



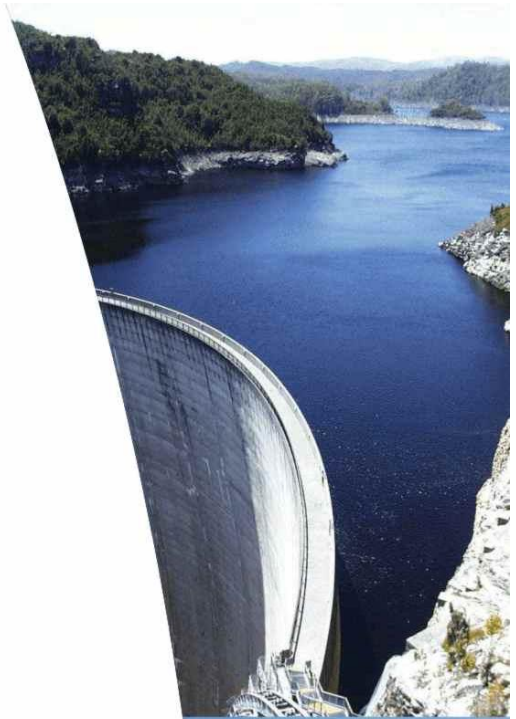
Hydro Tasmania
Consulting

Design Flood Hydrology Waiohine River Catchment

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21 May 2009

Prepared by
Hydro-Electric Corporation
ARBN: 072 377 158
ABN: 48 072 377 158
t/a **Hydro Tasmania Consulting**
89 Cambridge Park Drive, Cambridge
Tasmania, Australia





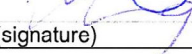
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Client contact	James Flanagan
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1. Introduction

A hydrological model was developed and calibrated for the combined Waiohine and Mangatarere River catchment. This model was used to produce design flood hydrographs at the following locations within the catchment:

- Waiohine River (191.6 km²), NZMG 2711429 East, 6015494 North
- Upper Mangatarere River (43 km²), NZMG 2723100 East, 6024378 North
- Kaipaitangata Stream (25.4 km²), NZMG 2719821.47 East, 6015300.35 North
- Lower Mangatarere River excluding Kaipaitangata and Upper Mangatarere catchment (88.6 km²), NZMG 2719915 East, 6013086 North

This document outlines the methodology, assumptions and results of the model development, calibration and production of design hydrographs. This study excludes the derivation of design rainfall depths which was undertaken by NIWA (February 2009).

Supporting information to this document includes the:

- hydrological model (Hydstra software) “Waiohine_Design_Model.tso”,
- its associated Microsoft Excel based interface “Stochastic Flood Model Interface - Waiohine.xls”, and
- a spreadsheet containing all the design flood hydrographs “Waiohine Flood Hydrographs.xls”.

2. Design Rainfalls

2.1 Design Rainfall Depths at Each Gauge Location

Design rainfalls have been supplied (NIWA, February 2009) for the following five GWRC rainfall gauges located in and surrounding the Waiohine and Mangatarere catchments:

- Waiohine River at Gorge (Phelps)
- Mangatarere River at Valley Hill
- Waingawa River at Angle Knob
- Tauherenikau at Bull Mound
- Waiohine River at Carkeek.

It has been assumed that the supplied rainfall information has been appropriately reviewed and no modifications have been made to any supplied data in this study. Table 2-1 over the page shows all the design rainfalls used in this analysis. Figure 2-1 and Figure 2-2 show the variation of the design rainfalls across the catchment for the AEP 1:100 and the PMP.

The PMP rainfall depths at each gauge location have been read from the supplied GIS grids contained in the supporting information of NIWA's High Intensity Rainfall report. No PMP rainfall depths were supplied for the 48 hour duration or for durations less than 6 hours. The 48 hour duration PMP rainfall depths have been interpolated from the 24 hour and 72 hour rainfall depths. No attempt was made to estimate the 1 hour and 2 hour PMP rainfall depths by extrapolating the 6 hour duration rainfalls.

In Figure 2-2, it can be seen that the 12 hour PMP rainfalls appear to sit outside of the slope of the PMP estimates for other durations. These values may be underestimated.

Table 2-1: Point design rainfall depths at each gauge location

Design rainfall storms for Phelps / Waiohine Gorge

	Duration (hrs)						
ARI	1	2	6	12	24	48	72
2	19	28	52	75	101	131	144
5	25	37	68	98	133	173	191
10	29	43	79	114	155	202	224
20	34	49	91	130	177	231	256
50	40	58	107	153	207	269	298
100	45	65	120	171	231	300	331
150	48	70	127	182	245	318	350
PMP			464	557	774	970	1106

Design rainfall storms for Valley Hill

	Duration (hrs)						
ARI	1	2	6	12	24	48	72
2	21	33	63	88	119	157	172
5	27	43	81	115	156	207	228
10	32	50	95	134	182	242	266
20	37	58	109	153	207	276	303
50	44	68	128	179	243	322	353
100	49	77	143	200	270	357	390
150	53	82	153	213	287	379	413
PMP			527	632	878	1110	1256

Design rainfall storms for Angle Knob

	Duration (hrs)						
ARI	1	2	6	12	24	48	72
2	31	53	111	169	240	317	349
5	41	69	144	220	313	416	460
10	48	80	168	255	364	484	536
20	55	92	192	292	415	551	609
50	65	109	225	341	485	641	707
100	74	123	252	381	539	711	782
150	79	131	269	405	572	753	826
PMP			653	783	1088	1370	1556

Design rainfall storms for Bull Mound

	Duration (hrs)						
ARI	1	2	6	12	24	48	72
2	26	44	87	130	184	229	263
5	33	57	112	169	240	301	348
10	39	67	131	197	279	352	407
20	45	77	150	225	319	402	465
50	53	91	176	264	374	469	542
100	60	102	198	295	417	522	602
150	65	109	211	314	443	554	638
PMP			548	658	914	1160	1307

Design rainfall storms for Carkeek

	Duration (hrs)						
ARI	1	2	6	12	24	48	72
2	26	44	93	142	206	268	304
5	34	57	120	185	269	351	400
10	40	66	139	215	312	409	465
20	46	76	159	245	356	465	528
50	55	90	187	287	415	541	612
100	62	101	209	319	461	600	676
150	66	108	223	339	489	635	714
PMP			635	762	1058	1320	1513

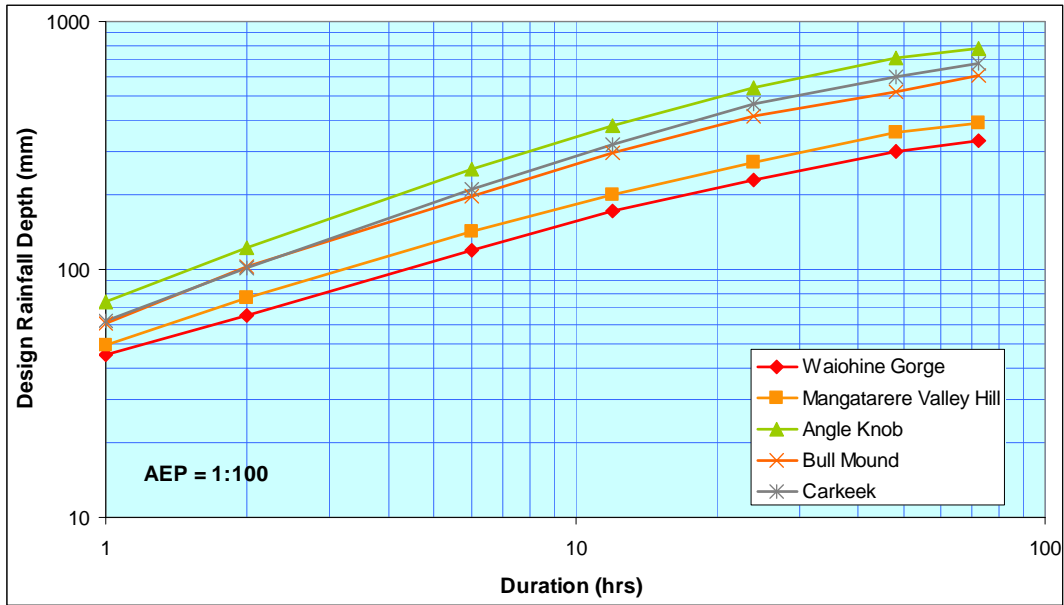


Figure 2-1: Variation of design rainfalls across the catchment. AEP 1:100

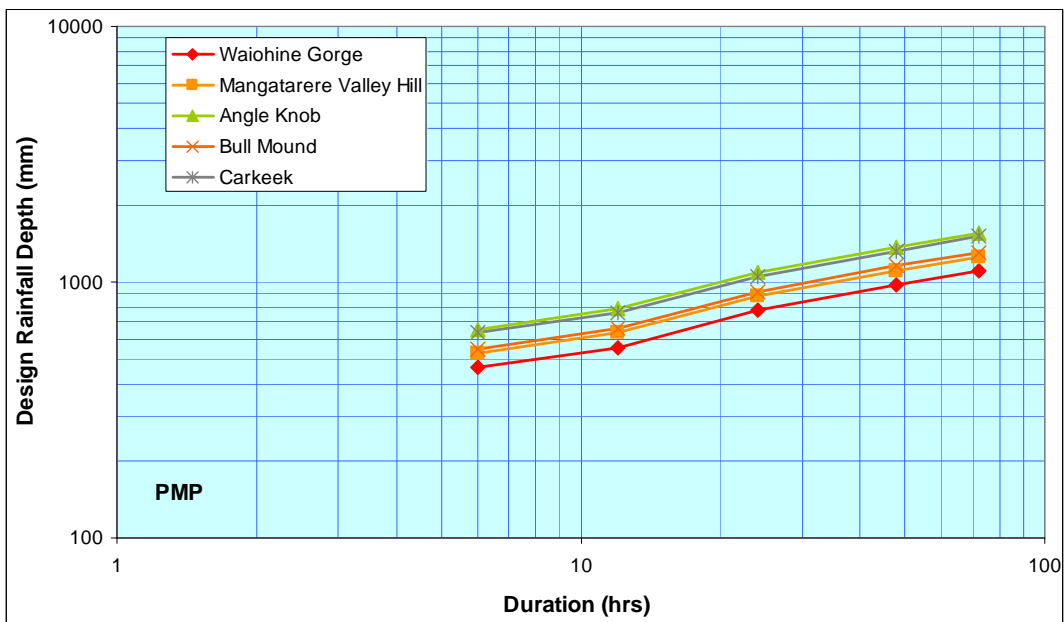


Figure 2-2: Variation of design rainfalls across the catchment. PMP

2.2 Spatial Rainfall Distribution

During calibration and the production of design hydrographs, the rainfalls at the five gauge locations have been distributed over the model sub-catchments. Thiessen Polygons have been applied to distribute the rainfalls. Figure 2-3 shows the influence of each rainfall gauge over the catchment. The rain gauge weighting to each model sub-catchment is shown in Table 3-1 in Section 3.

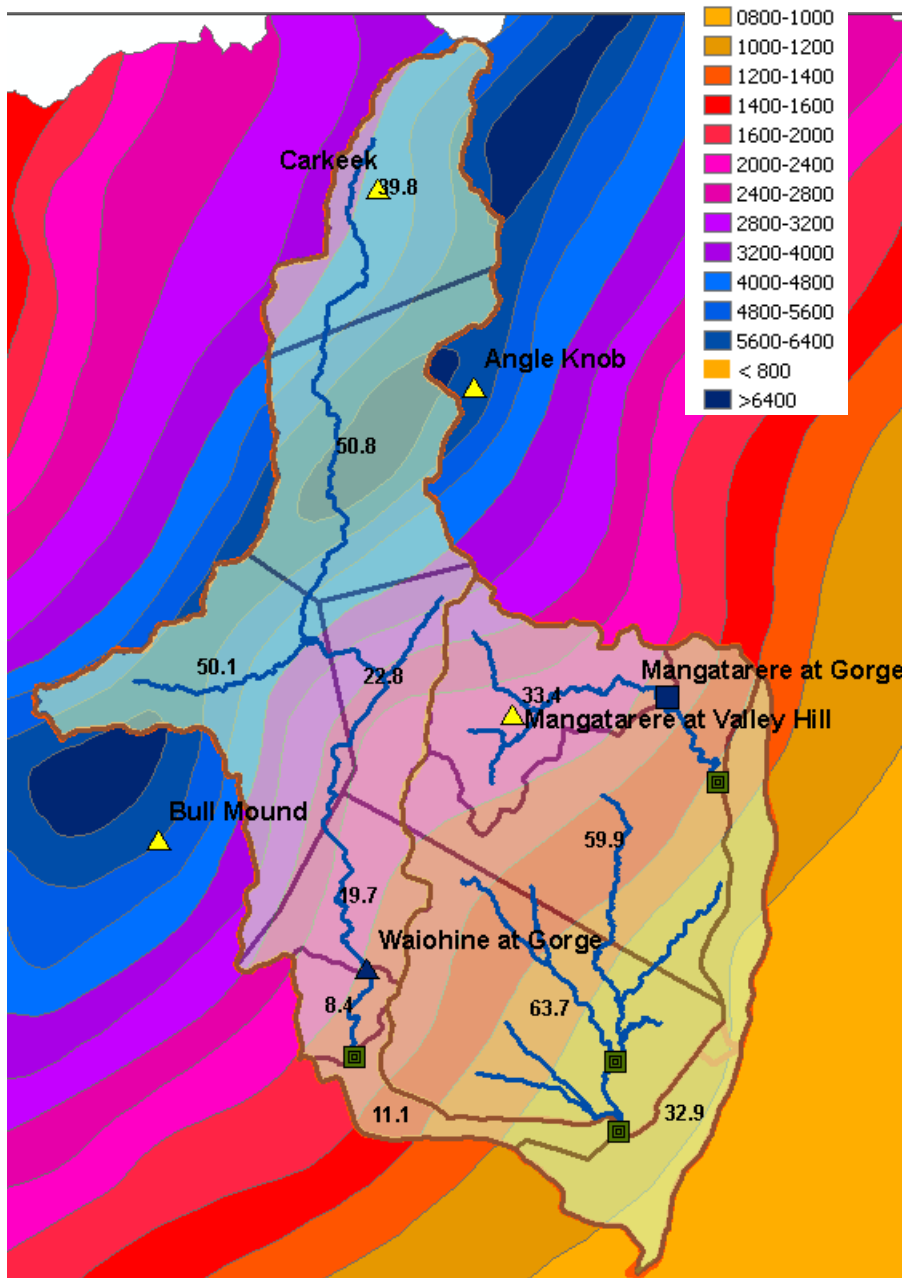


Figure 2-3: Spatial rainfall distribution. Numbers show the catchment areas influenced by each rainfall gauge. Background shows the mean annual rainfall isohyets for the catchment.

2.3 Areal Reduction Factors

Areal reduction factors must be applied to the supplied point rainfall estimates to convert them to catchment rainfalls. These factors vary depending on the size of the catchment and the duration of the rainfall.

Factors have been derived using the recommended methodology for South Eastern Australia (Australian Rainfall and Runoff, Siriwarden & Weinmann 1996). This methodology was adopted because no areal reduction factors were supplied. It is assumed that the areal reduction factors of South Eastern Australia should be applicable in North Island New Zealand catchments.

Areal reduction factors (shown in Table 2-2) have been derived for three catchments:

- The Waiohine River at Gorge and Mangatarere River at Gorge catchments where the design rainfalls are used to calibrate the model's loss parameters against the measured flow records at these sites (as documented in Section 4.3).
- The total Waiohine/Mangatarere catchment for the production of the design flood hydrographs.

These areal reduction factors are applied to the point design rainfalls before they are input to the rainfall/runoff model.

Table 2-2: Adopted areal reduction factors

Waiohine at Gorge (183 km²)

AEP	Duration (hrs)						
	1	2	6	12	24	48	72
1:2	0.76	0.79	0.83	0.86	0.93	0.95	0.96
1:5	0.76	0.79	0.83	0.86	0.93	0.94	0.95
1:10	0.76	0.79	0.83	0.86	0.93	0.94	0.95
1:20	0.76	0.79	0.83	0.86	0.92	0.94	0.94
1:50	0.76	0.79	0.83	0.86	0.92	0.93	0.94
1:100	0.76	0.79	0.83	0.86	0.92	0.93	0.93
1:150	0.76	0.79	0.83	0.86	0.91	0.92	0.93

Mangatarere at Gorge (33.5 km²)

AEP	Duration (hrs)						
	1	2	6	12	24	48	72
1:2	0.84	0.86	0.89	0.91	0.97	0.98	0.99
1:5	0.84	0.86	0.89	0.91	0.96	0.98	0.98
1:10	0.84	0.86	0.89	0.91	0.96	0.98	0.98
1:20	0.84	0.86	0.89	0.91	0.96	0.97	0.98
1:50	0.84	0.86	0.89	0.91	0.96	0.97	0.97
1:100	0.84	0.86	0.89	0.91	0.95	0.97	0.97
1:150	0.84	0.86	0.89	0.91	0.95	0.96	0.97

Total Waiohine Catchment (350 km²)

AEP	Duration (hrs)						
	1	2	6	12	24	48	72
1:2	0.72	0.75	0.81	0.84	0.92	0.94	0.95
1:5	0.72	0.75	0.81	0.84	0.91	0.94	0.95
1:10	0.72	0.75	0.81	0.84	0.91	0.93	0.94
1:20	0.72	0.75	0.81	0.84	0.91	0.93	0.94
1:50	0.72	0.75	0.81	0.84	0.90	0.92	0.93
1:100	0.72	0.75	0.81	0.84	0.90	0.92	0.92
1:150	0.72	0.75	0.81	0.84	0.89	0.91	0.92

Catchment average PMP rainfall depths have been supplied for the Waiohine and Mangatarere catchments and it is assumed that areal reduction factors have already been applied to these depths. To maintain the set up of the model, which inputs design rainfalls at the five rainfall gauges and then distributes them over the catchment, a relationship was sought between the point PMP estimates (extracted from the GIS grids) and the supplied catchment average PMP depths. To do this, catchment average rainfalls were derived from the point rainfalls using the Thiessen Polygons weightings and compared to the supplied catchment rainfall depths.

Table 2-3 shows that for the Waiohine catchment, the point rainfalls need to be factored by 0.8 to replicate the catchment average PMP depths. For the Mangatarere catchment this factor is 0.61. It is not understood why the factors differ significantly for each catchment. These factors were applied to the point PMP rainfall inputs to the model.

Table 2-3: Areal reduction factors for PMP rainfalls

Point PMP Rainfall Depth (mm)	Duration (hrs)				
	6	12	24	48	72
Waiohine Gorge	464	557	774	970	1106
Valley Hill	527	632	878	1110	1256
Angle Knob	653	783	1088	1370	1556
Bull Mound	548	658	914	1160	1307
Carkeek	635	762	1058	1320	1513
Waiohine River Catchment Average Rainfall					
Theisson Polygons	585	702	975	1227	1394
From NIWA Study	468	562	780		1115
Factor	0.8	0.8	0.8		0.8
Mangatarere River Catchment Average Rainfall					
Theisson Polygons	502	602	836	1054	1196
From NIWA Study	306	367	510		729
Factor	0.61	0.61	0.61		0.61

2.4 Temporal Patterns

Temporal patterns were supplied for the PMP rainfalls for durations of 12 hours and greater. The 6 hour duration PMP temporal pattern has been derived from the 12 hour pattern by halving the time period between each value. This is assumed to be appropriate as the PMP patterns exhibit a reasonably uniform distribution.

For all other AEPs sets of 30 temporal patterns were derived for each duration using the measured rainfall data. During the design flood modeling, a Monte Carlo approach is used to sample from the set of 30 temporal patterns and a series of model replicates is run to produce a distribution of results. The latest update of the hydrological flood modelling software RORB (Nathan, R) contains a feature that automatically derives these temporal patterns from an input rainfall dataset. The following method was applied:

- A catchment average rainfall dataset was derived for the Waiohine River at Gorge catchment based on the Theisson Weightings shown in Figure 2-3.
- The top 30 rainfall events were selected for each duration and the temporal patterns were derived from these events.
- The patterns were filtered to remove any embedded shorter duration rainfall events.

All the temporal patterns are plotted in Appendix B.

3. Catchment Model Details

A rainfall runoff model has been developed using Hydstra Modelling software. An Initial Loss / Continuing Loss (IL/CL) model was used to estimate the rainfall losses and non-linear channel routing was applied to each river length between each modelled sub-catchment. A separate set of routing and loss parameters has been derived for the Waiohine and Mangatarere catchments. Figures 3-1 to 3-3 and Table 3-1 show the model details including the sub catchments, reach lengths and the Hydstra model schematic.

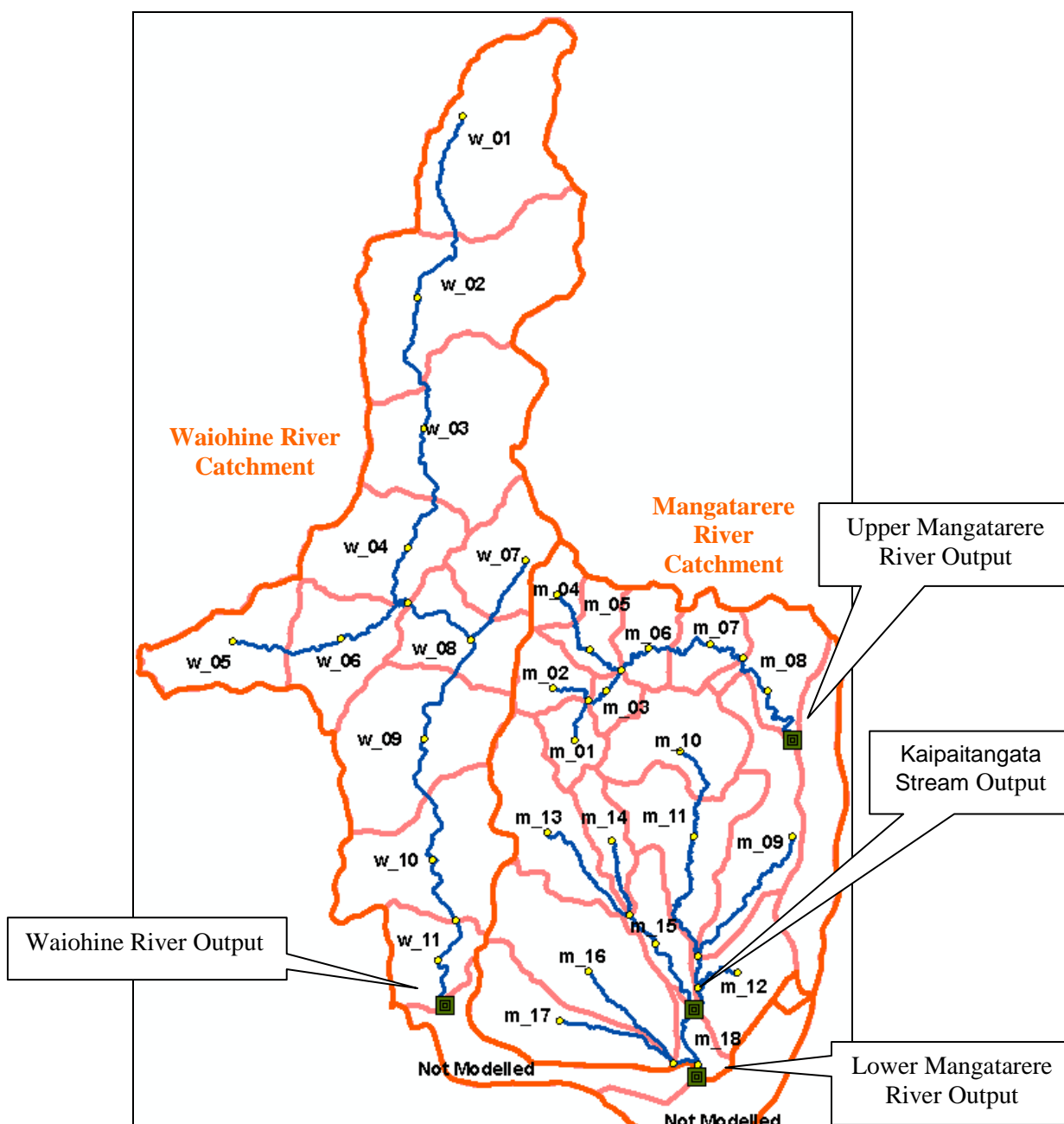


Figure 3-1: Catchment de-lineation showing the sub-catchment IDs. The squares show the locations of the output hydrographs.

Table 3-1: Model sub catchment details

Sub Area ID	Area (km²)	Rain Gauge Distribution
Upper Mangatarere Catchment		
m_01	4.5	Mangatarere Gorge
m_02	5.1	Mangatarere Gorge
m_03	2.6	Mangatarere Gorge
m_04	4.0	Mangatarere Gorge
m_05	5.1	Mangatarere Gorge
m_06	6.0	Mangatarere Gorge
m_07	6.1	Mangatarere Gorge
m_08	9.7	Mangatarere Gorge
Lower Mangatarere Catchment		
m_09	14.4	Mangatarere Gorge
m_10	12.6	Mangatarere Gorge
m_11	14.8	Mangatarere Gorge
m_12	10.3	Waiohine Gorge
m_13	14.4	0.5 x Mangatarere Gorge + 0.5 x Waiohine Gorge
m_14	4.8	0.5 x Mangatarere Gorge + 0.5 x Waiohine Gorge
m_15	6.2	Waiohine Gorge
m_16	19.8	Waiohine Gorge
m_17	13.6	Waiohine Gorge
m_18	3.0	Waiohine Gorge
Waiohine Catchment		
w_01	25.1	Carkeek
w_02	29.9	0.5 x Carkeek + 0.5 x Angle Knob
w_03	25.2	Angle Knob
w_04	14.9	0.5 x Angle Knob + 0.5 x Bull Mound
w_05	12.2	Bull Mound
w_06	12.0	Bull Mound
w_07	10.0	0.3 x Bull Mound + 0.7 x Mangatarere Gorge
w_08	11.3	0.15 x Bull Mound + 0.85 x Mangatarere Gorge
w_09	22.3	0.8 x Bull Mound + 0.2 x Mangatarere Gorge
w_10	20.2	Waiohine Gorge
w_11	8.4	Waiohine Gorge

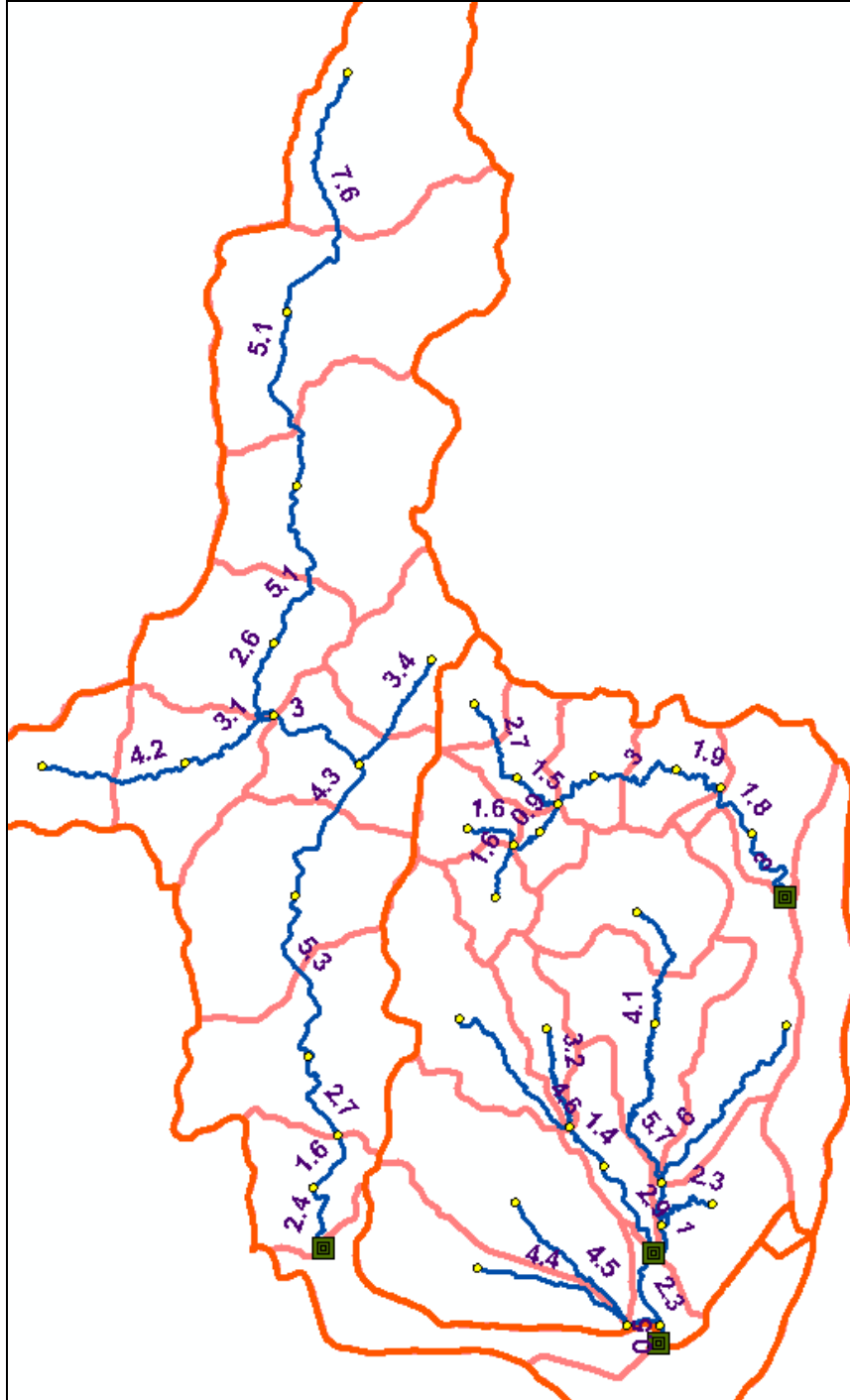


Figure 3-2: Model reach lengths

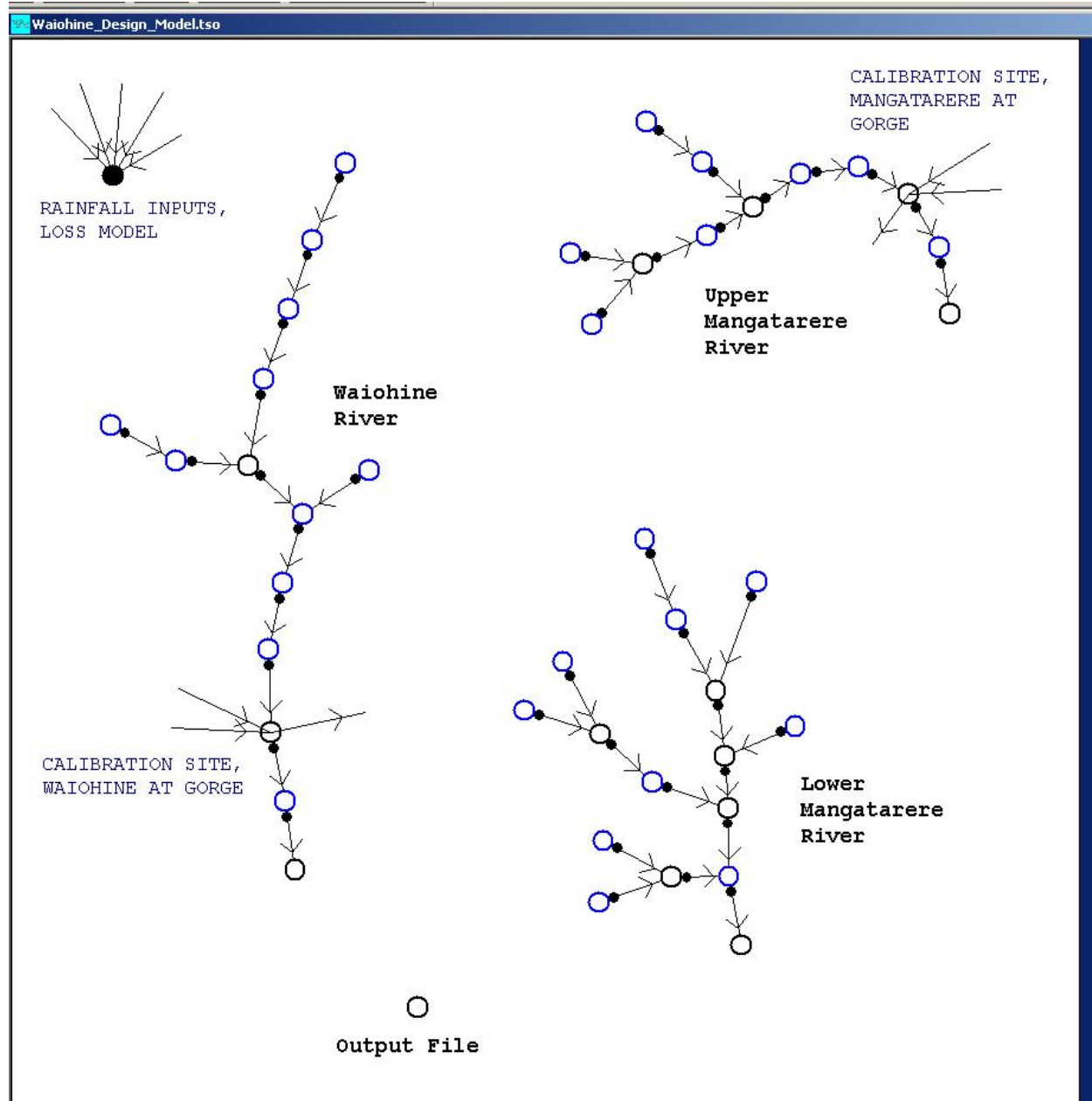


Figure 3-3: Hydstra model schematic

The model has been set up to output a hydrograph for the whole Lower Mangatarere catchment. This hydrograph was catchment area scaled to derive the hydrographs for the Kaipaitangata Stream and the remainder of the Lower Mangatarere catchment.

To undertake the multiple model runs required to produce results for all AEPs and durations, an interface was developed in Microsoft Excel. The interface feeds the input data into the model, runs the model and reads back the results.

4. Calibration

4.1 Baseflow Estimation

Baseflow has been separated from the measured event flows at Waiohine River at Gorge and Mangatarere River at Gorge. A numerical filtering approach outlined in the “Hydrological Recipes” guidelines (Grayson R et al) has been applied. The adopted event baseflows are included in the calibration event plots in Appendix A.

For the design runs a constant baseflow has been applied at each output location based on the average baseflow of the selected events for calibration. The adopted baseflow remains constant for all durations and AEPs considered. The following magnitudes of baseflow have been adopted at each output location:

- Waiohine River – 50 m³/s
- Upper Mangatarere – 5 m³/s
- Lower Mangatarere – 15 m³/s (3.35 m³/s for the Kaipaitangata, and 11.65 m³/s for the remainder of the lower Mangatarere).

4.2 Calibration of Routing Parameters

The channel routing parameters have been calibrated using the following methodology:

- The ten largest events were selected at each flow site. Events were selected at Waiohine River at Gorge back to 1988 to ensure that measured rainfalls are available from the majority of the gauges. Nine events were selected at Mangatarere River at Gorge due to the shortened length of record (and therefore reduced number of significant events).
- Measured rainfalls are input to the model. For the time period where Valley Hill rainfalls are not available, Waiohine River at Phelps has been used as a substitute.
- A single set of routing parameters has been adopted at in each catchment to obtain the best fit over all calibration events.
- The IL and CL are allowed to vary for each event.

Table 4-1 lists the event details, and adopted loss parameters for each catchment. It can be seen in this table that a time lag (delay) needed to be applied in addition to the channel routing to achieve the correct timing while not over-attenuating the event hydrograph. On average the flows at Waiohine at

Gorge (1 hour 10 mins) were delayed by an additional ten minutes compared to the flows at Mangatarere at Gorge (1 hour). So a delay of 10 minutes has been applied to the design hydrographs in the Waiohine River.

The calibration event comparison plots are displayed in Appendix A.

The adopted routing parameters are:

Waiohine Catchment: Alpha = 0.5 n = 0.7

Mangatarere Catchment : Alpha = 1.4 n = 0.7

Table 4-1: Calibration event details and results

Waiohine River at Gorge						
Event #	Flow Peak (m³/s)	Start	Finish	IL (mm)	CL (mm/hr)	DELAY
1	1400	17/01/1990 @ 06:00:00	19/01/1990 @ 00:00:00	20	2.5	2hrs 50mins
2	1350	12/03/1990 @ 00:00:00	15/03/1990 @ 00:00:00	5	0	1hr
3	1200	07/11/1994 @ 18:00:00	10/11/1994 @ 00:00:00	25	0	1hr 30mins
4	1130	21/11/1994 @ 12:00:00	24/11/1994 @ 00:00:00	30	0.5	1hr
5	1100	05/09/1998 @ 18:00:00	07/09/1998 @ 18:00:00	15	0	1hr 10mins
6	1050	27/10/1998 @ 12:00:00	29/10/1998 @ 18:00:00	90	1.2	1hr 10mins
7	1040	01/10/2000 @ 18:00:00	03/10/2000 @ 12:00:00	1	3.7	1hr 20mins
8	1000	06/11/1988 @ 00:00:00	07/11/1988 @ 00:00:00	40	4	1hr 40mins
9	1000	12/09/1988 @ 12:00:00	16/09/1988 @ 00:00:00	80	0	1hr 40mins
10	1000	11/02/2004 @ 06:00:00	13/02/2004 @ 00:00:00	20	2	1hr 10mins
Mangatarere River at Gorge						
Event #	Flow Peak (m³/s)	Start	Finish	IL (mm)	CL (mm/hr)	DELAY
1	105	02/10/2000 @ 00:00:00	04/10/2000 @ 00:00:00	0	5	0
2	100	09/10/2000 @ 00:00:00	10/10/2000 @ 12:00:00	10	7	1hr
3	100	09/06/2003 @ 12:00:00	12/06/2003 @ 00:00:00	10	3	30 mins
4	80	10/02/2004 @ 06:00:00	14/02/2004 @ 00:00:00	10	3.7	1hr
5	80	15/02/2004 @ 06:00:00	18/02/2004 @ 00:00:00	10	1.8	1hr 30mins
6	80	15/10/2004 @ 12:00:00	18/10/2004 @ 00:00:00	20	4.4	1hr 30mins
7	80	29/03/2005 @ 18:00:00	02/04/2005 @ 00:00:00	50	2	1hr
8	68	26/11/2006 @ 00:00:00	29/11/2006 @ 00:00:00	10	7.5	1hr 30mins
9	58	27/09/2004 @ 12:00:00	01/10/2004 @ 00:00:00	18	3.5	1hr

4.3 Calibration of Loss Parameters

To obtain the design loss parameters:

- The catchment model was run with design rainfall inputs and temporal patterns. Areal reduction factors were applied to the design rainfall depths based on the catchment areas above each gauge (documented in Section 2.3). 150 model replicates were run for each AEP and duration using Monte Carlo sampling of the 30 temporal patterns and the 50%ile of the distribution of results was selected.
- The channel routing parameters adopted from the event calibration (Section 4.2 above) were used.
- The modelled peak flows were compared to the measured flood frequency values at each gauge location. The losses were adjusted to obtain a best fit for AEP 1:5 to 1:100.

Figure 4-1 and Figure 4-2 show the flood frequency curves for the Waiohine and Mangatarere River sites including the fit of the modelled results. To achieve a good fit over all probabilities two sets of loss parameters were adopted at each site. For the more common floods, the losses had to be significantly reduced and in the Waiohine River catchment the losses were reduced to zero.

The adopted loss parameters are:

Waiohine Catchment (AEP 1:2 – 1:10):	IL = 0mm	CL = 0mm/hr
Waiohine Catchment (AEP 1:20 – 1:150):	IL = 25mm	CL = 0.5mm/hr
Mangatarere Catchment (AEP 1:2 – 1:10):	IL = 10mm	CL = 2.5mm/hr
Mangatarere Catchment (AEP 1:20 – 1:150):	IL = 30mm	CL = 3.2mm/hr

For the PMF, zero initial and continuing losses have been adopted for both catchments.

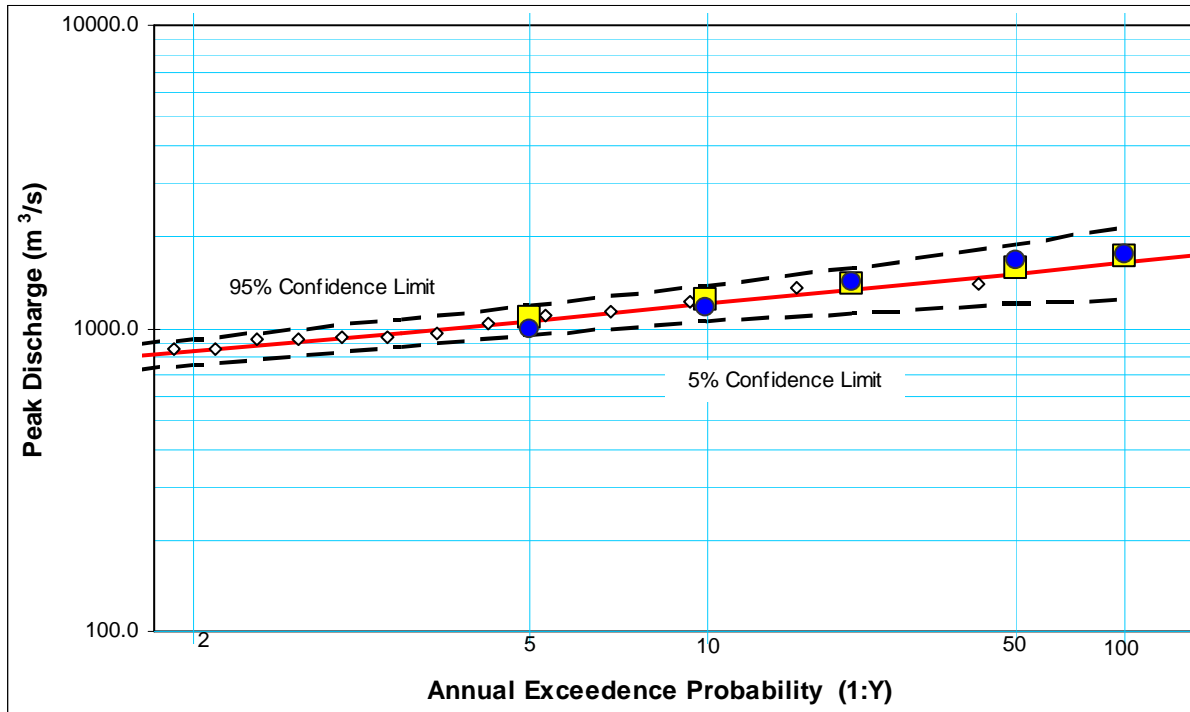


Figure 4-1: Waiohine River at Gorge flood frequency curve. Yellow squares represent supplied flood frequency values, blue circles are modelled flows.

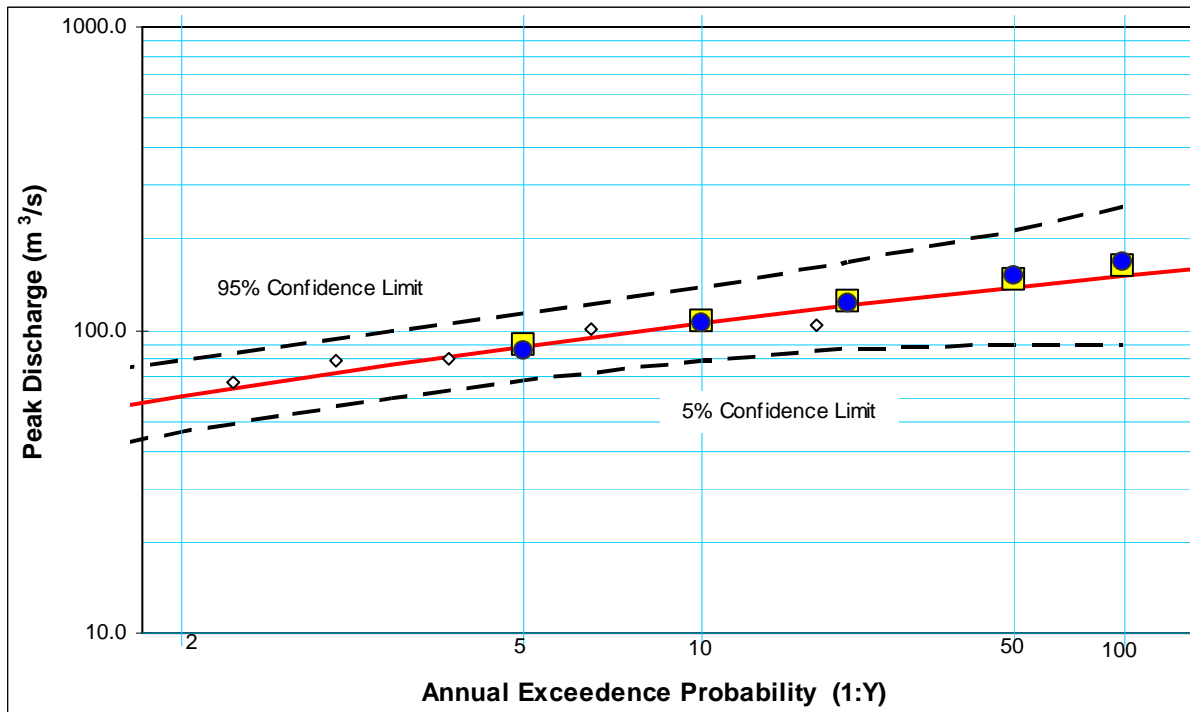


Figure 4-2: Mangatarere River at Gorge flood frequency curve. Yellow squares represent supplied flood frequency values, blue circles are modelled flows.

5. Design Flood Results

Design flood hydrographs have been produced at the following output locations:

- Waiohine River, NZMG 2711429 East, 6015494 North
- Upper Mangatarere River, NZMG 2723100 East, 6024378 North
- Kaipaitangata Stream, NZMG 2719821.47 East, 6015300.35 North
- Lower Mangatarere River (excluding Kaipaitangata and Upper Mangatarere catchment), NZMG 2719915 East, 6013086 North

The Lower Mangatarere River has been modeled as a single catchment and the Kaipaitangata Stream and Lower Mangatarere River (excluding Kaipaitangata) hydrographs have been produced by catchment area scaling the total Lower Mangatarere catchment.

Note that when producing the design hydrographs, areal reduction factors have been applied based on the whole Waiohine / Mangatarere River catchment area of 350 km² (refer to Section 2.3 for more details).

A critical duration analysis was undertaken at the output location on the Waiohine River as this location produces the majority of the flow in the catchment. Figure 5-1 shows that the 12 hour duration is critical for all AEP. At the PMP the critical duration reduces to 6 hours, however no shorter durations were analysed. As discussed in Section 2.1, the 12 hour PMP rainfall estimate may also be underestimated.

Table 5-1 shows the distribution of results at the Waiohine River output location as a result of using the 30 temporal patterns for each duration. As for the loss calibration, 150 replicate model runs were performed for each AEP and duration using a Monte Carlo sampling approach to randomly select from the set of 30 temporal patterns. The 50 percentile value is adopted from the distribution of results to preserve the probability of each event which assumes that there is an even likelihood of any of the 30 temporal patterns occurring during an extreme flood event. Note that at the PMP, the supplied temporal patterns were used.

Two hydrographs have been produced at the critical duration for each AEP, by selecting the two temporal patterns that result in a modelled peak flow that is similar to the 50 percentile value. This was because numerous temporal patterns would produce the same peak flow and by selecting two

temporal patterns a choice of hydrograph shapes can be made. The hydrographs are plotted in Appendix C.

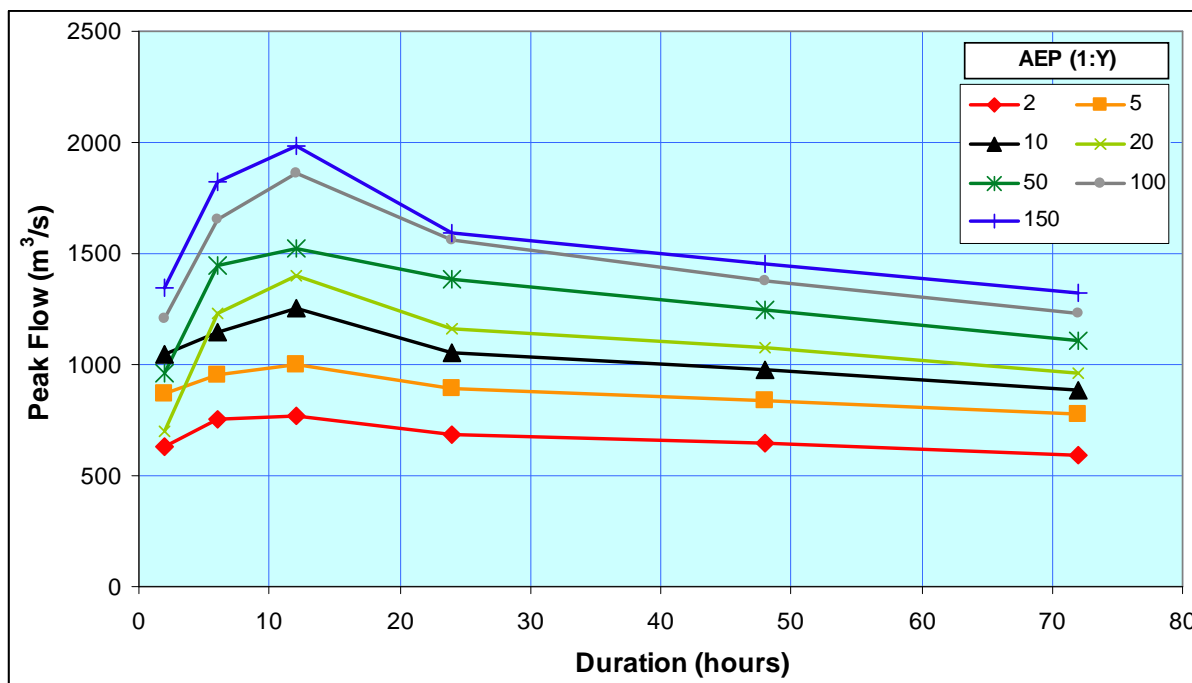


Figure 5-1: Critical duration analysis plot at the Waiohine River output location

Table 5-1: Modelled peak flows at the Waiohine River output location. 5% and 95% results show the range of peak modelled flows depending on the temporal pattern used.

AEP (1:Y)	5%	50%	95%
2	601	769	1006
5	768	997	1333
10	909	1255	1747
20	1007	1397	1880
50	1149	1523	2088
100	1283	1862	2303
150	1364	1982	2559
PMF		5868	

6. REFERENCES

NIWA, Thompson C. et al., “High Intensity Rainfall and Potential Impacts of Climate Change in the Waiohine Catchment”, GWRC (GW09301), February 2009.

Siriwardena, L. and Weinmann, P.E., 1996, “Derivation of areal reduction factors for design rainfalls in Victoria for rainfall durations 18-120 hours”. Report 96/4, CRC for Catchment Hydrology Working Document

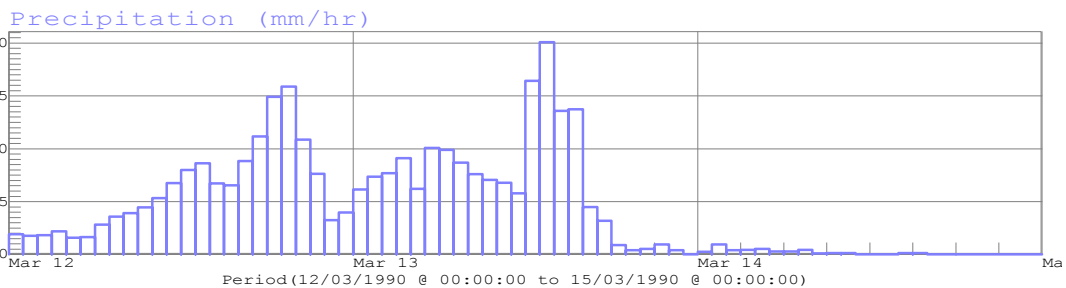
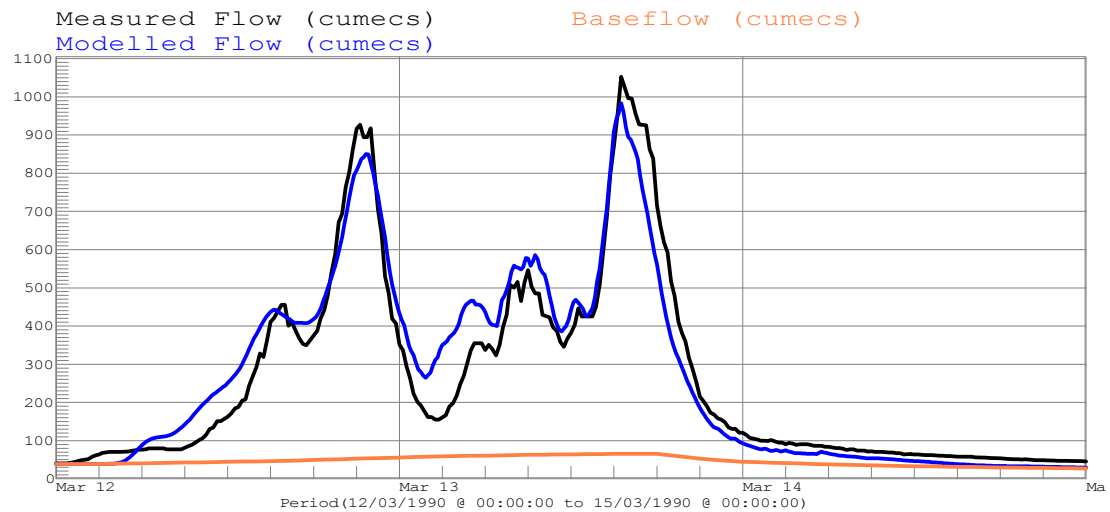
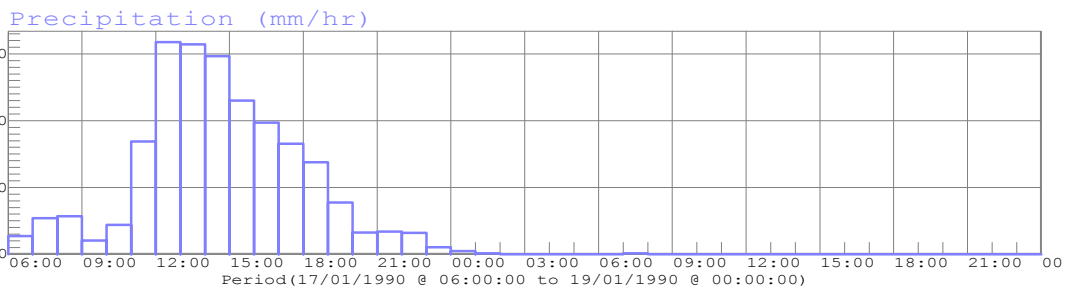
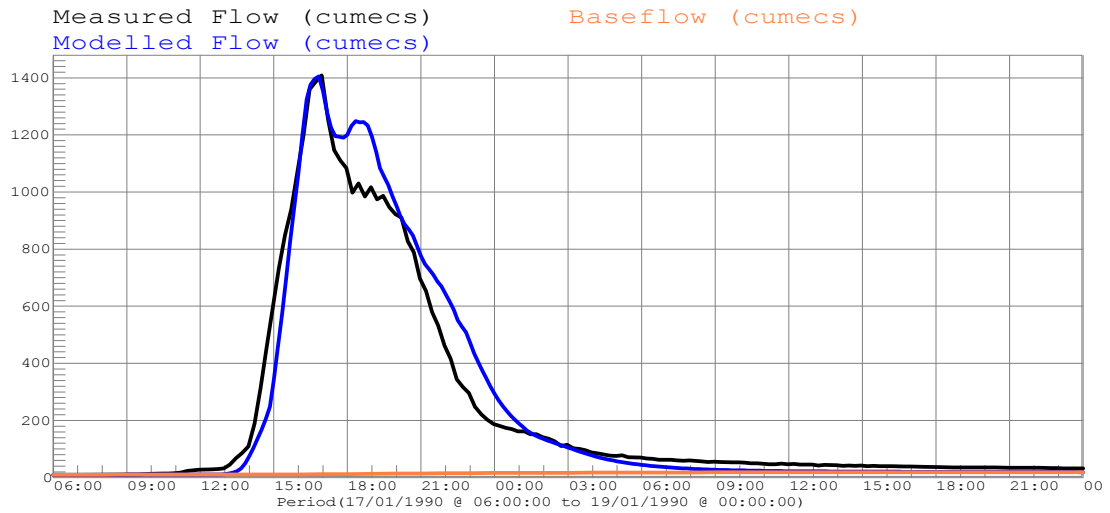
Grayson, R.B., Argent, R.M., Nathan, R.J., McMahon, T.A. and Mein, 1996, “Hydrological Recipes: Estimation Techniques in Australian Hydrology”, Cooperative Research Centre for Catchment Hydrology, Australia

Engineers Australia, 1988 – 1998, “Australian Rainfall and Runoff”, Australia

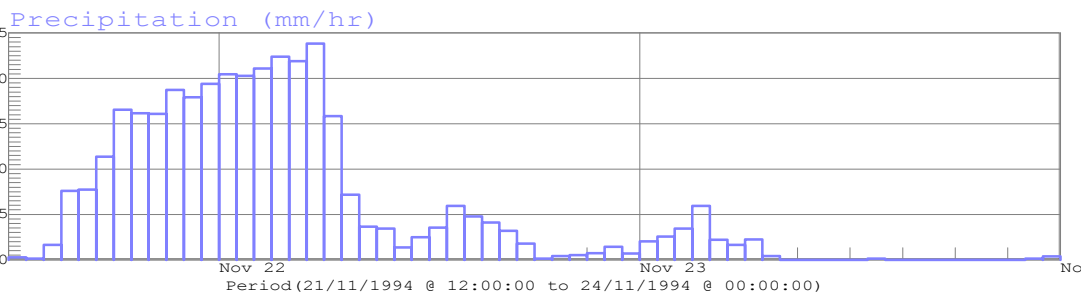
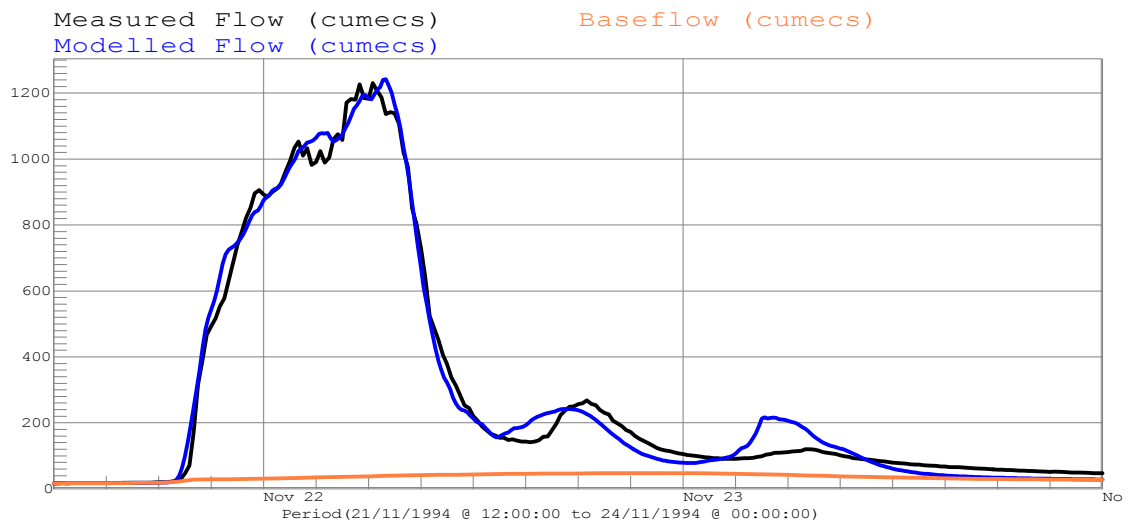
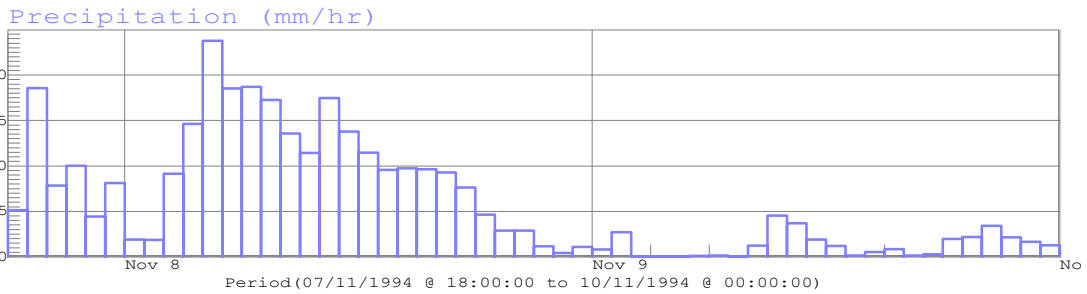
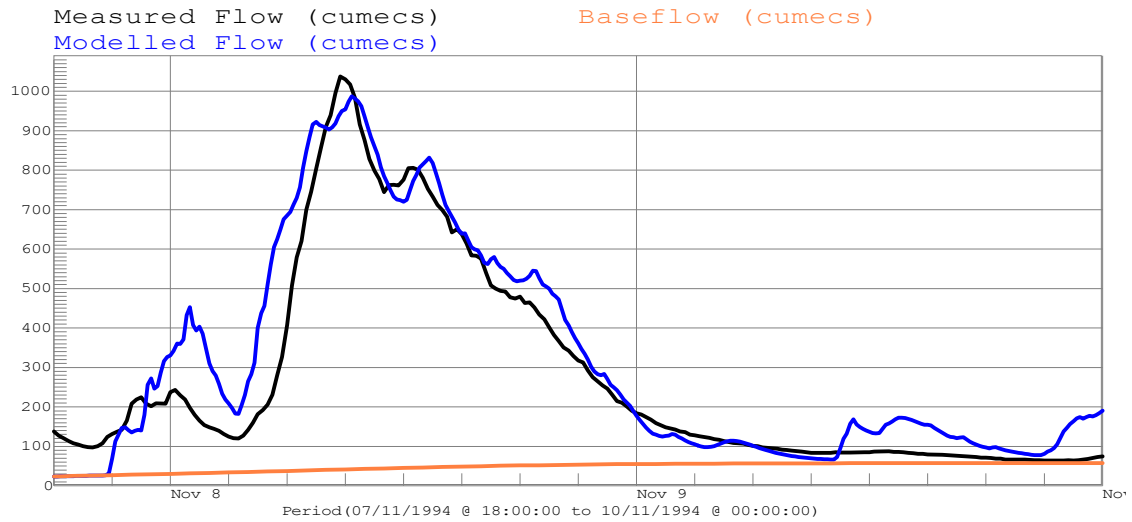
RORB Version 6, 2008, free software developed by a collaboration between Monash University (Russell Mein) and Sinclair Knight Merz (Rory Nathan), with support from the Melbourne Water Corporation.

7. APPENDIX A: EVENT CALIBRATION RESULTS

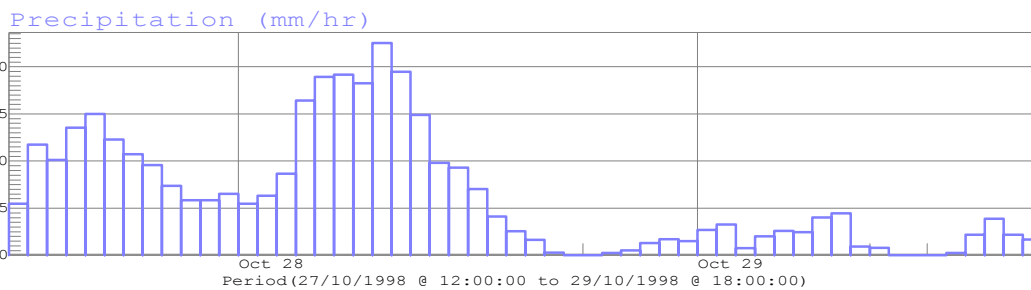
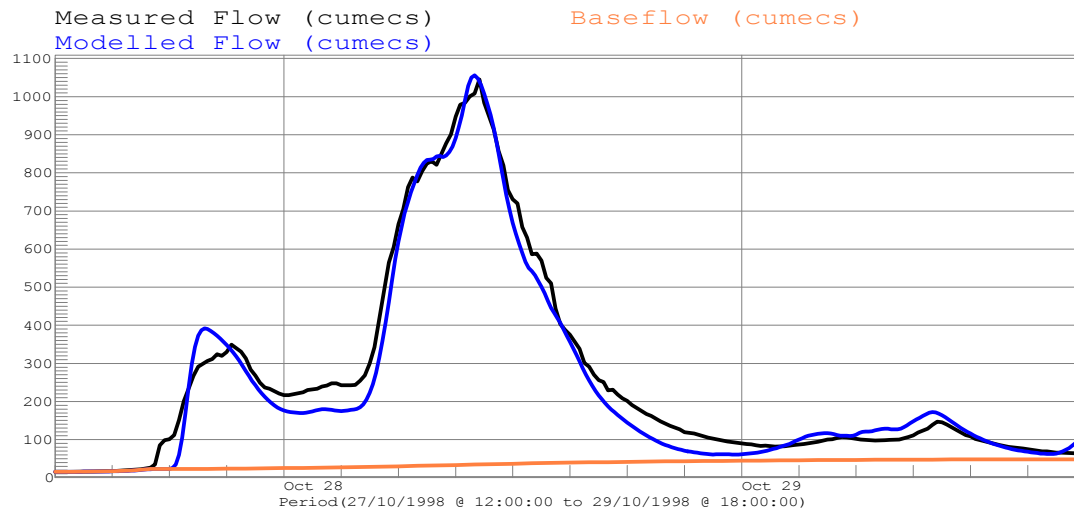
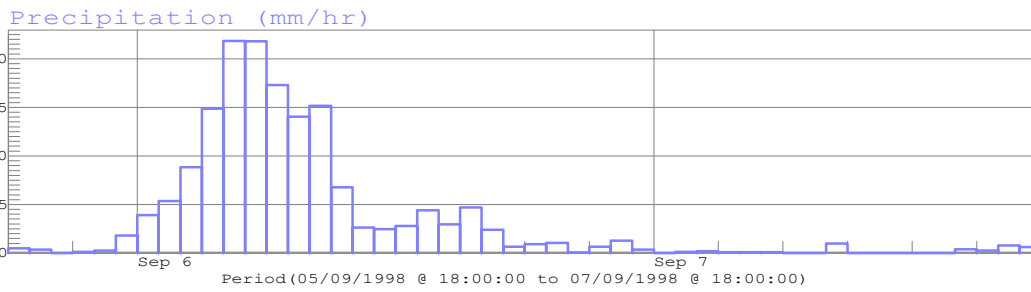
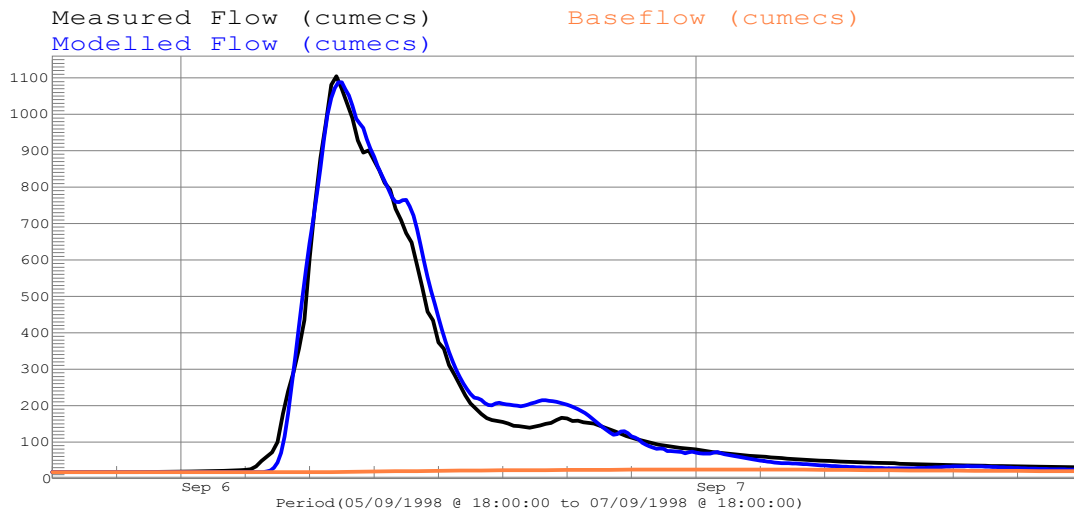
EVENTS 1 & 2 - WAIOHINE RIVER AT GORGE



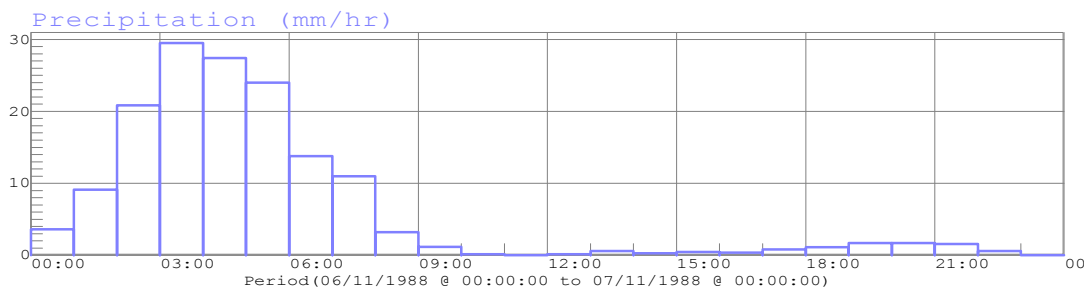
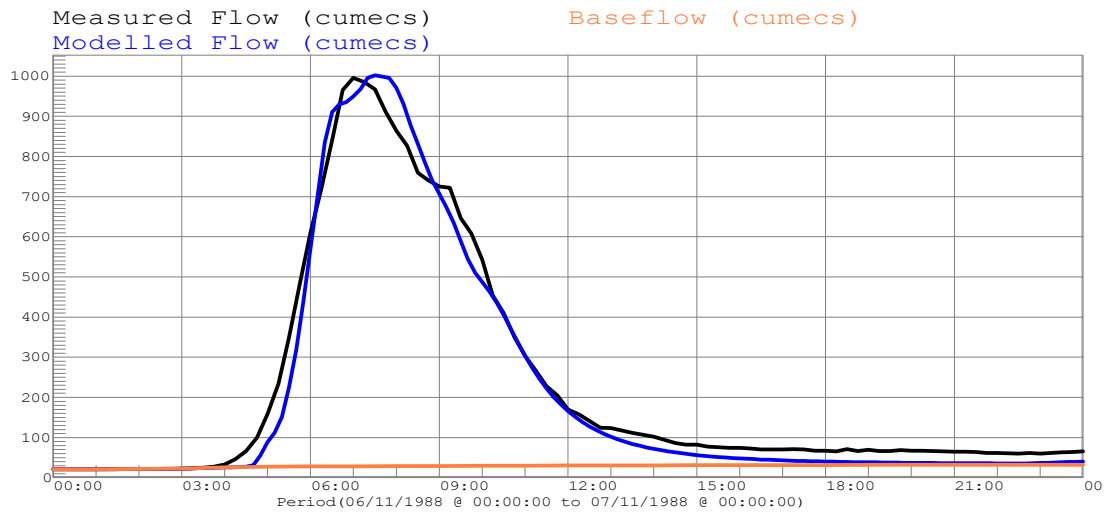
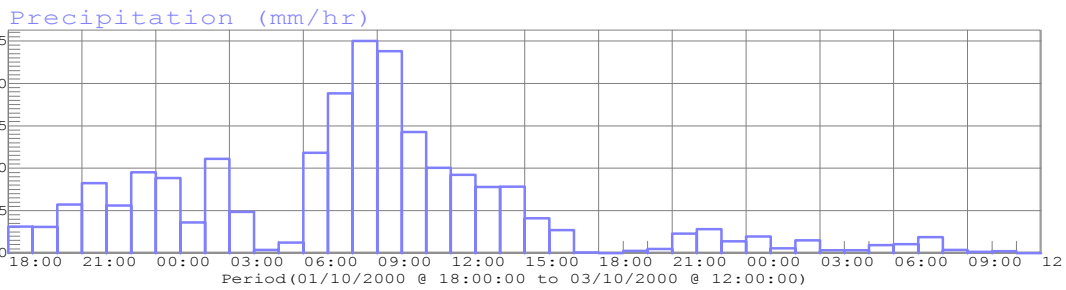
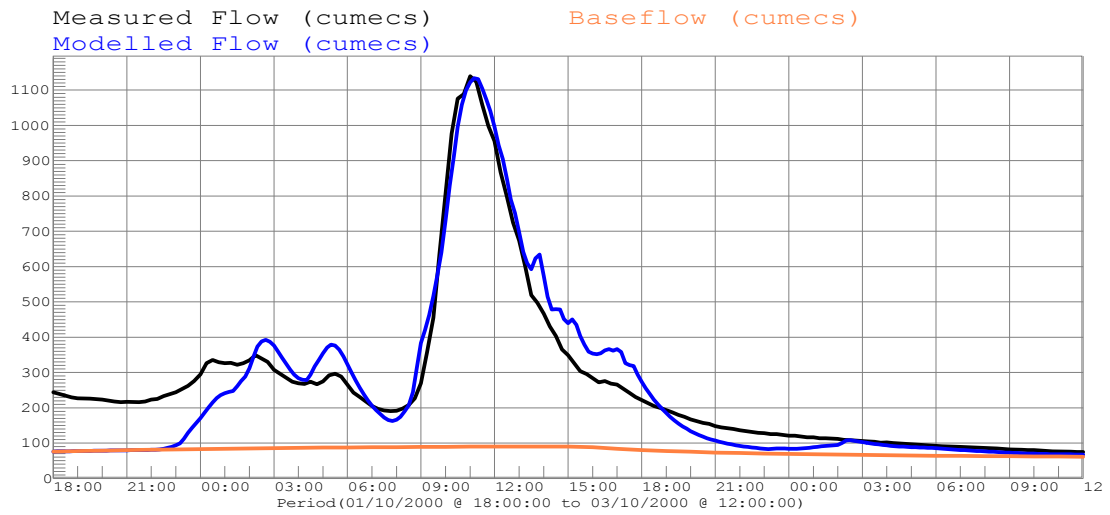
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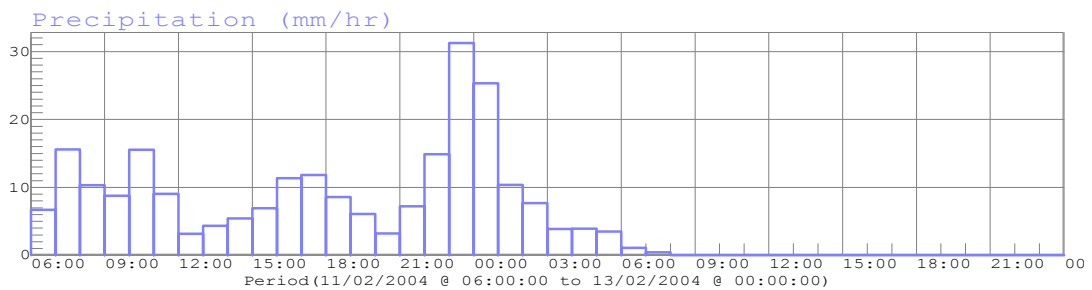
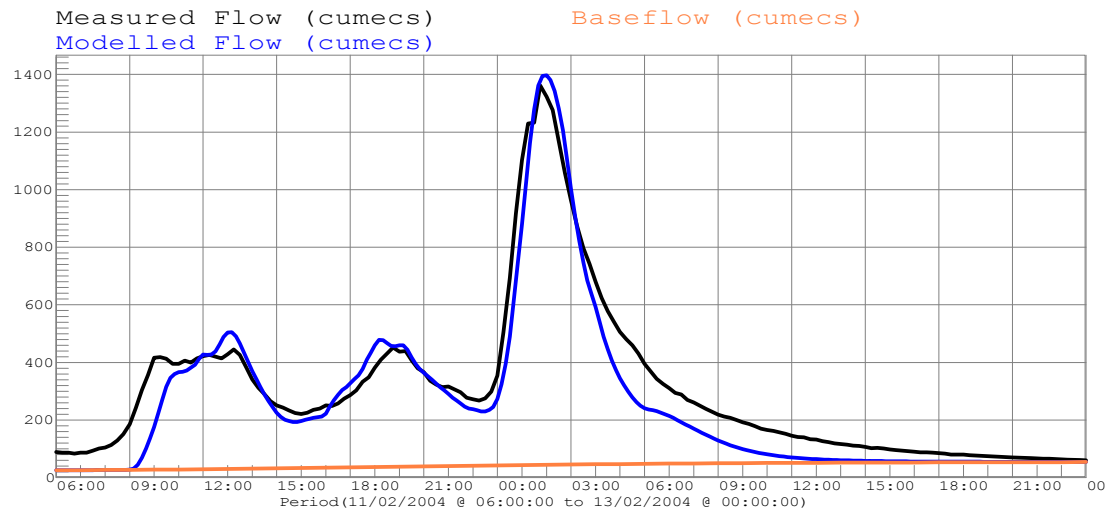
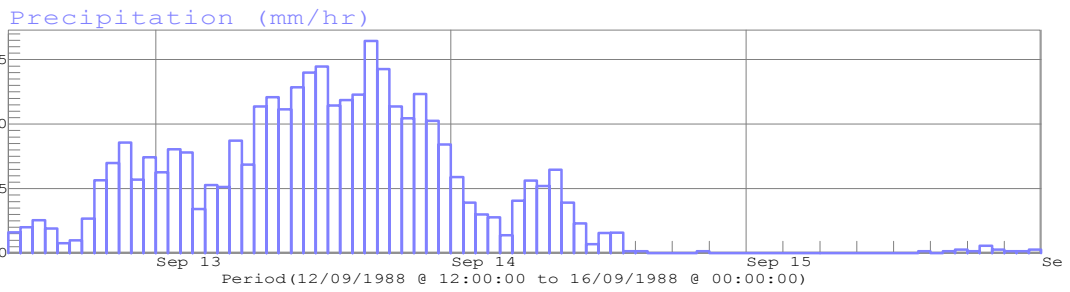
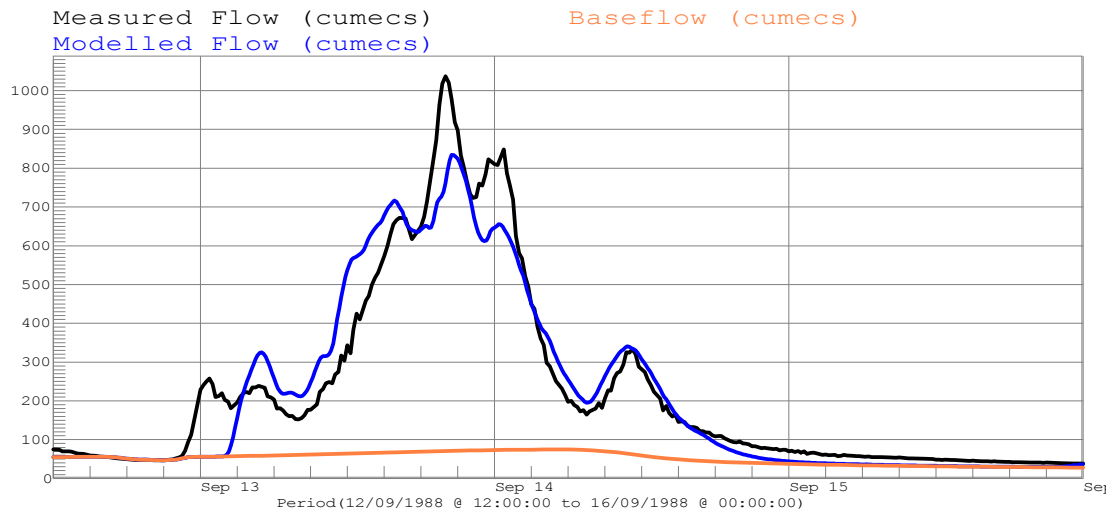
EVENTS 5 & 6 - WAIOHINE RIVER AT GORGE



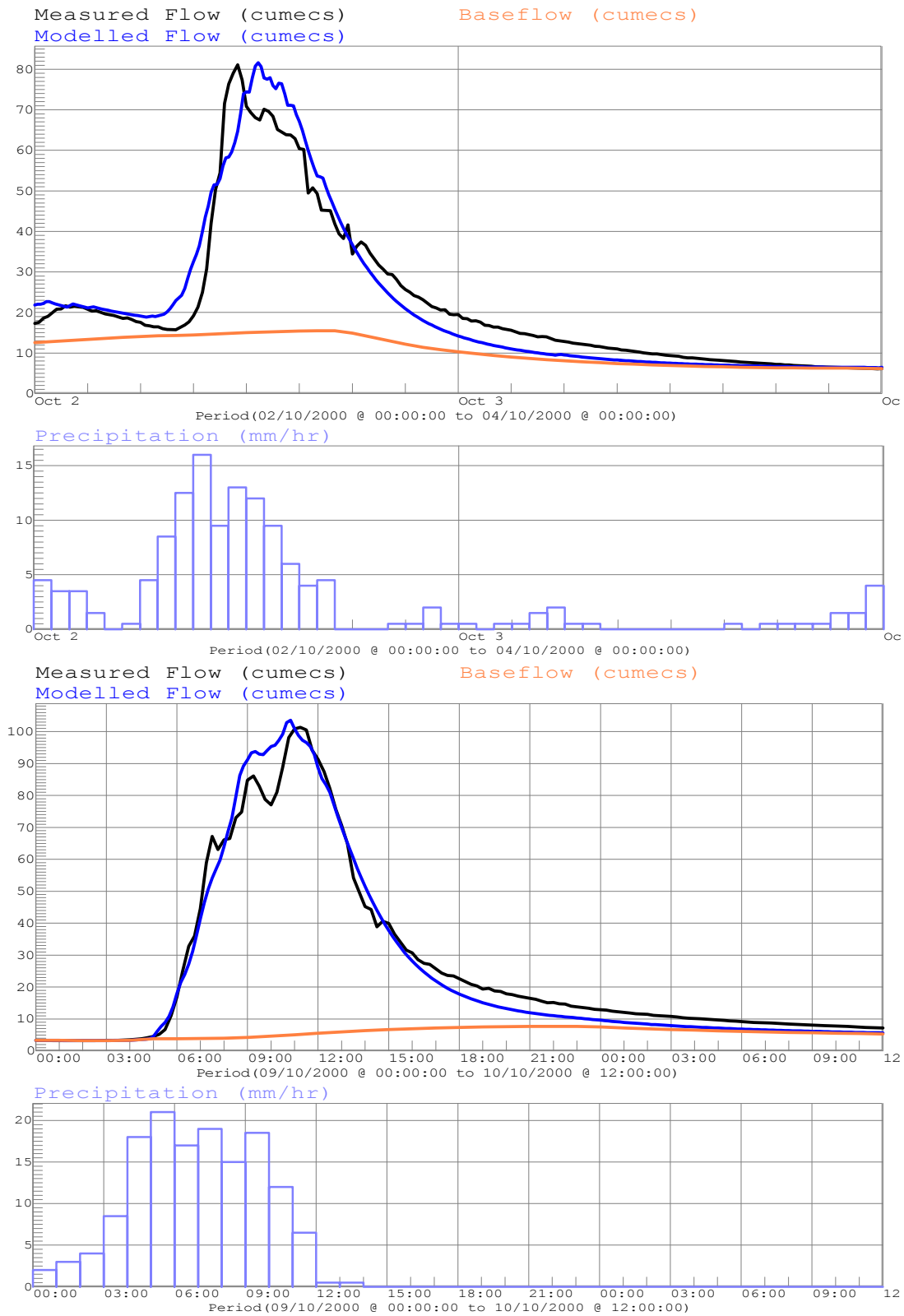
EVENTS 7 & 8 - WAIOHINE RIVER AT GORGE



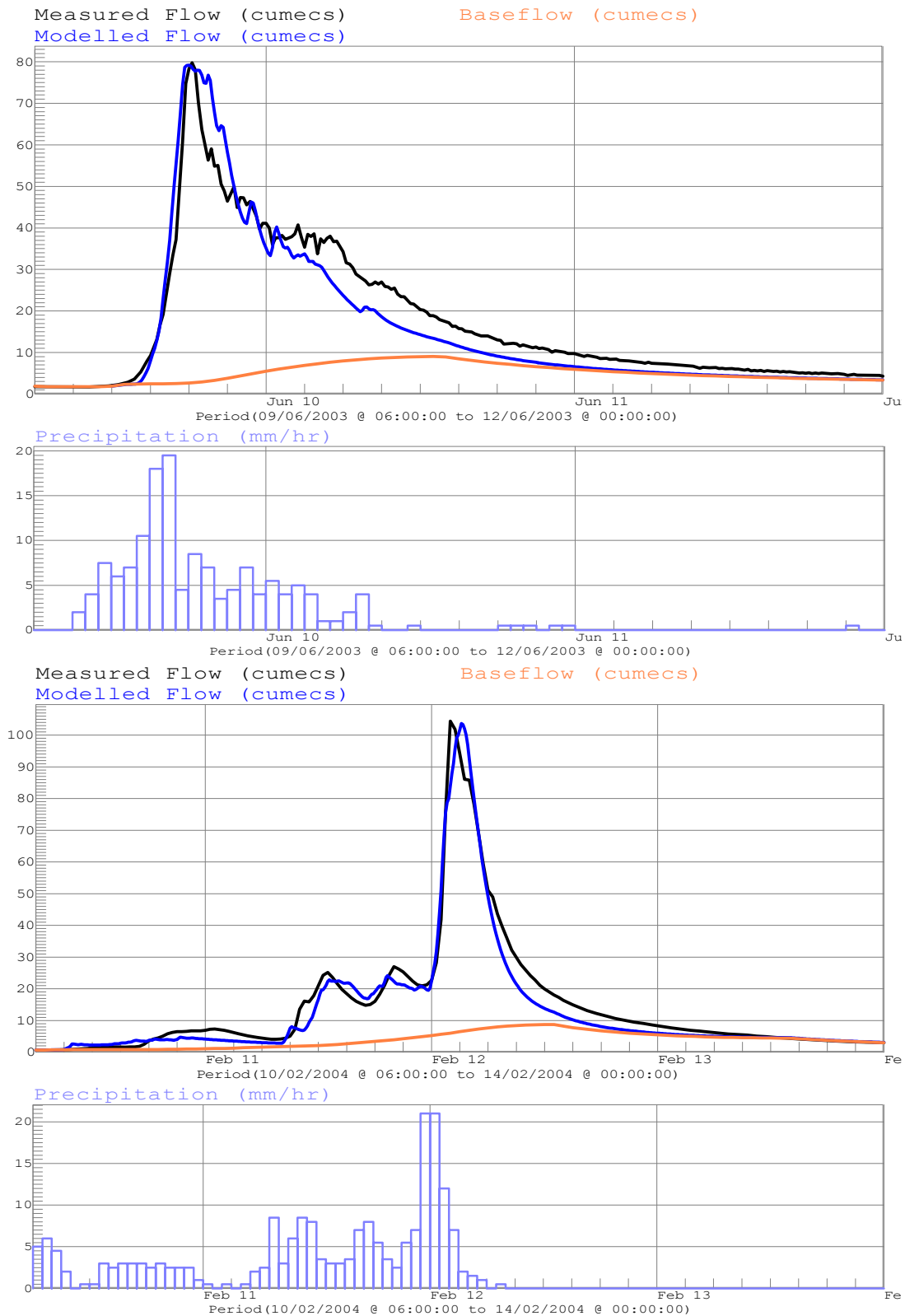
EVENTS 9 & 10 - WAIOHINE RIVER AT GORGE



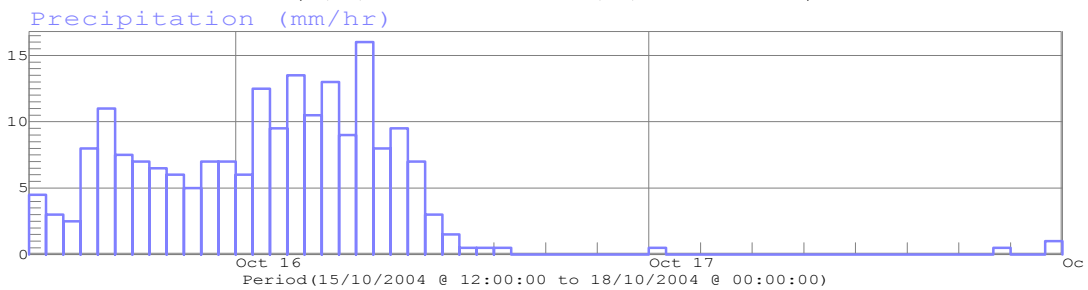
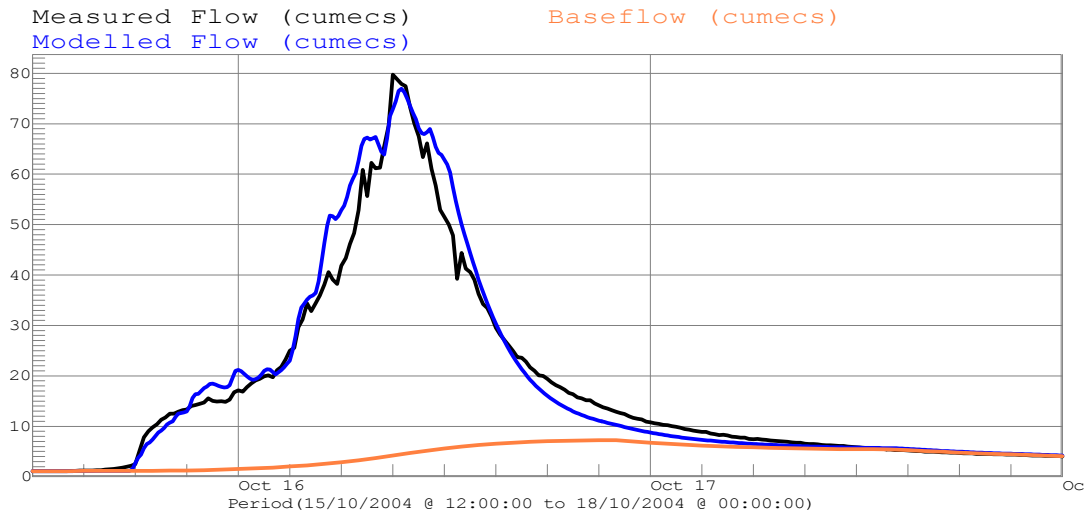
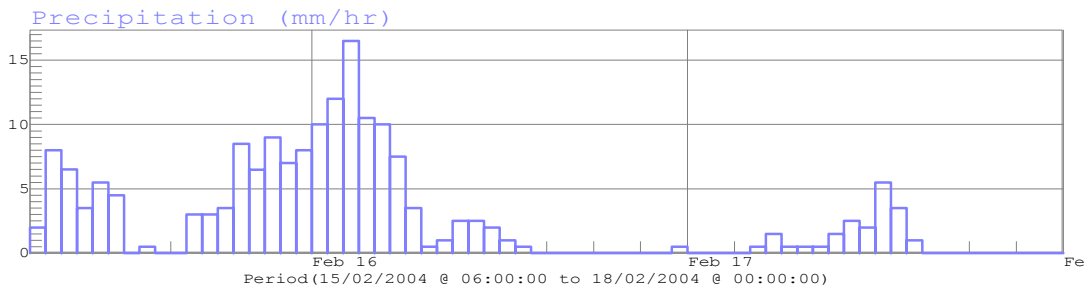
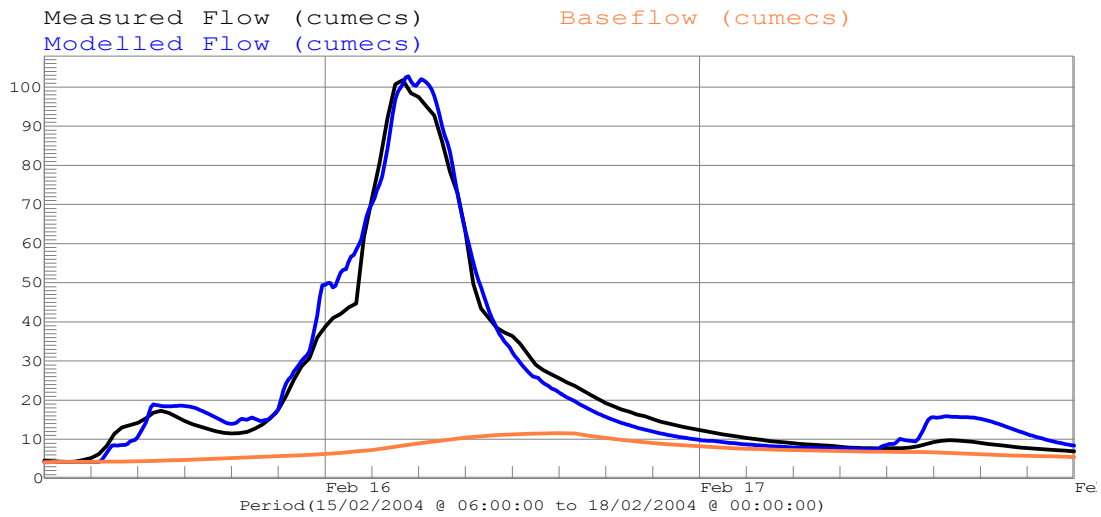
EVENTS 1 & 2 - MANGATARERE RIVER AT GORGE



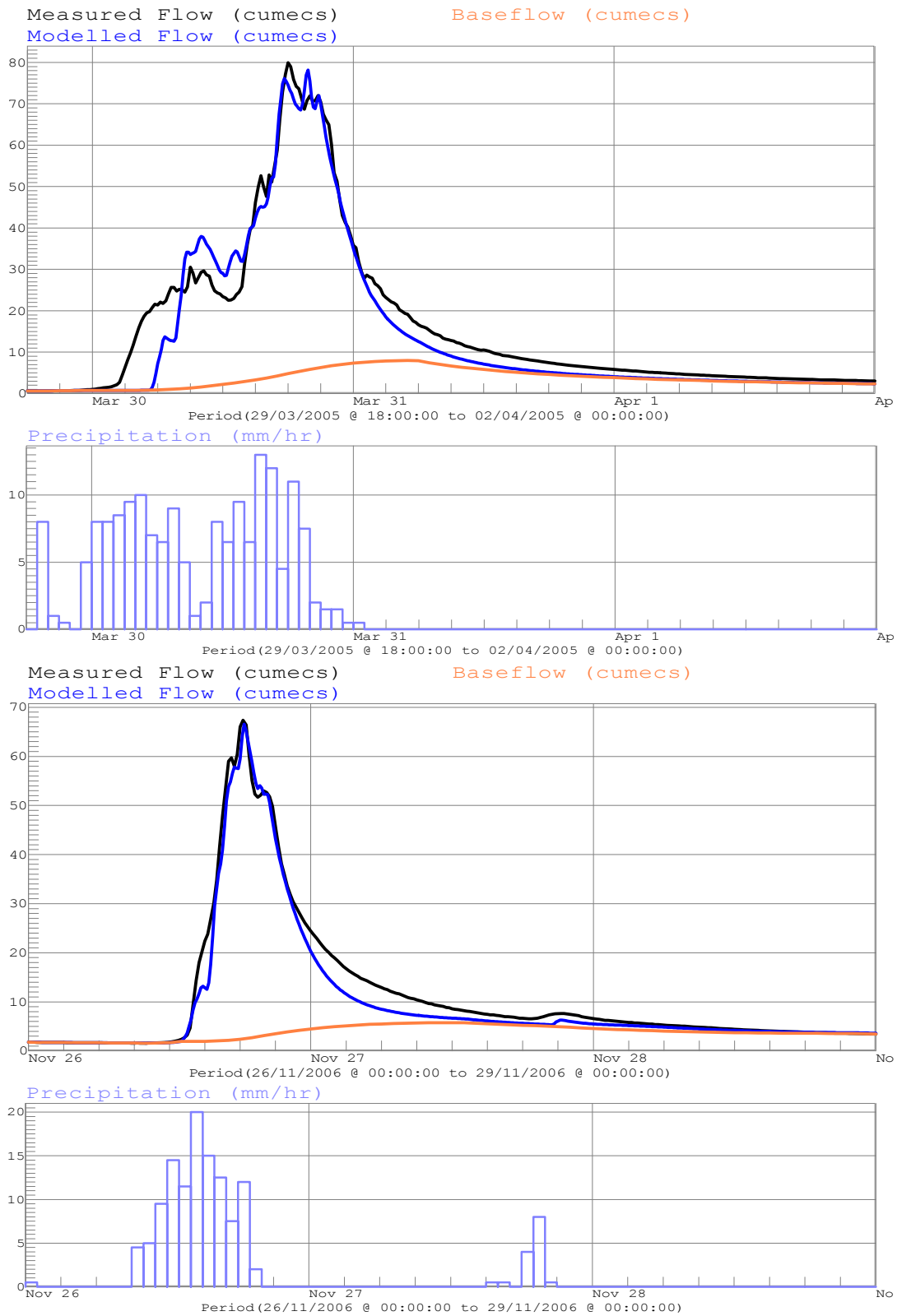
EVENTS 3 & 4 - MANGATARERE RIVER AT GORGE



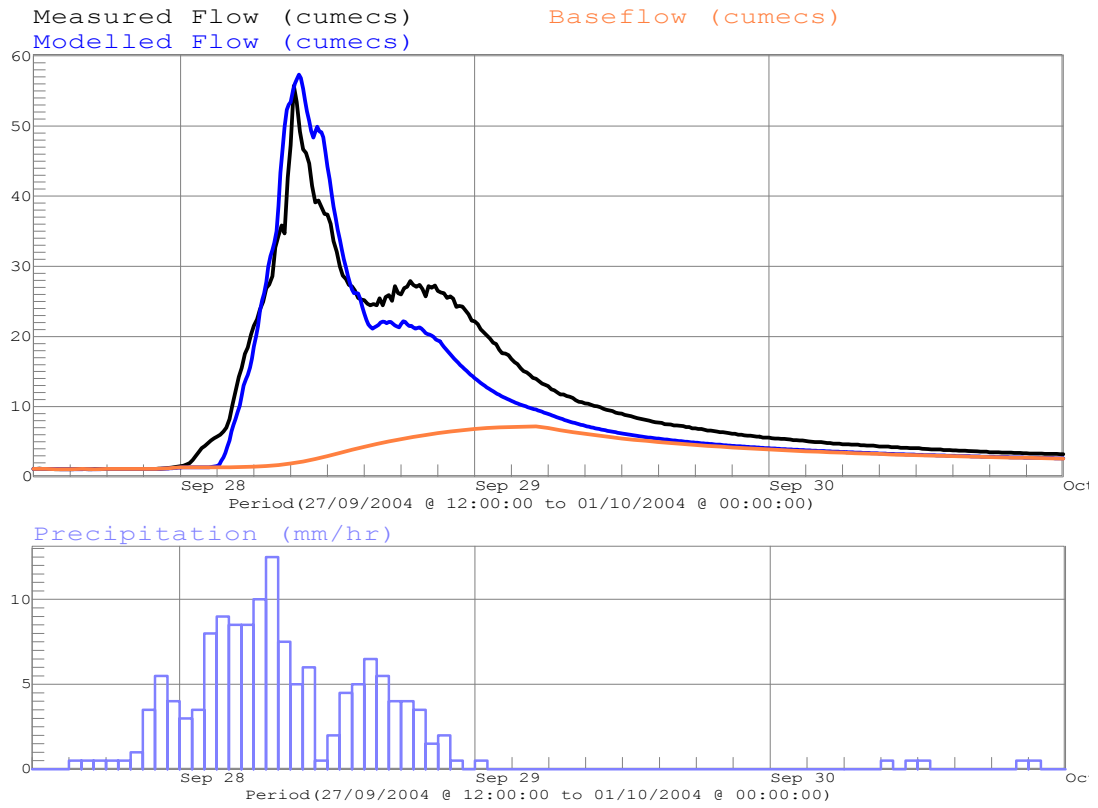
EVENTS 5 & 6 - MANGATARERE RIVER AT GORGE



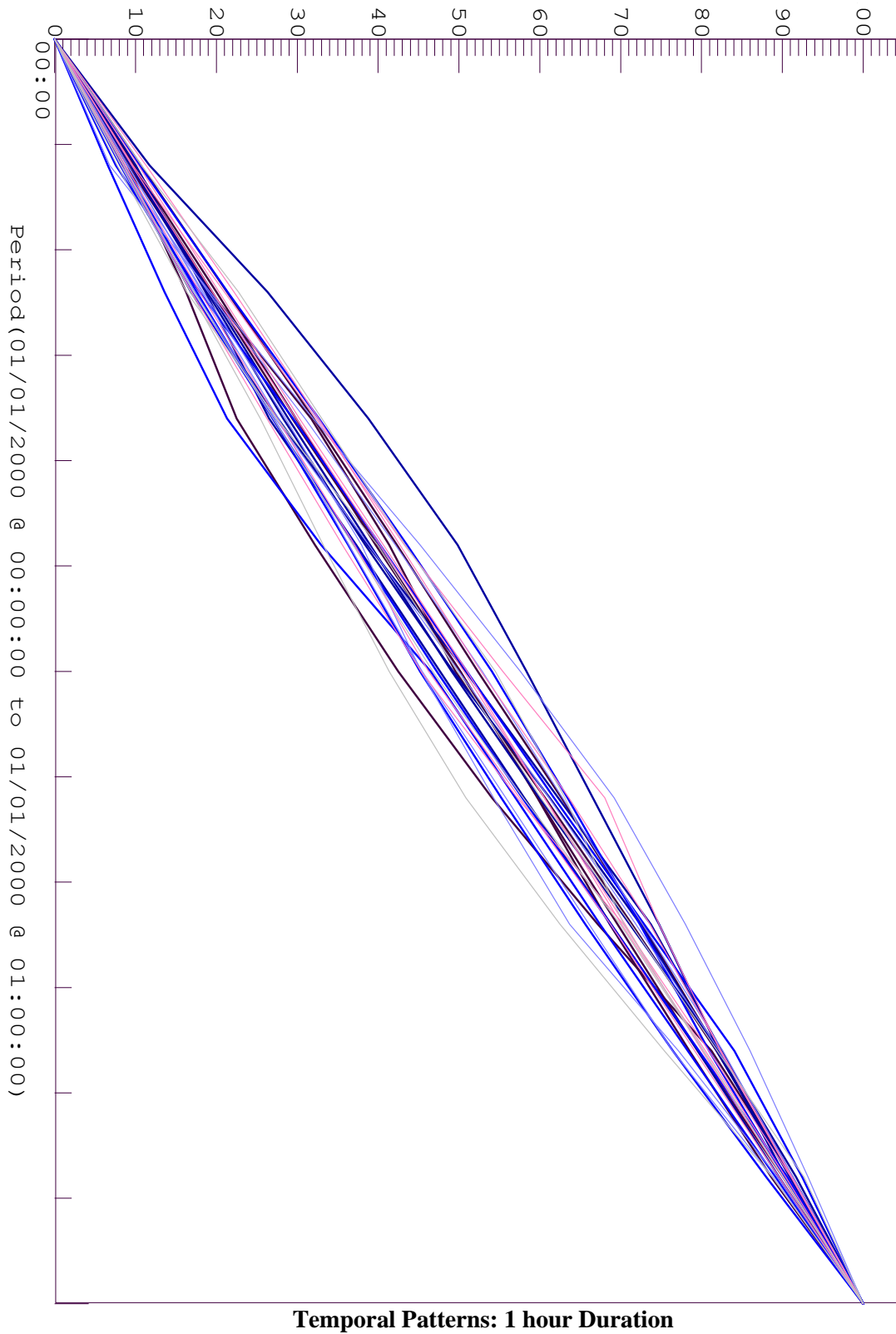
EVENTS 7 & 8 - MANGATARERE RIVER AT GORGE

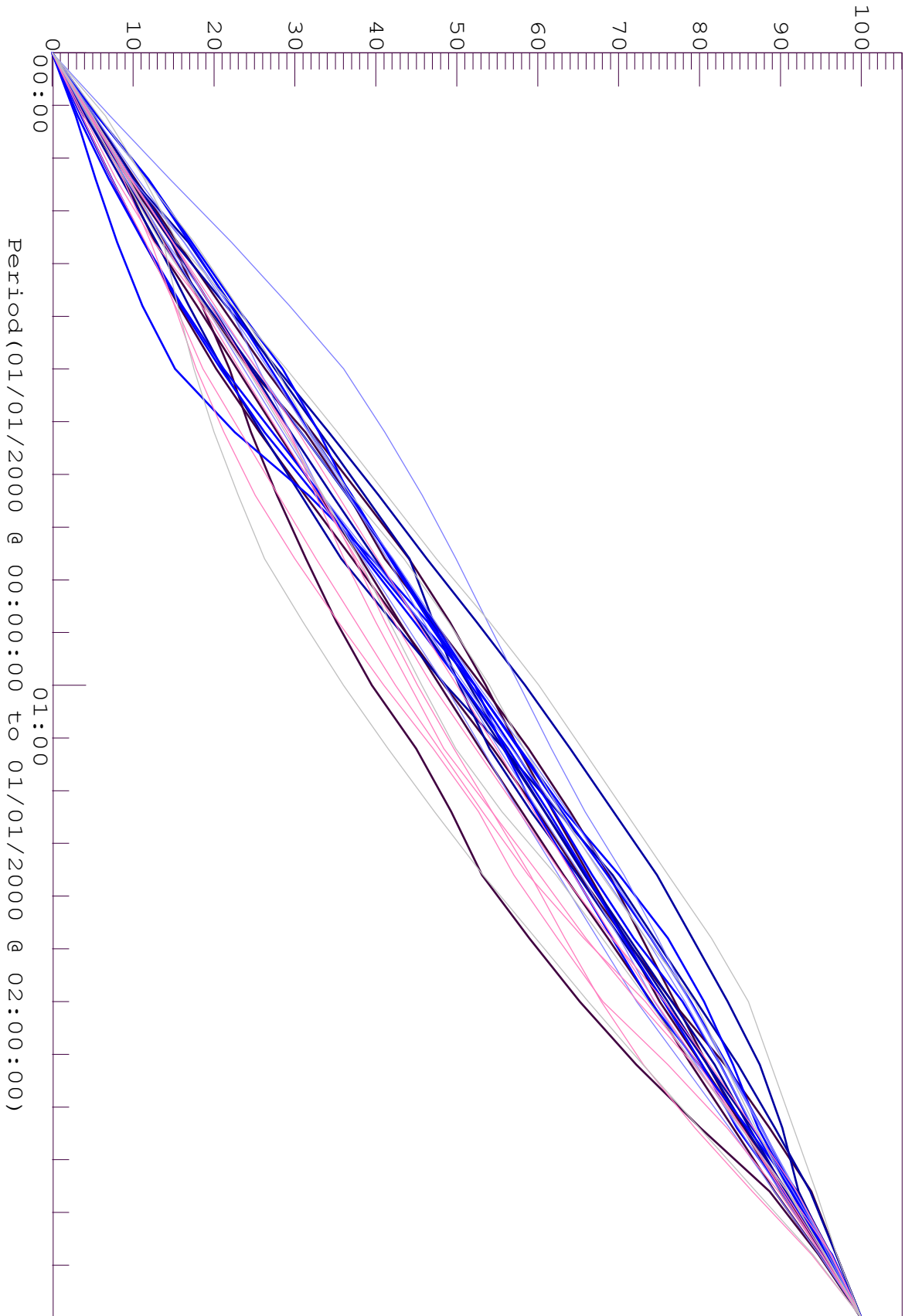


EVENT 9 - MANGATARERE RIVER AT GORGE

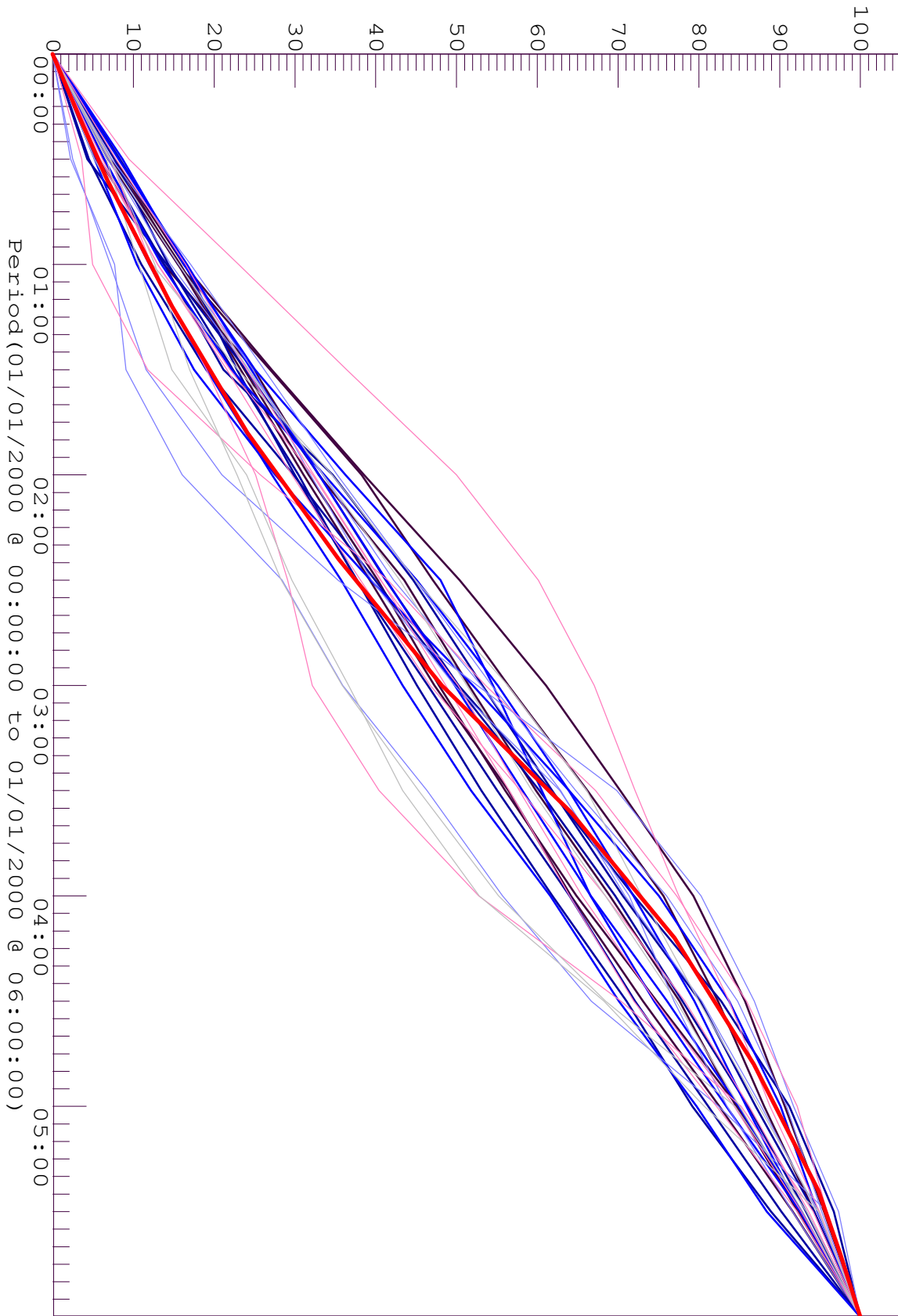


8. APPENDIX B: TEMPORAL PATTERNS

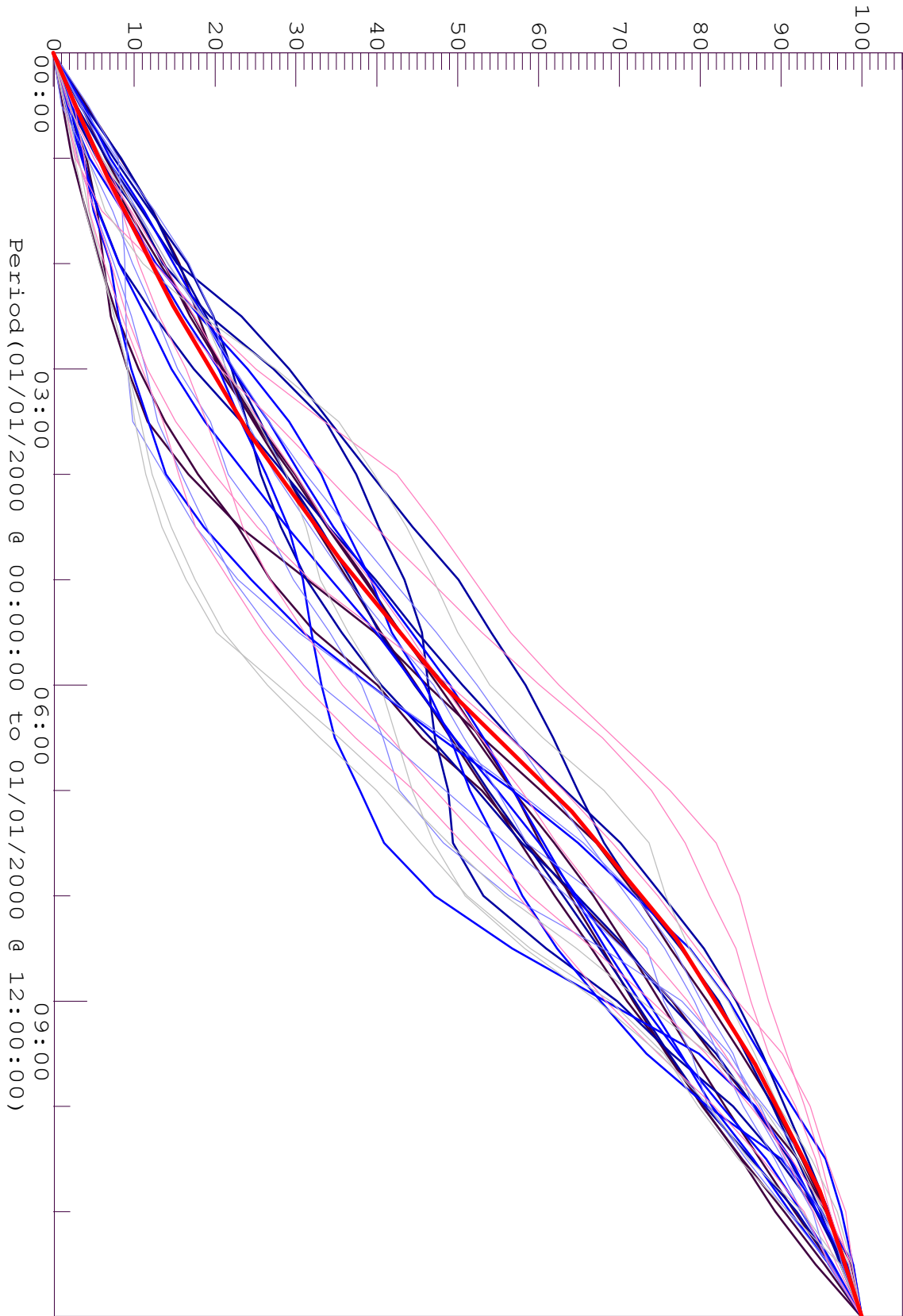




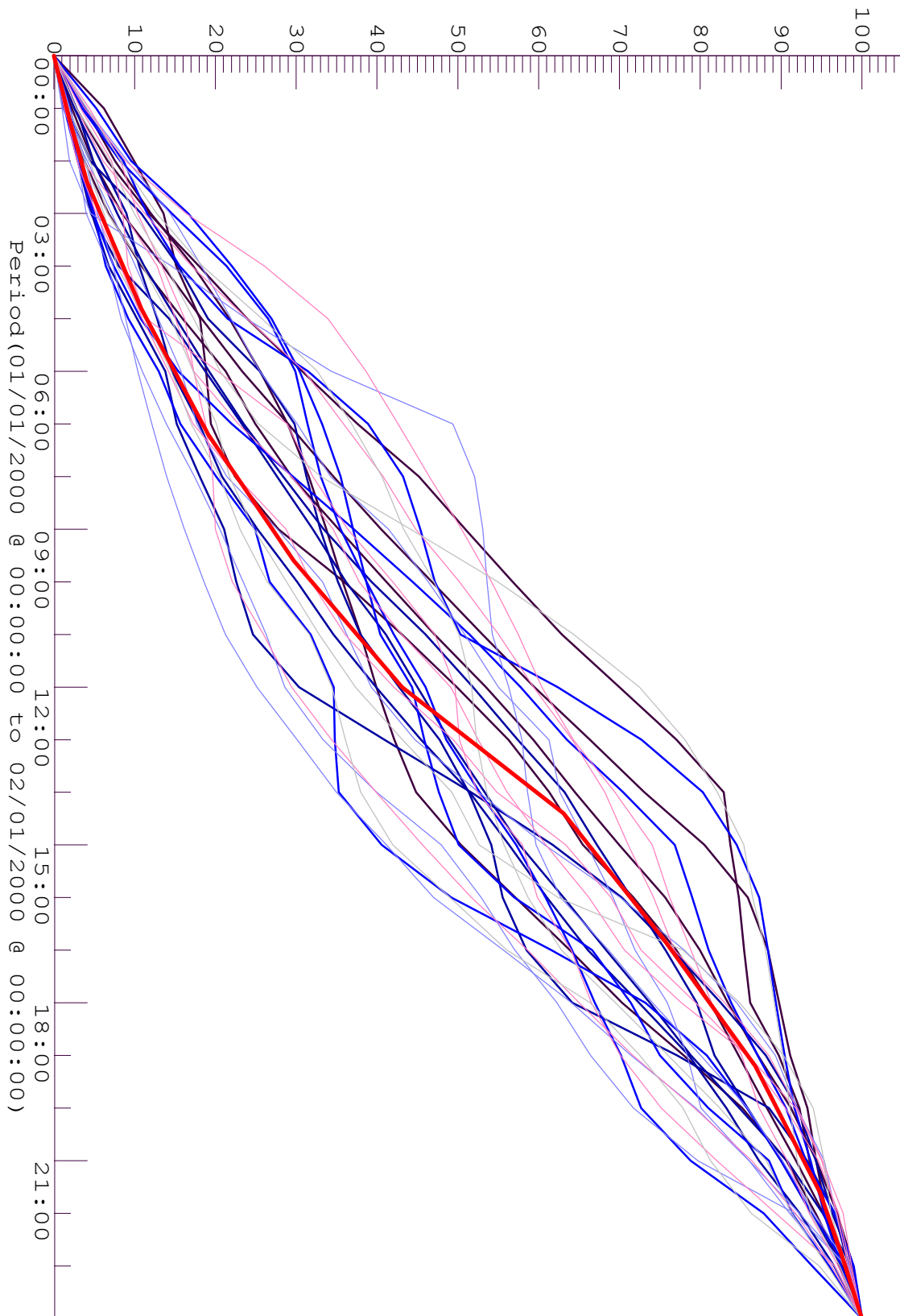
Temporal Patterns: 2 hour Duration



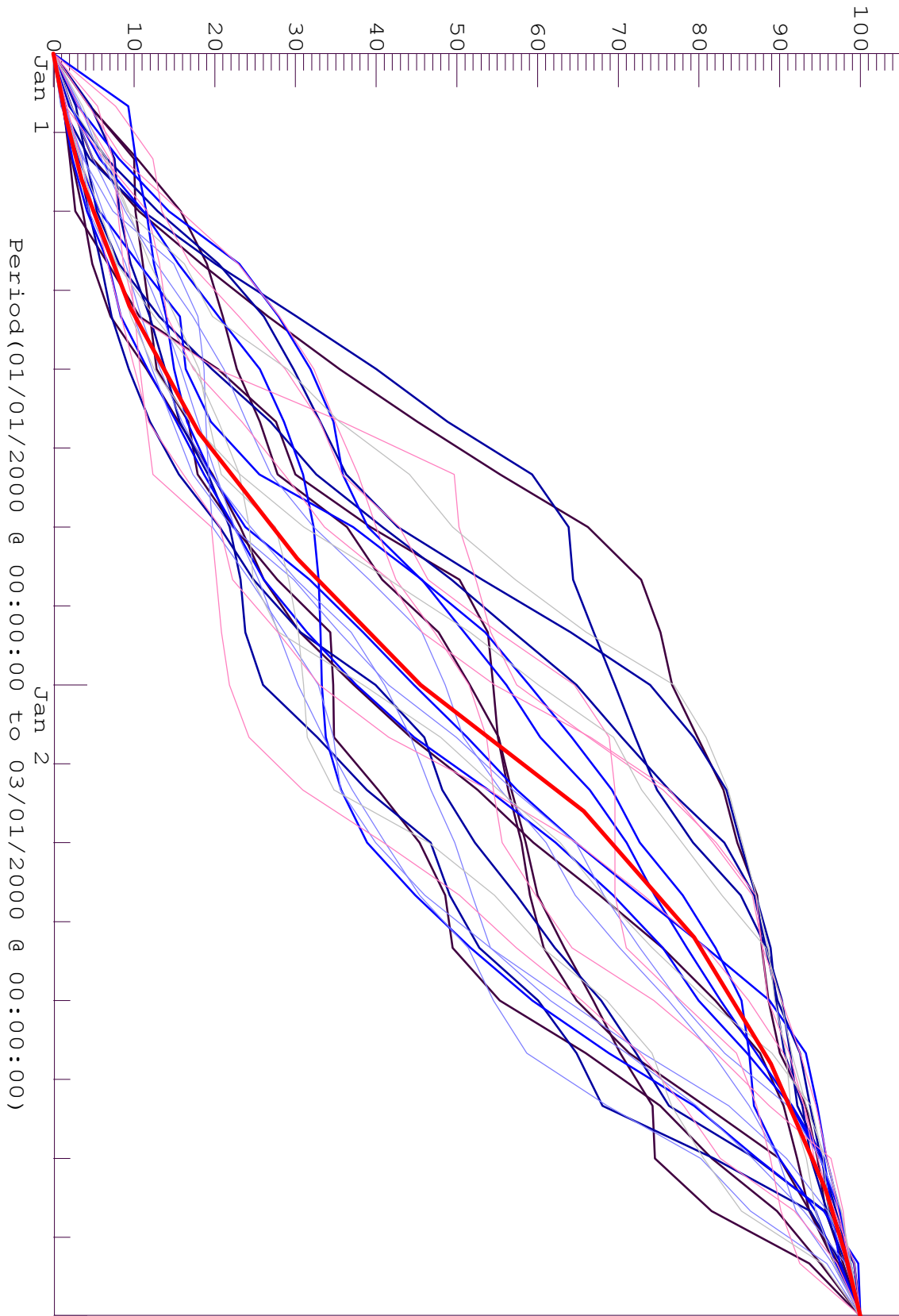
Temporal Patterns: 6 hour Duration. PMP temporal pattern is in bold red.



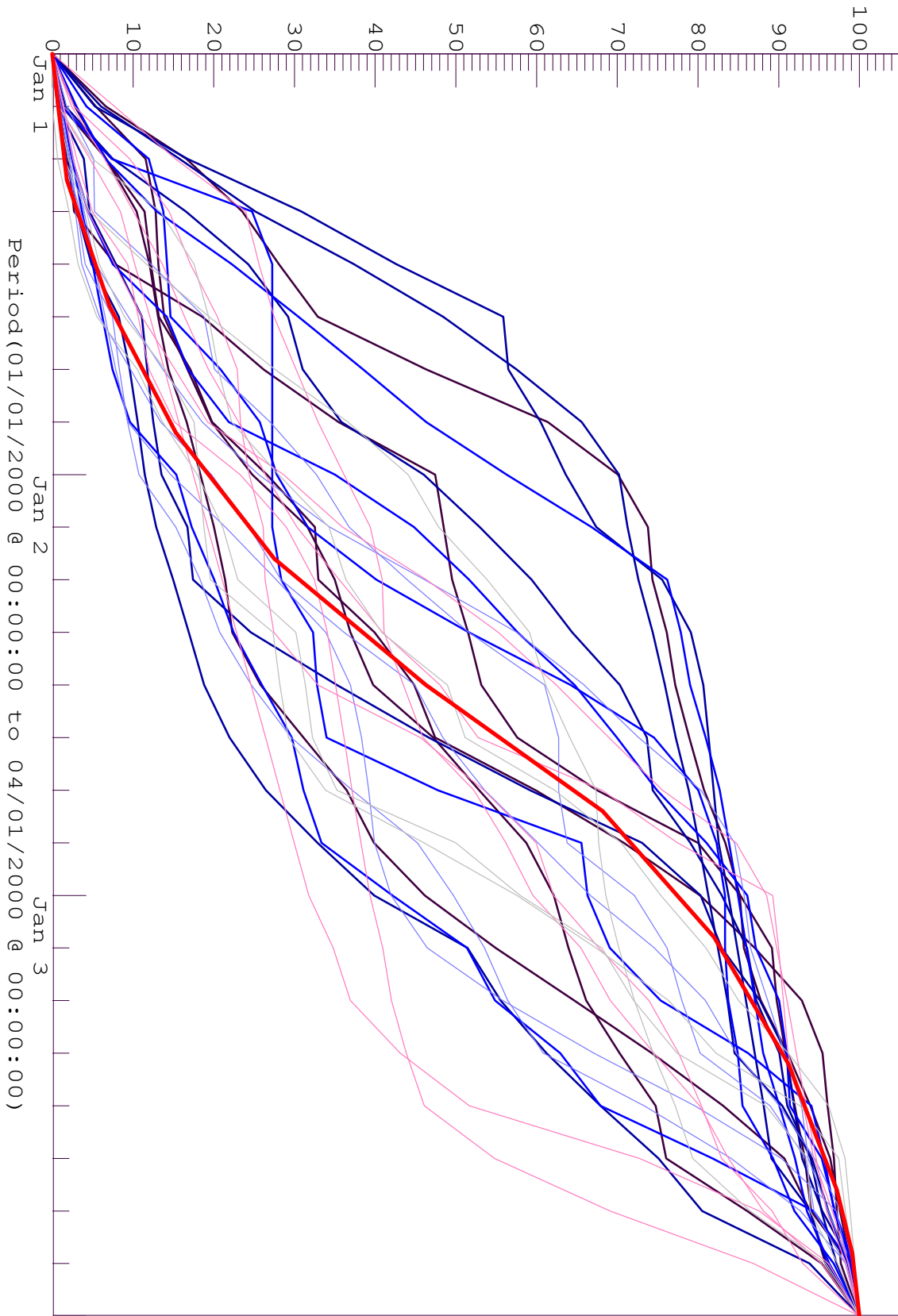
Temporal Patterns: 12 hour Duration. PMP temporal pattern is in bold red.



Temporal Patterns: 24 hour Duration. PMP temporal pattern is in bold red.

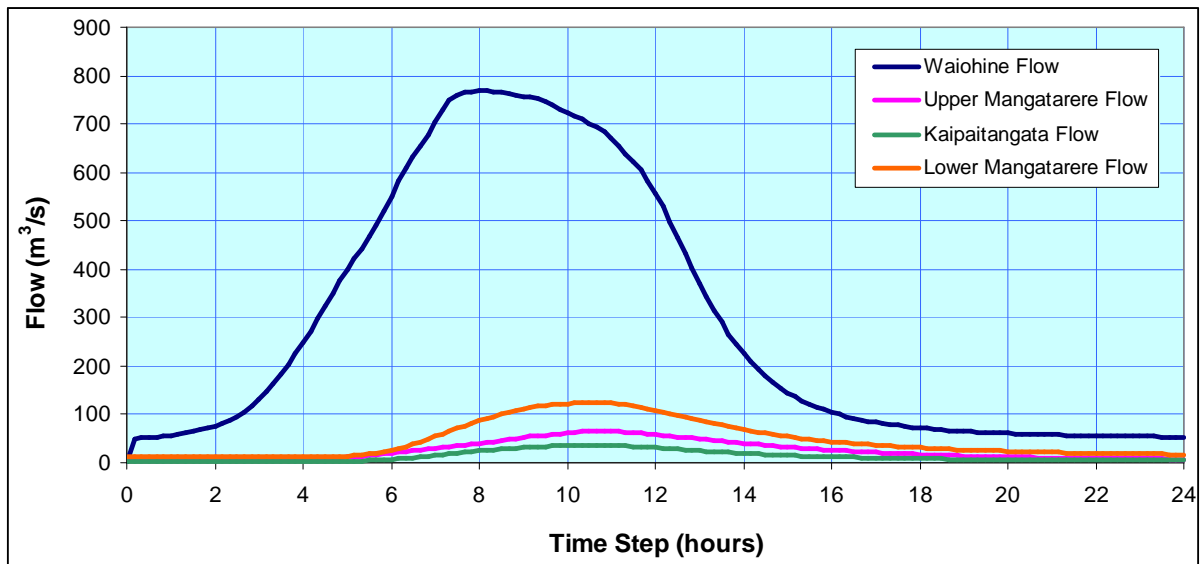


Temporal Patterns: 48 hour Duration. PMP temporal pattern is in bold red.

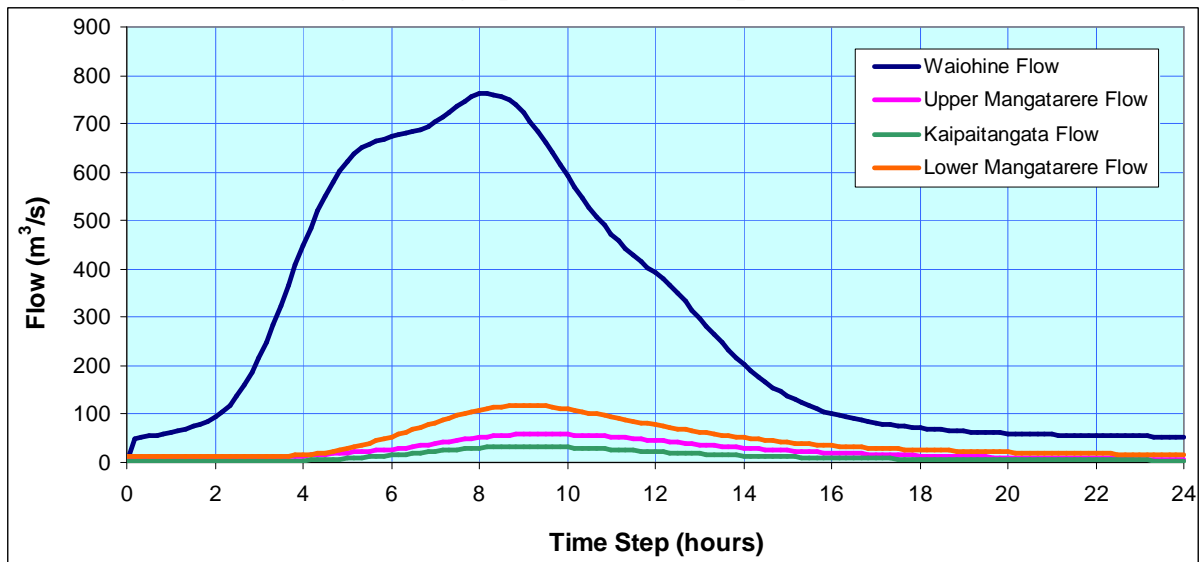


Temporal Patterns: 72 hour Duration. PMP temporal pattern is in bold red.

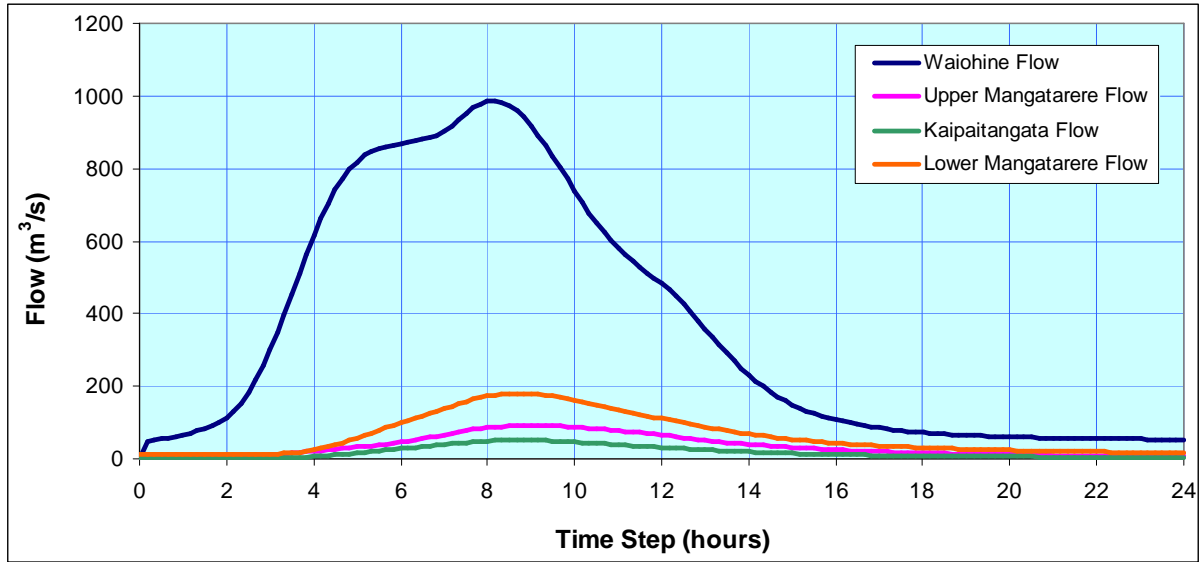
9. APPENDIX C: DESIGN HYDROGRAPHS



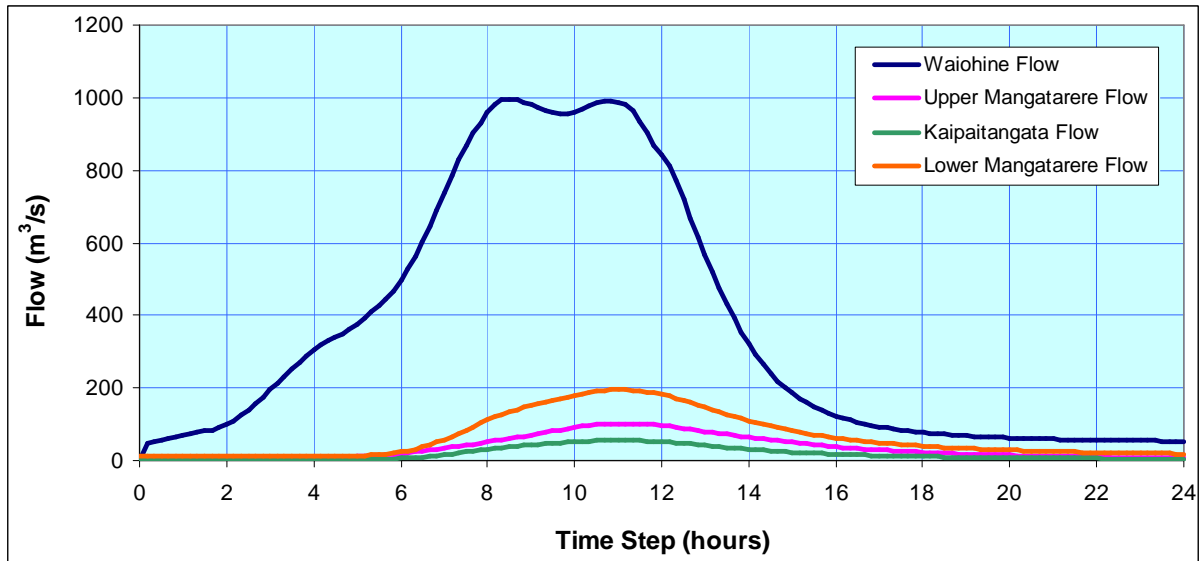
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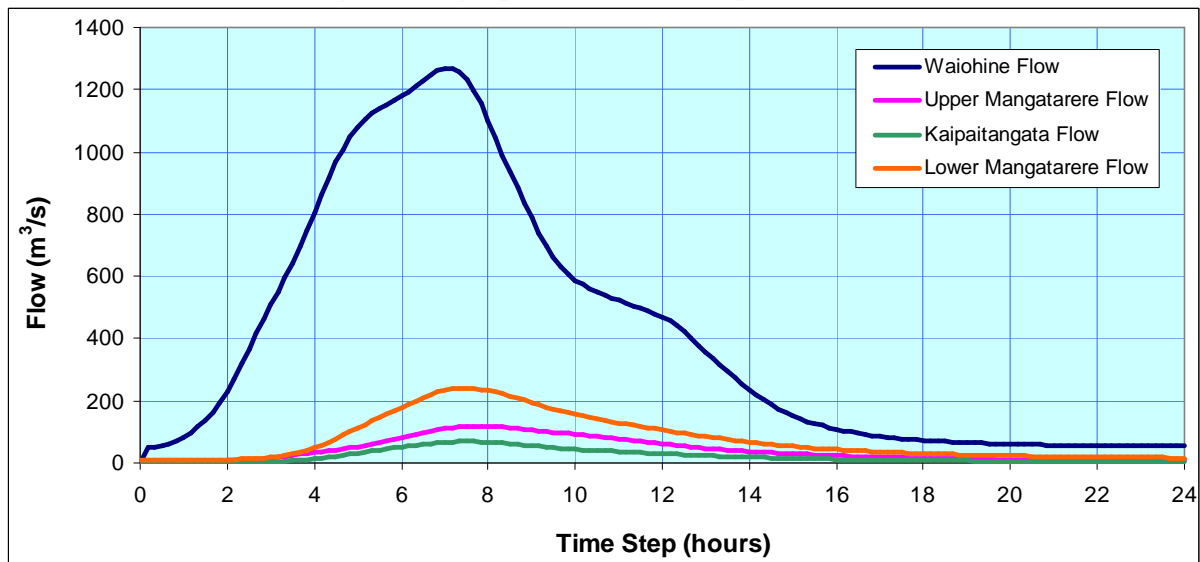
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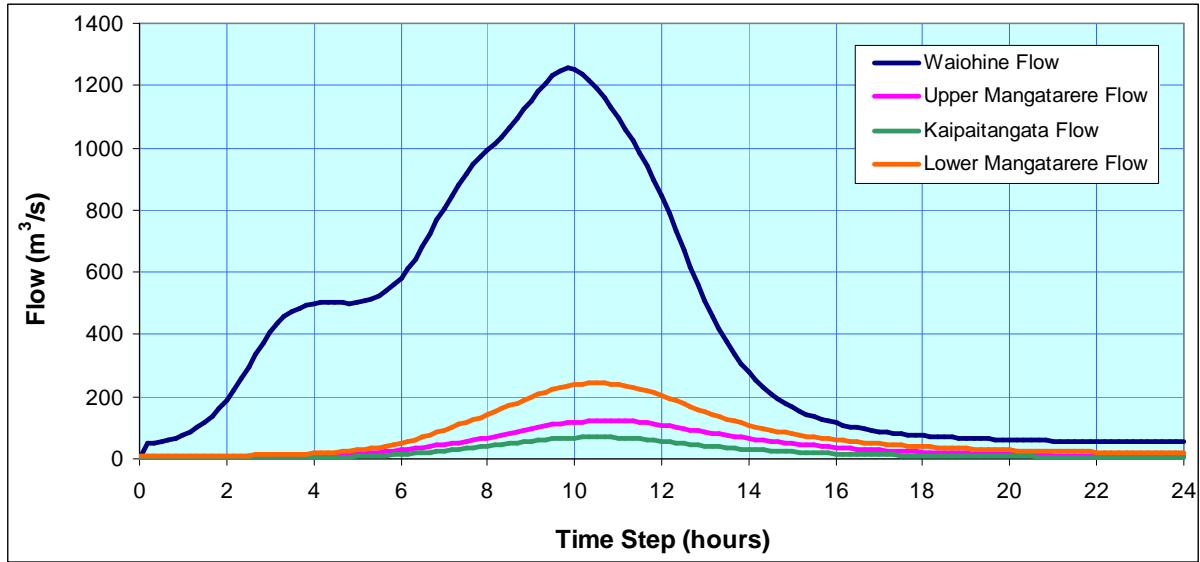
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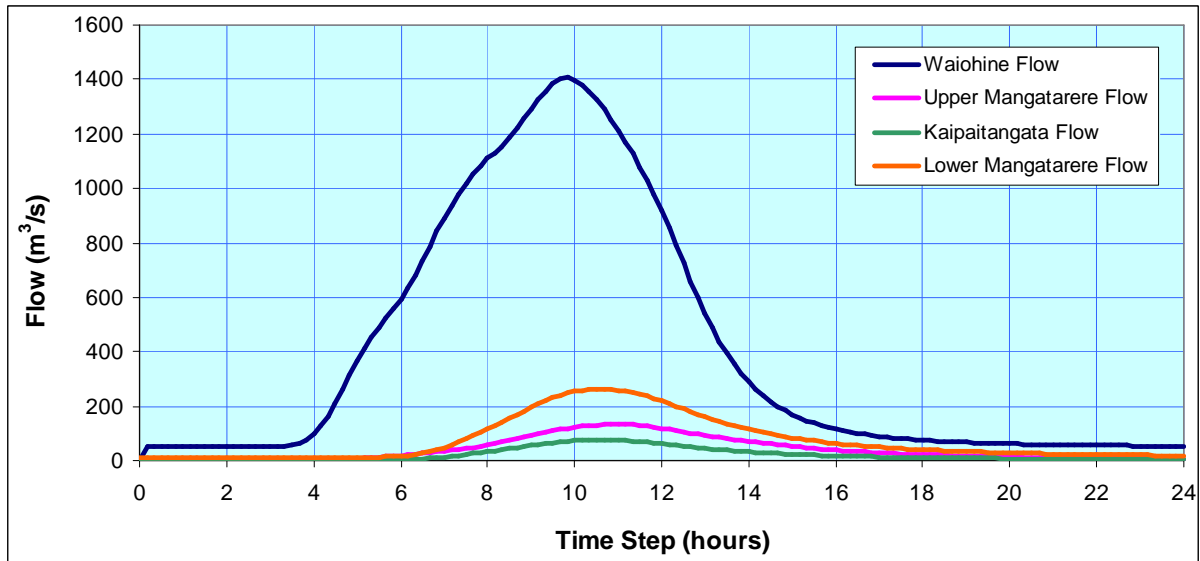
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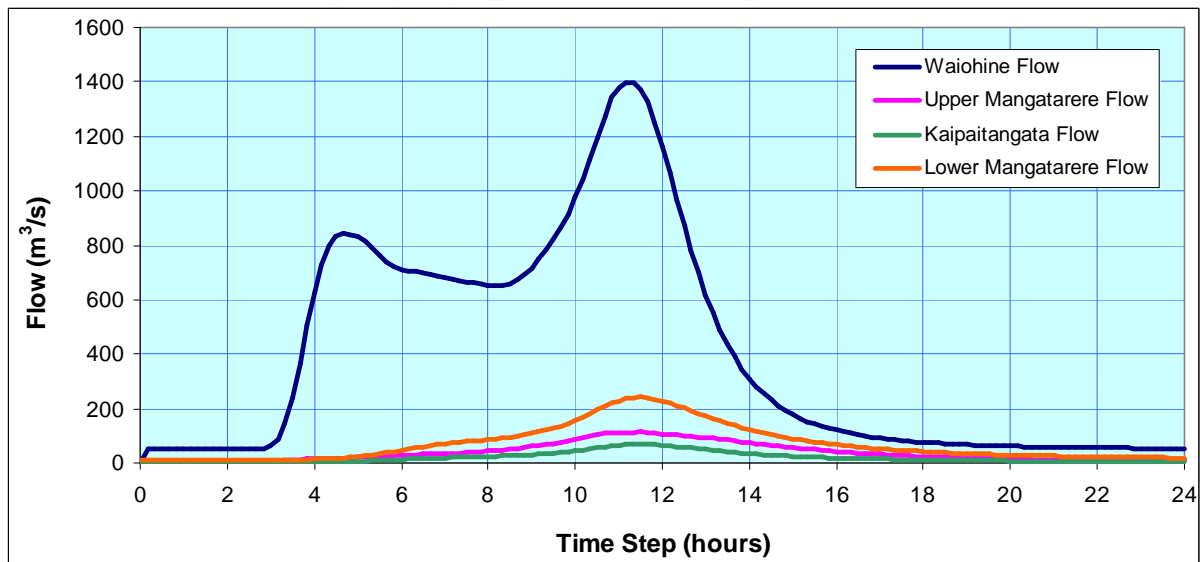
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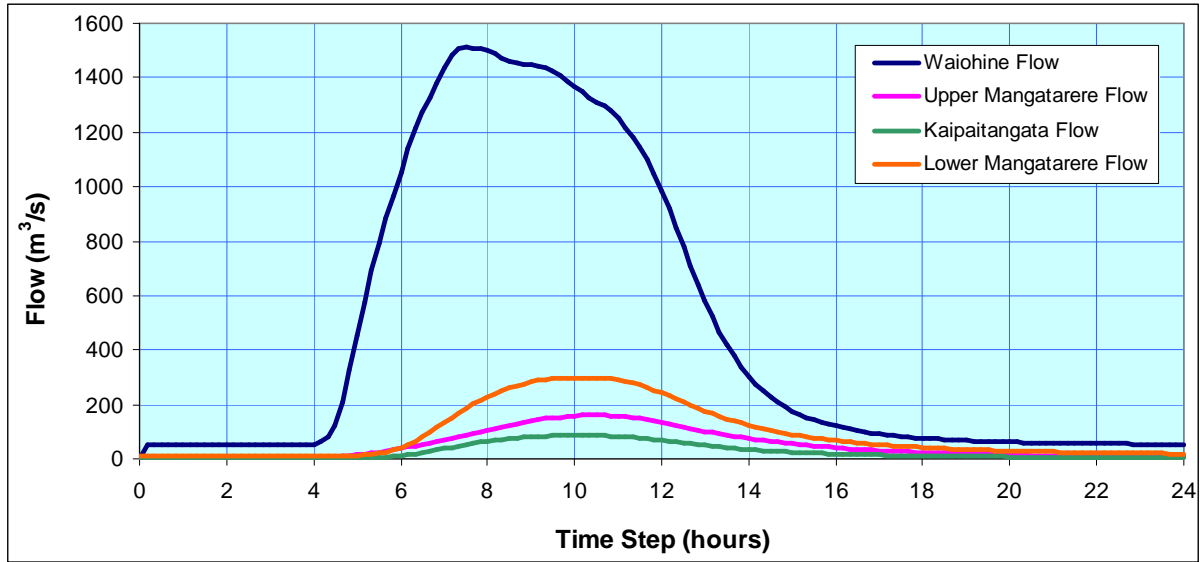
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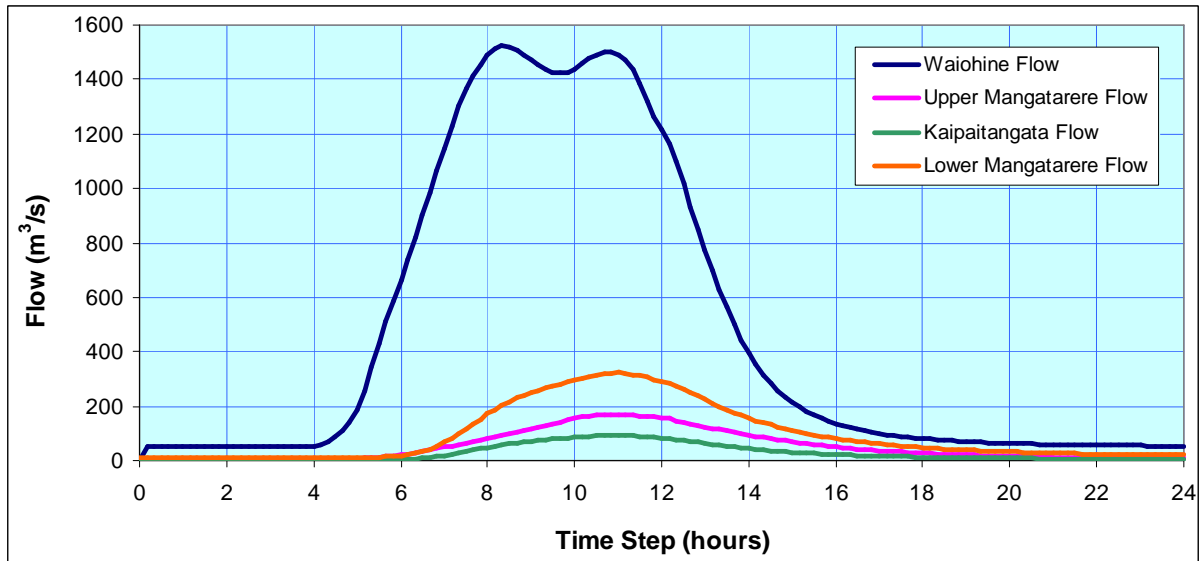
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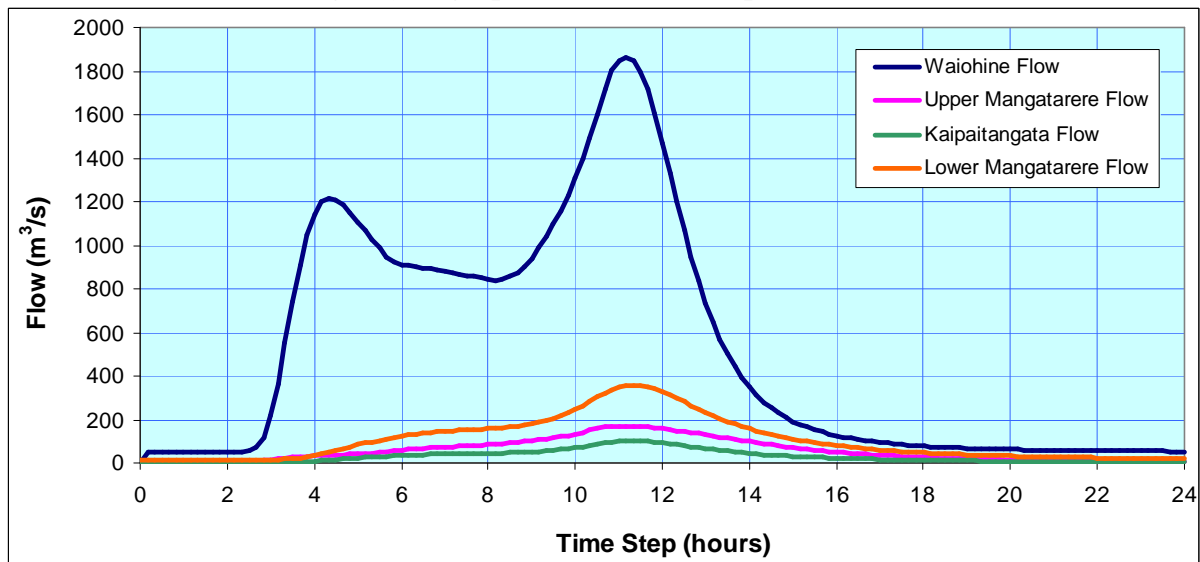
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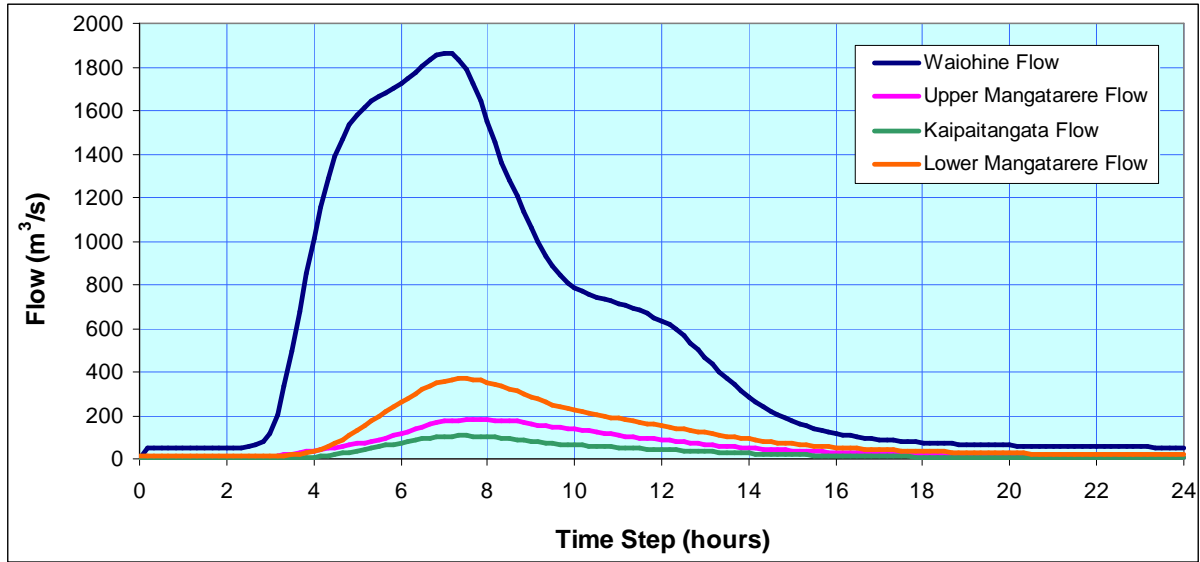
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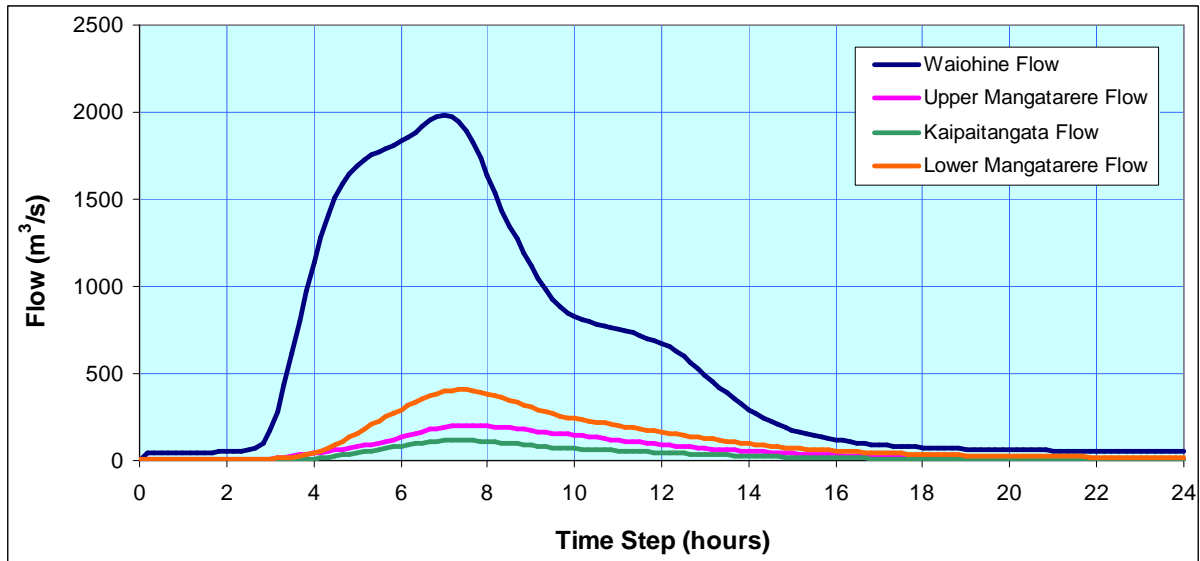
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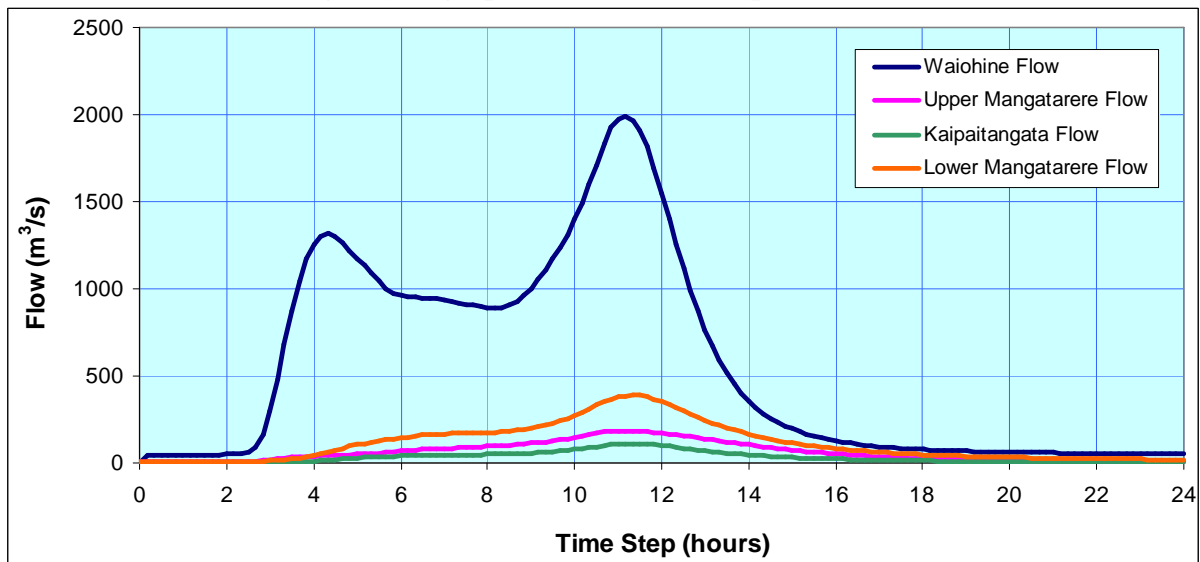
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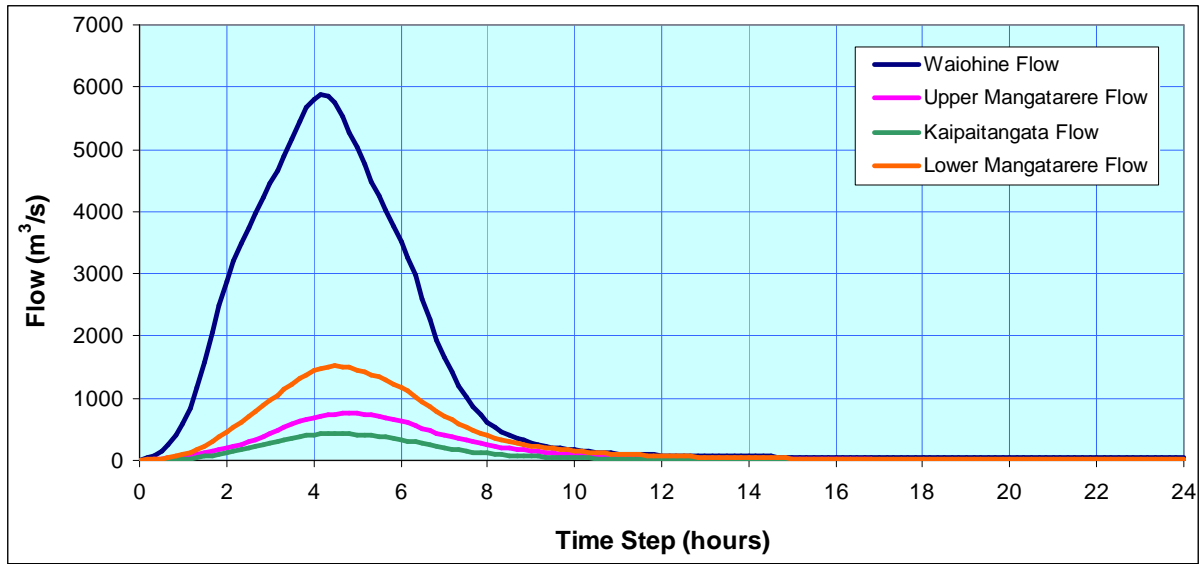
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Design Hydrographs: AEP 1:150. Temporal Pattern 1



Design Hydrographs: AEP 1:150. Temporal Pattern 2



Design Hydrographs: PMF

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