Model. The second step is a non-linear flow routing procedure for moving the rainfall excess through the catchment as runoff, and predicting the shape of the hydrograph.

A TimeStudio model is made up to two basic elements, nodes and links, which are connected together to form a network. Nodes represent subcatchment areas, stream confluences, and other locations of interest in the catchment. Links represent the channel network. Operating rules for nodes and links are defined using TimeStudio Basic script language.

5.2 Model configuration

The Mangaroa catchment was divided into seventeen subcatchments (A-Q) for modelling purposes (Figure 7). Subcatchment delineation was based on contour information, with each subcatchment generally representing a major tributary or several minor tributaries. The model nodes and links are shown in Figure 8. A model output link was placed at the Te Marua node 29830 to allow comparison between observed and modelled flows; however, output can be determined from any of the other nodes if required for the hydraulic modelling process.

Subcatchment areas and channel lengths were calculated using ArcGIS. Channel lengths were measured from the subcatchment centroid to the outlet, with the centroid being placed on a main stream. The model was set to 15-minute timesteps, which is equal to the flow data recording interval at Mangaroa River at Te Marua (29830).

Figure 7: Subcatchment delineation for a rainfall runoff model of the Mangaroa catchment

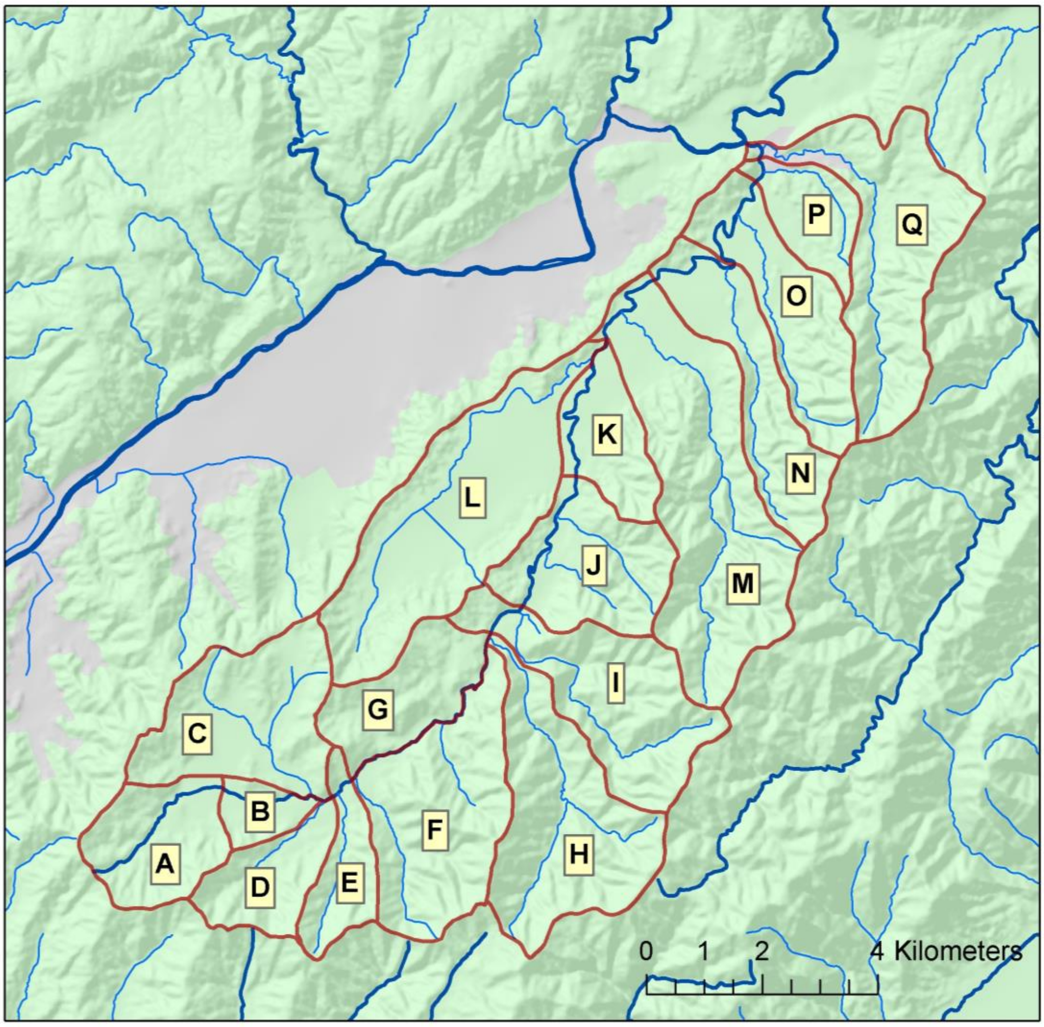
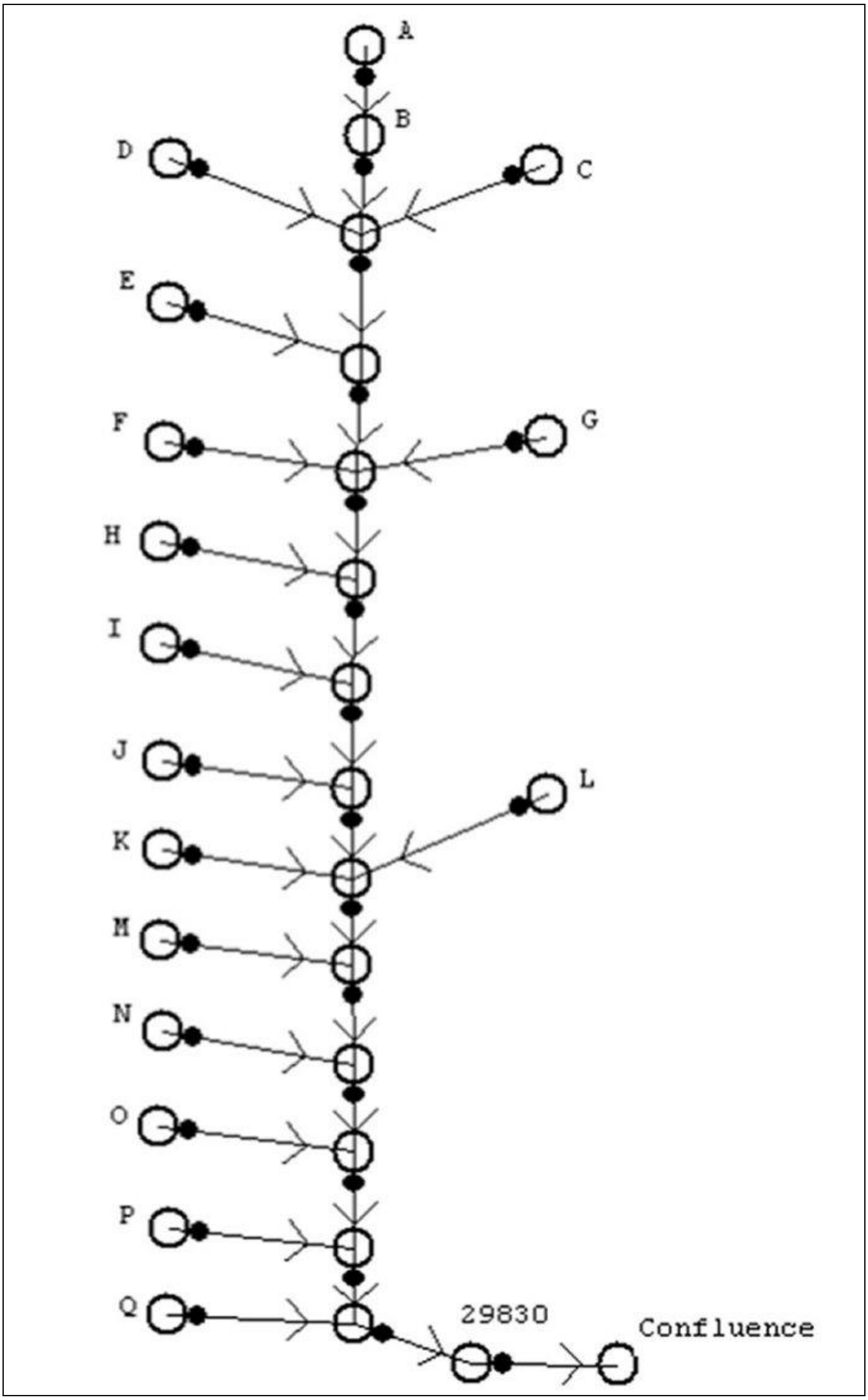


Figure 8: Schematic diagram of the rainfall runoff model of the Mangaroa catchment



The rainfall runoff model for the Mangaroa catchment was calibrated and validated using flow data from the Te Marua recorder site (29830). To select the high flow events for this process, all flood peaks greater than 150 m^3/s at Mangaroa River at Te Marua (29830) were listed. Once the events with no rainfall data available at Tasman Vaccine Limited (E15204) or Centre Ridge (E15122) were removed, the remaining events were assigned as either for calibration or validation (Table 8). This procedure resulted in six calibration and five validation events. The 15-minute flow data for each event was read into the '29830' node in the TimeStudio model so that modelled flow could be compared with observed flow.

Table 8: Flood events for the Mangaroa rainfall runoff model calibration and validation

Date	Peak flow (m^3/s)	Calibration / validation
20 January 1980	207	n/a (missing rainfall data)
10 April 1980	194	n/a (missing rainfall data)
21 May 1981	245	n/a (missing rainfall data)
11 December 1982	192	n/a (missing rainfall data)
18 October 1984	161	Calibration
19 August 1985	186	Validation
7 August 1991	156	Calibration
8 November 1994	194	Validation
4 October 1997	227	Calibration
21 October 1998	187	Validation
28 October 1998	239	Calibration
2 October 2000	189	Validation
3 October 2003	231	Calibration
16 February 2004	252	Validation
6 January 2005	247	Calibration

Data to represent rainfall in the Mangaroa catchment was taken from the Tasman Vaccine Limited (E15204), Centre Ridge (E15122), and Te Marua (E15019) raingauges. Initially, calibration was attempted using rainfall data from Tasman Vaccine Limited (E15204) and distributing this across the catchment according to the annual rainfall contours, but the calibration results were very poor. Significantly better results were achieved by incorporating actual rainfall data from Centre Ridge (E15122) and Te Marua (E15019). For events where no data is available for Te Marua (E15019) (events prior to 1993) the rainfall was estimated based on a correlation with Phillips (E1502A).

The rainfall stations were plotted on the rainfall contour map (Figure 5). The mean annual rainfall in each subcatchment as a proportion of the measured annual rainfall at the nearest rainfall station determined the rainfall volume for each subcatchment in the model, with Centre Ridge (E15122) representing all high altitude parts of the catchment (where annual rainfall is assumed to be greater than 1800 mm). For example, the mean annual rainfall in subcatchment A is approximately 1590 mm and no part of the subcatchment receives more than 1800 mm/year (according to Figure 5), therefore for that subcatchment a factor of 1.1 is applied to the Tasman Vaccine Limited (E15204) rainfall data.

Table 9 shows which rainfall stations(s) and adjustment factor(s) were used to represent rainfall in subcatchment in the model.

Table 9: Derivation of rainfall data for the rainfall runoff model

Subcatchment (Total area km^2)	Rainfall station representation	Factor applied to TVL rainfall	Factor applied to Centre Ridge rainfall	Factor applied to Te Marua rainfall
A	TVL	1.1	n/a	n/a
B	TVL	1.1	n/a	n/a
C	TVL	0.97	n/a	n/a
D	30% Centre Ridge, 70% TVL	1.1	0.9	n/a
E	50% Centre Ridge, 50% TVL	1.1	0.9	n/a
F	30% Centre Ridge, 70% TVL	1.1	0.9	n/a
G	TVL	1.0	n/a	n/a
H	70% Centre Ridge, 30% TVL	1.1	0.93	n/a
I	40% Centre Ridge, 60% TVL	1.1	0.9	n/a
J	TVL	0.95	n/a	n/a
K	Te Marua	n/a	n/a	0.95
L	TVL	1.1	n/a	n/a
M	25% Centre Ridge, 75% Te Marua	n/a	0.87	1.0
N	10% Centre Ridge, 90% Te Marua	n/a	0.87	0.98
O	5% Centre Ridge, 95% Te Marua	n/a	0.87	0.97
P	Te Marua	n/a	n/a	0.97
Q	40% Centre Ridge, 60% Te Marua	n/a	0.87	1.0

5.3 Model calibration

For the six calibration events in Table 8, the TimeStudio model was tested using both an AWBM and the Initial-Continuing loss function. The initial testing found that the use of AWBM did not result in noticeably better model performance. Therefore, the model was calibrated using the Initial-Continuing loss function, because the AWBM is significantly more complex to calibrate (it has many fixed parameters).

Table 10 shows the parameters required in the TimeStudio model of the Mangaroa catchment. The values of *Area* and *L* were fixed in the respective nodes and links. The values of *IL*, *CL*, α and *n* were assumed constant over the catchment. However, the exception is for subcatchment 'L' which represents the Black Stream catchment. This subcatchment is swampy and therefore considered to have different loss and routing properties to the rest of the Mangaroa catchment. Because there are no calibration data available for Black Stream the parameters were fixed (IL = 5 mm, CL = 1 mm, α = 1.5, n = 1.0) which results in a lower, flatter hydrograph than for the other subcatchments.

Table 10: Calibration parameters for a TimeStudio model of the Mangaroa catchment

Parameter	Description
Initial loss (IL)	Amount of water lost (mm) before rainfall becomes effective runoff
Continuing loss (CL)	Continuing loss rate (mm per hour) applied to the rainfall after IL is satisfied
α	Channel lag parameter for channel routing
n	Non-linearity parameter for channel routing
Area	Subcatchment area (km^2)
L	Channel length (km)

Therefore, the calibration process consisted of varying the values of *IL*, *CL*, α and *n* for the Mangaroa catchment with the exception of subcatchment L. The calibration was determined by visual assessment of the fit of the hydrograph at Mangaroa River at Te Marua (29830), calculation of the error in peak flow, and noting the timing error of the peak flow. The final parameters chosen were those which resulted in the lowest average error in peak flow and the best timing of peak flow. The calibrated parameter values are shown in Table 11.

Table 11: Calibration results for the Mangaroa catchment rainfall runoff model

Parameter	Best fit value	Average error in modelled peak flow (%)	Error in timing of peak flow
IL	5 mm	9.3%	-30 mins to +1 hour
CL	0.5 mm		
α	0.85		
n	0.77		

Appendix 2 contains the modelled and observed hydrographs for the six calibration events along with the model error statistics for each event. Note that the poorest model performance was for the 3 October 2003 storm event, where peak flow is underpredicted by about 15%. Unusual weather patterns resulted in this flood, with very large spatial variations in rainfall (Greater Wellington Regional Council, 2003). Thus it is likely that the use of the three gauges in the model has not adequately represented rainfall in the Mangaroa catchment for this event. When that event is omitted from the calibration statistics the average error reduces to 8%.

5.4 Model validation

Five flood events were used to validate the rainfall runoff model. The modelled hydrographs are compared with the observed hydrographs at Mangaroa at Te Marua (29830) in Figures 9 to 13. The model validation statistics are shown in Table 12.

Figure 9: February 2004 flood at Mangaroa River at Te Marua (29830) - model validation

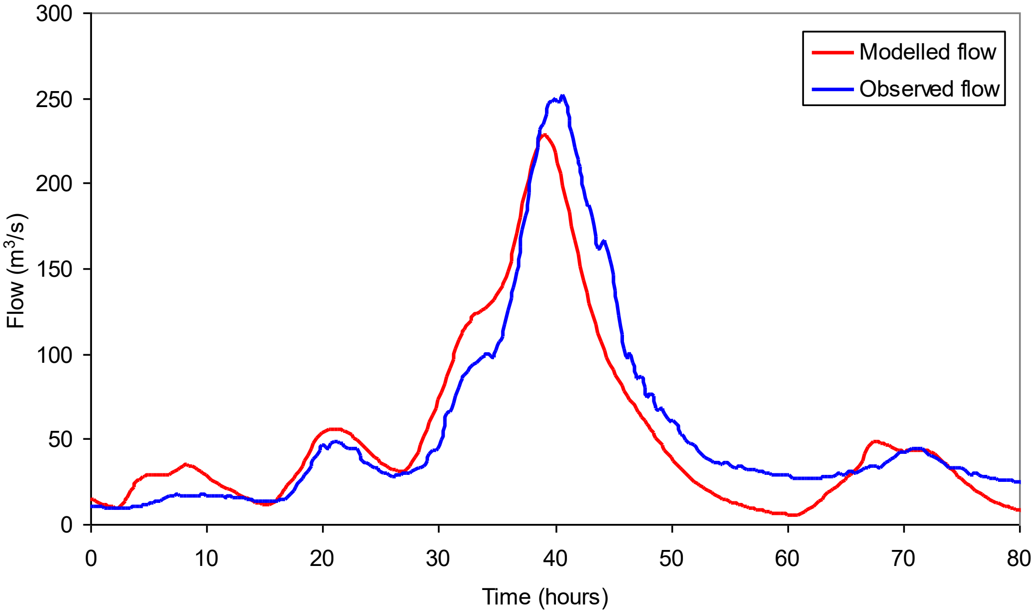


Figure 10: October 2000 flood at Mangaroa River at Te Marua (29830) - model validation

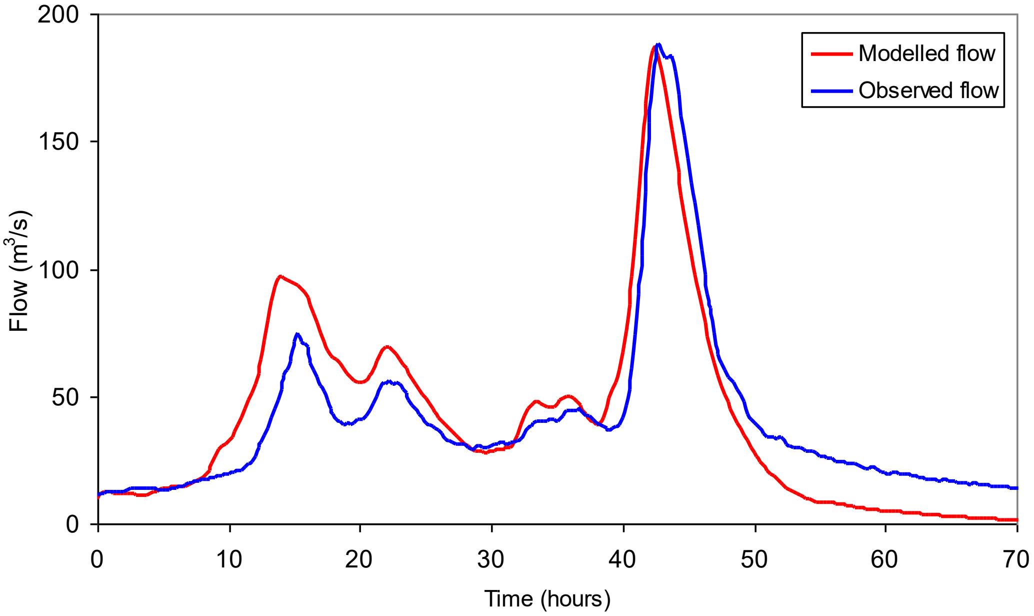


Figure 11: 21 October 1998 flood at Mangaroa River at Te Marua (29830) - model validation

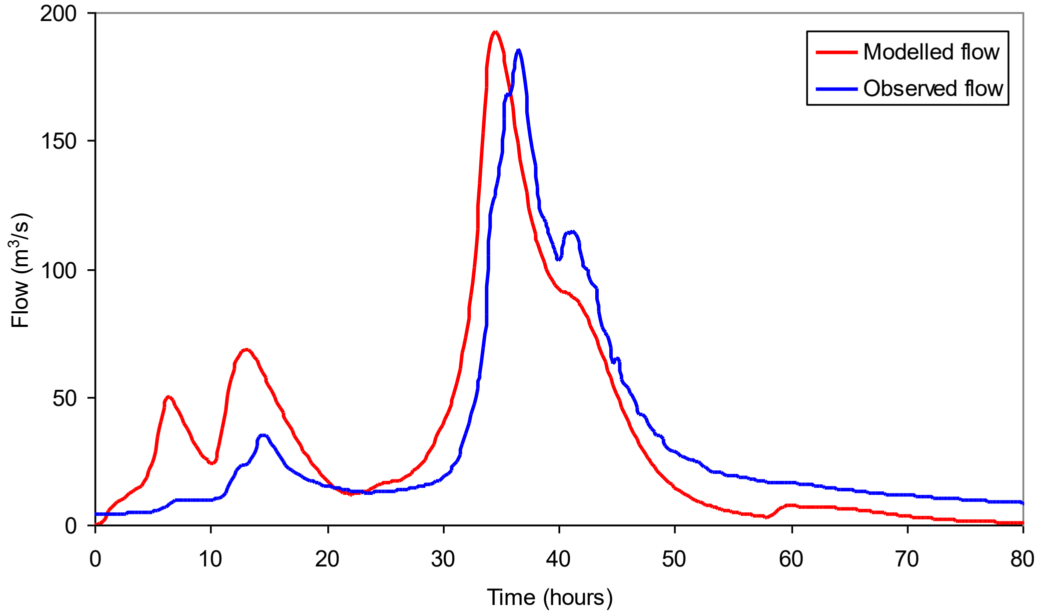


Figure 12: November 1994 flood at Mangaroa River at Te Marua (29830) - model validation

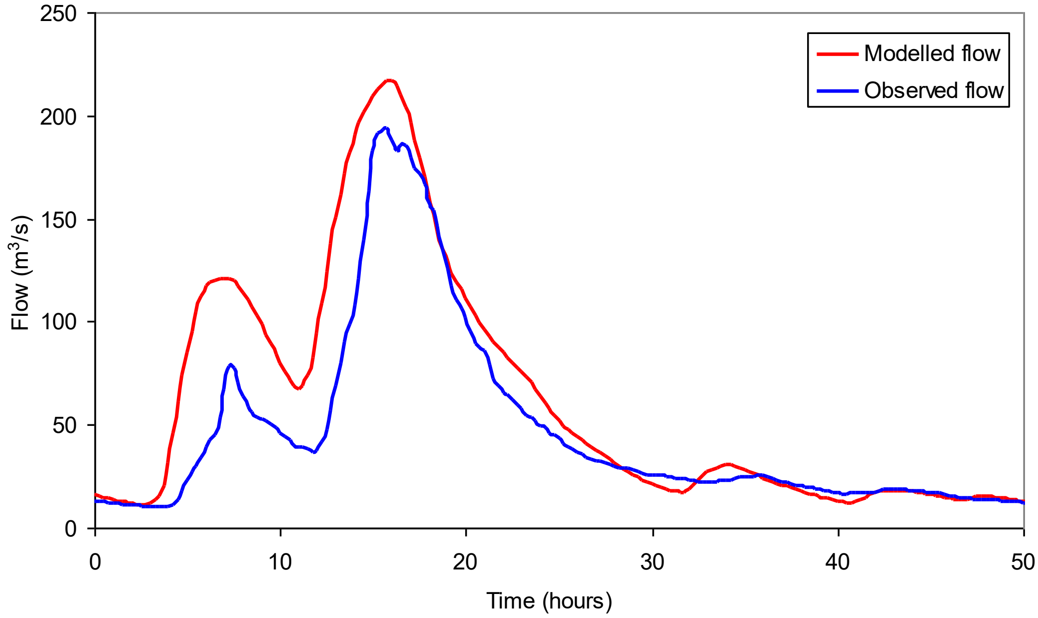


Figure 13: August 1985 flood at Mangaroa River at Te Marua (29830) - model validation

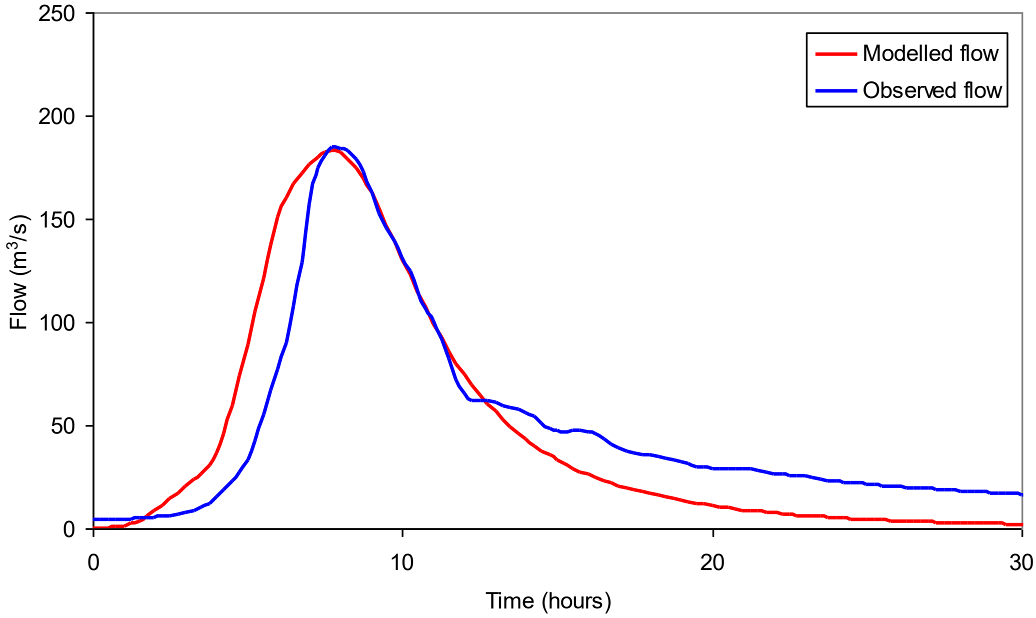


Table 12: Model validation results for Mangaroa River at Te Marua (29830)

	Event date					Average
	February 2004	October 2000	21 October 1998	November 1994	August 1985	
Error in peak flow (%)	-9.4	-0.6	3.8	12.0	-1.0	±5.4%
Mean absolute error (m^3/s)	15.5	11.9	15.4	42.9	13.2	19.8
Error in timing of peak	-45 minutes	-15 minutes	-1.75 hours	0	0	n/a

The rainfall runoff model produced good results for the validation events at Mangaroa River at Te Marua (29830). The maximum error in peak discharge was 12%, but for the other four events the error was less than 10%. In all cases the modelled hydrograph shape was a good match to the observed hydrograph. The validation results are seen as acceptable for using the rainfall runoff model to predict runoff from the design rainfall events.

5.5 Design storm modelling

The design rainfall events of 2 to 200 year return periods and PMP were run through the calibrated rainfall runoff model for the Mangaroa catchment to derive design peak flows. Note that when the PMP was run through the model to obtain the probable maximum flood the rainfall factors in Table 9 were not applied (as the PMP is already a catchment average rainfall).

Output hydrographs were obtained for Mangaroa River at Russells Road (combined flow from nodes A to D), Mangaroa River downstream of Mangaroa Valley Road (below the confluence of nodes K and L) and Mangaroa River at Te Marua recorder site (node 29380). Tables 13 to 15 show the modelled peak flows at the three output nodes for each storm duration. The critical duration (the duration that gives the maximum flood peak) for each location is highlighted.

Table 13: Modelled peak flows (m^3/s) for Mangaroa River near Russells Road (output from nodes A-D)[4]

	Duration					
	1 hour	2 hour	4 hour	6 hour	12 hour	24 hour
Q2	35.2	45.8	45.1	38.5	31.5	19.4
Q5	53.5	63.5	58.6	49.8	41.8	26.1
Q10	67.8	73.5	68.3	57.2	48.4	30.7
Q20	82.4	83.8	78.0	64.8	55.1	35.1
Q50	101.2	98.4	89.0	74.1	63.4	40.7
Q100	116.0	109.9	98.8	81.0	69.6	44.9
Q200	128.7	120.1	107.1	88.7	75.9	49.2
Probable maximum flood	383	422	404	373	n/a	n/a

Table 14: Modelled peak flows (m^3/s) for Mangaroa River downstream of Mangaroa Valley Road bridge (below node L confluence)

	Duration					
	1 hour	2 hour	4 hour	6 hour	12 hour	24 hour
Q2	39.6	68.4	106.2	117.2	97.8	66.4
Q5	63.1	99.9	143.0	149.2	130.2	90.1
Q10	79.1	118.7	169.5	172.2	151.1	105.8
Q20	96.8	138.5	196.5	195.7	171.8	121.1
Q50	122.9	166.2	229.4	224.7	198.7	141.0
Q100	139.5	192.7	259.0	247.3	219.2	156.1
Q200	155.8	209.6	284.3	270.7	240.6	171.3
Probable maximum flood	548	938	1231	1215		

[4] Note that QX is a flood of X year return period, resulting from the design storm of the same frequency.

Table 15: Modelled peak flows (m^3/s) for Mangaroa River at Te Marua (29830)

	Duration					
	1 hour	2 hour	4 hour	6 hour	12 hour	24 hour
Q2	43.5	76.1	126.0	168.2	145.1	105.4
Q5	67.4	110.4	171.7	201.5	191.4	140.5
Q10	84.9	131.4	203.6	234.6	220.2	162.5
Q20	104.0	154.4	238.8	271.1	252.3	186.9
Q50	132.0	188.2	287.9	322.5	297.8	221.3
Q100	153.4	222.8	334.7	366.3	336.5	250.4
Q200	173.3	242.8	372.6	402.7	377.2	273.7
Probable maximum flood	622	1126	1783	1864	n/a	n/a

5.6 Discussion of design flood modelling results

As shown by Tables 13 to 15, the critical duration for maximising flood peaks tends to increase with distance downstream, as expected. The critical duration at Mangaroa River at Te Marua (29830) was found to be 6 hours. The time of concentration at this location, determined using the Bransby-Williams formula, is about 7 hours. This gives confidence in the modelling results, given that no storm durations between 6 and 12 hours were modelled.

The maximum flood peaks from the design modelling are shown in Table 16. The rainfall runoff model validation process found the mean error in modelled peak flow was 5.4%. Thus it would be conservative to assume that the error introduced by the rainfall runoff model in deriving the peak flows could be up to 10%.

Table 16: Maximum modelled flood peaks (m^3/s) for the Mangaroa catchment

Location	Q2	Q5	Q10	Q20	Q50	Q100	Q200	PMF
Russells Road	45.8	63.5	73.5	83.8	101.2	116.0	128.7	422
Mangaroa Valley Road	117.2	149.2	172.2	196.5	229.4	259.0	284.3	1231
Te Marua	168.2	201.5	234.6	271.1	322.5	366.5	402.7	1864

The design peak flows are higher than those derived using the RORB model for the Hutt catchment (Pearson, 1990). The difference could be due to the fact that different rainfall data were used. Because the rainfall runoff model was calibrated specifically to floods recorded at Te Marua, and used an up-to-date rainfall depth-duration-frequency analysis, greater confidence can be placed on the TimeStudio results.

The hydrographs for the maximum flood peaks shown in Table 16 are the design hydrographs for the Mangaroa catchment. These are contained in Appendix 3 but will be discussed further in Section 6. Note that output hydrographs for any node in the rainfall runoff model can be obtained for hydraulic modelling purposes if required.

6. Flood frequency analysis

6.1 At-site flood frequency analysis

Two methods of at-site flood frequency analysis were performed – annual maximum series analysis and partial duration series analysis – for the length of record at Mangaroa River at Te Marua (29830) (May 1977 – February 2005). No historical flood records are available for analysis. Note that the at-site analysis assumed that the January 2005 flood event (which is the second largest flood on record) will be the annual maximum for 2005.

Prior to conducting the at-site flood frequency analysis, tests were made for independence and stationarity. All floods in the partial duration series were confirmed to be independent, although the independence of the 21 October 1998 and 28 October 1998 flood peaks is questionable. To be confident in the results the 21 October peak was omitted from the analysis. Stationarity was checked using a Mann-Whitney split-sample test. Stationarity of the record was accepted at the 95% confidence level.

The annual maximum series analysis was carried out by fitting various frequency distributions to the annual peaks using the L-moments method. The frequency distributions that provided the best fit to the data were EV1 and log Pearson Type 3 (see plots in Appendix 4). However, none of the distributions that were trialled provided a particularly good fit to the largest flood peaks on record. As discussed in Section 3.2.2 there are several high annual maxima of about the same magnitude. Although an EV3 distribution fits this situation well, the EV3 should not be used as it will lead to flood frequency being underestimated.

A partial duration series analysis, where all flood events on record are included, was carried out to compare to the annual maximum series results. An arbitrary threshold of 80 m^3/s was set, which resulted in 38 flood peaks in the 28 years of record. The exponential distribution was fitted to the peaks, as recommended by Pearson & Davies (1997).

Table 17 shows the results from the two types of at-site analysis. The difference between the annual maximum series and partial duration series results is within 10%. It is to be expected that the longer the flood record the closer the results obtained using the two methods will be.

Table 17: At-site flood frequency estimates (m^3/s) for Mangaroa River at Te Marua (29830)

	Annual maximum series		Partial duration series (exponential distribution)
	EV1	Log Pearson Type 3	
Q2	132	132	142
Q5	194	199	198
Q10	238	246	241
Q20	281	289	284
Q50	335	343	340
Q100	376	382	383
Q200	417	420	429

The at-site flood frequency estimates derived using the annual maximum series analysis are preferred to those of the partial duration series. The partial duration series is generally only recommended for short records and low return periods (Pearson, 2003). The preferred annual maximum series results are those derived using EV1 as this is the distribution most appropriate for New Zealand rivers.

6.2 Regional flood frequency analysis

A regional flood frequency estimation method was developed for New Zealand catchments by McKerchar & Pearson (1989). Refined flood contour maps for the Hutt catchments (Pearson, 1990) were used to derive the Mangaroa River flood frequency estimates in Table 18.

Table 18: Regional flood frequency estimates for the Mangaroa River at Te Marua (29830)

	Flow (m^3/s)
Q2	123
Q5	168
Q10	197
Q20	225
Q50	262
Q100	289
Q200	317

6.3 Flood frequency discussion and comparison of results

Table 19 shows a summary of the flood frequency estimates for the Mangaroa River at Te Marua. The rainfall runoff model estimates are those derived from modelling the design storms in Section 5.6. Also shown are the previous flood frequency estimates (from Pearson, 1990).

Table 19: Mangaroa River at Te Marua (29830) flood frequency estimates (m^3/s)

	Preferred	Regional	Rainfall runoff	Previous results

	at-site		model	(Pearson, 1990)
Q2	132	123	168	120
Q5	194	168	202	180
Q10	238	197	235	210
Q20	281	225	271	250
Q50	335	262	323	300
Q100	376	289	367	330
Q200	417	317	403	360
PMF	n/a	n/a	1864	n/a

The regional estimates are the most different from the results derived using the other methods; they are up to 25% lower than the at-site results. Given that an additional 17 years of flood data has been recorded since the regional flood estimation method was developed the at-site estimates are preferred to the regional estimates.

The at-site and rainfall runoff results are very similar: with the exception of the Q2 the results are within 5% of each other. This similarity gives confidence in the rainfall runoff model for the Mangaroa catchment.

Pearson & Davies (1997) recommend pooling the two best estimates of flood frequency to obtain the final flood frequency estimates for a catchment. Pooling lowers the standard error associated with the estimates. Therefore the preferred at-site results were pooled with the rainfall runoff results by averaging, to give the final flood frequency estimates and their standard errors (Table 20). In effect this process has had little effect on the at-site results because the modelled results were so similar.

Table 20: Final flood frequency estimates for the Mangaroa River at Te Marua (29830)

	Flow (m^3/s)	Standard error (m^3/s)
Q2	150	14
Q5	198	21
Q10	237	29
Q20	276	37
Q50	329	48
Q100	372	57
Q200	410	65
PMF	1864	n/a

The recommended flood frequencies are, on average, 13% higher than the previous flood frequency estimates for the Mangaroa River at Te Marua. This increase is displayed in other subcatchments of the Hutt River (e.g. Greater Wellington Regional Council, 2004). Greater confidence can be placed on the updated estimates as a considerably longer flood record from Mangaroa River at Te Marua (29830) is now available, and because the rainfall runoff model in this report was calibrated specifically for the Mangaroa catchment.

The design flood hydrographs produced by the rainfall runoff model need to be scaled so that the flood peaks at node 29830 match the final flood frequency estimates in Table 20. The scaled design hydrographs are shown in Appendix 3.

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Appendix 1: Design rainfall events

Design storms (mm) for Centre Ridge (E15122)

Duration	Increment (minutes)	% of total rainfall	Return period						
			2 years	5 years	10 years	20 years	50 years	100 years	200 years
1 hour	15	20	3.8	4.8	5.4	6.0	6.8	7.4	8.0
	30	30	5.7	7.2	8.1	9.0	10.2	11.1	12.0
	45	30	5.7	7.2	8.1	9.0	10.2	11.1	12.0
	60	20	3.8	4.8	5.4	6.0	6.8	7.4	8.0
2 hour	30	20	5.6	6.8	7.6	8.4	9.4	10.2	11.0
	60	30	8.4	10.2	11.4	12.6	14.1	15.3	16.5
	90	30	8.4	10.2	11.4	12.6	14.1	15.3	16.5
	120	20	5.6	6.8	7.6	8.4	9.4	10.2	11.0
4 hour	30	8	3.5	4.2	4.6	5.1	5.7	6.2	6.6
	60	12	5.3	6.4	7.0	7.7	8.5	9.2	9.8
	90	15	6.6	8.0	8.7	9.6	10.7	11.6	12.3
	120	15	6.6	8.0	8.7	9.6	10.7	11.6	12.3
	150	16	7.0	8.5	9.3	10.2	11.4	12.3	13.1
	180	14	6.2	7.4	8.1	9.0	9.9	10.8	11.5
	210	10	4.4	5.3	5.8	6.4	7.1	7.7	8.2
	240	10	4.4	5.3	5.8	6.4	7.1	7.7	8.2
6 hour	60	12	6.5	7.7	8.5	9.4	10.3	11.2	11.9
	120	18	9.7	11.5	12.8	14.0	15.5	16.7	17.8
	180	22	11.9	14.1	15.6	17.2	18.9	20.5	21.8
	240	19	10.3	12.2	13.5	14.8	16.3	17.7	18.8
	300	16	8.6	10.2	11.4	12.5	13.8	14.9	15.8
	360	13	7.0	8.3	9.2	10.1	11.2	12.1	12.9
12 hour	60	6	4.9	6.0	6.7	7.3	8.1	8.7	9.5
	120	6	4.9	6.0	6.7	7.3	8.1	8.7	9.5
	180	8	6.5	8.0	8.9	9.7	10.8	11.6	12.7
	240	9	7.3	9.0	10.0	10.9	12.2	13.1	14.3
	300	9	7.3	9.0	10.0	10.9	12.2	13.1	14.3
	360	14	11.4	14.0	15.6	16.9	18.9	20.3	22.2
	420	11	9.0	11.0	12.2	13.3	14.9	16.0	17.4
	480	9	7.3	9.0	10.0	10.9	12.2	13.1	14.3
	540	8	6.5	8.0	8.9	9.7	10.8	11.6	12.7
	600	8	6.5	8.0	8.9	9.7	10.8	11.6	12.7
	660	6	4.9	6.0	6.7	7.3	8.1	8.7	9.5
	720	6	4.9	6.0	6.7	7.3	8.1	8.7	9.5

Duration	Increment (minutes)	% of total rainfall	Return period 2 years	5 years	10 years	20 years	50 years	100 years	200 years
24 hour	60	3	3.2	4.2	4.7	5.2	5.9	6.4	7.0
	120	3	3.2	4.2	4.7	5.2	5.9	6.4	7.0
	180	3	3.2	4.2	4.7	5.2	5.9	6.4	7.0
	240	3	3.2	4.2	4.7	5.2	5.9	6.4	7.0
	300	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	360	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	420	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	480	5	5.4	6.9	7.9	8.7	9.9	10.7	11.6
	540	5	5.4	6.9	7.9	8.7	9.9	10.7	11.6
	600	6	6.5	8.3	9.4	10.5	11.9	12.9	13.9
	660	6	6.5	8.3	9.4	10.5	11.9	12.9	13.9
	720	5	5.4	6.9	7.9	8.7	9.9	10.7	11.6
	780	5	5.4	6.9	7.9	8.7	9.9	10.7	11.6
	840	5	5.4	6.9	7.9	8.7	9.9	10.7	11.6
	900	5	5.4	6.9	7.9	8.7	9.9	10.7	11.6
	960	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	1020	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	1080	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	1140	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	1200	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	1260	4	4.3	5.5	6.3	7.0	7.9	8.6	9.3
	1320	3	3.2	4.2	4.7	5.2	5.9	6.4	7.0
	1380	3	3.2	4.2	4.7	5.2	5.9	6.4	7.0
	1440	3	3.2	4.2	4.7	5.2	5.9	6.4	7.0

Design storms (mm) for Tasman Vaccine Limited (E15204)

Duration	Increment (minutes)	% of total rainfall	Return period 2 years	5 years	10 years	20 years	50 years	100 years	200 years
1 hour	15	20	4.2	5.6	6.6	7.6	8.8	9.8	10.6
	30	30	6.3	8.4	9.9	11.4	13.2	14.7	15.9
	45	30	6.3	8.4	9.9	11.4	13.2	14.7	15.9
	60	20	4.2	5.6	6.6	7.6	8.8	9.8	10.6
2 hour	30	20	6.0	7.8	8.8	9.8	11.2	12.2	13.2
	60	30	9.0	11.7	13.2	14.7	16.8	18.3	19.8
	90	30	9.0	11.7	13.2	14.7	16.8	18.3	19.8
	120	20	6.0	7.8	8.8	9.8	11.2	12.2	13.2
4 hour	30	8	3.4	4.3	5.0	5.6	6.3	7.0	7.5
	60	12	5.2	6.5	7.4	8.4	9.5	10.4	11.3
	90	15	6.5	8.1	9.3	10.5	11.9	13.1	14.1
	120	15	6.5	8.1	9.3	10.5	11.9	13.1	14.1
	150	16	6.9	8.6	9.9	11.2	12.6	13.9	15.0
	180	14	6.0	7.6	8.7	9.8	11.1	12.2	13.2
	210	10	4.3	5.4	6.2	7.0	7.9	8.7	9.4
	240	10	4.3	5.4	6.2	7.0	7.9	8.7	9.4

Duration	Increment (minutes)	% of total rainfall	Return period 2 years	5 years	10 years	20 years	50 years	100 years	200 years
6 hour	60	12	6.2	7.9	9.0	10.1	11.4	12.4	13.4
	120	18	9.4	11.9	13.5	15.1	17.1	18.5	20.2
	180	22	11.4	14.5	16.5	18.5	20.9	22.7	24.6
	240	19	9.9	12.5	14.3	16.0	18.1	19.6	21.3
	300	16	8.3	10.6	12.0	13.4	15.2	16.5	17.9
	360	13	6.8	8.6	9.8	10.9	12.4	13.4	14.6
12 hour	60	6	4.5	5.8	6.7	7.5	8.6	9.4	10.2
	120	6	4.5	5.8	6.7	7.5	8.6	9.4	10.2
	180	8	6.0	7.7	8.9	10.0	11.4	12.5	13.6
	240	9	6.7	8.7	10.0	11.3	12.9	14.1	15.2
	300	9	6.7	8.7	10.0	11.3	12.9	14.1	15.2
	360	14	10.5	13.6	15.6	17.6	20.0	21.9	23.7
	420	11	8.2	10.6	12.2	13.8	15.7	17.2	18.6
	480	9	6.7	8.7	10.0	11.3	12.9	14.1	15.2
	540	8	6.0	7.7	8.9	10.0	11.4	12.5	13.6
	600	8	6.0	7.7	8.9	10.0	11.4	12.5	13.6
	660	6	4.5	5.8	6.7	7.5	8.6	9.4	10.2
	720	6	4.5	5.8	6.7	7.5	8.6	9.4	10.2
24 hour	60	3	2.9	3.9	4.5	5.1	5.8	6.4	7.0
	120	3	2.9	3.9	4.5	5.1	5.8	6.4	7.0
	180	3	2.9	3.9	4.5	5.1	5.8	6.4	7.0
	240	3	2.9	3.9	4.5	5.1	5.8	6.4	7.0
	300	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	360	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	420	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	480	5	4.9	6.4	7.5	8.5	9.7	10.7	11.7
	540	5	4.9	6.4	7.5	8.5	9.7	10.7	11.7
	600	6	5.9	7.7	9.0	10.2	11.7	12.8	14.0
	660	6	5.9	7.7	9.0	10.2	11.7	12.8	14.0
	720	5	4.9	6.4	7.5	8.5	9.7	10.7	11.7
	780	5	4.9	6.4	7.5	8.5	9.7	10.7	11.7
	840	5	4.9	6.4	7.5	8.5	9.7	10.7	11.7
	900	5	4.9	6.4	7.5	8.5	9.7	10.7	11.7
	960	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	1020	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	1080	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	1140	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	1200	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	1260	4	3.9	5.1	6.0	6.8	7.8	8.5	9.3
	1320	3	2.9	3.9	4.5	5.1	5.8	6.4	7.0
	1380	3	2.9	3.9	4.5	5.1	5.8	6.4	7.0
	1440	3	2.9	3.9	4.5	5.1	4.3	6.4	7.0

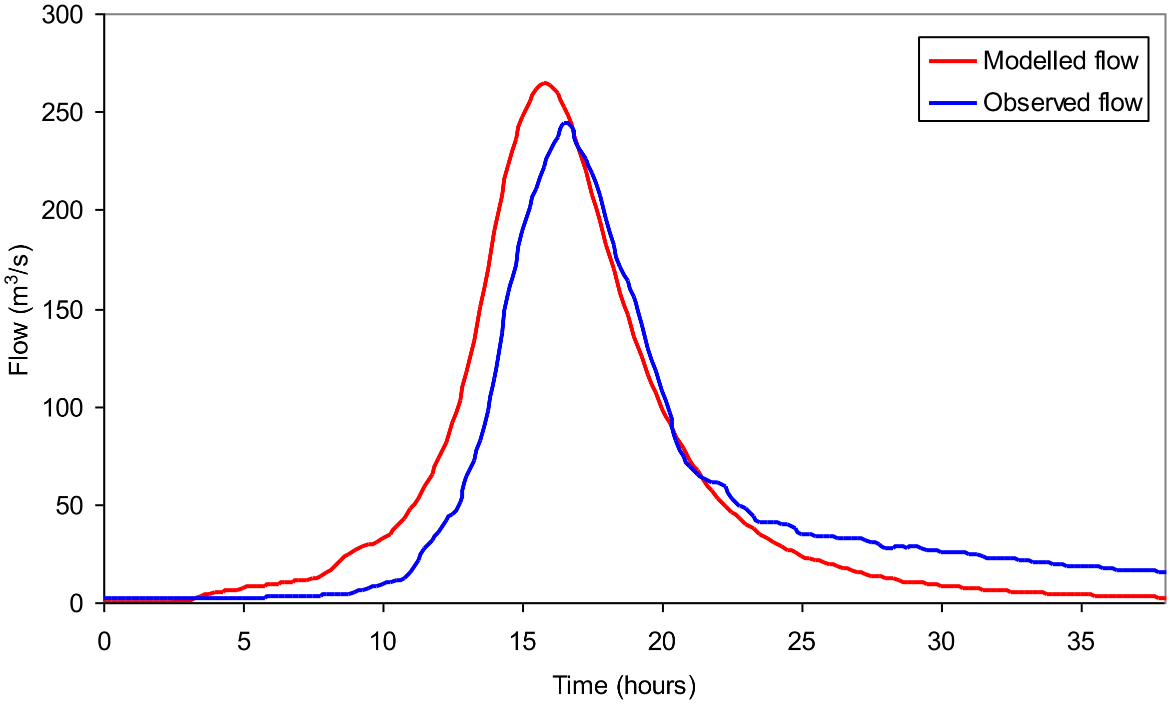
Design storms (mm) for Te Marua (E15019)

Duration	Increment (minutes)	% of total rainfall	Return period 2 years	5 years	10 years	20 years	50 years	100 years	200 years
1 hour	15	20	4.0	5.0	5.6	6.4	7.8	9.2	10.4
	30	30	6.0	7.5	8.4	9.6	11.7	13.8	15.6
	45	30	6.0	7.5	8.4	9.6	11.7	13.8	15.6
	60	20	4.0	5.0	5.6	6.4	7.8	9.2	10.4
2 hour	30	20	5.8	7.2	8.0	9.2	11.2	13.0	14.0
	60	30	8.7	10.8	12.0	13.8	16.8	19.5	21.0
	90	30	8.7	10.8	12.0	13.8	16.8	19.5	21.0
	120	20	5.8	7.2	8.0	9.2	11.2	13.0	14.0
4 hour	30	8	3.4	4.2	4.6	5.3	6.5	7.6	8.4
	60	12	5.0	6.2	7.0	7.9	9.7	11.4	12.6
	90	15	6.3	7.8	8.7	9.9	12.2	14.3	15.8
	120	15	6.3	7.8	8.7	9.9	12.2	14.3	15.8
	150	16	6.7	8.3	9.3	10.6	13.0	15.2	16.8
	180	14	5.9	7.3	8.1	9.2	11.3	13.3	14.7
	210	10	4.2	5.2	5.8	6.6	8.1	9.5	10.5
	240	10	4.2	5.2	5.8	6.6	8.1	9.5	10.5
6 hour	60	12	6.0	7.6	8.4	9.6	11.8	13.8	15.0
	120	18	9.0	11.3	12.6	14.4	17.6	20.7	22.5
	180	22	11.0	13.9	15.4	17.6	21.6	25.3	27.5
	240	19	9.5	12.0	13.3	15.2	18.6	21.9	23.8
	300	16	8.0	10.1	11.2	12.8	15.7	18.4	20.0
	360	13	6.5	8.2	9.1	10.4	12.7	15.0	16.3
12 hour	60	6	4.3	5.4	6.0	6.9	8.4	9.9	11.4
	120	6	4.3	5.4	6.0	6.9	8.4	9.9	11.4
	180	8	5.8	7.2	8.0	9.2	11.2	13.2	15.2
	240	9	6.5	8.1	9.0	10.4	12.6	14.9	17.1
	300	9	6.5	8.1	9.0	10.4	12.6	14.9	17.1
	360	14	10.1	12.6	14.0	16.1	19.6	23.1	26.6
	420	11	7.9	9.9	11.0	12.7	15.4	18.2	20.9
	480	9	6.5	8.1	9.0	10.4	12.6	14.9	17.1
	540	8	5.8	7.2	8.0	9.2	11.2	13.2	15.2
	600	8	5.8	7.2	8.0	9.2	11.2	13.2	15.2
	660	6	4.3	5.4	6.0	6.9	8.4	9.9	11.4
	720	6	4.3	5.4	6.0	6.9	8.4	9.4	11.4

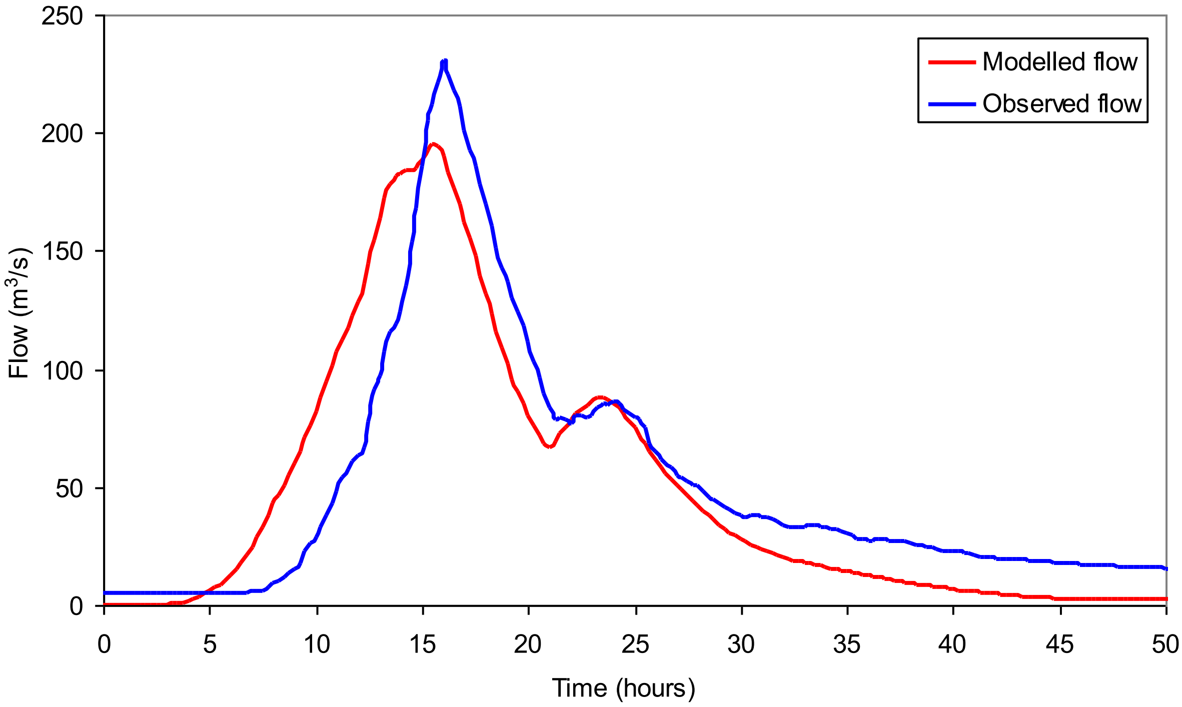
Duration	Increment (minutes)	% of total rainfall	Return period						
			2 years	5 years	10 years	20 years	50 years	100 years	200 years
24 hour	60	3	3.1	3.8	4.3	4.9	6.0	7.1	7.7
	120	3	3.1	3.8	4.3	4.9	6.0	7.1	7.7
	180	3	3.1	3.8	4.3	4.9	6.0	7.1	7.7
	240	3	3.1	3.8	4.3	4.9	6.0	7.1	7.7
	300	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	360	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	420	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	480	5	5.1	6.4	7.1	8.2	10.0	11.8	12.8
	540	5	5.1	6.4	7.1	8.2	10.0	11.8	12.8
	600	6	6.1	7.7	8.5	9.8	12.0	14.2	15.3
	660	6	6.1	7.7	8.5	9.8	12.0	14.2	15.3
	720	5	5.1	6.4	7.1	8.2	10.0	11.8	12.8
	780	5	5.1	6.4	7.1	8.2	10.0	11.8	12.8
	840	5	5.1	6.4	7.1	8.2	10.0	11.8	12.8
	900	5	5.1	6.4	7.1	8.2	10.0	11.8	12.8
	960	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	1020	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	1080	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	1140	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	1200	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	1260	4	4.1	5.1	5.7	6.6	8.0	9.4	10.2
	1320	3	3.1	3.8	4.3	4.9	6.0	7.1	7.7
	1380	3	3.1	3.8	4.3	4.9	6.0	7.1	7.7
	1440	3	3.1	3.8	4.3	4.9	6.0	7.1	7.7

Appendix 2: Calibration flood hydrographs

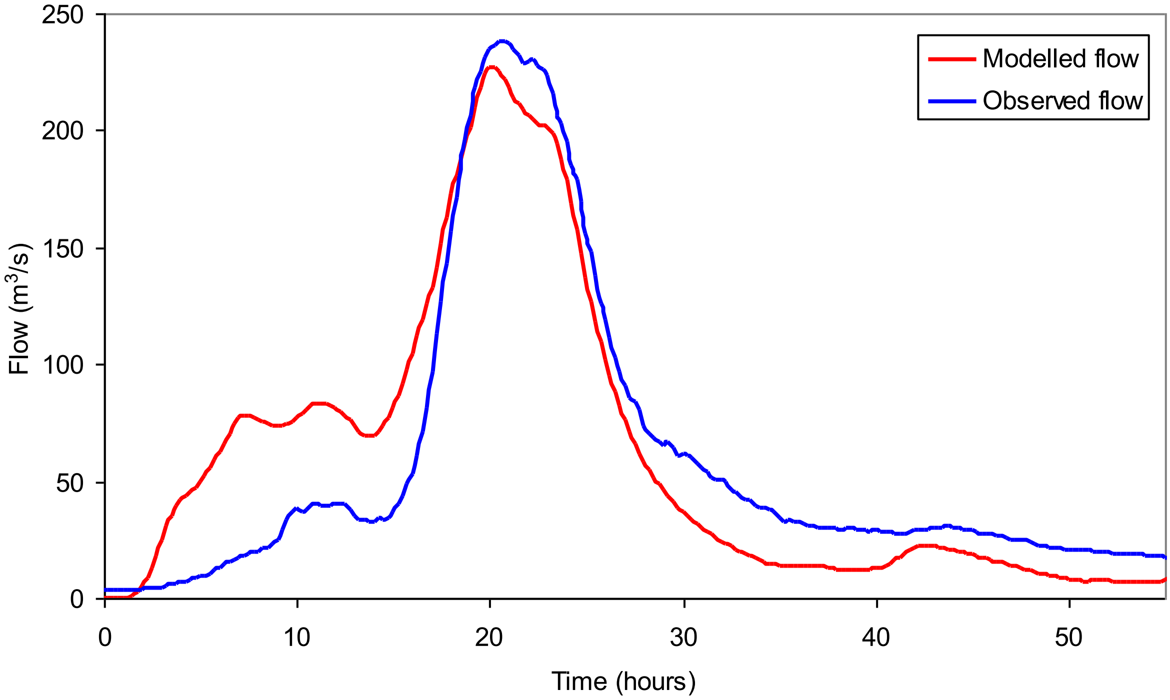
January 2005 calibration event



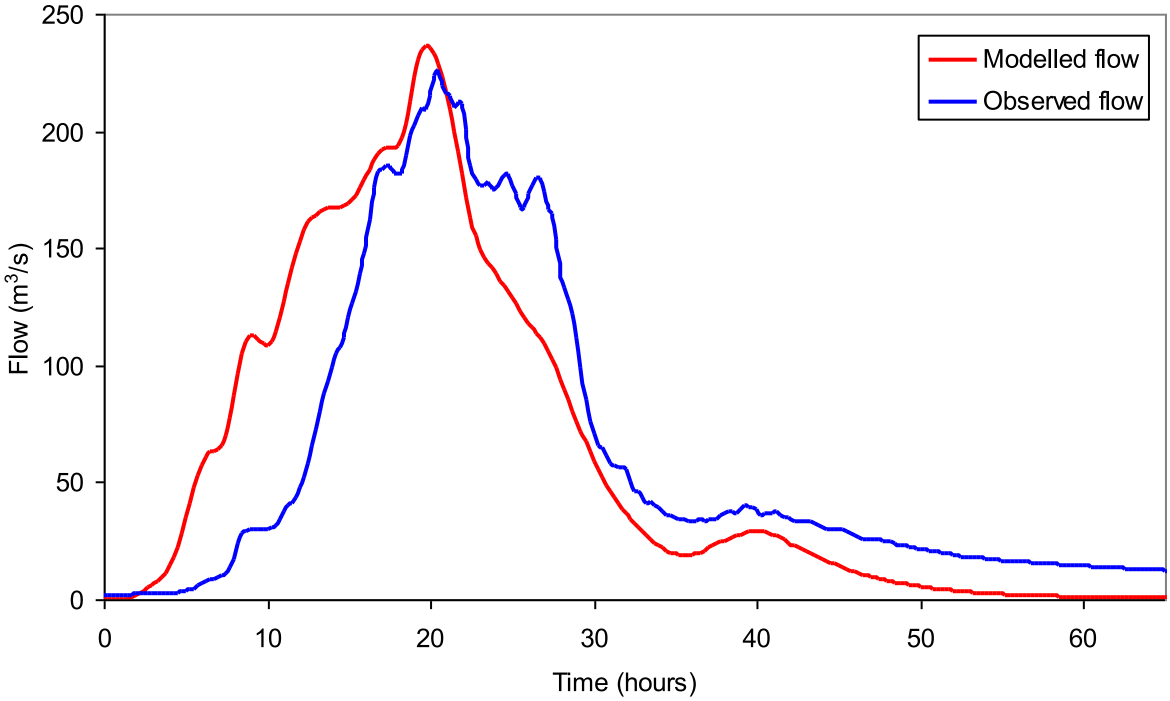
October 2003 calibration event



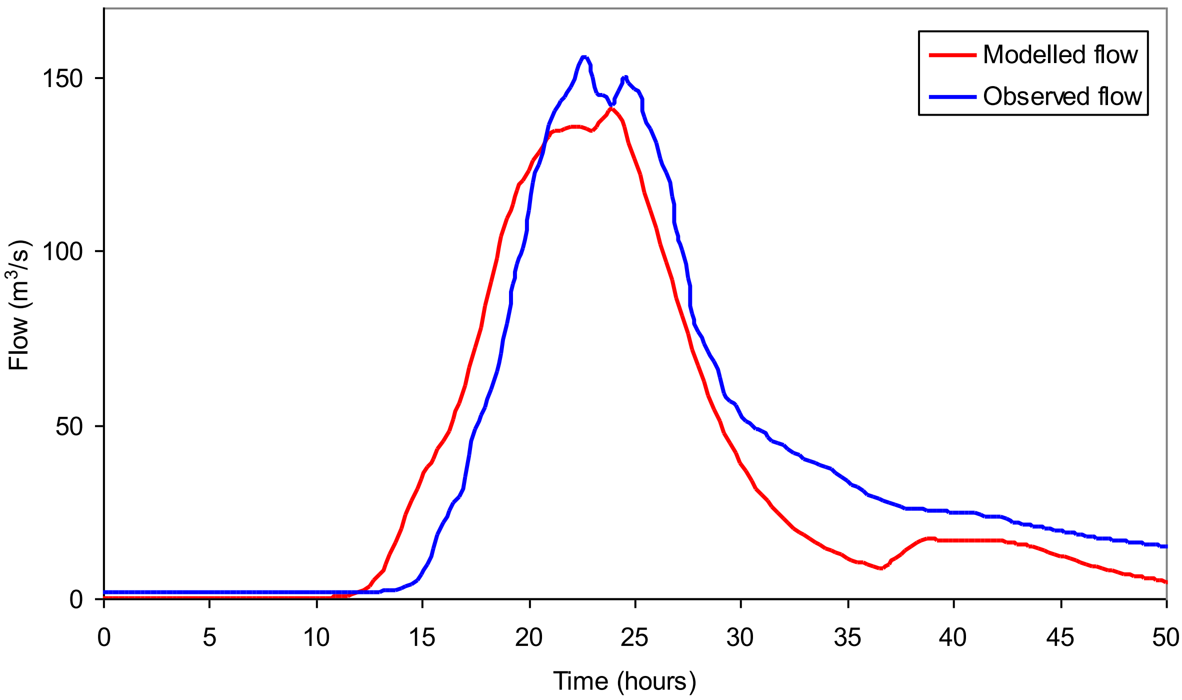
28 October 1998 calibration event



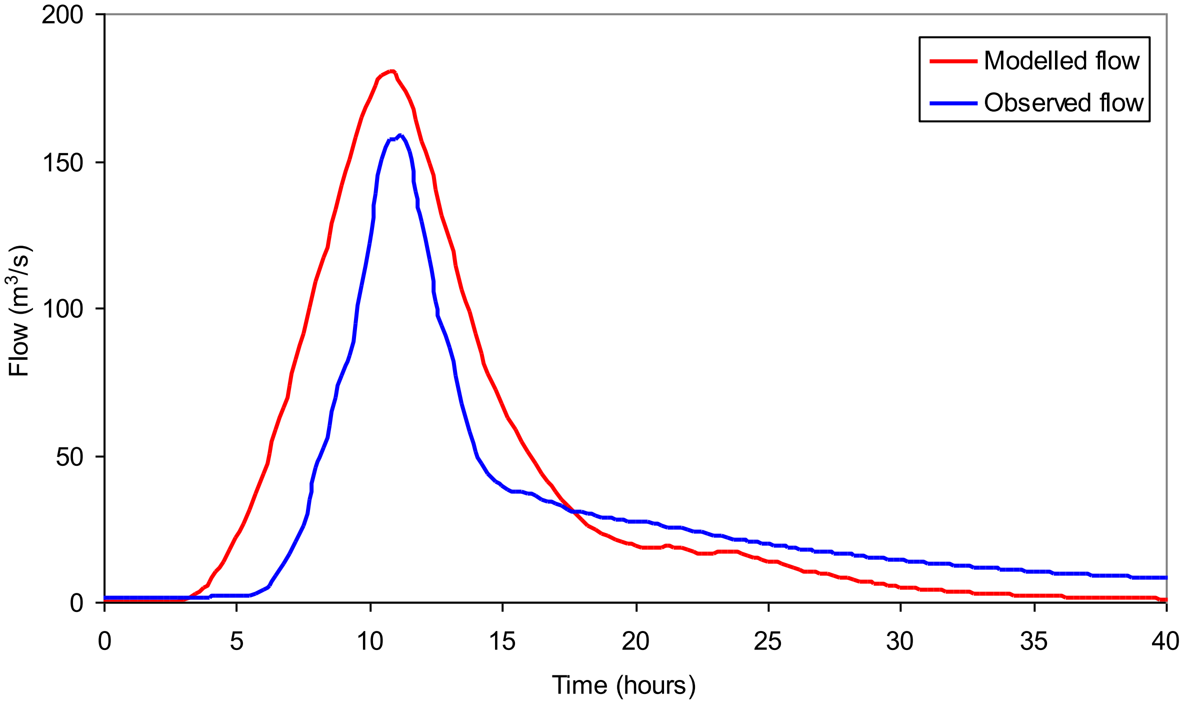
October 1997 calibration event



August 1991 calibration event

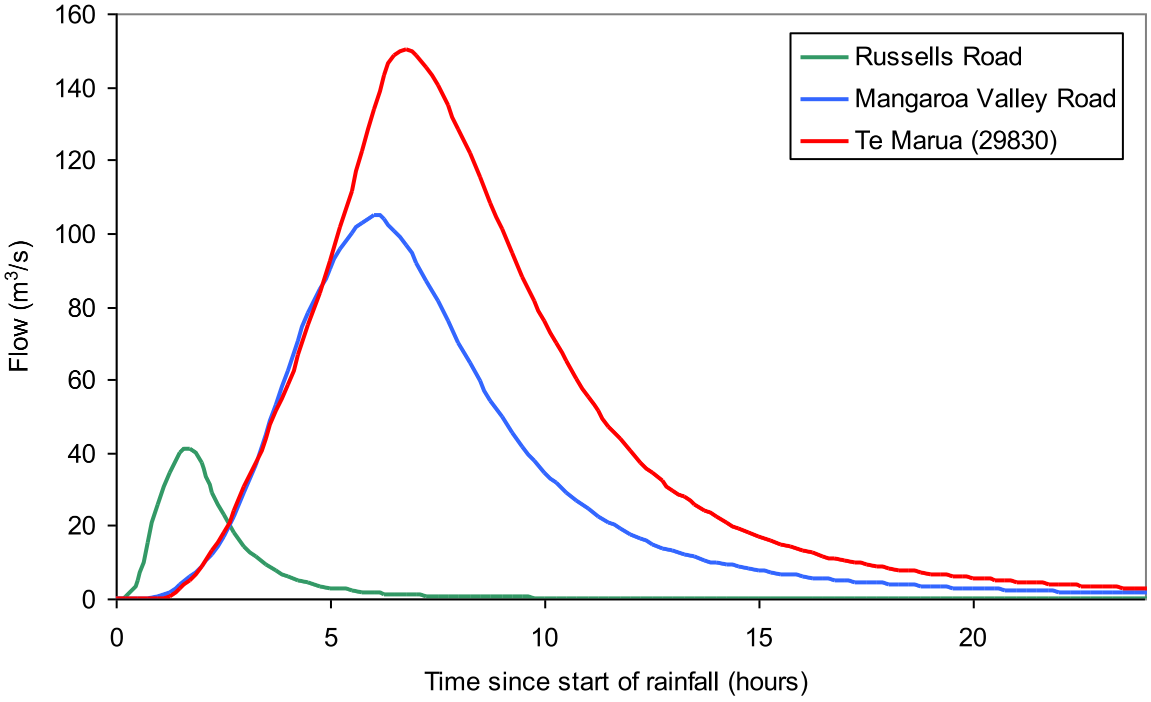


October 1984 calibration event

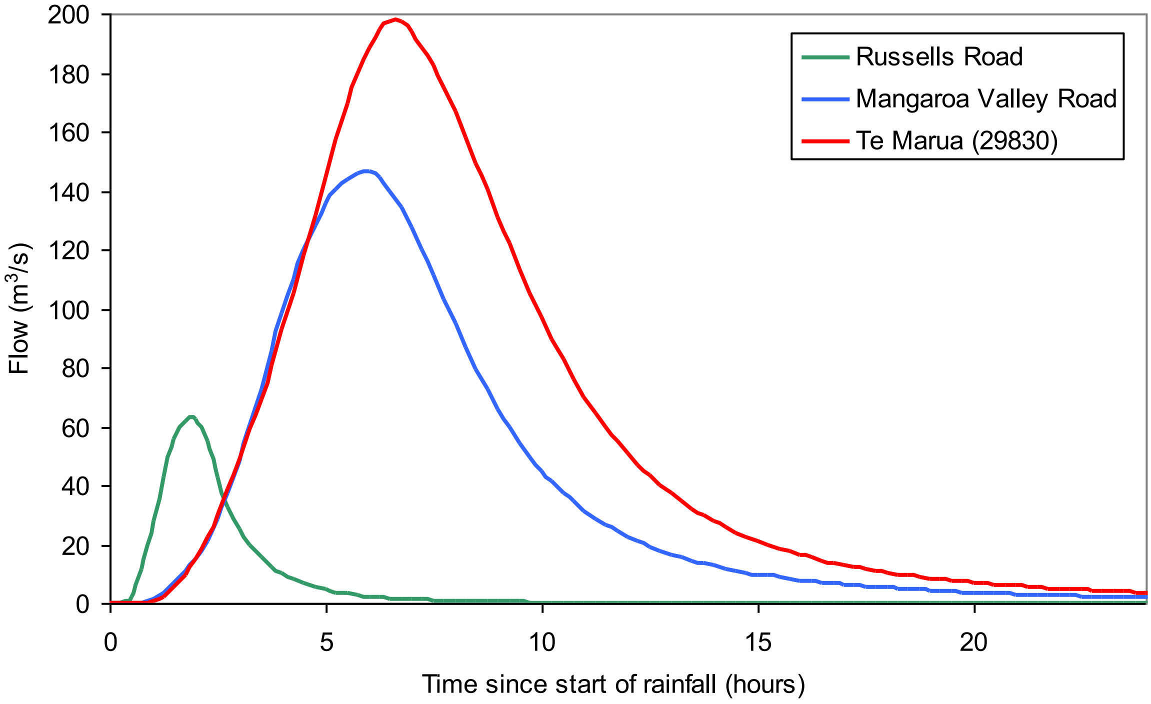


Appendix 3: Design flood hydrographs (scaled)

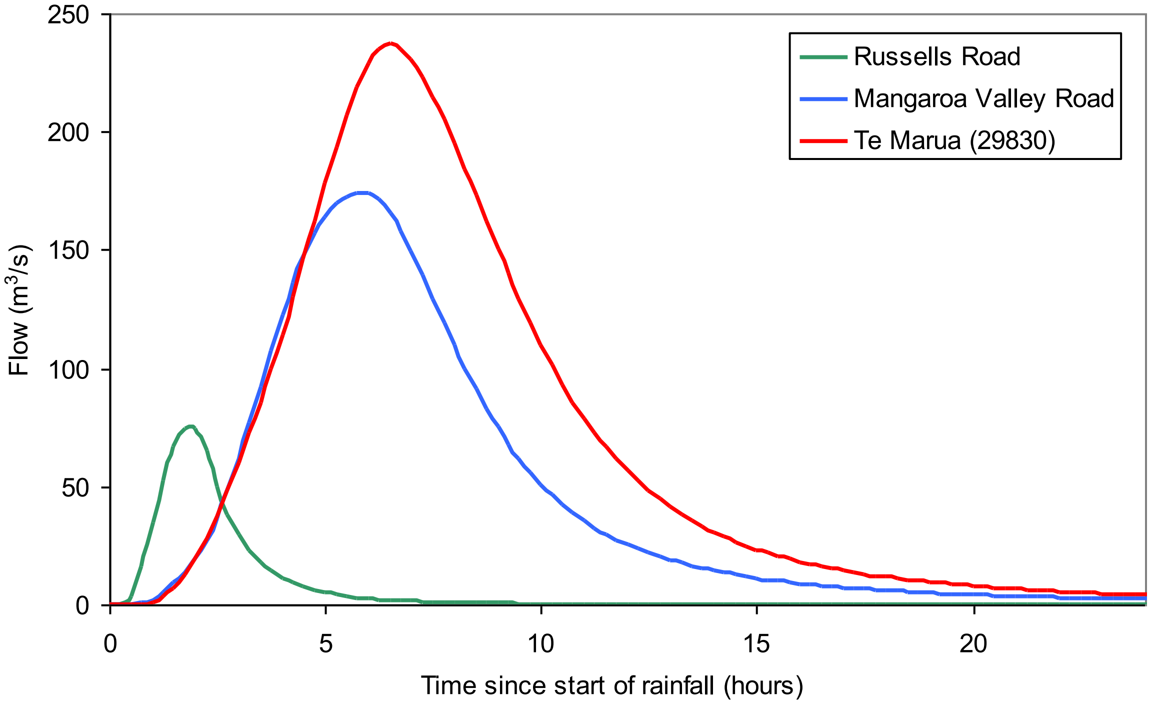
Q2 design hydrographs for the Mangaroa River



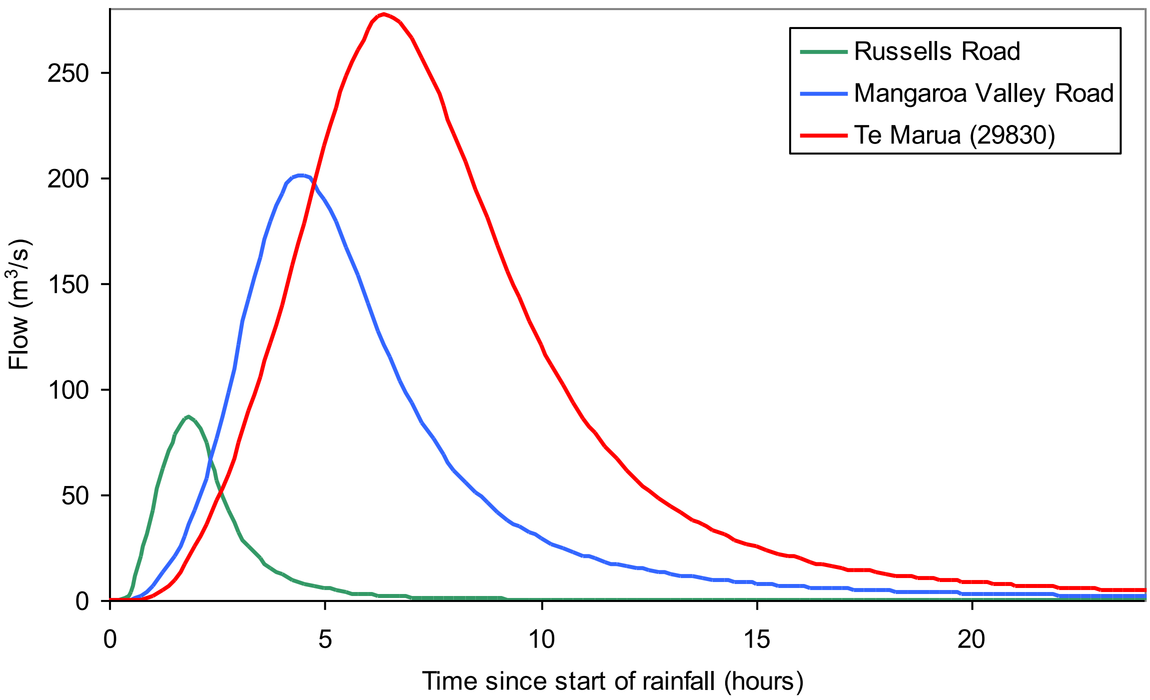
Q5 design hydrographs for the Mangaroa River



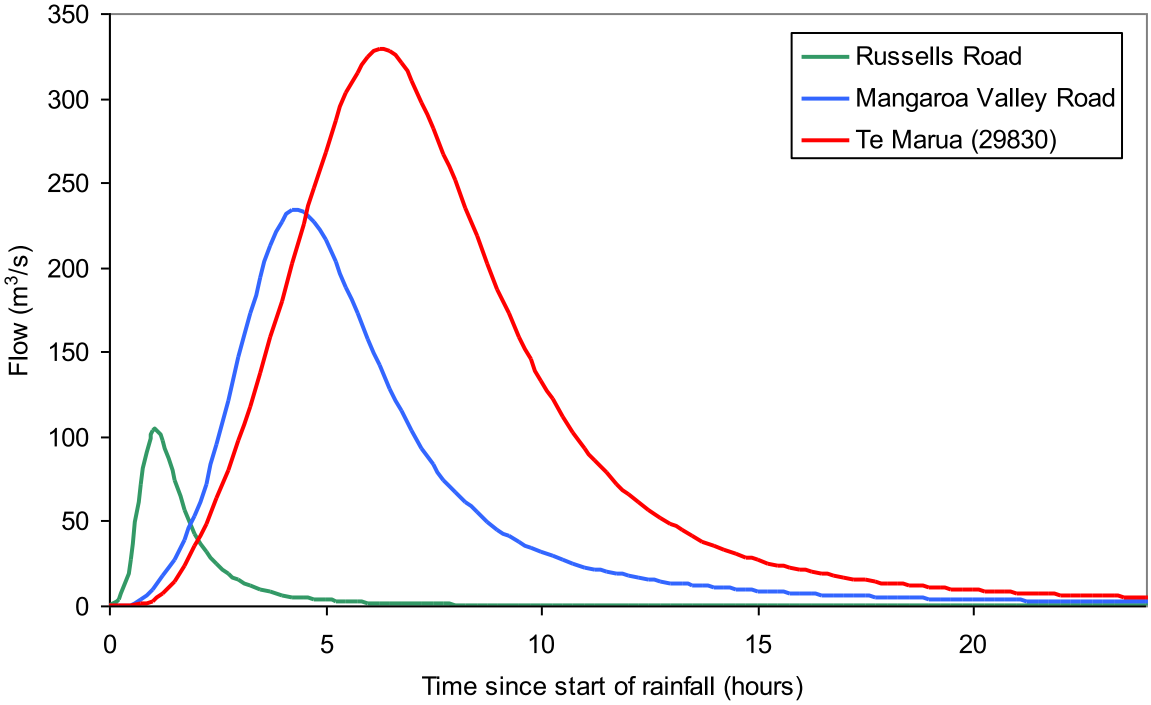
Q10 design hydrographs for the Mangaroa River



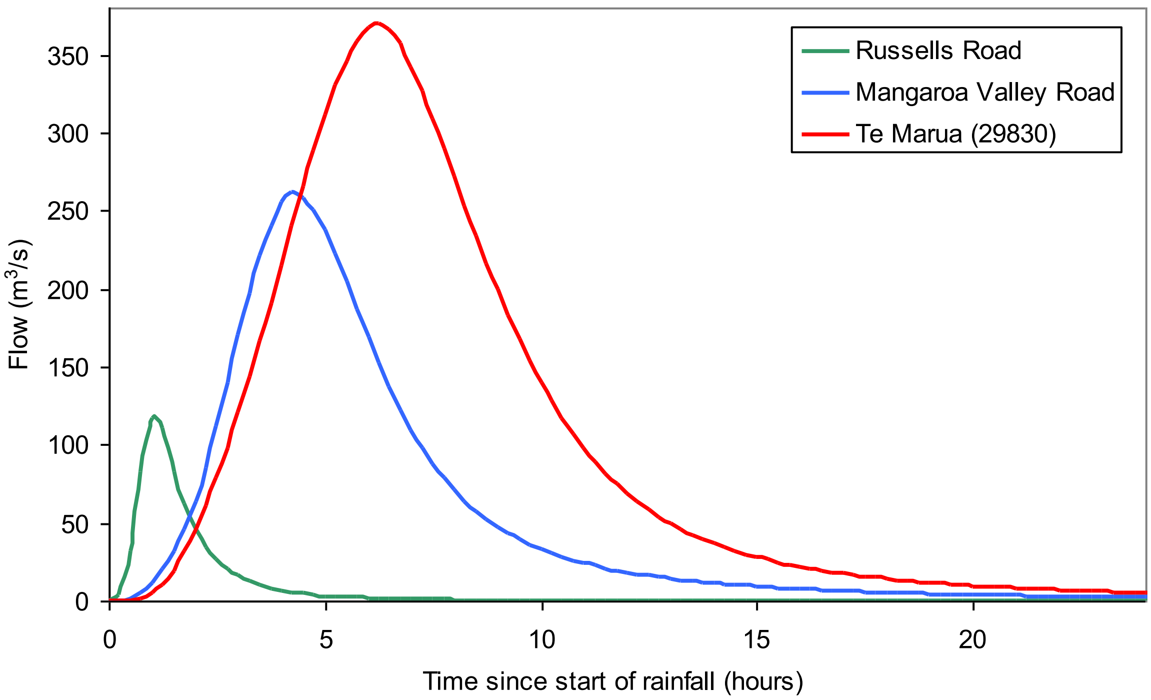
Q20 design hydrographs for the Mangaroa River



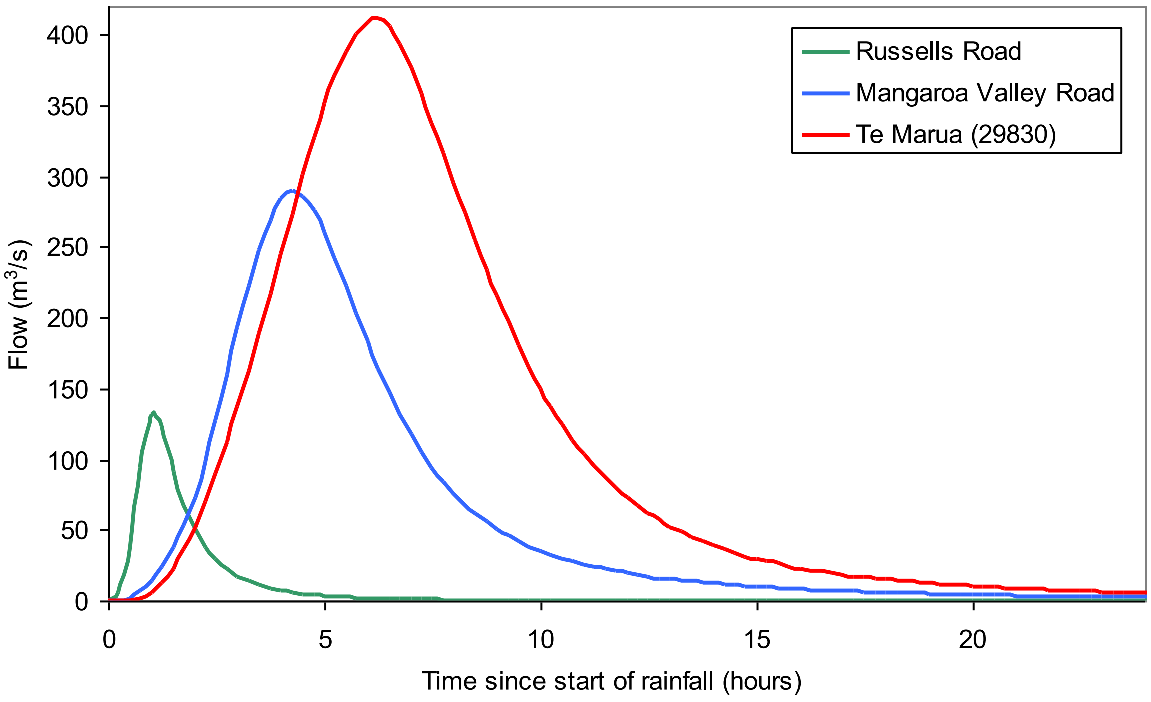
Q50 design hydrographs for the Mangaroa River



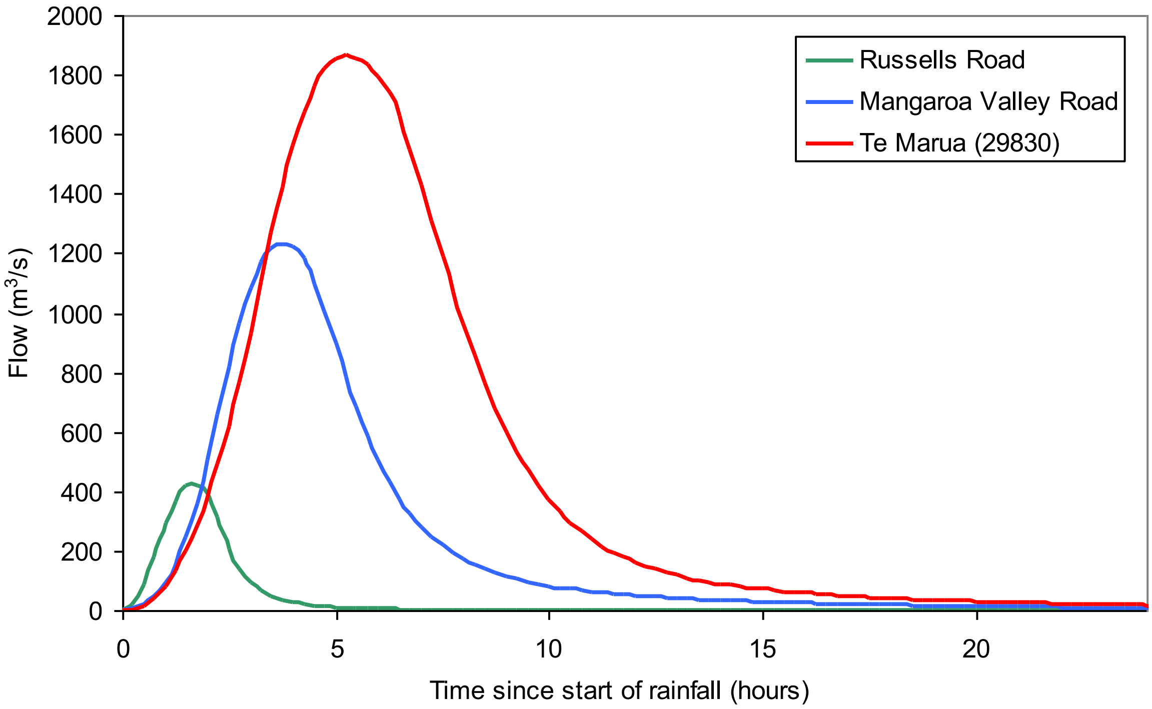
Q100 design hydrographs for the Mangaroa River



Q200 design hydrographs for the Mangaroa River

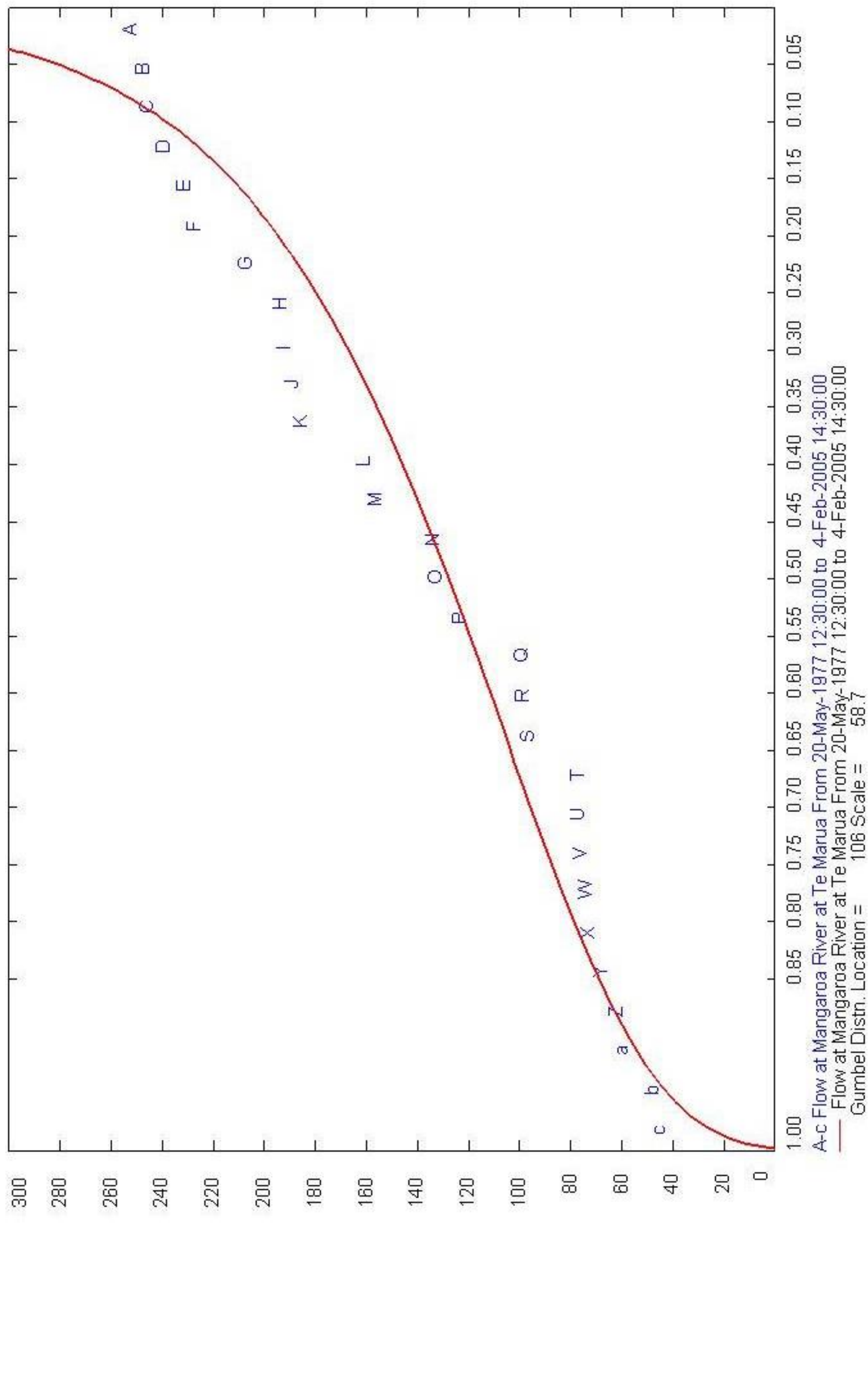


Probable maximum flood hydrographs for the Mangaroa River



Appendix 4: Annual maximum series plots

EV1 Distribution



Log Pearson type III Distribution