Effects of Land Use Change in the Waikato River Catchment between Karapiro and Taupo

Hydrological & Hydraulic Modelling of the Waikato and Waipa Catchments North of Karapiro Dam

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By Dr S A Joynes, November 2009

Contents

1 INTRODUCTION

This project is aimed at assessing the flood hydrology effects that potential changes in land-use within the Waikato River catchment upstream of Karapiro Dam.

This project will also identify the subsequent effects downstream of Karapiro Dam and the impacts on the flood protection works of the Lower Waikato Waipa Control Scheme. A key aspect of the project will involve consultation with key stakeholders and their technical advisors to ensure the outcomes of the investigations are based on a robust methodology and relevant information, and that the results can be used to inform future planning and decision making processes.

1.1 Main Project Brief

1. To provide a robust assessment of the effect of the conversion of forest plantation to pasture on the flood hydrology of the tributary catchments to the Waikato Hydro Lakes, covering the spectrum of risk/return period events.

2. To determine how changes in the source hydrology of the tributary catchments are transformed as they pass through the Waikato hydro lake system.

3. Determine the expected impacts of the changes in land use on the flood risks in the Lower Waikato River including protection standards for the LWWCS flood protection scheme.

4. Prepare a technical report setting out the methodology and results of the investigation that will inform Council's policy decision making and direction.

5. Establish a broad understanding and consensus on hydrological assessment relating to change of land use in the Upper Waikato within relevant sectors of the community.

1.2 Modelling Brief

This report is for items 3 and 4 of the main project brief. A comprehensive hydrological and hydraulic model was used (herein called MIKE11-NAM). It calculates water levels and flows in the Waikato and Waipa Rivers. MIKE11-NAM has been used extensively by Environment Waikato in the past 15 years for many projects. It includes all major structures, canals, tributaries and storage areas of the

Lower Waikato Waipa Control Scheme (LWWCS). The design flood events considered are the 5, 10, 20, 50, 100 and 500 year return periods.

MIKE11-NAM receives boundary inflows generated at Karapiro Dam as calculated for the Middle Waikato portion of the modelling.

The key issue in terms of the conclusions derived for this report are;

a) How will the changes in Karapiro Dam discharges translate into flood levels throughout the Lower Waikato Waipa Control Scheme?

b) If there are changes, what remedies need to be considered?

2 UPGRADING THE MIKE11-NAM MODEL

2.1 Purpose

Environment Waikato has used MIKE11-NAM as a predictive design tool for the Lower Waikato and Waipa Rivers since the early 1990's. In 2005 it was decided that the model would be upgraded so that it could be used for real-time flood forecasting. This was completed by the Danish Hydraulics Institute (DHI) in October 2006[1]. During this work the model was altered to allow for real-time measurement of rainfall at 2 gauging stations, Otewa and Te Kuiti. The FloodWatch model (on a dedicated computer) is set-up to run every 3 hours based on telemetered rain and river level gauging data. When discrepancies are found between the predicted and the measured hydraulics, FloodWatch adjusts its parameters by iteration to ensure the forecasting is more realistic. Flows generated by the Waipa River have a major influence on the flooding from Huntly to the Port Waikato. The model was broken up into two discrete models. The Waipa River model generates flows to Whatawhata. This flow is then used as a boundary condition to the Waikato River model. The FloodWatch model uses the 1998 cross-section survey of the Waikato River.

A major re-survey of the Waikato River and an extensive new and re-survey of the Waipa River was completed during 2006 and 2007. Therefore the MIKE11-NAM was upgraded. This provided an opportunity for a number of tidying up issues to also be addressed. For this report the updated model combines the Waikato and Waipa models into one comprehensive model.

2.2 Main Upgrade of the Model

The system has worked extremely well as a flood management tool, especially in the recent July / August flood.

The FloodWatch model uses the 1998 survey of the Waikato River. A major re-survey of the Waikato River and an extensive new and re-survey of the Waipa River was completed during 2006 and 2007.

The reasons for the survey were:

- The Waikato River survey is on a 10 year cycle to assess morphological changes.
- Previous surveys had cross-sections at 800-1000m intervals and it was decided that the intervals should be 500m.
- The Waipa River was surveyed as far south as Otewa whereas previously the model only extended to Whatawhata.

MIKE11-NAM was upgraded to reflect the new bathymetry. This gave the opportunity for a number of tidying up issues to be addressed.

The main elements to upgrading the model were;

a) Additional “A” cross sections were added to the Waikato River model to reflect the new regime whereby a surveyed cross sections exist at approximately 500m intervals,

b) The survey cross section ID numbers were input into the MIKE11-NAM cross section database for quick cross-referencing,

c) Waikato River chainage were adjusted to match as close as possible the survey chainages to give a final fix. This required some cross-sections to be moved up to 100m in the model. Most adjustments were less than 3m,

d) The Waipa River network was extended to accommodate the new survey up to Otewa. The Mangapu River was also added,

e) To create consistency with the “1998” model the bed roughness offsets in this new “2008 model” were adjusted to give the same roughness at the same river level,

f) Minor adjustments were made to the rainfall-runoff file to reflect the new chainages.

g) At the Port Waikato area, the model was reconfigured by deleting WAIKSN channel and a consistent WAIKATO channel was created with a small MOTU ISLAND channel,

h) Background maps were added to assist the modeller,

i) The model coordinates were converted from NZMG to NZTM.

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[1] Waikato River Flood Forecasting Model Update, DHI, October 2006

2.3 Assumptions

The following assumption should be noted

a) The floodplains where *as per* the 1998 model,

b) The rainfall-runoff subcatchments where not altered in the NAM component to keep consistency with the FloodWatch set up.

3 HYDROLOGY

The rainfall-run-off component of the model is done using the NAM routine in MIKE11. NAM uses a conceptual-type approach to predict the movement of rainfall by considering groundwater loss, soil moisture content, evapo-transpiration and run-off. Descriptions of the parameters are tabulated in Appendix G. DHI made some changes to the model when they calibrated the NAM components in 2006. They changed the number of subcatchments for the Waipa River to reflect the telemetered sites. Appendix H shows the sub-catchment break-up of the Waipa and Waikato Rivers and Appendix I give the subcatchments areas.

3.1 Rainfall sites

13 rain gauges are used to provide input to the NAM model. These are at

Whangamarino	Otewa
Hamilton	Puniu at Barton's Corner
Mangatangi	Te Kuiti
Mangawara	Whareriki
Maungatautari	Ngaroma
Ruakura – NIWA	Waitangaruru
Waingaro – Ruakiwi Road	

3.2 Influence of Rain Gauge Sites

Design and measured rain depths can be applied through the average weighting process. Table 3.1 shows the influence of each rain gauge site on the NAM model based on the catchment area it covers. It shows that, all things being equal, the Whangamarino rain gauge needs to be more accurate than the Ngaroma gauge to get better run-off results. Even so, since the highest percentage is only 17% this is a reasonable spread amongst the 13 gauges.

Table 3.1 – Influence of each raingauge site in the NAM model set-up

Rain Gauge Site	Percentage Influence (based on catchment area)
Whangamarino	17%
Mangatangi	4%
Maungakawa	10%
Waingaro	8%
Ruakura	7%
Hamilton	10%
Maungatautari	5%
Puniu	12%
Te Kuiti	6%
Otewa	7%
Waitangaruru	6%
Whareriki	4%
Ngaroma	4%

Table 3.2 shows the change in influence when the actual rainfall from 21 July to 21 August is applied to the weightings. This time the Whangamarino influence has almost halved, Hamilton even more so and Waitangaruru rising from 6% to 15%. This tells us that for this specific flood event the model needs to ensure the catchment calibrations that use the Waitangaruru gauge is reasonably accurate. The same applies less so to Otewa.

Table 3.2 - Rainfall Influence of rainfall for 21 June to 21 July 2008 event

Rain Gauge Sites	Rainfall measured (mm)	Influence and rain
Whangamarino	460	10%
Mangatangi	1205	7%
Maungakawa	803	11%
Waingaro	535	6%
Ruakura	489	5%
Hamilton	269	4%
Maungatautari	1111	7%
Puniu	426	7%
Te Kuiti	546	4%
Otewa	1095	11%
Waitangaruru	1801	15%
Whareriki	1249	6%
Ngaroma	1597	8%

4 HYDRAULICS

The representation of the network of channels within the model has changed little since the DHI calibration. The only exception is the extension of the Waipa River up to Otewa. This adds a further 22km to the upstream end of the Waipa River. There have been no changes made to any of the hydraulic structures within the various drainage systems.

4.1 Floodplains

The floodplains in the Lower Waikato are included as part of the main channel configuration and not as a separate flow channel. The relative roughness of the floodplain area compared to the main channel was set at 3. Using, for example, the floodplain width of 100m for a cross-section near Rangiriri, the impact of this extra roughness was to reduce conveyance by 6%. For typical flood flows along this reach of 1,000m^3/s this assumption could create an error of about 60m^3/s but more realistically about 30m^3/s.

4.2 Sources of Error

Using models to predict the behaviour of the real world is based on assumptions that have been empirically tested over time. It is important to understand the potential sources of error to give context to the results. This is especially so in this particular study because we need to understand the sensitivity of the effects of deforestation and evaluate an upper and lower flood level for the flood protection scheme.

Table 4.1 shows potential errors and their impact in three categories.

Table 4.1 - The source of error and its magnitude based on a large flood event.

Category	**Reason**	**Magnitude for this study**
Catchment run-off	Generated by the calibration of specific catchments and then extrapolated to un-gauged catchments	Up to 5% for total catchments – 50m^3/s
Rating curve	Inaccuracy of the measurements and unable to rate at all flows and levels.	Up to 10% - 100m^3/s
Bed roughness	A Manning's n range of 0.028 to 0.04, which are both reasonable values, change the flood level peak at Mercer by 320mm	200mm

5 MODEL CALIBRATION

5.1 General Methodology

The options available when undertaking any calibration exercise are to change the following main parameters;

a) Rainfall-runoff parameters,

b) Horizontal bed roughness in terms of reaches,

c) Vertical bed roughness in terms of channel depth,

d) Off-channel storage.

Vertical bed roughness is being utilised in that the floodplains have a general resistance factor of 3.0 compared to the main flow channel. Therefore for many of the cross-sections there is a discontinuity to reflect out-of-channel flows.

The calibration tools available are the water level gaugings which have been rated to provide flows. The rating curves for each of these sites also provide an opportunity to understand the general flow / water level relationship.

5.2 Assumptions

The following assumptions were used.

a) The rainfall-runoff parameters would not be changed. These parameters were calibrated by the Danish Hydraulic Institute when FloodWatch was set up,

b) The vertical bed roughness would not be changed,

c) Off-channel storage would not be changed.

d) Tide level boundary varied according to known ranges.

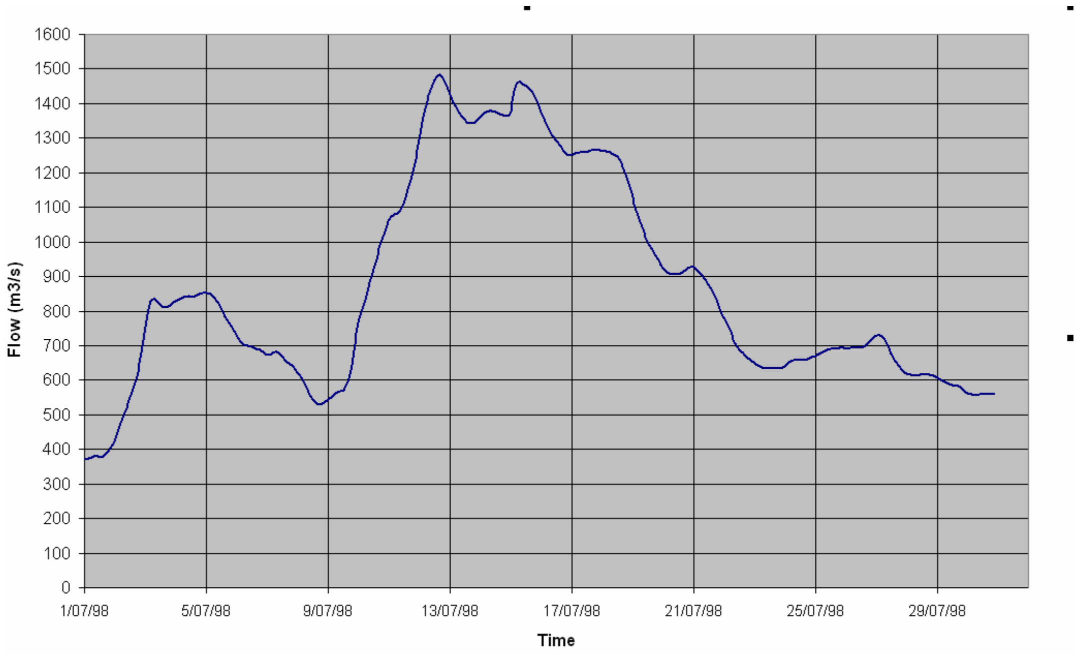
Therefore only the reach bed roughness was changed to match the measured rating curves. The issues with this approach are explained in later sections.

The following 3 flood events have been calibrated. Two of the floods are winter events (1998 and 2008) while the February 2004 flood was chosen to represent a summer event. The 1998 and 2004 was modelled using the old hydraulic model used in FloodWatch while 2008 is modelled using the latest data and configuration.

5.3 1998 Flood

The July 1998 storm produced the largest flood event in recent years. The peak flow at Mercer was estimated to be 1500m^3/s. This equates to a 1 in 100 year flood. This flood therefore ensures the model is calibrated against an "extreme" event to ensure the design events do not have to be extrapolated. Figure 5.1 shows the flows at Ngaruawahia. It can be seen that a small annual flow occurs about a week before the main flood. The steep increase in flow over 3 days shows the catchment is saturated.

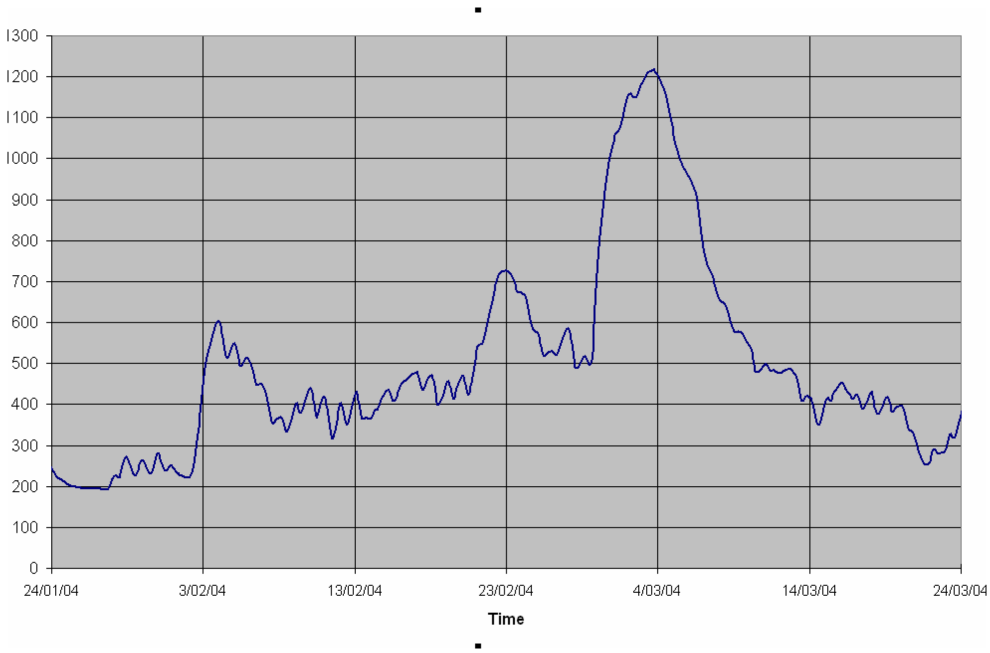
Figure 5.1 – Flows at Ngaruawahia - July 1998



5.4 2004 Flood

This flood event was chosen because it was a summer flood. The flow return period at Ngaruawahia was 1 in 20 years. In terms of simulating a summer flood there is one negative aspect of this event. There was minor annual return period "flood" prior to the main flood and therefore the catchment was not "dry". Figure 5.2 shows the flow hydrograph at Ngaruawahia for the flood event and the preceding 40 days.

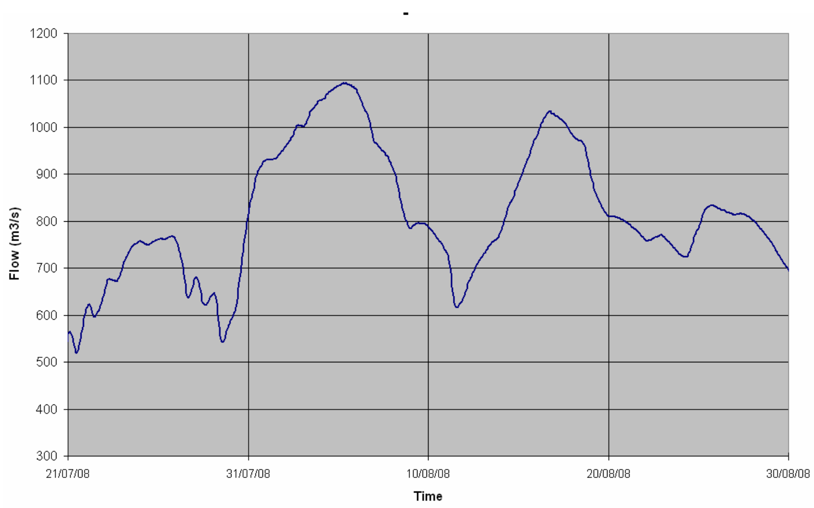
Figure 5.2 – Flows at Ngaruawahia - February 2004



5.5 2008 Flood

This was another typical winter flood event. The return period was about 1 in 15 years in most gauged locations. Figure 5.3 shows the flow hydrograph at Ngaruawahia. It can be seen there are 3 peaks. The first peak is the annual flow, the second peak the 1 in 15 year flow and the third peak the 1 in 10 year flow. Again the catchment is saturated before the main flood.

Figure 5.3 – Flows at Ngaruawahia - August 2008



5.6 Calibration Simulations

All three flood events were calibrated to match known measured rating curves. Figures B1 to B 5, C1 to C4 and D1 to D5 in Appendices B to D show the rating curves comparisons. The methodology applied was to ensure the modelled rating curve was pivoted around the centre of the measured rating curve so that there was as little bias as possible through the water depth range. In every case the curves matched at the peak or the modelled curve was below the measured curve. On close examination there are potential errors along the ratings curves. Table 5.1 shows the error ranges for each flood event at the peak of the flood.

Table 5.1 – Potential Errors at the peak of a flood due to model / measured rating curve differentials

Location	Event	Potential Error
Hamilton	1998	Very little
	2004	Very little
	2008	Very little
Ngaruawahia	1998	200mm or 70m^3/s
	2004	150mm or 100m^3/s
	2008	200mm or 50m^3/s
Rangiriri	1998	200mm or 35m^3/s
	2004	150mm or 100m^3/s
	2008	very little
Control Gate	1998	very little
	2008	50mm or 30m^3/s
Mercer	2008	very little
Whatawhata	1998	800mm or 125m^3/s
	2004	1200mm or 175m^3/s
	2008	very little

By comparing the modelled rating curves against those that were measured there are a number of issues. Firstly in all cases the modelled values (when not accurate) either gave a greater flow at a given level OR a lower level at a given flow. Hamilton rating was very good. Ngaruawahia always gave an error of at least 150mm or 50m^3/s. The Whatawhata site gave the largest error.

5.7 Flow and Water Level Hydrographs

If it is assumed that the rating curves are acceptable then what do the flow and water level hydrographs look like? Figures B6 to B18, C5 to C17, D6 to D17 in Appendix B to D show the graphs. The tables in Appendix E summarises the differences.

In all cases the model could not replicate the peak flows (and thus levels) at the Hamilton site. Assuming the Hamilton rating is good suggests the input flows (predominantly from Karapiro Dam) are too low. However if flows were increased (by changing the hydrological parameters) then modelled flows at Ngaruawahia, Rangiriri and Mercer would worsen the calibration. This creates a dilemma.

The Whatawhata site needs improving. Its modelled flood levels are consistently too low. A solution would be to increase flows by 150m^3/s (by changing the hydrological parameters) through Otorohanga and Whatawhata. When doing this the1998 flow comparison is worse, the 2004 flow is better and the 2008 flow is mixed. Water levels at Otorohanga and Whatawhata were improved. However putting an extra 150m^3/s through the Waipa tributary and into the Waikato would compromise results at Ngaruawahia and downstream. The conclusion would be not to increase flows.

Another solution would be to increase bed roughness for Waipa River. Presently Manning's M is set in the range 15 to 25 and so is quite rough anyway and therefore increasing roughness will be backward step. When referencing *The Roughness Characteristics of NZ Rivers* book published by NIWA the M value for the Waipa River at Whatawhata is 26 for a flow of 628m^3/s. Therefore the bed roughness is already a reasonable value. In addition to this, by increasing the bed roughness the peak flows will reduce. These are already too low. Therefore it can be concluded that further adjusting the bed roughness along the Waipa River will give no improvement.

5.8 Strategy to Improve Calibration

The model has been calibrated for 3 flood events. The key calibration technique is to get the measured and modelled ratings curves to match. This causes potential errors because the bed roughness is assumed uniform through the height of the cross-section. However many rating curves are generally reasonable except there is sometimes a lot of noise in the lower parts of the cross-section and the upper parts diverge.

When examining the flow and water level hydrographs it is difficult to make a specific change at one location that does not compromise another location. It is tempting to increase run-off for certain sub-catchment but the downstream flood levels would be compromised.

The final calibrated Manning's M Values for the reaches are given in Table 5.3. The range of values for the 3 floods is within reasonable limits. The 2008 M values will be used in the design flood events. Note that the Waipa River is configured differently for chainages and reach names for 1998 and 2004 versus 2008.

5.9 Ratio of Flow Contribution

Figures F1 to F6 in Appendix F show the flow ratios of the Waikato and Waipa Rivers at Ngaruawahia for both the measured and modelled flows. The minimum contribution from the Hamilton to Ngaruawahia reach (a proxy for the Karapiro Dam outflow) is given in Table 5.2.

Table 5.2 – Minimum flow contribution from Karapiro Dam

	Modelled	**Measured**
July 1998	33%	42%
February 2004	39%	50%
August 2008	43%	42%

Table 5.3 – Final calibrated Manning's M values

Reach	River	Chainage (m)	1998	2004	2008
Otorohanga	WAIPA	0			25
	WAIPA	63,275			25
Otorohanga	UPPER WAIPA	22,389	20	20	
	UPPER WAIPA	11,1107	20	20	
Whatawhata	WAIPA	64,309			20
	WAIPA	140,340			20
Whatawhata	WAIPA	100,000	16	20	
	WAIPA	128,900	16	20	
	WAIKATO	0	36	36	36
	WAIKATO	20,759	36	36	36
Hamilton	WAIKATO	21,028	30	30	25
	WAIKATO	45,858	30	30	25
Ngaruawahia	WAIKATO	46,488	30	30	31
	WAIKATO	59,694	30	30	31
	WAIKATO	60,746	30	30	31
	WAIKATO	72,289	30	30	31
Rangiriri	WAIKATO	72,831	28	28	28
	WAIKATO	90,273	28	28	28
Mercer / Control Gate	WAIKATO	90,661	33	33	30
	WAIKATO	112,476	33	33	30
	WAIKATO	113,260	33	33	33
	WAIKATO	134,221	33	33	33
	WAIKATO	134,684	33	33	33
	WAIKATO	150,891	33	33	33

The August 2008 event comparison was good. However, for July 1998 and February 2004 the modelled contribution is about 10% lower than that measured. This is because the modelled flows through Hamilton are lower than that measured.

5.10 Calibration Conclusions

The calibration of the model has been undertaken using 4 tests. These are a) flows, b) water levels, c) rating curves and d) flow ratios at Ngaruawahia.

The results were mixed but considering the number of calibration points and by using the same hydrological parameters the results were reasonable. Overall the 1998 calibration was probably the best and the 2008 calibration marginally better than the 2004.

Therefore it is best to leave the calibrated model "as-is" bearing in mind that the changes in flows at Karapiro Dam due to land-use change is a relative test on flood levels in the Lower Waikato Waipa Flood Control Scheme and not an absolute test.

6 DESIGN STORMS

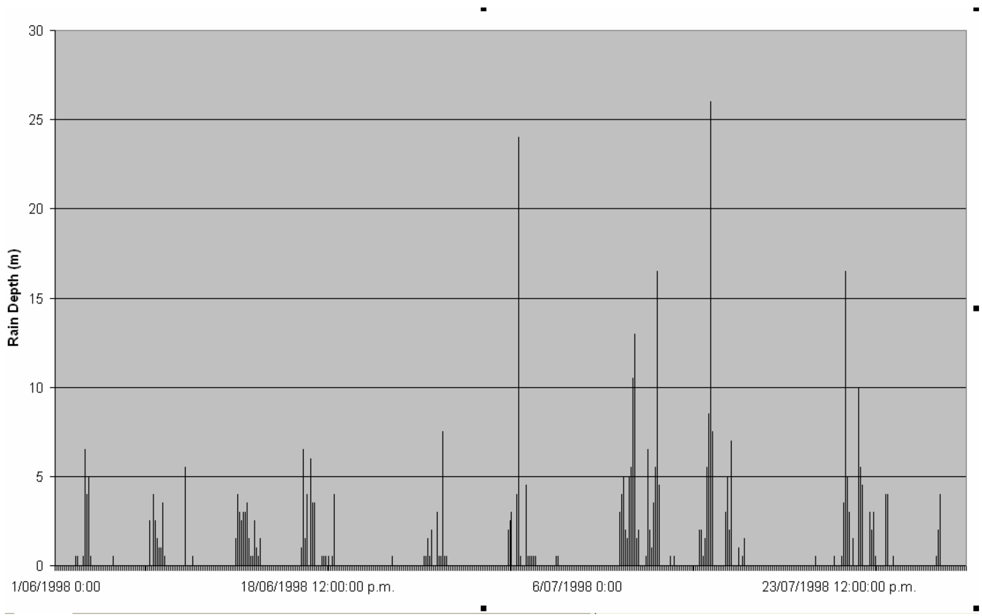
6.1 Introduction

The 2008 hydrological/hydraulic model was used for all design flood events. The 5, 10, 20, 50, 100 and 500 year design rainfall events were required to generate flood levels in the Lower Waikato. Analysis was undertaken using the rainfall pattern of the 1998 flood (a greater than 7-day rainfall) and the 1958 flood (3-day rainfall).

6.2 1998 Style Storm

Originally the LWWCS was designed using a 3-day rain event. This rain event may not replicate antecedent conditions now being modelled using MIKE11-NAM. It was decided that the rainfall pattern that caused the 1998 flood would be used. The rainfall pattern for the Whangamarino gauge is shown below in Figure 6.1.

Figure 6.1 – Rainfall pattern measured at Whangamarino site July 1998



6.2.1 Design Rainfall Derivation

The steps to generate the hyetographs for each of the 13 rain-gauge sites were;

Step 1 - Calculate rain depths using HIRDS. Table 6.1 gives the gauge locations in NZTM coordinates while Table 6.2 gives the calculated rain depth.

Table 6.1 – Rain gauge locations for HIRDS calculation

Location	Northing	Easting
Whangamarino	6432787	2693330
Mangatangi	6452391	2706265
Maungakawa:	6419838	2721346
Ruakiwi Road	6383448	2684273
EW-Hamilton:	6377236	2712303
Ruakura:	6377791	2715669
Maungatautari:	6349534	2739800
Barton’s Corner	6350882	2711143
Ngaroma:	6316090	2732405
Te Kuiti	6316128	2701004
Waitangaruru:	6311114	2672958
Wharekiri:	6302082	2725100
Otewa:	6323961	2715594

Table 6.2 – Rain depths generated by HIRDS

	Return Period Years					
Location	5	10	20	50	100	500
Whangamarino	105	128	149	183	216	313
Mangatangi	158	196	229	283	336	486
Maungakawa:	118	138	160	196	231	336
Ruakiwi Road	110	130	150	183	215	311
EW-Hamilton:	96	117	134	162	189	274
Ruakura:	96	117	134	162	189	274
Maungatautari:	123	144	164	197	228	330
Barton’s Corner	107	124	141	169	196	284
Ngaroma:	155	185	210	249	285	414
Te Kuiti	118	141	160	191	221	320
Waitangaruru:	167	196	220	260	298	432
Wharekiri:	152	176	199	236	270	392
Otewa:	127	148	168	199	229	332

Note that the 5 year rain was calculated by interpolation and the 500 year rain by extrapolation.

Step 2 – Extract 1998 Rain Profile

Extract measured rain depths for the period 1st June 1998 to 1st August 1998 for each rain gauge.

Step 3 – Calculate the maximum 3-day rain depth for each rain gauge

Step 4 – Decide on the Area Reduction Factor

The ARF was set to 0.6 based on discussions and agreement of the Technical Expert Panel.

Step 5 – Calculate final scale factors

The rain depth for each gauge is the ratio of steps 1 and 3 multiplied by the ARF in step 4. For example for the 100-year storm at Whangamarino, the measured 3-day 1998 maximum rain was 93mm, the HIRDS rain depth is 216mm. This gives a final ratio of 216 / 93 x 0.6 = 1.39.

Step 6 – Multiply 1998 rain depths by ratios calculated in step 5

Do this for all rain gauges and return periods.

These rain depths were then applied to the MIKE11-NAM model for the 2008 model.

6.2.2 Input flows at Karapiro

The key inputs to this modelling work are the flows generated by the hydrological model of the Middle Waikato which is then routed through Karapiro Dam. The Karapiro flow was input for each return period using TOPNET and HEC-HMS. The TOPNET model was developed, calibrated and run by NIWA and the HEC-HMS modelling was done by Sinclair Knights Merz Ltd in conjunction with Environment Waikato. The purpose of having two hydrological models of the Middle Waikato was to compare outputs against each other and for the land-use changes. This reduces the significance of using one methodology that may influence the final results

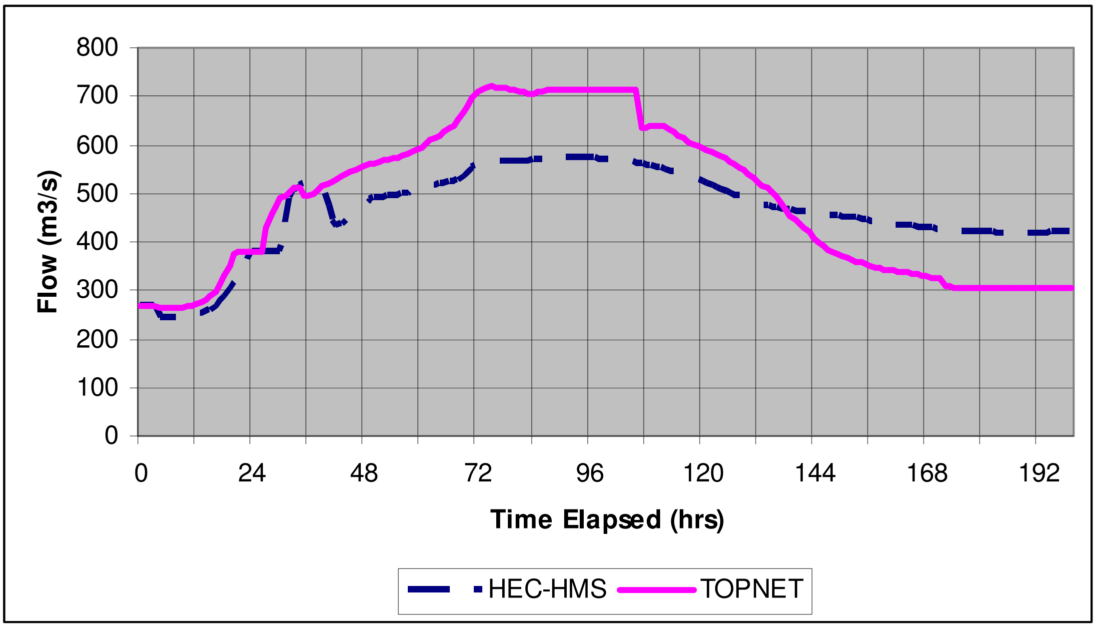
When TOPNET and HEC-HMS were run for both the current land-use and the converted land-use it was found the peak flow at Karapiro changed very little. Table 6.3 shows the Karapiro Dam peak flows. It can be seen that the TOPNET model increased Karapiro flows by 1.2% for the 500-year event while HEC-HMS gave a corresponding 2.2% increase. These changes in flow are relatively trivial. Therefore it was decided to only simulate the current land-use scenario. The key examination therefore is to test the flood level sensitivity at key locations for each hydrological method.

Table 6.3 – Comparison of hydrological methods and land-use change

	Return Period (years)					
	500	100	50	20	10	5
TOPNET						
Current	926	720	628	552	519	466
Converted	937	732	634	556	520	467
Increase	11	12	6	4	1	1
HEC-HMS						
Current	730	574	510	475	448	434
Converted	746	577	510	475	447	434
Increase	26	3	01	0	1	0

Figure 6.2 gives an example of the Karapiro flow hydrograph calculated both methods. Clearly TOPNET is generating a peak flow 25% greater than HEC-HMS and with a 9% greater volume.

Figure 6.2 – The 100-year Karapiro Flow for TOPNET & HEC-HMS



6.2.3 Design Storm Simulations

All 6 return periods were run for both TOPNET and HEC-HMS. Table 6.4 shows the peak flows at Ngaruawahia.

Table 6.4 – Peak Flow Comparison at Ngaruawahia – 1998 Style Rainfall

Return Period (years)	TOPNET (m3/s)	HEC-HMS (m3/s)	Absolute Difference (m3/s)	% Difference
5	864	829	35	4.1
10	867	888	21	2.4
20	1,050	959	91	8.7
50	1,217	1,099	118	9.7
100	1,403	1,256	147	10.5
500	1,985	1,786	199	10.0

The differences in the hydrological method in the Middle-Waikato are not greater than 10.5% but in real terms it is still 147m3/s. This difference can generate a reasonable difference in peak flood level. The hydraulic differences due to the hydrology model need to be assessed. Table 6.5 gives the flood levels at Ngaruawahia for 3 return periods.

Table 6.5 – Peak Water Level Comparison (RL(m)) at Ngaruawahia– 1998 Style Rainfall

Return Period (years)	TOPNET RL(m)	HEC-HMS RL(m)	Difference (m)
20	12.52	12.27	0.25
50	12.96	12.67	0.29
100	13.40	13.06	0.34

Table 6.5 shows that, as the flood frequency reduces, the greater the difference in flood levels at Ngaruawahia between TOPNET and HEC-HMS. This is surprising since the greater rain depths should saturate the catchments and the run-off converges to 100% in the latter part of the storm.

6.2.4 Changes Simulated in the Lower Waikato

The flows and flood levels for full set of return periods were then generated to examine how the change in flows due to hydrological method may affect flood levels in the Lower Waikato. Table 6.6 summarises the findings.

Table 6.6 - Differences in flows and water levels due to the hydrological method– 1998 Style Rainfall.

Location	Model Chainage	20 year	50 year	100 year
Main Channel Water Level Differences (m)				
Hamilton	WAIKATO 33806.00	0.45	0.62	0.71
Ngaruawahia	WAIKATO 53730.00	0.25	0.30	0.34
Huntly	WAIKATO 67661.00	0.22	0.25	0.28
Rangiriri	WAIKATO 84010.00	0.20	0.20	0.19
Control Gate	WAIKATO 106537.00	0.20	0.23	0.23
Mercer	WAIKATO 109215.00	0.18	0.21	0.22
Tuakau	WAIKATO 120038.00	0.17	0.18	0.18
Tributary Water Level Differences (m)				
Mangatawhiri at Railway Bridge	MANGATAWHIRI 2483.00	0.19	0.21	0.17
Lake Waikare Northern Spillway	LAKE_WAIKERE-NORTHERN SPILLWAY 0.00	0.00	0.00	0.05
Mangawara at McConnell Road	MANGAWARA RIVER 20260.00	0.05	0.05	0.05
Waipa at Maroheno Stream	WAIPA 136112.00	0.17	0.18	0.21
Whakapipi	WHAKAPIPI 2857.50	0.16	0.17	0.16
Whangape at Rotongaro outlet	WHANGAPE DS 10576.00	0.17	0.17	0.20
Main Channel Flow Differences (m3/s)				
Hamilton	WAIKATO 33566.00	78	115	142
Ngaruawahia	WAIKATO 54024.50	91	119	147
Rangiriri	WAIKATO 84319.50	89	111	115
Control Gate	WAIKATO 106770.00	81	100	105
Mercer	WAIKATO 109628.50	81	100	105
Tuakau	WAIKATO 120314.00	79	98	104

Table 6.6 shows that the water level differences range from 0.17m to 0.71m in the main channel. The average difference is about 0.25m and the contextual impact on freeboard allowance must be considered.

Table 6.7 gives a summary of stopbank lengths along the Waikato River Main Channel against their protection standard return period and freeboard.

Table 6.7 – Stopbank Aggregate Lengths for Return Period and Freeboard Protection

		Return Period (years)	
		20 (MEDIUM)	100 (HIGH)
Freeboard (mm)	300	9km	50km
	600	26km	12km

For 100 year flows the differences in hydrological method is 0.34m at Ngaruawahia to 0.18m in Tuakau. This uses 36% to 68% of the freeboard budget for 12km of stopbanks and 60% to >100% of the allowance for 50km of stopbanks due to the hydrological analysis methodology used. Typically the freeboard allowance is based on a combination of unknown hydrological and hydraulic parameters. If the weighting between the 2 phenomena are 50-50 then the analysis shows the hydrological methods generate water level differences higher than that preferred.

6.2.5 Limitation of rating curves

The calibration of the model and its subsequent design flow simulations rely on good rating curves. A check was made on the applicability of the rate curves at high flood levels.

Examining the Ngaruawahia gauge, the peak 500 year flood level is RL15.54m while the rating curve reaches RL13.8m. The corresponding figures at Rangiriri are RL9.37m and RL9.05m. Therefore the extrapolation at Ngaruawahia is gravely erroneous while at Rangiriri the technique is slightly optimistic.

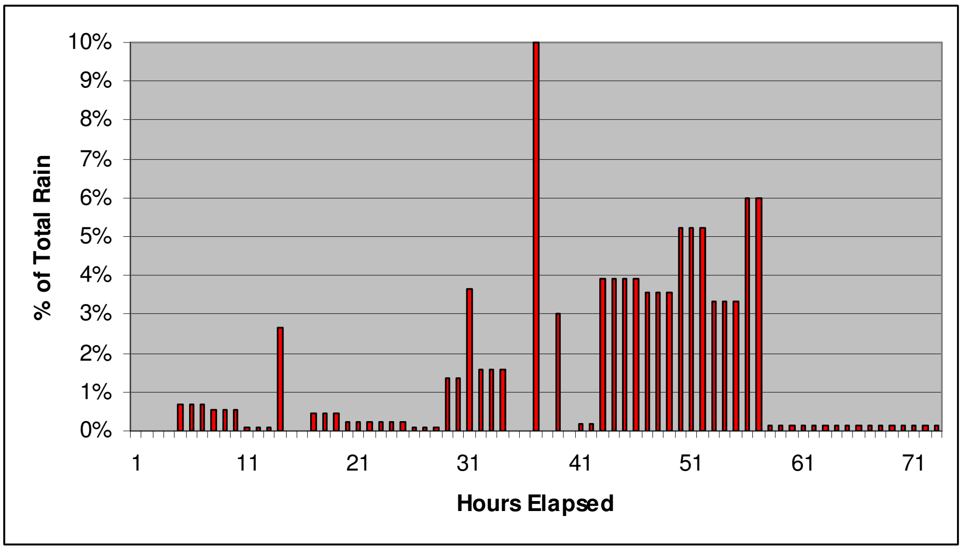
The flows and levels for the 100 year event fall within the measured bounds and thus should be reasonable.

6.3 The 1958 Style Storm

6.3.1 Introduction

The 1958 storm caused widespread flooding. It was a summer event. The rainfall pattern of this storm was applied to the HIRDS rainfalls for each return period using the same methodology as the 1998 style event. The rainfall pattern is shown in Figure 6.3 below.

Figure 6.3 – Rainfall pattern for 1958 style storm



6.3.2 Input flows at Karapiro

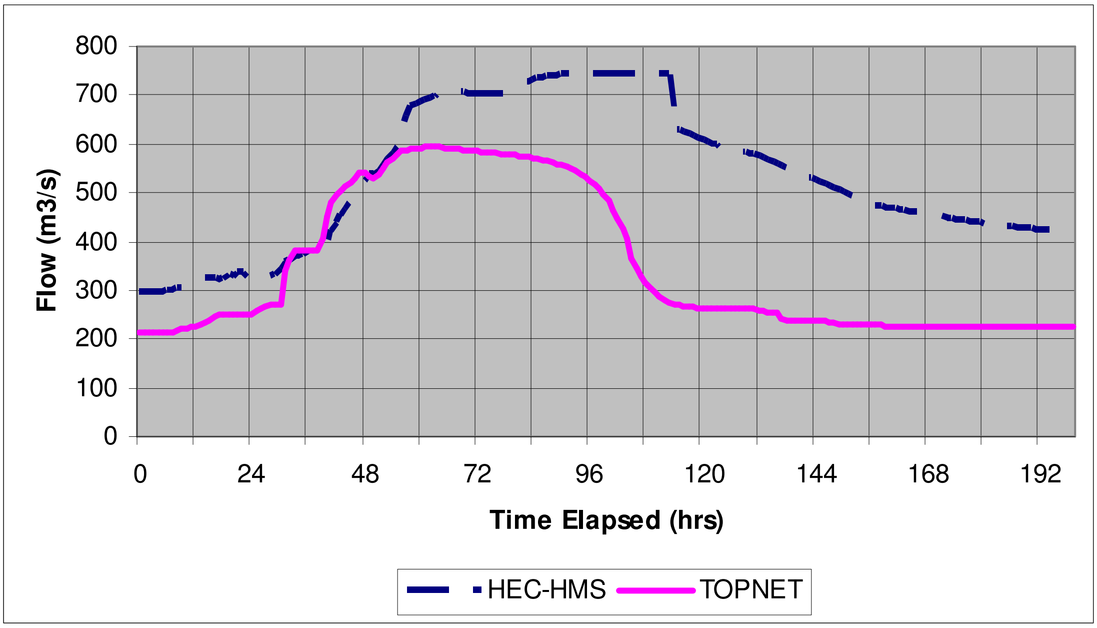
The TOPNET and HEC-HMS hydrological models were used in the Middle Waikato and routed through Karapiro Dam. An area reduction factor of 0.75 was applied to the rainfall depths. Table 6.8 summarises the peak flows generated at Karapiro Dam for the current and converted cases for both the TOPNET and HEC-HMS analyses. In this case the impact of land-use change is much greater. While TOPNET only showed a 1.2% difference at the 100-year return period the HEC-HMS method generated a 2.7% difference. Therefore land-use changes have impact on flows at Karapiro Dam for less frequent events.

Table 6.8 – Comparison of hydrological methods and land-use change – 1958 Style

	Return Period (years)					
	500	**100**	**50**	**20**	**10**	**5**
TOPNET						
Current	1,088	594	526	512	491	466
Converted	1,154	601	531	509	491	468
Increase	66	7	5	-3	0	2
HEC-HMS						
Current	1,160	742	601	530	522	493
Converted	1,300	762	605	533	522	493
Increase	140	20	4	3	0	0

Figure 6.4 shows an example flow hydrograph comparison at Karapiro Dam. In this case HEC-HMS is higher by 25% for flows and 49% for volumes. Interestingly this is opposite to the 1998 style rainfall analysis where TOPNET was much higher.

Figure 6.4 – The 100-year Karapiro Flow for TOPNET & HEC-HMS - Current Land-use – 1958 Style



6.3.3 Design Storm Simulations

All 6 return periods were run for both TOPNET and HEC-HMS. Table 6.9 shows the peak flows at Ngaruawahia.

Table 6.9 – Peak Flow Comparison at Ngaruawahia – 1958 Style Rainfall

Return Period (years)	TOPNET (m3/s)	HEC-HMS (m3/s)	Absolute Difference (m3/s)	% Difference
5	614	650	36	5.8
10	674	717	41	6.4
20	728	793	65	8.9
50	915	947	32	3.4
100	1091	1143	52	4.8
500	1866	1854	12	0.6

The differences in the hydrological method used in the Middle-Waikato range create flow changes at Ngaruawahia of between 0.6% and 8.9%. Similar to the 1998 analysis, these differences can generate a variation in peak flood levels. Table 6.10 gives the flood levels at Ngaruawahia for 3 return periods. It can be seen that the difference is below the margin of error for the models as described in Section 4.2.

Table 6.10 – Peak Water Level Comparison (RL(m)) at Ngaruawahia

Return Period (years)	TOPNET RL(m)	HEC-HMS RL(m)	Difference (m)
20	11.54	11.54	0.00
50	12.12	12.21	0.09
100	12.60	12.74	0.14

Table 6.10 shows that, depending on which method are used, TOPNET and HEC-HMS can influence flood levels at Ngaruawahia by 0.00m to 0.14m. Therefore for this type of storm event the hydrological method used is not important.

Table 6.11 shows the differences in key attributes for the 2 hydrological methods. Along the main channel the worst difference is at Hamilton for the 100-year flood. The difference of 0.65m, while large, is probably due to the large difference in Karapiro Dam inputs that have not attenuated very well in the Hamilton reach. Focusing on areas within the LWWCS, the differences range from 0.07m to 0.20m, which is reasonable and not unexpected.

The impact within the tributaries is mixed and depends on how connected the area of concern is to the main channel.

Finally the flow differences in the main channel are within a reasonable tolerance level.

Table 6.11 - Differences in flows and water levels at key locations due hydrological method and current land-use – 1958 style.

Location	**Model Chainage**	**20 year**	**50 year**	**100 year**
Main Channel Water Level Differences (m)				
Hamilton	WAIKATO 33806.00	-0.24	-0.39	-0.65
Ngaruawahia	WAIKATO 53730.00	-0.20	-0.09	-0.14
Huntly	WAIKATO 67661.00	-0.16	-0.07	-0.12
Rangiriri	WAIKATO 84010.00	-0.15	-0.08	-0.11
Control Gate	WAIKATO 106537.00	-0.11	-0.09	-0.13
Mercer	WAIKATO 109215.00	-0.10	-0.08	-0.12
Tuakau	WAIKATO 120038.00	-0.09	-0.08	-0.12
Tributary Water Level Differences (m)				
Mangatawhiri at Railway Bridge	MANGATAWHIRI 2483.00	-0.09	-0.07	-0.11
Lake Waikare Northern Spillway	LAKE_WAIKERE-NORTHERN SPILLWAY 0.00	-0.01	-0.02	-0.02
Mangawara at McConnell Road	MANGAWARA RIVER 20260.00	-0.02	0.00	-0.01
Waipa at Maroheno Stream	WAIPA 136112.00	-0.13	-0.01	0.00
Whakapipi	WHAKAPIPI 2857.50	-0.08	-0.08	-0.11
Whangape at Rotongaro outlet	WHANGAPE DS 10576.00	-0.15	-0.10	-0.19
Main Channel Flow Differences (m3/s)				
Hamilton	WAIKATO 33566.00	-30	-79	-148
Ngaruawahia	WAIKATO 54024.50	-65	-32	-53
Rangiriri	WAIKATO 84319.50	-56	-31	-53
Control Gate	WAIKATO 106770.00	-35	-32	-53
Mercer	WAIKATO 109628.50	-35	-32	-53
Tuakau	WAIKATO 120314.00	-37	-32	-51

6.3.4 Changes Simulated in the Lower Waikato

Change in flows and water levels due to land-use change that may affect flood levels in the Lower Waikato are given in Table 6.12.

Table 6.12 - Differences in flows and water levels due to land-use change.

		HEC-HMS			TOPNET		
		Return Period (years)					
Location	**Model Chainage**	**20**	**50**	**100**	**20**	**50**	**100**
Main Channel Water Level Differences (m)							
Hamilton	WAIKATO 33806.00	0.01	0.03	0.11	-0.03	0.04	0.04
Ngaruawahia	WAIKATO 53730.00	0.00	0.00	0.04	0.03	0.02	0.03
Huntly	WAIKATO 67661.00	0.01	0.01	0.04	0.02	0.01	0.02
Rangiriri	WAIKATO 84010.00	0.00	0.01	0.04	0.02	0.02	0.03
Control Gate	WAIKATO 106537.00	0.00	0.01	0.04	0.01	0.02	0.02
Mercer	WAIKATO 109215.00	0.00	0.01	0.04	0.01	0.02	0.03
Tuakau	WAIKATO 120038.00	0.00	0.01	0.03	0.01	0.01	0.03
Tributary Water Level Differences (m)							
Mangatawhiri at Railway Bridge	MANGATAWHIRI 2483.00	0.00	0.01	0.04	0.00	0.00	0.02
Lake Waikare Northern Spillway	LAKE_WAIKERE-NORTHERN SPILLWAY 0.00	0.00	0.00	0.00	0.00	0.00	0.01
Mangawara at McConnell Road	MANGAWARA RIVER 20260.00	0.00	0.00	0.00	0.00	0.00	0.01
Waipa at Maroheno Stream	WAIPA 136112.00	0.00	0.00	0.02	0.02	0.02	0.03
Whakapipi	WHAKAPIPI 2857.50	0.00	0.00	0.03	0.01	0.01	0.02
Whangape at Rotongaro outlet	WHANGAPE DS 10576.00	0.01	0.01	0.02	0.02	0.02	0.02
Main Channel Flow Differences (m3/s)							
Hamilton	WAIKATO 33566.00	3	5	21	0	7	6
Ngaruawahia	WAIKATO 54024.50	1	1	18	9	6	11
Rangiriri	WAIKATO 84319.50	0	2	17	7	6	12
Control Gate	WAIKATO 106770.00	0	2	17	3	6	11
Mercer	WAIKATO 109628.50	0	2	17	3	5	12
Tuakau	WAIKATO 120314.00	1	3	21	3	7	10

It can be seen that the greatest increase due to land-use change in the LWWCS reach is 0.04m at Ngaruawahia for the 100 year flood using HEC-HMS.

Comparisons within the LWWCS tributaries show all differences to be less than 0.05m

6.3.5 Discussion

A 1958 rainfall style flood was modelled for the full set of return periods using both TOPNET and HEC-HMS hydrological models. A difference in flood levels occurs due to the land conversion. It would be prudent to treat the 500 year flood event with caution because of the over-topping of stopbanks. Moreover the limitation of the rating curves has also been reached.

There are two tests. Firstly what is the difference in the hydrological method and what is the difference due to land-use change.

Table 6.13 shows that the hydrological method has a greater influence on flood level differences than land-use. The 1998 style flood had TOPNET generate the highest flow at Karapiro Dam while it was the opposite for the 1958 style flood.

Table 6.13 - Differences in water levels at key locations due hydrological method and land-use – 100 year storm (m)

	1998 style (long rainfall)		**1958 style (3-day rainfall)**	
	Hydrological Method	**Land-use (1)**	**Hydrological Method**	**Land-use (2)**
Ngaruawahia	0.34	0.00	0.14	0.04
Rangiriri	0.19	0.00	0.11	0.04
Mercer	0.22	0.00	0.12	0.04

Note (1) Assumed as zero. No calculation done but inferred from little change at Karapiro Dam. (2) Largest difference chosen between both methods.

The long duration storm for the 1998 style showed that 100% of the flood level change is attributed to the hydrological method. However when the 1958 style is considered (the hydrology method used in the original design of the LWWCS) the attribution due to the hydrological method is reduced to 75%. More importantly the methodology differences and the land-use differences are well within the error estimates discussed in Section 4.2.

There is minimal impact on the tributaries.

6.4 Impact of 500-year Event

The 500 year return period storm was modelled based on the 1958 and 1998 Karapiro flows. This was done to determine the impact of land conversion in Hamilton and Huntly. Comparisons could not be made with other downstream locations because the stopbanks would overtop and this phenomena was not modelled.

6.4.1 Changes in Hamilton

Table 6.14 shows the flood levels for the 500-year event, the 2 rainfall styles and the land conversions at MIKE11 chainage 33,806m (Bridge St gauging site).

Table 6.14 – 500 year Flood Levels

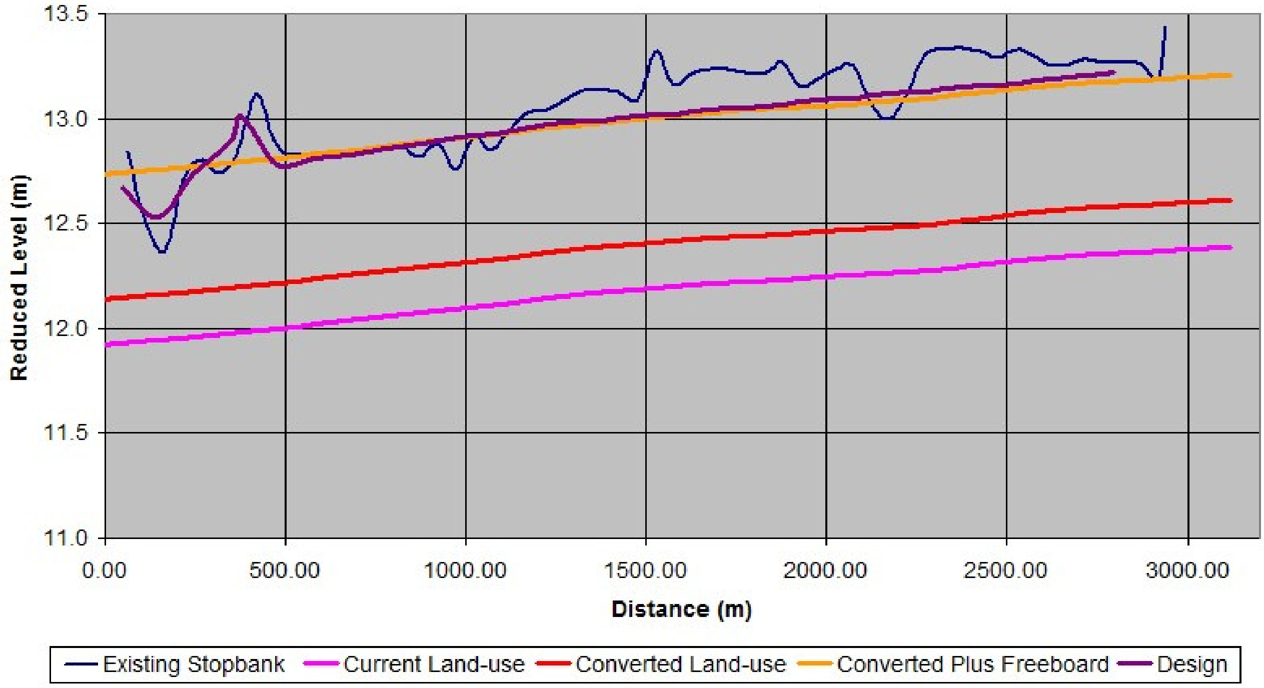
Rainfall Style	Land-use	Hydrological Model	Peak Flood Level RL(m)
1958	Current	TOPNET	17.31
		HEC-HMS	17.62
	Converted	TOPNET	17.59
		HEC-HMS	18.15
1998	Current	TOPNET	17.04
		HEC-HMS	16.24

The results show that the 1958 style event gives the highest flood level and for the worst-case scenario (HEC-HMS) the impact of the land conversion is an increase of 0.53m. Potentially the future flood level could rise to RL18.15m at the Bridge St bridge gauge site. These levels are beyond the highest levels for the measured rating curve.

6.4.2 Impact in Huntly

Figure 6.5 shows the modelled flood profiles against the i) existing stopbank, ii) design levels and iii) the 600mm freeboard along the Huntly South stopbank. The flood profiles are based on the HEC-HMS results for the 1958 style rainfall.

Figure 6.5 – Huntly South Stopbank Profiles, 1958, HEC-HMS



The land conversion raises flood levels by about 0.22m. However the graph clearly indicated that even with the land conversion the design stopbank heights will not be breached.

7 SUMMARY

A MIKE11-NAM model was used to test the differences in flow regimes routed through Karapiro Dam. The model was updated and improved to reflect better survey data. It was calibrated for 3 recent flood events. By constraining the calibration to retaining the DHI 2006 calibration parameters the results were mixed but reasonable. There is a lot of reliance on the measured ratings being correct.

Design flood events were analysed using HIRDS rainfall scaled with the 1998 rainfall and 1958 profiles.

The Middle Waikato hydrology models (TOPNET and HEC-HMS) showed that peak flow changes at Karapiro Dam due to land-use change was trivial for 1998 and clearer for the 1958 style event.

A comparison was made at Ngaruawahia between the TOPNET and HEC-HMS methods. The percentage difference in flows was no greater than 11%. The difference in flood level was up to 0.38m due to the hydrological method and 0.04m due to land-use change. This would mean that 116% of the freeboard allowance of 50km of stopbanks is taken up by hydrological analysis. This may be a concern if undertaking design work but is a moot point for this study which is only interested in comparisons due to land-use change.

7.1 Recommendations for Model Improvement

- Undertake an attribution analysis to determine which hydraulic and hydrological parameters influence the differences in flood levels for TOPNET, HEC-HMS and MIKE11-NAM.
- Consider adjusting the NAM parameters based on the 2008 flood event to improve the calibration.

Appendix A

General Data

Appendix B

July 1998 Calibration Graphs

Figure B1 - Hamilton Rating Curve - July 1998 Calibration

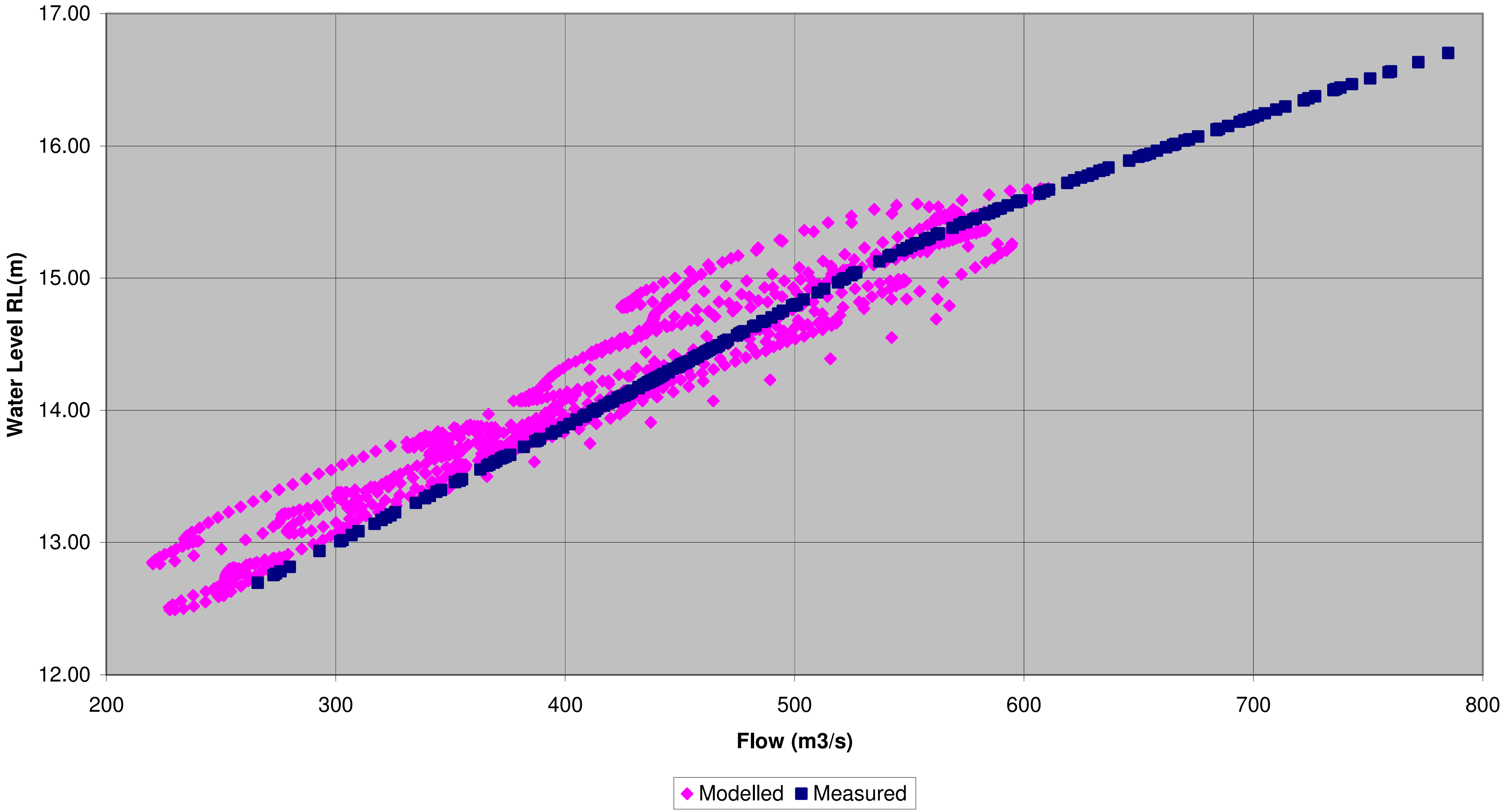


Figure B2 - Ngaruawahia Rating Curve - July 1998 Calibration

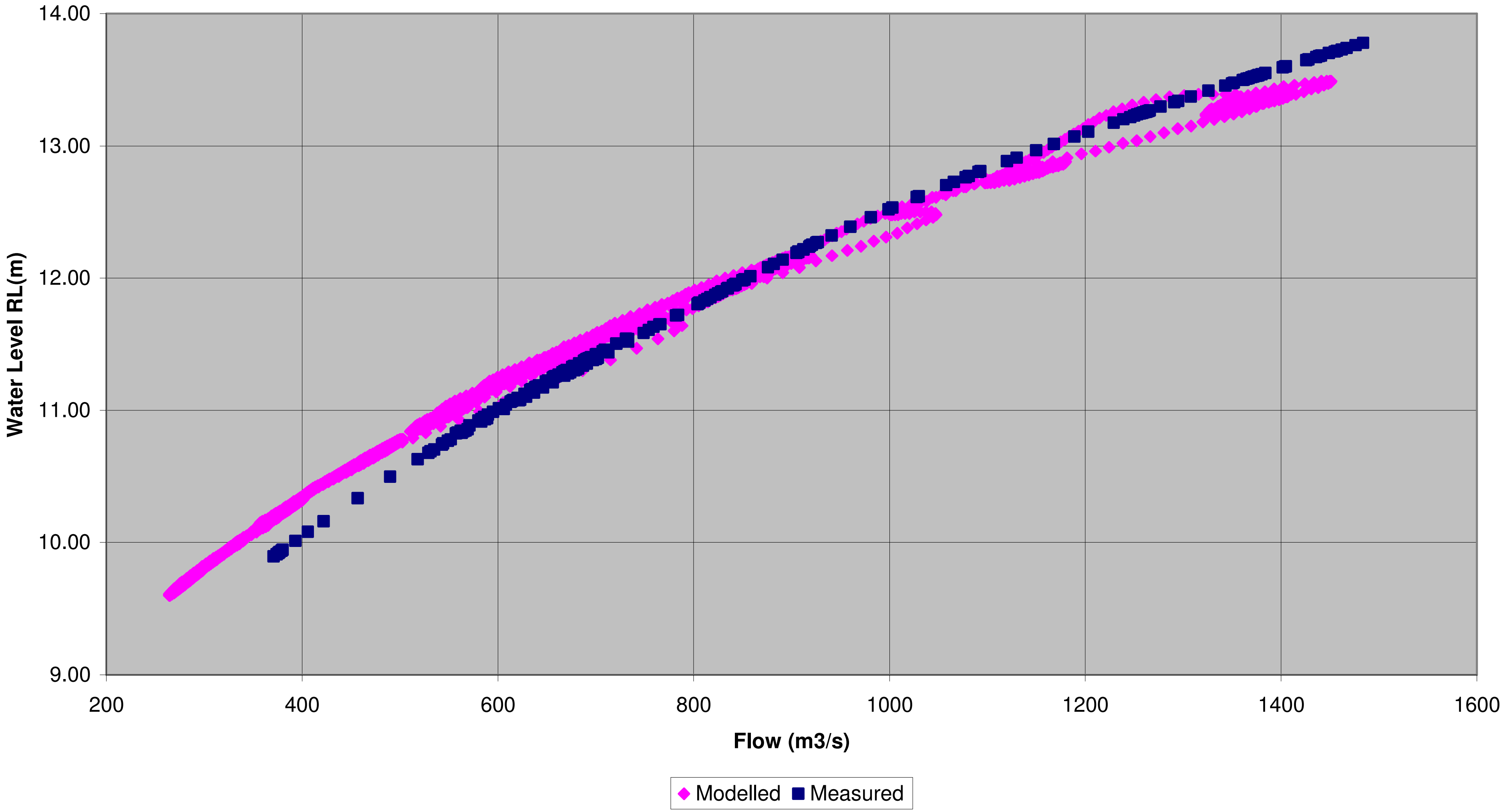


Figure B3 - Rangiriri Rating Curve - July 1998 Calibration

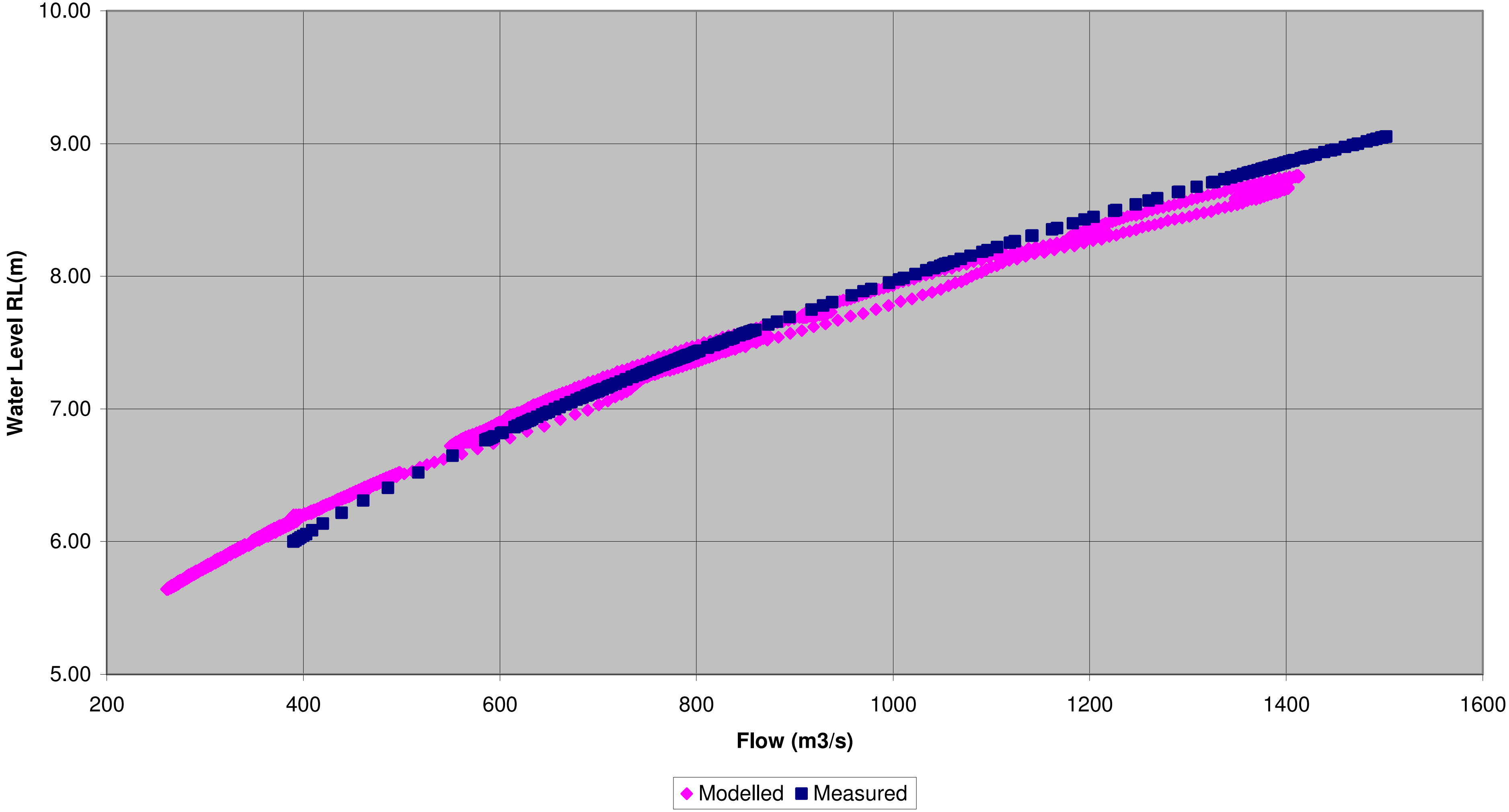


Figure B4 - Control Gate Rating Curve - July 1998 Calibration

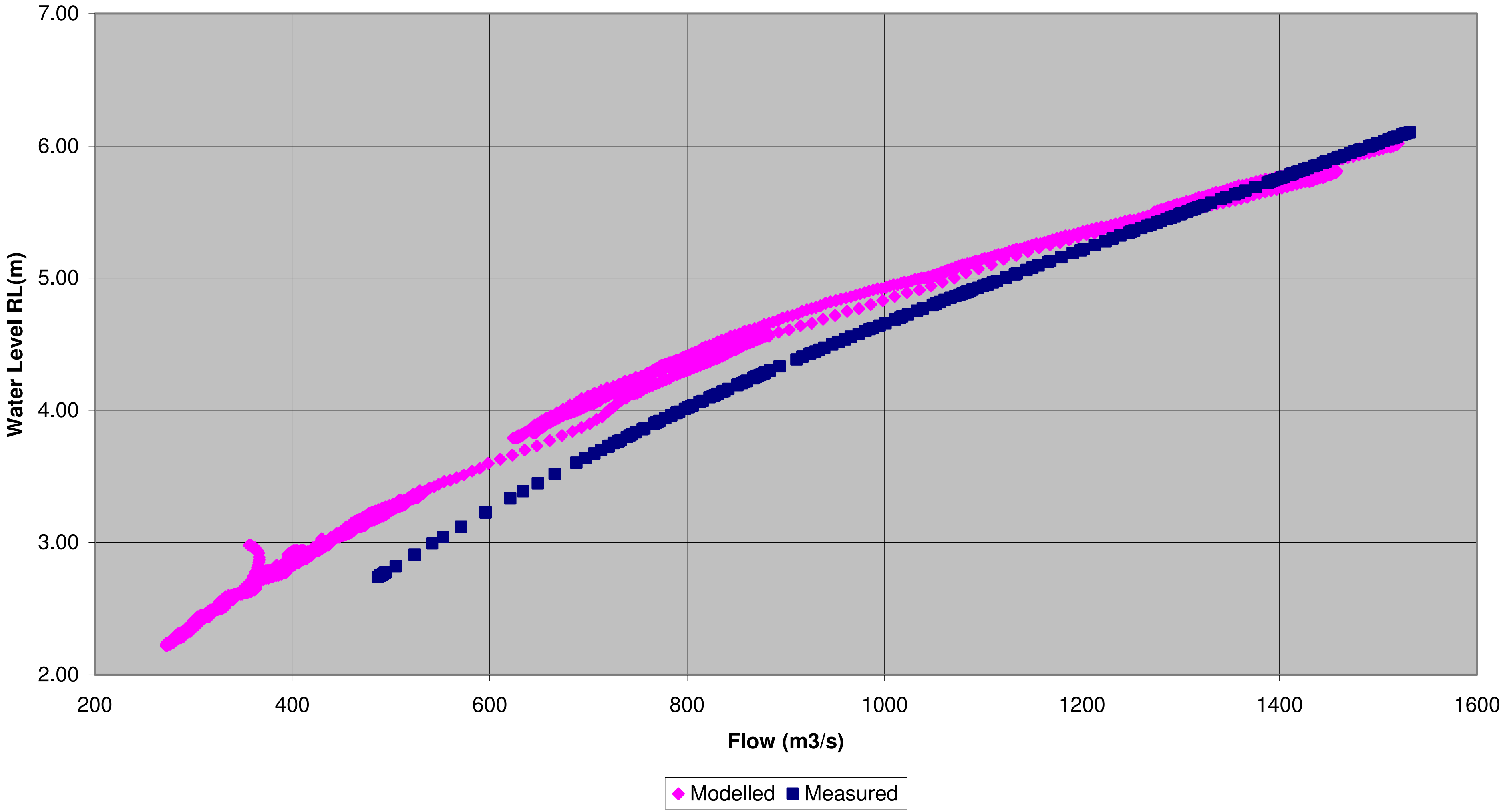


Figure B5 - Whatawhata Rating Curve - July 1998 Calibration

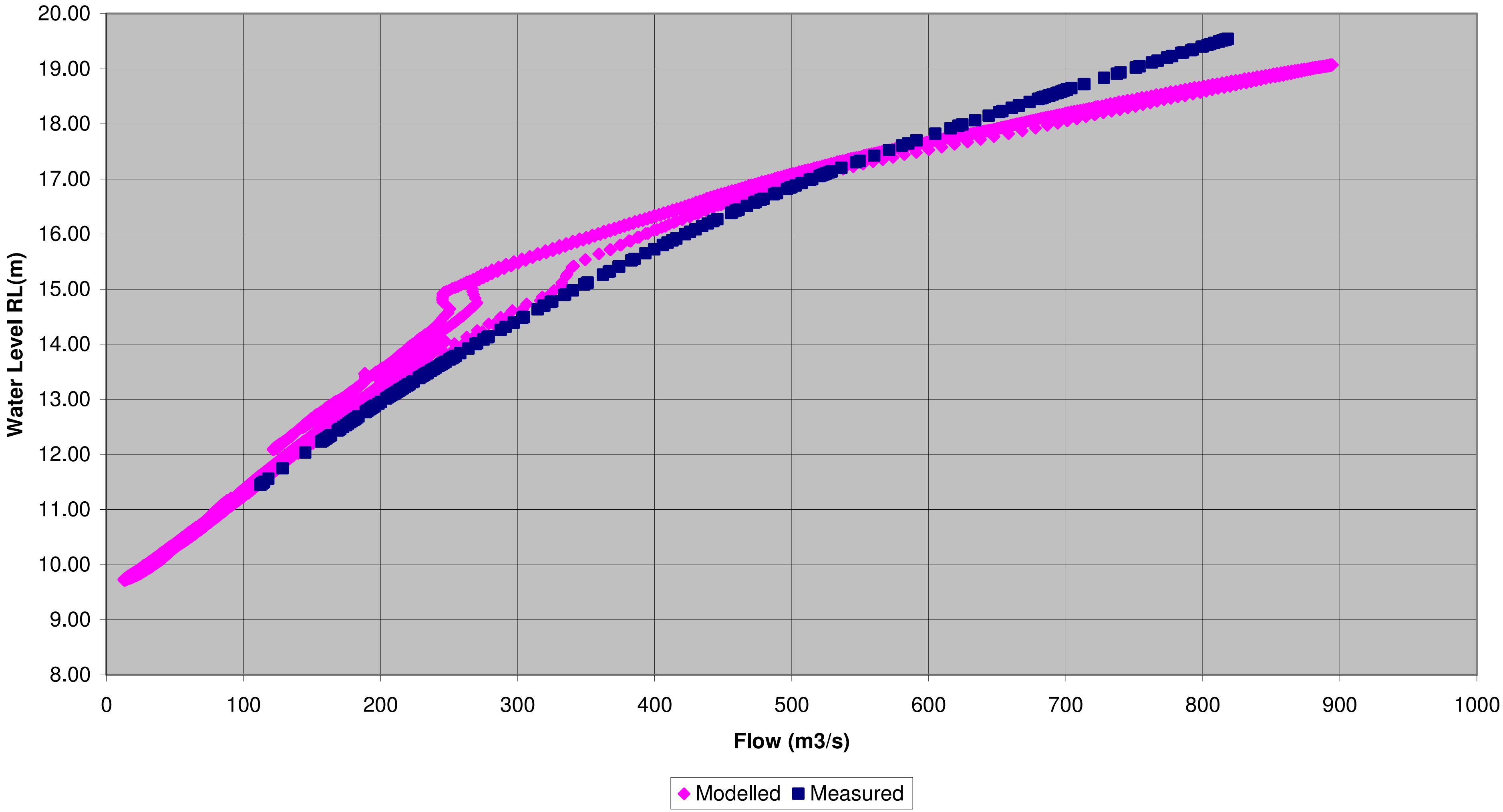


Figure B6 - Measured and Modelled Flows July 1998 at Hamilton

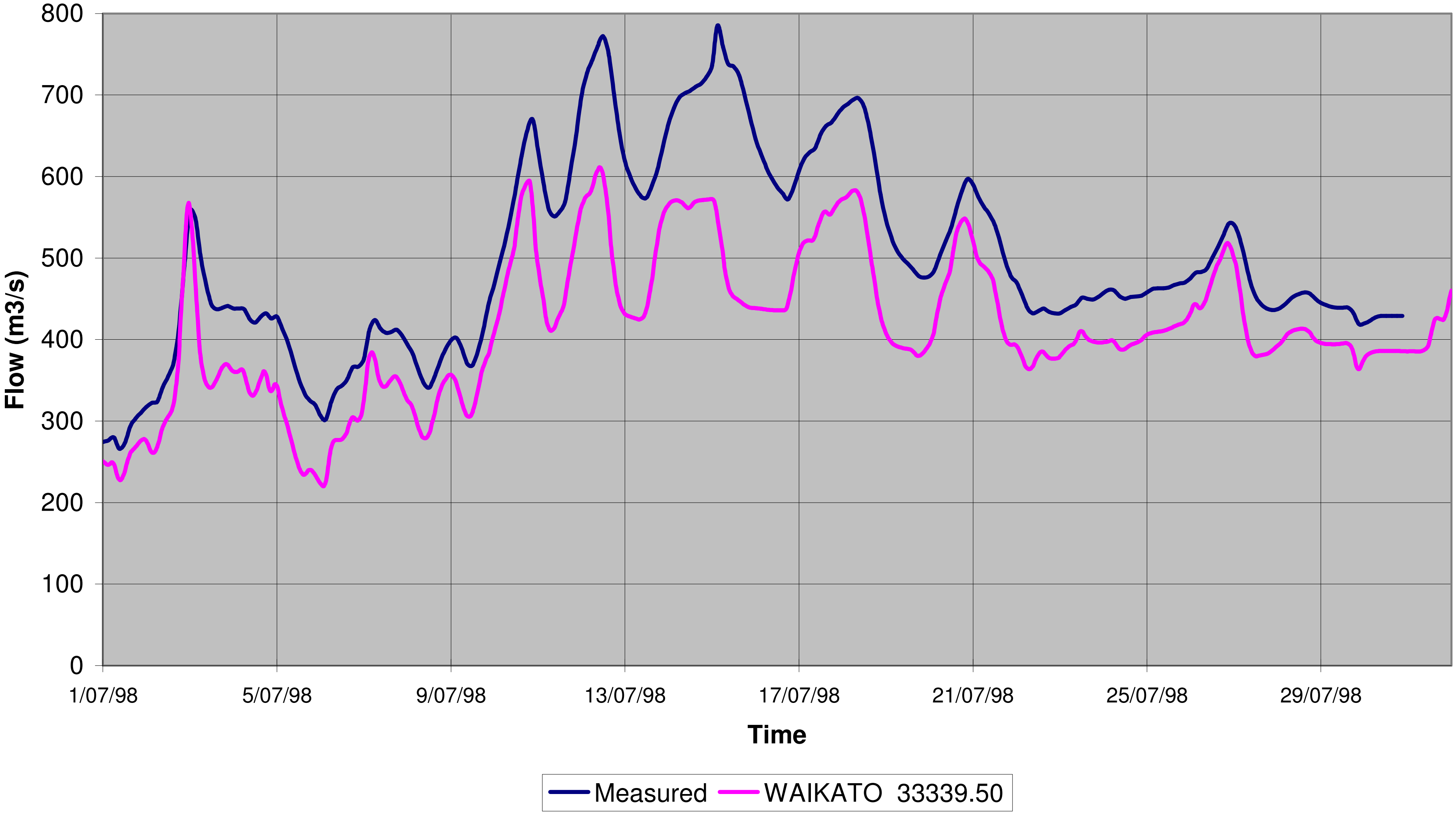


Figure B7 - Measured and Modelled Flows July 1998 at Ngaruawahia

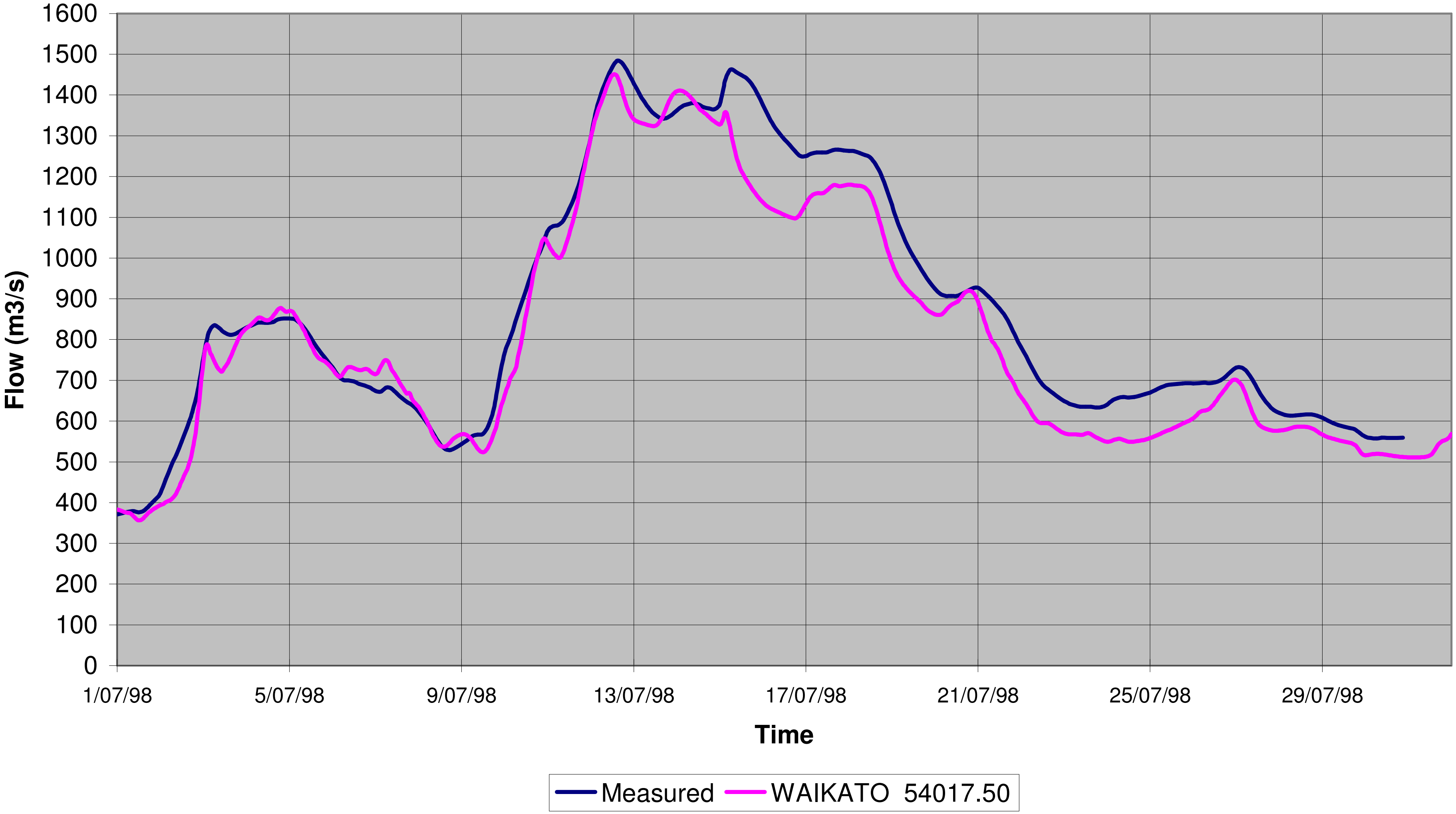


Figure B8 - Measured and Modelled Flows July 1998 at Rangiriri

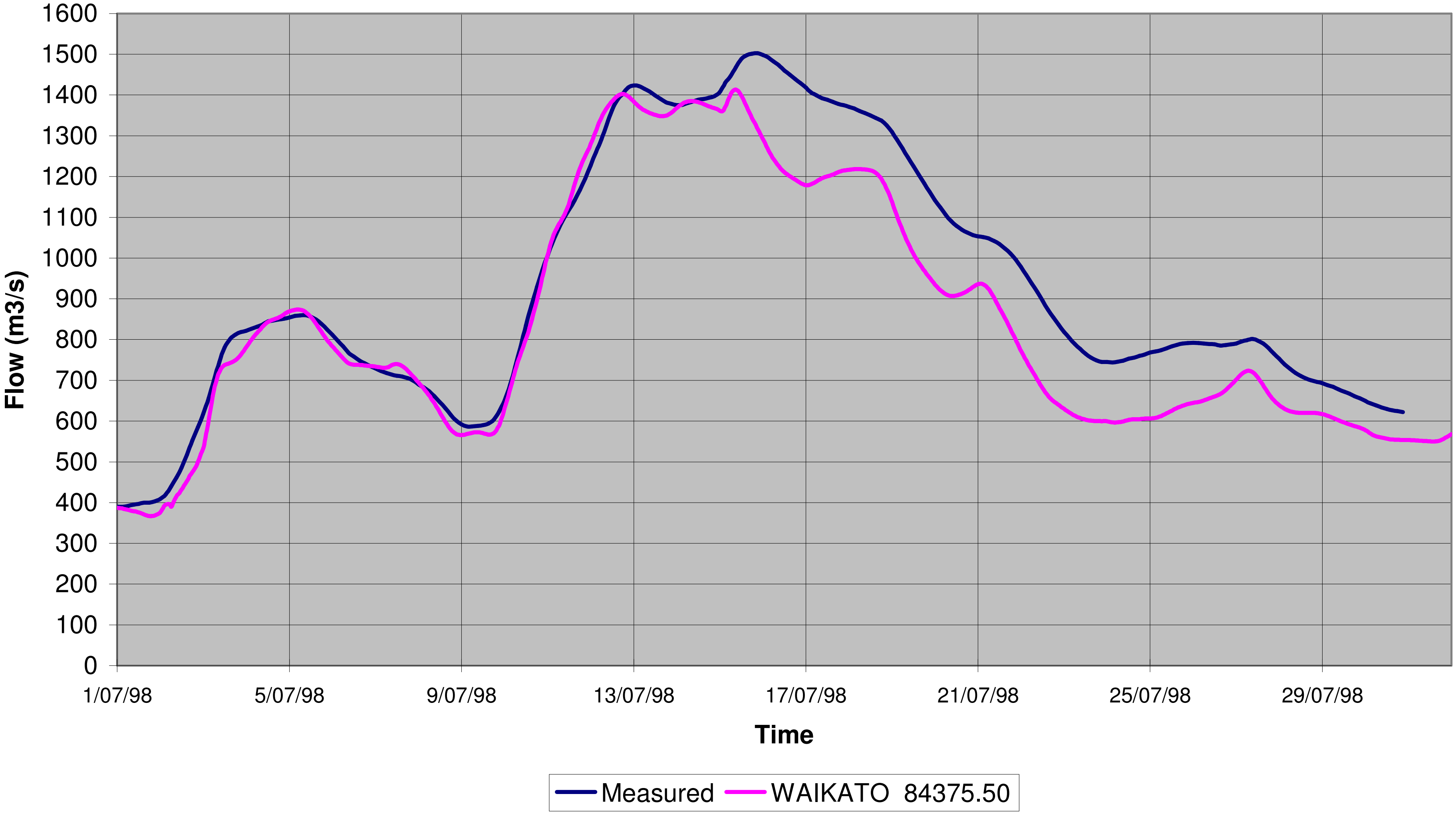


Figure B9 - Measured and Modelled Flows July 1998 at Mercer

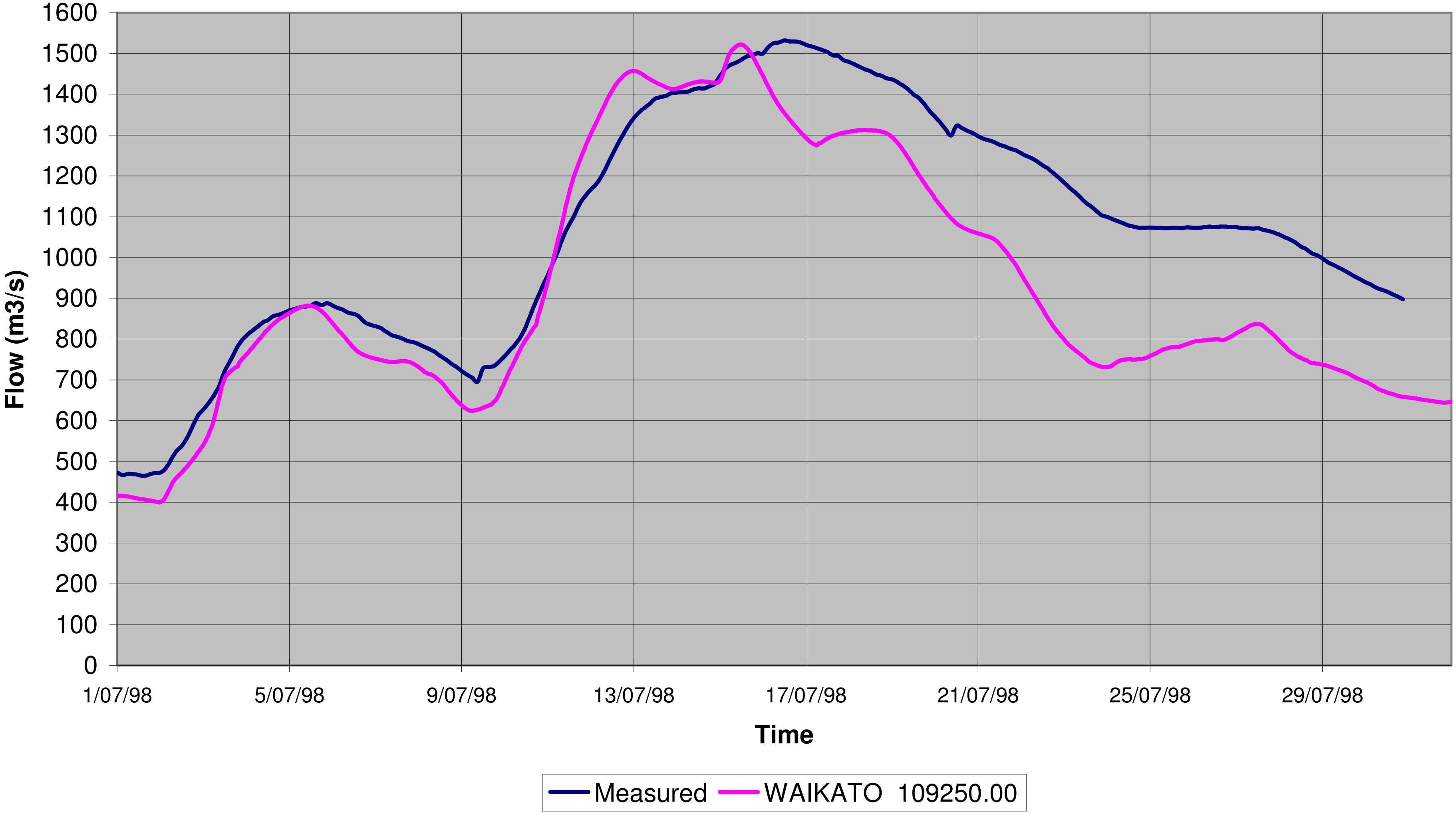


Figure B10 - Measured and Modelled Flows July 1998 at Otorohanga

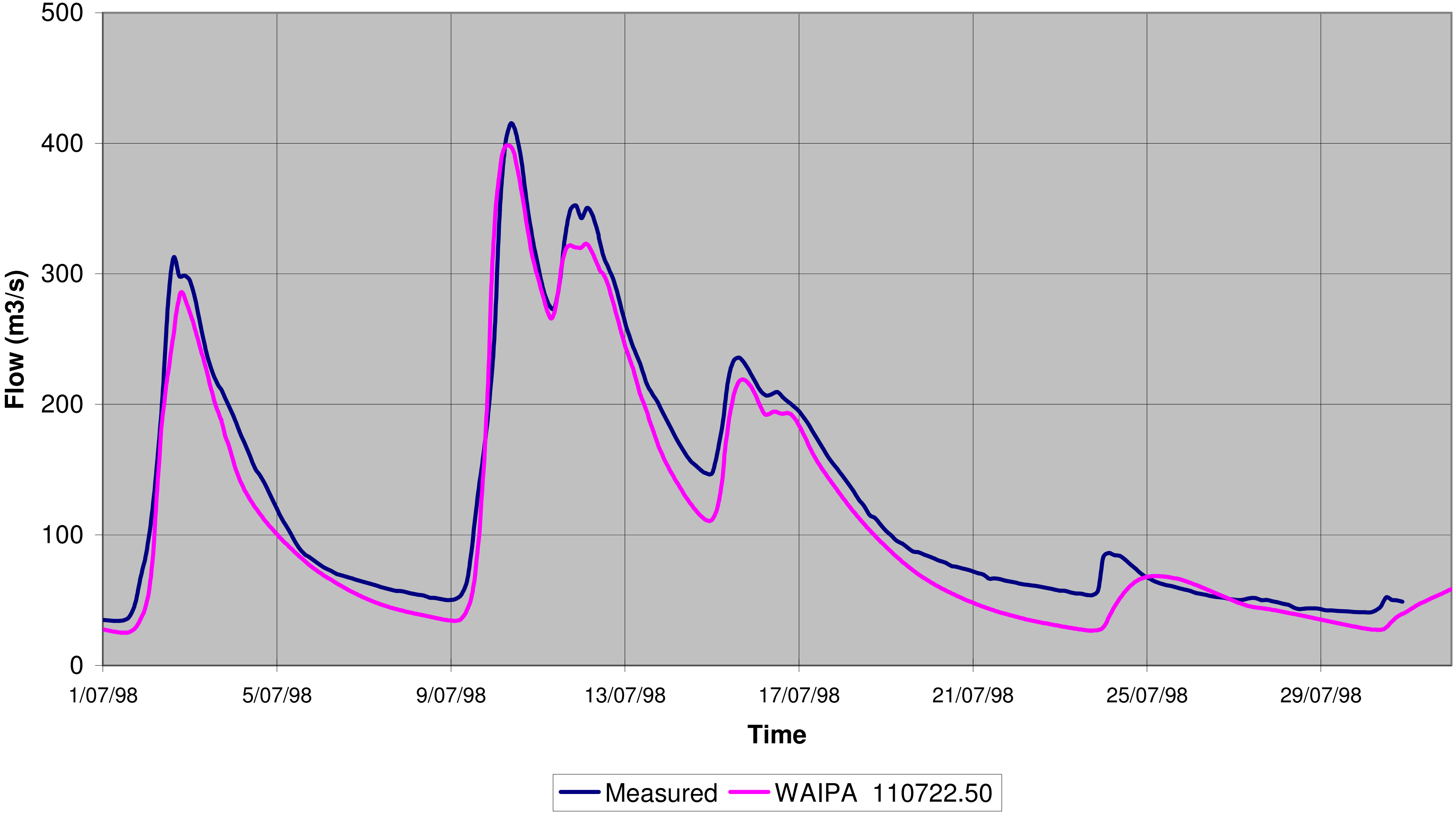


Figure B11 - Measured and Modelled Flows July 1998 at Whatawhata

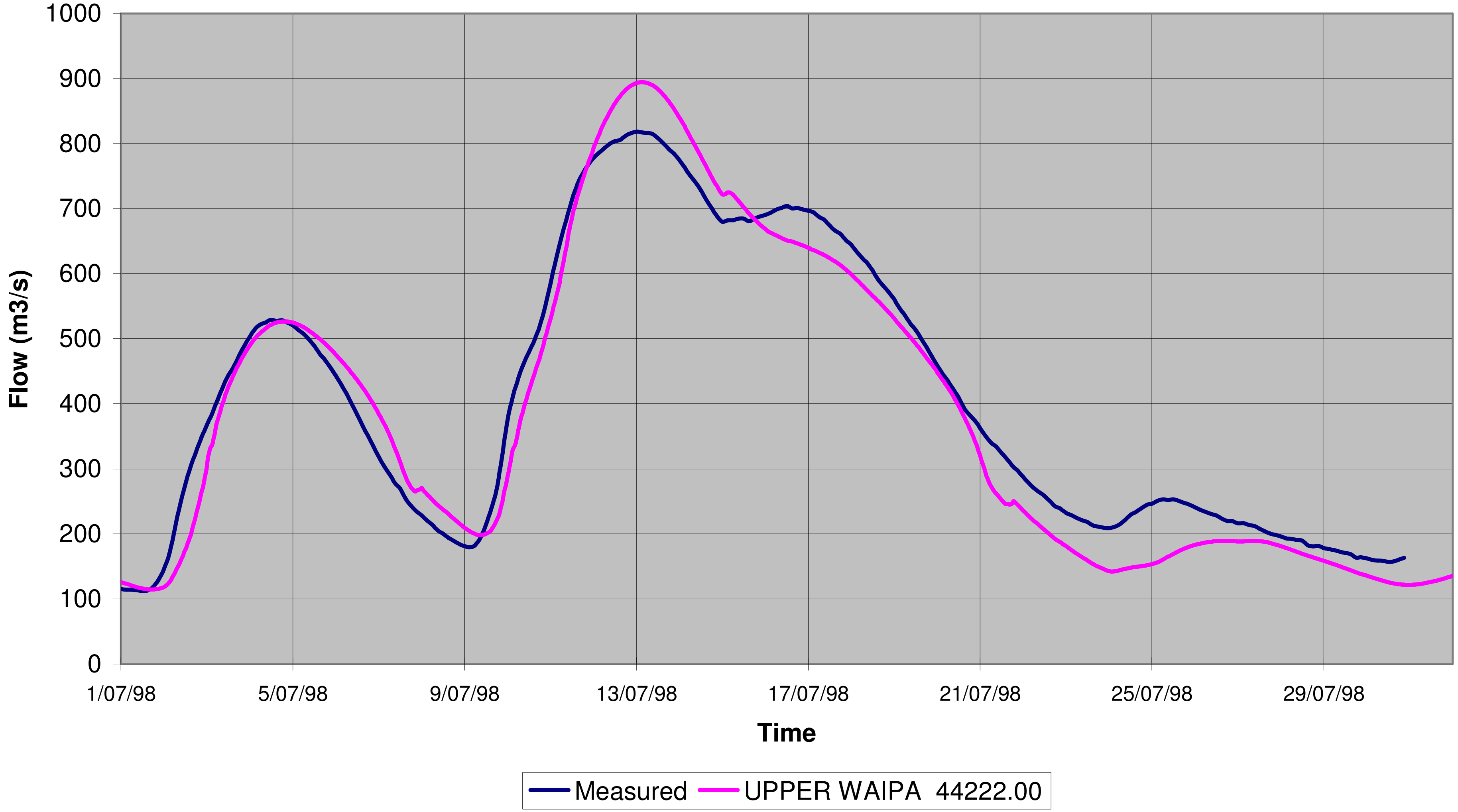


Figure B12 - Measured and Modelled Water Levels July 1998 at Hamilton

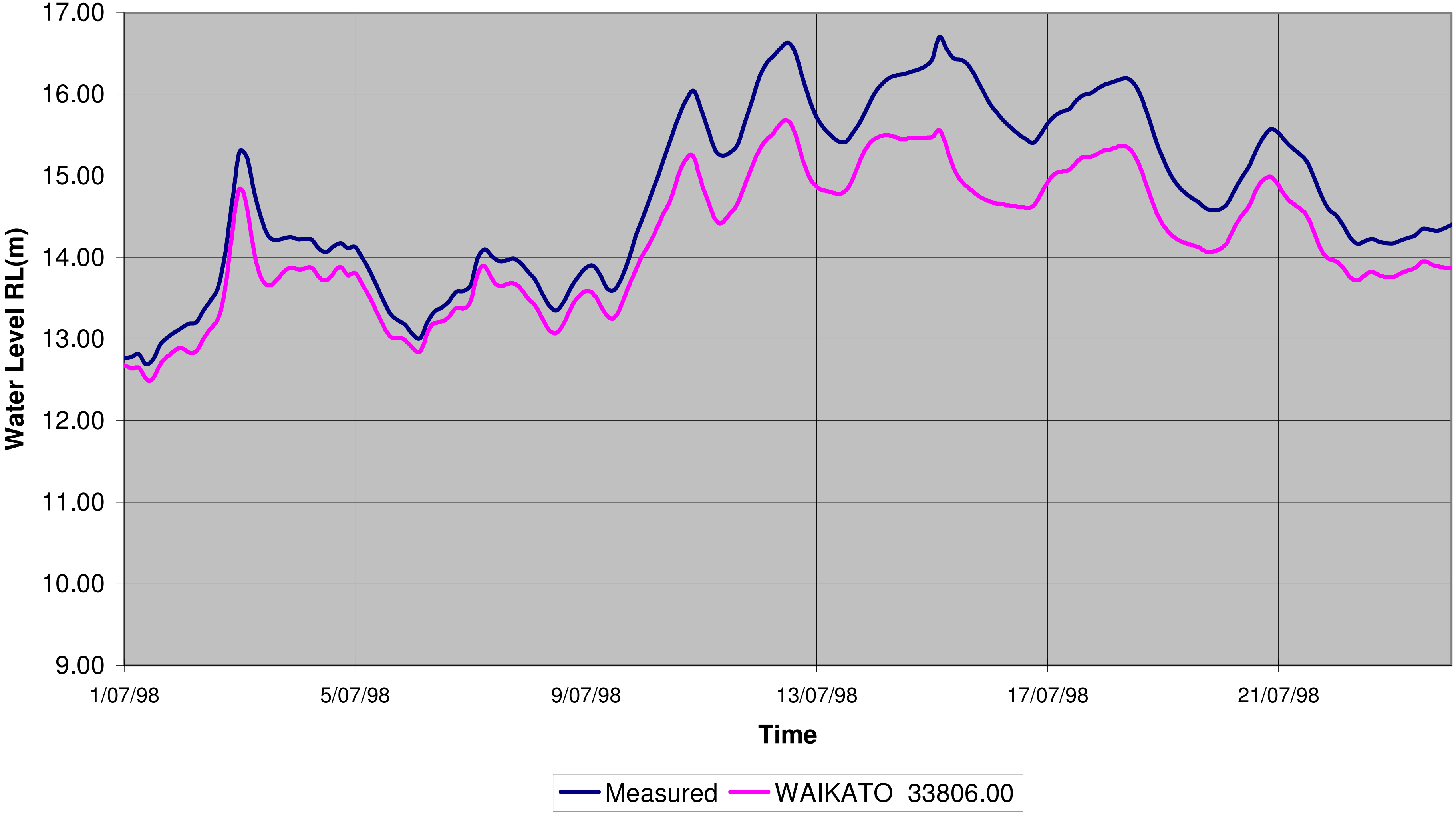


Figure B13 - Measured and Modelled Water Levels July 1998 at Ngaruawahia

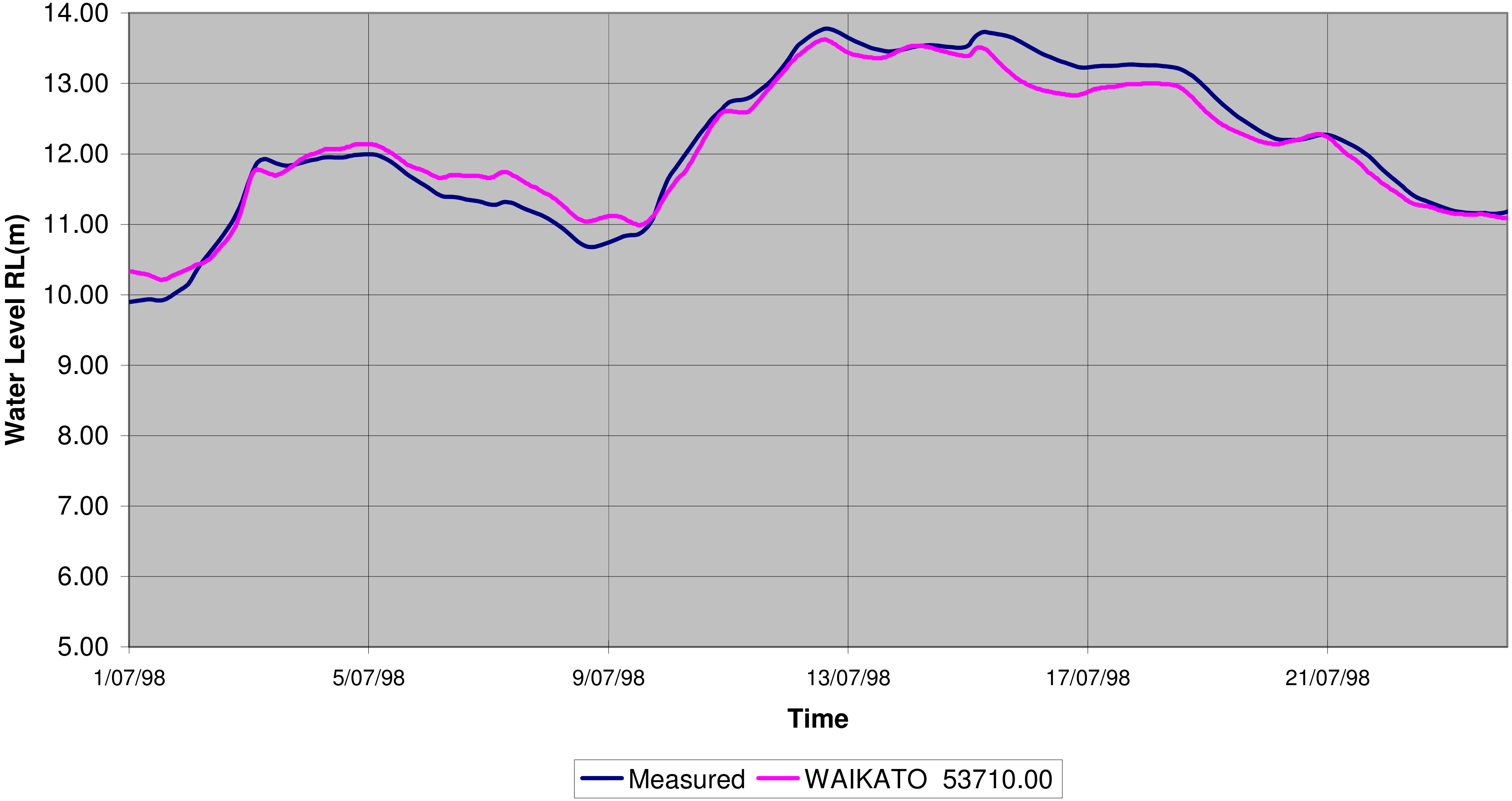


Figure B14 - Measured and Modelled Water Levels July 1998 at Rangiriri

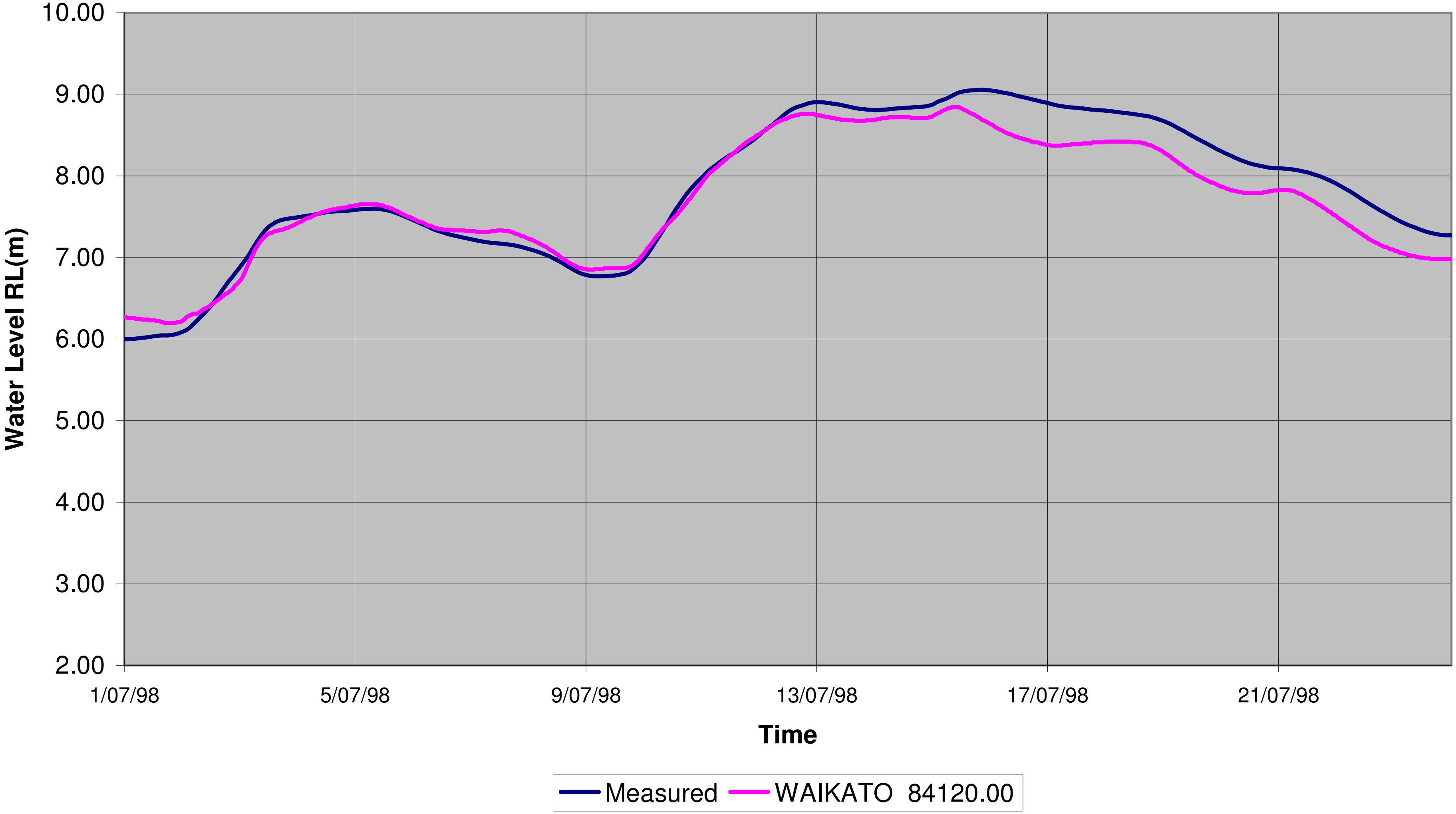


Figure B15 - Measured and Modelled Water Levels July 1998 at Control Gate

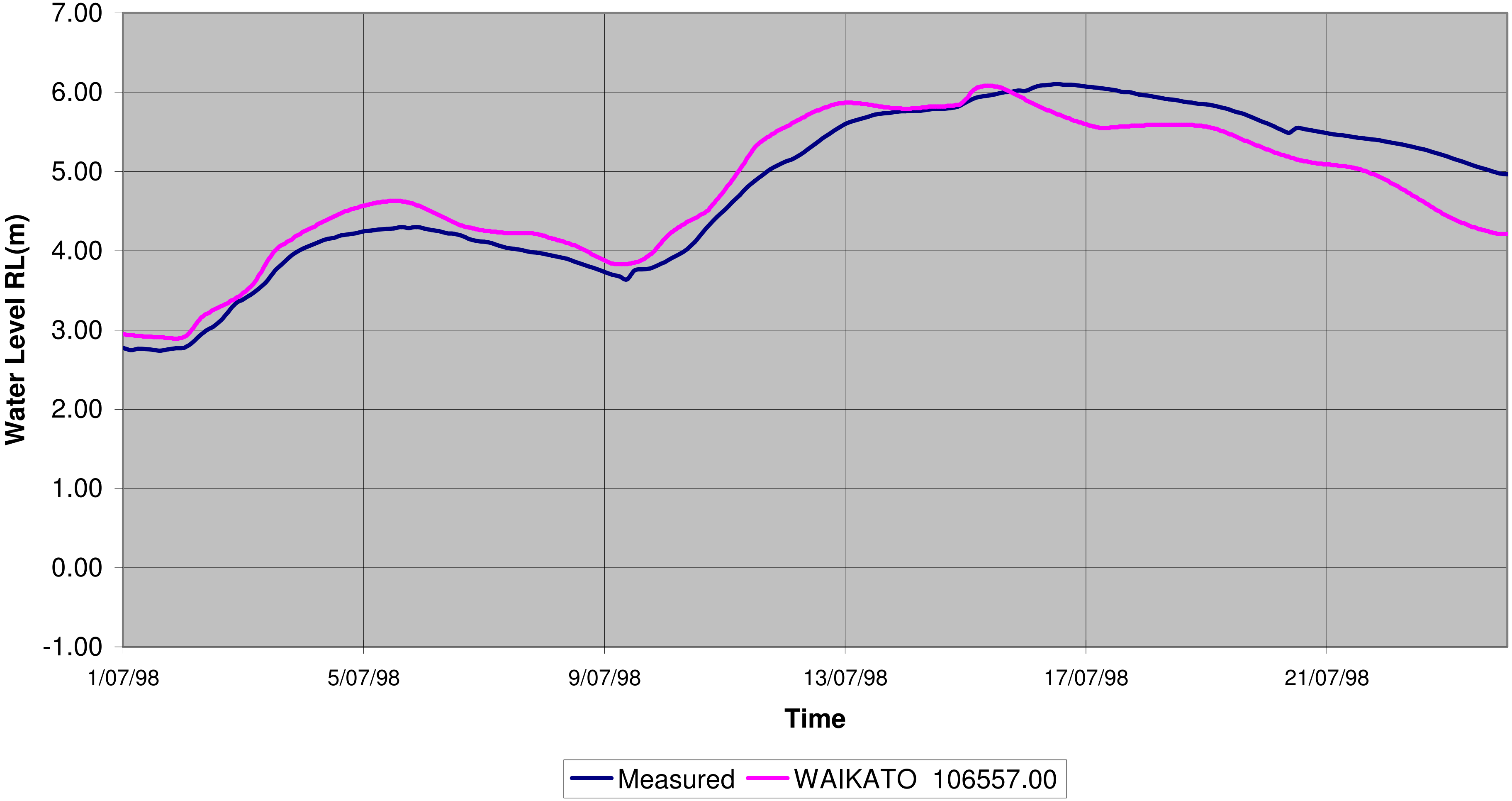


Figure B16 - Measured and Modelled Water Levels July 1998 at Mercer

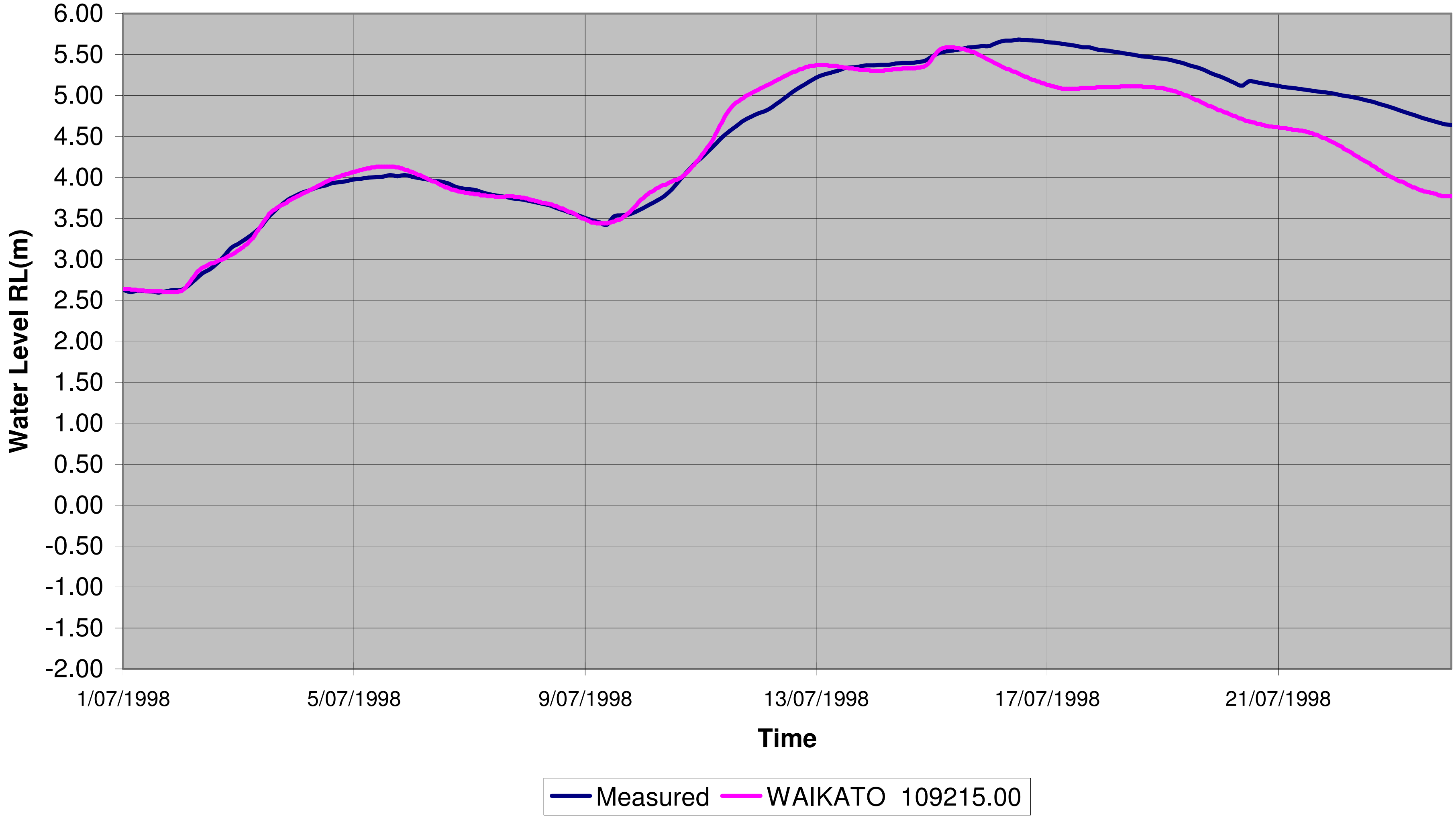


Figure B17 - Measured and Modelled Water Levels July 1998 at Otorohanga

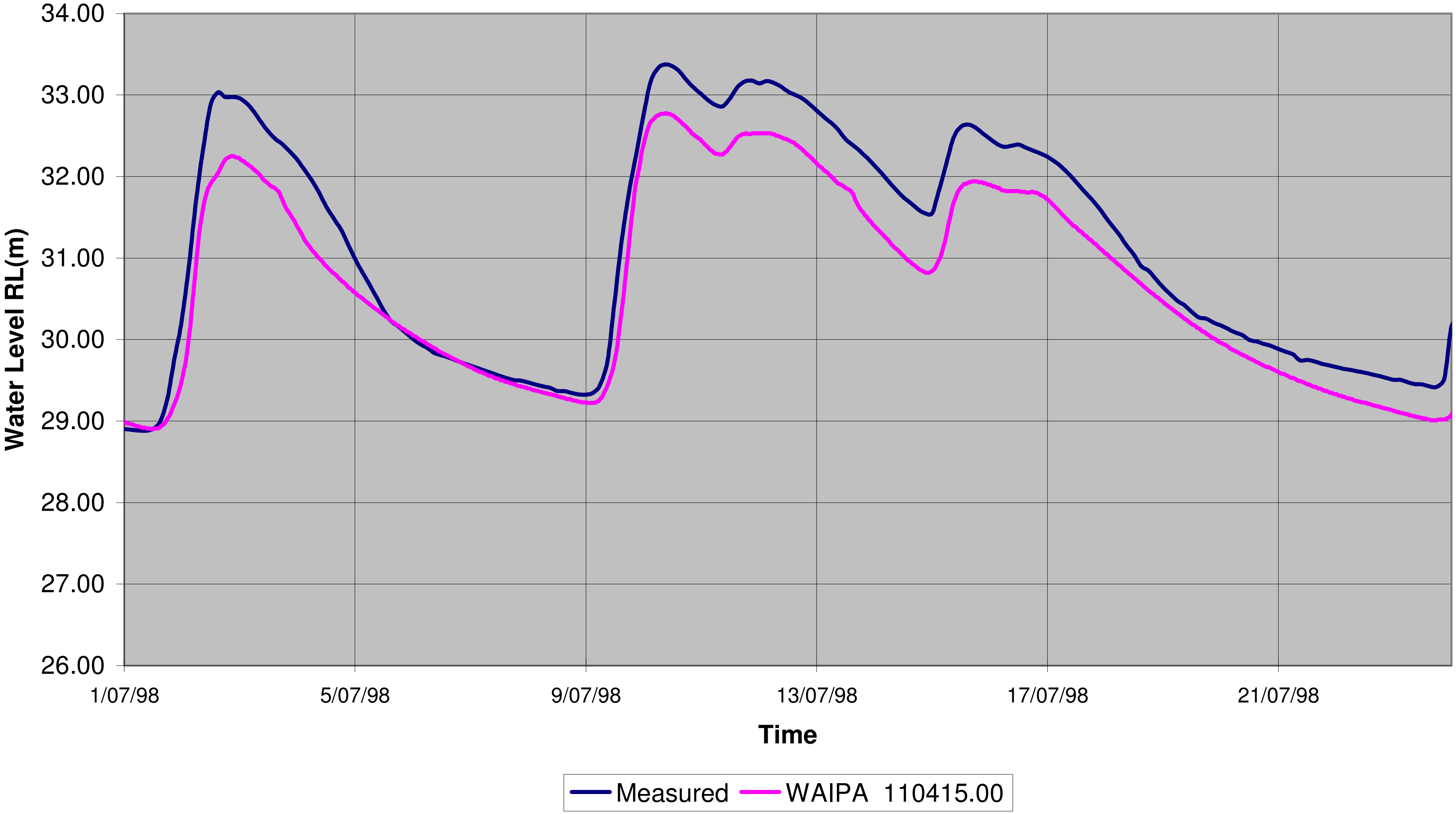
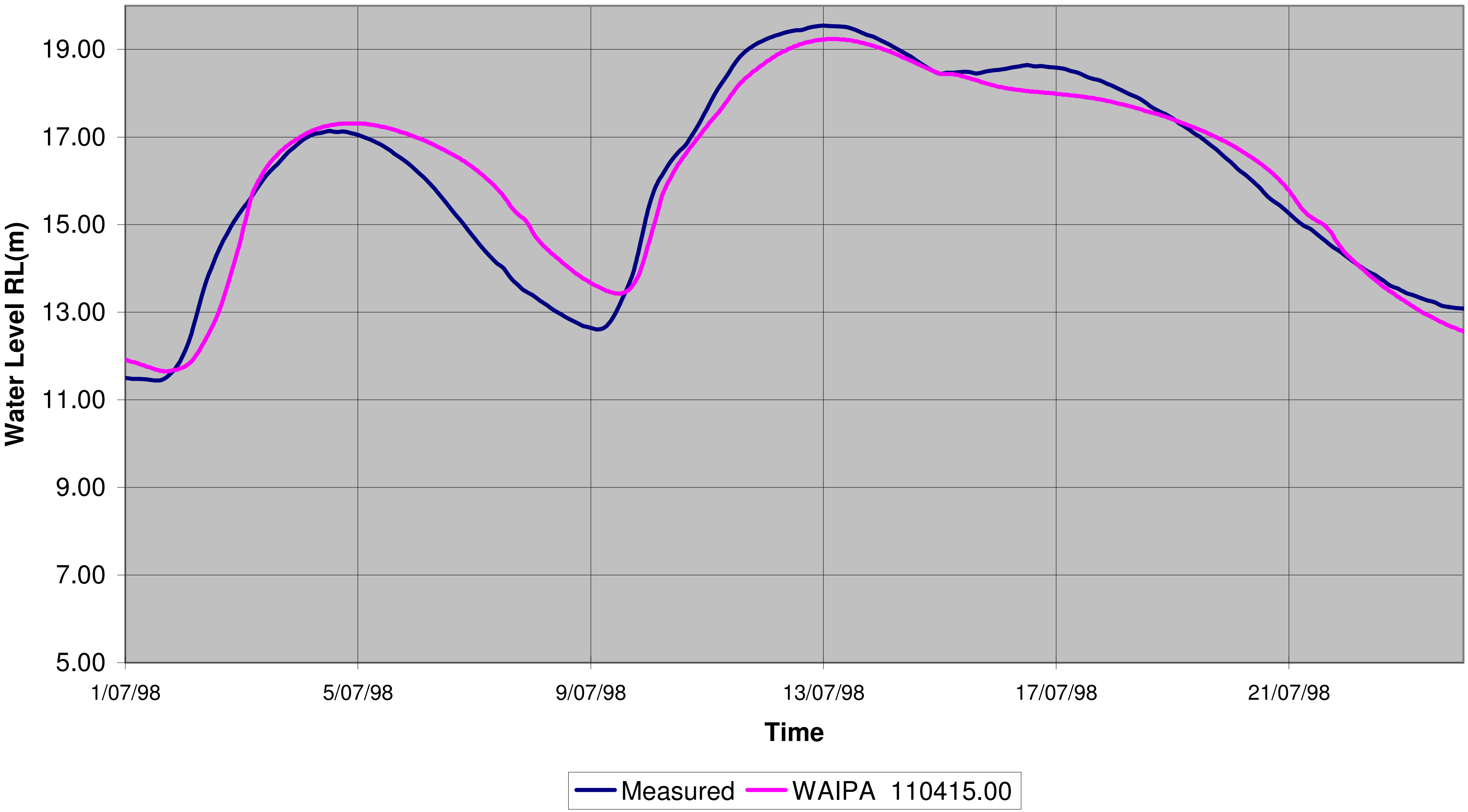


Figure B18 - Measured and Modelled Water Levels July 1998 at Whatawhata



Appendix C

February 2004 Calibration Graphs

Figure C1 - Hamilton Rating Curve - February 2004 Calibration

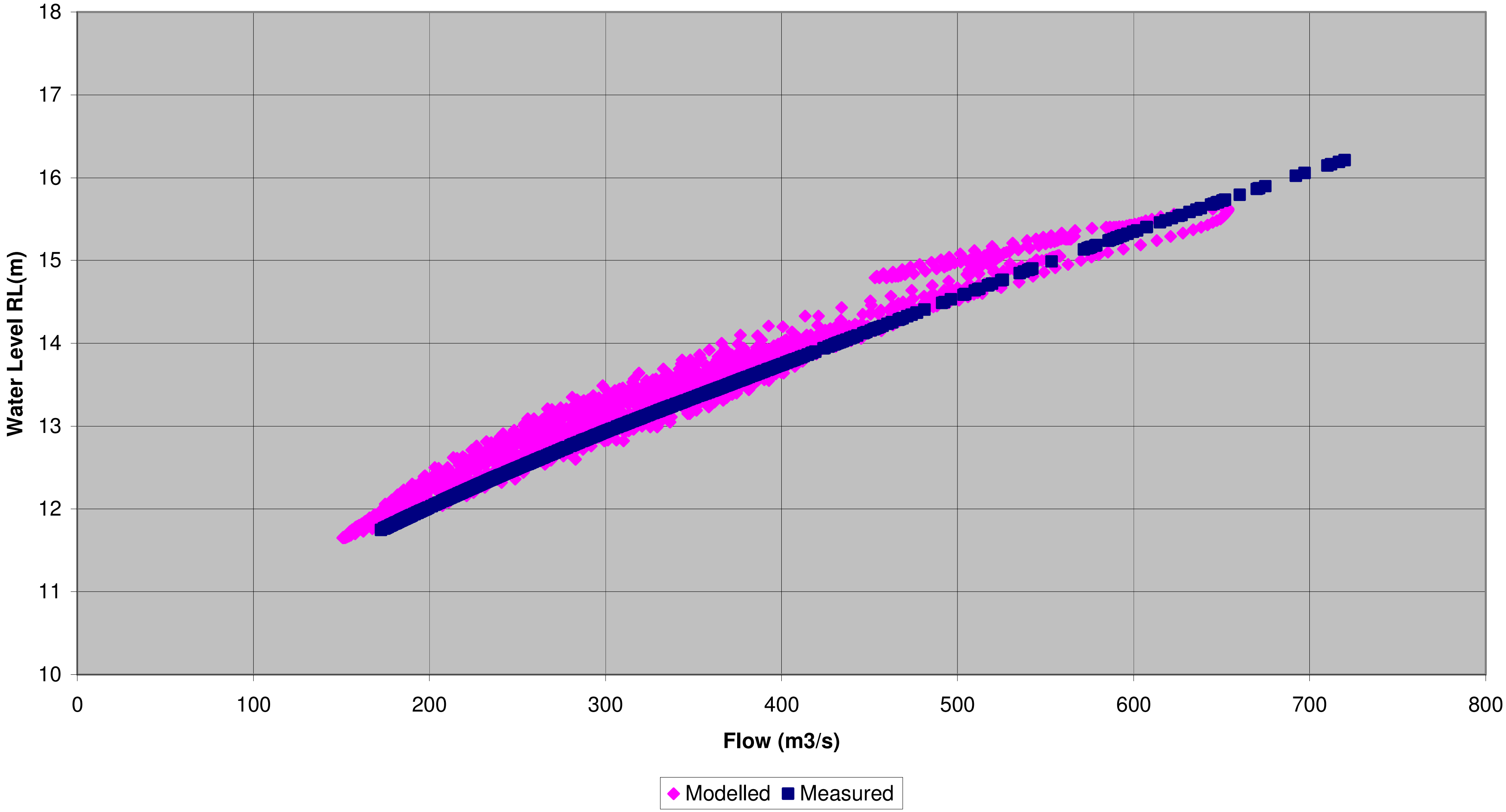


Figure C2 - Ngaruawahia Rating Curve - February 2004 Calibration

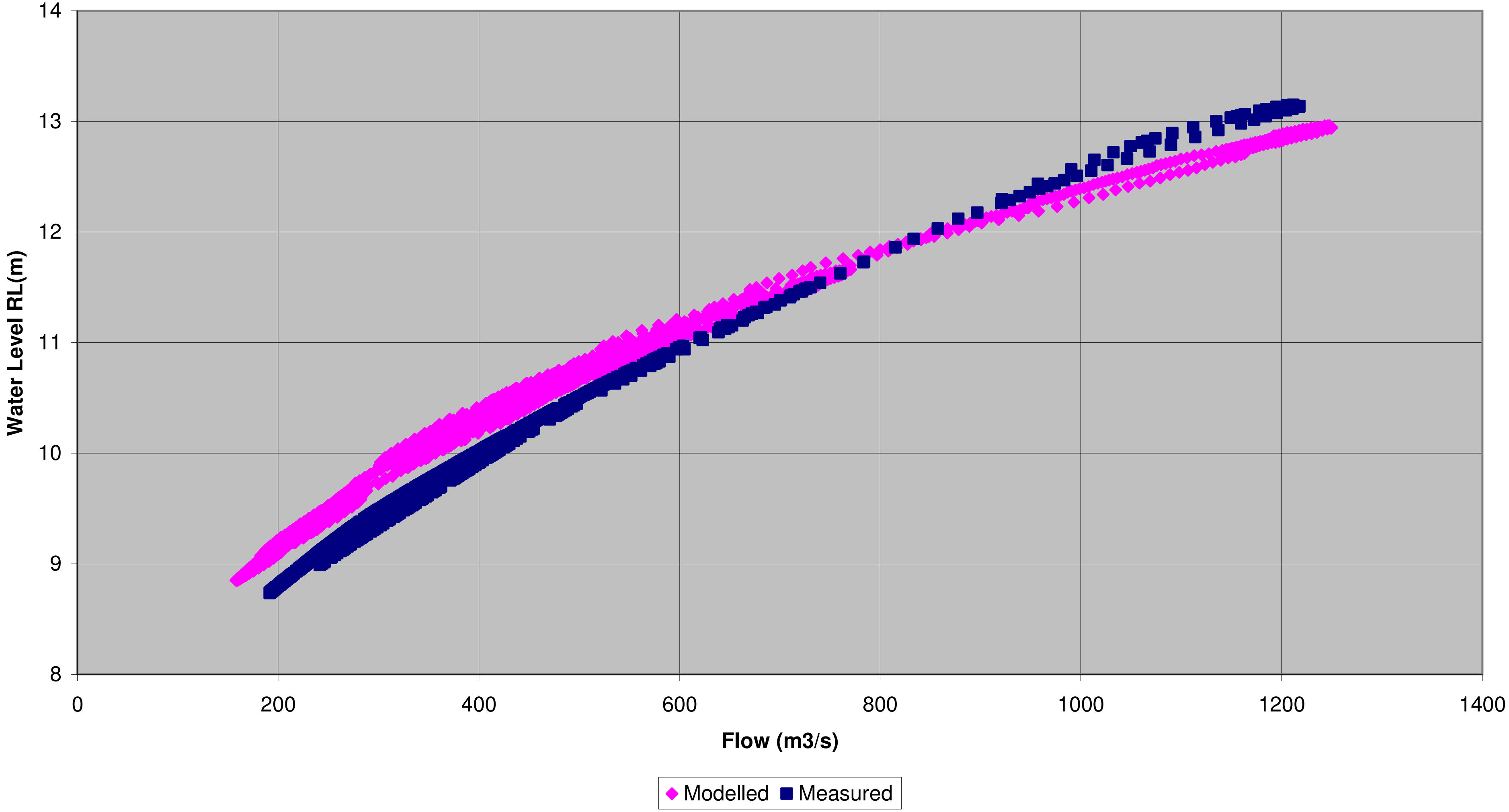


Figure C3 - Rangiriri Rating Curve - February 2004 Calibration

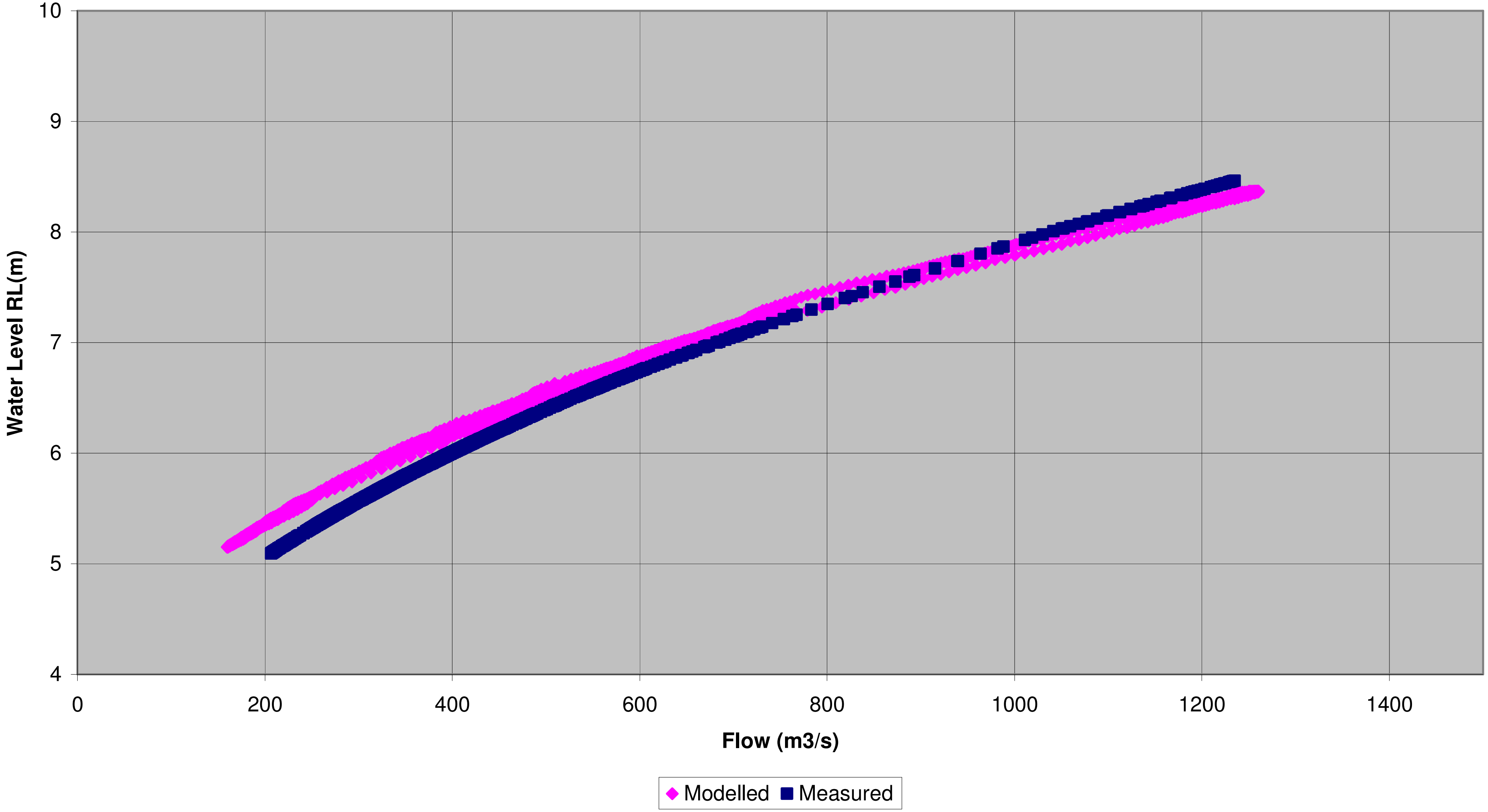


Figure C4 - Whatawhata Rating Curve - February 2004 Calibration

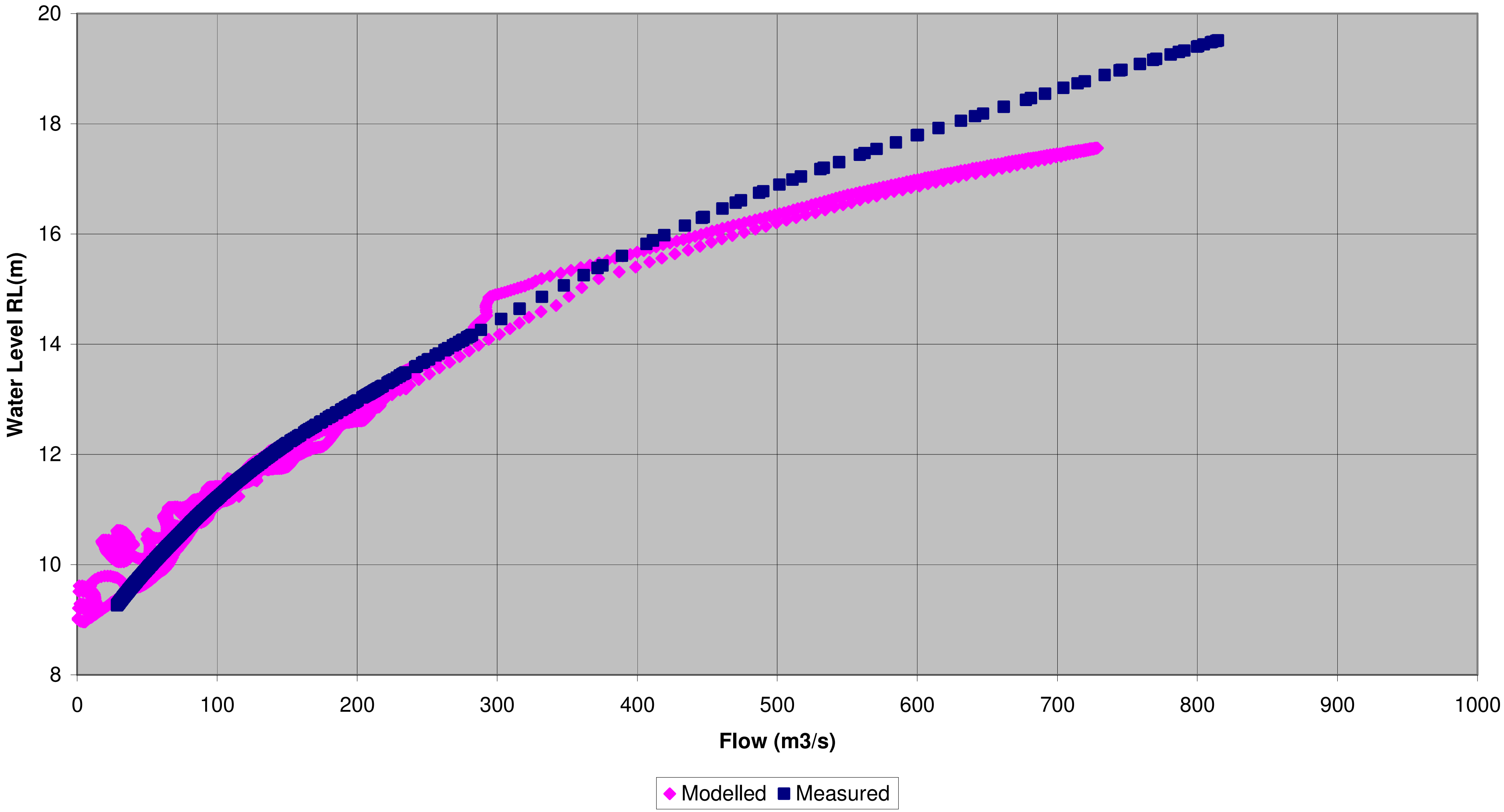


Figure C5 - Measured and Modelled Flows February 2004 at Hamilton

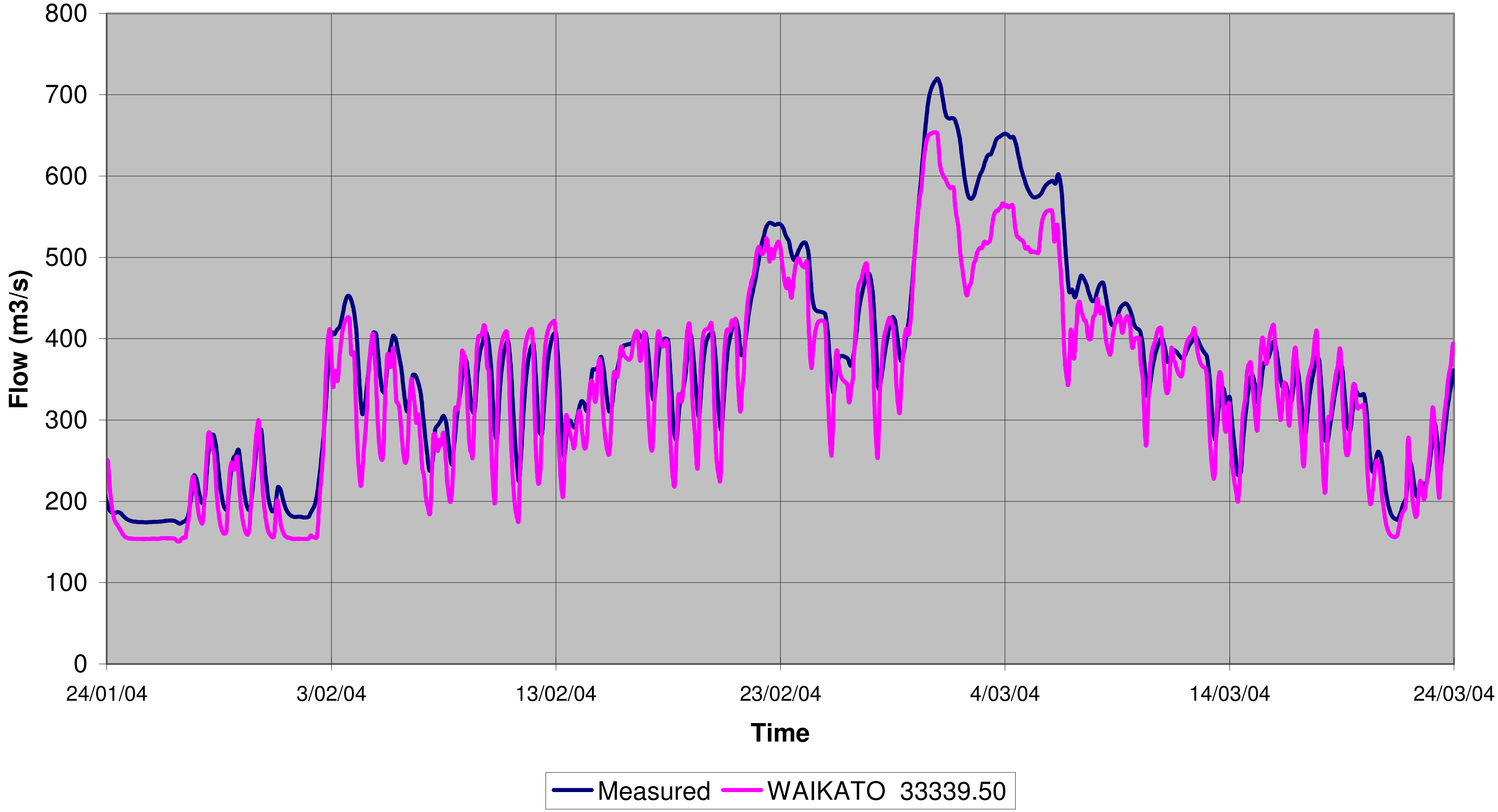


Figure C6 - Measured and Modelled Flows February 2004 at Ngaruawahia

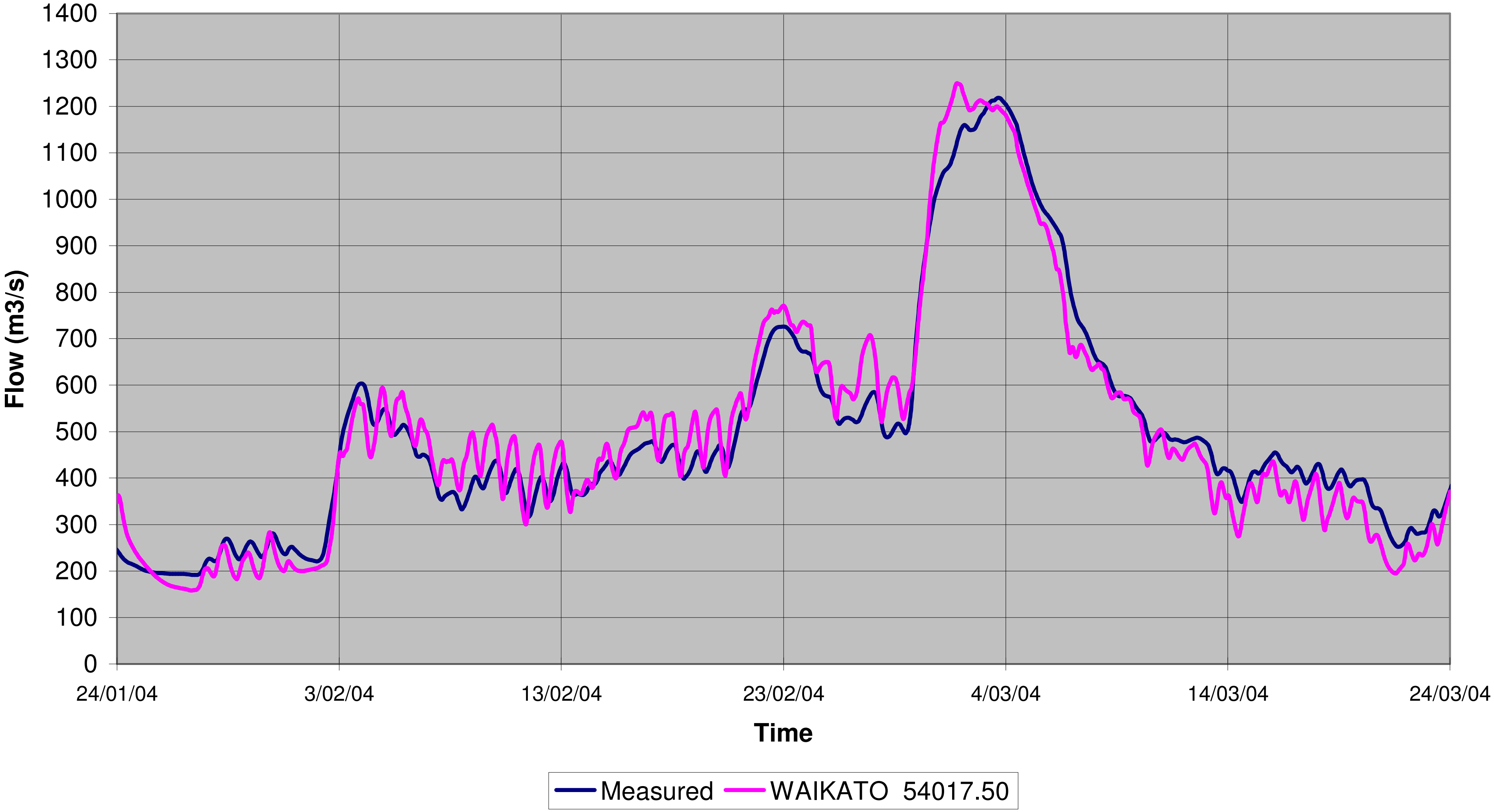


Figure C7 - Measured and Modelled Flows February 2004 at Rangiriri

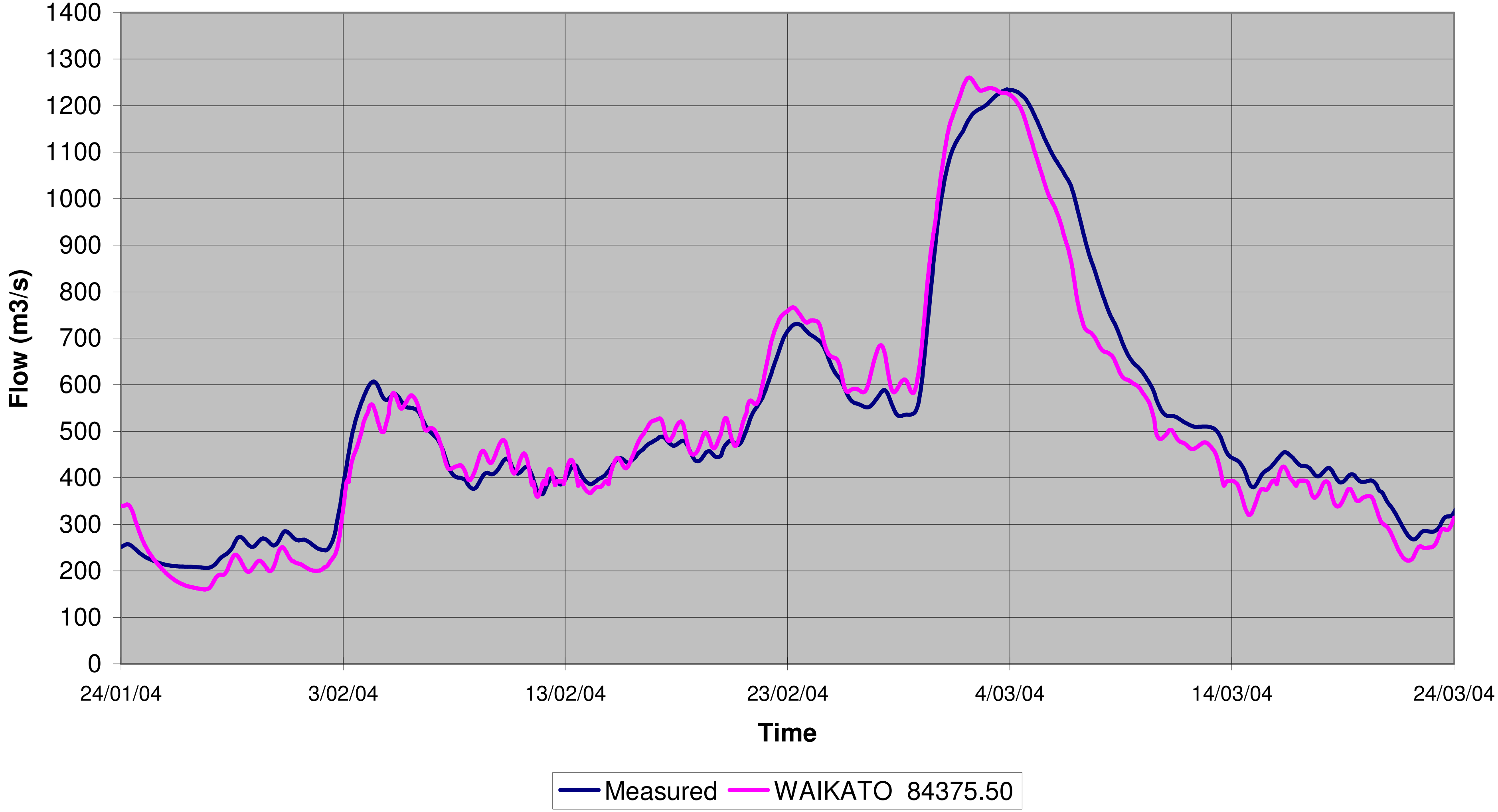


Figure C8 - Measured and Modelled Flows February 2004 at Mercer

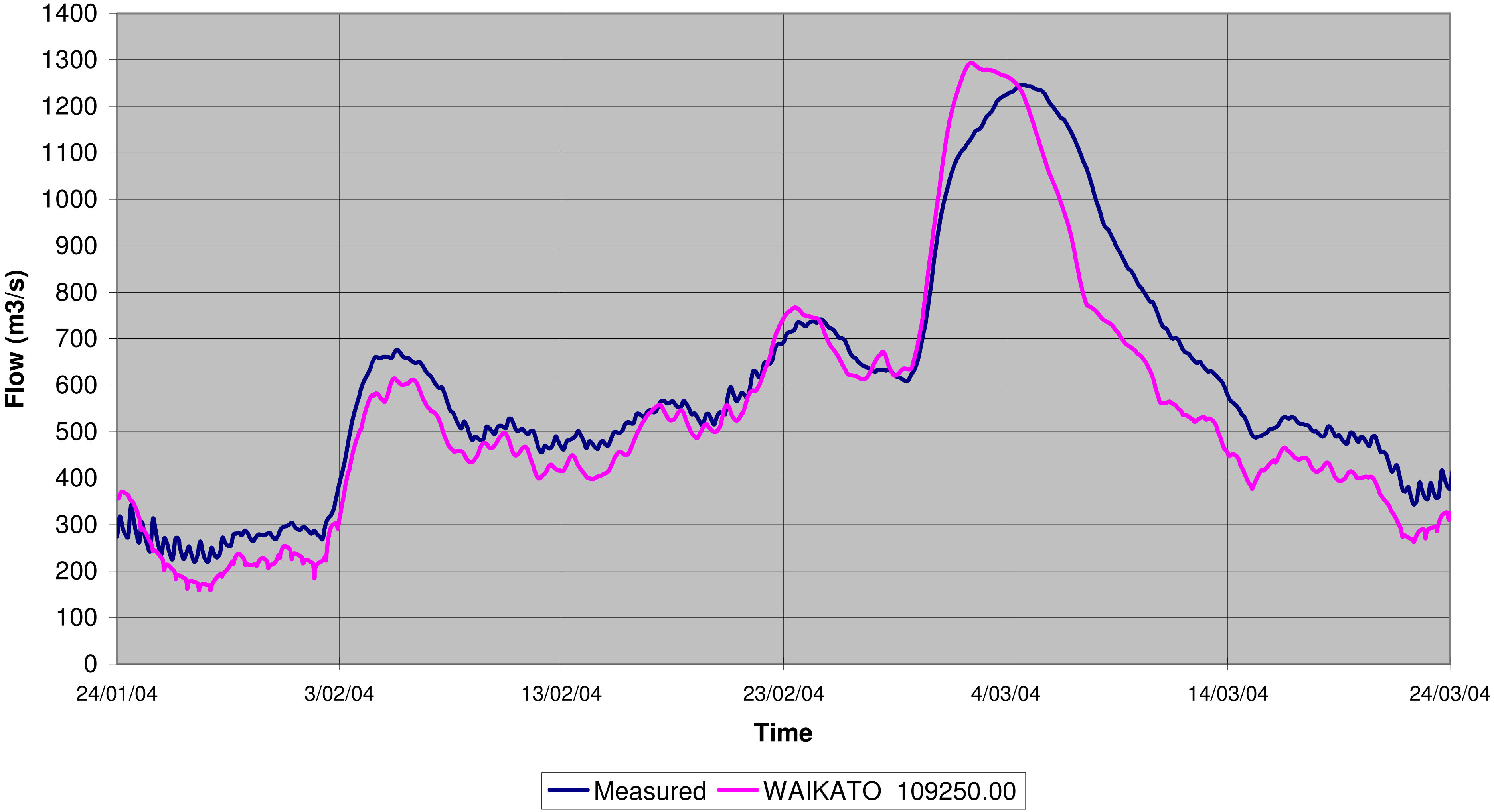


Figure C9 - Measured and Modelled Flows February 2004 at Otorohanga

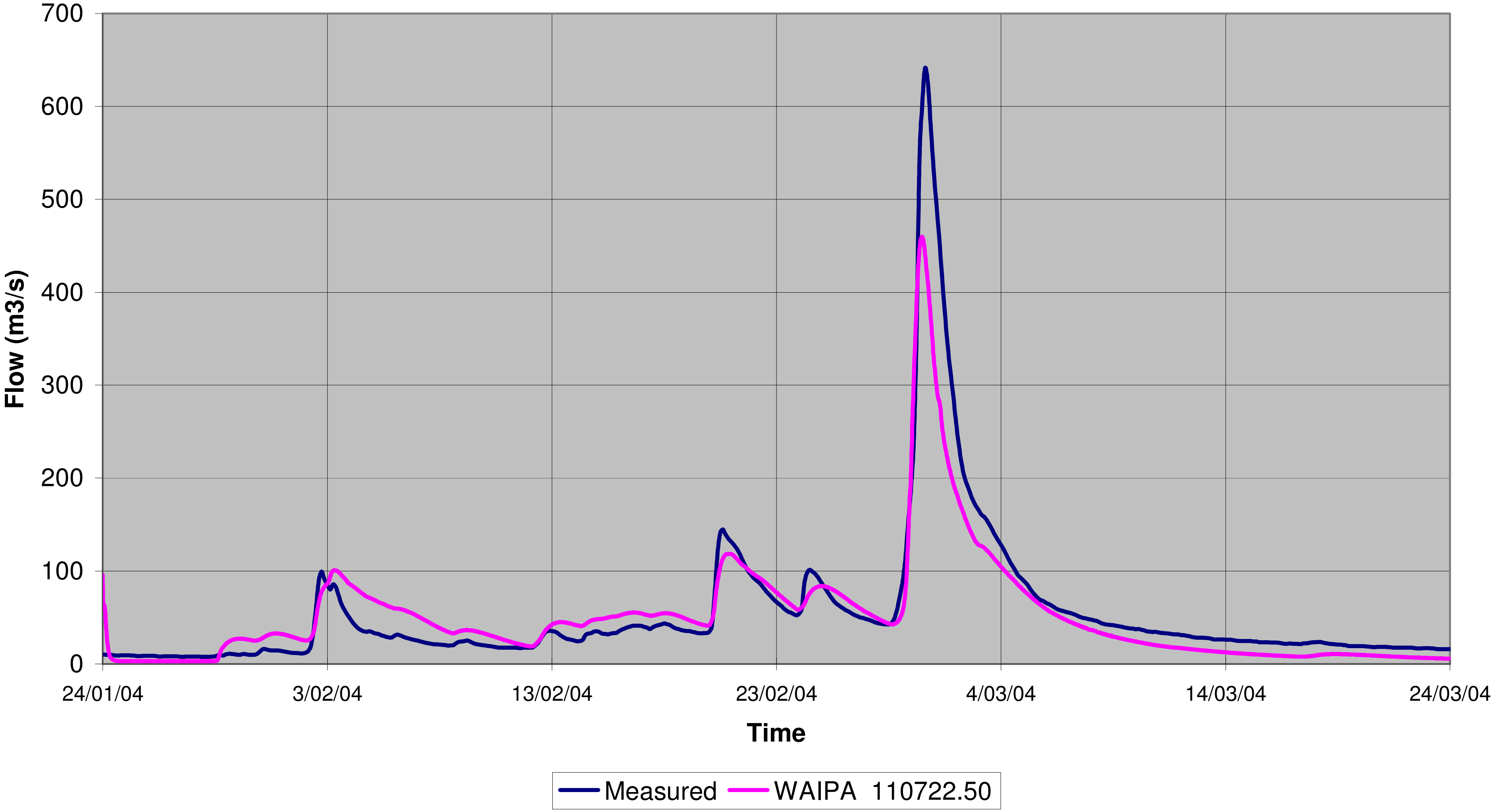


Figure C10 - Measured and Modelled Flows February 2004 at Whatawhata

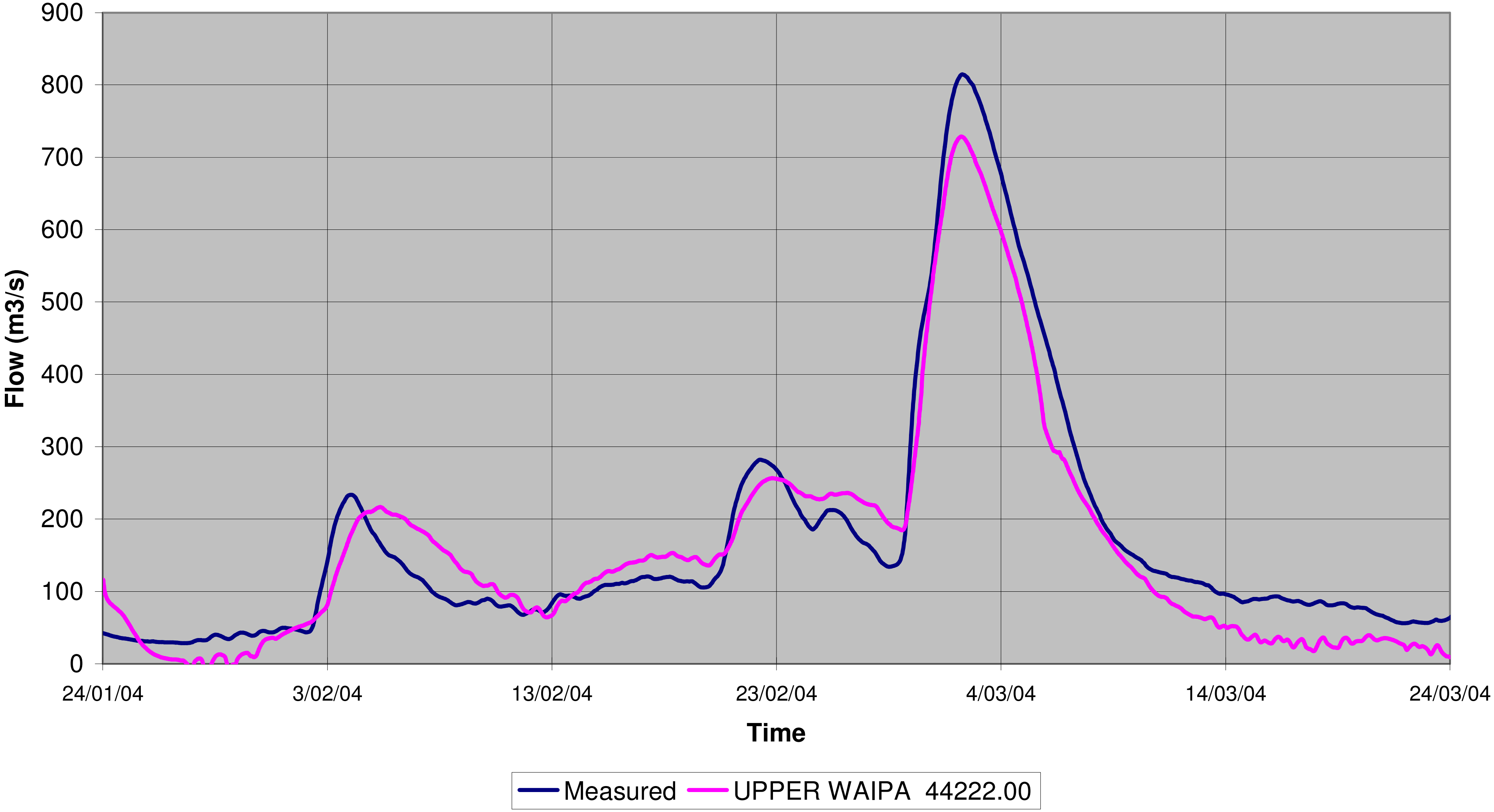


Figure C11 - Measured and Modelled Water Levels February 2004 at Hamilton

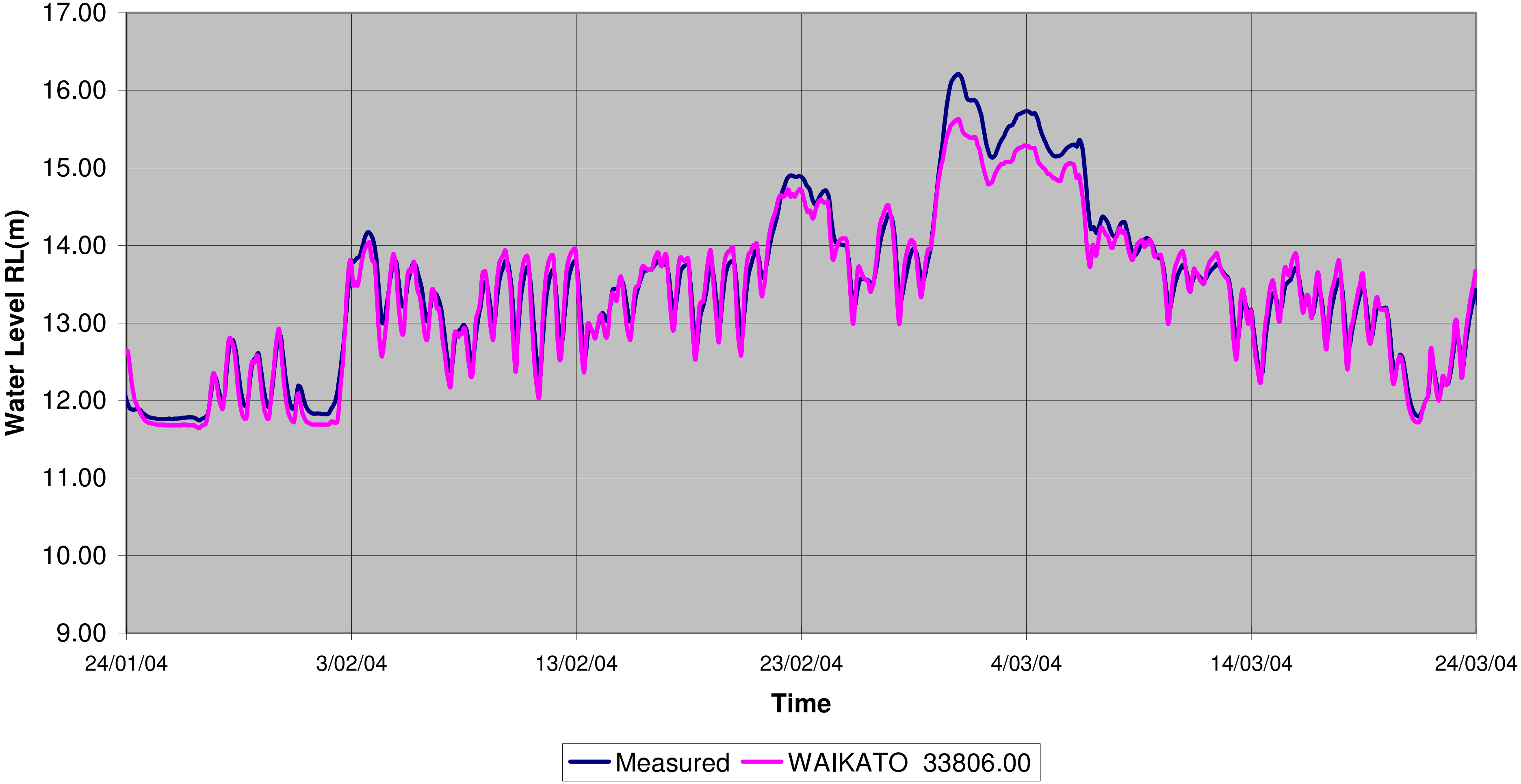


Figure C12 - Measured and Modelled Water Levels February 2004 at Ngaruawahia

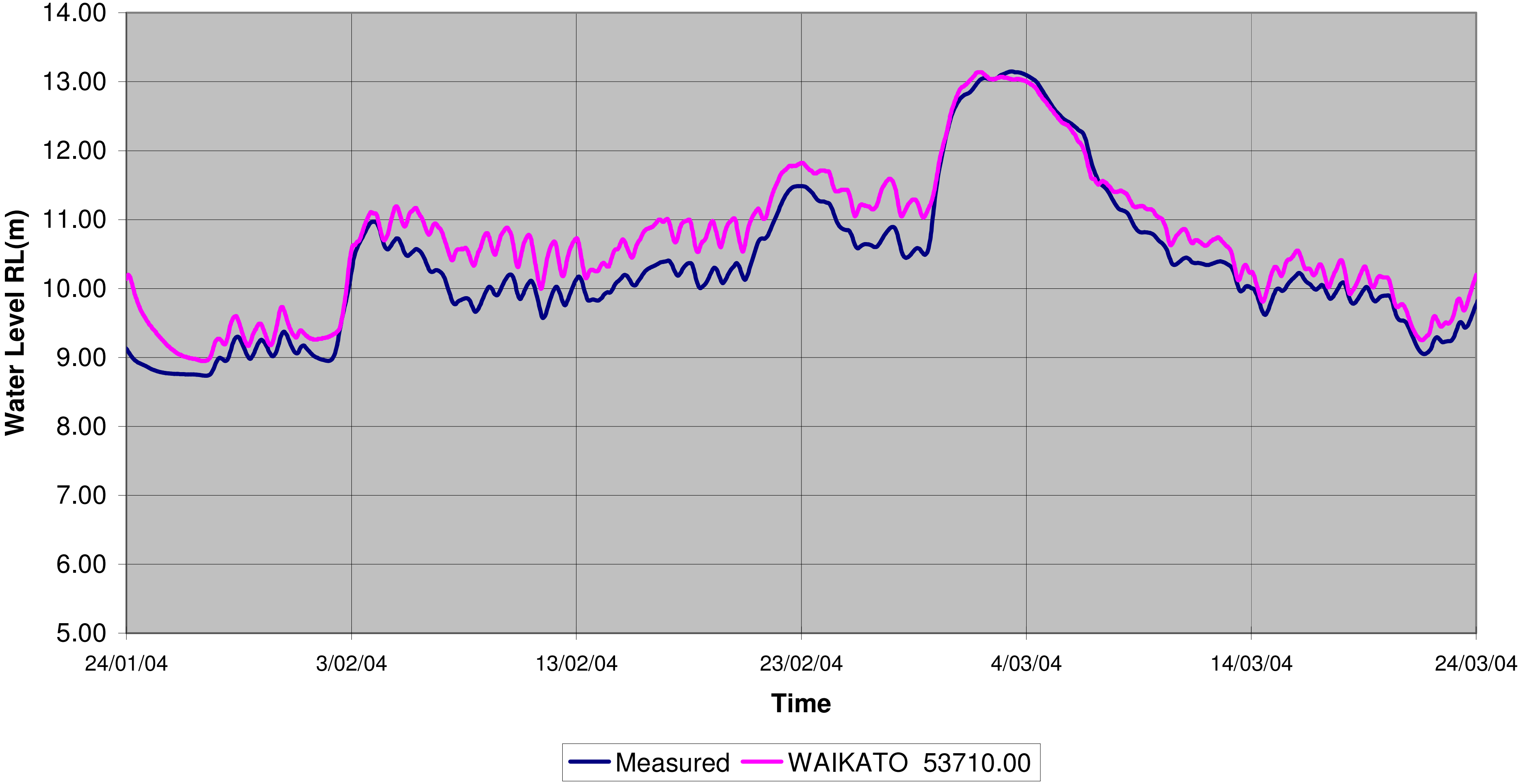


Figure C13 - Measured and Modelled Water Levels February 2004 at Rangiriri

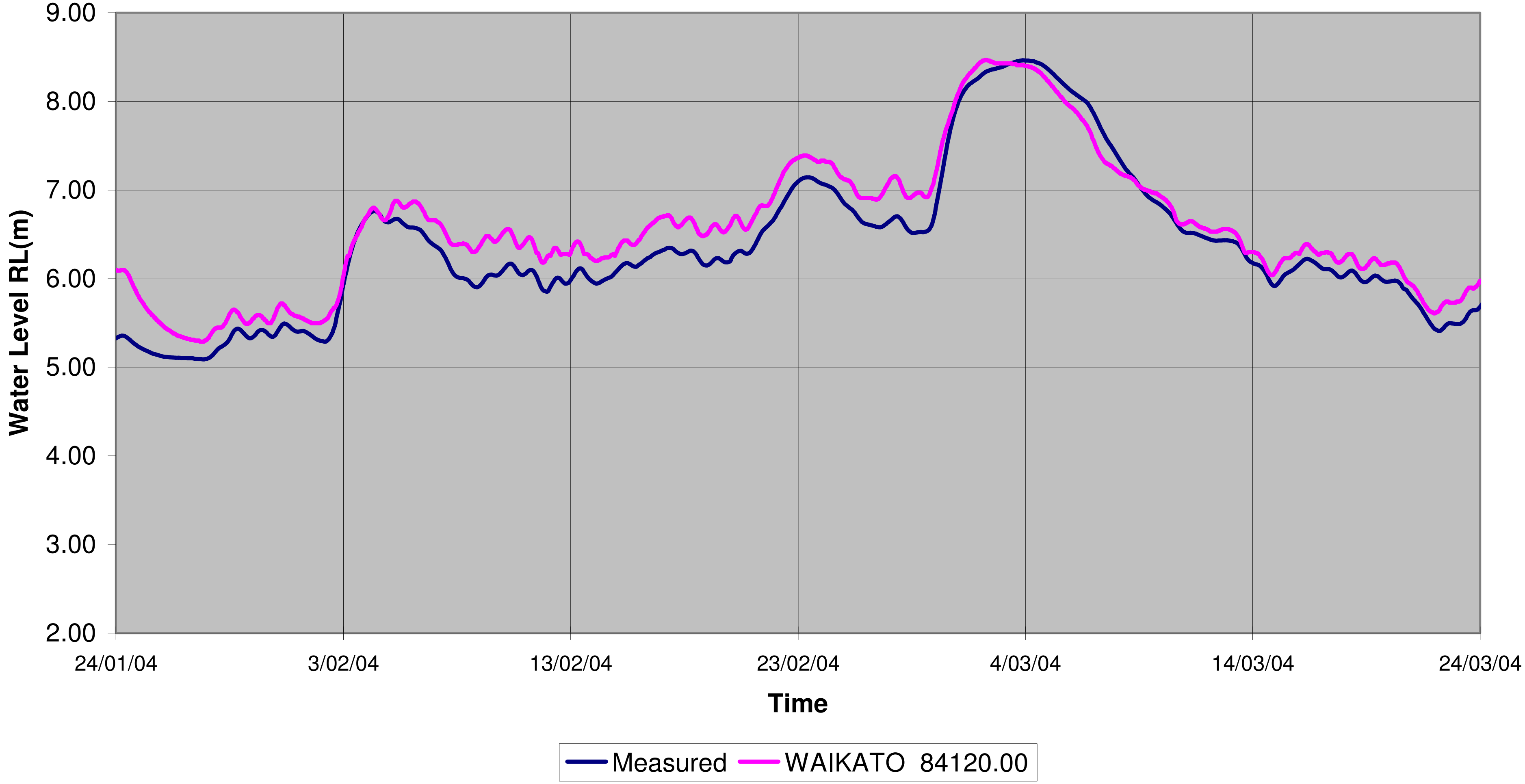


Figure C14 - Measured and Modelled Water Levels February 2004 at Control Gate

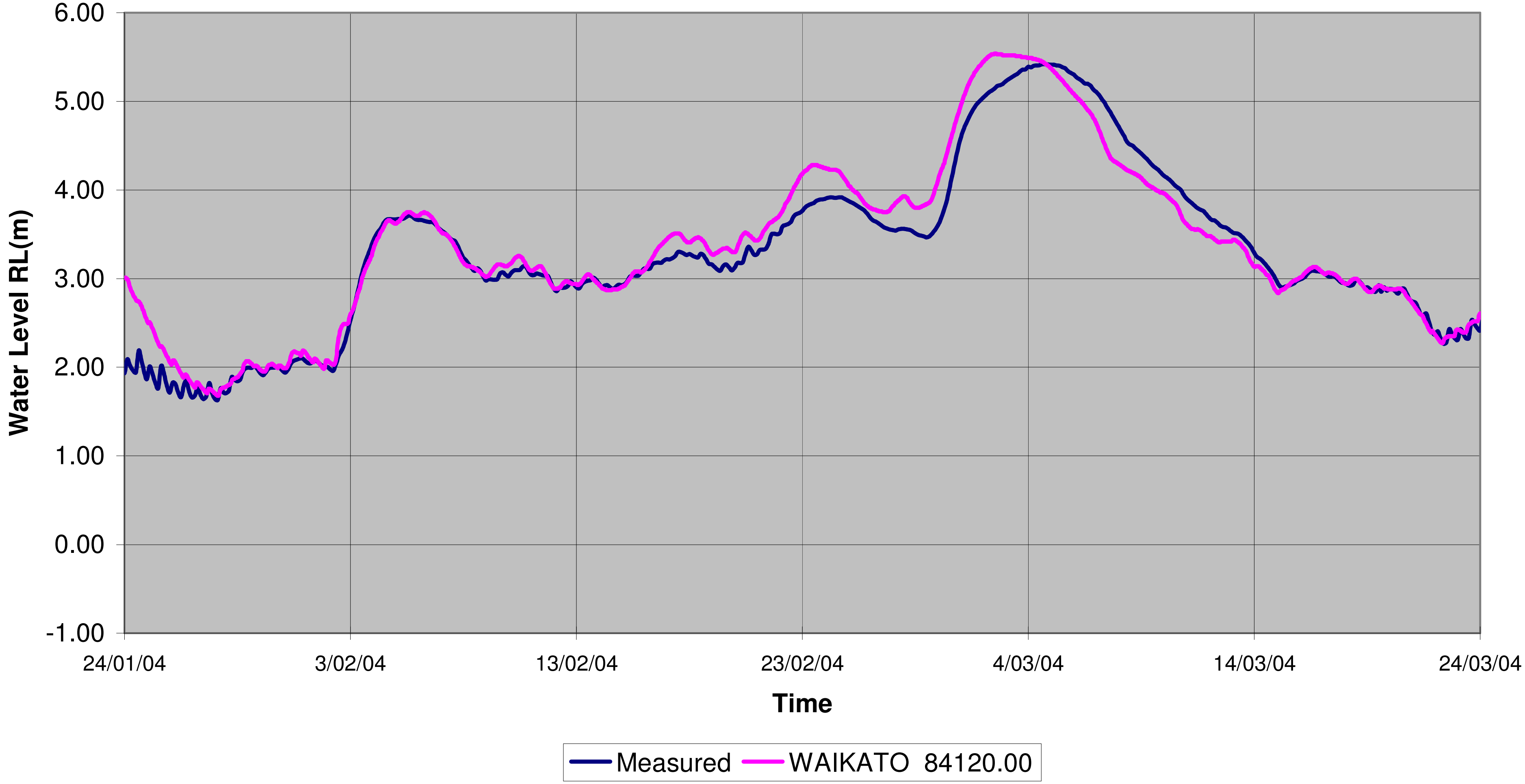


Figure C15 - Measured and Modelled Water Levels February 2004 at Mercer

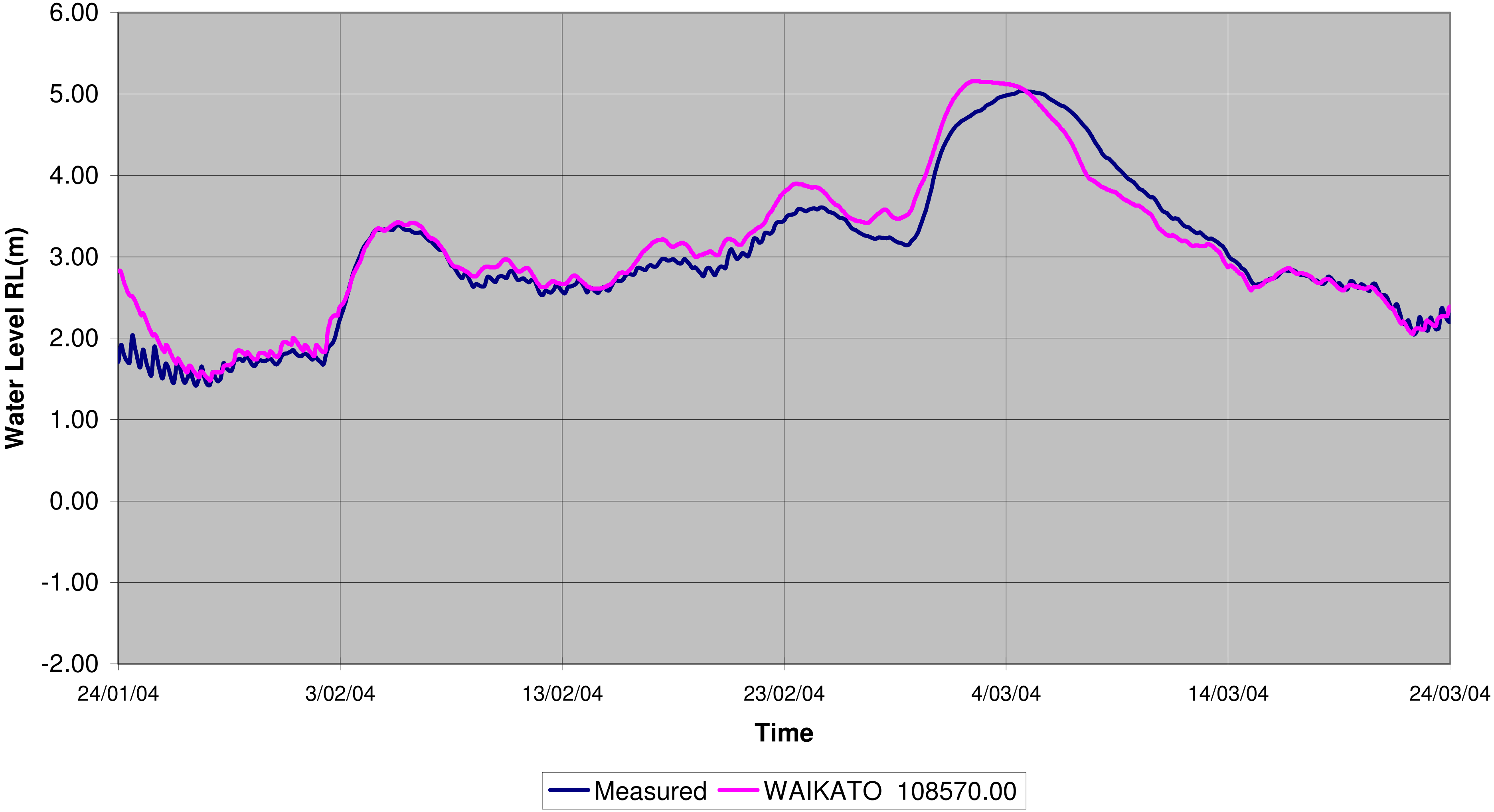


Figure C16 - Measured and Modelled Water Levels February 2004 at Otorohanga

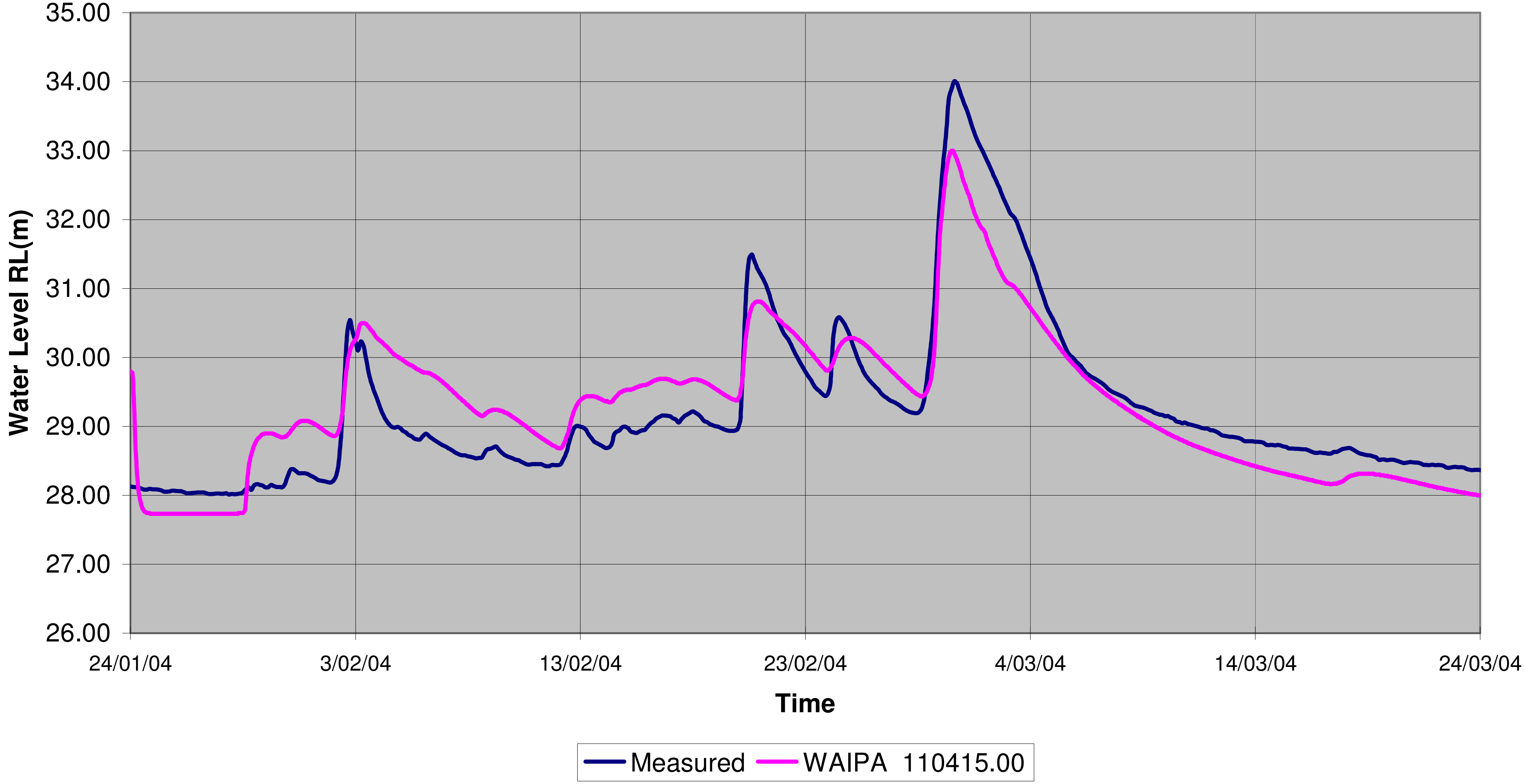
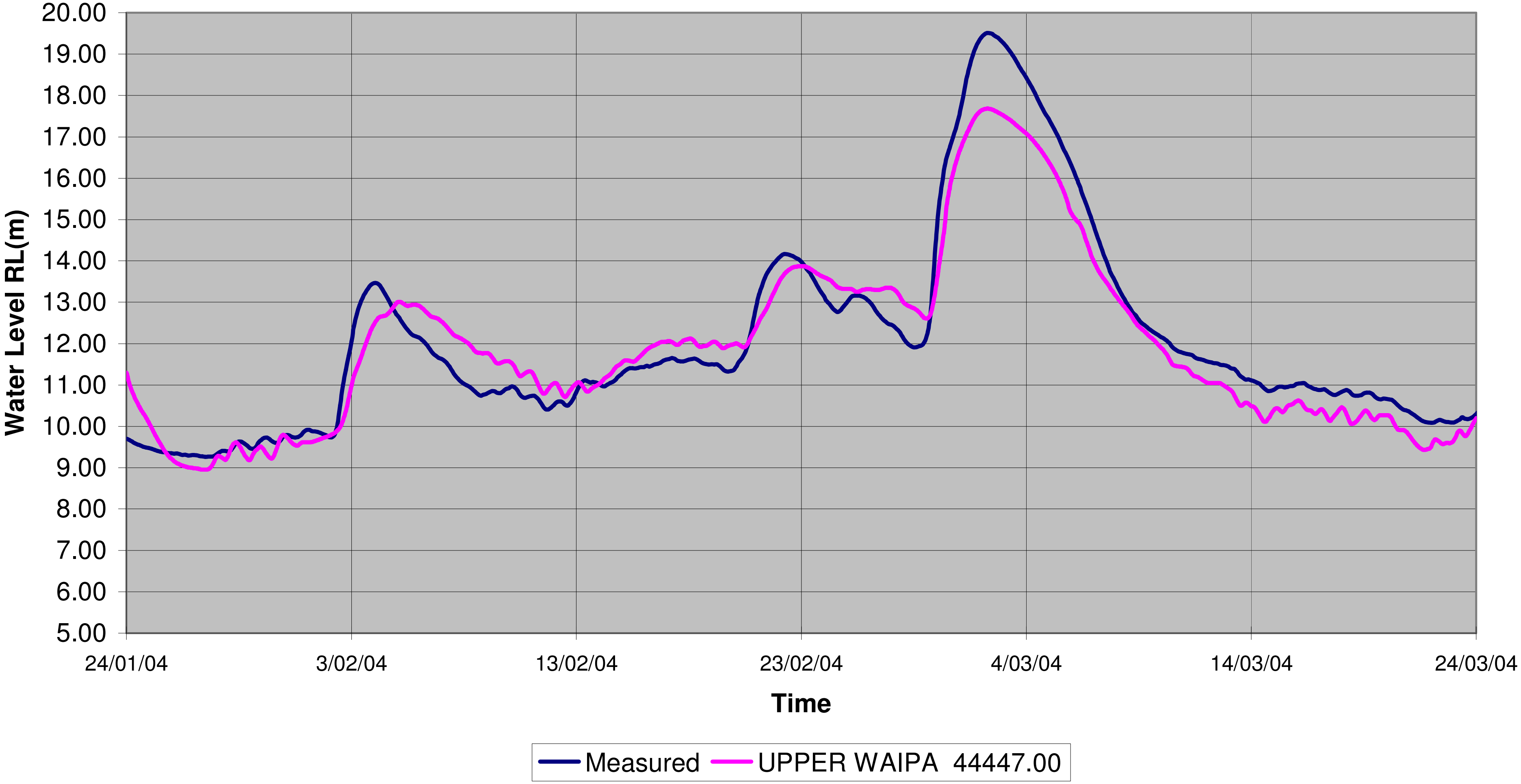


Figure C17 - Measured and Modelled Water Levels February 2004 at Whatawhata



Appendix D

August 2008 Calibration Graphs

Figure D1 - Hamilton Rating Curve - August 2008 Calibration

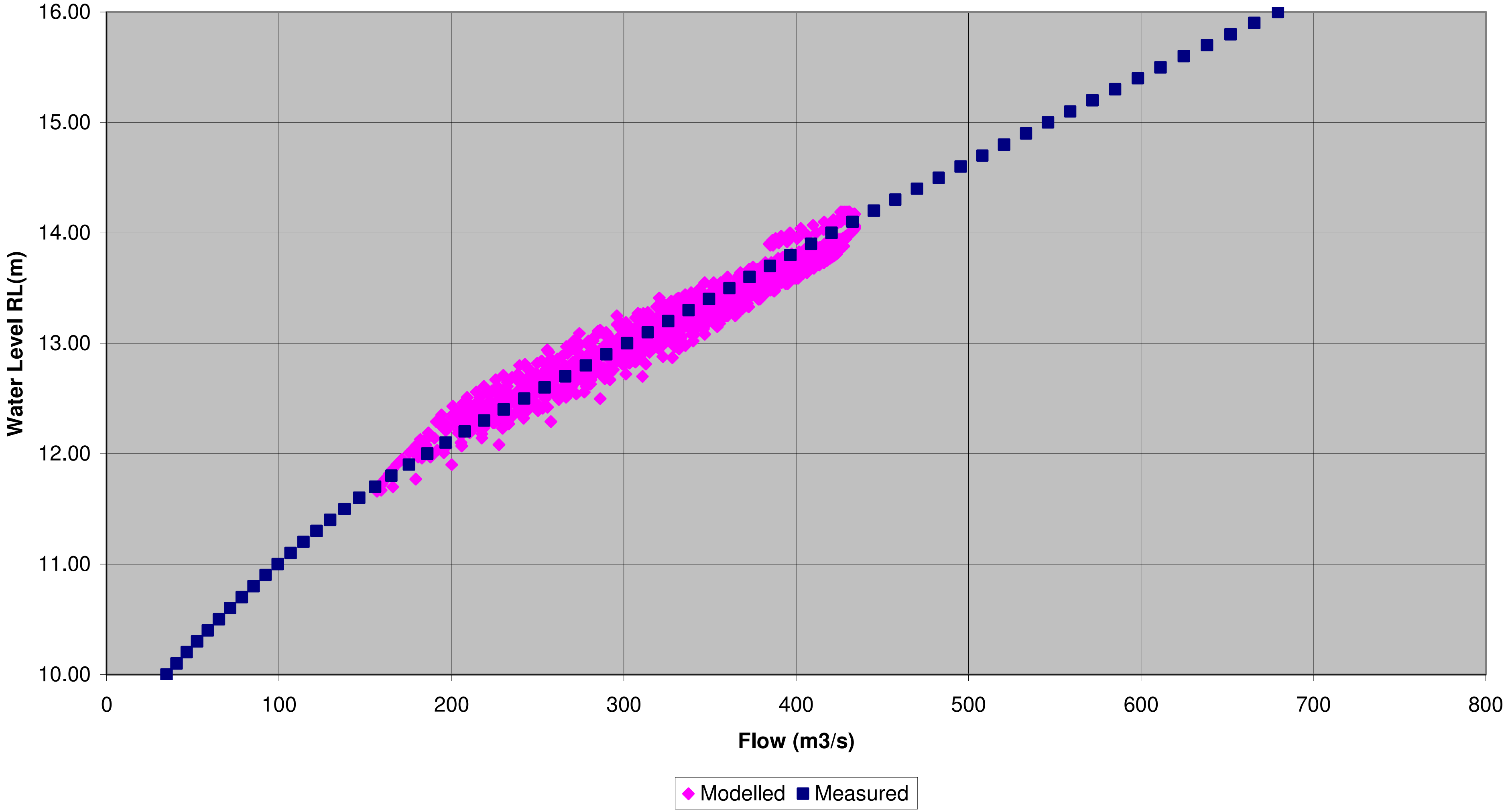


Figure D2 - Ngaruawahia Rating Curve - August 2008 Calibration

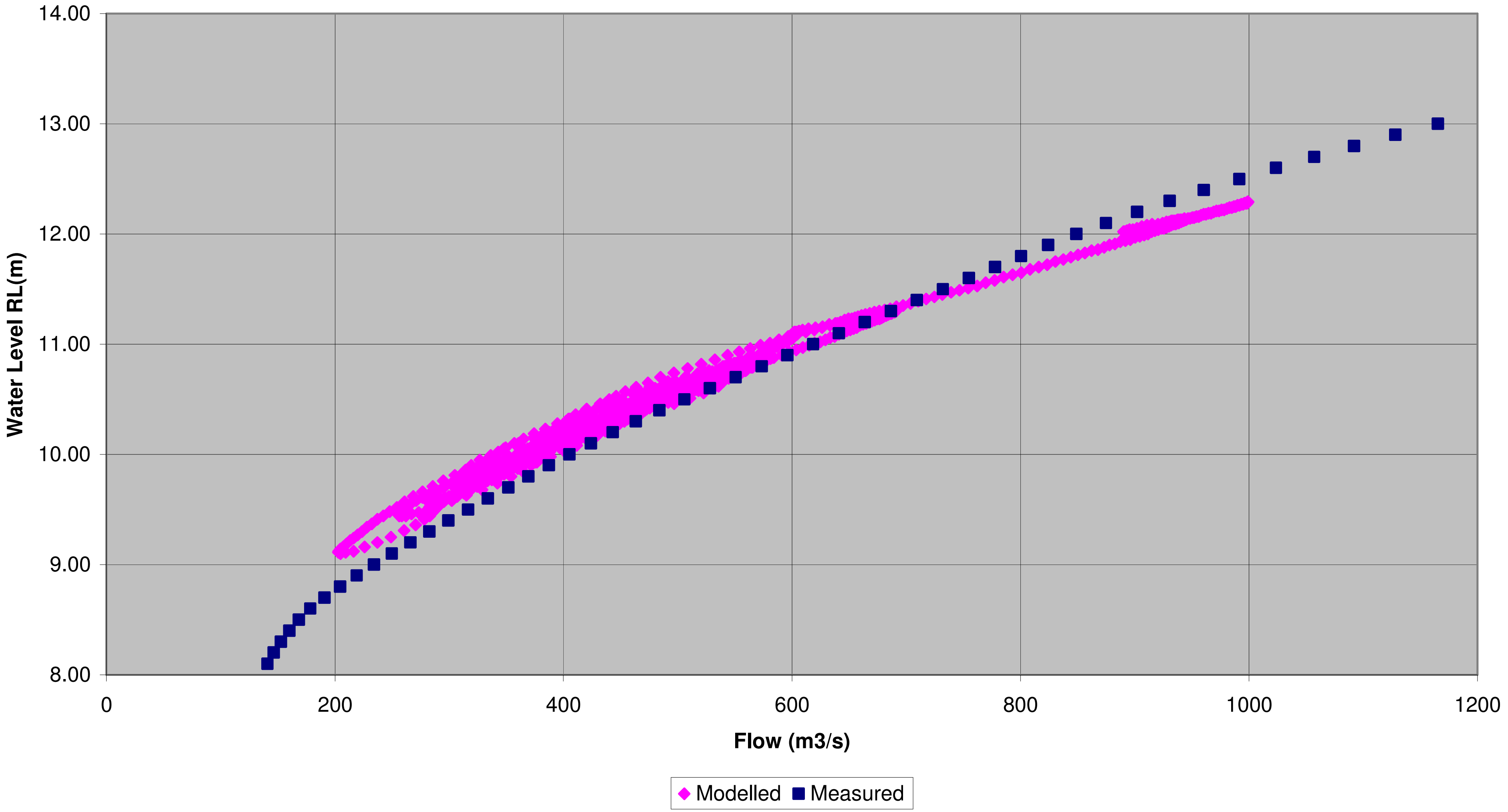


Figure D3 - Rangiriri Rating Curve - August 2008 Calibration

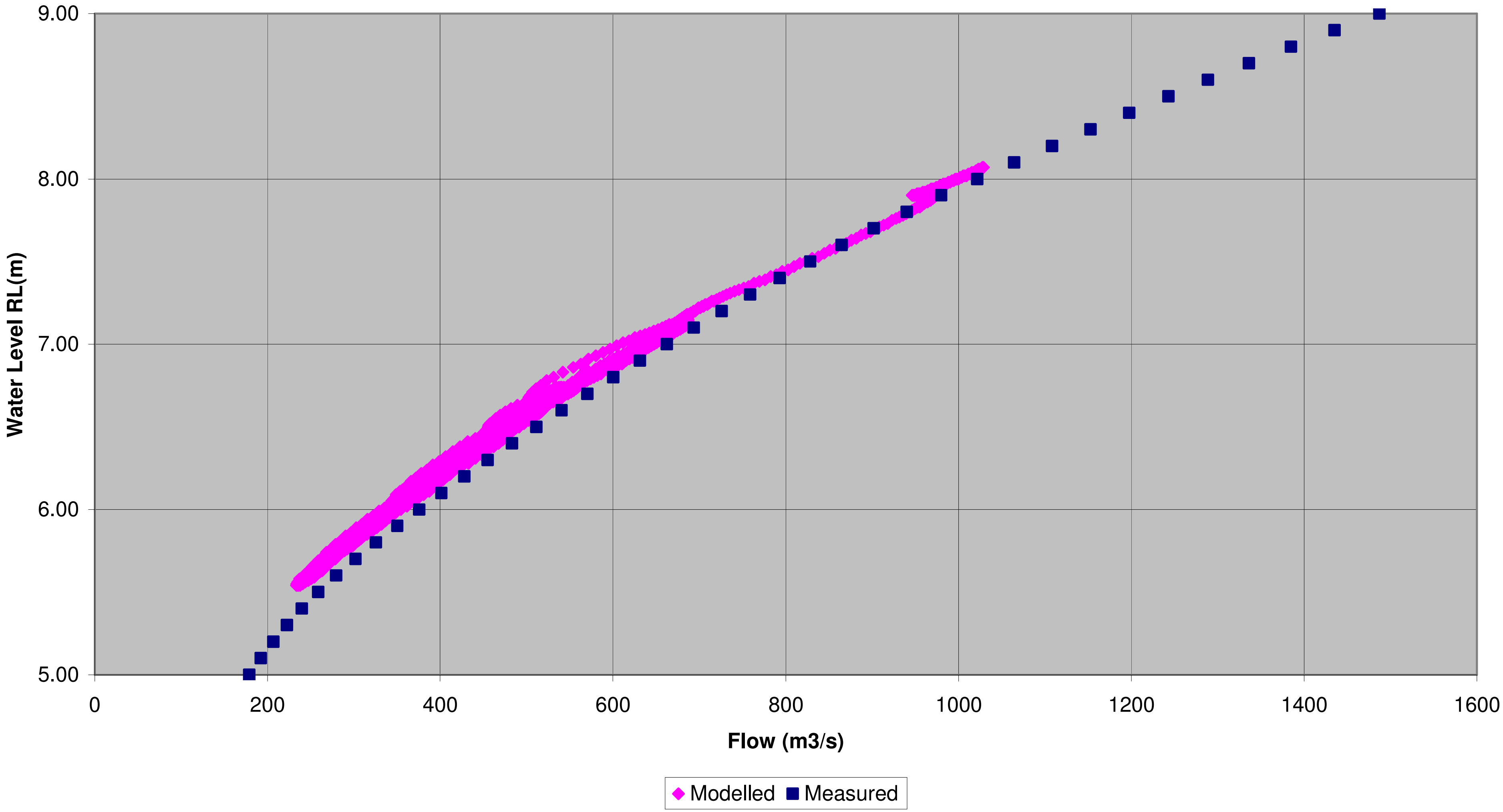


Figure D4 - Mercer Rating Curve - August 2008 Calibration

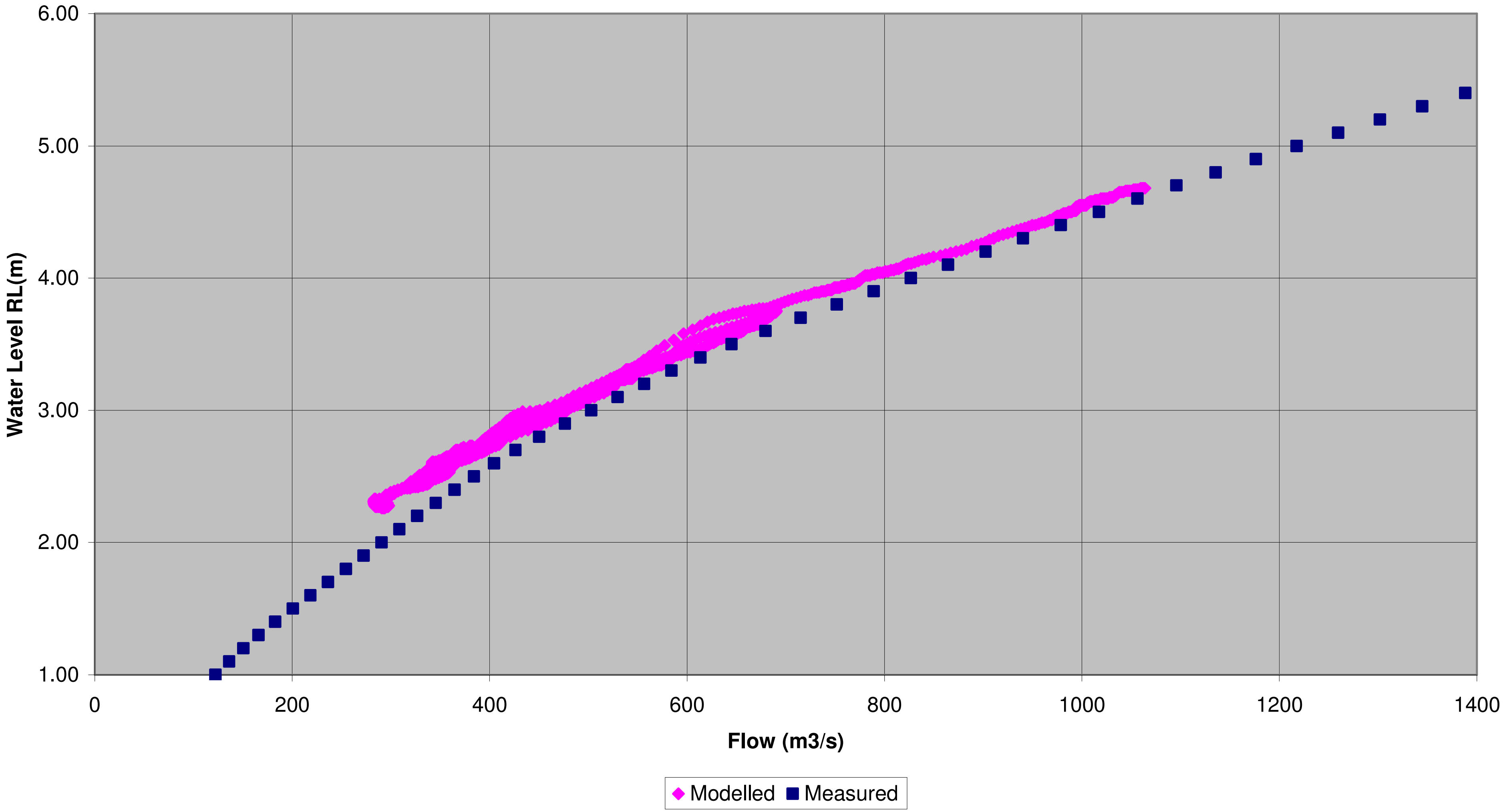


Figure D5 - Whatawhata Rating Curve - August 2008 Calibration

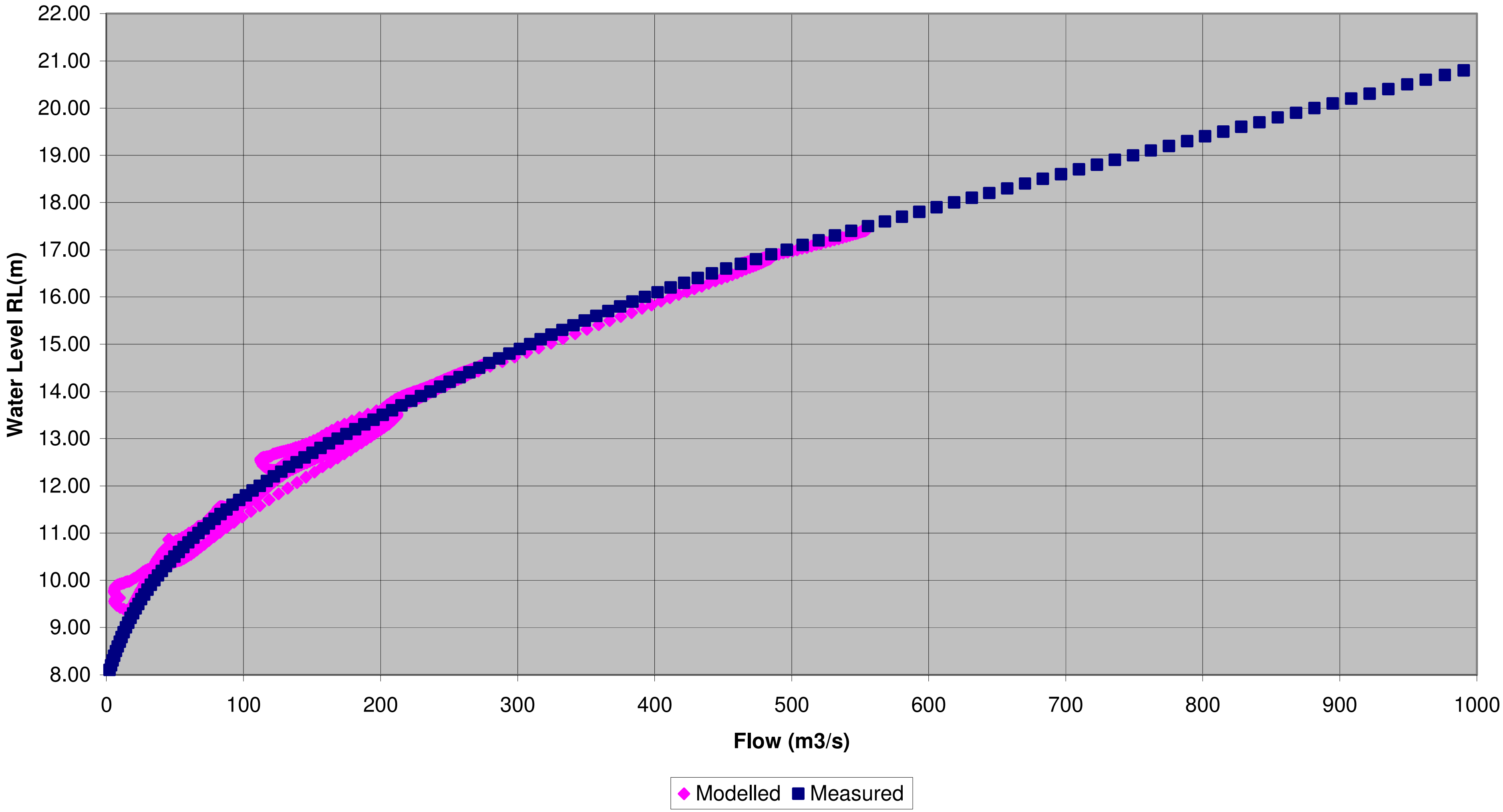


Figure D6 - Measured and Modelled Flows at Hamilton - August 2008

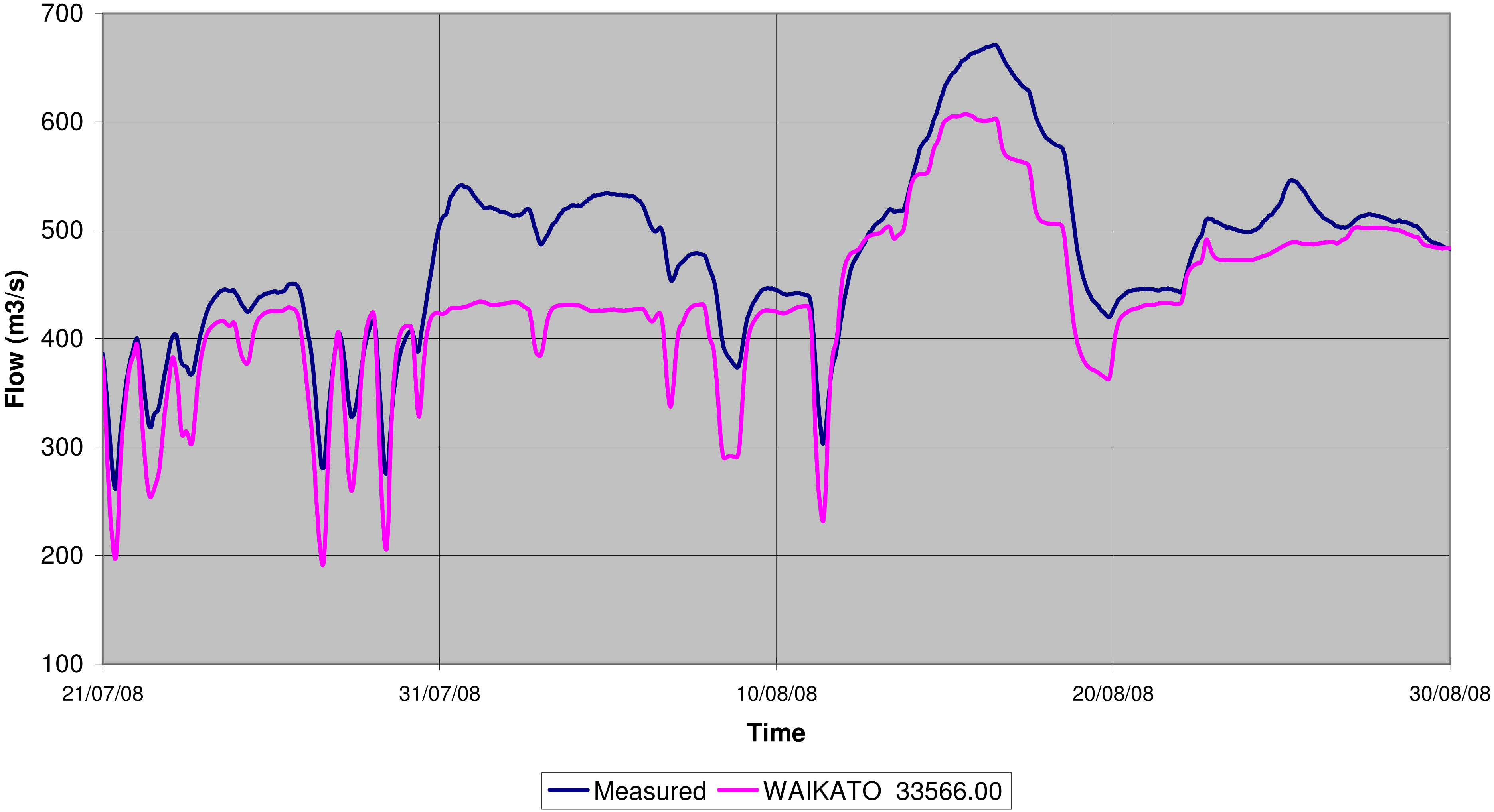


Figure D7 - Measured and Modelled Flows at Ngaruawahia - August 2008

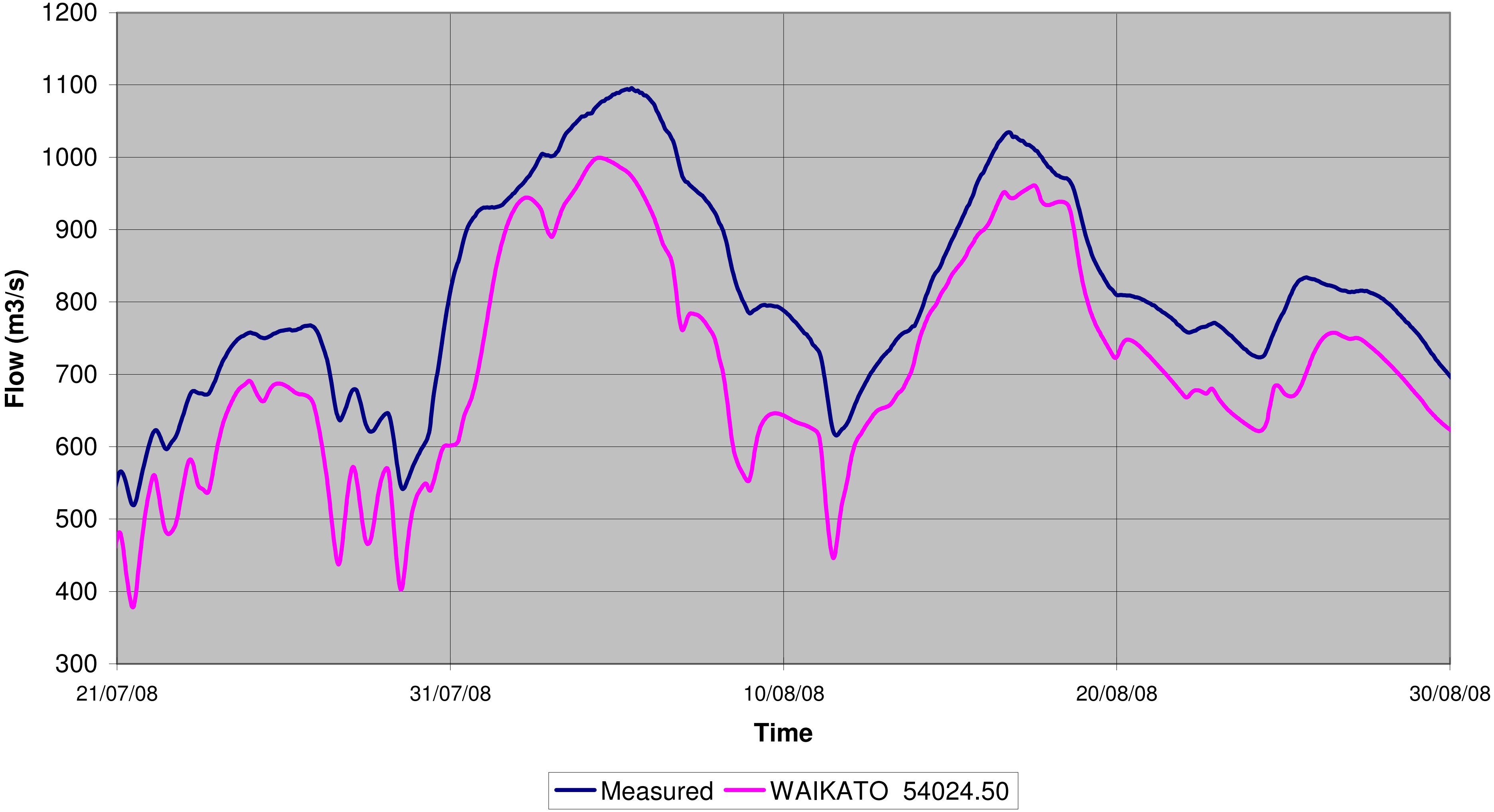


Figure D8 - Measured and Modelled Flows at Rangiriri - August 2008

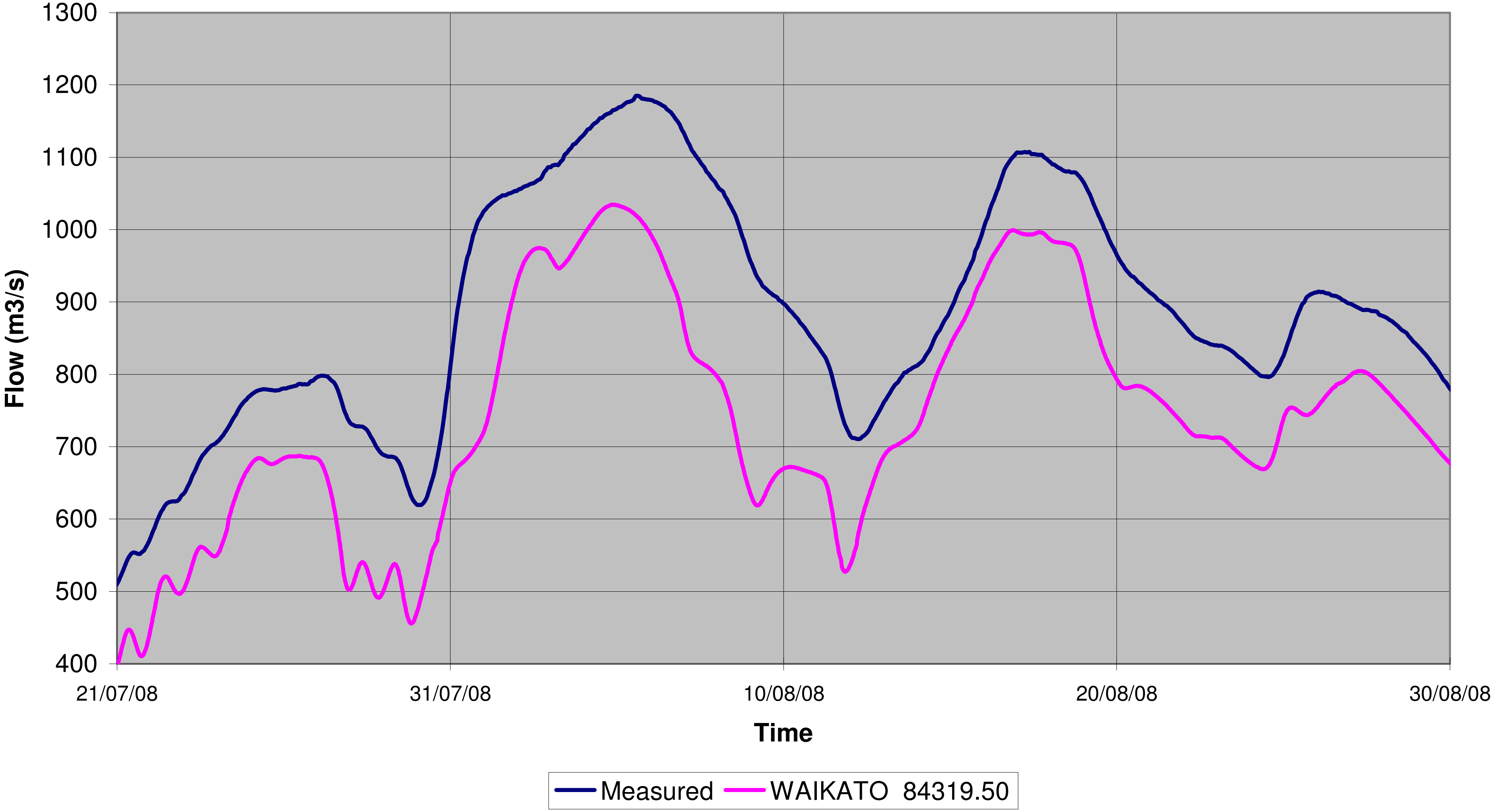


Figure D9 - Measured and Modelled Flows at Mercer - August 2008

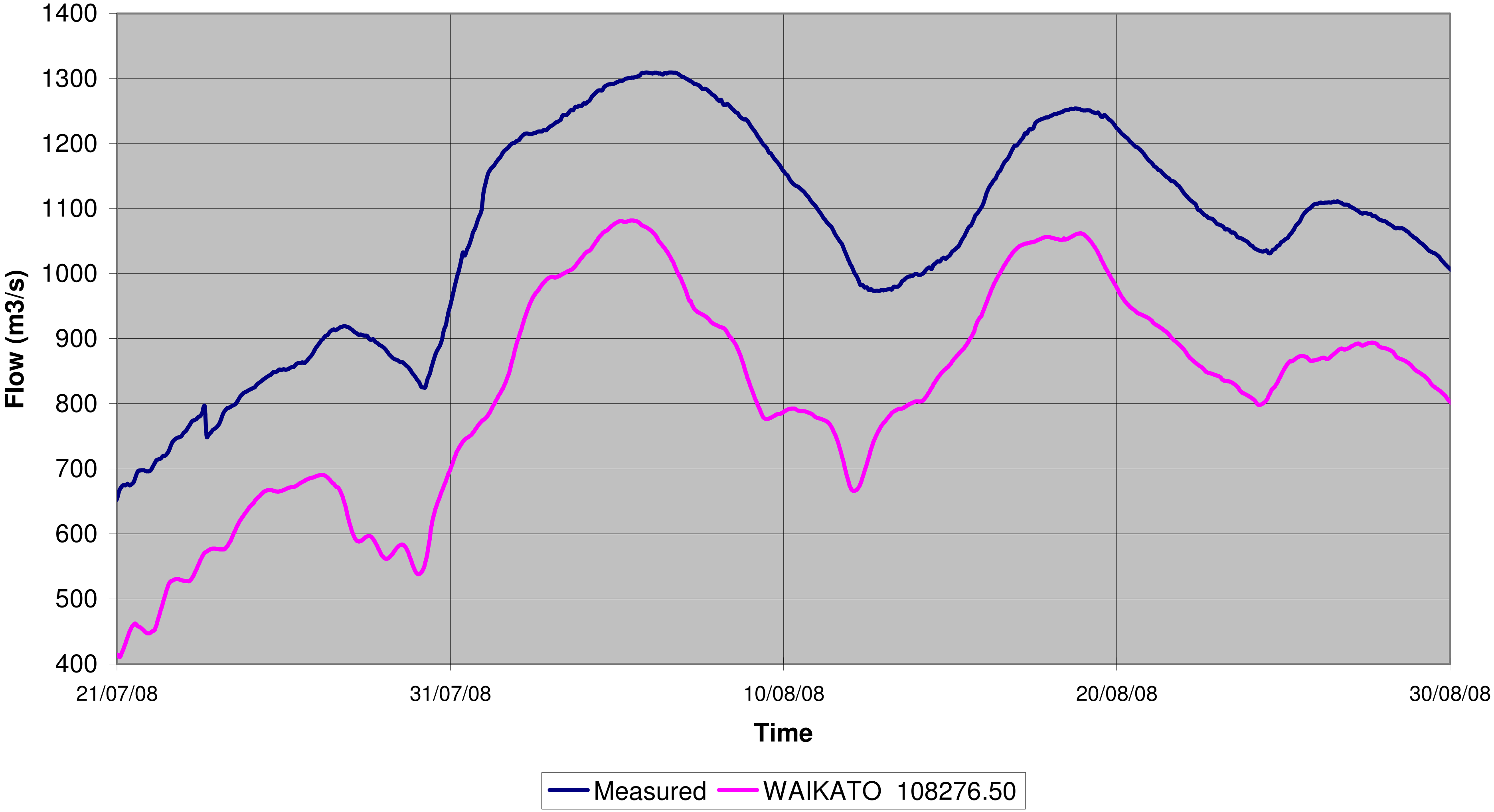


Figure D10 - Measured and Modelled Flows at Otorohanga - August 2008

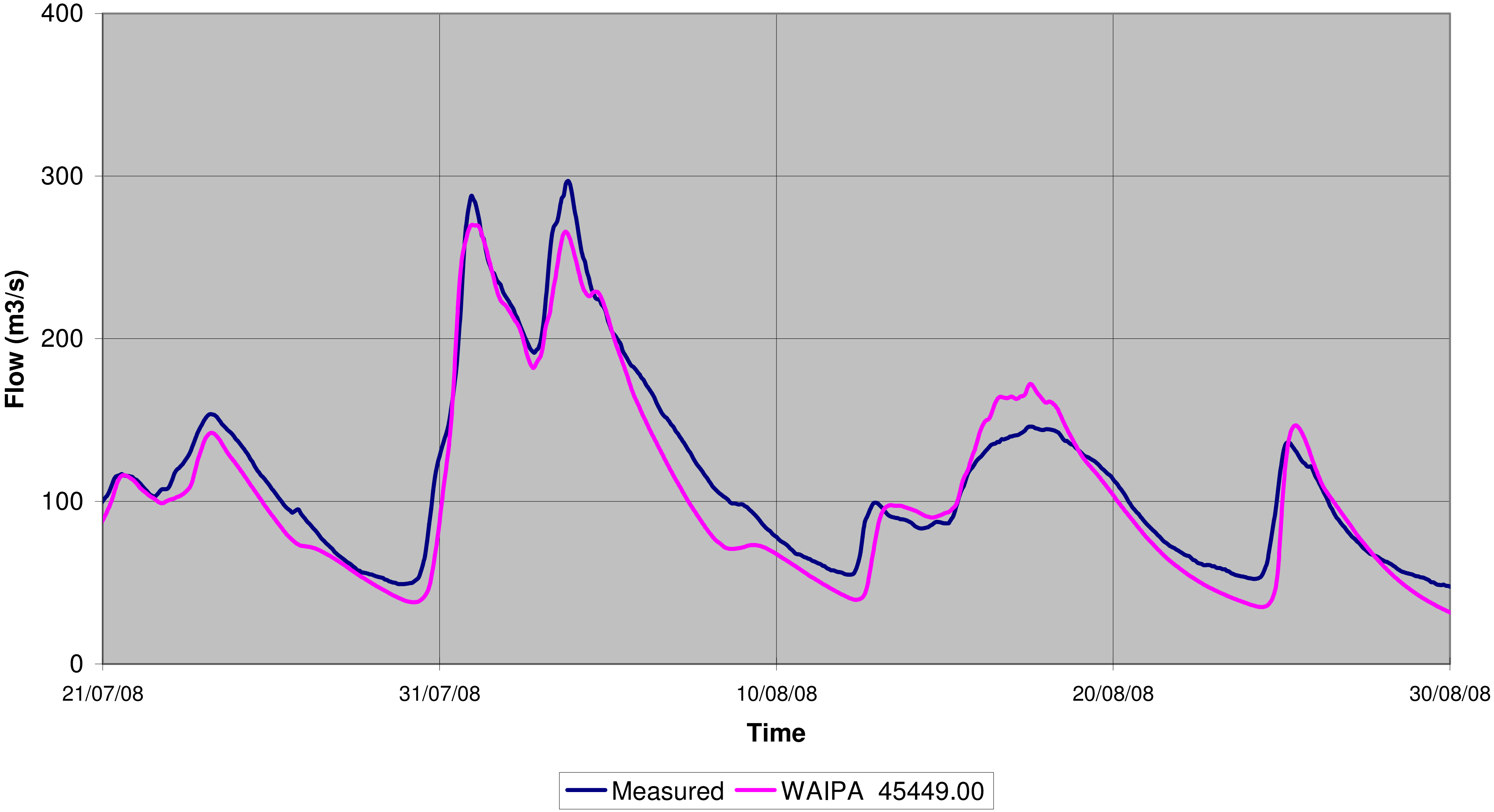


Figure D11 - Measured and Modelled Flows at Whatawhata - August 2008

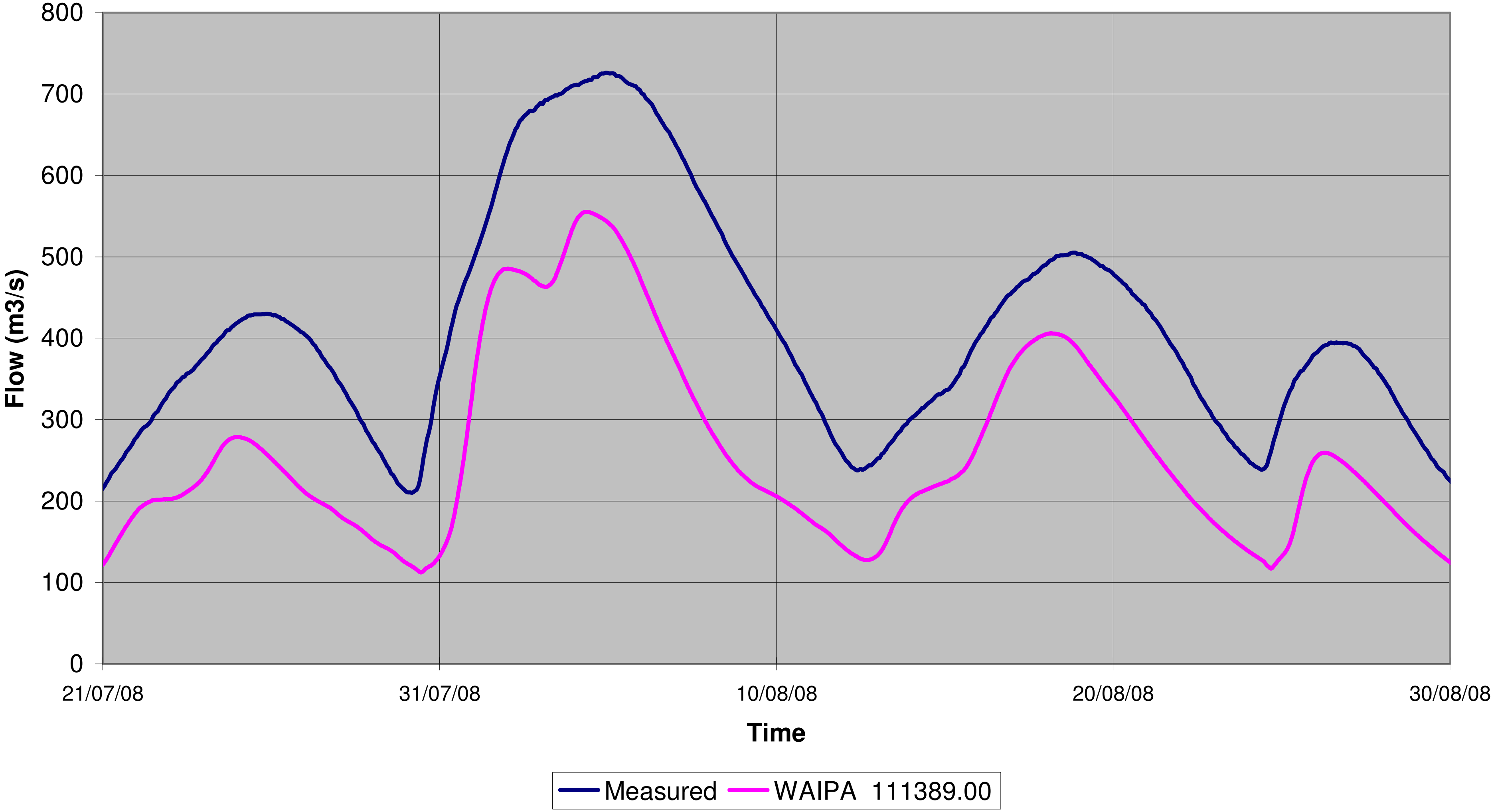


Figure D12 - Measured and Modelled Flood Levels at Hamilton - August 2008

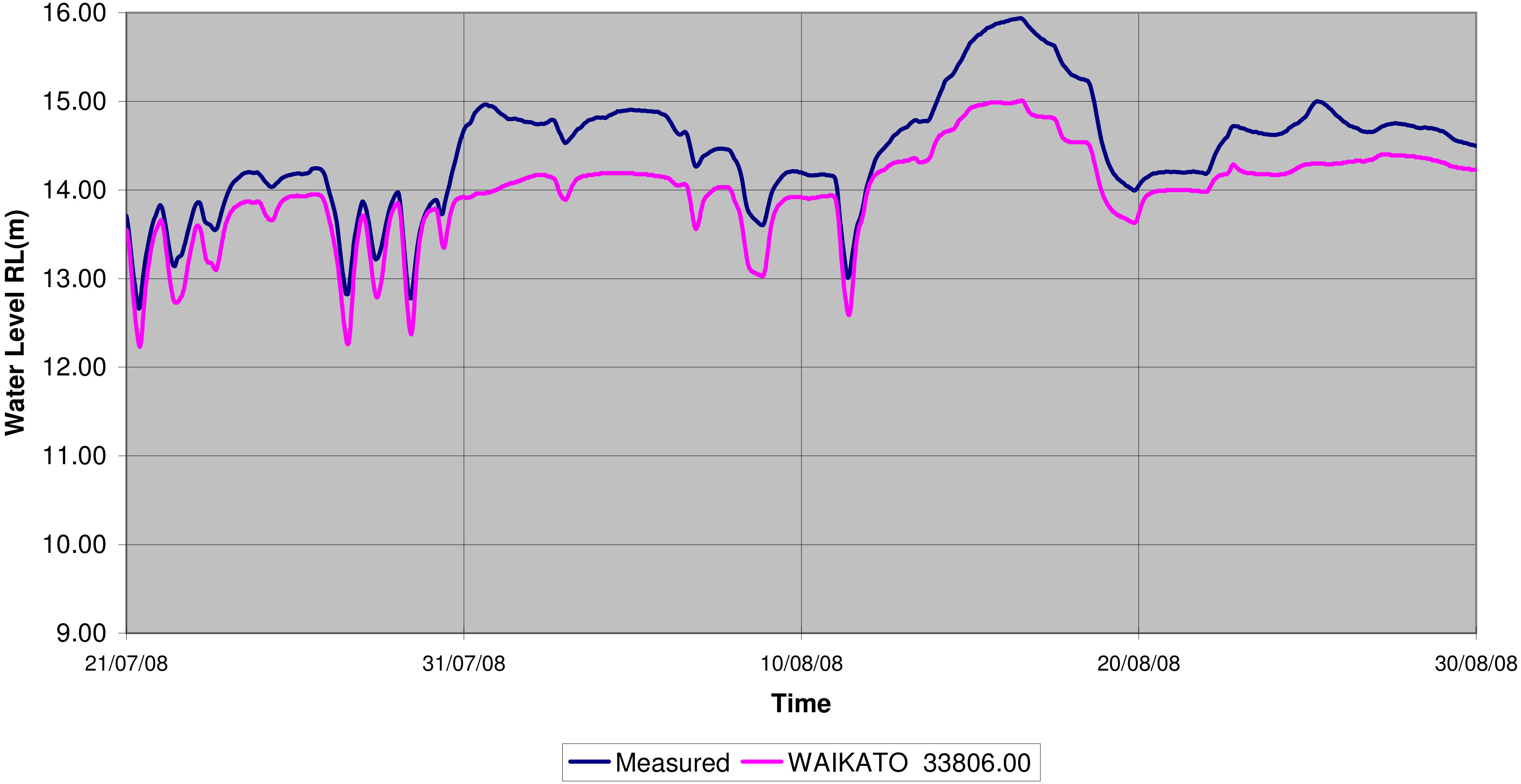


Figure D13 - Measured and Modelled Flood Levels at Ngaruawahia - August 2008

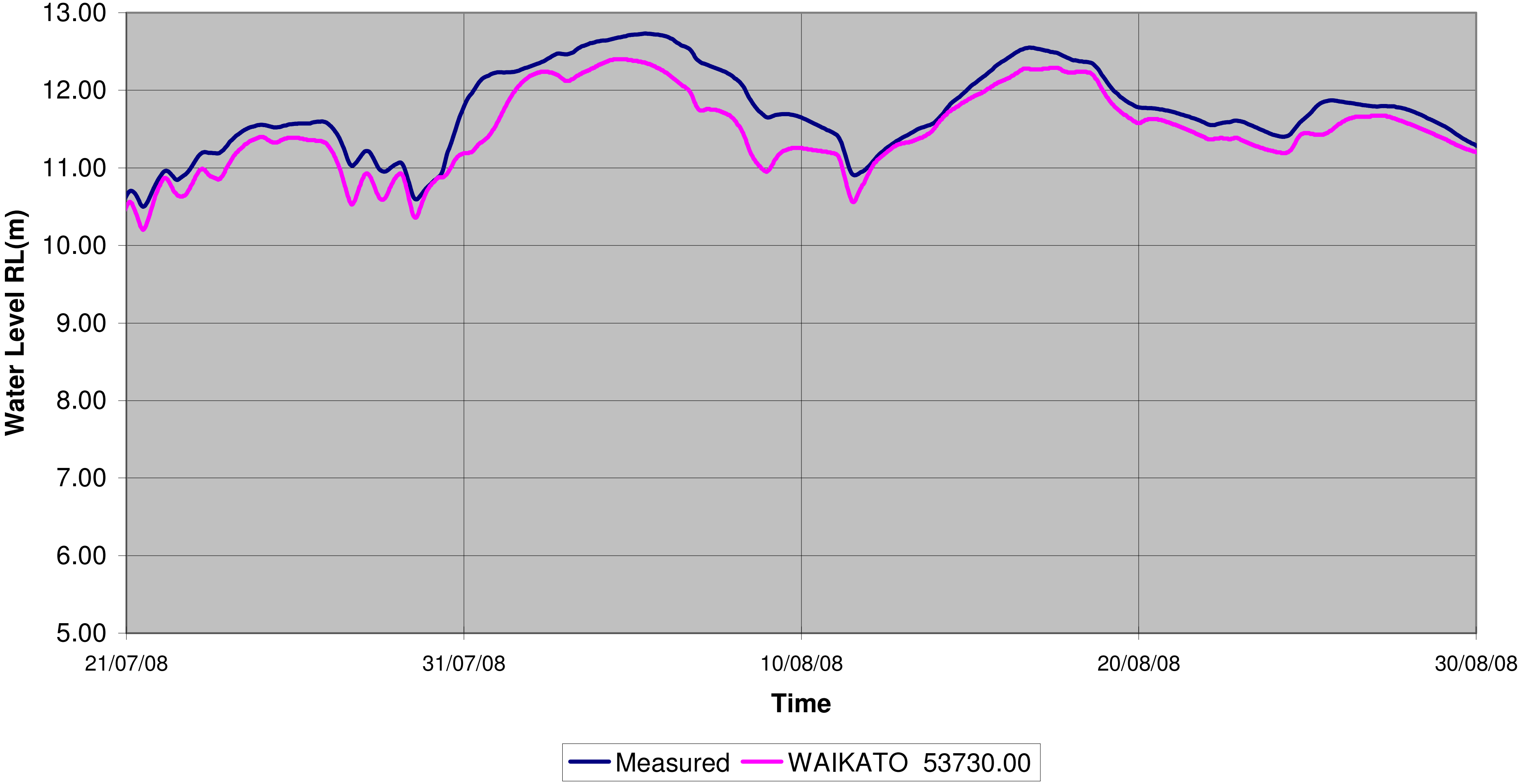


Figure D14 - Measured and Modelled Flood Levels at Rangiriri - August 2008

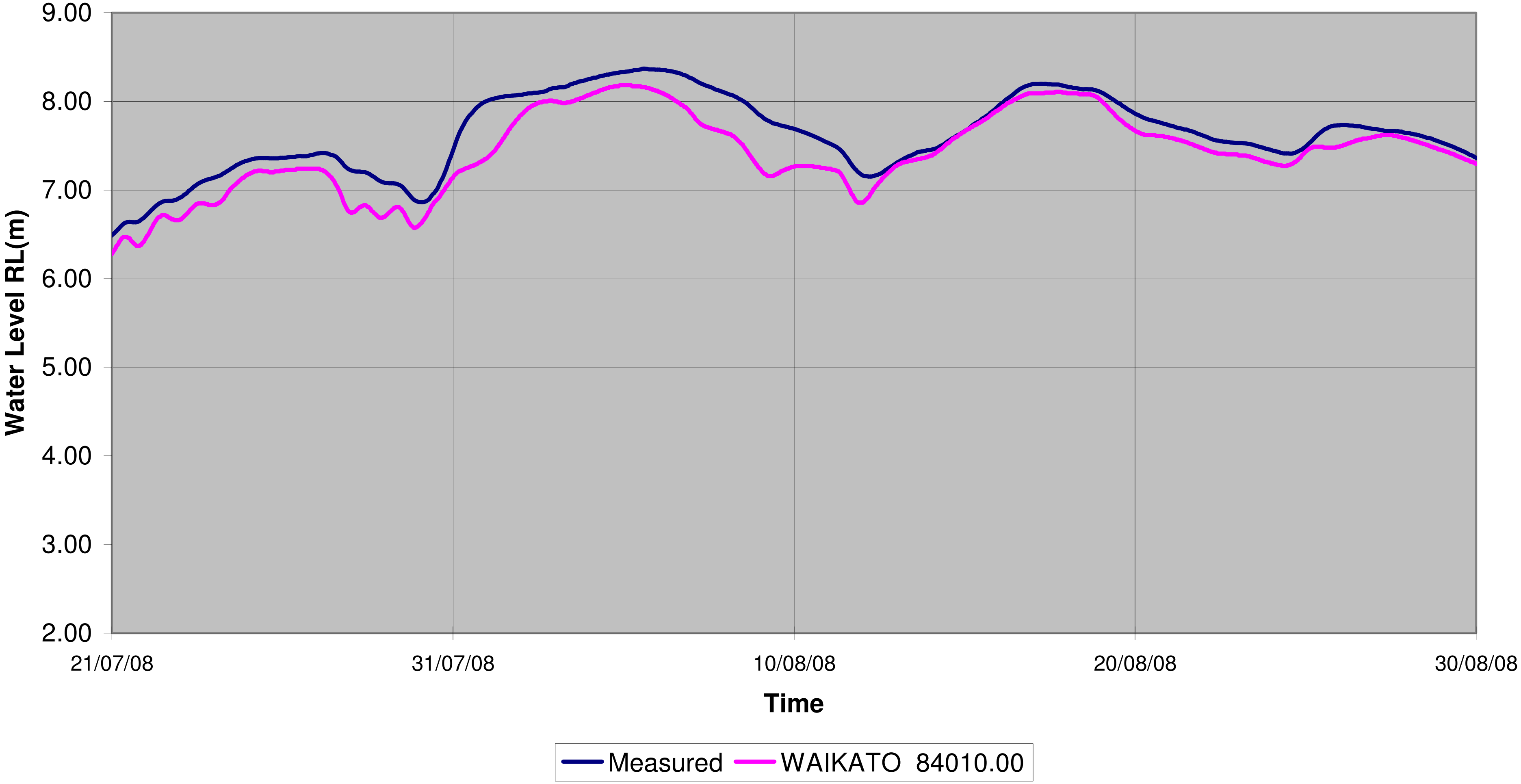


Figure D15 - Measured and Modelled Flood Levels at Mercer - August 2008

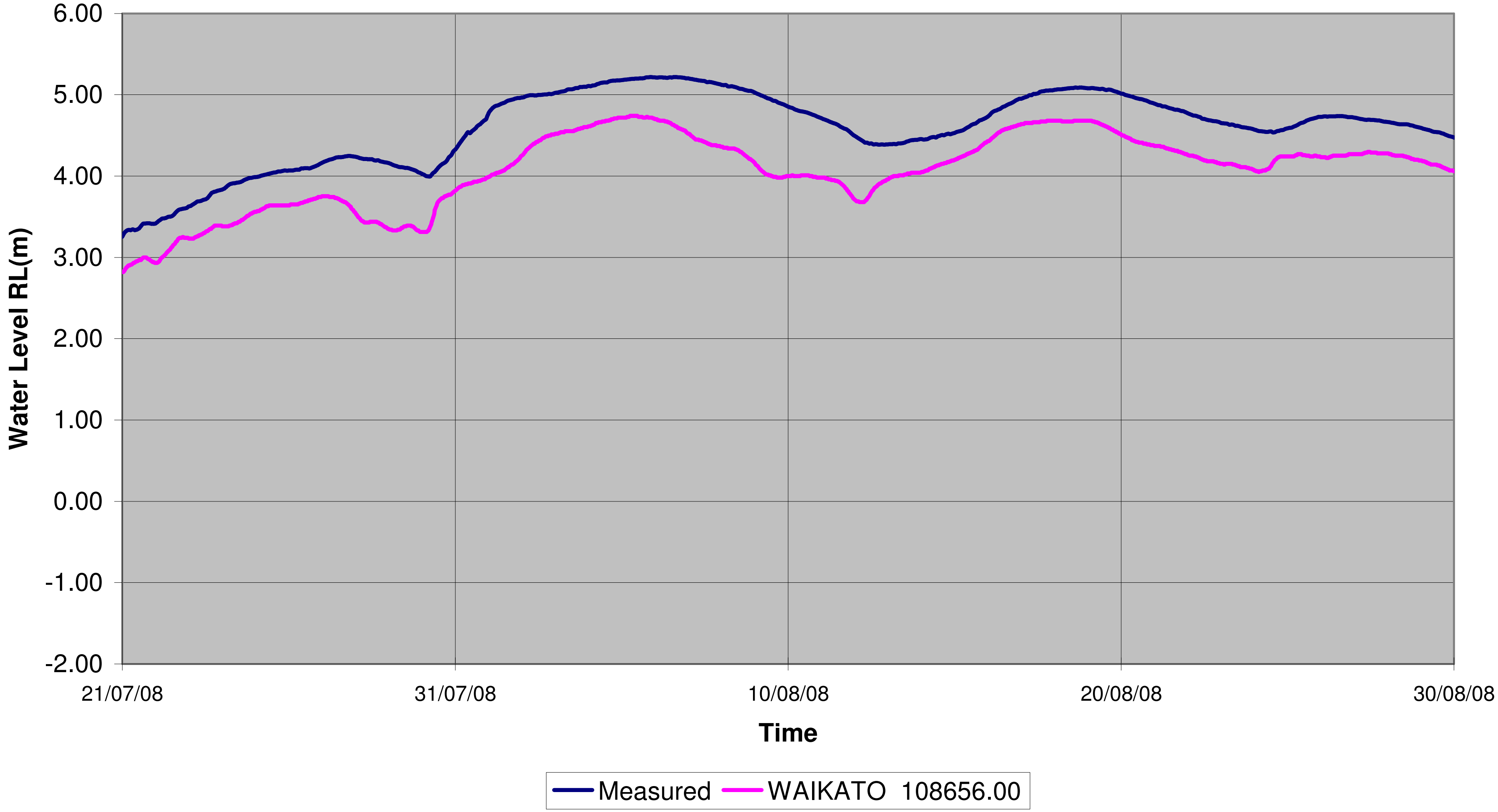


Figure D16 - Measured and Modelled Flood Levels at Otorohanga - August 2008

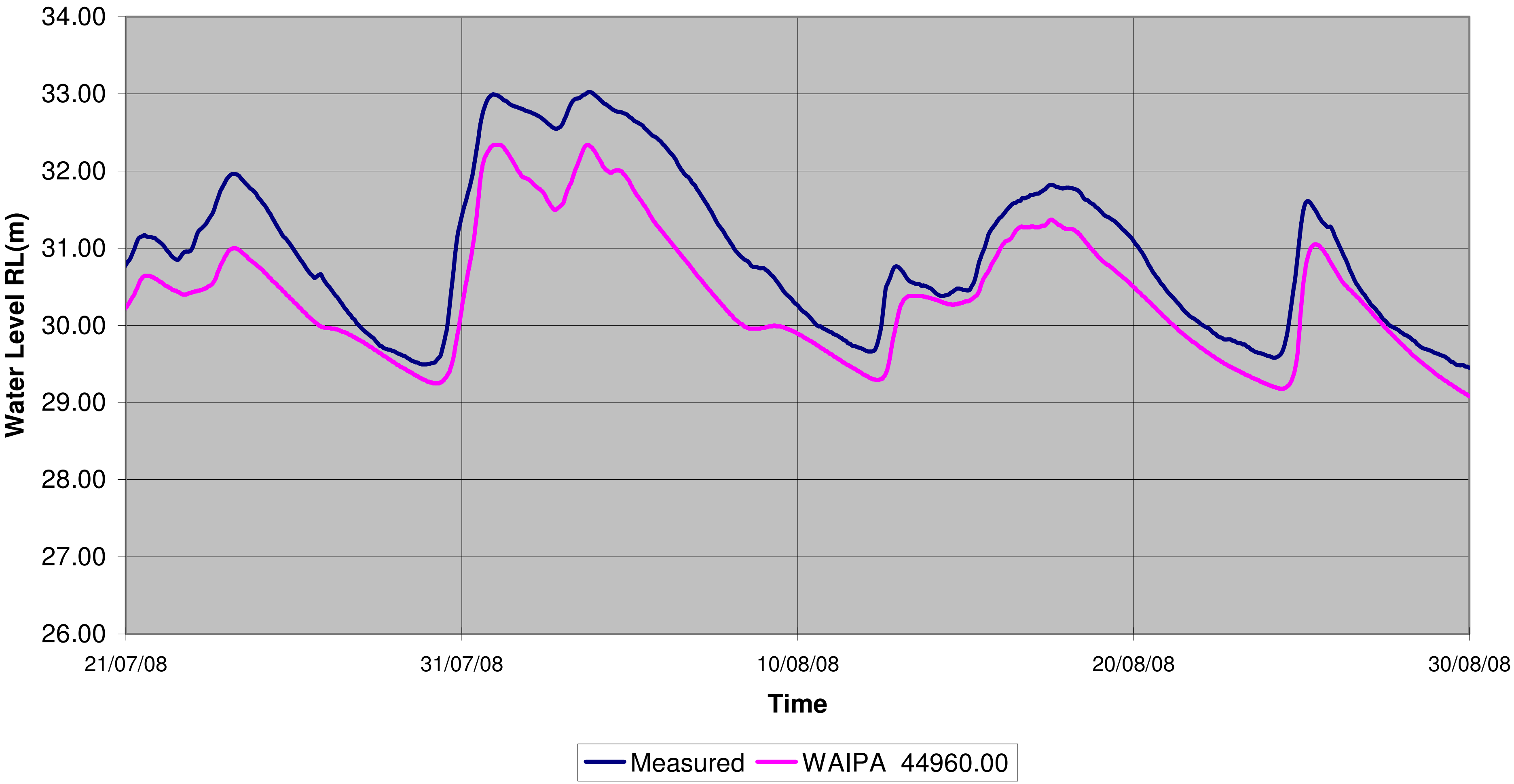
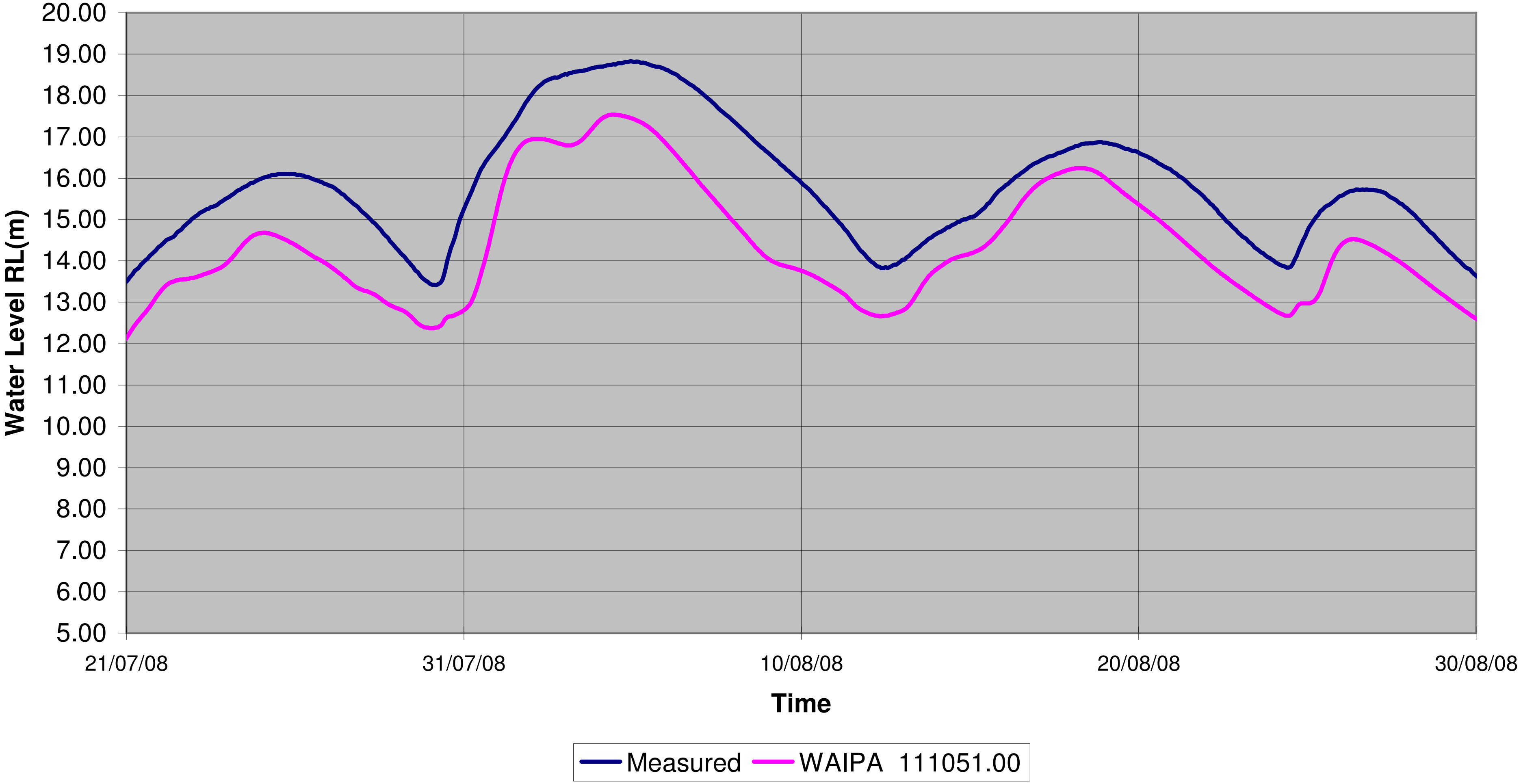


Figure D17 - Measured and Modelled Flood Levels at Whatawhata - August 2008



Appendix E

Calibration Differences for the 3 flood events

The following tables highlight the correctness of fit of the various parameters in the calibration hydrographs and rating curves. Results are in terms of modelled results with the following used to highlight good and poor calibration.

Acceptable		Unacceptable	

Rating Curves

July 1998 Event

Location	Figure	Lower	Mid	At the peak
Hamilton	B1	Too rough, range 0.5m	Ok, range 1m	Excellent
Ngaruawahia	B2	Too rough, range 0.3m	Good	Good
Rangiriri	B3	Good	Good	Good
Control Gate	B4	Too rough by 0.5m	Too rough by 0.4m	Good
Whatawhata	B5	Good, range 1m	Good, range 0.2m	Too smooth, range 15m

February 2004

Location	Figure	Lower	Mid	Upper
Hamilton	C1	Ok, range 0.5m	Ok, range 0.3m	Excellent
Ngaruawahia	C2	Too rough, range 0.5m	Good	Too smooth, range 0.3m
Rangiriri	C3	Little too rough, range 0.2m	Good	Little too smooth, range 0.15m
Whatawhata	C4	Good	Good, range 0.2m	Too smooth, range 1m

August 2008

Location	Figure	Lower	Mid	Upper
Hamilton	D1	Good	Good	Excellent
Ngaruawahia	D2	Too rough, range 0.3m	Good	Too smooth, range 0.1m
Rangiriri	D4	Little too rough by 0.1m	Little too rough by 0.1m	Perfect
Mercer	D4	Too high, range 0.2m	Little too high range 0.1m	Good, almost perfect
Whatawhata	D5	Good	Good	Perfect

Flow Hydrographs

July 1998 Event

Location	Figure	Peaks	Timing	Volume (estimate)
Hamilton	B6	180 too low	Good	Poor
Ngaruawahia	B7	Excellent	Excellent	Too low
Rangiriri	B8	100 too low	Very good	Too low
Mercer	B9	Very good	1 –day too early	Too low
Otorohanga	B10	Very good	Excellent	Little too low
Whatawhata	B11	100 too high	Excellent	Good

February 2004

Location	Figure	Peaks	Timing	Volume (estimate)
Hamilton	C5	50 too low	Good	Too low
Ngaruawahia	C6	Good	1 day early	Good
Rangiriri	C7	Good	1.5 days early	Good
Mercer	C8	Good	2 days early	Ok
Otorohanga	C9	200 too low	Good	Too low
Whatawhata	C10	80 too low	Good	Too low

August 2008

Location	Figure	Peaks	Timing	Volume (estimate)
Hamilton	D6	60 too low	Good	Poor
Ngaruawahia	D7	100 too low	Good	Too low
Rangiriri	D8	170 too low	Good	Poor
Mercer	D9	200 loo low	Good	Poor
Otorohanga	D10	Good	Excellent	Ok
Whatawhata	D11	180 too low	Good	Poor

Water Levels

July 1998 Event

Location	Figure	Peaks	Timing
Hamilton	B12	1m too low repeatedly	Good
Ngaruawahia	B13	Good	Excellent
Rangiriri	B14	0.15m too low	A little early
Control Gate	B15	Excellent	1-day early
Mercer	B16	Good	1-day early
Otorohanga	B17	1m too low	Excellent
Whatawhata	B18	0.15m too low	Excellent

February 2004

Location	Figure	Peaks	Timing
Hamilton	C11	0.5m too low	Excellent
Ngaruawahia	C12	0.1m too high	Good
Rangiriri	C13	0.1m too high	Good
Control Gate	C14	0.2m too high	2 days early
Mercer	C15	0.2m too high	2 days early
Otorohanga	C16	1.8m too low	Excellent
Whatawhata	C17	1.5m too low	Good

August 2008

Location	Figure	Peaks	Timing
Hamilton	D12	1m too low	Excellent
Ngaruawahia	D13	0.3m too low	Good
Rangiriri	D14	0.2m too low	Good
Mercer	D15	0.7m too low	Good
Otorohanga	D16	0.6m too low	Half day late
Whatawhata	D17	1.3m too low	1 day late

Appendix F

Influences of Flows at Ngaruawahia

Figure F1 - Influence of Measured Karapiro Outflows at Ngaruawahia - July 1998

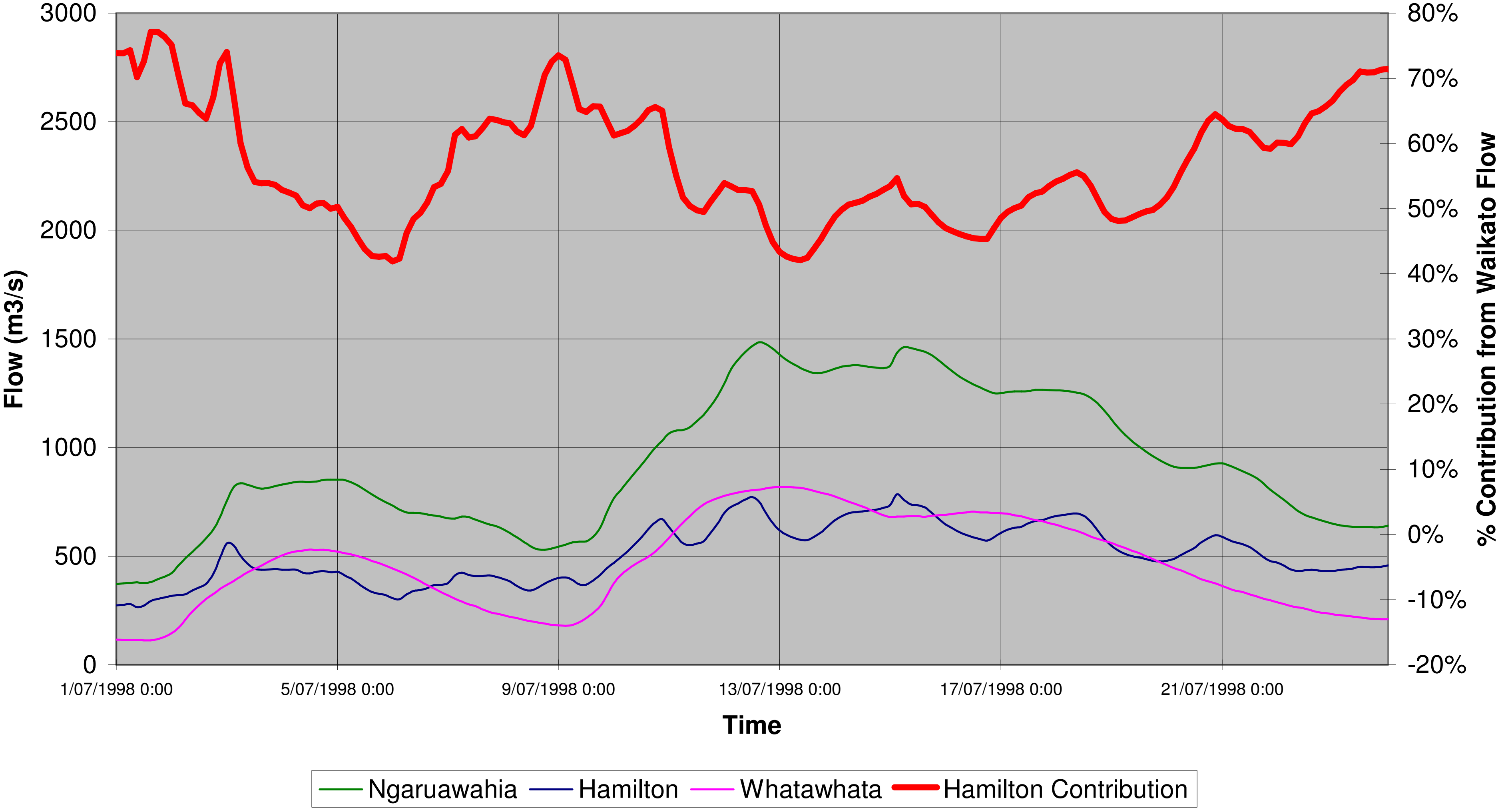


Figure F2 - Influence of Measured Karapiro Outflows at Ngaruawahia - February 2004

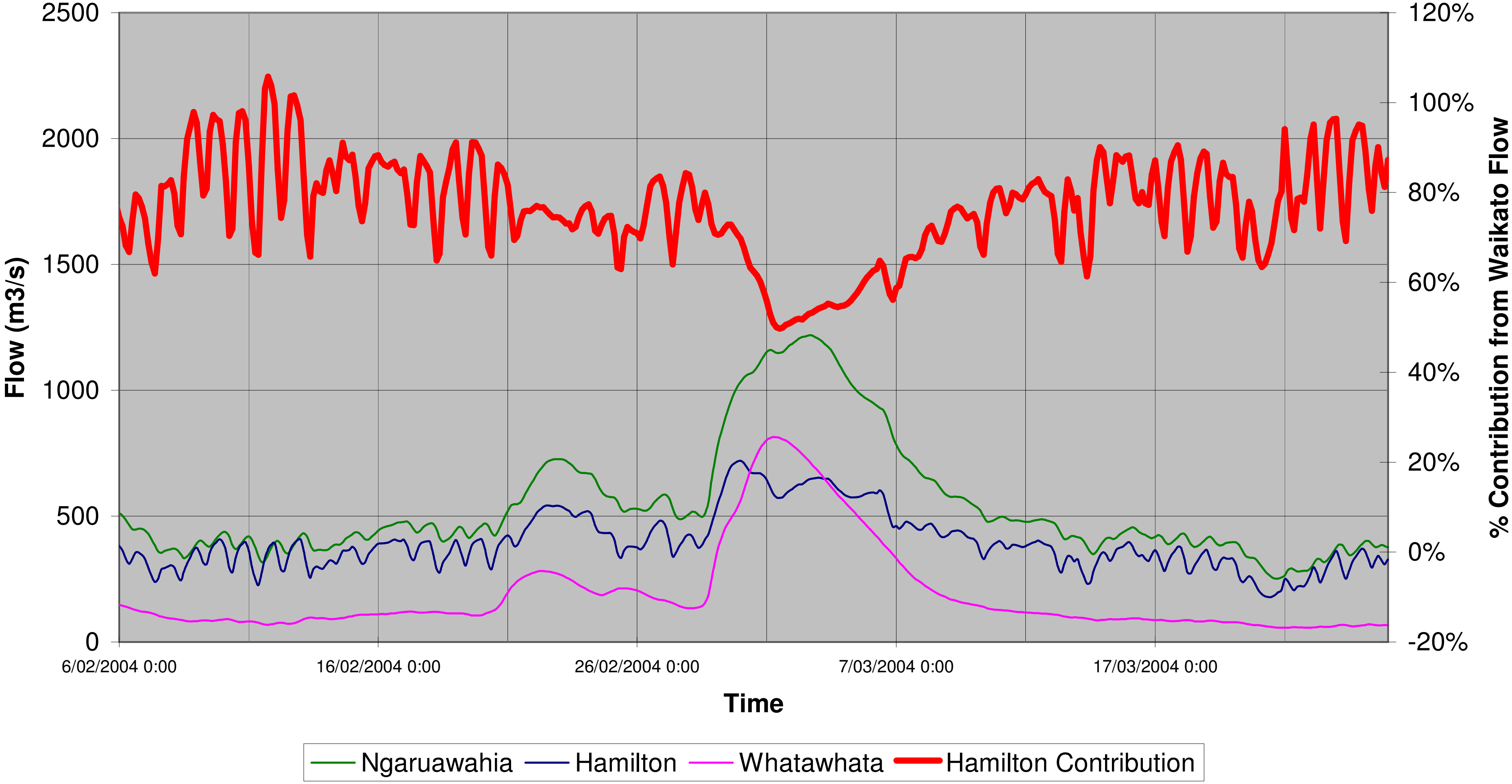


Figure F3 - Influence of Measured Karapiro Outflows at Ngaruawahia - August 2008

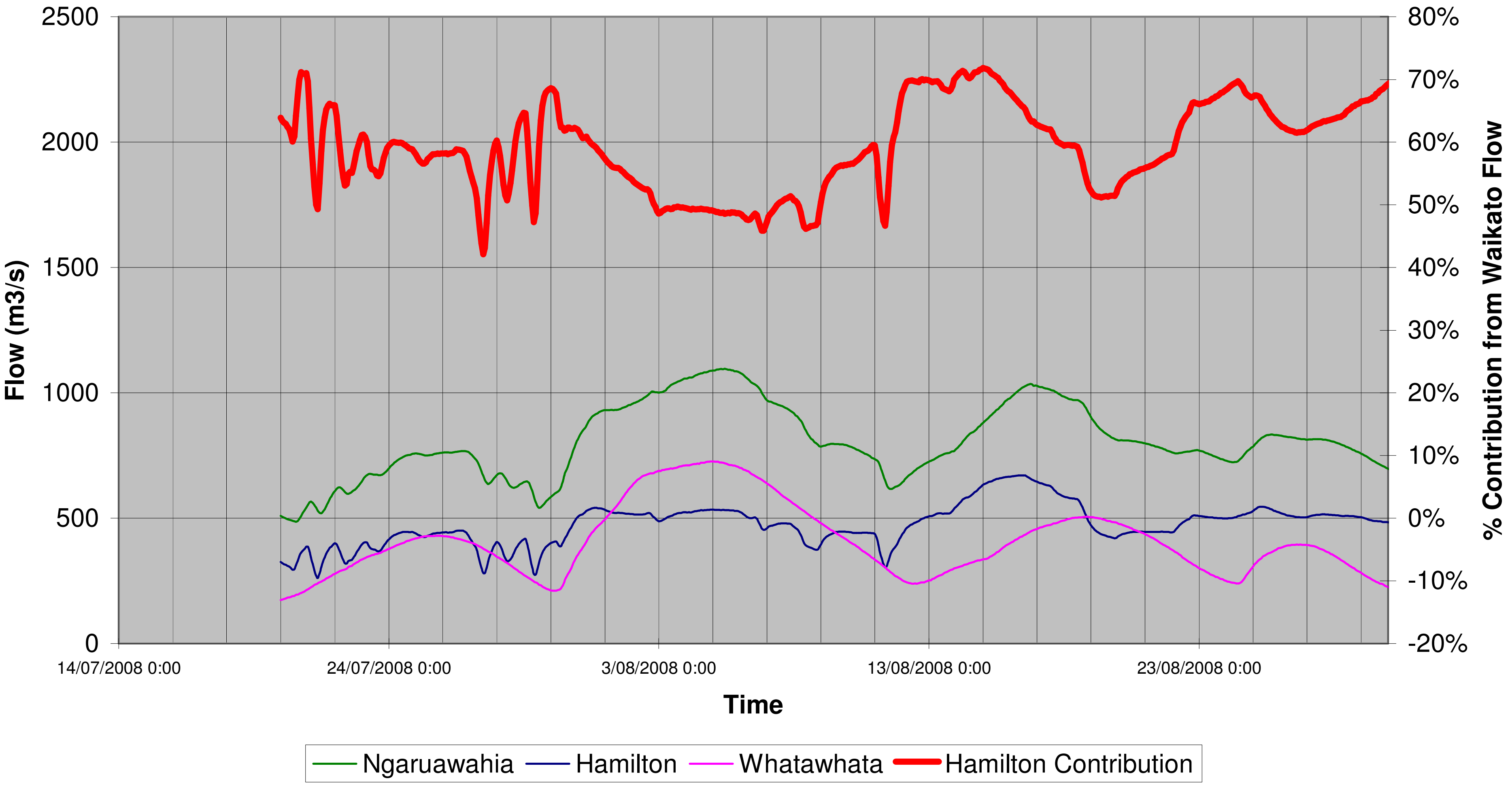


Figure F4 - Influence of Modelled Karapiro Outflows at Ngaruawahia - July 1998

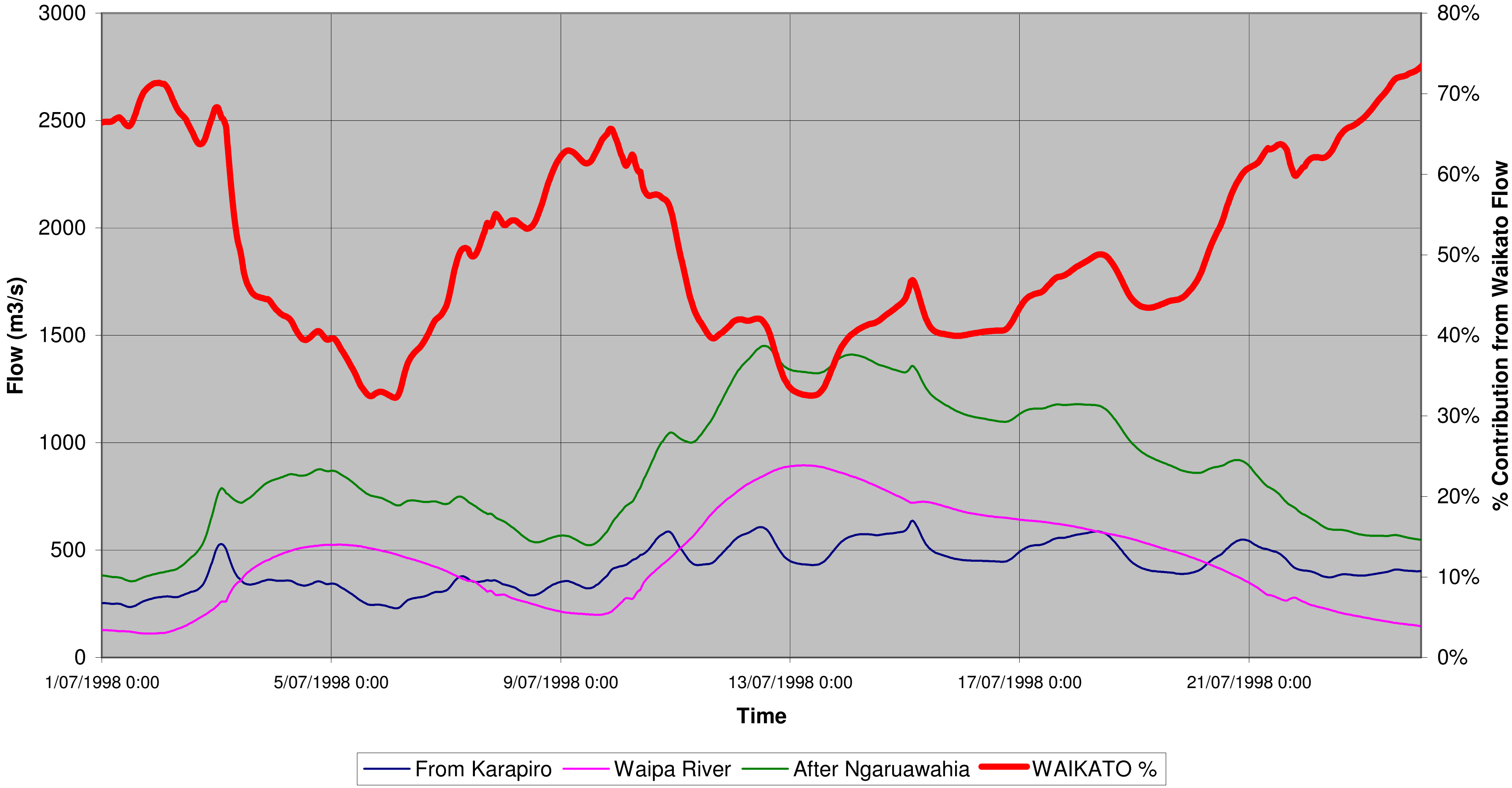


Figure F5 - Influence of Modelled Karapiro Outflows at Ngaruawahia - February 2004

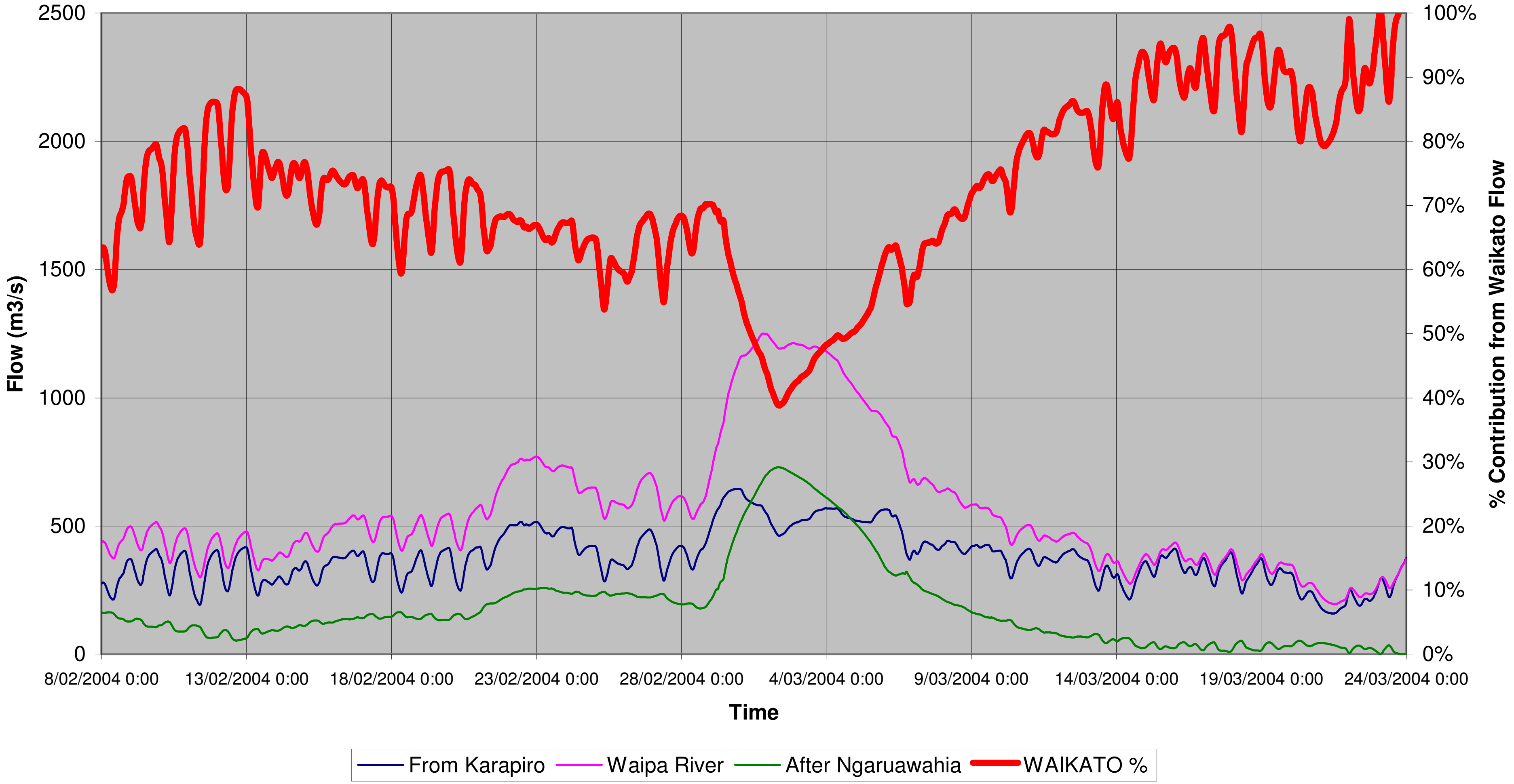
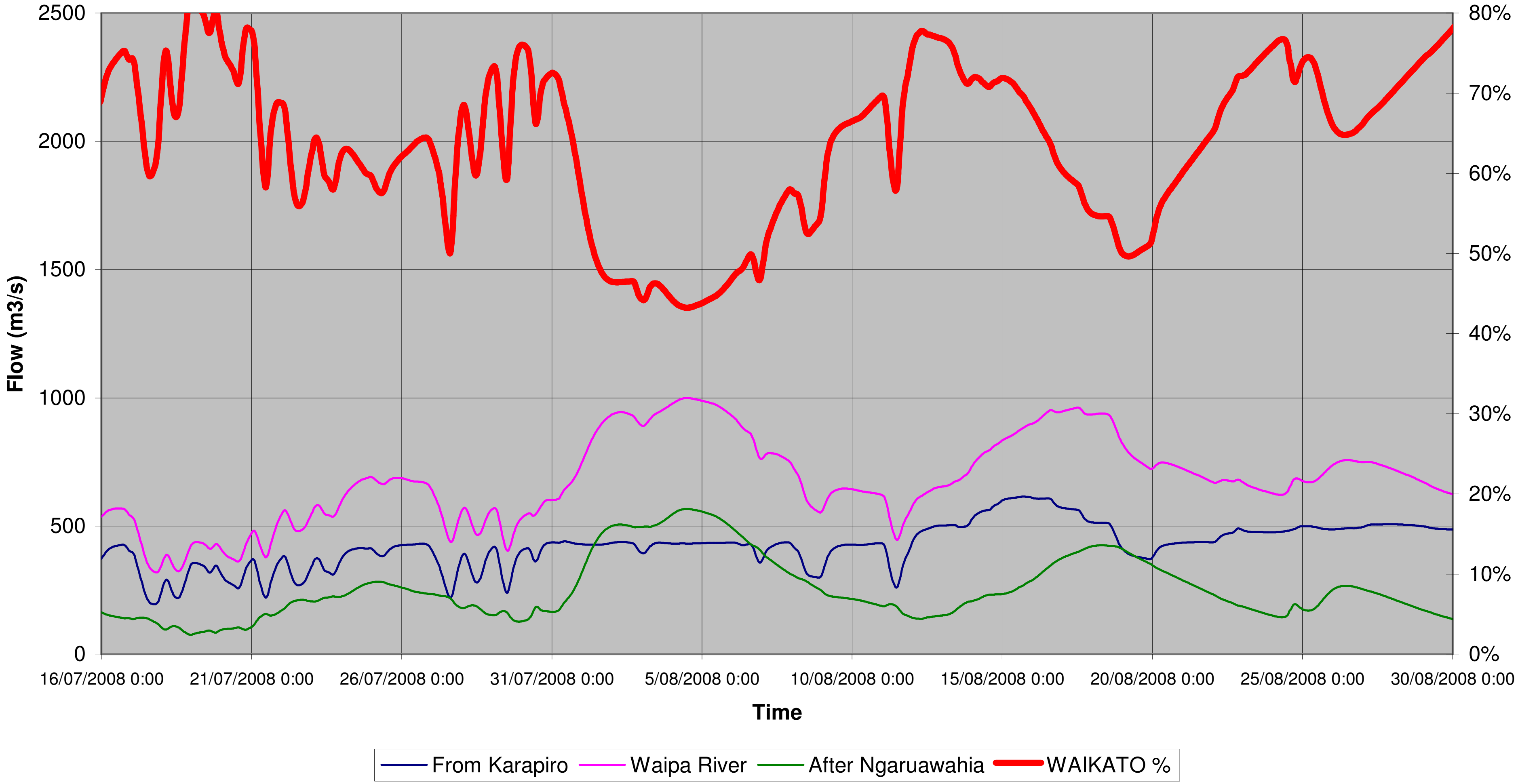


Figure F6 - Influence of Modelled Karapiro Outflows at Ngaruawahia - August 2008



Appendix G

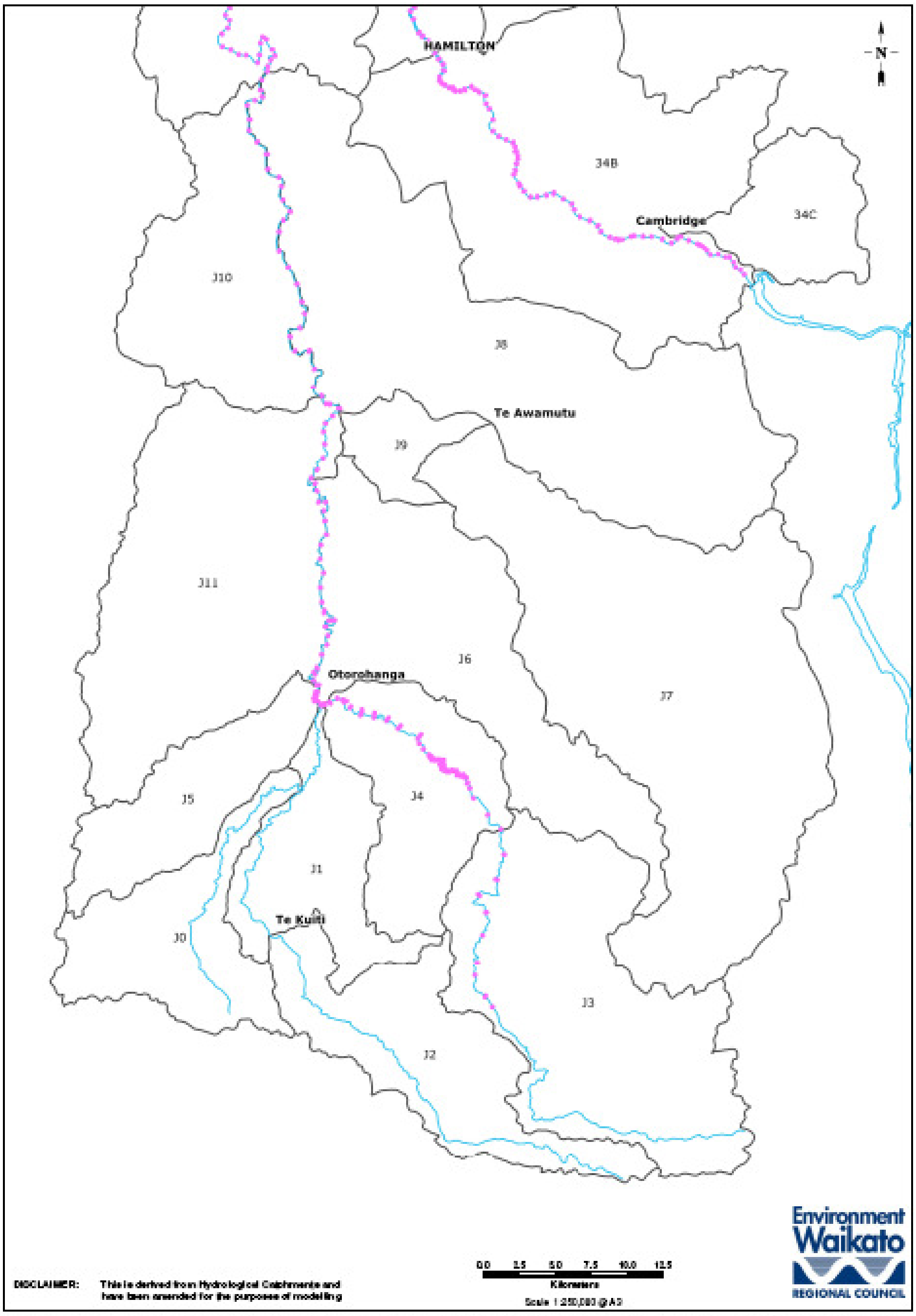
NAM Parameter Definition

Parameter	Role in NAM model	Physical factors affecting
Umax	Umax is the maximum content of the upper storage (mm). Umax is filled by rainfall and reduced evapo-transpiration (at the full specified potential evapo-transpiration or PET rate) and drained by interflow. Umax is important for water balance, especially for small events and at the start of large events. One important characteristic of Umax is that it must be used up before and overland flow occurs. Following a short dry period, the amount of rainfall that must occur before any overland flow occurs can be used to estimate Umax. Umax normally varies from between 1 (impervious surface) to 30mm (forested areas)	Surface interception capacity
Lmax	Lmax is the maximum content of the lower storage (mm) or root zone. Lmax is filled by infiltration and reduced by evapo-transpiration (at a lower rate than the specified PET). The proportion of Lmax which is filled at any particular time L/Lmax is a very important parameter as it affects all other processes including infiltration, recharge, evaporation and interflow. Lmax is important for seasonal water balance, especially for evaporation during dry periods, and the distribution of rainfall to evaporation, direct run-off and groundwater. Lmax is not directly important for flood flow volumes, rather, (1-TOF). Lmax and the actual value of L (or L/Lmax in relation to TOF) are considered more important. In other words, for flood flows, Lmax, TOF and actual value of L are all important.	Root zone capacity, soil type, land use
CQOF	CQOF is the maximum volumetric run-off coefficient and varies between zero and 1. At any time the actual volumetric runoff coefficient will be less than CQOF and will be dependent on	Catchment slope, infiltration capacity, soil type

	L/Lmax in relation to TOF.	
CK1,2	CK1,2 is the time response parameter for overland flow and interflow (hr). It affects the timing of the flood peak and is very important calibration parameter for flood flows. CK12 is related to the catchment response time (ie time of concentration)	Catchment slope
CKIF	CKIF is the time constant for releasing interflow (hr) before it is joined with overland flow. It affects the rate at which interflow is released from Umax. It is usually not an important parameter for flood flows and consequently a large variation is usually found (relative insensitivity of flood flows to variations in CKIF	Catchment slope, soil permeability
CKBF	CKBF is the time constant for releasing baseflow (hr) It affects the rate baseflow is released from groundwater. It is can important parameter for water resource systems which require a reliable estimate of the baseflow. It is usually not important for flood flows	Aquifer permeability
TOF	TOF is the root zone threshold for overland flow. It varies from 0 to 1 but is highly dependent on the actual value of Lmax. TOF is an important parameter for flood flow reproduction	Surface retention
TIF	TIF is the root zone threshold for interflow. It varies from 0 to 1 but is highly dependent on the actual value of Lmax. TIF is an important parameter for interflow reproduction, but since interflow is usually small it becomes relatively unimportant.	
TG	TG is the root zone threshold for recharge. It varies between 0 and 1.but is highly dependent on the actual value of Lmax. TG is an important parameter for groundwater recharge reproduction but is also important for flood flows since what does not get channelled to overflow or to groundwater goes to fill Lmax.	

Appendix H

Sub-catchment Plans


N
HAMILTON
34B
34C
Cambridge
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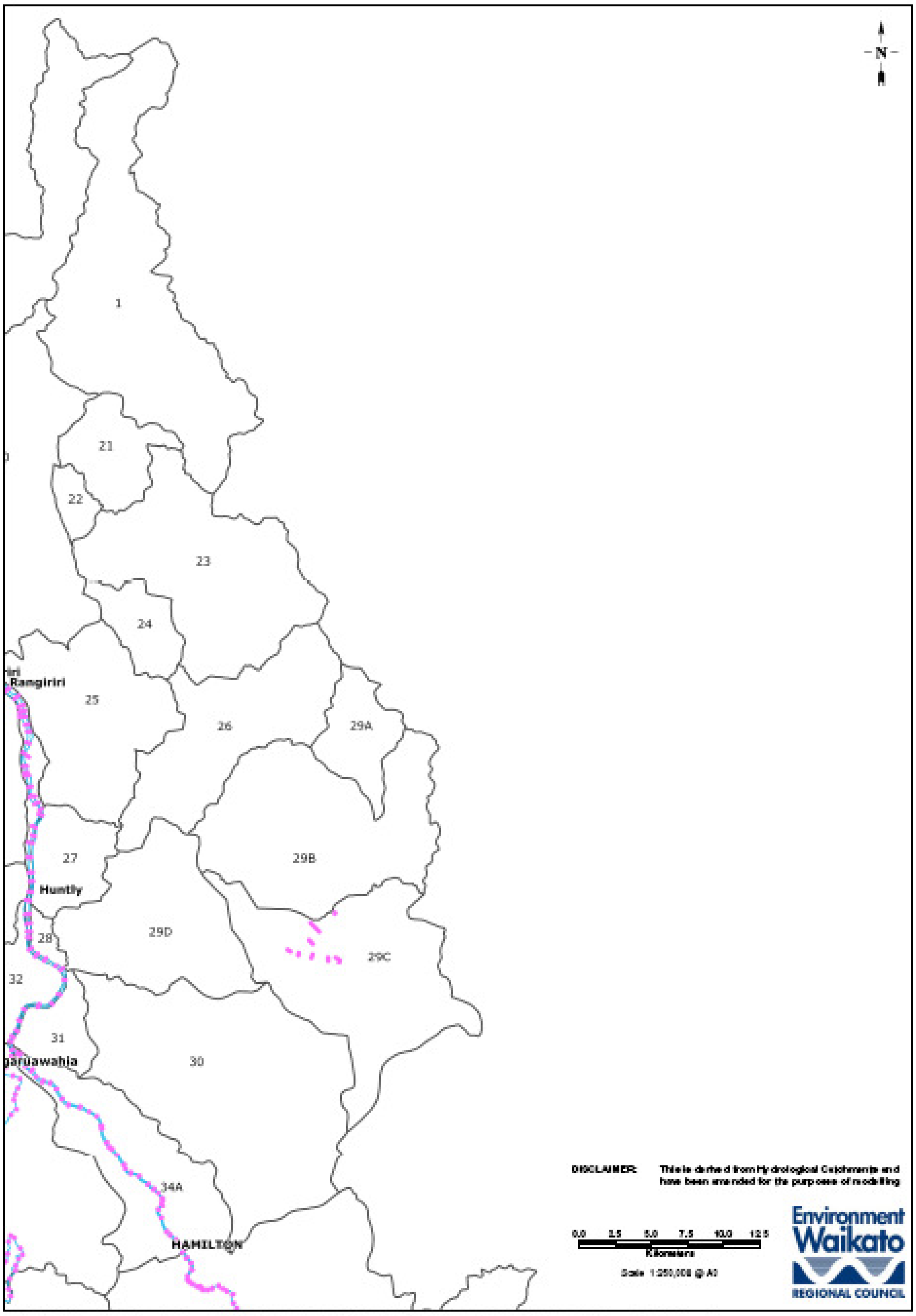
J8
Te Awamutu
J9
J11
J6
J7
Otorohanga
J5
J4
J1
Te Kuiti
J0
J3
J2
Environment Waikato
REGIONAL COUNCIL
DISCLAIMER: This is derived from Hydrological Catchments and have been amended for the purposes of modelling
0.0 2.5 5.0 7.5 10.0 12.5
Kilometers
Scale 1:250,000 @ A3


N
1
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Rangiriri
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29A
29B
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Huntly
29D
28
29C
32
31
garuawahia
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34A
HAMILTON
DISCLAIMER: This is derived from Hydrological Catchments and have been amended for the purposes of modelling
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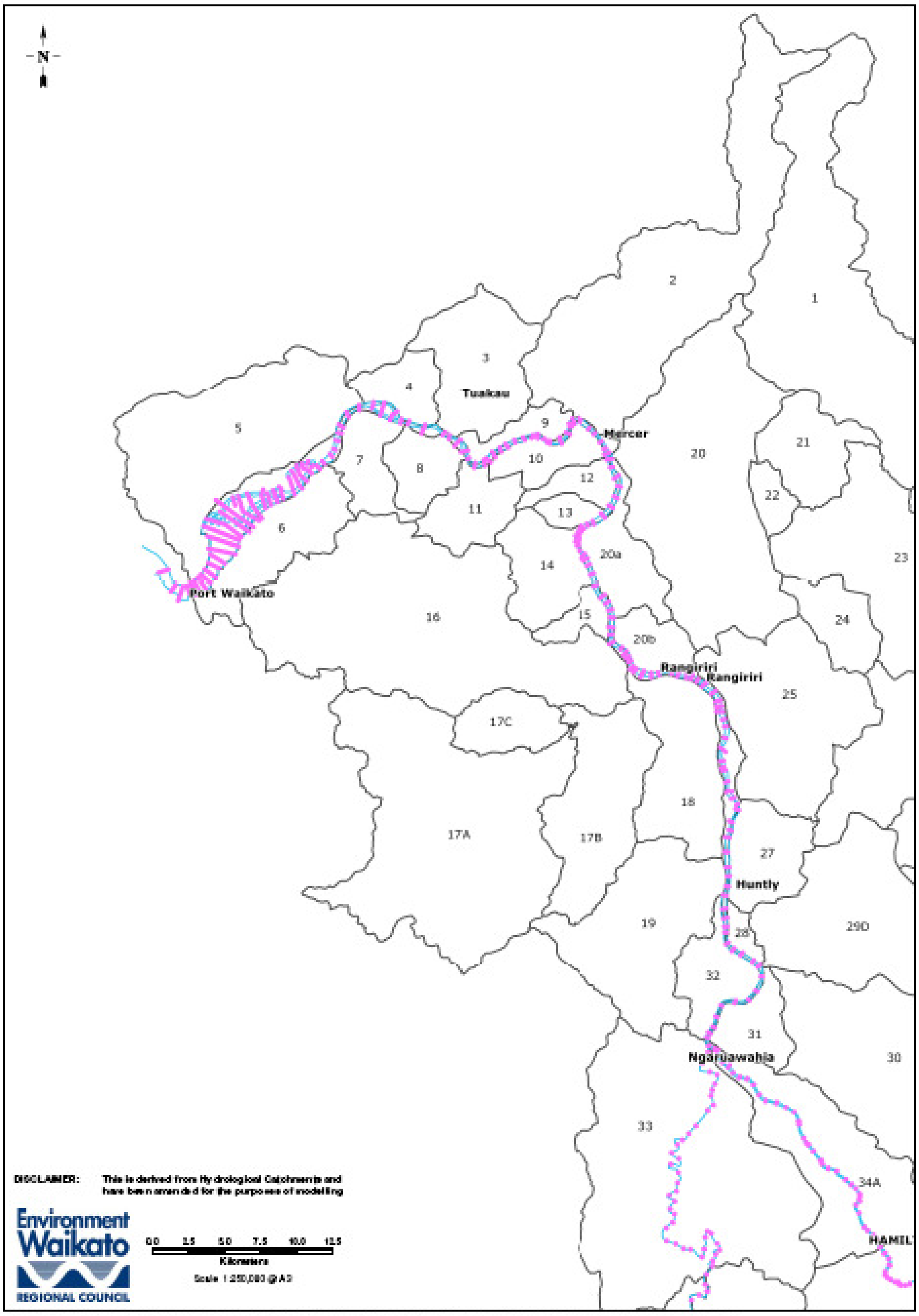
Kilometers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20a
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28
29D
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31
32
33
34A
Tuakau
Mercer
Port Waikato
Rangiriri
Rangiriri
Huntly
Ngaruawahia
DISCLAIMER: This is derived from Hydrological Catchments and have been amended for the purposes of modelling
Environment Waikato
REGIONAL COUNCIL
0.0 2.5 5.0 7.5 10.0 12.5
Kilometers
Scale 1:250,000 @ A3

Appendix I

Catchment Details and Rain Gauge Influence

Duplicate catchment labels show where major catchments have been divided further

Catchment	Area (km2)	Whangamarino	Mangatangi	Zero	Maungakawa	Waingaro Ruakiwi Road	Ruakura	Hamilton	Maungatautari	Puniu Barton's Corner	Te Kuiti	Otewa	Waitangaruru	Wharekiri	Ngaroma
1	157.5	0.05	0.95	0.001											
2	54.9	0.4	0.59	0.001	0.01										
3	42.2	0.9	0.05	0.001	0.05										
4	21.2	0.7	0.2	0.001	0.1										
5	128.4	0.98	0.01	0.001	0.01										
6	46.1	0.98	0.01	0.001	0.01										
7	24.9	0.98	0.01	0.001	0.01										
8	22.3	0.98	0.01	0.001	0.01										
9	12.9	0.98	0.01	0.001	0.01										
10	19	0.98	0.01	0.001	0.01										
11	28.5	0.98	0.01	0.001	0.01										
12	13.2	0.98	0.01	0.001	0.01										

Catchment	Area (km2)	Whangamarino	Mangatangi	Zero	Maungakawa	Waingaro Ruakiwi Road	Ruakura	Hamilton	Maungatautari	Puniu Barton's Corner	Te Kuiti	Otewa	Waitangaruru	Wharekiri	Ngaroma
13	8.3	0.98	0.01	0.001	0.01										
14	36.3	0.98	0.01	0.001	0.01										
15	10.9	0.9		0.001	0.05	0.05									
16	216.2	0.7		0.001	0.05	0.25									
17	209.7	0.45		0.001	0.1	0.45									
18	15.4	0.4		0.001	0.4	0.2									
19	94.9	0.2		0.001	0.2	0.6									
20	67.3	0.7	0.1	0.001	0.2										
21	38	0.05	0.65	0.001	0.3										
22	11.3	0.05	0.65	0.001	0.3										
23	139.6	0.03	0.02	0.001	0.95										
24	27.1	0.3	0.1	0.001	0.6										

Catchment	Area (km2)	Whangamarino	Mangatangi	Zero	Maungakawa	Waingaro Ruakiwi Road	Ruakura	Hamilton	Maungatautari	Puniu Barton's Corner	Te Kuiti	Otewa	Waitangaruru	Wharekiri	Ngaroma
25	104.7	0.5		0.001	0.3	0.2									
26	103.3	0.02	0.03	0.001	0.95										
27	7.5	0.3		0.001	0.35	0.35									
27	27.3														
28	6			0.001	0.1	0.6	0.3								
31	23.2	0.05		0.001		0.45	0.5								
32	27.3	0.05		0.001		0.5	0.45								
33	231.3			0.001		0.9	0.05	0.05							
34	92.6			0.001		0.05	0.9	0.05							
57	24.4	0.4	0.59	0.001	0.01										
58	2.6	0.3	0.6	0.001	0.1										
59	31.6	0.3	0.6	0.001	0.1										
59	23.7														

Catchment	Area (km2)	Whangamarino	Mangatangi	Zero	Maungakawa	Waingaro Ruakiwi Road	Ruakura	Hamilton	Maungatautari	Puniu Barton's Corner	Te Kuiti	Otewa	Waitangaruru	Wharekiri	Ngaroma
59	19.4														
60	30.3	0.9		0.001	0.05	0.05									
61	18	0.4		0.001	0.4	0.2									
62	26.7	0.4		0.001	0.4	0.2									
63	57.7	0.6		0.001	0.2	0.2									
64	20.5	0.6		0.001	0.2	0.2									
65	19.5	0.6		0.001	0.2	0.2									
66	26.4	0.6		0.001	0.2	0.2									
71	208			0.001			0.05	0.9	0.05						
71	96			0.001			0.05	0.9	0.05						
71	55			0.001			0.05	0.9	0.05						
71	75			0.001			0.05	0.9	0.05						

Catchment	Area (km2)	Whangamarino	Mangatangi	Zero	Maungakawa	Waingaro Ruakiwi Road	Ruakura	Hamilton	Maungatautari	Puniu Barton's Corner	Te Kuiti	Otewa	Waitangaruru	Wharekiri	Ngaroma
72	85.6			0.001				0.2	0.6	0.2					
75	22.2	0.9	0.05	0.001	0.05										
76	42.6	0.9	0.05	0.001	0.05										
77	37.6	0.9	0.05	0.001	0.05										
78	8	0.9	0.05	0.001	0.05										
29-	34.54			0.001	0.98	0.01	0.01								
30-	142.29			0.001		0.04	0.95	0.01							
30-	70			0.001		0.04	0.95	0.01							
67-	11.27			0.001	0.98			0.02							
67-	20.99			0.001	0.98			0.02							
67-	19.73			0.001	0.85			0.15							
67-	10.32			0.001	0.98			0.02							

Catchment	Area (km2)	Whangamarino	Mangatangi	Zero	Maungakawa	Waingaro Ruakiwi Road	Ruakura	Hamilton	Maungatautari	Puniu Barton's Corner	Te Kuiti	Otewa	Waitangaruru	Wharekiri	Ngaroma
67-	4.95			0.001	0.85			0.15							
67-	17.77			0.001	0.8	0.1	0.1								
67-	15.61														
67-	10.2														
67-	8.77			0.001	0.75			0.25							
68-	15.19			0.001	0.98	0.01	0.01								
68-	12.55			0.001	0.98			0.02							
69-	1.27			0.001	0.75			0.25							
69-	2.49			0.001	0.75			0.25							
69-	3			0.001	0.65			0.35							
69-	34.55			0.001	0.6	0.1	0.3								
69-	31.07			0.001	0.6	0.1	0.3								

Catchment	Area (km2)	Whangamarino	Mangatangi	Zero	Maungakawa	Waingaro Ruakiwi Road	Ruakura	Hamilton	Maungatautari	Puniu Barton's Corner	Te Kuiti	Otewa	Waitangaruru	Wharekiri	Ngaroma
69-	24.3			0.001	0.65			0.35							
69-	1.02			0.001	0.5			0.5							
69-	43.58			0.001	0.5			0.5							
70-	26.23			0.001	0.1	0.1	0.8								
70-	41.75			0.001	0.1	0.1	0.8								
70-	26.39			0.001	0.1	0.1	0.8								
70-	9.91			0.001	0.1	0.1	0.8								
J1	121.13			0.001							0.54	0.06	0.4		
J5	109.88			0.001							0.45	0.05	0.5		
J9	41.8			0.001			0.01	0.01	0.01	0.96		0.01			
J10	185.21			0.001			0	0.255		0.545			0.2		
J8	487.5			0.001			0	0.23	0.245	0.515		0.01			
J4	142.25			0.001							0.06	0.94			

Catchment	Area (km2)	Whangamarino	Mangatangi	Zero	Maungakawa	Waingaro Ruakiwi Road	Ruakura	Hamilton	Maungatautari	Puniu Barton's Corner	Te Kuiti	Otewa	Waitangaruru	Wharekiri	Ngaroma
J6	264.41			0.001						0.6	0.18	0.2			0.02
J11	338.24			0.001						0.25	0.15	0.1	0.5		
J2	173.37			0.001							0.509	0.055		0.436	
J3	319.32			0.001								0.399		0.465	0.136
J7	517.38			0.001					0.208	0.205		0.195			0.392
J0	135.65			0.001							0.4	0.01	0.59		