Horizons Regional Council
Flood Forecasting System
Upper Manawatu Catchment

Prepared By:
Hydro Tasmania
ARBN 072 377 158
ABN 48 072 377 158
4 Elizabeth Street, Hobart
Tasmania, Australia

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1 INTRODUCTION

Hydro Tasmania Consulting (HTC) has been engaged by Horizons Regional Council (HRC) to develop a flood forecasting system to facilitate flood management and emergency response for all significant river systems in the council's area. The system is comprised of hydrological and hydraulic models that interact with Horizon's hydrometric database to predict flow and water level forecasts at key locations. Once completed, the Horizons Regional Council Flood Forecasting System (HRCFFS) will cover the majority of catchments that the council is responsible for.

The HRCFFS project is being completed in a series of 5 stages by HTC. This report has been produced during Stage 4 of the project and covers the flood forecasting system developed for the Upper Manawatu River catchment to the Upper Gorge flow gauge. This report is the third in a suite of documents covering the methodology, assumptions and performance of each model that makes up the HRCFFS. The other two reports are referenced below:

> Peterson, J, Ludlow, C, (2007) "Horizons Regional Council Flood Forecasting System: Whanganui Catchment Operating Manual", Hydro Tasmania Consulting, Australia
>
> Cox, G, Murray, R, (2006) "Horizons Regional Council Flood Forecasting System: Manawatu Catchment Operating Manual", Hydro Tasmania Consulting, Australia

A series of online flood inundation mapping tools are reliant on the model forecasts produced by the HRCFFS. At the time of issue of this report, these web-based tools have been produced at Wanganui and just upstream of the confluence of the Mangatainoka and Makakahi Rivers. A third mapping tool is being developed for the region just upstream of Upper Gorge. The reports relating to these projects are referenced below:

> West, N, (2008) "Mangatainoka & Makakahi Rivers Flood Mapping and Website Development", Hydro Tasmania Consulting, Australia
>
> Ludlow, C, Robinson, K, (2007) "Whanganui River Flood Forecasting System Flood Map Preparation and On-Line Real Time Map Presentation", Hydro Tasmania Consulting, Australia

Note that the information provided in this report documents the status of the Upper Manawatu model (named "Upper_Gorge_Hydrologic_Model.tso") at the time of issue of this report. The model and operating system may be subject to changes following the date of issue. It is for this reason that all the documentation related to the HRCFFS should remain collated to maintain a single point of reference.

2 SYSTEM OVERVIEW

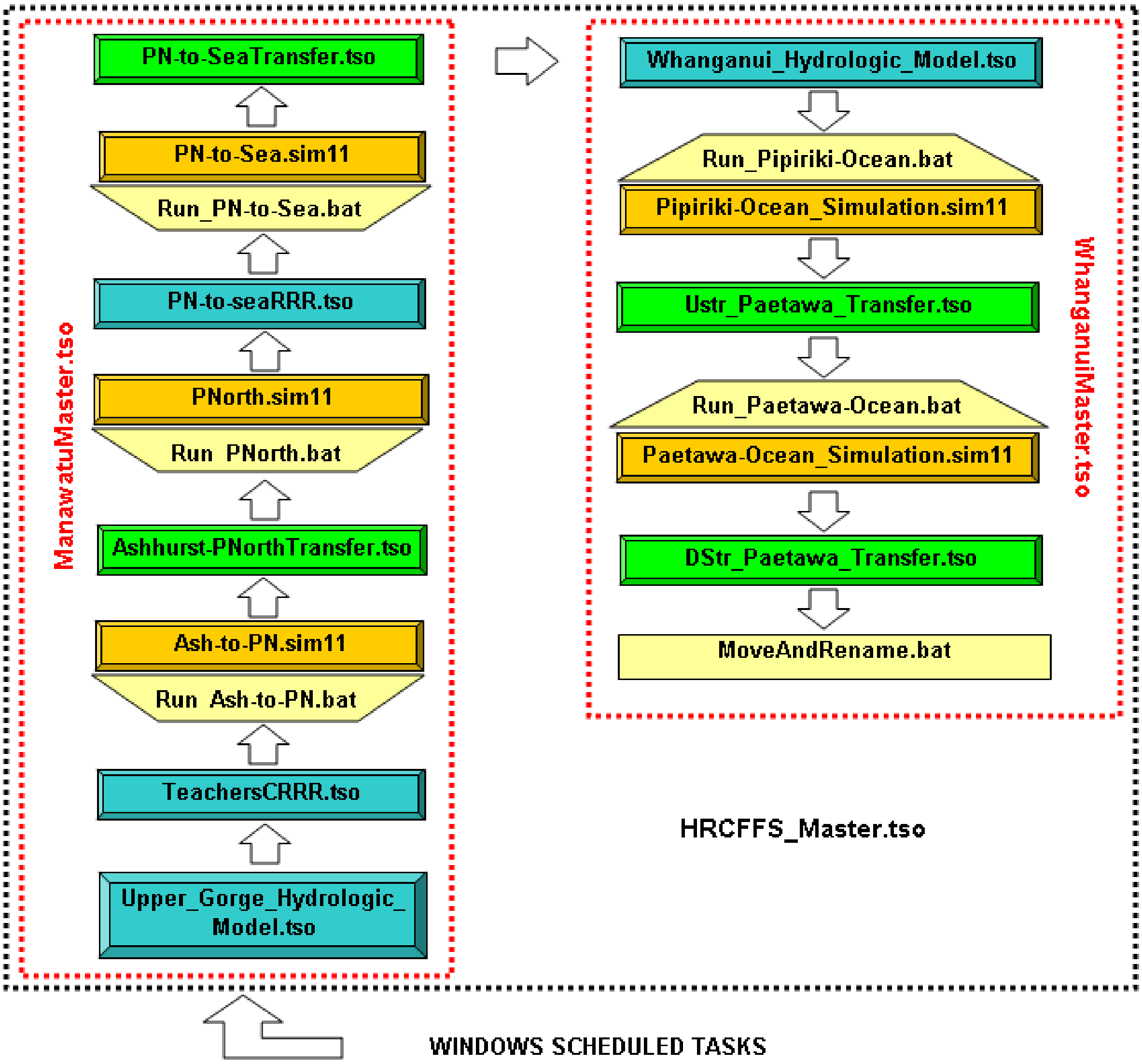


Figure 2-1: Interactions of the Components of the HRCFFS at Completion of Stage 3, representing the Scheduled Real-Time Operating System.

A diagram of the components that make up the HRCFFS is shown in Figure 2-1 above. In general each of the modelled catchments comprise of hydrological rainfall-runoff models to forecast flow at various points throughout the catchment either for input to the hydraulic models or output directly at river gauge locations. The hydraulic models use these forecast flows to produce forecast levels at key locations in each catchment. Inputs and outputs are ultimately sourced and written to Hilltop database files. The Hilltop database and web-based viewer packages (as developed by HRC) are being used as the viewer interface for all output data produced by the HRCFFS.

As shown above the Upper Manawatu hydrologic model, “Upper_Gorge_Hydrologic_Model.tso”, is executed first as part of the Manawatu Master Model.

All HRCFFS components as shown in Figure 2-1 are defined in more detail below.

Master Model

Software: Hydstra Modelling (formerly TimeStudio or Hydrol)
Inputs/Outputs: All Hydstra models and Mike11 (.sim11) modelling files.
Comments:
These models synchronise the run times of all models and run them in the correct order. During real-time operation of the system, the Master Model runs over a generic time period (normally set as -24 hrs to +48 hrs). Via an Excel based user-interface or by executing the appropriate batch file, some various settings can be changed such as start/finish dates, the location and name of the Hilltop input and output files and some various run-modes of the hydrologic and hydraulic models (refer to Section 3 for more details). It is the Master Model that applies all these changes to all other models prior to running them. There are master models for the separate Manawatu and Whanganui catchments and also a master model that combines both systems (HRCFFS_Master).

Hydrologic Models

Software: Hydstra Modelling (formerly TimeStudio or Hydrol)
Inputs: Flows, rainfall and forecast rainfalls from Hilltop.
Outputs: Modelled flows for hydraulic model (.dfs0) and archived in Hilltop if outside of the hydraulic model extents.
Comments:
The Upper Manawatu hydrologic model is discussed in detail in this report. All other hydrologic models are documented in the previous reports issued as part of the HRCFFS (referenced in the Introduction to this report).

Hydraulic Model Executer

Software: MS-DOS batch file
Comments:
The hydraulic model cannot be run directly from within a Hydstra model (the Master Model) so a batch command is required. The same batch file also saves the latest hydraulic model output file as a hotstart file for the next run and extracts selected outputs from the Mike11 model (.res11 file format) into a multi-column text file format by executing the ResRead.exe application (an additional application to Mike11 supplied by the same software developers, DHI).

Hydraulic Models

Software: Mike11
Inputs: Forecast flows and tidal data from hydrological and transfer models (.dfs0).
Outputs: Forecast flows and water levels (Mike11 output file, .res11).
Comments:
The hydraulic models are discussed in detail in the previous reports issued as part of the HRCFFS.

Data Transfer Models

Software: Hydstra Modelling

Inputs: Hilltop data required for input to Mike 11 (.hts), or Mike11 output data for input to a downstream hydraulic model, or archive to Hilltop (.res11 converted to multi-column text file in the Hydraulic Model Executer – discussed above).

Outputs: Inputs for Mike11 (.dfs0) or outputs archived back to the Hilltop database.

Comments:

Transfer models are used primarily to change the file format of time series data so that it can be recognised either by Mike11 or Hilltop. Real-time error corrections at flow gauge locations are also performed in these models along with some other basic arithmetic functions (e.g. the preparation of the forecast tide information). The DStr_Paetawa_Transfer.tso model also provides key information (by producing a .xml file) for the web based real-time flood mapping of the lower Whanganui River catchment. References to the flood inundation mapping reports are given in the Introduction section of this report.

Housekeeping Executable

Software: MS-DOS batch file

Comments:

This file was produced to routinely archive log files produced by the Master Model as to avoid system failure due to the file size of the log. In future stages these house-keeping tasks will perform additional roles such as the creation of a diagnostic archive of Mike11 runs and the production of data timeliness and condition monitoring reports. More discussion on potential house-keeping tasks is given in the Recommendations for Future Improvements section at the end of this report.

3 SYSTEM OPERATION

3.1 REAL-TIME OPERATION - SCHEDULED RUNS

In its current set-up (at the completion of Stage 4 of the project) the HRCFFS is automated using Windows Scheduled Tasks. A separate task is set up for the Manawatu and Whanganui components of the system (currently enabled) and a third task is available to run the Manawatu and Whanganui combined (currently disabled).

Each task has a single command to execute the appropriate Master Model. In its current state the tasks are scheduled to run every half hour, and the models produce results on a 15 minute time step.

A shortcut to the Scheduled Tasks has been created on the live modeling server.

3.2 SINGLE RUN

Single runs are likely to be performed for two reasons:

1. If the automated system has failed, then a manual initialisation run (rough start) may be required. A rough start will set Mike11 to run from an initial parameter file rather than setting up initial conditions from the outputs of the previous run (hotstart file). This will provide a more stable environment for Mike11 and help get the system back up and running. More details on Hotstart File vs Parameter File are given in the Hydraulic Modelling section of the Whanganui report.

   To run the flood forecasting system through a roughstart open the required batch file from the list below:

   C:\HRCFloodFS\Models\Whanganui\RunWhanganuiFloodModels_NoHotstart.bat

   C:\HRCFloodFS\Models\Manawatu\RunManawatuFloodModels_NoHotstart.bat

   C:\HRCFloodFS\Models\ RunHRCFFS_FloodModels_NoHotstart.bat

   Shortcuts have been set up on the desktop of the live modelling server to each of these file locations. Once the models have successfully run through a rough start then the Scheduled Tasks should run automatically without fail.

2. A single run may be performed as a scenario run. An Excel based user interface exists for both the Manawatu and Whanganui systems. The file locations for these interfaces are shown below.

   C:\HRCFloodFS\Models\Manawatu\Manawatu-UserInterfaceV1.xls

   C:\HRCFloodFS\Models\Whanganui\Whanganui-UserInterfaceV1.xls

   The interface, shown in Figure 3-1 below, gives the added availability to change some settings and perform a manual run.

   The results will be outputted to the Hilltop database where they can be viewed.

Settings that can be changed include:

- Model Start and Finish times. Either generic or fixed dates and times can be used. Generic times state the time with reference to now, for example (-1)/(0)/(0) means one day ago in this month on this year.
- Hilltop input and output file locations. It is recommended that if a scenario run is to be completed, then the output file location/name should be changed to avoid overwriting any existing information.
- Modelling Mode – there are three modes: Mode 1 uses no rainfall inputs in the model, ie it just routes measured flows through the catchment. Mode 2 uses measured rainfall inputs only, no forecast rainfall is used. Mode 3 uses all available input data including forecast rainfalls.
- The option of applying real-time flow error correction or not. This could be useful to perform a historical run with error correction turned off to review the calibration of the hydrological models.
- The option of running Mike11 with a hotstart file or a parameter file. The difference between the two has been discussed in (1) above. Generally for scenario runs, it would be expected that Use Hotstart file will be set to "N", especially if model run times have been adjusted.
- A check box is available to save any changes in settings to the model. Otherwise the settings will only apply to the single run and not to any future runs of the model.

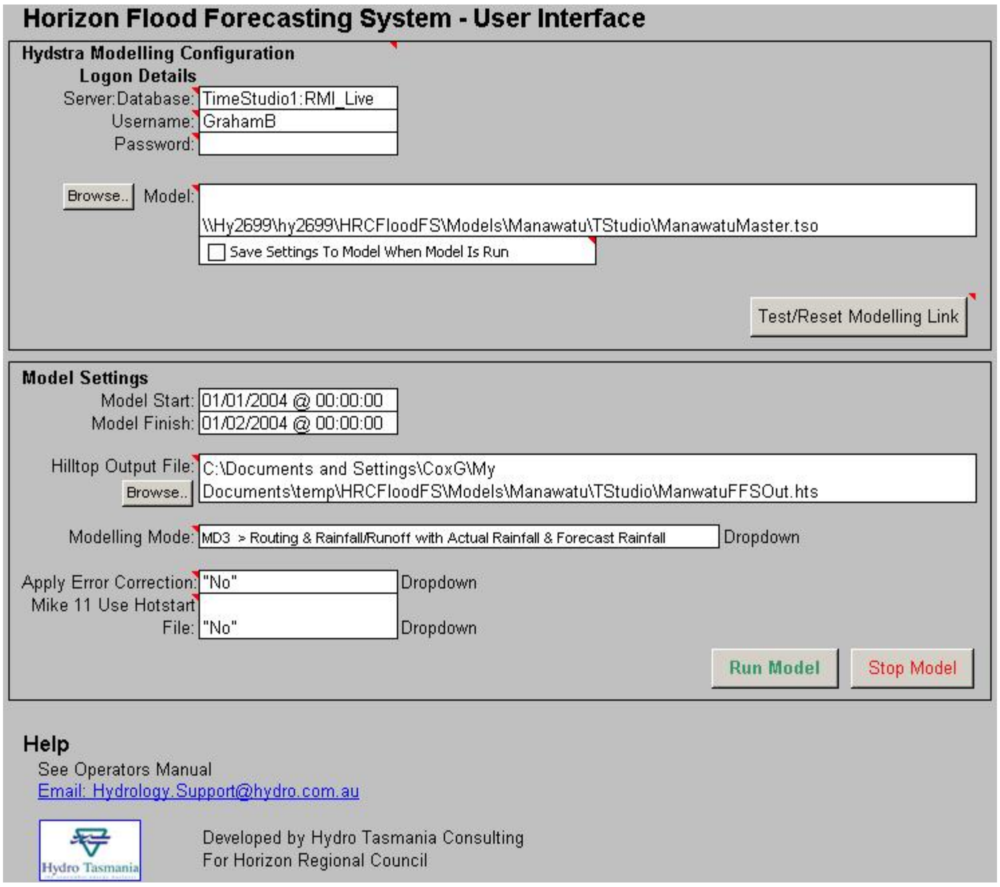
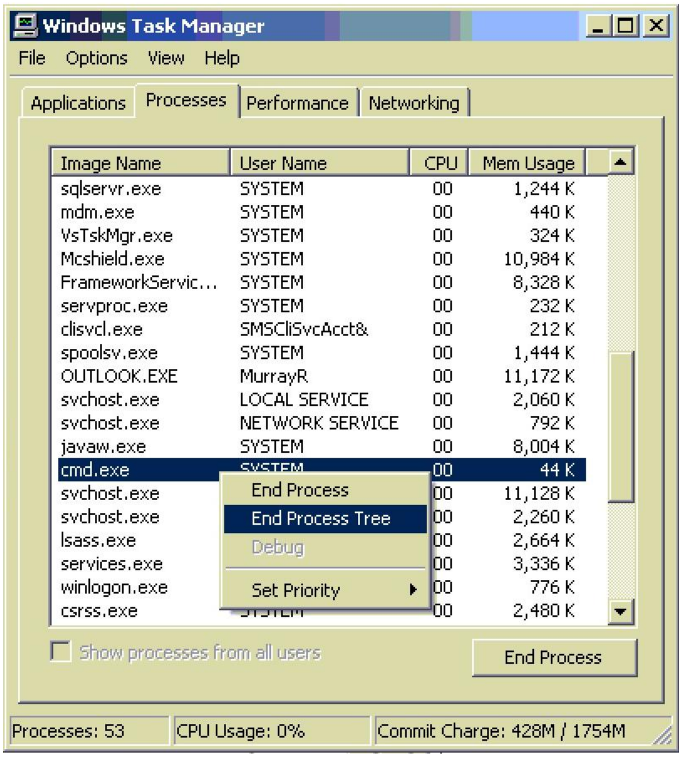


Figure 3-1 Screenshot of Manawatu-UserInterfaceV1.xls.

To terminate the models at any time, open Windows Task Manager, right click on the process **cmd.exe**, and select **End Process Tree** from the menu (see graphic below):



4 HYDROLOGIC MODEL PROCESSES AND METHODOLOGY

A computer simulation model was developed using Hydstra Modelling. The sub-catchments, described above, are represented by model "nodes" and connected together by "links". A schematic of this model is displayed in Figure 4-1.

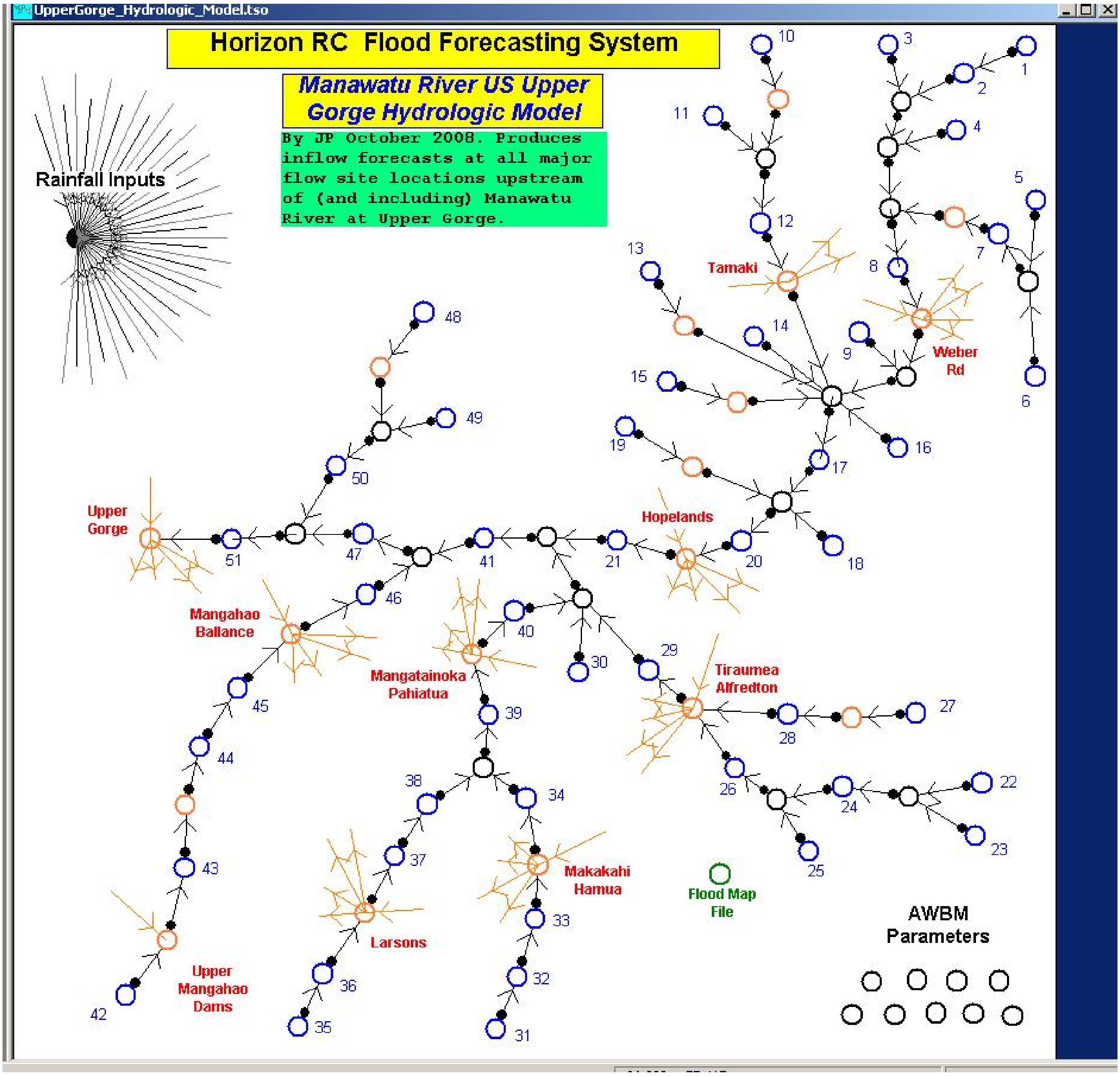


Figure 4-1: Hydstra Model Schematic

The general model process is as follows. Rainfall is calculated for each sub-catchment by interpolating rainfall from surrounding gauges and supplied forecasts from the Met Bureau. The AWBM rainfall/runoff model converts this rainfall to runoff which is routed overland in each sub-catchment via a catchment routing function. The flow is then directed through the river network via a channel routing function. The modeling processes are discussed in more detail in the following sections.

4.1 RAINFALL GAP FILLING AND INTERPOLATION ALGORITHM

Figure 4-2 below and the equations that follow it, provide a detailed methodology for the selection and factoring of data from surrounding rainfall gauges during the infilling of missing rainfall data at each gauge, or the spatial distribution of rainfall information at sub-catchment centroids. The gap filling code is located in the Global node where all the rainfall inputs are collated, and the interpolation code is located as a function (accessed by right mouse clicking on the white space of the model and selecting the Properties form).

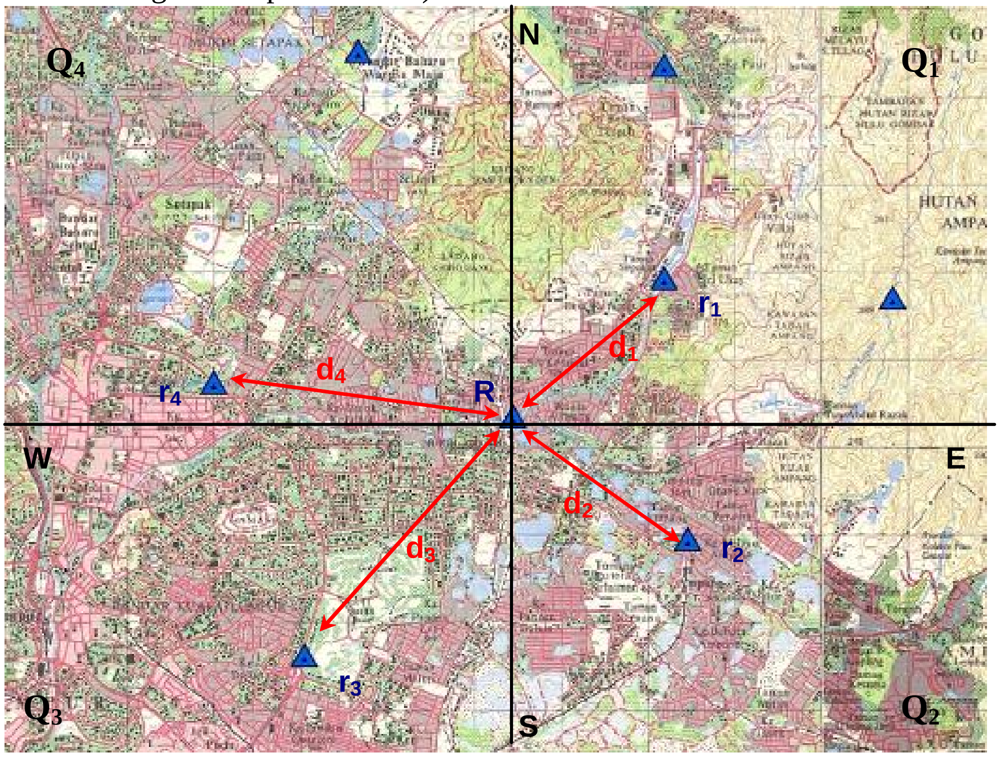


Figure 4-2: Rain Gauge Weighting by Quadrants

The diagram above represents the situation where a rain gauge, R, is having a period of missing data replaced with data from surrounding gauges. Note that in the case of rainfall distribution to a sub catchment centroid, the procedure is exactly the same with the centroid being located at “R”.

A total weighting factor is calculated first using the following equation,

$$\textbf{Total Weighting, } T_W = \frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3} + \frac{1}{d_4}$$

This accounts for situations where there may not be a rain gauge in each quadrant (Q). Note that the maximum number of rain gauges used to estimate the rainfall at location R is four, one for each quadrant. This procedure will be applied until there is no available measured rainfall data left in the catchment. As a result, this process may at times use as little as one rain gauge. Only one rainfall gauge per quadrant is selected, always the closest (i.e. the smallest value of d_Q).
The inverse distance weighting of the rainfall gauge in each quadrant is determined with the following equation,

$$\textbf{Weighting per Quadrant, } W_Q = \frac{1}{d_Q} \times \frac{1}{T_W}.$$

The actual contribution of rainfall from each gauge is then,

$$\textbf{Rainfall Contribution per Quadrant, } RC_Q = W_Q \times \frac{MAR_R}{MAR_Q} \times r_Q$$

where MAR is the mean annual rainfall .

The total rainfall estimate is the combination of each of these rainfall contributions as shown in the equation below,

$$\textbf{Total In-filled Rainfall, R} = \sum \textbf{RC}_Q$$

When there is no measured rainfall data in the catchment then the model will revert to the forecast rainfall algorithm and provide a rainfall estimate at each rain gauge location.
For the infilling of missing rainfall data, this procedure is performed during each time step of the model. When determining the rainfall distribution to each sub catchment in the model, the procedure is performed once at the beginning of the model run.

A 'Threshold' algorithm was added to the gap filling code to account for the feature of HRC's rain gauge network where data is generally only sent back when there is a gauge bucket tip. With this arrangement, there is a possibility that data could be null but the gauge still operating OK. The algorithm works by assuming that if the gauge data is null and interpolated rainfall is high (above the threshold) then the gauge is assumed to be not working and the interpolated rainfall is adopted. For low intensities interpolated rainfall the gauge is assumed to be working OK and the gauge rainfall is set to zero. The InterpThreshold_mmphr variable in the model node defines this threshold and can be adjusted if required. A typical setting is 5mm/hr.

4.2 RAINFALL/RUNOFF ALGORITHM

The Australian Water Balance Model (AWBM, Boughton, W) has been applied to calculate the catchment runoff based on the rainfall inputs. The code operates in each blue node (shown in the model schematic) and the fixed AWBM parameters are located in the bottom right corner of the model display. The AWBM model is a relatively simple water balance model with the following characteristics:

- it has few parameters to fit,
- the model representation is easily understood in terms of the actual outflow hydrograph,
- the parameters of the model can largely be determined by analysis of the outflow hydrograph,
- the model accounts for partial area rainfall-run-off effects,
- run-off volume is insensitive to the model parameters.

The AWBM model uses 3 surface soil and 1 ground water store to model the catchment runoff process. The 3 soil water stores account for parts of the catchment with different runoff rates. The model produces two outputs; direct runoff (after the contents of any of the soil stores is exceeded) and baseflow at a rate proportional to the water depth in the ground water store. Ground water is recharged from a proportion of excess rainfall. Soil stores are depleted by evapotranspiration which is estimated from seasonal daily pan evaporation.

The Two Tap version of AWBM was developed by R.Parkyn of Hydro Tasmania. It adds an additional baseflow release (2nd tap) and also reduces ground water recharged as ground water store gets 'saturated' (see INF explanation below).

The model parameters are:

Surface Store Parameters:

Cap1, Cap2 & Cap3 (mm): Storage capacity of each soil store.
A1, A2 & A3: Area proportion of each store. Set to zero if store not required.
S1, S2 & S3 (mm): Contents of soil stores. (Changes as model runs)

Surface Store Parameters:

GWstore (mm): Contents of ground water store. (Changes as model runs)
INF*:* Proportion of soil store excess which infiltrates to ground water. This is calculated each time step based on:

INFBase: Default proportion of soil store excess which infiltrates to ground water.
GWstoreSat (mm): depth in ground water store when INF begins to reduce from INFBase.
GWstoreMax (mm): depth in ground water store when INF becomes zero. INF reduces linearly from INFBase to zero as GWstore goes from GWstoreSat to GWstoreMax.

K1: baseflow recession constant 1.
K2: baseflow recession constant 2.(2nd tap)
H_GW (mm): depth in ground water store when K2 begins to add to baseflow.

Boughton & Chiew (2003) have shown that when using the AWBM model, the total amount of runoff is mainly affected by the average surface storage capacity and much less by how that average is spread among the three surface capacities and their partial areas. Given an average surface storage capacity (Ave), the three partial areas and the three surface storage capacities can be assumed to be:

Partial area of smallest store	A_1=0.134
Partial area of smallest store	A_2=0.433
Partial area of smallest store	A_3=0.433

Capacity of smallest store	$C_1=(0.01*Ave/A_1)=0.075*Ave$
Capacity of smallest store	$C_2=(0.33*Ave/ A_2)=0.762*Ave$
Capacity of smallest store	$C_3=(0.66*Ave/ A_3)=1.524*Ave$

The AWBM processes are shown schematically in Figure 4-3.

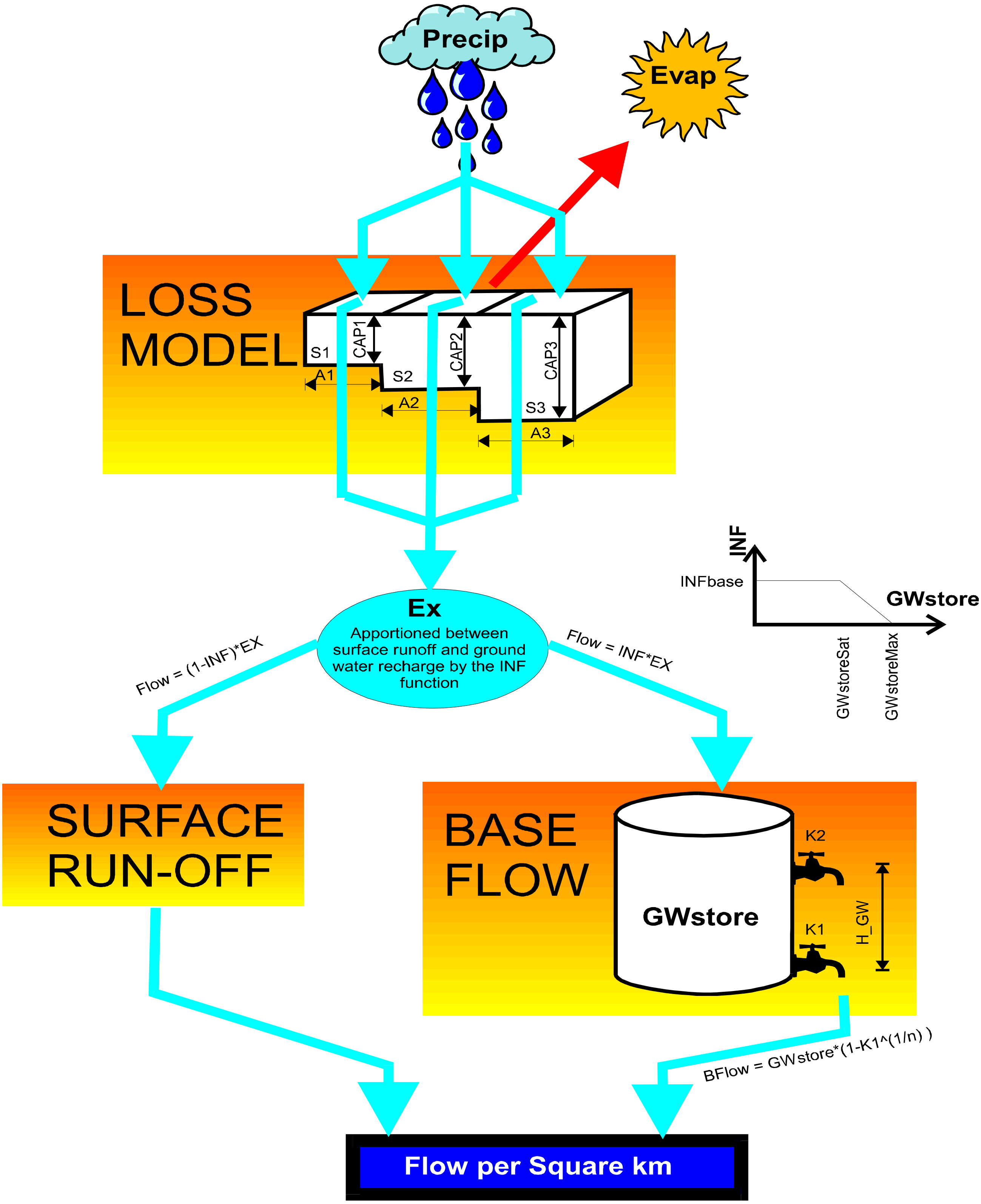


Figure 4-3 Australian Water Balance Model Schematic

4.3 CATCHMENT ROUTING ALGORITHM

In this method direct run off, which is determined by the AWBM water balance model is routed through a conceptual non-linear reservoir to simulate the catchment run-off process for individual sub-catchments. This code is located in the blue sub catchment nodes (as seen in the model schematic, Figure 4-1).

The catchment lag K of the sub-catchment storage is assumed to be proportional to the square root of the sub-catchment area (this is a similar process to that adopted for the Watershed Bounded Network Model of Boyd). Direct run-off is applied to the sub-catchment centroid.

The non-linear storage equation is assumed to be a power function of discharge:

$\mathbf{Sc = K.Q^m}$ (Pilgrim, 1987)

where:

$\mathbf{K = \beta.A^{0.5}}$ (Carroll, 1993)

and.

Sc = Sub-catchment Storage (m^3)

β = Catchment Lag Parameter

A = Sub-catchment Area (km^2)

Q = Sub-catchment Outflow to the Stream at the centroid (m^3/s)

m = Non-linearity Parameter

This relation of K to area is the same as that adopted by Carroll (1993) for URBS and is also used in a similar form in the Watershed Bounded Network Model (Boyd *et. al.* 1987).

Parameters required by Hydstra Modelling and their suggested bounds are:

β	Catchment Lag Parameter	Between 0.0 and 5.0
A	Sub-catchment Area (km^2)	Greater than 0.0 (km^2)
m	Non-linearity Parameter	Between 0.0 and 1.0

4.4 CHANNEL ROUTING ALGORITHM

The channel routing algorithm is applied in each of the black links with a circle at the leading end, as shown in the model schematic (Figure 4-1). A common method employed in non-linear routing models is a power function storage relation.

$\mathbf{S = K.Q^n}$

K is a dimensional empirical coefficient, the reach lag (time). In the case of Hydstra Modelling:

$K = \alpha.L_i$

and

L_i = Channel length (km)

α = Channel Lag Parameter

n = Non-linearity Parameter

Q = Outflow from Channel Reach (m^3/s)

Parameters required by Hydstra/TSM Modelling and their legal bounds are:

α	Channel Lag Parameter	Between 0.0 and 5.0
L	Channel Length (km)	Greater than 0.0 (km)
n	Non-linearity Parameter	Between 0.0 and 1.0

4.5 FORECAST RECESSION CORRECTION ALGORITHM

During forecast periods of low flows a recession equation is applied in preference to the modelled data at each significant measured flow gauge. When the modelled flows fall below a specified threshold the modelled data is replaced with the following recession equation.

$$\mathbf{Q_{recession} = (Q_{last} - const) \times k + const}$$

Where

Q_{last} = the flow value of the previous time step

const = a value representing the minimum flow of the river at that point

k = a recession shaping factor.

At times below the threshold, the uncorrected modelled data is used if it is greater than the flow resulting from the recession equation (e.g. during the onset of forecast event). No recession equation is applied if the modelled flows are greater than the threshold.

The equation parameters have been determined by investigating two observed recession periods at each flow station as shown in Figure 4-4 below. Only the Manawatu River at Upper Gorge gauge has a recession correction applied to it at this stage. The reasons for this are discussed further in the Recommendations section later in this report. The recession factors determined below only apply when the model is run on a 15 minute time step.

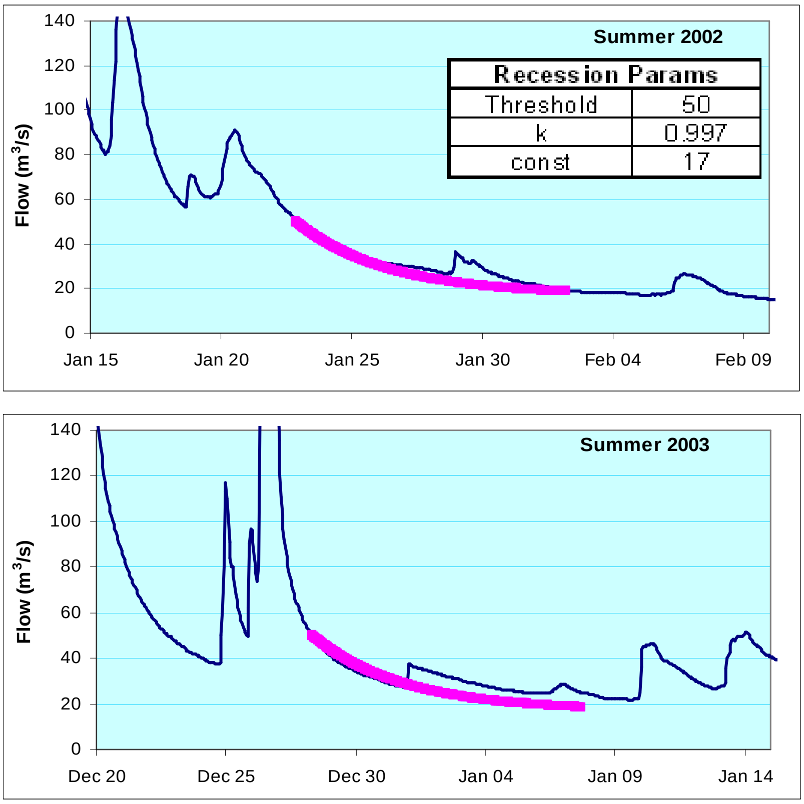


Figure 4-4: Low Flow Recession Equation at Upper Gorge

4.6 FORECAST ERROR CORRECTION ALGORITHM

During normal flood forecasting operation the model will use an error correction algorithm to adjust the modelled flow to the measured flow at specific gauges within the catchment. An amplitude correction method will be applied using the process outlined below:

1. During all time periods where measured data is available and of a suitable quality, this data will be used in preference to the modelled data.

2. During all other time periods (i.e. when measured data is not available), the difference between measured data and modelled data from the last time step where measured data is available (measured – modelled) is added to the modelled data. If no measured data is available throughout the entire model run, then the difference remains at zero and the modelled data is unaffected.

3. As the time without measured data increases, the difference between measured data and modelled data is reduced by a decay factor of 0.99 during each time step.

Note that there are a few variations of amplitude error correction currently in use in the models that make up the HRCFFS.

In the lower Manawatu models the algorithm is based on an autocorrelation function of the model error. A soil moisture correction was also applied to two locations in the lower Manawatu catchment but at the time of issue of this report, the soil moisture algorithm was disabled due to increased real-time inaccuracies. The methodology of the error corrections used in the lower Manawatu are discussed in the Manawatu report.

In the Whanganui model a new amplitude correction process is being trialled. This one adopts a linear decay of the difference (as opposed to the factor of 0.99) and adopts two separate decay periods depending on whether the hydrograph is on the rise or in recession. The decay period determines the time length of the linear reduction of the difference between measured and modelled until it reaches zero.

Each correction method has its limitations in real-time operation. More detail on the concept of error corrections is given in the Recommedations section at the end of this report.

4.7 FLOOD FLOW ATTENUATION IN THE MANAWATU RIVER

The Upper Manawatu River exhibits an increased attenuation of flows when they reach high flood magnitudes. This was evident during calibration when the range of higher magnitude floods were showing good comparisons of event volumes but a significant over prediction of modelled peaks (as seen in Figure 4-5 over the page).

To account for this, adjustments were made to the channel routing at three locations in the Manawatu River by increasing the channel lag parameter and (in some cases) the reach length once the flow exceeds a range of predefined thresholds. All flow up to the first threshold would travel down the river using the standard routing parameters, but any flow above this threshold would be influenced by increased lag parameters. Multiple sets of increased lag parameters (either two or three) have been adopted and apply within pre-defined flow ranges as shown in Table 4-1. The channel lag parameter Alpha has been increased by applying a multiplier to the standard Alpha that was determined at each location during the calibration process. This approach was also used to account for the significant flood restrictions of the Manawatu Gorge.

Table 4-1: Flood Flow Attenuation Parameters

Location	Weber Rd	Hopelands	Upper Gorge
Reach ID	rMUG_12	rMUG_29	rMUG_83
Flow Range 1 (m^3/s)	< 700	< 800	< 750
Alpha Factor 1	1	1	1
Length 1 (km)	4.24	7.64	0.67
Flow Range 2 (m^3/s)	700 - 800	800 - 900	750 - 900
Alpha Factor 2	3	1.8	3
Length 2 (km)	4.24	7.64	4
Flow Range 3 (m^3/s)	> 800	> 900	900 - 1500
Alpha Factor 3	7	3.5	5
Length 3 (km)	4.24	7.64	5
Flow Range 4 (m^3/s)	-	-	> 1500
Alpha Factor 4	-	-	12
Length 4 (km)	-	-	10

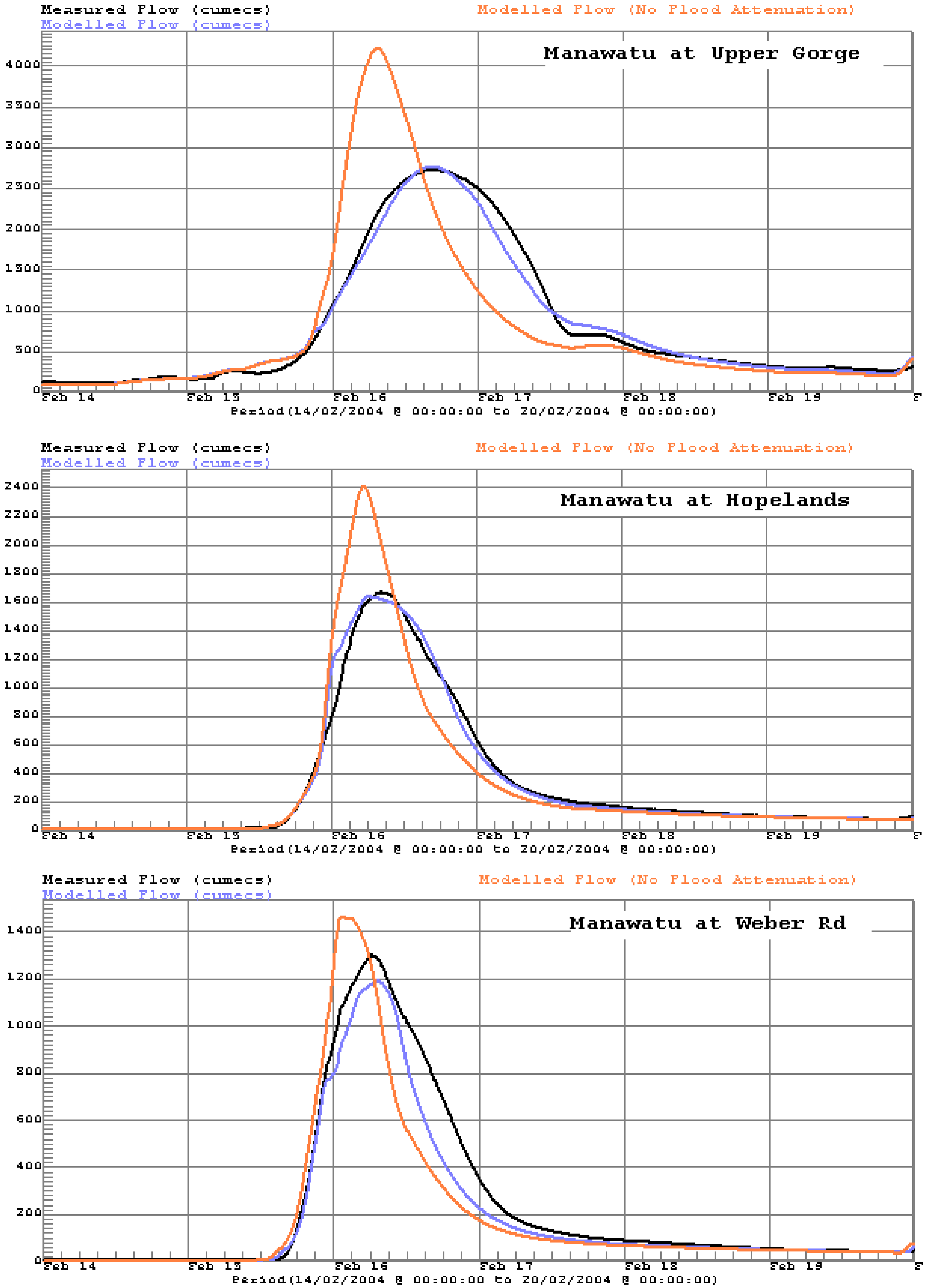


Figure 4-5: Impact of the Flood Flow Attenuation during the February 2004 Event

4.8 OPERATING ASSUMPTIONS OF THE UPPER MANGAHAO DAMS

Limited real-time information is available for the lakes and associated hydropower development in the Upper Mangahao catchment. For this reason the operational assumptions have been kept reasonably simple. It is likely that increasing the complexity of the model rules and assumptions would lead to little improvement in the accuracy of the results.

The model accounts for the impact of the Upper Mangahao dams by assuming the following:

- For historical timesteps the measured stage at Upper Mangahao Dam 1 is read into the model.
- As soon as the measured stage series is unavailable, the head to storage volume relationship is used to calculate the corresponding storage volume of the lake (shown in Figure 4-6 below). Note that in these plots a head of 0m corresponds to a lake level (above sea level) of 354m which in turn corresponds to a stage height of -4.231 from the measured stage.
- For all forecast timesteps (or if the measured stage is not available) the level is calculated using the head to storage volume relationship. Storage volume is calculated as previous storage volume + inflow – 10 m^3/s (through the power station).
- All inflow (less the 10 m^3/s assumed to go through the power station) is assumed to spill and travel down the Mangahao River if the stage exceeds 16.7 m (i.e. a head of 20.931m).

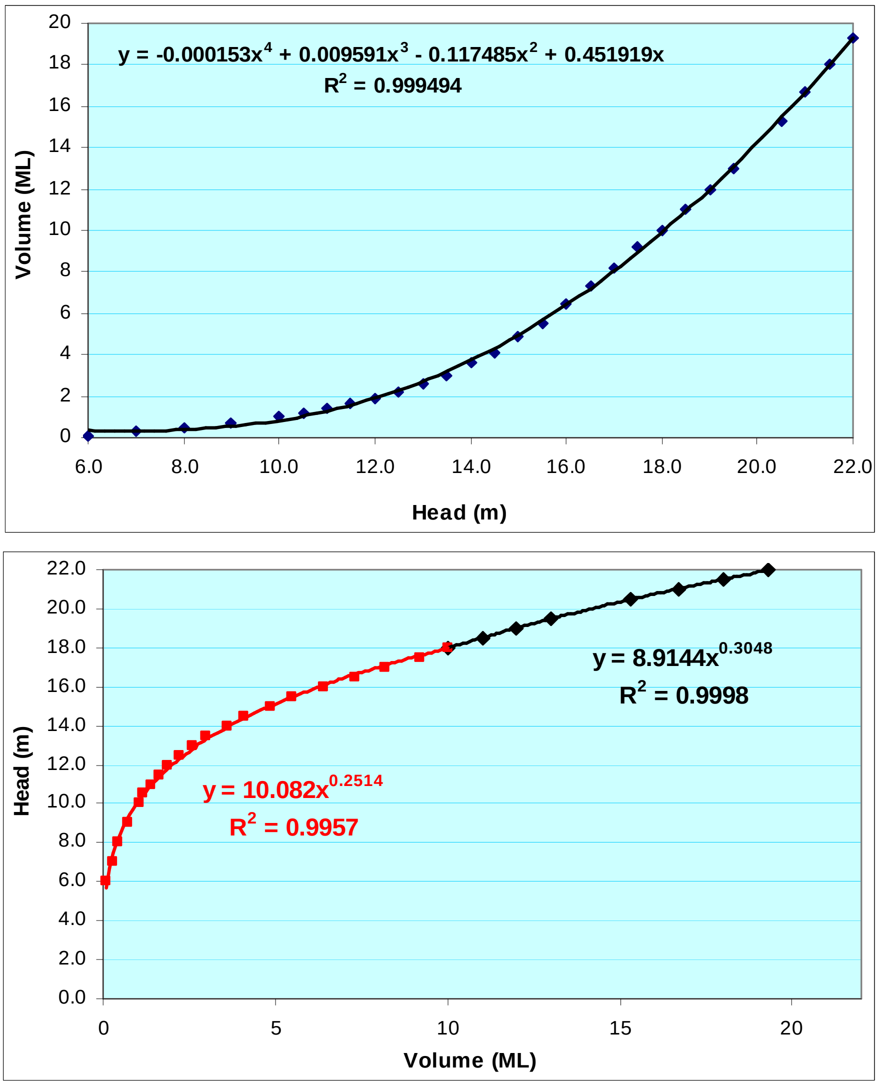


Figure 4-6: Lake Head to Storage Volume (and Reverse) Relationships for Upper Mangahao No 1 Dam

5 HYDROLOGIC MODEL DETAILS

5.1 MEASURED INPUT DATA

All measured data (rainfall and flow) was provided by Horizons Regional Council (HRC) in a Hilltop Database. The supplied data has been assumed to be of a suitable quality for use in the model for historical calibration and real-time operation. If uncertainties with the measured data arose, they were discussed openly throughout the development of the model. A map of the primary sites used to develop the Upper Manawatu model is shown in Figure 5-1 below.

In addition to the flow, rainfall and evaporation inputs shown in the map and discussed in the following sections, real-time stage is being input to the model at Upper Mangahao Dam No 1. Each rainfall gauge also has a corresponding forecast rainfall input (located adjacent to it as seen in the model schematic, Figure 4-1). Forecast rainfalls have not been investigated in this report.

Figure 5-1: Location of Measured Site Information in the Upper Manawatu Catchment. Rainfall Stations Labelled in Blue and Flow Stations Labelled in Black.

5.1.1 Evaporation Data.

Monthly average evaporation values from Station D06212 Dannevirke have been used in the model. The values are linearly smoothed in between months.

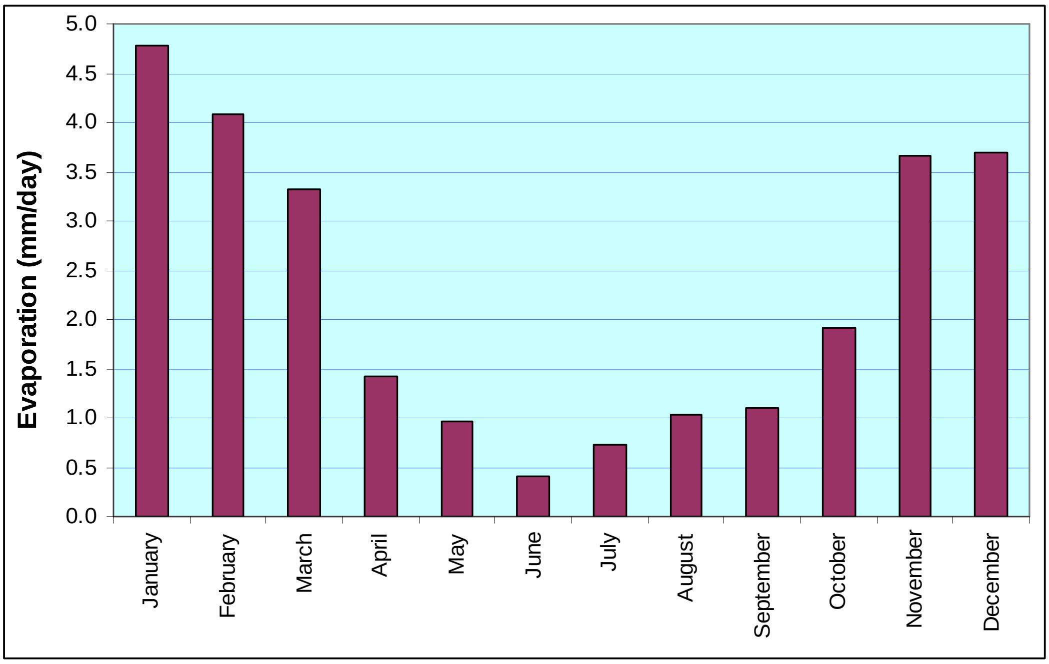


Figure 5-2: Average Potential Evapotranspiration adopted in the Upper Gorge catchment model.

5.1.2 Measured Rainfall Data

The rainfall sites shown in Figure 5-1 and Table 5-1 were considered for use in the model. Of these sites, all gauges have been included except for the Waihi gauge due to a lack of available data and its low relevance to the Upper Manawatu catchment. In general a good distribution of gauges is present over the catchment except for the central to north-eastern region. Figure 5-3 shows the variation of mean annual rainfalls across the catchment at each gauge location.

The long-term average measured data at each gauge has been cross-compared to the output from a GIS grid that was developed using the supplied isohyets for the Horizons Region (Table 5-1). Adopted values are highlighted red if the long-term calculated average differed greatly from the value selected off the grid. Two of these sites (Mangatainoka at Hillwood Hukanui and Tiraumea at Ohehua Repeater) are highly influential gauges over the model subcatchments (as seen in Table 5-5 later in the report).

Table 5-1: Rain Gauge Details

Site Name	Data Source	Easting m	Northing m	Altitude m	MAR mm (isohyet map)	Start Year	Finish Year	Years	Total Rain mm	MAR mm (gauge)	Adopted MAR mm
Akitio at Toi Flat	Rainfall	2787700	6091900	259	1200	1990	2007	17	20400	1200	1200
Kumeti at Rua Roa	Rainfall	2768200	6108500	270	1485	1990	2007	17	24100	1418	1450
Makuri at Bee 4 Trig	Rainfall	2769000	6067200	480	1400	2003	2007	3.08	6800	2205	**1600**
Manawatu at Apiti Track	Rainfall	2778100	6124200	533	1835	1990	2007	17	31500	1853	1850
Mangaone at Milson Line	Rainfall	2731100	6095300	38	880	2001	2007	5.67	5150	908	900
Mangatainoka at Hillwood Hukanui	Rainfall	2735700	6066200	235	1830	1990	2007	17	35000	2059	**1920**
Pohangina at Alphabet Hut	SCADA Rainfall	2753900	6109700	385	1250	1997	2007	10	13600	1360	1300
Pohangina at Delaware Ridge	Rainfall	2763900	6122100	945	2200	1990	2007	17	37500	2206	2200
Pohangina at Makawakawa Divide	Rainfall	2767100	6119600	1140	3300	1990	2007	17	60000	3529	3400
Tamaki at Tamaki Reserve	Rainfall	2768500	6115900	400	2200	1990	2007	17	38000	2235	2200
Tiraumea at Alfredton	Rainfall	2751800	6054700	152	1200	1990	2007	16.58	20000	1206	1200
Tiraumea at Ohehua Repeater	SCADA Rainfall	2755400	6079000	265	1400	1990	2007	17	15500	912	**1200**
Upper Mangahao at No.1 Dam	Rainfall	2719600	6061600	390	2930	1990	2007	17	52500	3088	3000
Waihi at S.H.52	Rainfall	2789200	6080400	50	1200	-	-	-	-	-	-
Ruamahanga at Mt Bruce	Rainfall	2729290	6047000		2200	1990	2007	16.88	43500	2578	2400
Ruamahanga at Bannister Basin	Rainfall	2718847	6049143	1006	6200	1990	2007	16.09	102600	6375	6200
East Waitewaewae at Oriwa	Rainfall	2708251	6048052	1085	2700	1991	2007	14.36	71000	4943	**3800**
Kahuterawa at Scotts Road	SCADA Rainfall	2728800	6076700	400	1800	1999	2007	8	12100	1513	1600
Mangahao at Kakariki	Rainfall	2731700	6068500	180	2600	1990	2007	17	46000	2706	2650

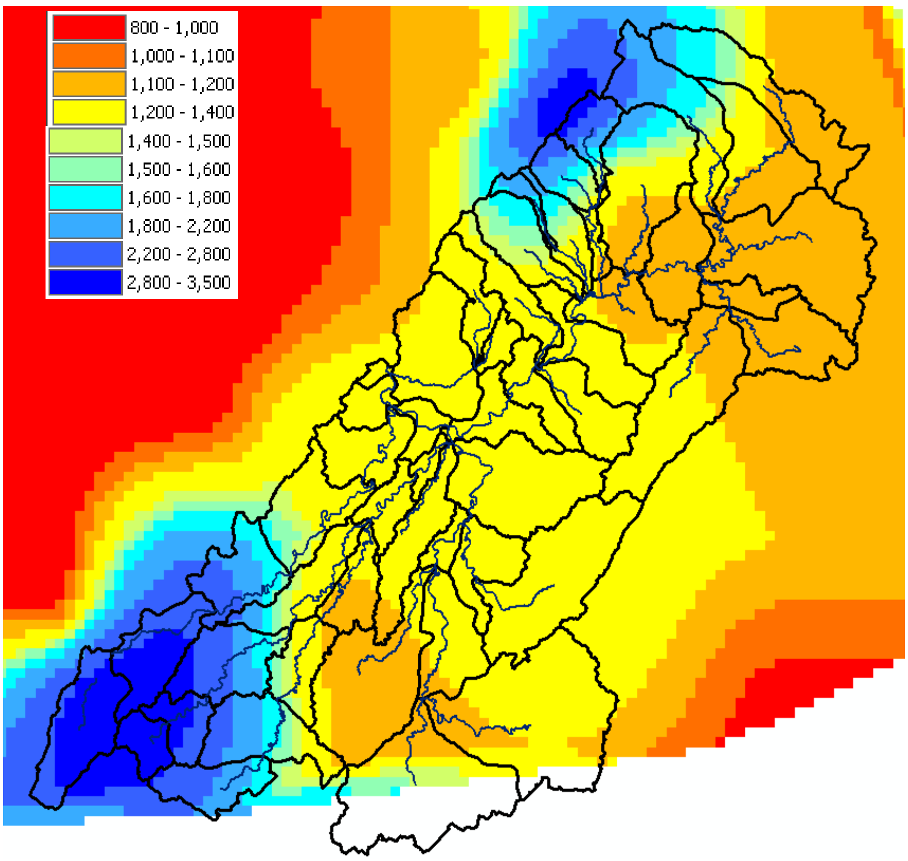


Figure 5-3 Mean Annual Rainfall Grid

5.2 MEASURED FLOW DATA

Figure 5-1 shows the locations of the primary sites included in the Upper Manawatu model for calibration and real-time error correction. The model has been developed with site nodes in place for an additional 8 secondary sites should there be a future need to include the measured site information into the model, or alternatively if modelled data needs to be extracted at the locations of these sites. These locations are marked in model interface with orange nodes as can be seen in the model schematic, Figure 4-1 in Section 4. These 8 sites are:

- Mangatoro at Mangahei Rd
- Tamaki at Water Supply Weir
- Kumeti at Te Rehunga
- Oruake Retaki at Oringe
- Raparapawai at Jacksons Rd
- Makuri at Tuscan Hills
- Mangahao at Kakariki
- Manga-atua at Hutchinsons

For calibration and review purposes, the rainfall gauge distribution was determined for the total catchment upstream of each primary flow gauge. This information is shown in Table 5-2 over the page and was calculated by averaging the rainfall gauge weightings at each catchment sub-area upstream of the measured flow gauge. The weightings at each sub-area are automatically determined according to the model's rainfall distribution algorithm.

This information is used to measure the catchment average precipitation and runoff coefficients both during events and over the long-term. Note that to achieve a better calibration at some sites the average precipitation within certain calibration regions needed to be factored. This is not reflected in the table over the page, or in the calculated runoff coefficients that are displayed later in the report. More detail on how this data was used is supplied in the Calibration section.

Table 5-2: Catchment Area and Rainfall Gauge Contribution at each Measured Flow Gauge

	Area km²	Apiti Track	Delware Ridge	Makawakawa Divide	Tamaki	Alphabet Hut	Kumeti Rua Roa	Akitio Toi Flat	Milson Line	Ohehua Repeater	Kahuterawa Scotts	Mangahao Kakariki	Mangatainoka Hillwood	Upper Mangahao	Tiraumea Alfredton	Makuri Bee Trig	Waitewaewae Oriwa	Bannister Basin	Mt Bruce
Weber Rd	712.98	0.233	0.000	0.000	0.068	0.000	0.119	0.428	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.000	0.000
Tamaki	77.22	0.077	0.052	0.101	0.392	0.065	0.294	0.049	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hopelands	1361.23	0.143	0.005	0.009	0.083	0.042	0.210	0.284	0.006	0.082	0.008	0.003	0.011	0.004	0.009	0.025	0.001	0.002	0.005
Tiraumea at Ngaturi	750.25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.082	0.032	0.082	0.269	0.155	0.129	0.000	0.000	0.064	0.230
Mangatainoka Larsons Br	57.44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.255	0.000	0.000	0.169	0.000	0.391	0.000	0.000	0.000	0.042
Makakahi at Hamua	161.31	0.000	0.000	0.000	0.000	0.034	0.000	0.000	0.050	0.421	0.046	0.000	0.070	0.000	0.197	0.075	0.000	0.000	0.017
Mangatainoka Susp Br	408.26	0.000	0.000	0.000	0.000	0.013	0.000	0.020	0.020	0.401	0.029	0.000	0.051	0.000	0.226	0.161	0.000	0.000	0.013
Mangahao Ballance	277.42	0.000	0.000	0.000	0.000	0.038	0.000	0.000	0.127	0.213	0.086	0.189	0.239	0.107	0.036	0.000	0.000	0.000	0.000
Upper Gorge	3177.47	0.061	0.002	0.003	0.035	0.040	0.099	0.126	0.026	0.172	0.032	0.036	0.101	0.050	0.070	0.031	0.001	0.016	0.056

5.3 SUBCATCHMENT DELINEATION

The Upper Manawatu River catchment has been divided into 51 sub-areas. The sub-areas have been selected to provide break points at all existing flow gauge locations and to best capture the spatial distribution of the rainfall gauge network around the catchment.

Figure 5-4 shows the sub-catchment breakdown for the Upper Manawatu River Catchment along with the sub-catchment identifiers. The properties of each sub-catchment are listed in Table 5-3. Figure 5-5 and Table 5-4 show the properties of the reach (river) lengths.

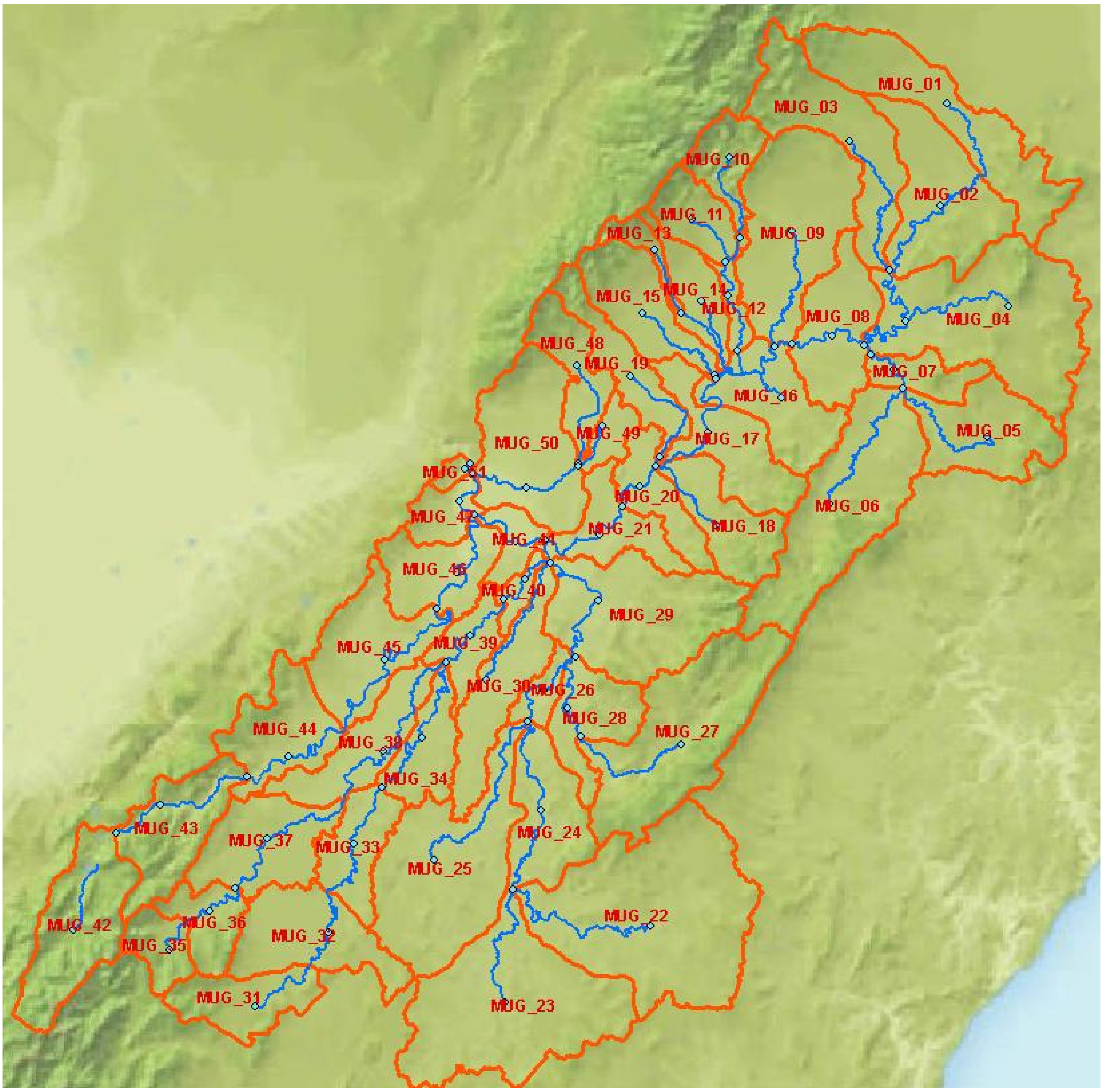


Figure 5-4: Subcatchment Breakdown Showing Location of Catchment Identifiers

Table 5-3: Subcatchment Node Details

Subarea ID	Easting	Northing	Mean Annual Rainfall (mm)	Area (km^2)	Calibration Zone
MUG_01	2787420	6121760	1350	100.3	WeberRd
MUG_02	2786902	6113731	1210	90.6	WeberRd
MUG_03	2779649	6118808	1600	87.7	WeberRd
MUG_04	2792341	6105753	1200	152.3	WeberRd
MUG_05	2790561	6095357	1200	66.9	Mangatoro
MUG_06	2777993	6090082	1275	127.3	Mangatoro
MUG_07	2783171	6100698	1200	25.0	Mangatoro
MUG_08	2778209	6103373	1200	62.8	WeberRd
MUG_09	2775015	6111659	1285	115.9	Manawatu
MUG_10	2770089	6117562	2500	31.9	Tamaki
MUG_11	2767030	6112655	1890	32.4	Tamaki
MUG_12	2769988	6106538	1300	12.9	Tamaki
MUG_13	2764106	6110168	1770	11.6	Tamaki
MUG_14	2767837	6106101	1400	33.5	Tamaki
MUG_15	2763098	6105194	1480	56.1	Tamaki
MUG_16	2774223	6098471	1200	63.3	Manawatu
MUG_17	2768317	6095709	1260	60.5	Manawatu
MUG_18	2768967	6088372	1200	50.7	Manawatu
MUG_19	2762173	6100226	1400	44.0	Manawatu
MUG_20	2762968	6091408	1200	37.0	Manawatu
MUG_21	2759752	6087650	1200	43.2	Manawatu
MUG_22	2763787	6056702	1400	197.9	Tiraumea
MUG_23	2752174	6050630	1200	161.0	Tiraumea
MUG_24	2755066	6065809	1200	62.2	Tiraumea
MUG_25	2746537	6061906	1200	132.6	Tiraumea
MUG_26	2755258	6075302	1200	15.2	Tiraumea
MUG_27	2766197	6071013	1400	134.2	Tiraumea
MUG_28	2757138	6073904	1200	47.1	Tiraumea
MUG_29	2759679	6082433	1200	117.0	Tiraumea
MUG_30	2750715	6076148	1200	60.6	Tiraumea
MUG_31	2732283	6050305	2250	46.4	Makakahi
MUG_32	2738150	6056172	1700	72.0	Makakahi
MUG_33	2740121	6063118	1450	42.9	Makakahi
MUG_34	2745613	6071520	1250	38.9	Makakahi
MUG_35	2725478	6054811	3500	25.3	Larsons
MUG_36	2728716	6057815	3000	32.2	Larsons
MUG_37	2733269	6063635	2500	67.3	Pahiatua
MUG_38	2742468	6070487	1350	54.8	Pahiatua
MUG_39	2749473	6079622	1200	28.5	Pahiatua
MUG_40	2753803	6084127	1200	10.9	Pahiatua
MUG_41	2753064	6087119	1200	19.3	Manawatu
MUG_42	2717863	6056319	3800	81.4	Mangahao
MUG_43	2724797	6066245	2850	63.5	Mangahao
MUG_44	2734935	6070117	2060	60.1	Mangahao
MUG_45	2742609	6077756	1200	72.3	Mangahao
MUG_46	2748311	6084691	1200	51.8	Mangahao
MUG_47	2748526	6090262	1200	22.5	Manawatu
MUG_48	2757921	6101072	1330	39.6	Manawatu
MUG_49	2759942	6096241	1350	15.4	Manawatu
MUG_50	2753919	6091352	1200	93.1	Manawatu
MUG_51	2749047	6092848	1150	5.3	Manawatu

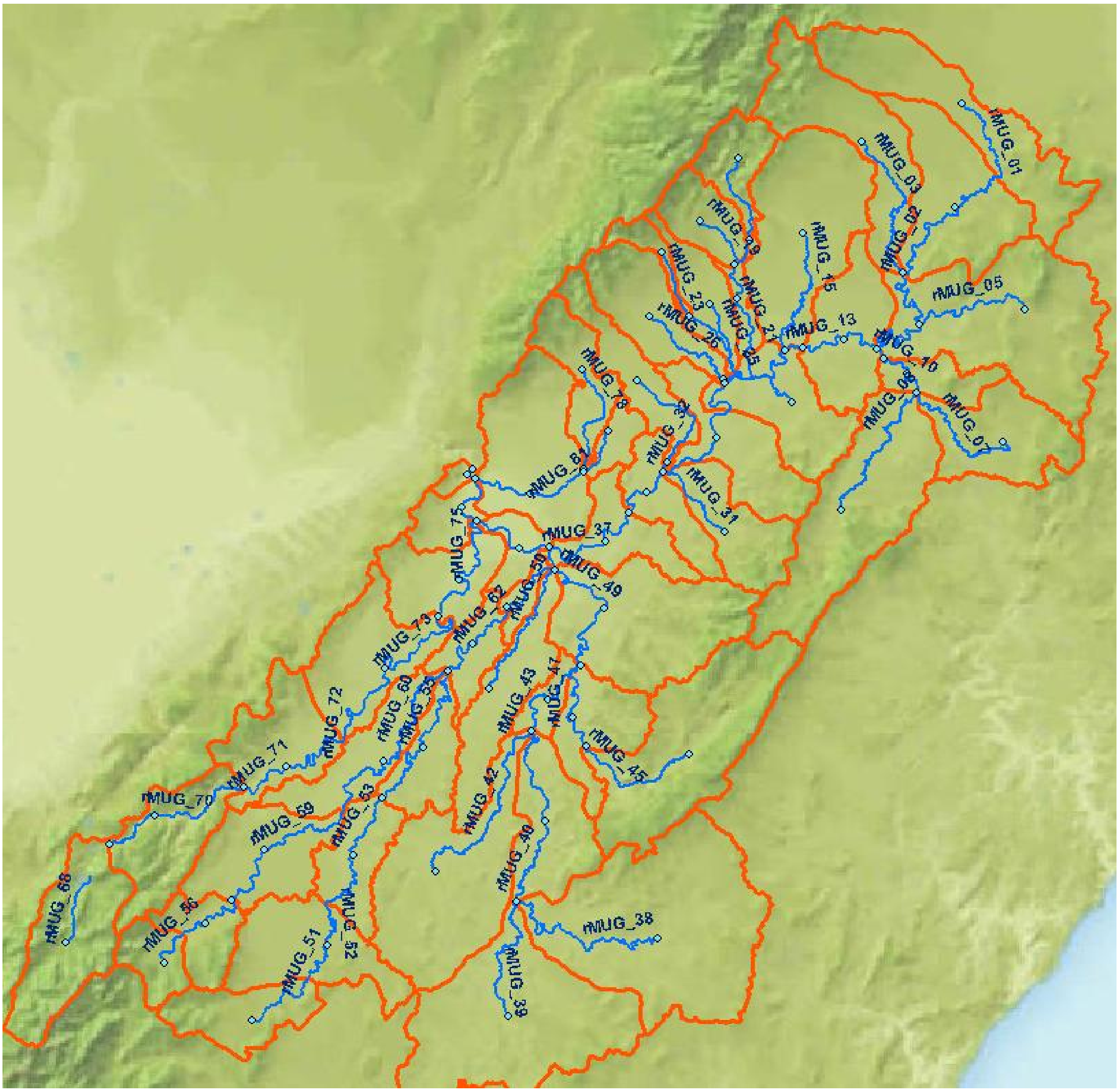


Figure 5-5: Location of Reach Identifiers

Table 5-4: Reach Length Details

Reach ID	Length (km)	Reach ID	Length (km)
rMUG_01	15.24	rMUG_43	4.76
rMUG_02	11.38	rMUG_44	4.90
rMUG_03	17.07	rMUG_45	11.67
rMUG_04	9.87	rMUG_46	3.41
rMUG_05	12.50	rMUG_47	7.85
rMUG_06	9.89	rMUG_48	7.57
rMUG_07	14.15	rMUG_49	6.72
rMUG_08	15.85	rMUG_50	13.99
rMUG_09	2.86	rMUG_51	12.68
rMUG_10	3.32	rMUG_52	13.21
rMUG_11	1.31	rMUG_53	6.27
rMUG_12	4.24	rMUG_54	7.69
rMUG_13	5.03	rMUG_55	11.22
rMUG_14	1.77	rMUG_56	6.43
rMUG_15	14.79	rMUG_57	4.77
rMUG_16	8.70	rMUG_58	6.56
rMUG_17	8.36	rMUG_59	17.22
rMUG_18	2.51	rMUG_60	12.63
rMUG_19	5.72	rMUG_61	5.34
rMUG_20	3.74	rMUG_62	4.80
rMUG_21	6.01	rMUG_63	3.21
rMUG_22	4.30	rMUG_64	2.78
rMUG_23	5.78	rMUG_65	1.83
rMUG_24	8.71	rMUG_66	2.69
rMUG_25	8.58	rMUG_67	4.97
rMUG_26	10.46	rMUG_68	6.29
rMUG_27	0.55	rMUG_69	5.12
rMUG_28	7.77	rMUG_70	9.09
rMUG_29	7.64	rMUG_71	4.98
rMUG_30	5.81	rMUG_72	17.72
rMUG_31	8.64	rMUG_73	11.97
rMUG_32	10.44	rMUG_74	5.46
rMUG_33	0.73	rMUG_75	8.00
rMUG_34	2.36	rMUG_76	1.90
rMUG_35	3.51	rMUG_77	3.33
rMUG_36	4.34	rMUG_78	9.85
rMUG_37	5.86	rMUG_79	0.17
rMUG_38	21.31	rMUG_80	4.41
rMUG_39	13.92	rMUG_81	5.07
rMUG_40	8.88	rMUG_82	6.07
rMUG_41	10.31	rMUG_83	0.67
rMUG_42	19.77	rMUG_84	0.57

NOTE: Shaded reaches contain coincident links in the model which have varying lag parameters to increase attenuation of flood flows. Refer to Section 4.7 for more details.

5.4 RAINFALL DISTRIBUTION

Table 5-5 over the page shows the rain gauge weighting factors for each sub catchment in the model.

This table can be used to identify the rainfall gauges that are used with the most frequency throughout the catchment and therefore which are most critical to the reliability of modelled results. It must be stated however, that surrounding rainfall gauges that appear to have little influence in the hydrological model are likely to provide much support as backup gauges at times when real-time data is not available at the more critical gauges.

The rainfall interpolation applied in the hydrological model (discussed in Section 4.1) is an automated approach that is applied generically for each catchment sub-area. This allows the model to be adaptable to future changes in the rain gauge network. The table below shows the result of the automated process and can be used to investigate whether each sub-area has been best represented by the rainfall gauges that surround it.

Note that the weightings for a given sub area do not necessarily add up to 1. This is due to the application of a factor relating the mean annual rainfalls at the gauge to the sub-area centroid.

5.5 MODEL OUTPUTS

The model writes outputs back to Hilltop at each of the primary flow locations. The modelled flow at Manawatu at Upper Gorge is used as an input to the "TeachersCRRR.tso" hydrologic model.

Model outputs at each site include:

- **Predicted Flow** – Primary modelled flow output. Includes error correction at the site (if it is enabled).
- **Predicted Flow (uncorrected)** – Provides a continuous flow output without error correction applied at the site. Note that error corrections that are applied at upstream sites will influence the modelled flows in this record.
- **Predicted Flow 6 hr** – Provides a single point from the "Predicted Flow" series at 6 hours in the future for each scheduled run of the model. This creates a time series of 6 hour look-ahead estimates that won't get overwritten by subsequent model runs.
- **Predicted Flow 12 hr** – Provides a single point from the "Predicted Flow" series at 12 hours in the future for each scheduled run of the model. This creates a time series of 12 hour look-ahead estimates that won't get overwritten by subsequent model runs.

In addition to the outputs to Hilltop, two files are written to the c:\temp directory if "Calibr_Mode_YN" is set to "Y" in the Global Node of the model.

RG_Weightings.txt outputs the rainfall gauge weightings for each sub-catchment of the model.

Results_File.csv outputs long-term and event statistics comparing modelled and measured flows for each site. It can be used to monitor the ongoing performance of the model as new flood events occur in the catchment. Refer to the Recommendations section for some more discussion on model review.

Table 5-5: Rainfall Gauge Weightings at each Sub Catchment Centroid – all Gauges

SubCatch	Apiti Track	Delware Ridge	Makawakawa Divide	Tamaki	Alphabet Hut	Kumeti Rua Roa	Akitio Toi Flat	Milson Line	Ohehua Repeater	Kahuterawa Scotts Rd	Mangahao Kakariki	Mangatainoka Hillwood	Upper Mangahao	Tiraumea Alfredton	Makuri Bee Trig	Waitewaewae Oriwa	Bannister Basin	Mt Bruce
cMUG_01	0.40	0.00	0.00	0.16	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_02	0.28	0.00	0.00	0.00	0.00	0.25	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_03	0.25	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_04	0.51	0.00	0.00	0.21	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_05	0.00	0.00	0.00	0.00	0.00	0.22	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00
cMUG_06	0.00	0.00	0.00	0.00	0.00	0.12	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_07	0.00	0.00	0.00	0.00	0.00	0.26	0.54	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_08	0.00	0.00	0.00	0.00	0.00	0.40	0.36	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_09	0.14	0.00	0.00	0.20	0.00	0.31	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_10	0.00	0.13	0.00	0.35	0.16	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_11	0.15	0.00	0.24	0.59	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_12	0.07	0.00	0.00	0.00	0.00	0.67	0.09	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_13	0.00	0.12	0.00	0.20	0.24	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_14	0.00	0.00	0.00	0.00	0.33	0.50	0.13	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_15	0.00	0.00	0.05	0.00	0.00	0.71	0.09	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_16	0.11	0.00	0.00	0.00	0.00	0.31	0.29	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_17	0.00	0.00	0.00	0.13	0.00	0.30	0.24	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_18	0.00	0.00	0.00	0.00	0.33	0.36	0.17	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_19	0.00	0.00	0.00	0.00	0.00	0.20	0.25	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00
cMUG_20	0.00	0.00	0.00	0.00	0.21	0.22	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00
cMUG_21	0.00	0.00	0.00	0.00	0.17	0.16	0.00	0.00	0.44	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00
cMUG_22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.32	0.00	0.00	0.00	0.16	0.41
cMUG_23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.28	0.00	0.00	0.00	0.10	0.32
cMUG_24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.61	0.10	0.17	0.00	0.00	0.00	0.00
cMUG_25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.18	0.00	0.28	0.00	0.20	0.00	0.00	0.00	0.00
cMUG_26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.13	0.00	0.00	0.00	0.00	0.61
cMUG_27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.30	0.00	0.36	0.00	0.00	0.00	0.20
cMUG_28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.40	0.00	0.24	0.00	0.00	0.00	0.09
cMUG_29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.16	0.00	0.20	0.00	0.21	0.00	0.00	0.00	0.00
cMUG_30	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.19	0.57	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_31	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.17	0.61	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.10	0.00	0.10	0.00	0.00	0.11	0.00	0.00	0.00
cMUG_33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.10	0.00	0.00	0.07
cMUG_34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.46	0.36	0.00	0.00	0.00
cMUG_35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.15	0.00	0.40	0.00	0.00	0.00	0.00
cMUG_36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.18	0.00	0.38	0.00	0.00	0.00	0.07
cMUG_37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.07	0.00	0.00	0.00	0.11	0.11	0.00	0.00	0.00
cMUG_38	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.24	0.00	0.00	0.00	0.00	0.15	0.51	0.00	0.00	0.00
cMUG_39	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.55	0.00	0.00	0.00	0.00	0.15	0.16	0.00	0.00	0.00
cMUG_40	0.00	0.00	0.00	0.00	0.11	0.10	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00
cMUG_41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.20	0.21	0.00
cMUG_42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.37	0.37	0.00	0.00	0.00	0.00	0.00
cMUG_43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.21	0.31	0.39	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.32	0.00	0.00	0.19	0.00	0.17	0.00	0.00	0.00	0.00
cMUG_45	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.27	0.45	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_46	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.23	0.49	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_47	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.33	0.34	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_47	0.00	0.00	0.00	0.00	0.31	0.28	0.18	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_49	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.37	0.38	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_50	0.00	0.00	0.00	0.00	0.23	0.17	0.00	0.00	0.38	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cMUG_51	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.33	0.29	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No. SubAreas Influenced	**8**	**2**	**2**	**7**	**16**	**20**	**20**	**8**	**34**	**11**	**4**	**15**	**6**	**13**	**11**	**1**	**3**	**7**

6 MODEL CALIBRATIONS

6.1 CALIBRATION METHODOLOGY AND ADOPTED PARAMETERS

Model calibration involved adjusting catchment parameters so that the modelled data best replicated the record at measured flow sites. The calibration process uses all available measured rainfall inputs and no corrections to measured flows in the catchment. This process determines the optimum parameters so that the model best represents the catchment and river characteristics given the measured rainfall available. During the historical calibration no flow correction is being applied at upstream gauges. When operating in real-time, the model will be using forecast rainfall inputs which are likely to affect the results shown in the Sections below.

The historical calibration has been measured against performance indicators as specified in Chinese Standards (as referenced in the technical paper titled "Evaluation of Hydrologic and Hydraulic Models for Real-Time Flood Forecasting use in the Yangtze River Catchment", 8th National Conference on Hydraulics in Water Engineering, ANA Hotel Gold Coast, Australia 13-16 July 2004). These criteria have been used to standardise the method of assessing the model calibration performance over all catchments in the HRCFFS. The forecast accuracy determined on the basis of the CD and QR indicators is classified into Grades A, B or C according to criteria shown in Table 6-1.

Table 6-1: Accuracy Grading of Flood Forecast Elements according to Chinese Standards

Accuracy Grade A B C	A	B	C
Coefficient of Determination	CD>=0.90	0.90>CD>=0.70	0.70>CD>=0.50
Qualifying Rate (%)	QR>=85.0	85.0>QR>=70.0	70.0>QR>=60.0
Chinese Standards (2000) Recommendation	Suitable for making official forecasts	Suitable for making official forecasts	only suitable for making 'reference' forecasts.*

*Models that cannot make at least Grade C are not recommended for use in flood forecasting.

Qualifying rates (QR) = % of events that are qualified (A qualified event is one where the difference in modelled and observed peaks and volumes is <= 20%).
Coefficient of Determination (CD) = Measure of goodness of fit (R^2).

Calibration has been investigated over a period from 1990 to 2007 depending on the available record at each primary flow site. However a bias has been given to the time period starting from 2000. This is because at many of the sites, initial calibration results suggested that a different set of parameters would be optimum over 2000 - 2007 than from 1990 - 2007. This could be attributed to a number of factors including changing methodology and technologies relating to data recording, the availability of more rainfall information later in the period or even the change in nature of storms and conditions in the catchment. Regardless of the reasons, it was decided that the adopted parameters would be more suitable for forecasting in current conditions if they are based around more recent events.

Calibration results at each primary each site includes:

- A summary of the Chinese Standards performance indicators and recommendation, and a long-term flow volume comparison. The summary has been provided for the full run period (1990 – 2007) and also from 2000.
- Tabulated event statistics comparing peaks and volumes. Event runoff coefficients have been produced to provide more detail on the nature of the catchment and how representative the surrounding network of rainfall gauges are. Note that the runoff coefficients are based on the

catchment average rainfalls prior to the application of any additional factoring of the average catchment precipitation variable in the model. Up to 15 flood events have been selected for all sites except at Upper Gorge where 20 events have been chosen. A bias has been given towards events that occur in the period from 2000 for events smaller than the top 5 in some regions of the catchment (particularly in the Mangatainoka and Tiraumea catchments).

- A plot of the peak and volume error for each event.
- Monthly and seasonal volume balances.
- Event plots.
- A sample time series plot.

The adopted parameter regions and routing parameters are shown below in Figure 6-1 and Table 6-2 over the page. The following types of parameters have been adjusted during the calibration process:

- The AWBM parameters over 9 separate regions. Varying regions were mostly defined for the catchment area upstream of a particular calibration gauge, but in some cases the regions were extended to the end of the river (e.g. Mangahao) or to adjacent sub catchments (e.g. Tamaki).
- The channel and catchment routing parameters (Alpha and Beta). These parameters generally vary according to each of the nine calibration regions; however there are some exceptions with the use of Alpha in the model. The biggest exceptions are in the Upper Mangahao where an Alpha of 1.2 has been applied to the dam site, and at the lower reaches of some tributaries (just before they meet with the Manawatu River) the Manawatu Alpha of 0.9 has been applied.
- To reduce the attenuation of the channel routing process but still allow for a time lag, some delays have been applied at the calibration site of interest.
- Rainfall scaling factors have been applied at many of calibration regions. Either fixed or monthly variable scaling factors have been used and they apply a proportional scaling to all sub area within the region. Rainfall had to be increased in all cases where scaling factors were applied. The factors were required for all sub areas in the southern half of the Upper Manawatu catchment, especially in the Mangatainoka and Mangahao River catchments.

The calibration results are shown for each site in the following sections.

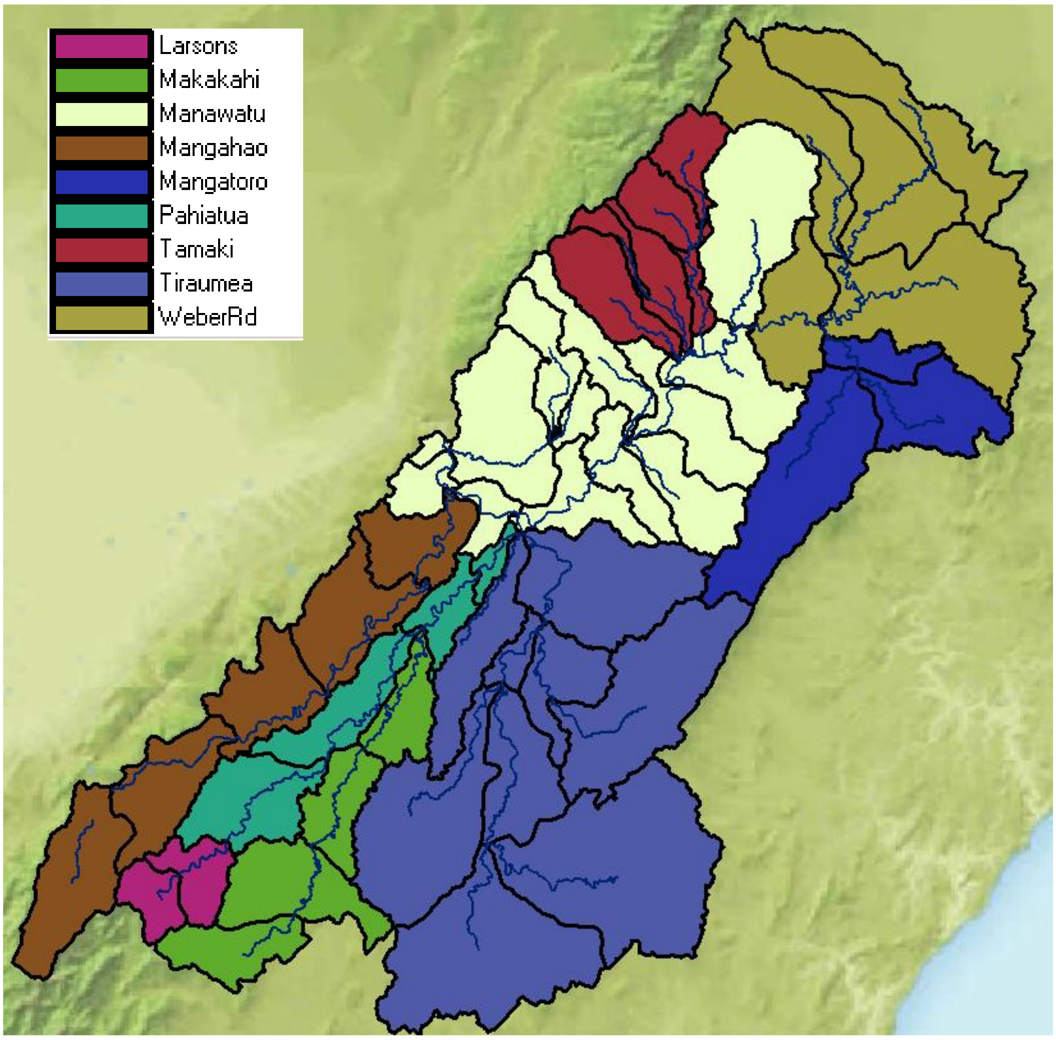


Figure 6-1: Calibration Regions – Upper Manawatu River Catchment

Table 6-2: Adopted Calibration Parameters

	Manawatu	WeberRd	Mangatoro	Tamaki	Tiraumea	Makakahi	Larsons	Pahiatua	Mangahao
Alpha	0.9	1.2	0.9	1.2	2.6	1	1.5	0.7	0.6
CapAve	70	35	60	100	45	40	50	30	90
INFbase	0.45	0.4	0.65	0.7	0.58	0.65	0.85	0.9	0.45
K1	0.8	0.78	0.7	0.88	0.98	0.95	0.92	0.9	0.93
K2	0.6	0.99	0.7	0.91	0.98	0.7	0.75	0.7	0.7
H_GW	18	33	16	45	40	20	20	65	50
GWstoreSat	20	30	25	100	70	40	49	70	79
GWstoreMax	22	45	30	150	70.1	50	50	71	80
Beta	0.6	0.5	0.5	0.8	0.8	0.8	0.8	0.8	0.8
RainScaleF	1	1	*	1	*	*	1.15	*	1.2

* Monthly variable rainfall scaling factors applied as shown below.

Managatoro	Dec-Mar: 1, Apr-Jun: 1.1, Jul-Nov: 1.25
Tiraumea	Feb-Jun: 1, Jul-Jan: 1.1
Makakahi	Feb: 1.15, Mar-Jun: 1, Jul-Jan: 1.2
Pahiatua	Jan-Feb: 1.15, Mar-Dec: 1.25

Site	**Delay (hrs)**
Mangatoro at Mangahei Rd	2
Manawatu at Hopelands	2
Makakahi at Hamua	1.5
Mangatainoka at Pahiatua	3
Mangahao at Ballance	2

6.2 CALIBRATION RESULTS - MANAWATU RIVER AT UPPER GORGE

In addition to the standard set of calibration outputs, Figure 6-2 shows the response of the model during the Feb 2004 event if rainfall is set to zero at various stages throughout the event. This shows the achievable lead-time of a well calibrated event if there is no forecast rain input. The plot shows that 6-9 hours of lead-time is achievable but only once the flood event is already on the rise.

Chinese Standards Performance Indicators:

From 1991: QR = 80% CD = 0.93 Accuracy Grading = B

From 2000: QR = 92% CD = 0.94 Accuracy Grading = A

Recommendation: Suitable for making official forecasts.

Measured Flow Volume = 48,906 Mm^3 (from 1991) 19,736 Mm^3 (from 2000)
Modelled Flow Volume = 47,530 Mm^3 (from 1991) 19,282 Mm^3 (from 2000)

Table 6-3: Calibration Event Details – Manawatu at Upper Gorge

	Event Start	Event Finish	Measured Peak Flow (m3/s)	Modelled Peak Flow (m3/s)	Difference (%)	Measured Volume (Mm3)	Modelled Volume (Mm3)	Difference (%)	Rainfall Volume (Mm3)	Measured Runoff Coeff	Modelled Runoff Coeff
1	14/02/2004 @ 00:00	24/02/2004 @ 00:00	2720.73	2764.76	1.62	539.18	516.70	-4.17	683.56	0.79	0.76
2	20/07/1992 @ 00:00	26/07/1992 @ 00:00	2469.34	1798.49	-27.17	308.05	260.46	-15.45	321.22	0.96	0.81
3	17/08/2004 @ 00:00	22/08/2004 @ 00:00	1912.40	1826.07	-4.51	266.68	276.12	3.54	277.41	0.96	1.00
4	09/04/1991 @ 12:00	16/04/1991 @ 00:00	1830.41	1852.38	1.20	263.95	275.93	4.54	350.56	0.75	0.79
5	27/09/2004 @ 18:00	05/10/2004 @ 00:00	1537.18	1435.20	-6.63	201.62	218.21	8.23	245.74	0.82	0.89
6	11/10/1992 @ 12:00	21/10/1992 @ 00:00	1507.20	1124.31	-25.40	286.23	219.32	-23.38	323.05	0.89	0.68
7	19/10/1998 @ 12:00	27/10/1998 @ 00:00	1415.88	1459.51	3.08	211.94	232.45	9.67	267.92	0.79	0.87
8	06/10/2000 @ 12:00	17/10/2000 @ 00:00	1411.05	1362.19	-3.46	309.95	328.85	6.10	339.34	0.91	0.97
9	13/08/2001 @ 18:00	19/08/2001 @ 00:00	1354.63	1423.24	5.07	191.81	184.40	-3.86	258.20	0.74	0.71
10	04/07/2006 @ 00:00	12/07/2006 @ 00:00	1281.19	1463.11	14.20	256.51	254.51	-0.78	303.39	0.85	0.84
11	14/02/1992 @ 12:00	21/02/1992 @ 00:00	1334.51	919.36	-31.11	175.98	145.24	-17.47	335.12	0.53	0.43
12	04/01/2005 @ 18:00	09/01/2005 @ 06:00	1256.73	1270.87	1.13	103.51	91.01	-12.08	151.79	0.68	0.60
13	28/09/2003 @ 00:00	03/10/2003 @ 06:00	1243.80	1490.58	19.84	203.63	243.27	19.46	289.84	0.70	0.84
14	01/06/1997 @ 00:00	09/06/1997 @ 00:00	1215.67	1183.67	-2.63	178.72	182.96	2.37	230.93	0.77	0.79
15	15/10/2004 @ 00:00	28/10/2004 @ 00:00	1195.18	1212.03	1.41	304.40	295.39	-2.96	359.81	0.85	0.82
16	27/11/1999 @ 12:00	06/12/1999 @ 00:00	1182.64	1337.42	13.09	192.93	221.49	14.80	349.58	0.55	0.63
17	20/01/2004 @ 00:00	26/01/2004 @ 00:00	1028.55	1003.38	-2.45	148.86	141.24	-5.12	362.83	0.41	0.39
18	27/02/2004 @ 00:00	07/03/2004 @ 00:00	967.79	977.24	0.98	239.46	208.63	-12.88	285.48	0.84	0.73
19	19/07/2006 @ 00:00	27/07/2006 @ 00:00	944.39	776.13	-17.82	181.46	153.60	-15.35	142.39	1.27	1.08
20	21/10/2006 @ 00:00	29/10/2006 @ 00:00	1076.08	845.41	-21.44	276.77	237.85	-14.06	321.79	0.86	0.74
	Average				***10.21***			***9.81***		***0.80***	***0.77***

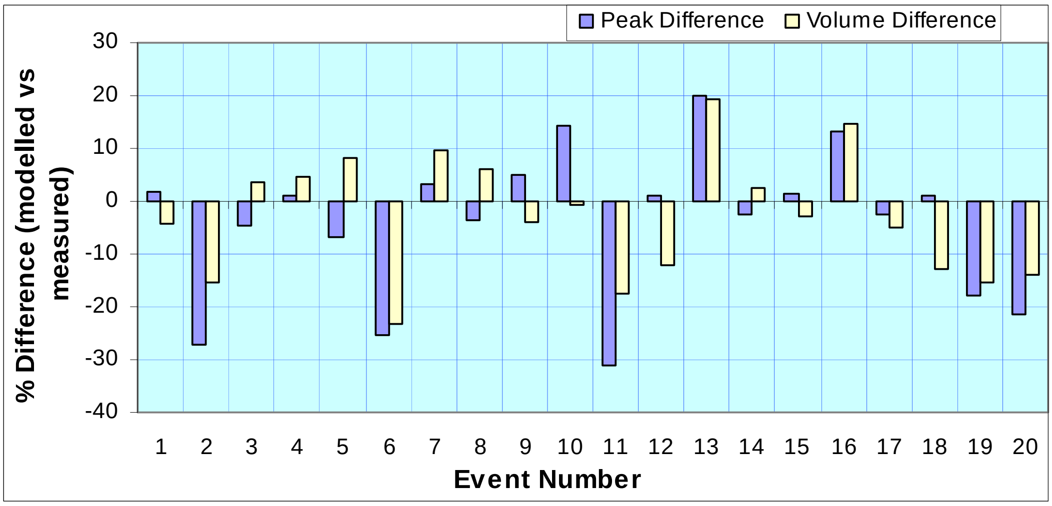


Figure 6-2: Modelled vs Measured Event Differences – Manawatu at Upper Gorge

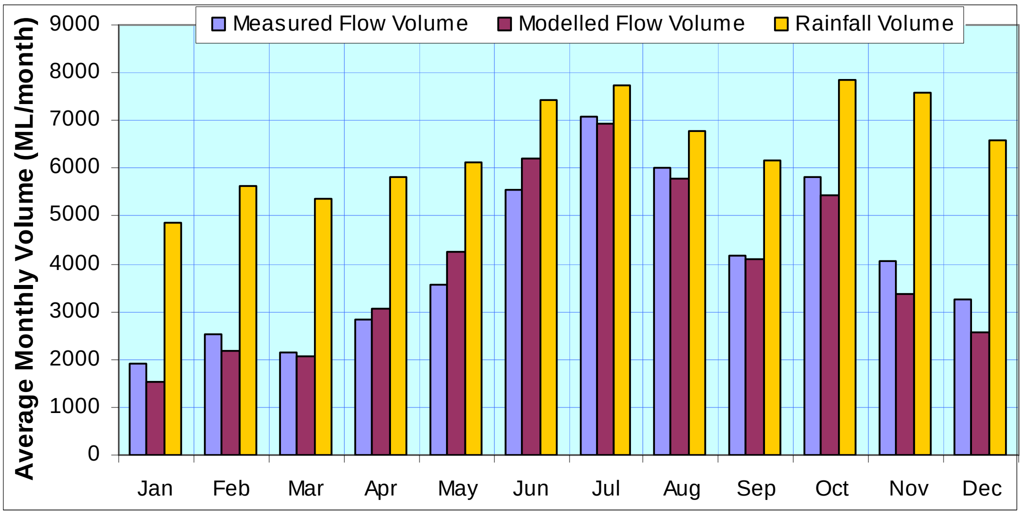
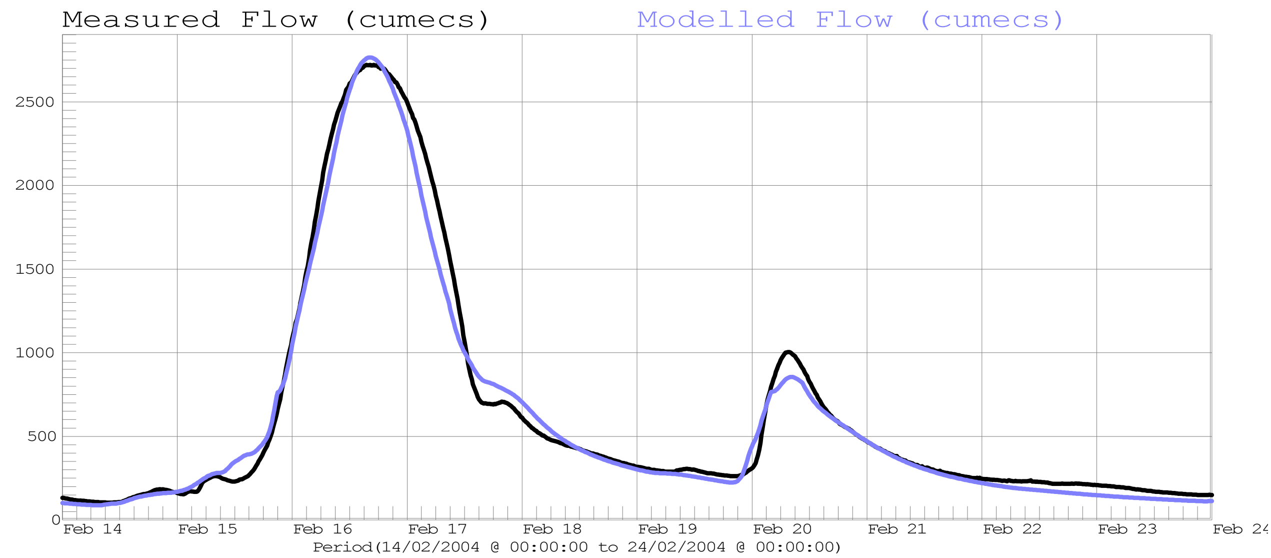
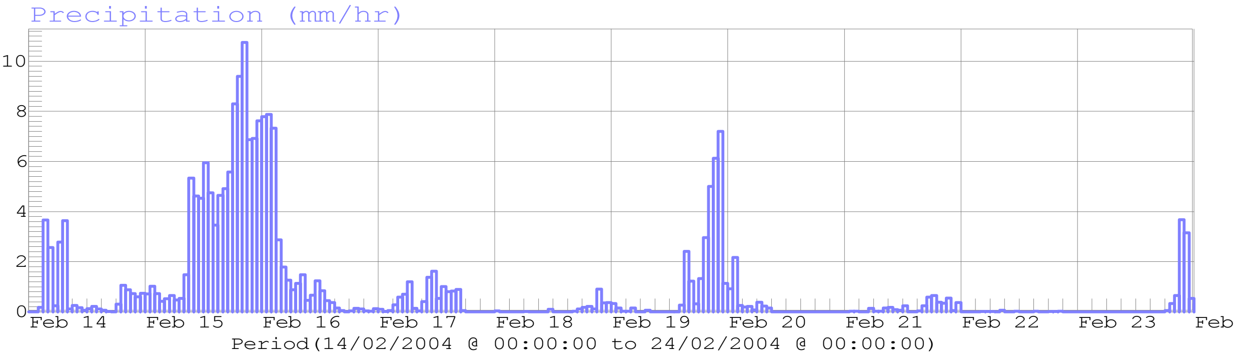
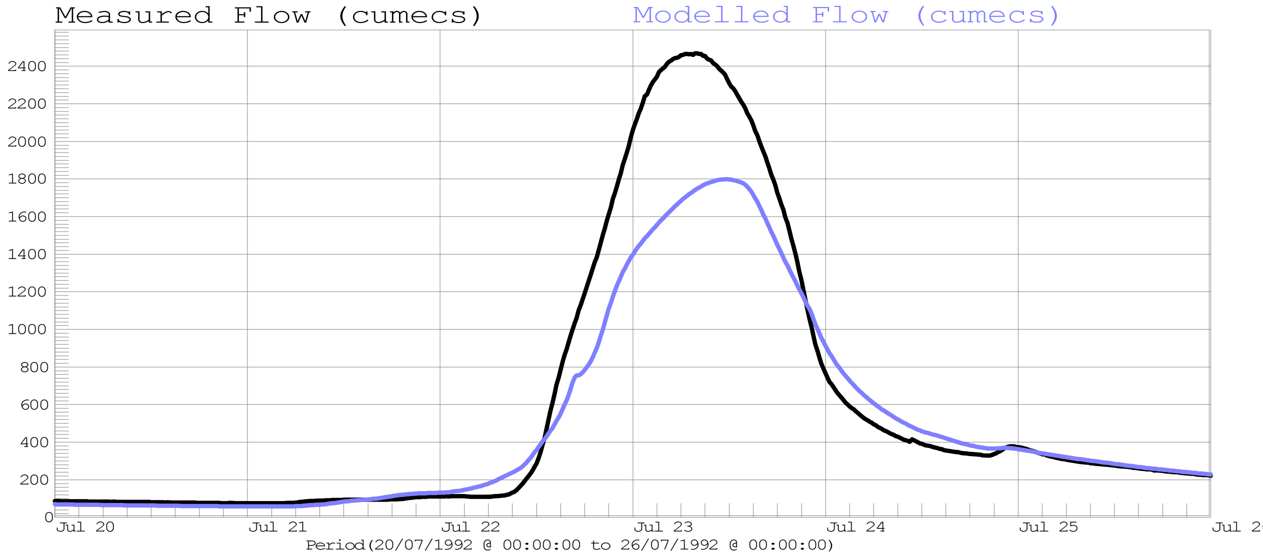


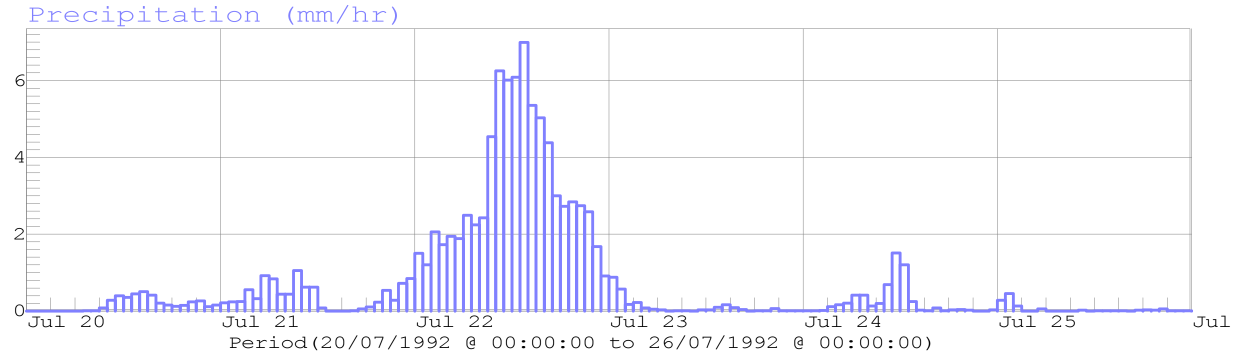
Figure 6-3: Monthly Average Volumes – Manawatu at Upper Gorge

EVENT COMPARISON - MANAWATU @ UPPER GORGE

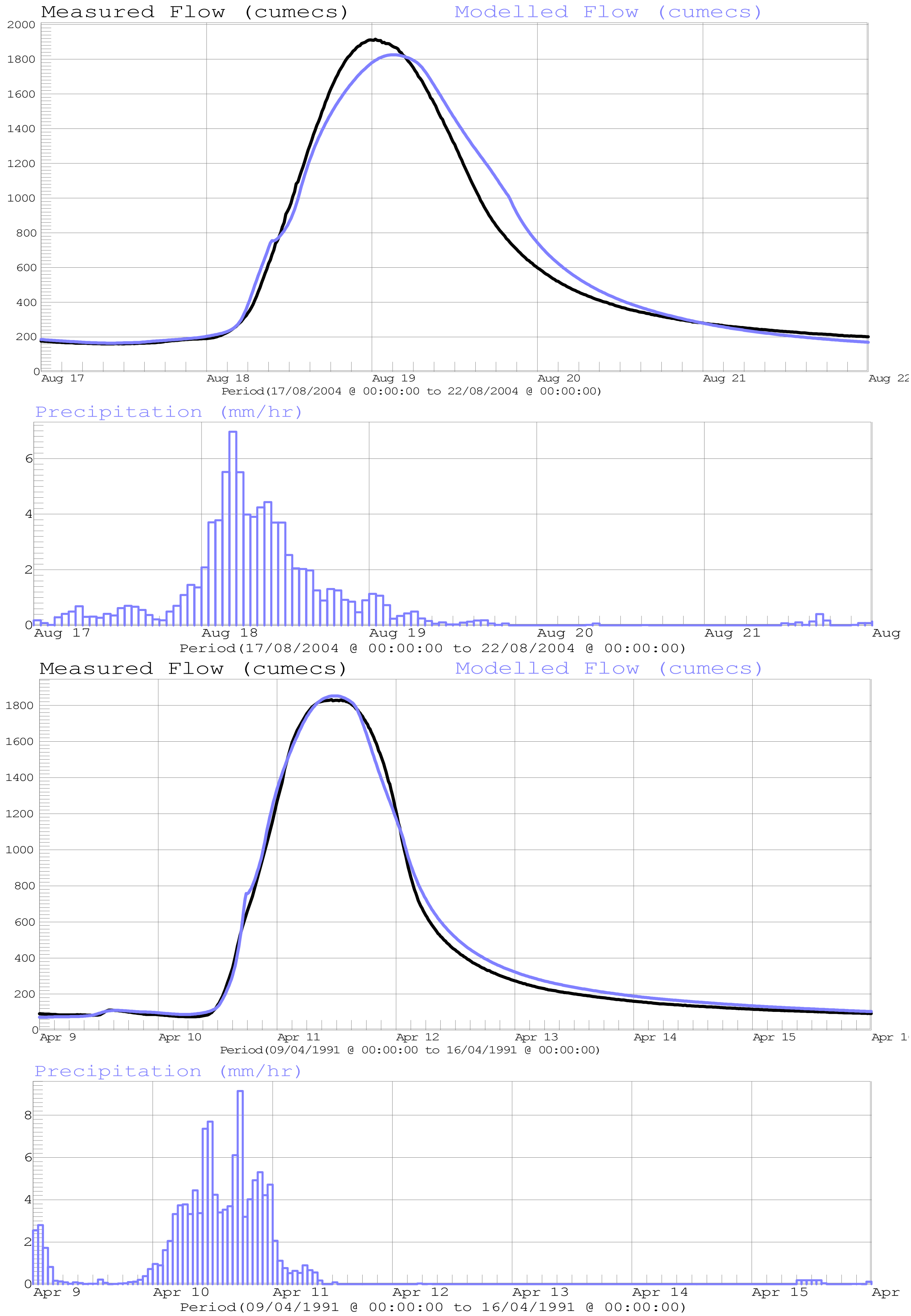




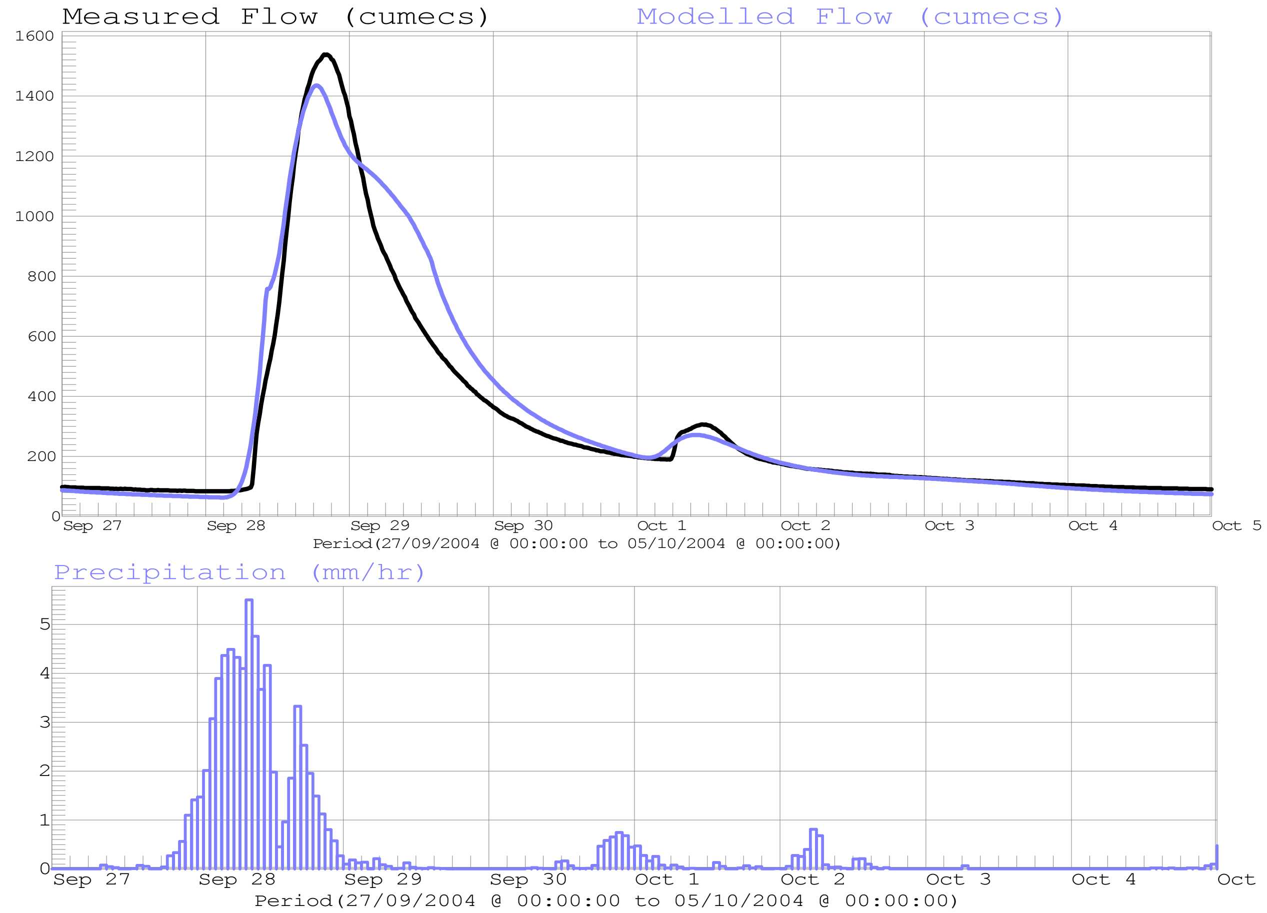


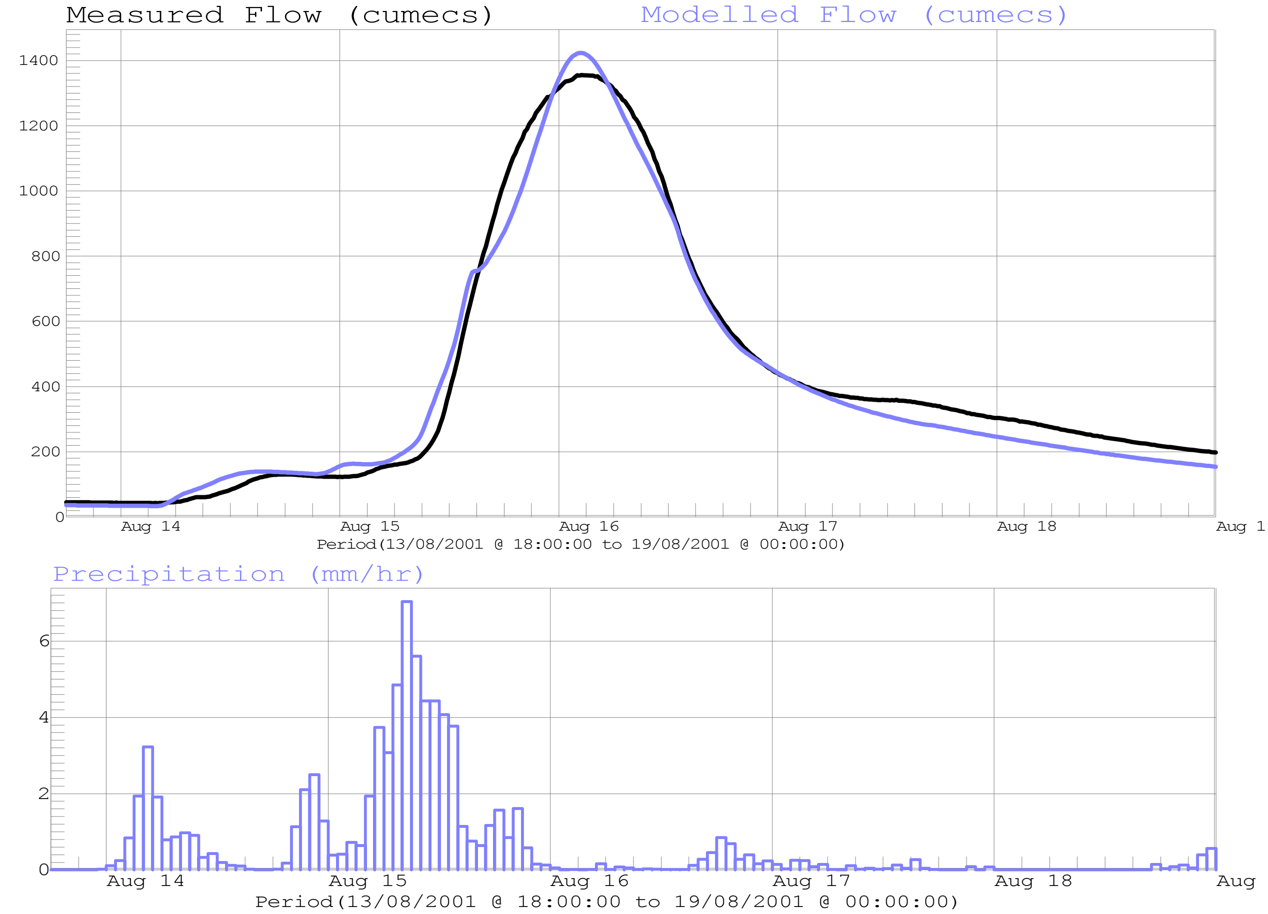


EVENT COMPARISON - MANAWATU @ UPPER GORGE

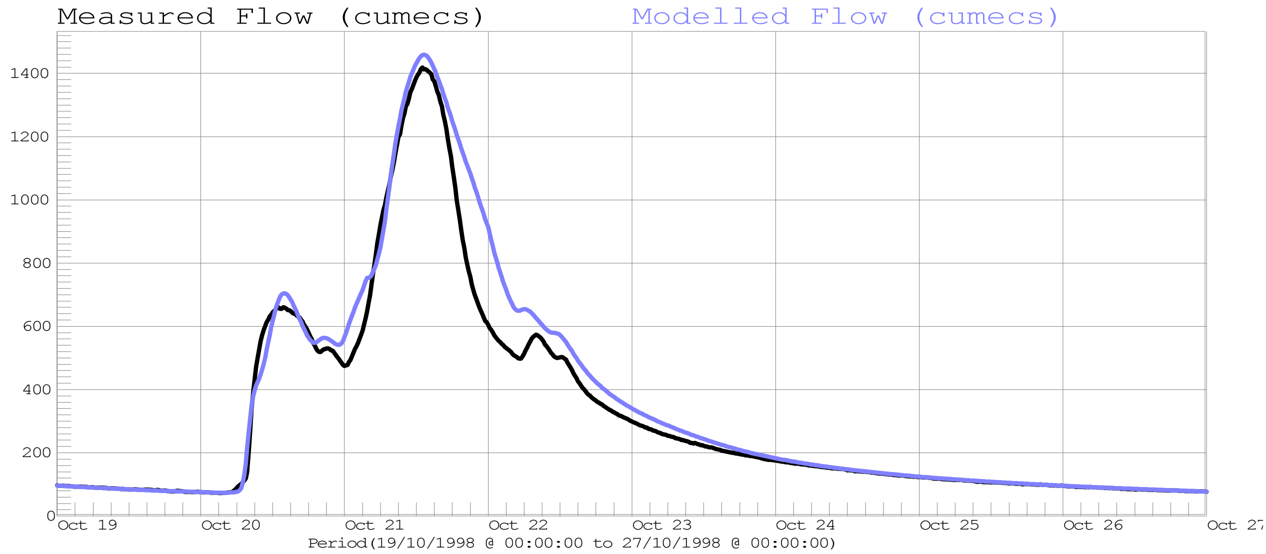


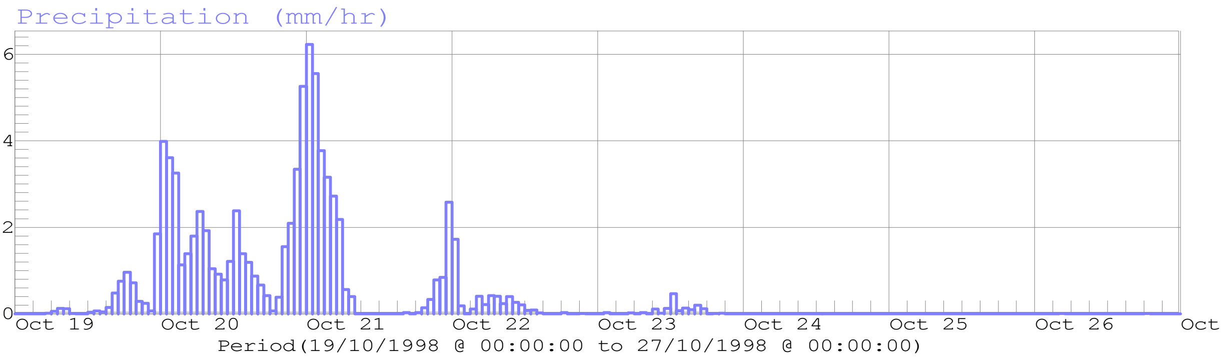
EVENT COMPARISON - MANAWATU @ UPPER GORGE

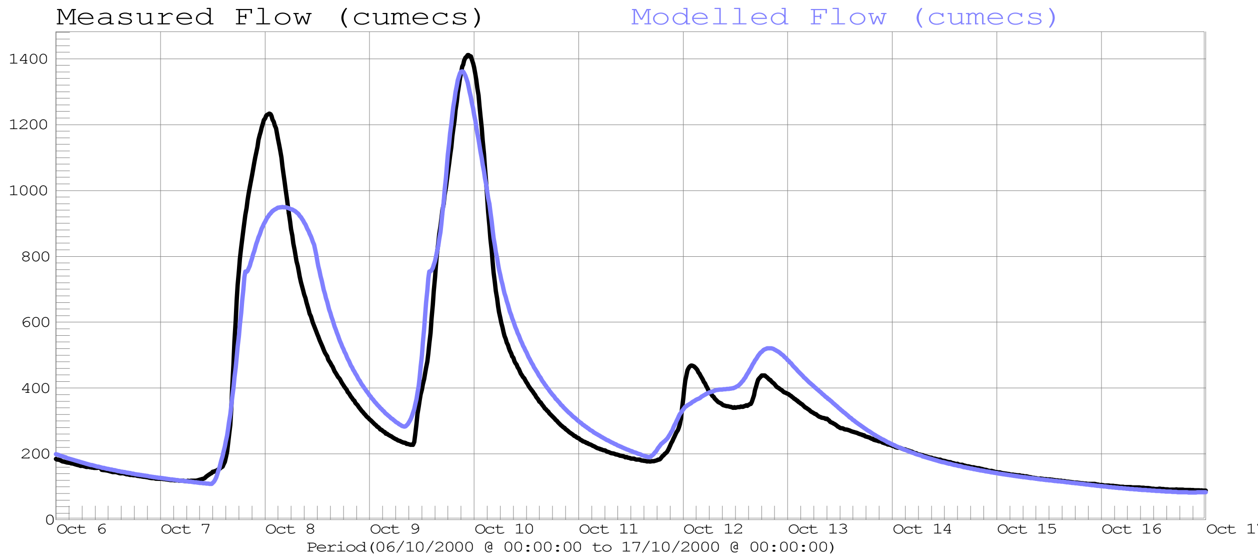


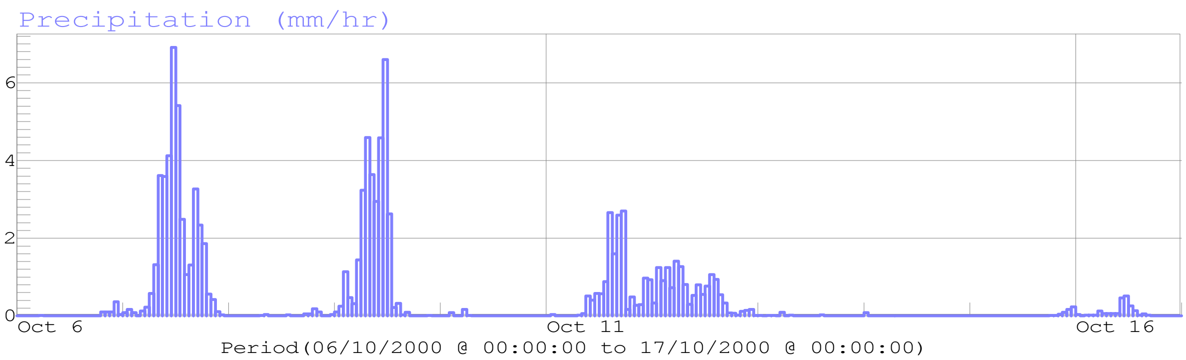


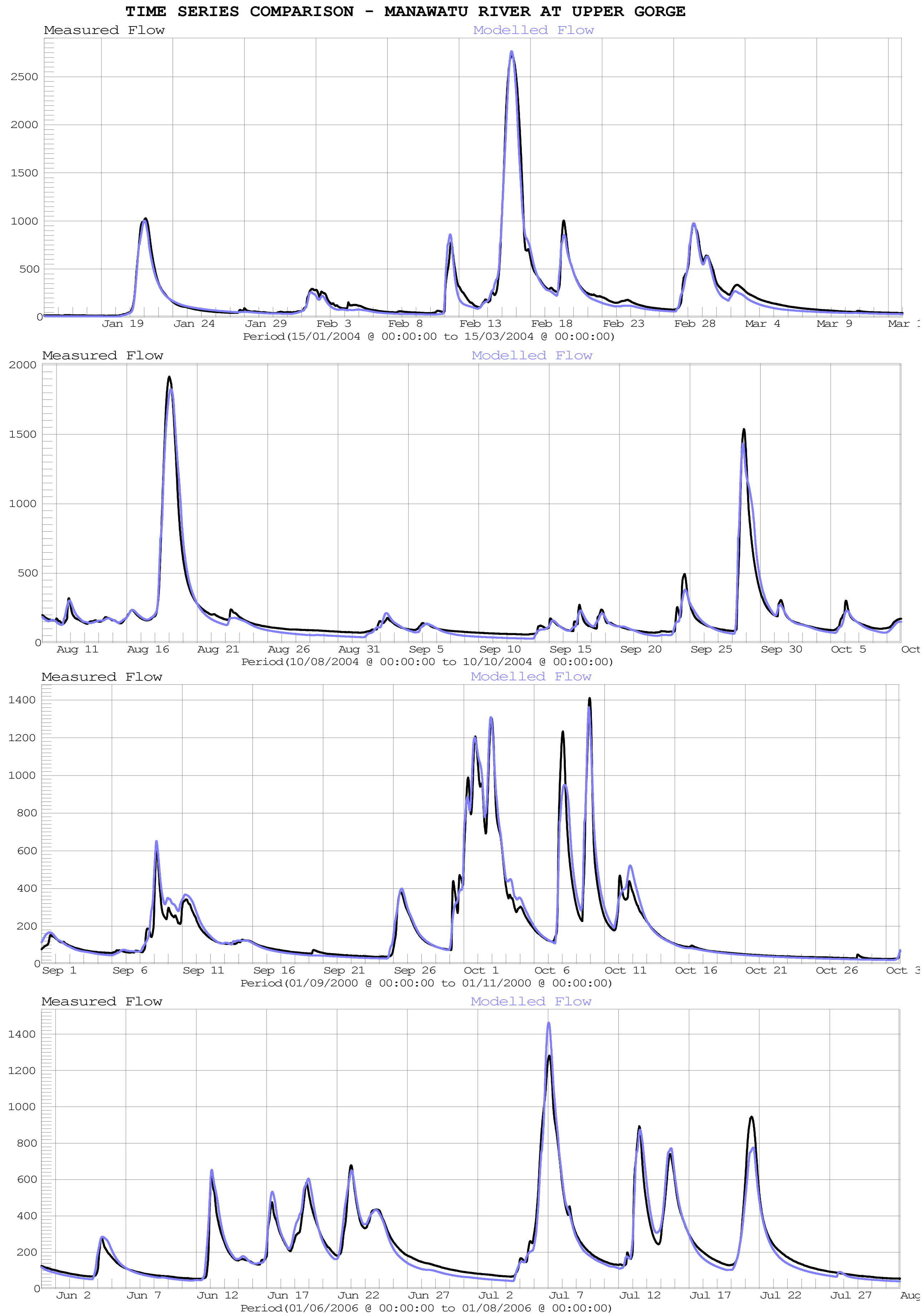
EVENT COMPARISON - MANAWATU @ UPPER GORGE










TIME SERIES COMPARISON - MANAWATU RIVER AT UPPER GORGE
Measured Flow
Modelled Flow
Period(15/01/2004 @ 00:00:00 to 15/03/2004 @ 00:00:00)
Measured Flow
Modelled Flow
Period(10/08/2004 @ 00:00:00 to 10/10/2004 @ 00:00:00)
Measured Flow
Modelled Flow
Period(01/09/2000 @ 00:00:00 to 01/11/2000 @ 00:00:00)
Measured Flow
Modelled Flow
Period(01/06/2006 @ 00:00:00 to 01/08/2006 @ 00:00:00)

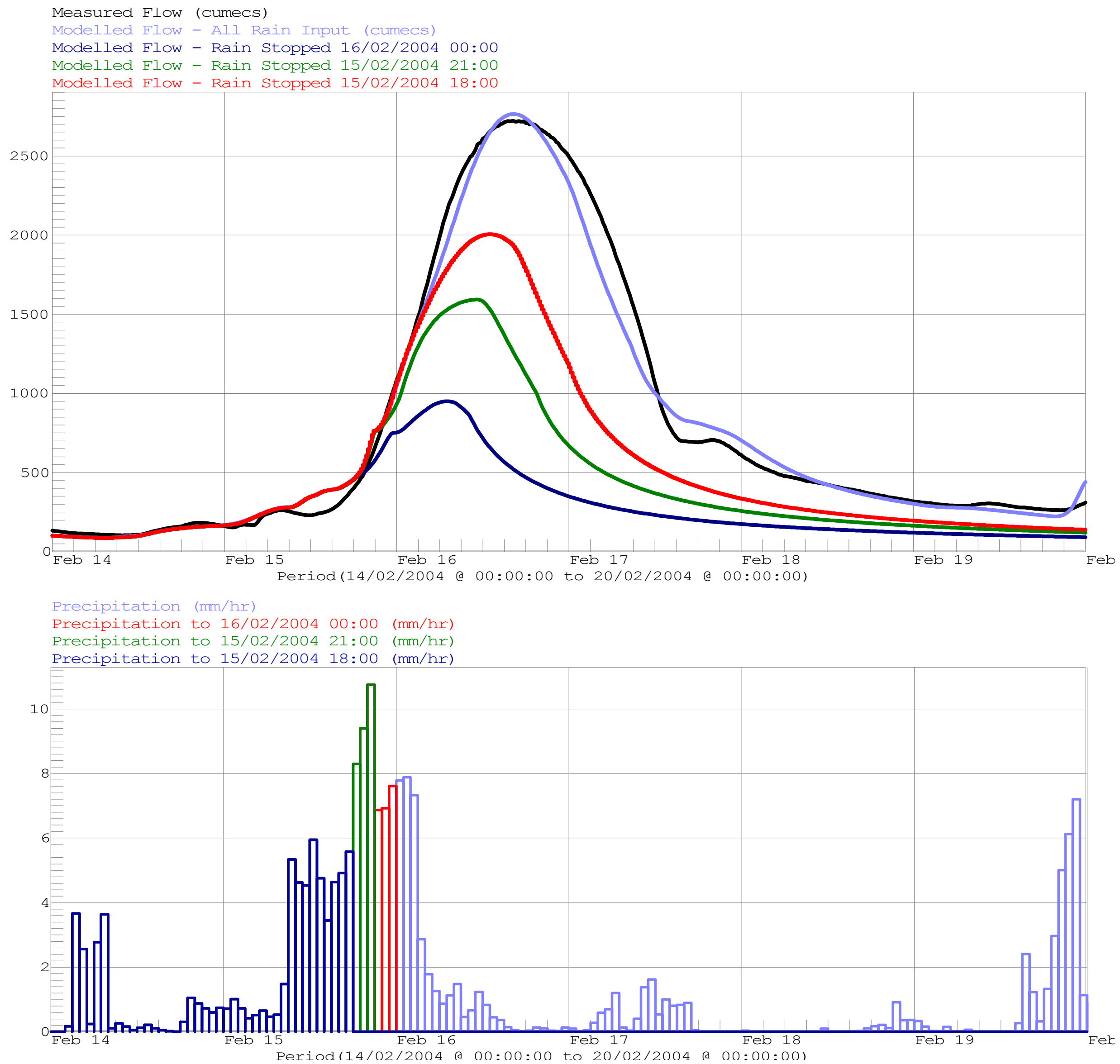


Figure 6-4: Achievable Lead-Time at Upper Gorge if Input Rain is set to Zero at Varying Times During the Feb 2004 Event.

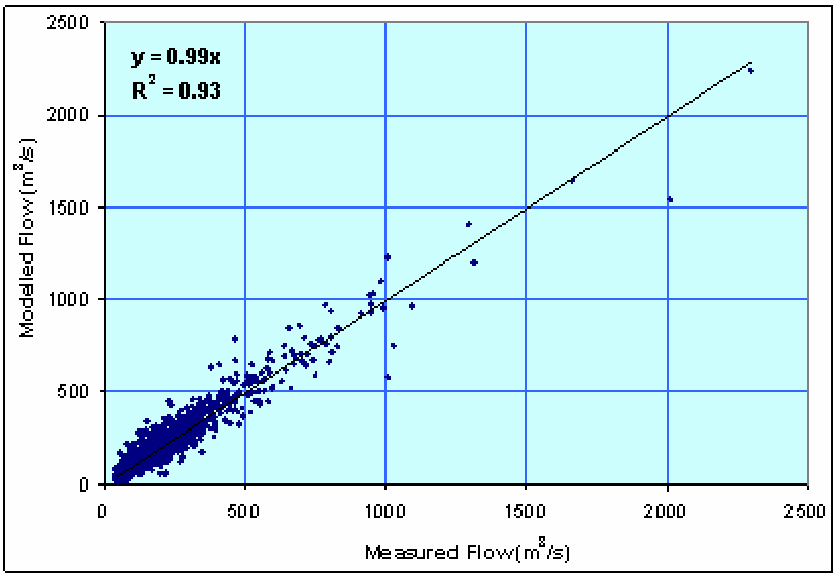


Figure 6-5: Modelled vs Measured Scatter Plot Showing Goodness of fit at Manawatu at Upper Gorge

6.3 CALIBRATION RESULTS - MANAWATU RIVER AT WEBER RD

Results for Manawatu at Weber Rd have been produced using record from 2004 which was the period of available data. The site has been identified as having some issues with the upper end of its rating, potentially over-estimating in the upper end by around 10%. This has been taken into consideration when calibrating at this site.

The modelled results at the Mangatoro river gauge were investigated and found to be much lower than the measured flows. To achieve a good fit the rainfall had to be scaled by an additional 60%. Because site data was only available from 2006, little emphasis was given to this site and an overall calibration at Weber Rd was given priority.

Chinese Standards Performance Indicators:

QR = 100% CD = 0.87 Accuracy Grading = B

Recommendation: Suitable for making official forecasts.

Measured Flow Volume = 1782 Mm^3
Modelled Flow Volume = 2059 Mm^3

Table 6-4: Calibration Event Details – Manawatu at Weber Rd

	Event Start	Event Finish	Measured Peak Flow (m3/s)	Modelled Peak Flow (m3/s)	Difference (%)	Measured Volume (Mm3)	Modelled Volume (Mm3)	Difference (%)	Rainfall Volume (Mm3)	Measured Runoff Coeff	Modelled Runoff Coeff
1	15/02/2004 @ 00:00	19/02/2004 @ 00:00	1299.05	1189.81	-8.41	111.73	92.47	-17.24	118.07	0.95	0.78
2	17/10/2004 @ 12:00	21/10/2004 @ 00:00	714.78	681.19	-4.70	40.37	36.27	-10.16	37.34	1.08	0.97
3	17/08/2004 @ 00:00	22/08/2004 @ 00:00	761.15	758.61	-0.33	76.64	72.20	-5.80	59.05	1.30	1.22
4	20/01/2004 @ 00:00	25/01/2004 @ 00:00	615.12	622.43	1.19	54.09	58.90	8.89	108.30	0.50	0.54
5	19/07/2006 @ 12:00	24/07/2006 @ 00:00	408.56	342.89	-16.07	44.33	36.73	-17.14	38.42	1.15	0.96
6	04/07/2006 @ 00:00	11/07/2006 @ 00:00	633.15	628.25	-0.77	65.41	62.60	-4.29	72.12	0.91	0.87
7	20/10/2005 @ 00:00	25/10/2005 @ 00:00	412.86	340.03	-17.64	39.28	33.16	-15.57	47.21	0.83	0.70
	Average				-6.68			-8.76		0.96	0.86

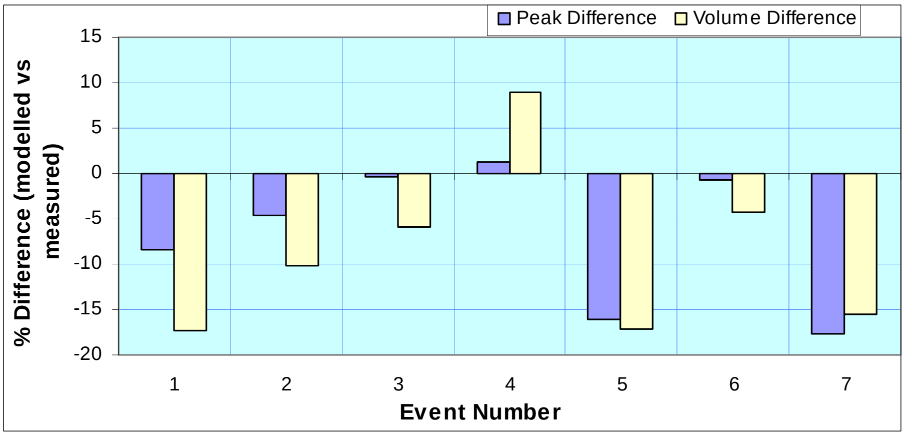


Figure 6-6: Modelled vs Measured Event Differences – Manawatu at Weber Rd

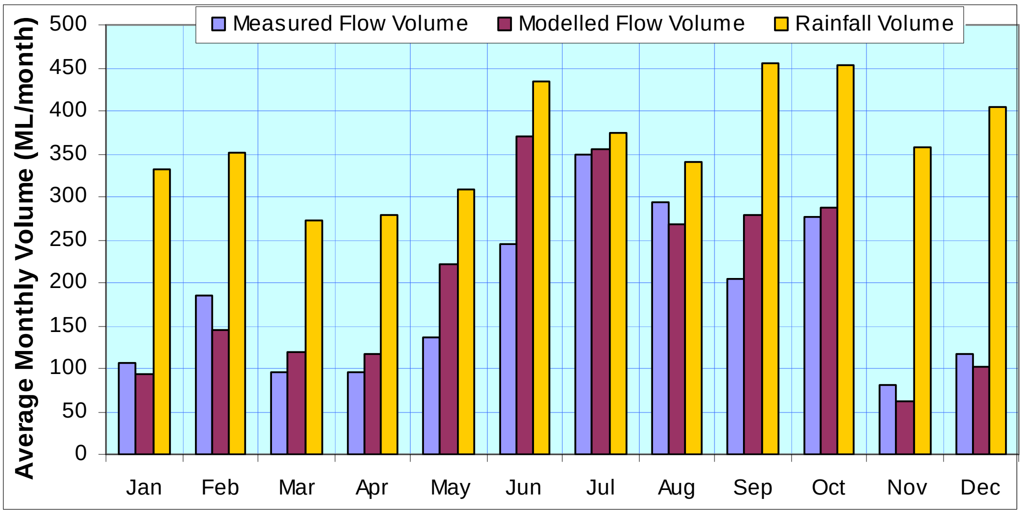
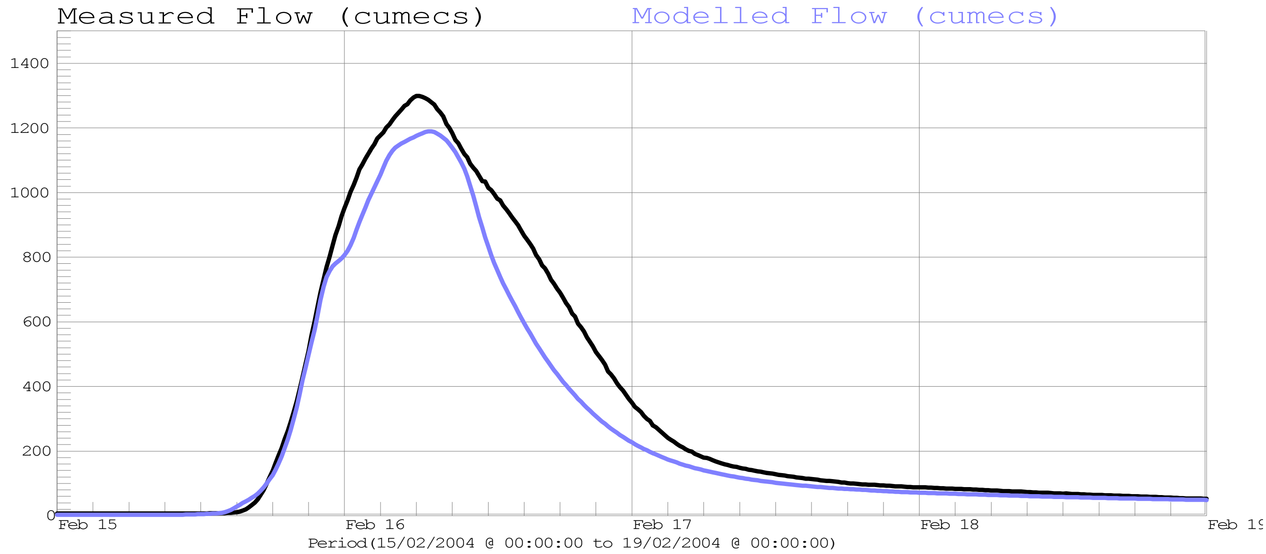
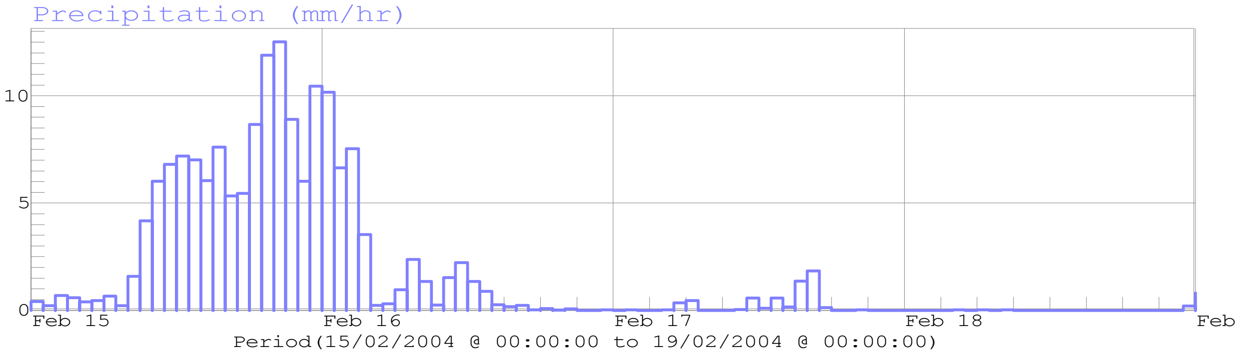
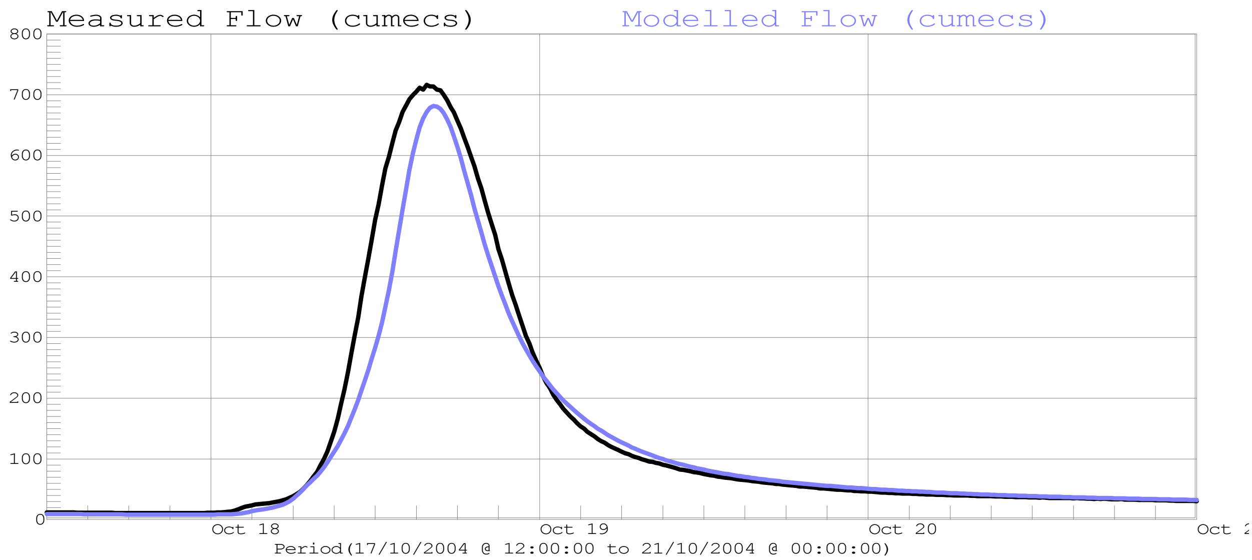


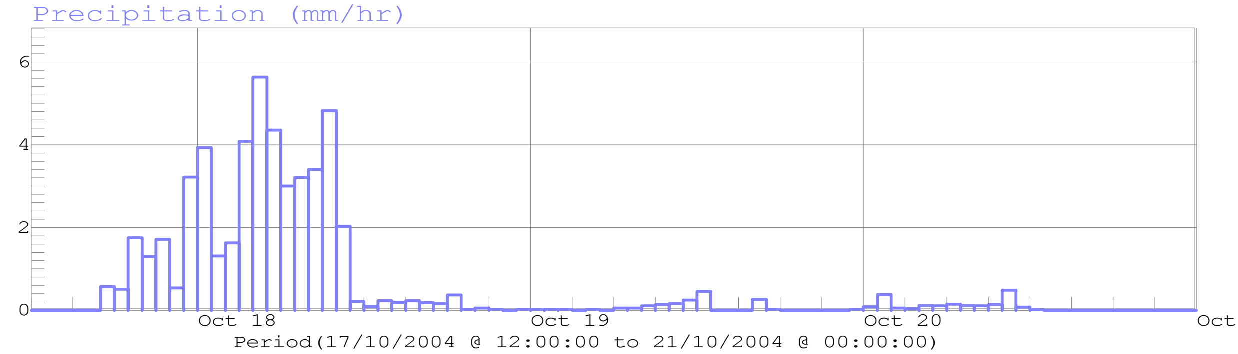
Figure 6-7: Monthly Average Volumes – Manawatu at Weber Rd

EVENT COMPARISON - MANAWATU AT WEBER RD

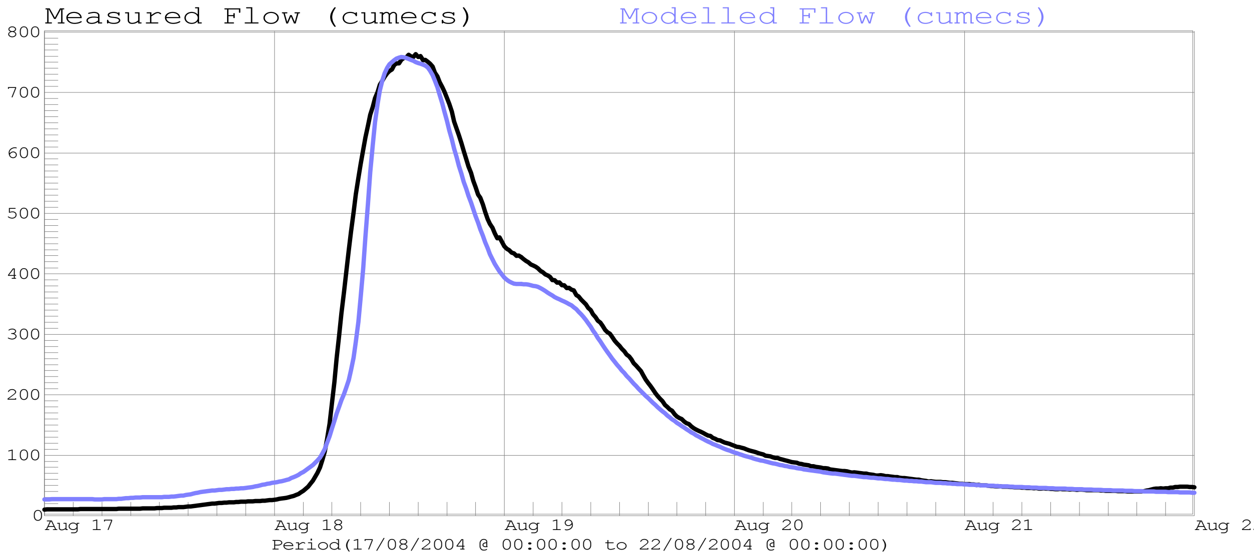


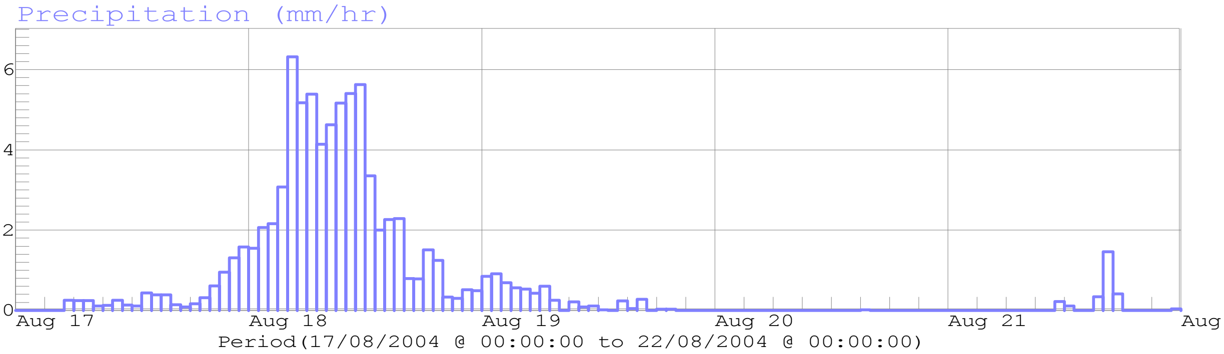


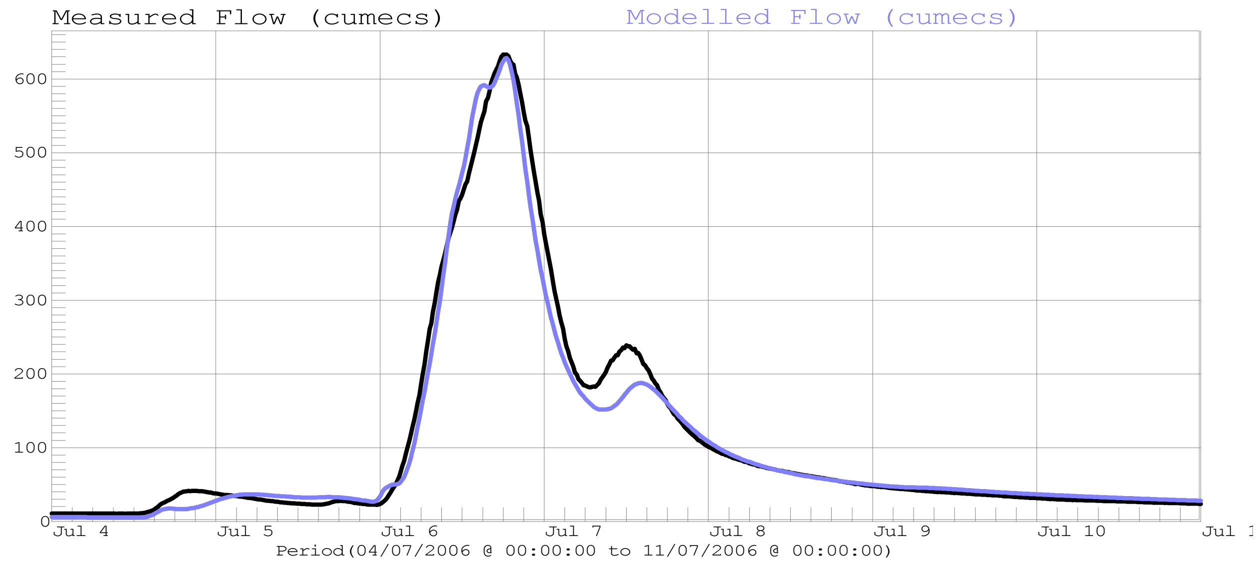


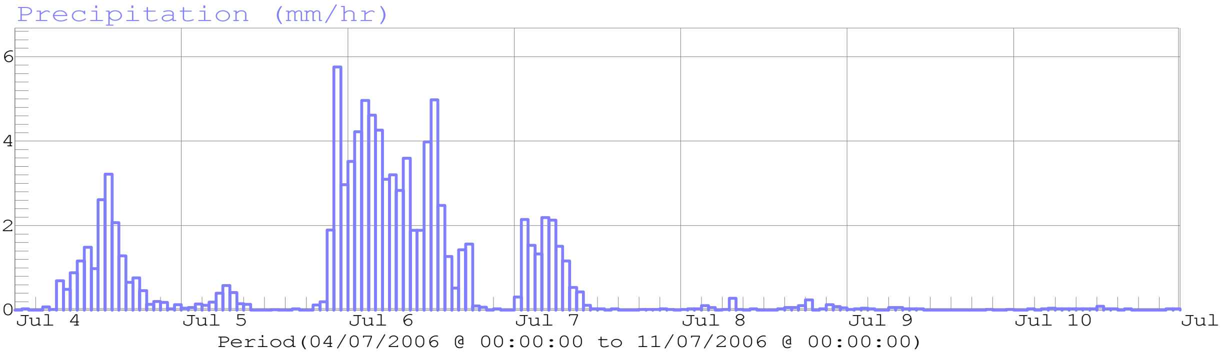


EVENT COMPARISON - MANAWATU AT WEBER RD

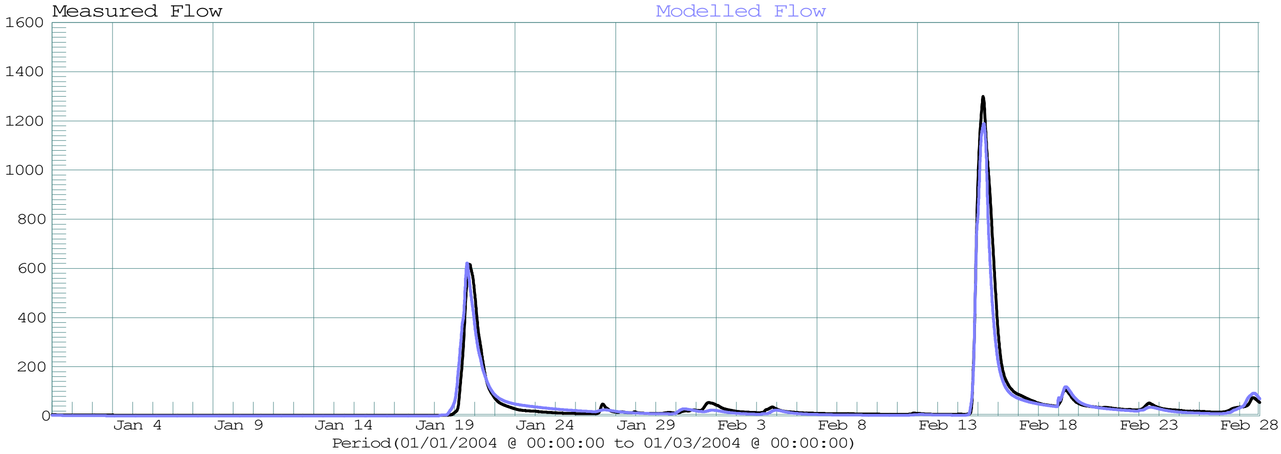


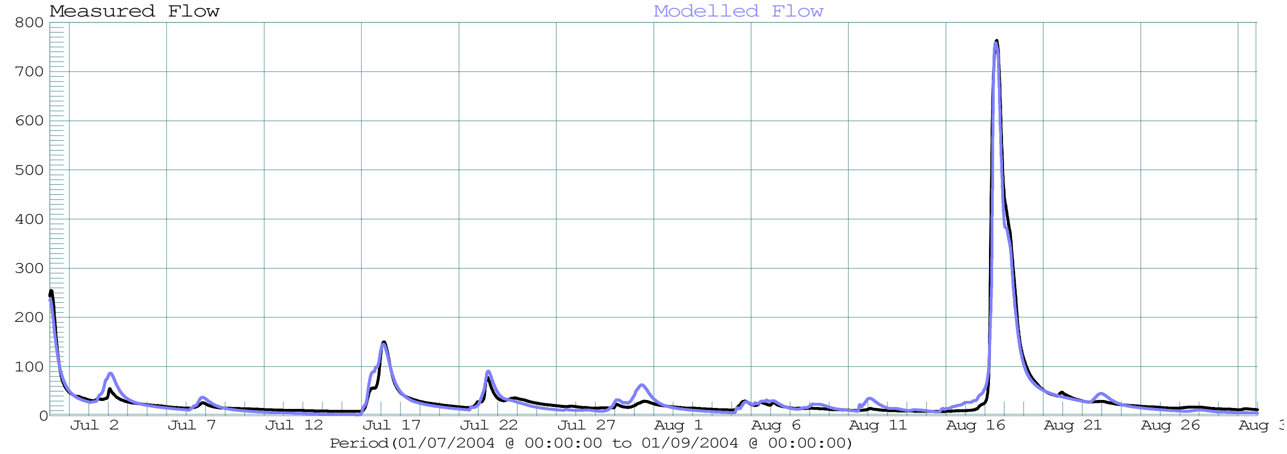


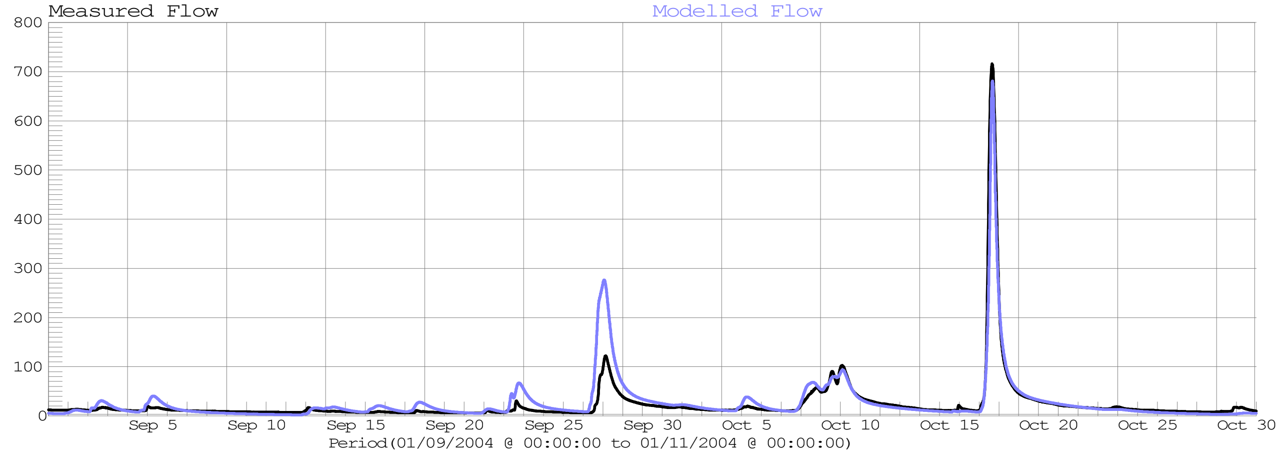


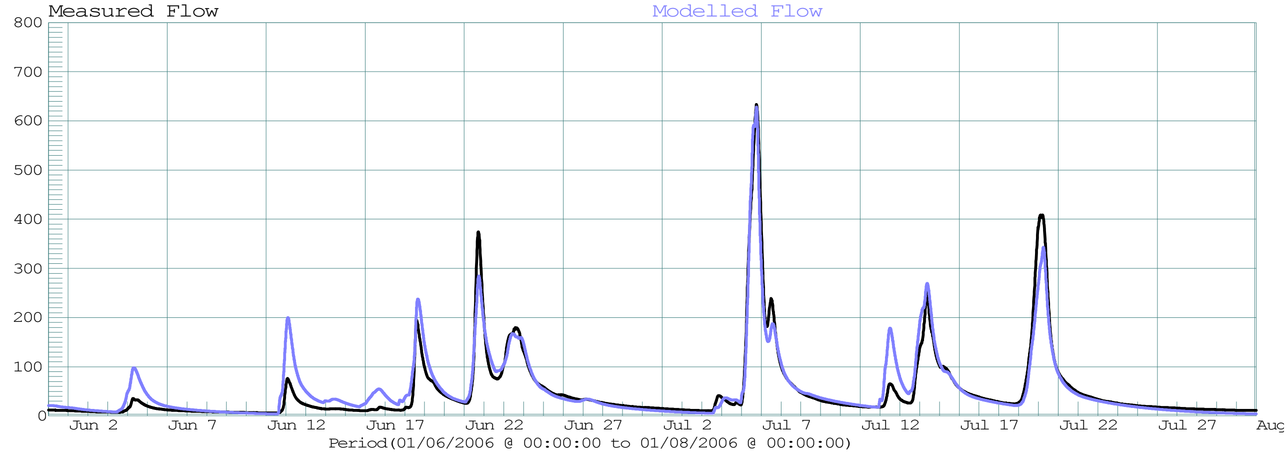


TIME SERIES COMPARISON - MANAWATU RIVER AT WEBER RD









6.4 CALIBRATION RESULTS - MANAWATU RIVER AT HOPELANDS

The rating at Hopelands was found to be over-estimating flows by about 4-5% in the upper end. This had little impact on the selection of calibration parameters at this site.

A time series comparison plot is provided for the Tamaki at Stephensons, as a regional set of parameters was adopted for this part of the catchment given its unique catchment response (as discussed during the September 2007 site visit).

Chinese Standards Performance Indicators:

From 1991: QR = 73% CD = 0.85 Accuracy Grading = B

From 2000: QR = 100% CD = 0.87 Accuracy Grading = B

Recommendation: Suitable for making official forecasts.

Measured Flow Volume = 14,019 Mm^3 (from 1991) 6,284 Mm^3 (from 2000)
Modelled Flow Volume = 14,759 Mm^3 (from 1991) 6,334 Mm^3 (from 2000)

Tamaki at Stephensons:

Run time: 01/01/2005 – 01/01/2007

CD (R^2) = 0.84

Measured Flow Volume = 213 Mm^3
Modelled Flow Volume = 211 Mm^3

Table 6-5: Calibration Event Details – Manawatu at Hopelands

	Event Start	Event Finish	Measured Peak Flow (m3/s)	Modelled Peak Flow (m3/s)	Difference (%)	Measured Volume (Mm3)	Modelled Volume (Mm3)	Difference (%)	Rainfall Volume (Mm3)	Measured Runoff Coeff	Modelled Runoff Coeff
1	14/02/2004 @ 00:00	21/02/2004 @ 00:00	1668.67	1642.32	-1.58	176.74	177.57	0.47	286.63	0.62	0.62
2	21/07/1992 @ 12:00	26/07/1992 @ 00:00	1654.06	1234.24	-25.38	118.52	110.16	-7.06	146.97	0.81	0.75
3	17/08/2004 @ 00:00	24/08/2004 @ 00:00	996.98	1018.67	2.18	123.96	121.14	-2.27	145.07	0.85	0.84
4	08/04/1991 @ 00:00	16/04/1991 @ 00:00	702.24	1230.21	75.18	88.01	139.56	58.57	209.05	0.42	0.67
5	27/11/1999 @ 12:00	04/12/1999 @ 00:00	1004.51	1061.14	5.64	110.48	135.26	22.42	211.34	0.52	0.64
6	01/06/1997 @ 00:00	08/06/1997 @ 00:00	834.38	921.03	10.38	88.24	104.54	18.48	125.75	0.70	0.83
7	17/10/2004 @ 18:00	23/10/2004 @ 00:00	786.63	746.87	-5.05	66.15	61.53	-6.98	86.81	0.76	0.71
8	04/07/2006 @ 00:00	11/07/2006 @ 00:00	783.90	865.06	10.35	109.42	105.53	-3.56	139.09	0.79	0.76
9	14/08/2001 @ 00:00	20/08/2001 @ 00:00	748.58	822.94	9.93	83.74	82.43	-1.56	119.79	0.70	0.69
10	24/07/1994 @ 00:00	29/07/1994 @ 00:00	772.85	777.81	0.64	73.79	83.59	13.28	110.11	0.67	0.76
11	02/11/1991 @ 06:00	09/11/1991 @ 06:00	698.07	656.20	-6.00	90.94	89.16	-1.96	143.19	0.64	0.62
12	19/01/2004 @ 00:00	26/01/2004 @ 00:00	694.40	804.48	15.85	74.82	88.57	18.38	207.66	0.36	0.43
13	04/04/1995 @ 00:00	15/04/1995 @ 00:00	554.98	649.16	16.97	105.01	144.95	38.04	213.89	0.49	0.68
14	20/08/2003 @ 18:00	30/08/2003 @ 00:00	538.29	501.04	-6.92	109.62	111.95	2.13	146.21	0.75	0.77
15	11/02/2002 @ 00:00	18/08/2002 @ 00:00	525.02	423.08	-19.42	576.66	638.91	10.80	1098.97	0.52	0.58
	Average				*13.72*			*13.94*		*0.64*	*0.69*

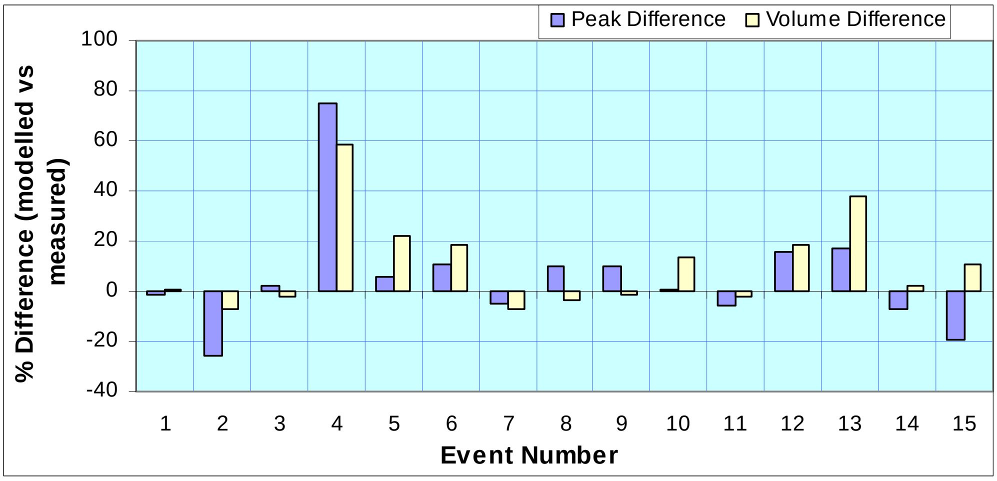


Figure 6-8: Modelled vs Measured Event Differences – Manawatu at Hopelands

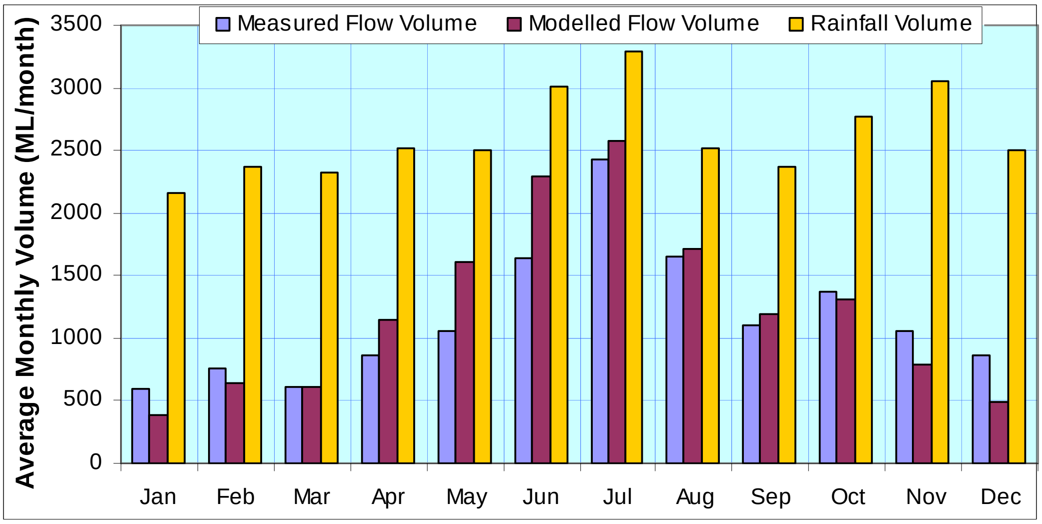
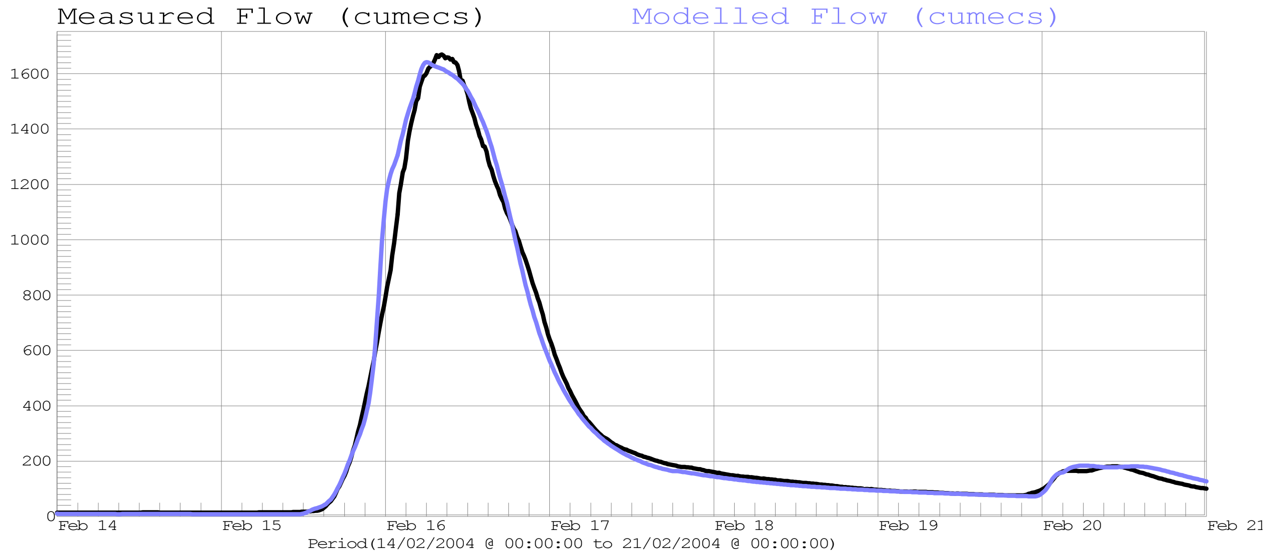
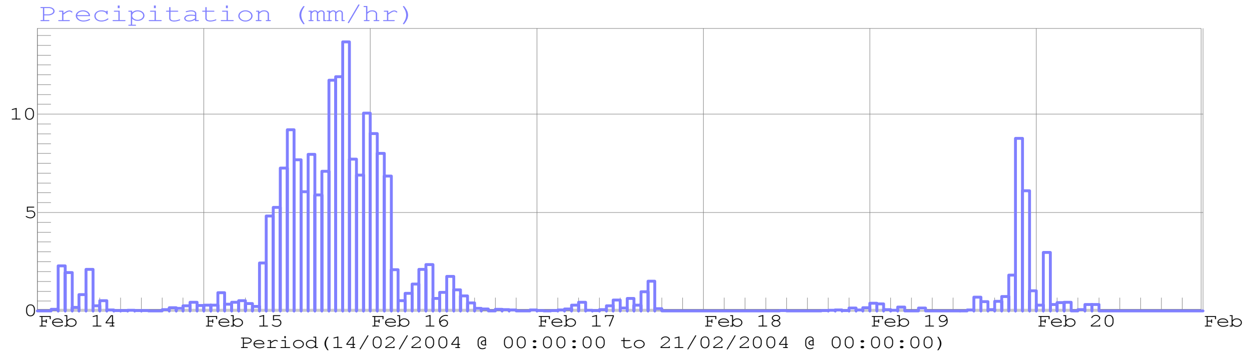
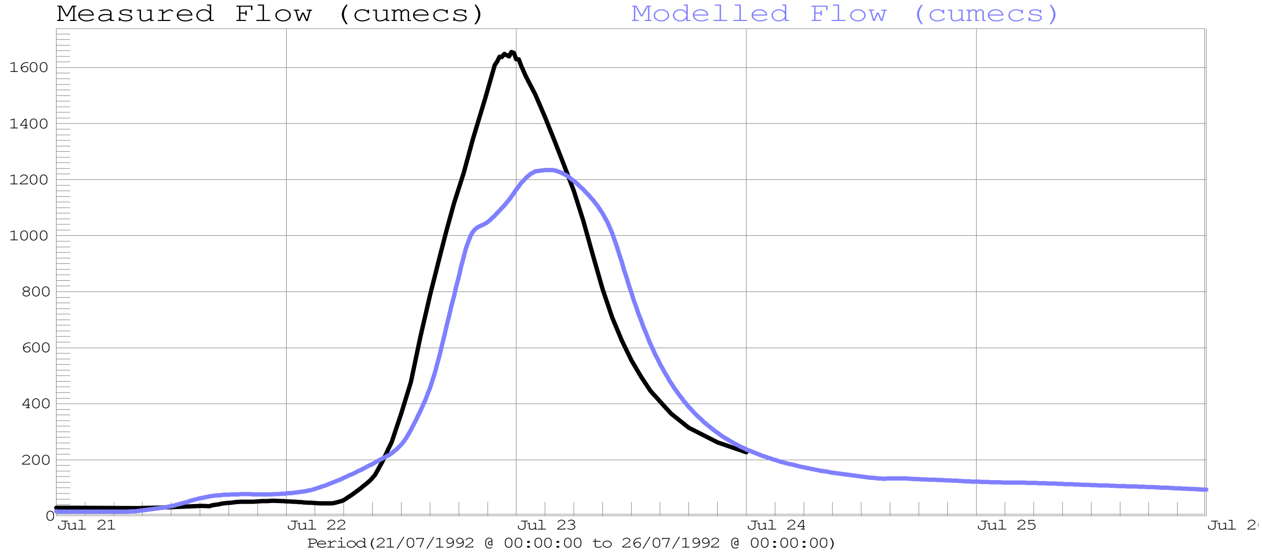


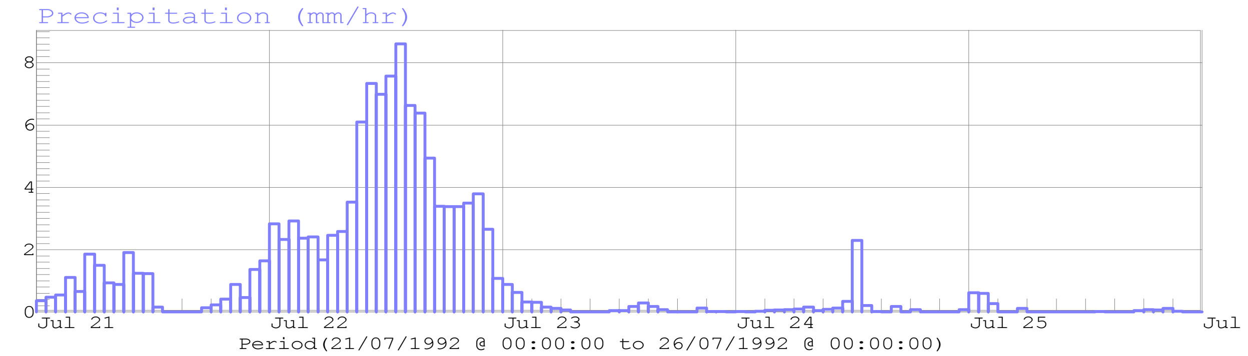
Figure 6-9: Monthly Average Volumes – Manawatu at Hopelands

EVENT COMPARISON - MANAWATU @ HOPELANDS

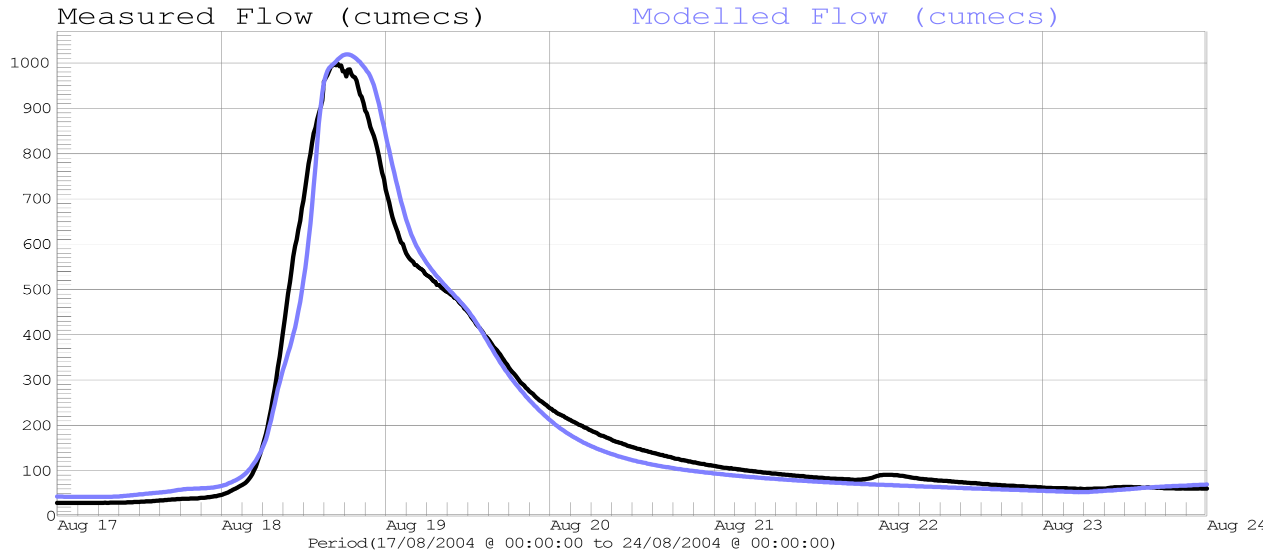


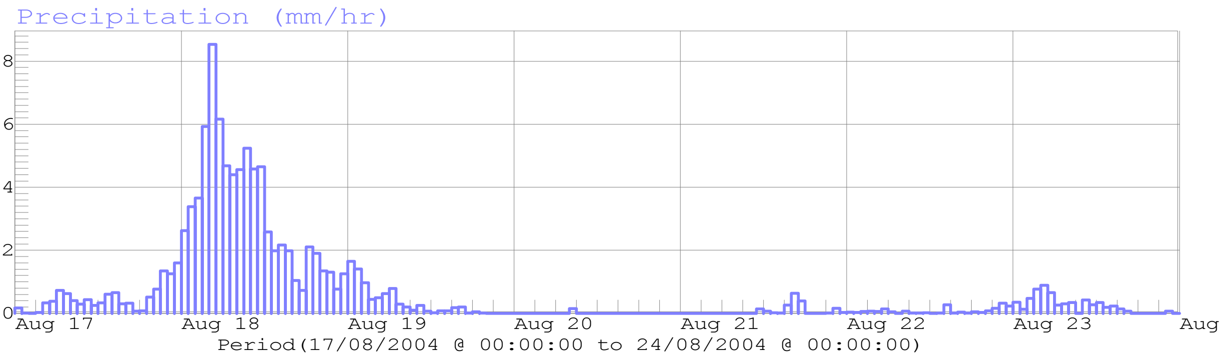


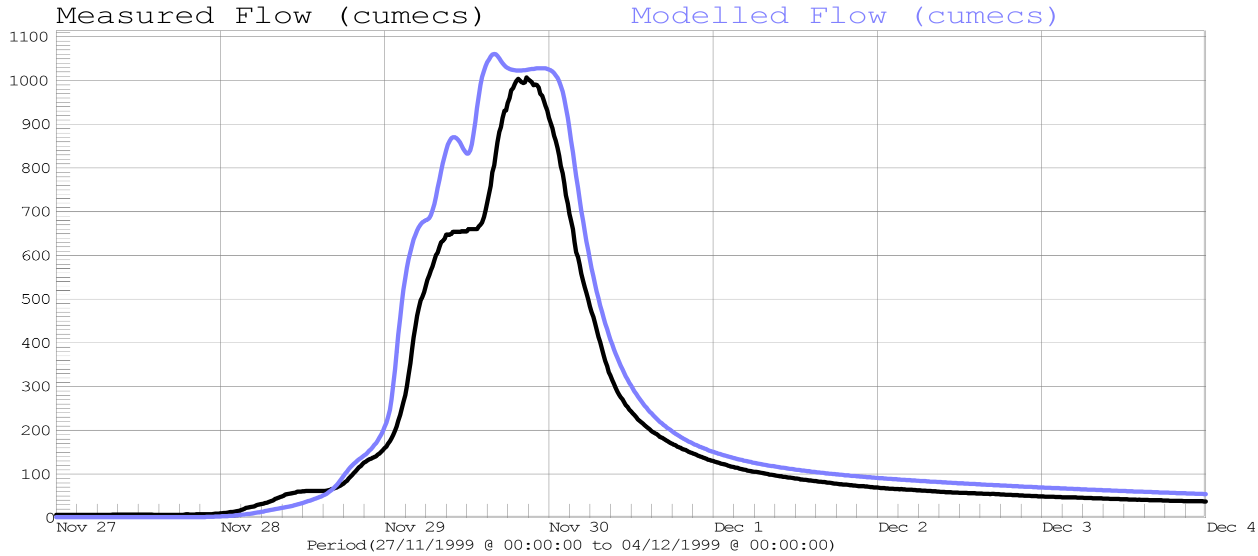


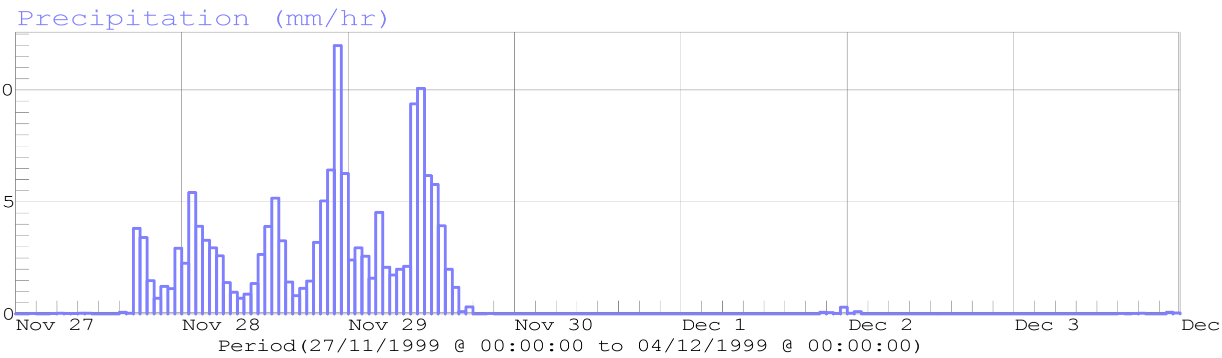


EVENT COMPARISON - MANAWATU @ HOPELANDS

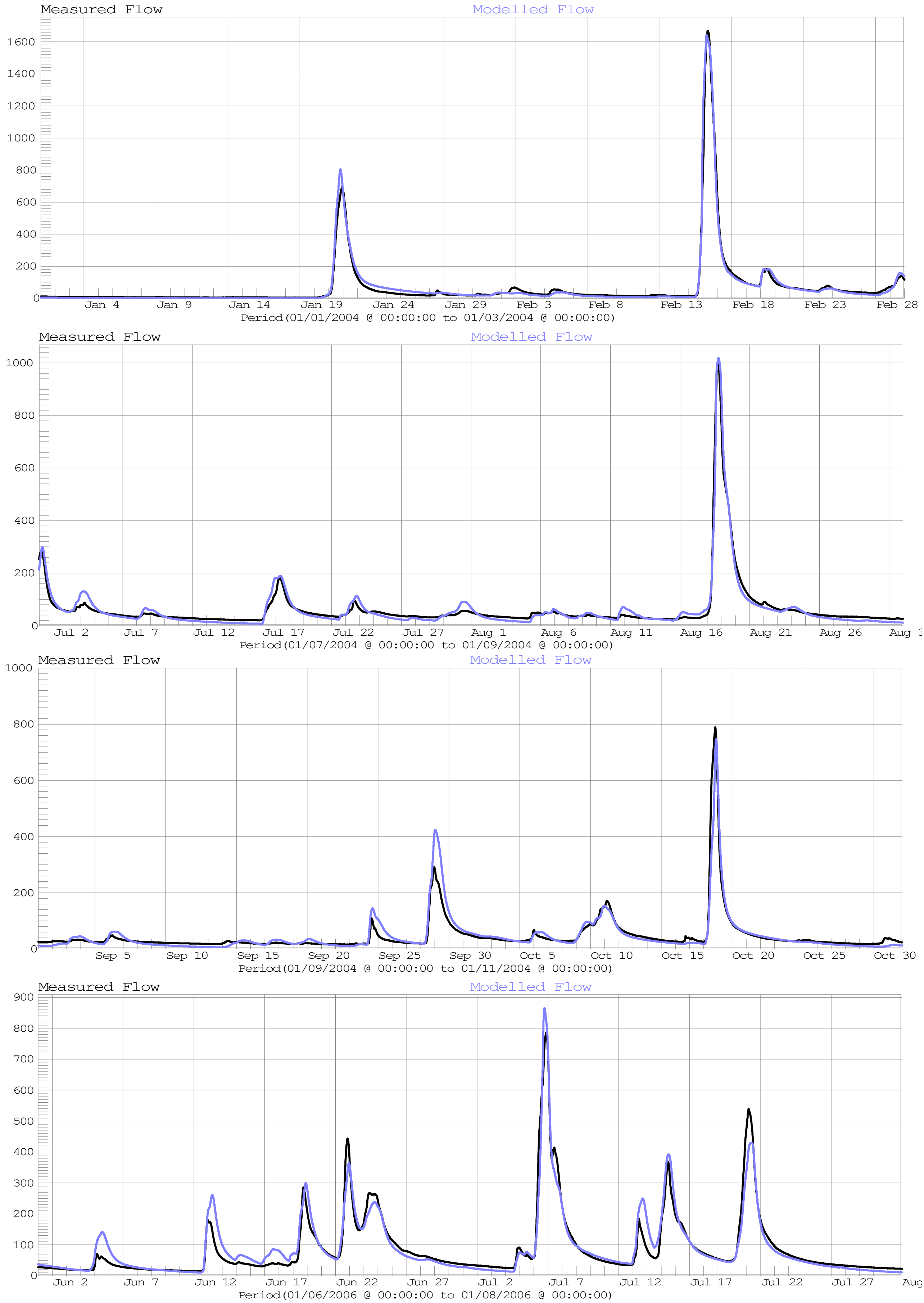


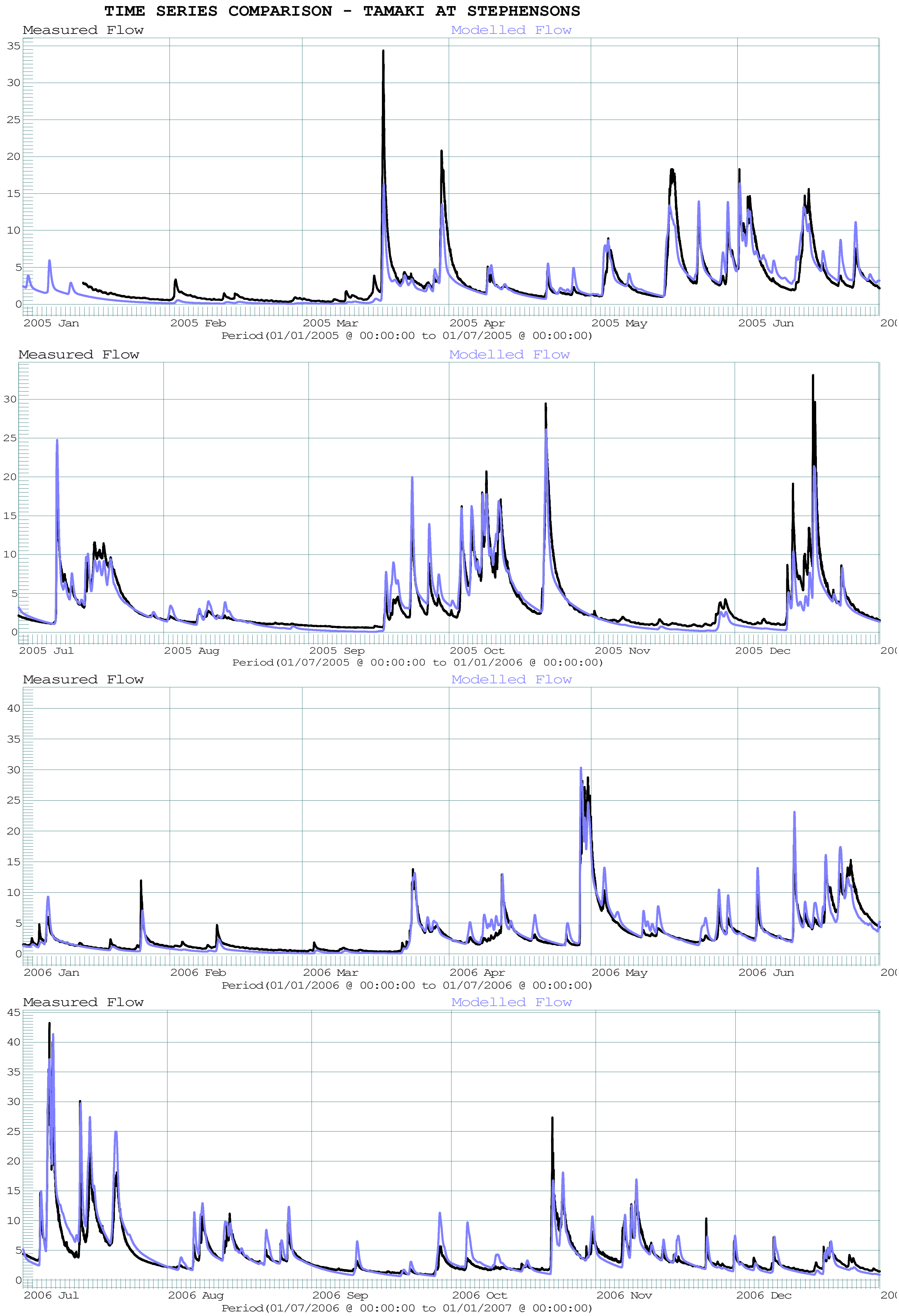






TIME SERIES COMPARISON - MANAWATU RIVER AT HOPELANDS




TIME SERIES COMPARISON - TAMAKI AT STEPHENSONS
Measured Flow
Modelled Flow
2005 Jan
2005 Feb
2005 Mar
2005 Apr
2005 May
2005 Jun
Period(01/01/2005 @ 00:00:00 to 01/07/2005 @ 00:00:00)
Measured Flow
Modelled Flow
2005 Jul
2005 Aug
2005 Sep
2005 Oct
2005 Nov
2005 Dec
Period(01/07/2005 @ 00:00:00 to 01/01/2006 @ 00:00:00)
Measured Flow
Modelled Flow
2006 Jan
2006 Feb
2006 Mar
2006 Apr
2006 May
2006 Jun
Period(01/01/2006 @ 00:00:00 to 01/07/2006 @ 00:00:00)
Measured Flow
Modelled Flow
2006 Jul
2006 Aug
2006 Sep
2006 Oct
2006 Nov
2006 Dec
Period(01/07/2006 @ 00:00:00 to 01/01/2007 @ 00:00:00)

6.5 CALIBRATION RESULTS - TIRAUMEA AT NGATURI

This catchment has produced some of the worst results. Parameters have been adopted to achieve a better outcome according to the Chinese Standards Performance Indicators but it can be seen in the % difference plot that there may be a bias towards an under-estimation of events. Due to the good overall calibration at Upper Gorge the calibration for Tiraumea has been finalised but future monitoring of the model performance will be beneficial.

Chinese Standards Performance Indicators:

From 1991: QR = 60% CD = 0.77 Accuracy Grading = C

From 2000: QR = 67% CD = 0.74 Accuracy Grading = C

Recommendation: Suitable for making reference forecasts.

Measured Flow Volume = 9,502 Mm^3 (from 1991) 4,104 Mm^3 (from 2000)
Modelled Flow Volume = 8,613 Mm^3 (from 1991) 3,754 Mm^3 (from 2000)

Table 6-6: Calibration Event Details – Tiraumea at Ngaturi

	Event Start	Event Finish	Measured Peak Flow (m3/s)	Modelled Peak Flow (m3/s)	Difference (%)	Measured Volume (Mm3)	Modelled Volume (Mm3)	Difference (%)	Rainfall Volume (Mm3)	Measured Runoff Coeff	Modelled Runoff Coeff
1	14/02/2004 @ 00:00	19/02/2004 @ 12:00	738.96	840.58	13.75	99.89	87.86	-12.04	122.22	0.82	0.72
2	08/04/1991 @ 12:00	15/04/1991 @ 00:00	730.50	524.07	-28.26	81.54	55.75	-31.63	99.66	0.82	0.56
3	17/08/2004 @ 12:00	22/08/2004 @ 00:00	669.54	752.12	12.33	82.60	86.81	5.09	74.29	1.11	1.17
4	21/07/1992 @ 06:00	26/07/1992 @ 00:00	644.26	597.59	-7.24	74.59	61.75	-17.22	67.18	1.11	0.92
5	12/10/1992 @ 18:00	21/10/1992 @ 00:00	546.79	342.44	-37.37	84.61	55.96	-33.86	77.53	1.09	0.72
6	27/09/2004 @ 12:00	03/10/2004 @ 00:00	279.22	299.22	7.16	36.97	38.85	5.10	47.06	0.79	0.83
7	14/08/2001 @ 00:00	19/08/2001 @ 12:00	418.49	289.20	-30.89	57.55	40.07	-30.37	65.23	0.88	0.61
8	29/09/2000 @ 12:00	06/10/2000 @ 12:00	298.90	348.80	16.69	66.12	68.00	2.84	78.02	0.85	0.87
9	19/01/2004 @ 12:00	25/01/2004 @ 00:00	275.42	141.86	-48.49	39.36	21.74	-44.77	79.46	0.50	0.27
10	19/07/2006 @ 12:00	27/07/2006 @ 00:00	346.81	223.62	-35.52	46.82	35.77	-23.60	34.23	1.37	1.05
11	06/10/2000 @ 18:00	17/10/2000 @ 00:00	337.44	282.96	-16.14	82.97	77.04	-7.15	80.77	1.03	0.95
12	28/09/2003 @ 00:00	03/10/2003 @ 06:00	316.10	415.77	31.53	47.33	58.37	23.32	64.65	0.73	0.90
13	14/07/2005 @ 00:00	25/07/2005 @ 00:00	283.25	236.24	-16.60	58.99	50.74	-13.99	64.20	0.92	0.79
14	04/07/2006 @ 00:00	12/07/2006 @ 00:00	339.10	359.27	5.95	69.30	62.67	-9.56	69.68	0.99	0.90
15	20/10/2006 @ 00:00	29/10/2006 @ 00:00	279.03	285.23	2.22	63.10	63.04	-0.09	77.22	0.82	0.82
	Average				*22.00*			*18.61*		*0.92*	*0.81*

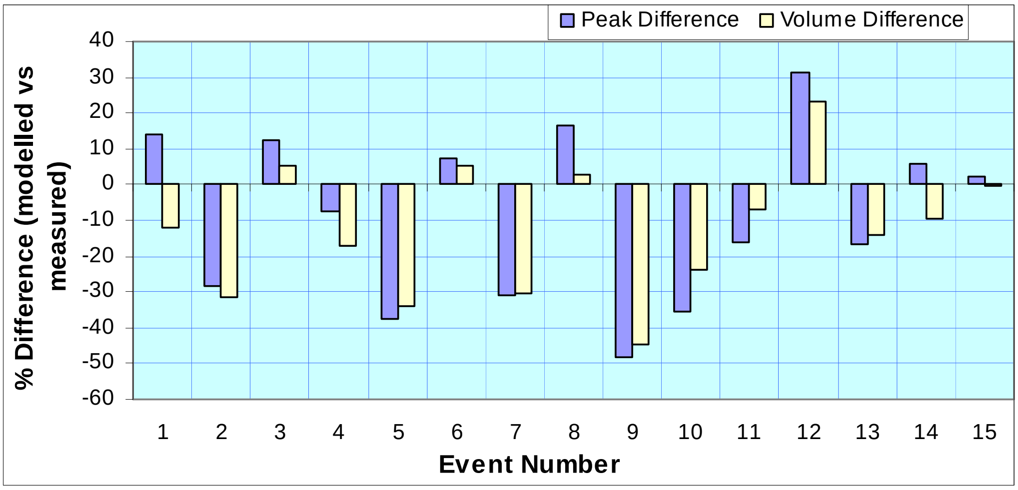


Figure 6-10: Modelled vs Measured Event Differences – Tiraumea at Ngaturi

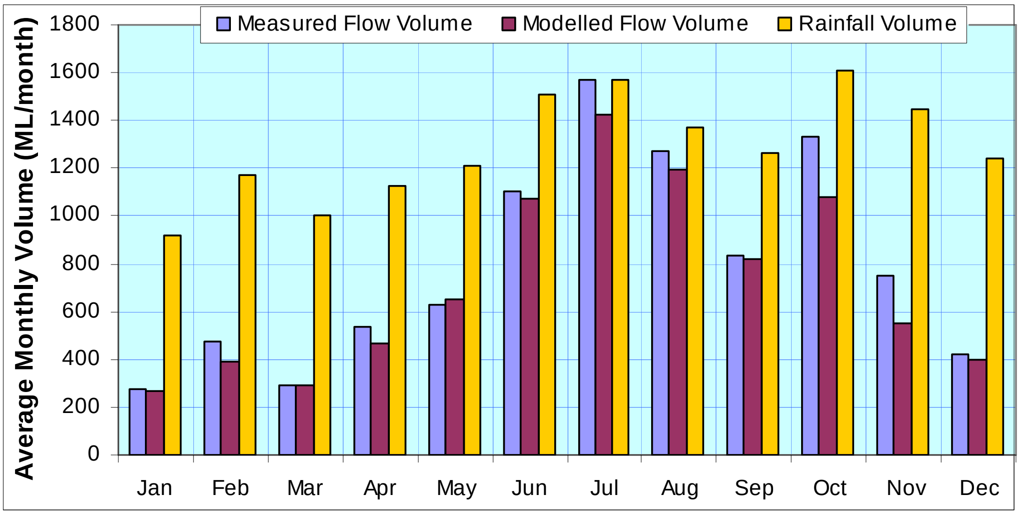
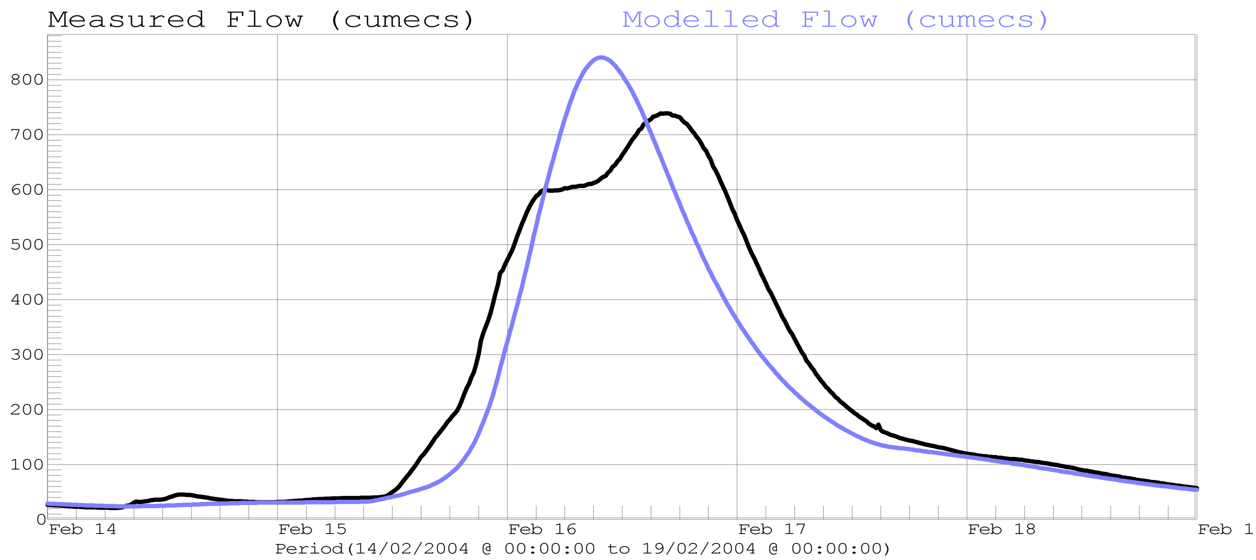
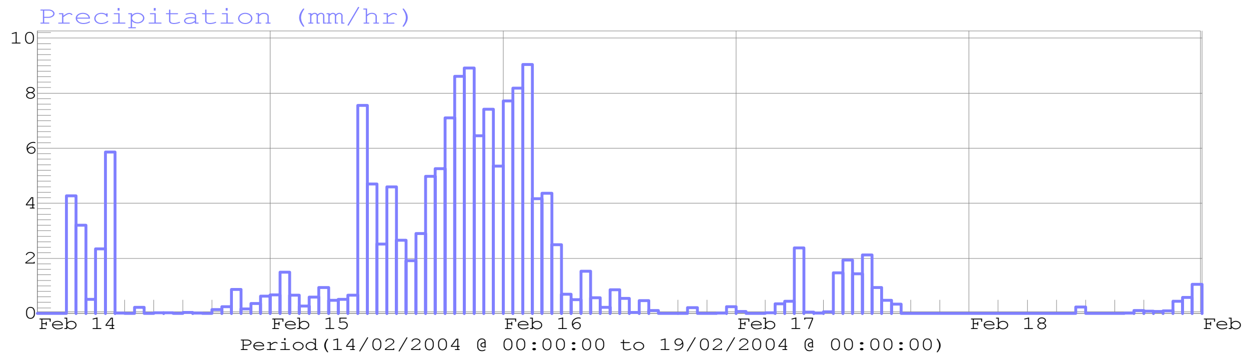
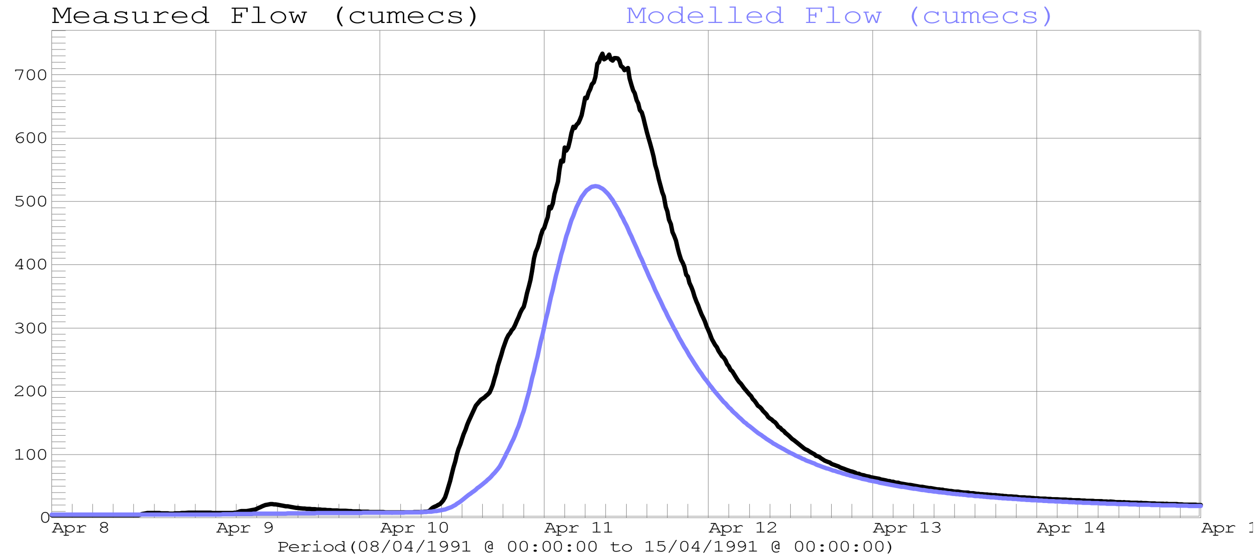


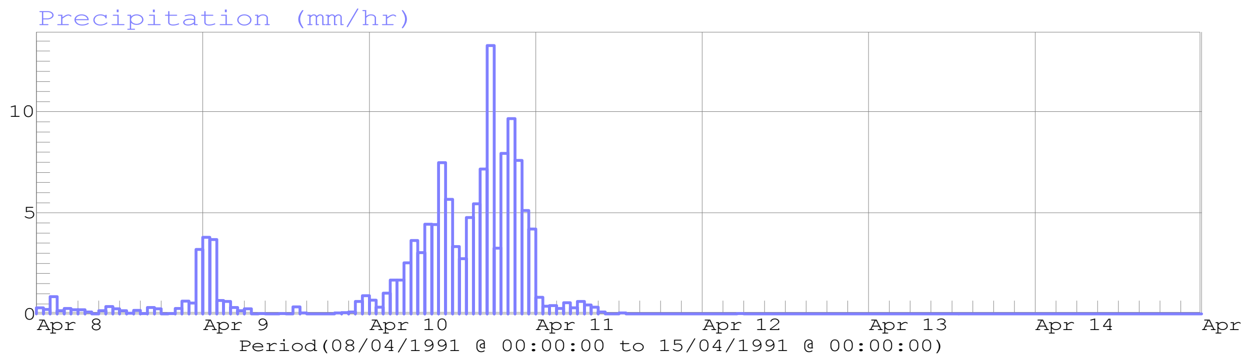
Figure 6-11: Monthly Average Volumes – Tiraumea at Ngaturi

EVENT COMPARISON - TIRAUMEA @ NGATURI

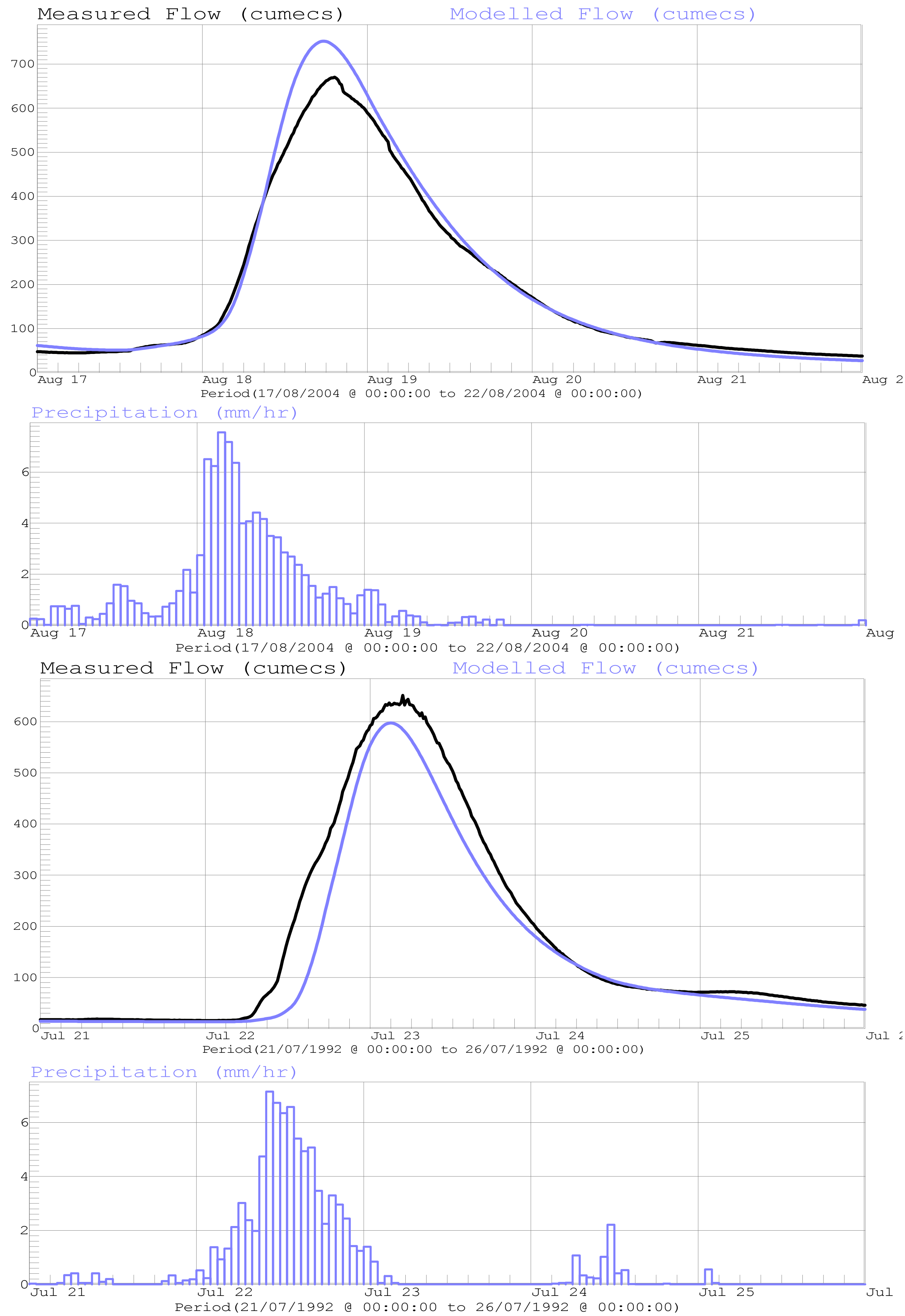




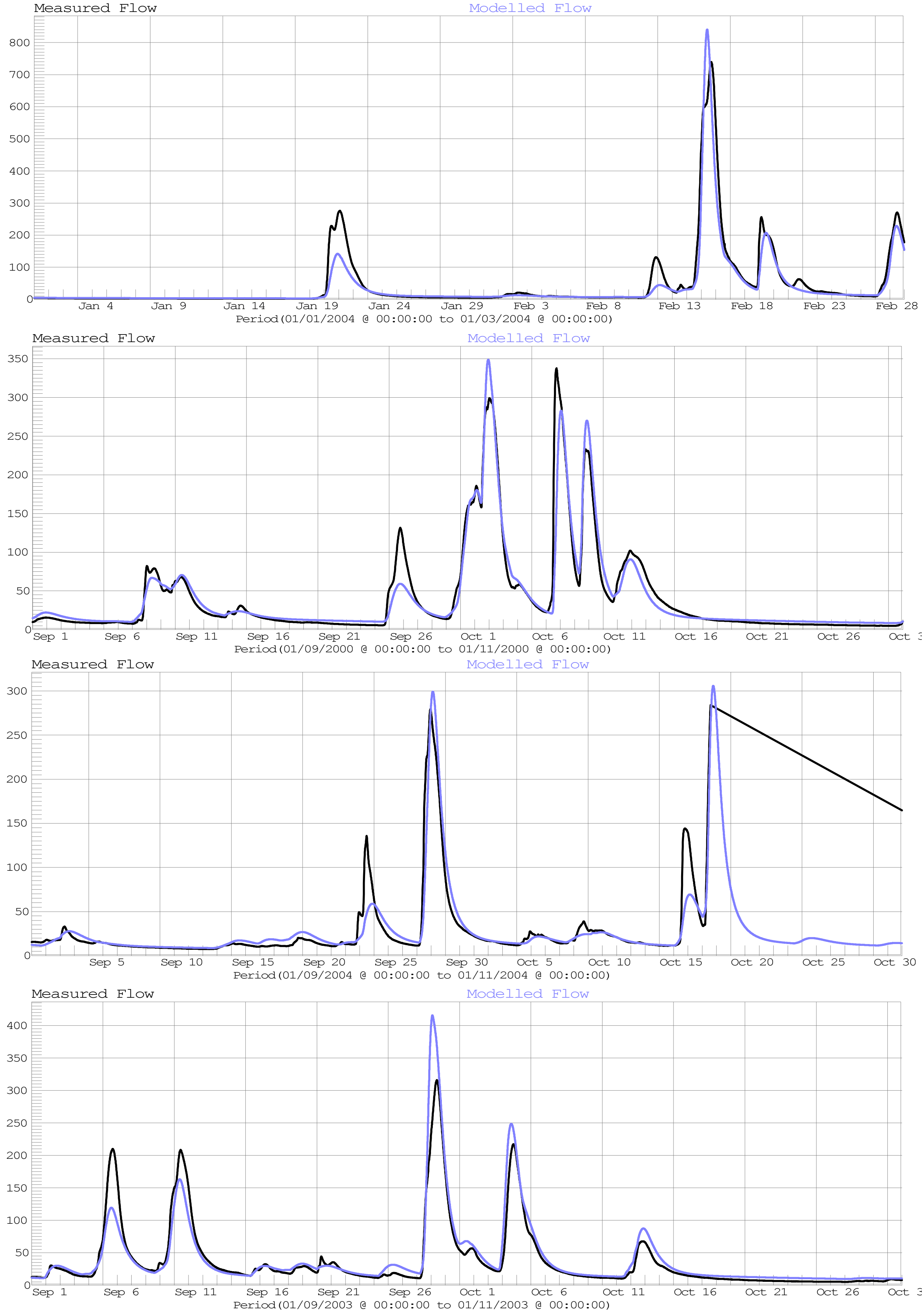




EVENT COMPARISON - TIRAUMEA @ NGATURI



TIME SERIES COMPARISON - TIRAUMEA



6.6 CALIBRATION RESULTS - MAKAKAHI AT HAMUA

Chinese Standards Performance Indicators:

From 1991: QR = 80% CD = 0.88 Accuracy Grading = B

From 2000: QR = 85% CD = 0.90 Accuracy Grading = A

Recommendation: Suitable for making official forecasts.

Measured Flow Volume = 4,104 Mm^3 (from 1991) 1,450 Mm^3 (from 2000)
Modelled Flow Volume = 3,754 Mm^3 (from 1991) 1,503 Mm^3 (from 2000)

Table 6-7: Calibration Event Details – Makakahi at Hamua

	Event Start	Event Finish	Measured Peak Flow (m3/s)	Modelled Peak Flow (m3/s)	Difference (%)	Measured Volume (Mm3)	Modelled Volume (Mm3)	Difference (%)	Rainfall Volume (Mm3)	Measured Runoff Coeff	Modelled Runoff Coeff
1	10/02/2004 @ 00:00	19/02/2004 @ 00:00	298.17	351.82	17.99	37.15	37.75	1.62	41.92	0.89	0.90
2	27/09/2004 @ 18:00	30/09/2004 @ 18:00	271.75	254.38	-6.39	13.47	14.11	4.75	14.25	0.95	0.99
3	10/04/1991 @ 00:00	14/04/1991 @ 00:00	167.49	276.09	64.84	13.70	13.92	1.61	15.18	0.90	0.92
4	09/10/2000 @ 00:00	11/10/2000 @ 00:00	481.70	393.25	-18.36	17.01	13.85	-18.58	11.97	1.42	1.16
5	22/07/1992 @ 00:00	26/07/1992 @ 00:00	174.67	163.20	-6.56	13.33	12.95	-2.80	12.54	1.06	1.03
6	25/07/2000 @ 00:00	01/08/2000 @ 00:00	187.54	159.03	-15.20	12.58	13.08	3.97	12.02	1.05	1.09
7	29/09/2002 @ 00:00	03/10/2002 @ 00:00	176.19	150.15	-14.78	10.47	10.47	0.00	10.82	0.97	0.97
8	29/09/2000 @ 06:00	06/10/2000 @ 12:00	311.03	288.88	-7.12	43.85	42.06	-4.08	38.65	1.13	1.09
9	27/02/2004 @ 00:00	04/03/2004 @ 00:00	212.38	243.87	14.83	18.20	18.35	0.80	21.81	0.83	0.84
10	17/08/2004 @ 00:00	21/08/2004 @ 00:00	162.67	174.92	7.53	15.29	15.65	2.33	12.97	1.18	1.21
11	26/11/2006 @ 00:00	29/11/2006 @ 12:00	220.56	131.73	-40.27	9.55	8.17	-14.43	8.47	1.13	0.97
12	01/10/2003 @ 00:00	07/10/2003 @ 00:00	209.37	243.38	16.24	20.05	22.33	11.41	17.03	1.18	1.31
13	04/01/2005 @ 12:00	08/01/2005 @ 00:00	168.28	169.51	0.73	8.47	8.82	4.09	11.91	0.71	0.74
14	14/10/2004 @ 12:00	18/10/2004 @ 00:00	203.22	255.46	25.70	11.49	12.43	8.19	15.41	0.75	0.81
15	27/07/2000 @ 00:00	31/07/2000 @ 00:00	187.54	159.03	-15.20	10.91	11.24	3.00	10.01	1.09	1.12
	Average				*18.12*			*5.44*		*1.02*	*1.01*

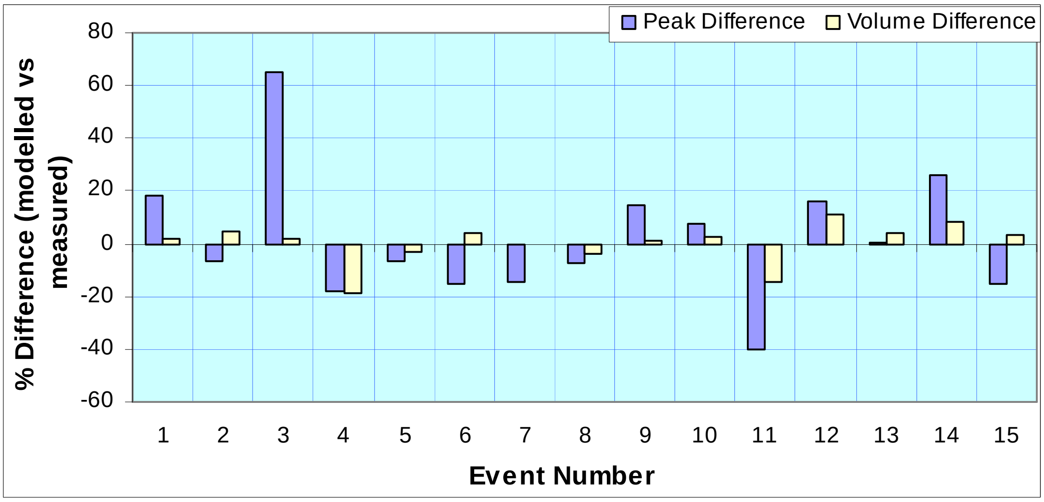


Figure 6-12: Modelled vs Measured Event Differences – Makakahi at Hamua

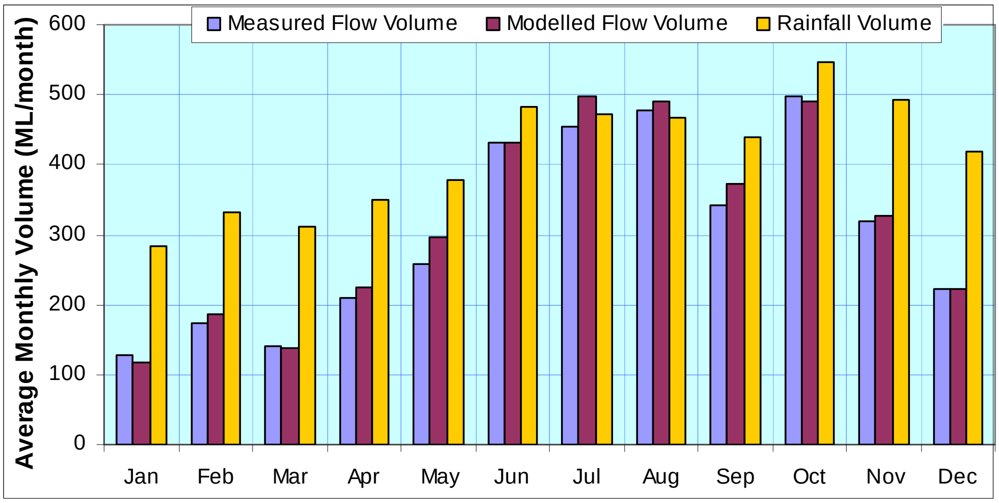
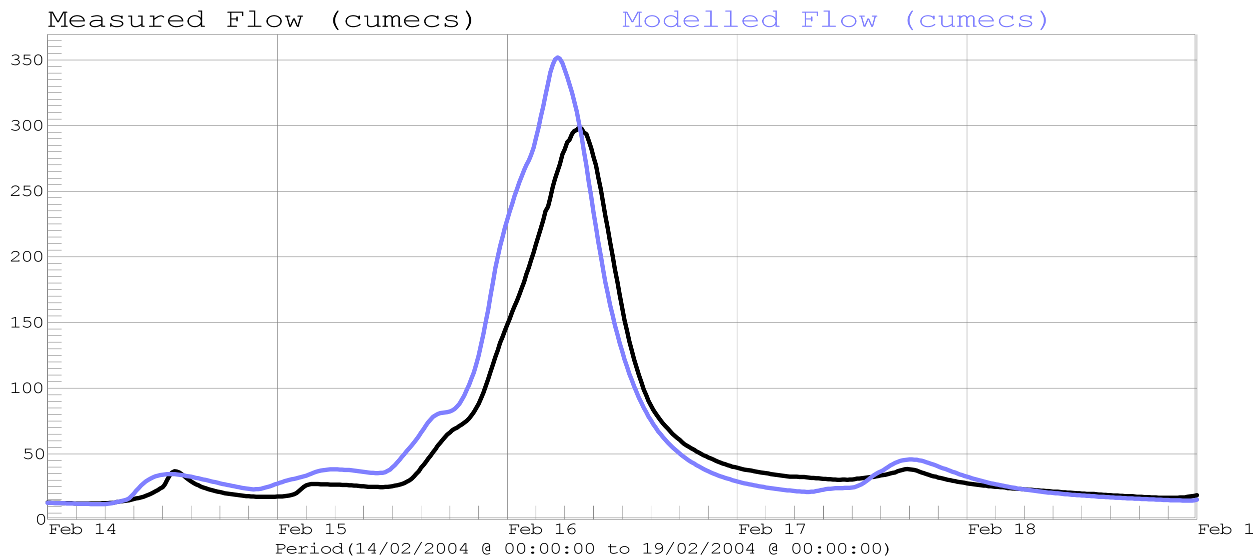
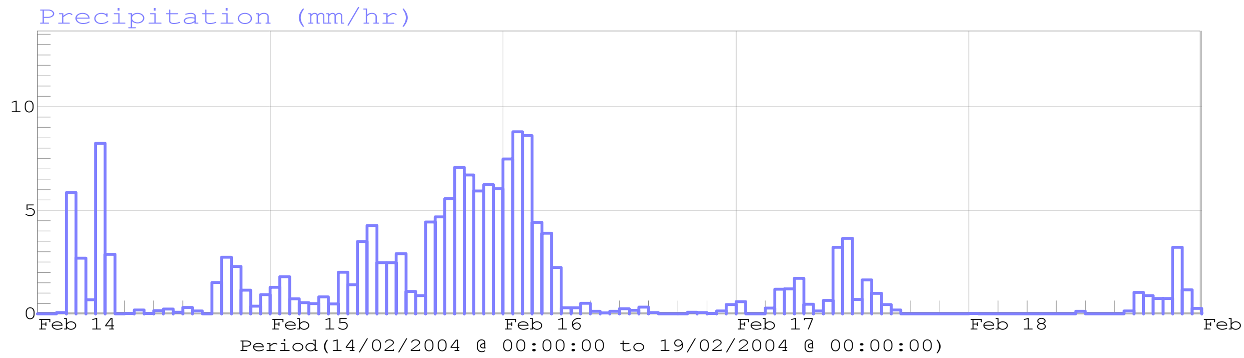
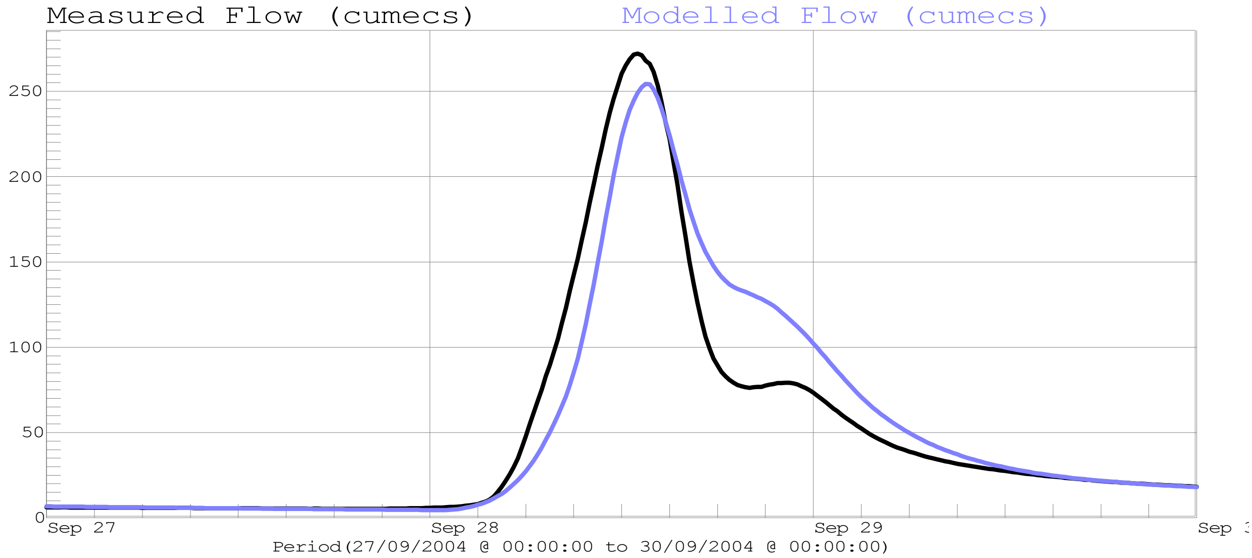


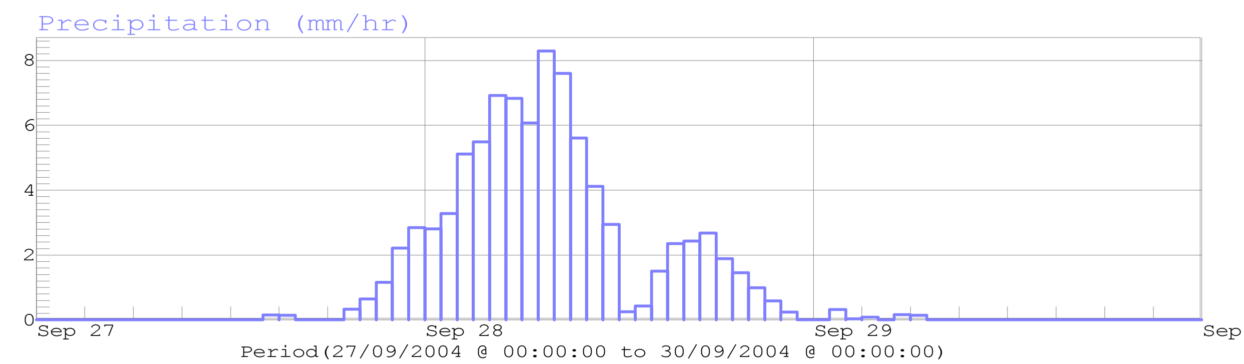
Figure 6-13: Monthly Average Volumes – Makakahi at Hamua

EVENT COMPARISON - MAKAKAHI @ HAMUA

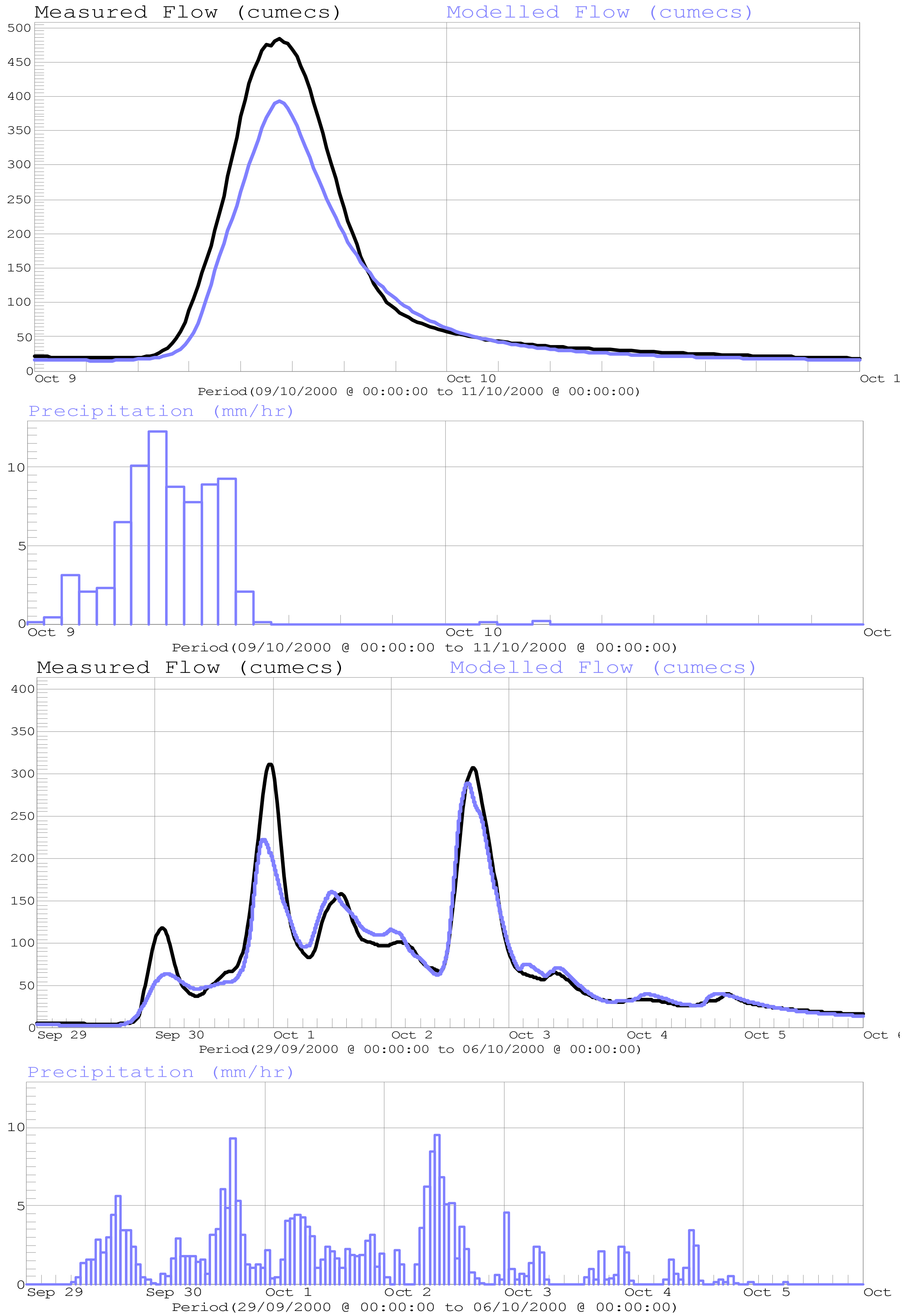




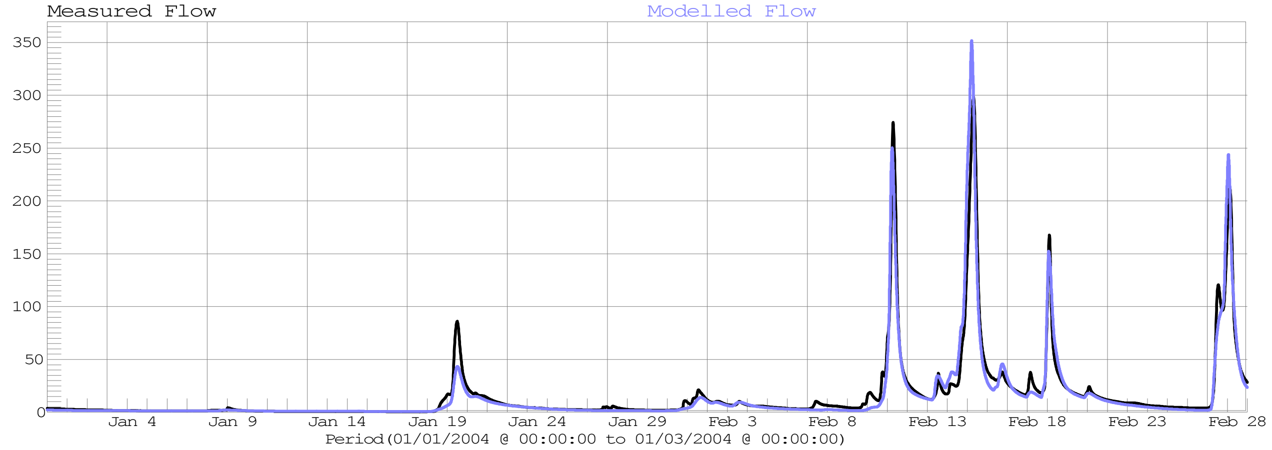


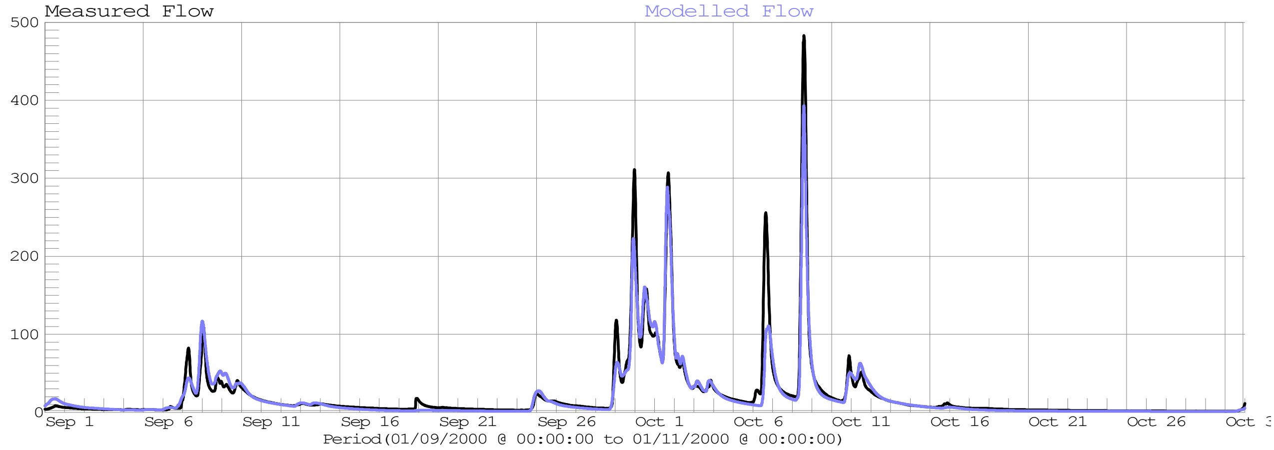


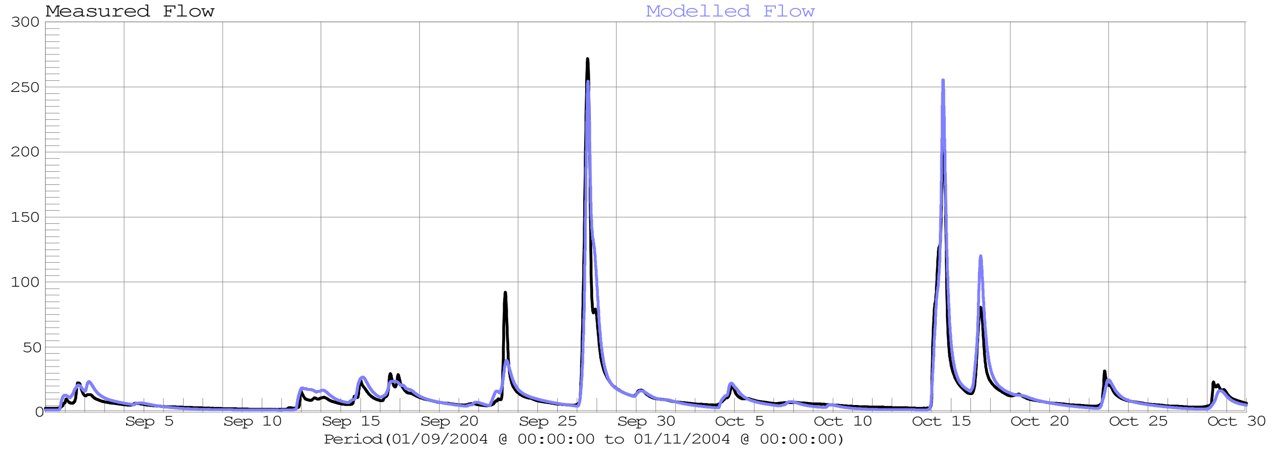
EVENT COMPARISON - MAKAKAHI @ HAMUA

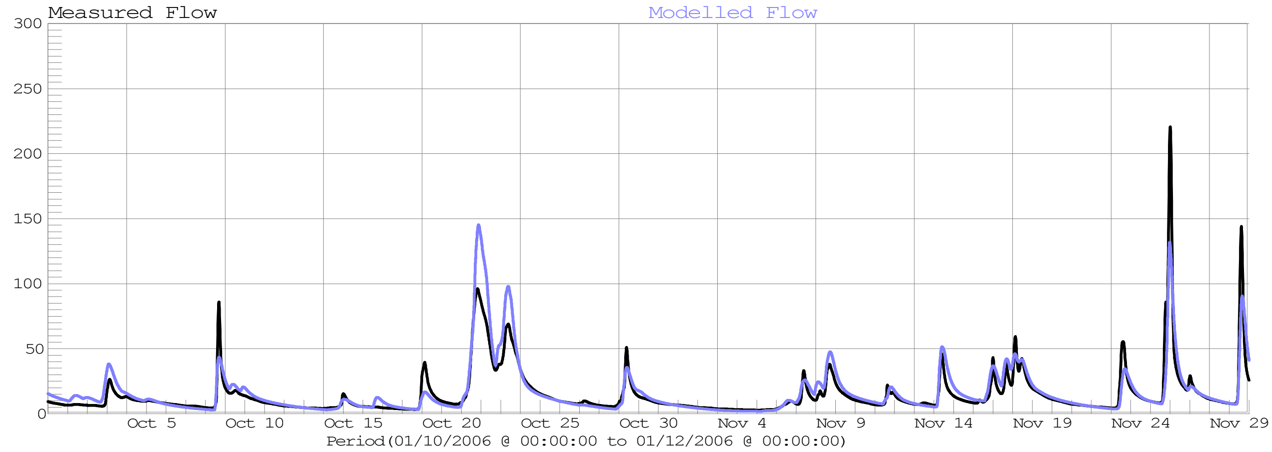


TIME SERIES COMPARISON - MAKAKAHI AT HAMUA









6.7 CALIBRATION RESULTS - MANGATAINOKA AT LARSONS RD

Chinese Standards Performance Indicators:

From 1991: QR = 73% CD = 0.81 Accuracy Grading = B

From 2000: QR = 77% CD = 0.84 Accuracy Grading = B

Recommendation: Suitable for making official forecasts.

Measured Flow Volume = 2,920 Mm^3 (from 1991) 1,130 Mm^3 (from 2000)
Modelled Flow Volume = 3,011 Mm^3 (from 1991) 1,178 Mm^3 (from 2000)

Table 6-8: Calibration Event Details – Mangatainoka at Larsons Rd

	Event Start	Event Finish	Measured Peak Flow (m3/s)	Modelled Peak Flow (m3/s)	Difference (%)	Measured Volume (Mm3)	Modelled Volume (Mm3)	Difference (%)	Rainfall Volume (Mm3)	Measured Runoff Coeff	Modelled Runoff Coeff
1	10/02/2004 @ 00:00	18/02/2004 @ 00:00	270.89	286.74	5.85	22.71	23.66	4.20	23.40	0.97	1.01
2	20/09/2000 @ 00:00	03/10/2000 @ 12:00	261.95	220.47	-15.83	29.99	28.61	-4.60	27.40	1.09	1.04
3	27/09/2004 @ 12:00	30/09/2004 @ 00:00	228.51	254.08	11.19	9.72	9.84	1.22	9.65	1.01	1.02
4	13/11/1994 @ 18:00	18/11/1994 @ 00:00	244.67	142.33	-41.83	18.22	16.16	-11.34	15.39	1.18	1.05
5	08/10/2000 @ 12:00	11/10/2000 @ 00:00	240.79	230.43	-4.30	8.97	7.59	-15.32	6.43	1.39	1.18
6	05/09/1998 @ 12:00	07/09/1998 @ 12:00	239.33	237.31	-0.85	8.08	8.00	-1.04	7.77	1.04	1.03
7	04/01/2005 @ 12:00	08/01/2005 @ 00:00	237.13	282.03	18.93	9.61	10.37	7.97	10.43	0.92	0.99
8	25/01/2001 @ 18:00	27/01/2001 @ 12:00	234.44	222.84	-4.95	6.16	5.58	-9.37	6.03	1.02	0.93
9	25/07/2000 @ 12:00	30/07/2000 @ 12:00	163.16	171.52	5.12	5.94	6.60	11.06	6.13	0.97	1.08
10	17/06/2002 @ 12:00	20/06/2002 @ 00:00	157.51	163.40	3.74	7.67	8.00	4.41	7.31	1.05	1.10
11	14/07/2003 @ 12:00	19/07/2003 @ 00:00	148.28	140.88	-4.99	7.51	6.99	-6.85	6.77	1.11	1.03
12	19/02/2004 @ 12:00	21/02/2004 @ 00:00	154.34	112.69	-26.99	3.12	3.31	6.14	3.14	0.99	1.06
13	14/11/2004 @ 00:00	18/11/2004 @ 00:00	157.48	68.79	-56.32	4.49	3.60	-19.91	5.41	0.83	0.66
14	15/10/2004 @ 00:00	17/10/2004 @ 12:00	194.42	211.78	8.93	12.30	11.82	-3.94	11.30	1.09	1.05
15	26/11/2006 @ 00:00	28/11/2006 @ 00:00	171.81	126.45	-26.40	3.83	3.94	2.92	3.91	0.98	1.01
	Average				15.75			7.35		1.04	1.02

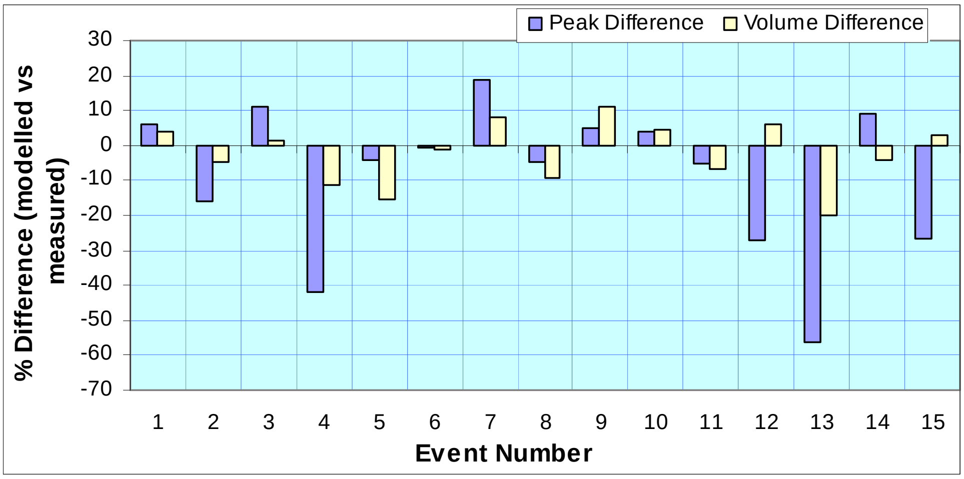


Figure 6-14: Modelled vs Measured Event Differences – Mangatainoka at Larsons

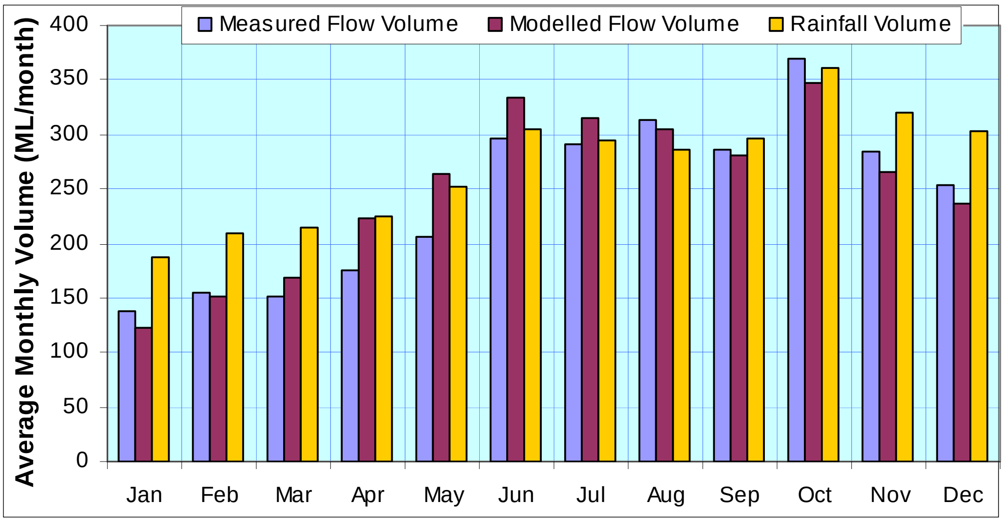
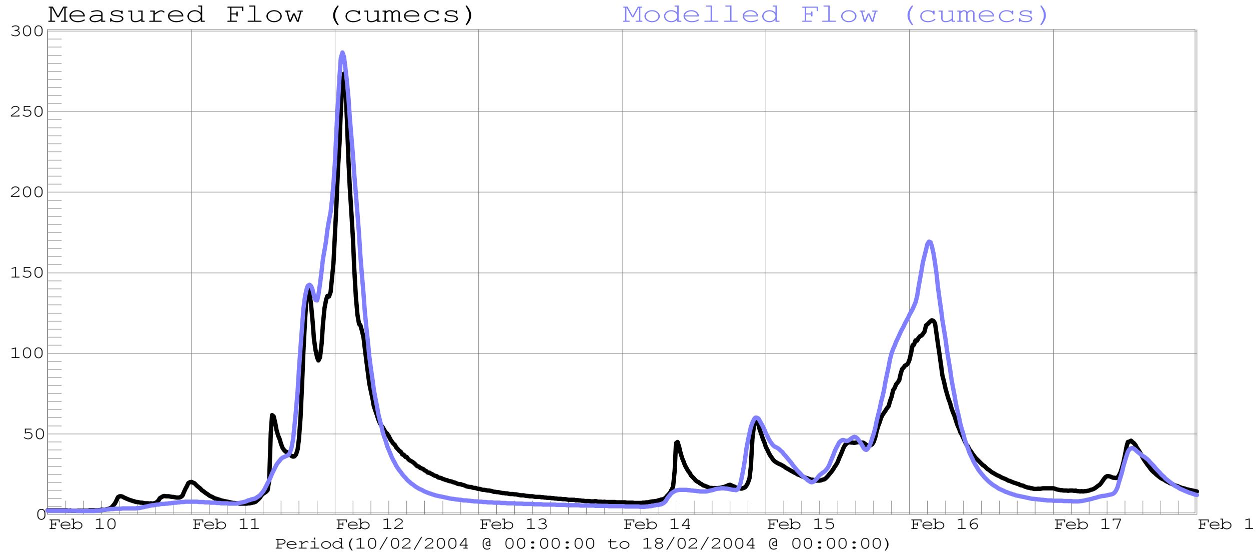
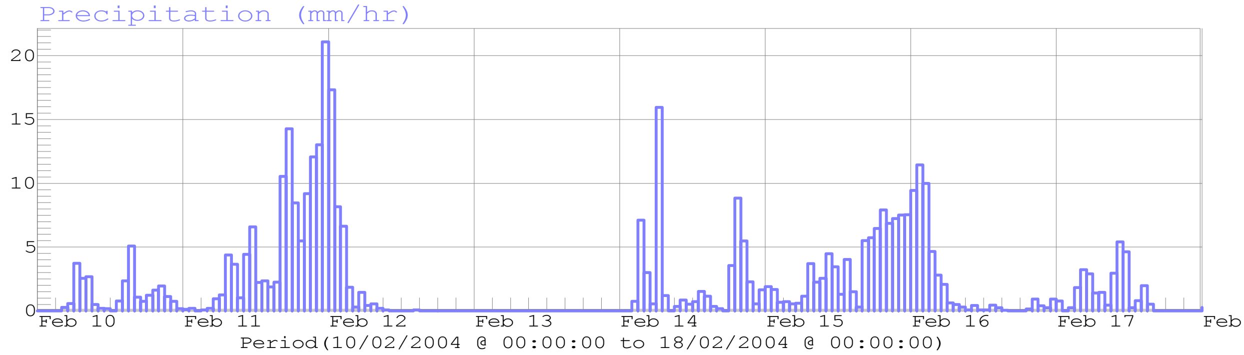
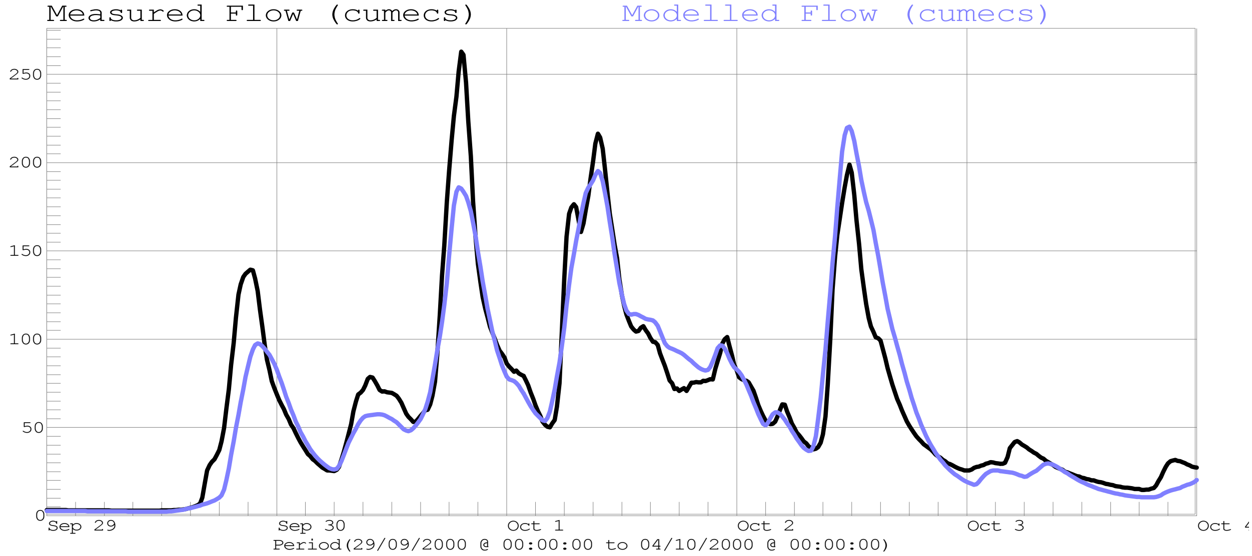


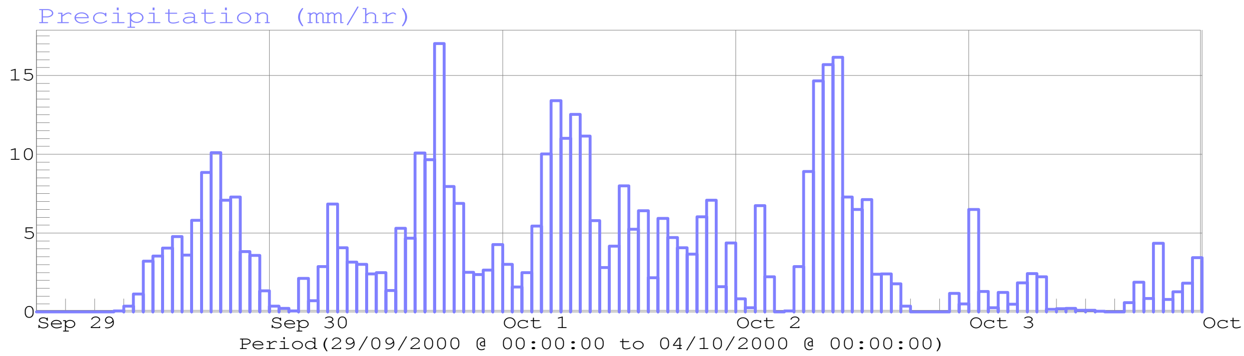
Figure 6-15: Monthly Average Volumes – Mangatainoka at Larsons Rd

EVENT COMPARISON - MANGATAINOKA @ LARSONS RD

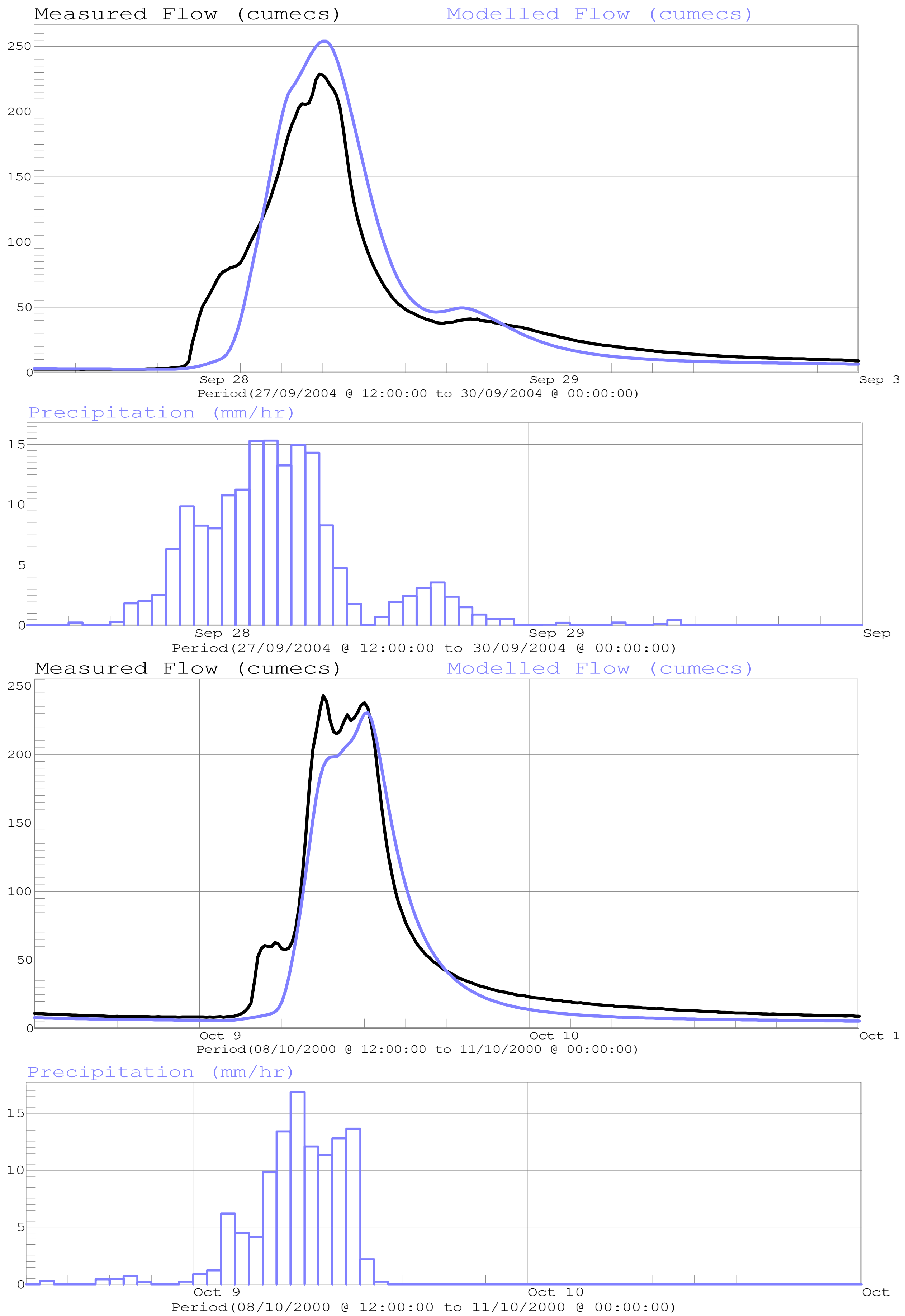


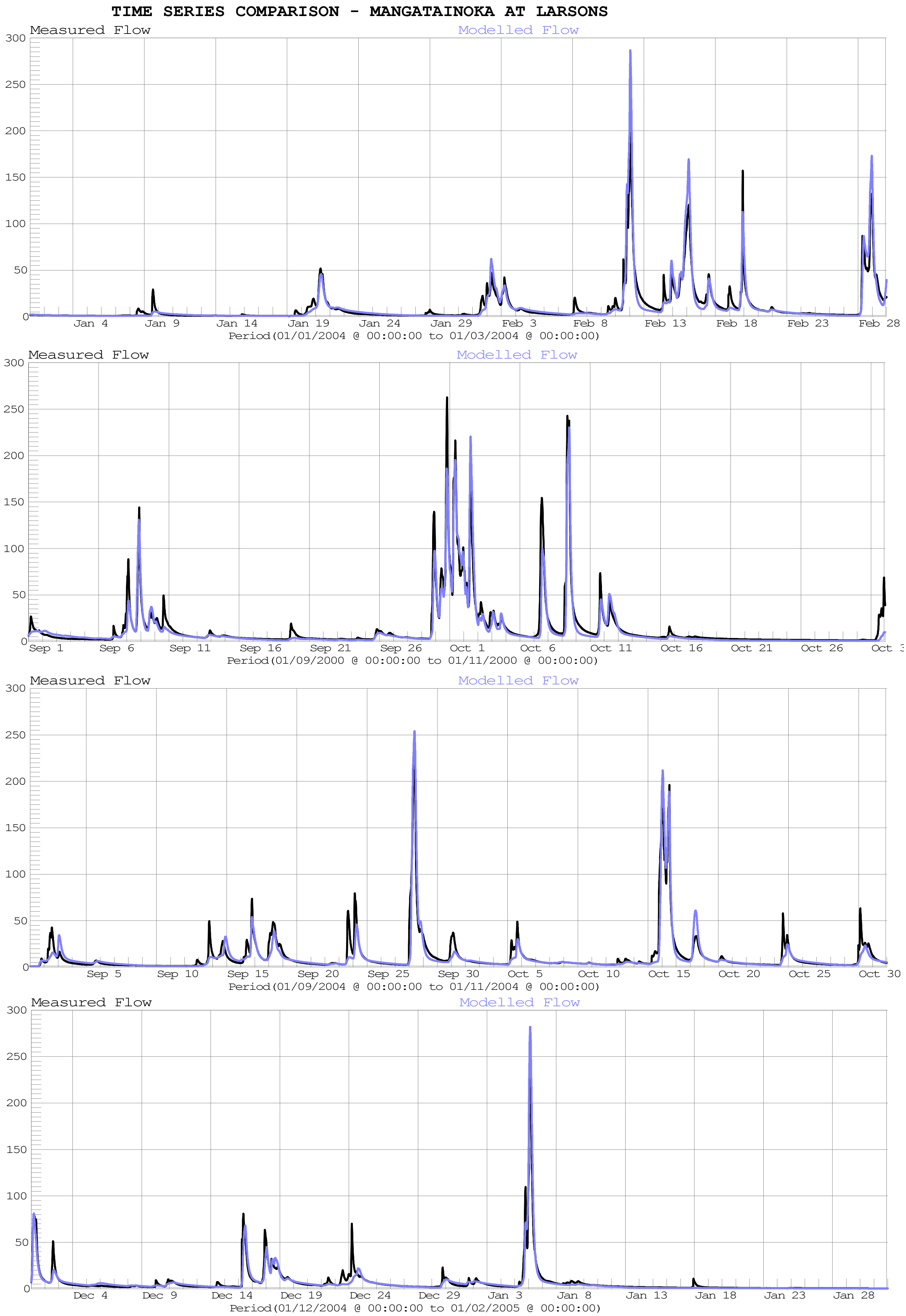






EVENT COMPARISON - MANGATAINOKA @ LARSONS RD




TIME SERIES COMPARISON - MANGATAINOKA AT LARSONS
Measured Flow
Modelled Flow
300
250
200
150
100
50
0
Jan 4
Jan 9
Jan 14
Jan 19
Jan 24
Jan 29
Feb 3
Feb 8
Feb 13
Feb 18
Feb 23
Feb 28
Period(01/01/2004 @ 00:00:00 to 01/03/2004 @ 00:00:00)
Measured Flow
Modelled Flow
Sep 1
Sep 6
Sep 11
Sep 16
Sep 21
Sep 26
Oct 1
Oct 6
Oct 11
Oct 16
Oct 21
Oct 26
Oct 3
Period(01/09/2000 @ 00:00:00 to 01/11/2000 @ 00:00:00)
Measured Flow
Modelled Flow
Sep 5
Sep 10
Sep 15
Sep 20
Sep 25
Sep 30
Oct 5
Oct 10
Oct 15
Oct 20
Oct 25
Oct 30
Period(01/09/2004 @ 00:00:00 to 01/11/2004 @ 00:00:00)
Measured Flow
Modelled Flow
Dec 4
Dec 9
Dec 14
Dec 19
Dec 24
Dec 29
Jan 3
Jan 8
Jan 13
Jan 18
Jan 23
Jan 28
Period(01/12/2004 @ 00:00:00 to 01/02/2005 @ 00:00:00)

6.8 CALIBRATION RESULTS - MANGATAINOKA AT PAHIATUA

Despite the good calibrations achieved at the two upstream sites (Mangatainoka at Larsons Rd and Makakahi at Hamua), this site almost fails to qualify according to the Chinese Standards Performance Indicators. The calibration at the upstream sites achieves a good to excellent correlation (CD) and the event volumes manage to qualify for all events considered. This suggests that there are timing issues between the combining of flows from the Mangatainoka and Makakahi Rivers but this was investigated by applying a range of flow delays on both rivers which resulted in no improvement of the results.

The upstream inundation and overland flow during events of this magnitude may be causing enough impact on the routing of floods down the river which cannot be modelled by standard rainfall-runoff-routing methodology in a hydrologic model. The site exhibits an interesting hydrograph rise during flood events which in some cases is less steep than the recession.

The reliability of the forecasts at this site does not impact the flood map selection process linked to the Mangatainoka online flood mapping tool as the magnitudes of the forecasts at the two upstream sites are used to determine the appropriate map.

Chinese Standards Performance Indicators:

From 1991: QR = 53% CD = 0.89 Accuracy Grading = < C

From 2000: QR = 62% CD = 0.90 Accuracy Grading = C

Recommendation: Suitable for making reference forecasts (for period from 2000).

Measured Flow Volume = 10,365 Mm^3 (from 1991) 4,101 Mm^3 (from 2000)
Modelled Flow Volume = 11,470 Mm^3 (from 1991) 4,537 Mm^3 (from 2000)

Table 6-9: Calibration Event Details – Mangatainoka at Pahiatua

	Event Start	Event Finish	Measured Peak Flow (m3/s)	Modelled Peak Flow (m3/s)	Difference (%)	Measured Volume (Mm3)	Modelled Volume (Mm3)	Difference (%)	Rainfall Volume (Mm3)	Measured Runoff Coeff	Modelled Runoff Coeff
1	14/02/2004 @ 00:00	19/02/2004 @ 00:00	598.42	745.59	24.59	58.93	62.74	6.47	68.58	0.86	0.91
2	27/09/2004 @ 12:00	30/09/2004 @ 00:00	697.74	680.29	-2.50	35.32	38.00	7.58	41.30	0.86	0.92
3	10/04/1991 @ 00:00	14/04/1991 @ 00:00	453.28	630.73	39.15	33.05	38.14	15.41	37.41	0.88	1.02
4	09/10/2000 @ 00:00	11/10/2000 @ 00:00	851.61	778.07	-8.64	38.14	33.05	-13.35	28.16	1.35	1.17
5	05/01/2005 @ 00:00	09/01/2005 @ 00:00	584.41	581.56	-0.49	31.74	31.79	0.15	39.22	0.81	0.81
6	19/10/1998 @ 12:00	24/10/1998 @ 00:00	565.30	767.04	35.69	58.47	65.01	11.19	63.27	0.92	1.03
7	12/06/2002 @ 12:00	20/06/2002 @ 12:00	406.39	376.74	-7.30	63.32	63.86	0.85	58.62	1.08	1.09
8	15/10/2004 @ 12:00	21/10/2004 @ 00:00	531.72	559.12	5.15	51.80	58.05	12.06	60.01	0.86	0.97
9	26/11/2006 @ 00:00	30/11/2006 @ 00:00	364.97	239.67	-34.33	21.44	18.68	-12.86	18.07	1.19	1.03
10	29/09/2002 @ 00:00	03/10/2002 @ 00:00	343.63	312.82	-8.97	25.36	23.25	-8.32	25.04	1.01	0.93
11	25/01/2001 @ 18:00	28/01/2001 @ 12:00	503.30	349.02	-30.65	19.54	16.07	-17.73	27.78	0.70	0.58
12	27/02/2004 @ 00:00	04/03/2004 @ 00:00	395.70	502.42	26.97	48.40	48.31	-0.18	58.32	0.83	0.83
13	11/07/2006 @ 12:00	18/07/2006 @ 00:00	363.63	375.28	3.20	40.60	44.54	9.71	39.46	1.03	1.13
14	03/10/2003 @ 00:00	07/10/2003 @ 00:00	423.26	564.01	33.25	38.16	43.10	12.96	37.69	1.01	1.14
15	21/10/2006 @ 00:00	27/10/2006 @ 00:00	317.02	380.23	19.94	52.02	58.33	12.14	55.57	0.94	1.05
	Average				18.63			9.20		0.96	0.97

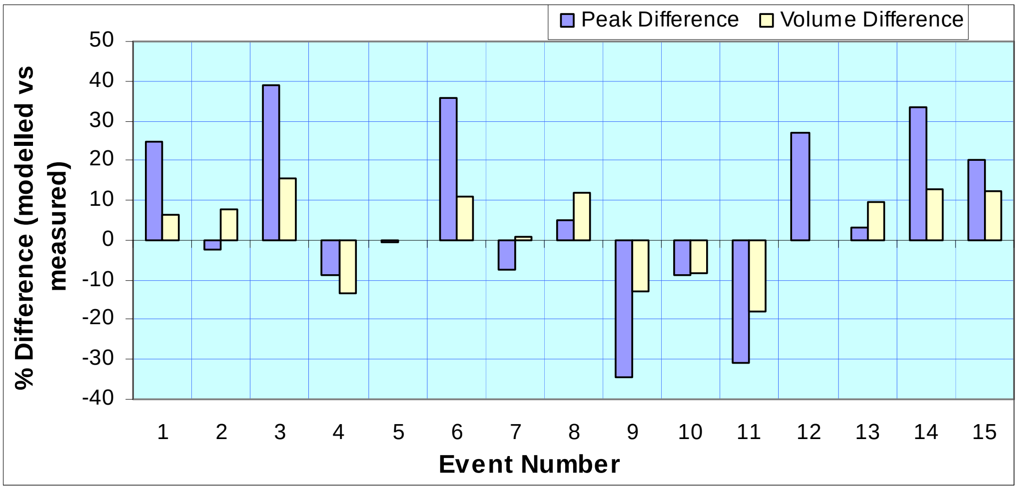


Figure 6-16: Modelled vs Measured Event Differences – Mangatainoka at Pahiatua

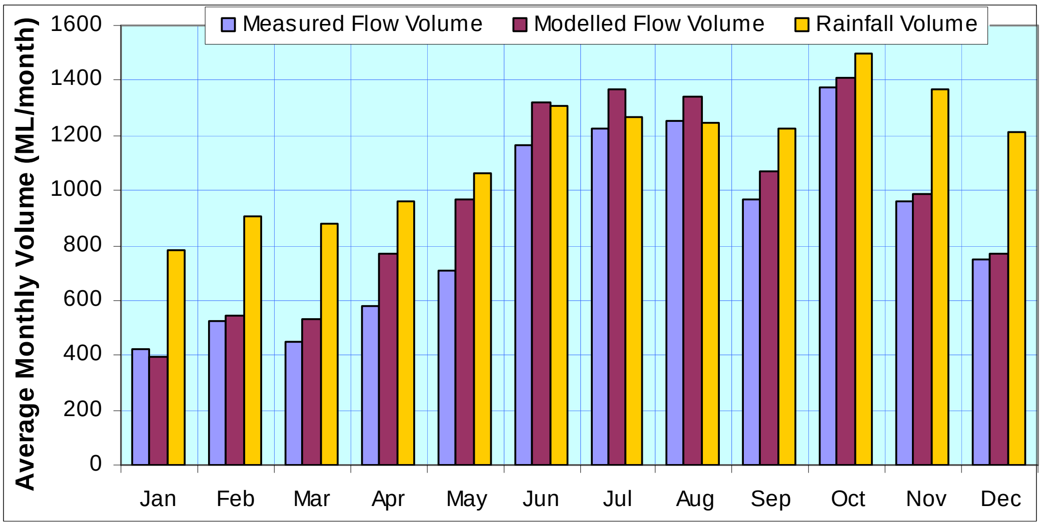
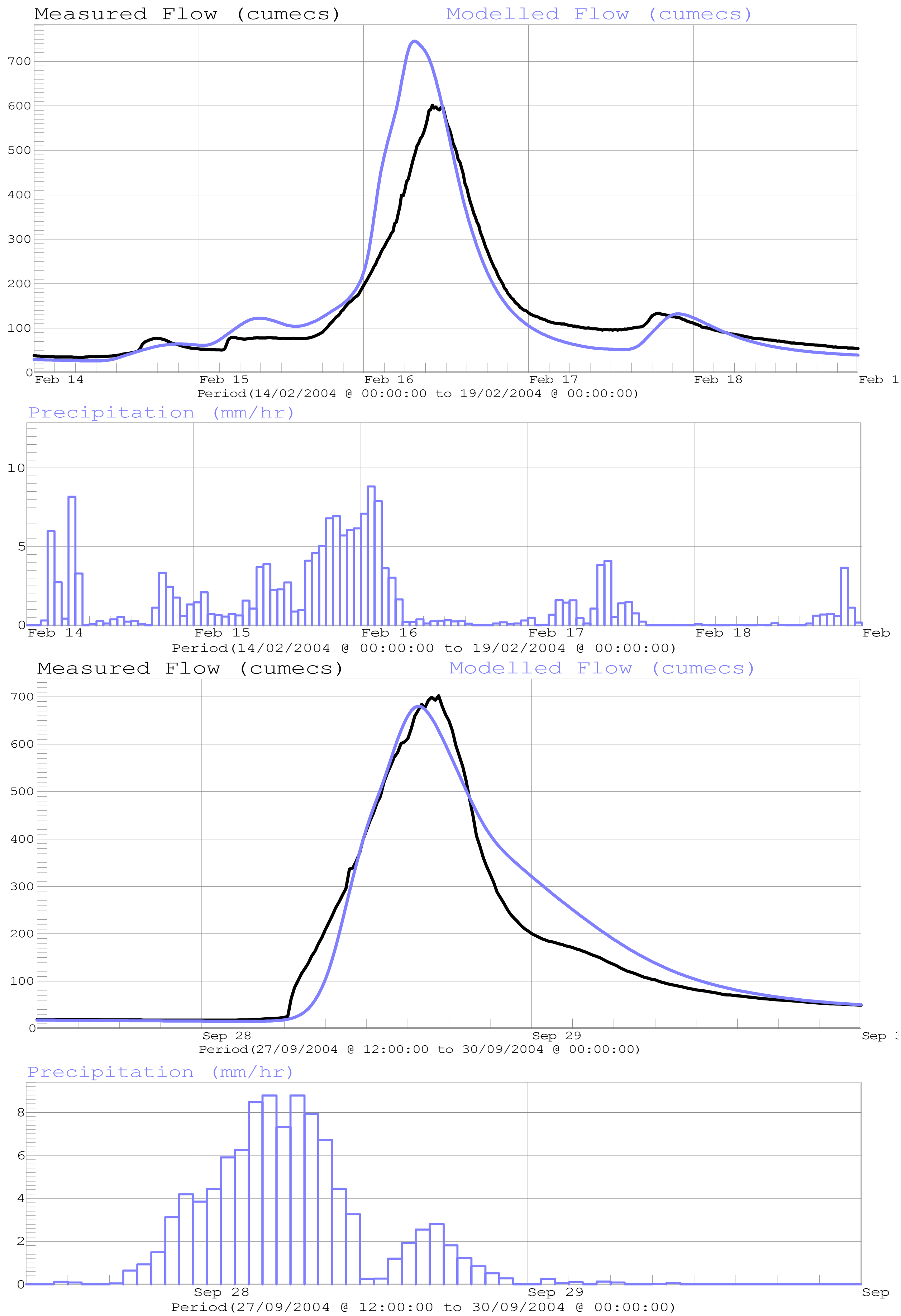
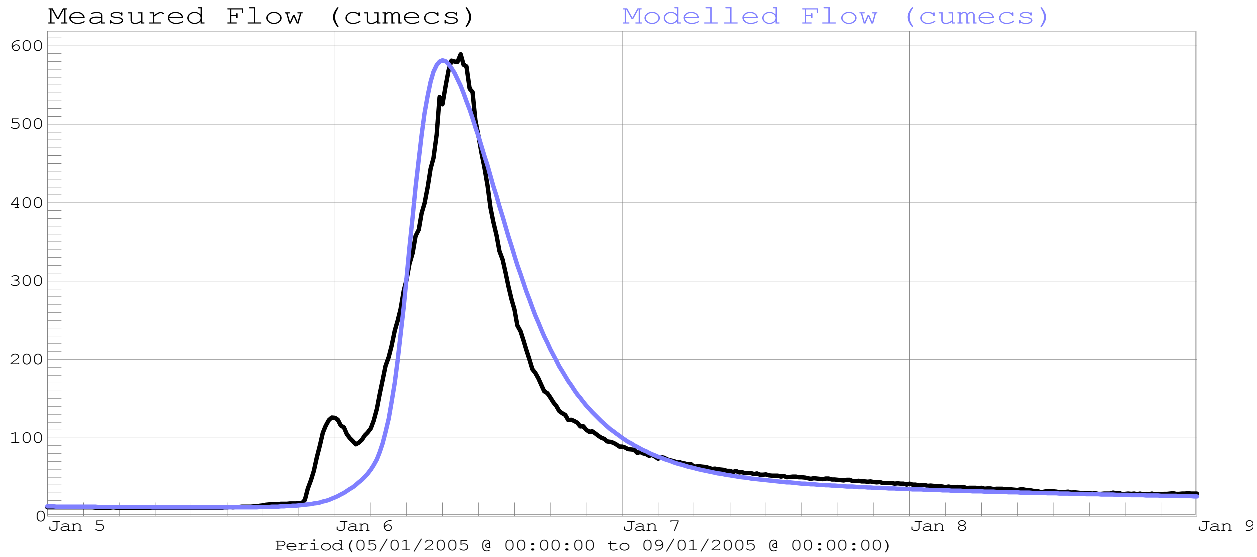


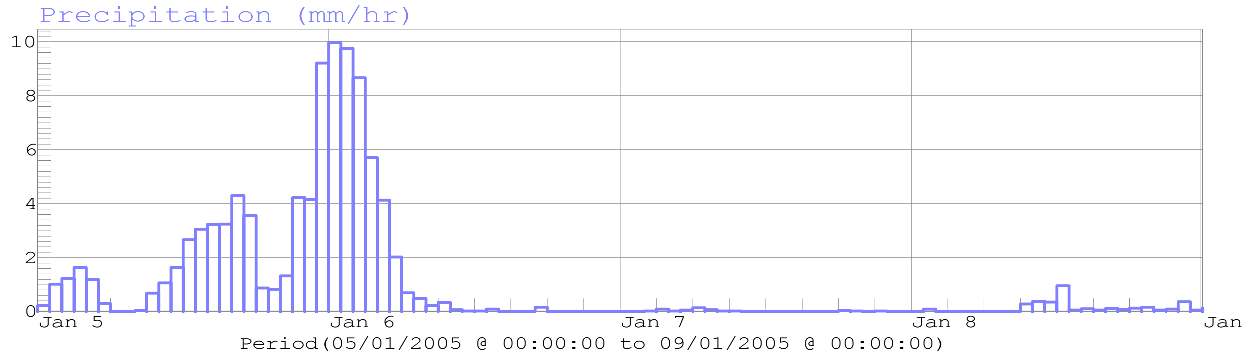
Figure 6-17: Monthly Average Volumes – Mangatainoka at Pahiatua

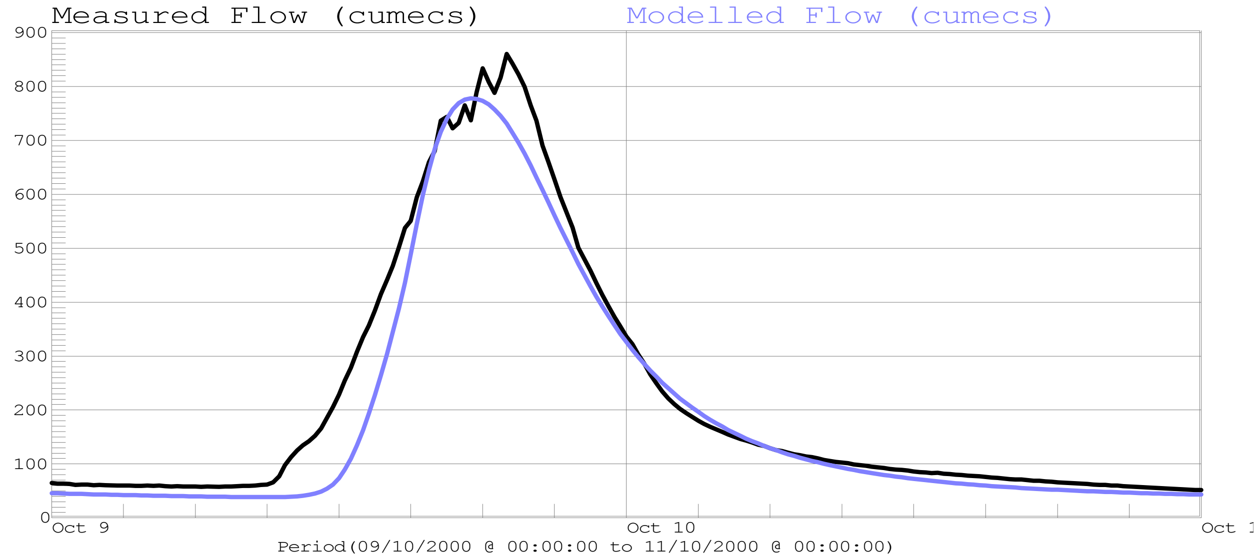
EVENT COMPARISON - MANGATAINOKA @ PAHIATUA

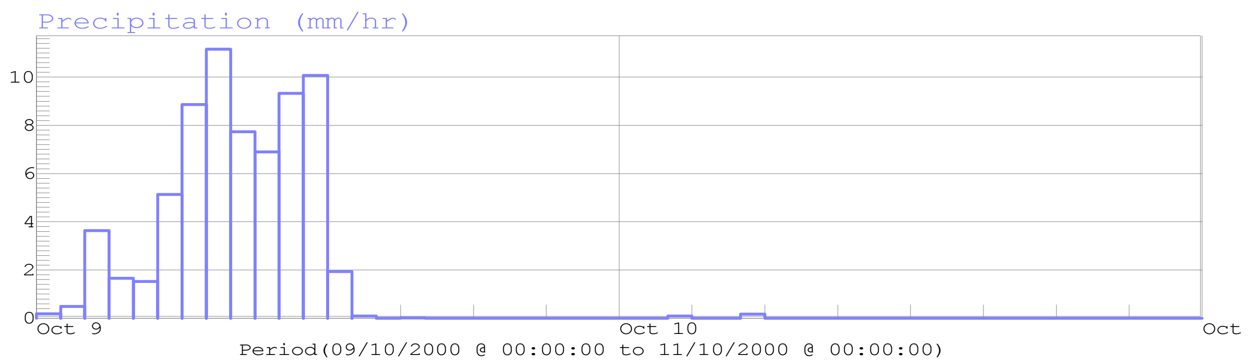


EVENT COMPARISON - MANGATAINOKA @ PAHIATUA

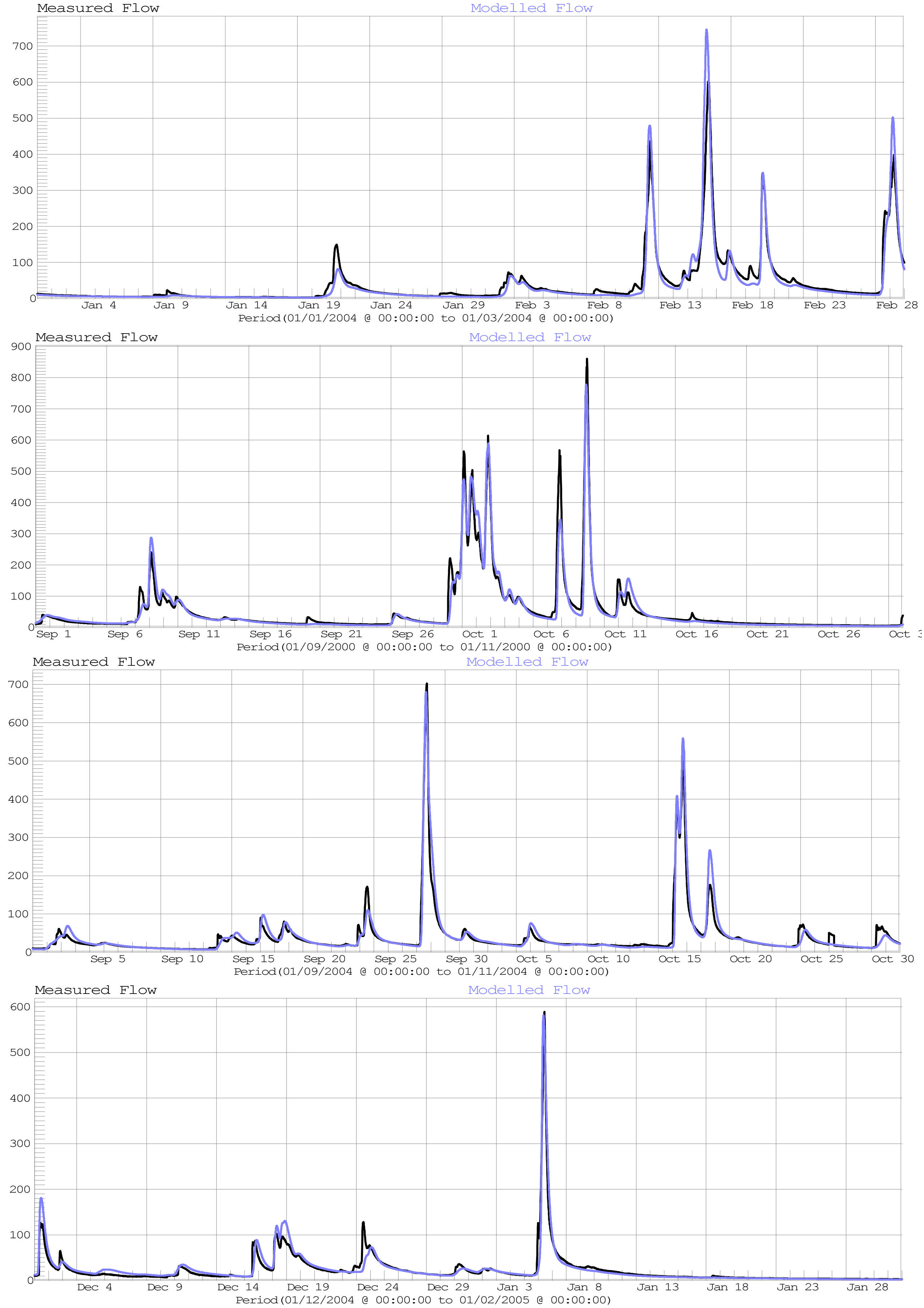








TIME SERIES COMPARISON - MANGATAINOKA AT PAHIATUA



6.9 CALIBRATION RESULTS - MANGAHAO AT BALLANCE

Five significant under-predictions in event peaks reduce the accuracy grading to a C. These events were investigated to see if the simplified rules for the Upper Mangahao Dams were linked to the problem. But in all cases the measured stage was above the magnitude that would initiate spill according to the model rule.

Due to a slight over prediction in the higher priority events, this parameter set was deemed adequate.

Chinese Standards Performance Indicators:

From 2000: QR = 67% CD = 0.89 Accuracy Grading = C

Recommendation: Suitable for making reference forecasts.

Measured Flow Volume = 3,208 Mm^3
Modelled Flow Volume = 3,342 Mm^3

Table 6-10: Calibration Event Details – Mangahao at Ballance

	Event Start	Event Finish	Measured Peak Flow (m3/s)	Modelled Peak Flow (m3/s)	Difference (%)	Measured Volume (Mm3)	Modelled Volume (Mm3)	Difference (%)	Rainfall Volume (Mm3)	Measured Runoff Coeff	Modelled Runoff Coeff
1	11/02/2004 @ 12:00	24/02/2004 @ 00:00	647.47	693.26	7.07	81.23	88.77	9.28	91.79	0.88	0.97
2	27/09/2004 @ 18:00	01/10/2004 @ 00:00	841.61	907.06	7.78	37.95	38.69	1.94	43.88	0.86	0.88
3	05/01/2005 @ 00:00	08/01/2005 @ 00:00	971.63	1151.32	18.49	39.18	40.34	2.96	43.81	0.89	0.92
4	09/10/2000 @ 00:00	11/10/2000 @ 00:00	481.26	553.17	14.94	18.45	21.24	15.15	17.93	1.03	1.18
5	15/10/2004 @ 06:00	20/10/2004 @ 00:00	783.95	808.28	3.10	57.43	56.13	-2.25	54.19	1.06	1.04
6	15/07/2003 @ 00:00	20/07/2003 @ 00:00	494.83	424.93	-14.13	25.77	24.28	-5.78	26.95	0.96	0.90
7	13/02/2004 @ 12:00	19/02/2004 @ 00:00	423.67	506.09	19.45	39.22	45.95	17.15	49.91	0.79	0.92
8	29/09/2000 @ 06:00	06/10/2000 @ 00:00	719.24	754.40	4.89	96.10	101.72	5.85	97.94	0.98	1.04
9	25/01/2001 @ 18:00	28/01/2001 @ 00:00	710.23	485.72	-31.61	20.48	16.66	-18.67	23.74	0.86	0.70
10	23/11/2006 @ 12:00	26/11/2006 @ 00:00	483.47	307.33	-36.43	18.07	12.53	-30.67	15.78	1.14	0.79
11	27/03/2001 @ 00:00	30/03/2001 @ 00:00	458.94	297.74	-35.12	14.72	11.41	-22.52	23.22	0.63	0.49
12	20/12/2003 @ 12:00	27/12/2003 @ 12:00	464.37	390.98	-15.80	24.20	25.89	7.00	34.91	0.69	0.74
13	28/12/2000 @ 00:00	02/01/2001 @ 00:00	568.03	379.37	-33.21	26.28	24.77	-5.75	39.06	0.67	0.63
14	04/08/2004 @ 12:00	10/08/2004 @ 00:00	431.04	309.49	-28.20	25.91	29.38	13.41	35.44	0.73	0.83
15	28/09/2006 @ 12:00	03/10/2006 @ 00:00	380.75	419.69	10.23	28.56	25.37	-11.17	24.56	1.16	1.03
	Average				*18.62*			*11.15*		*0.89*	*0.87*

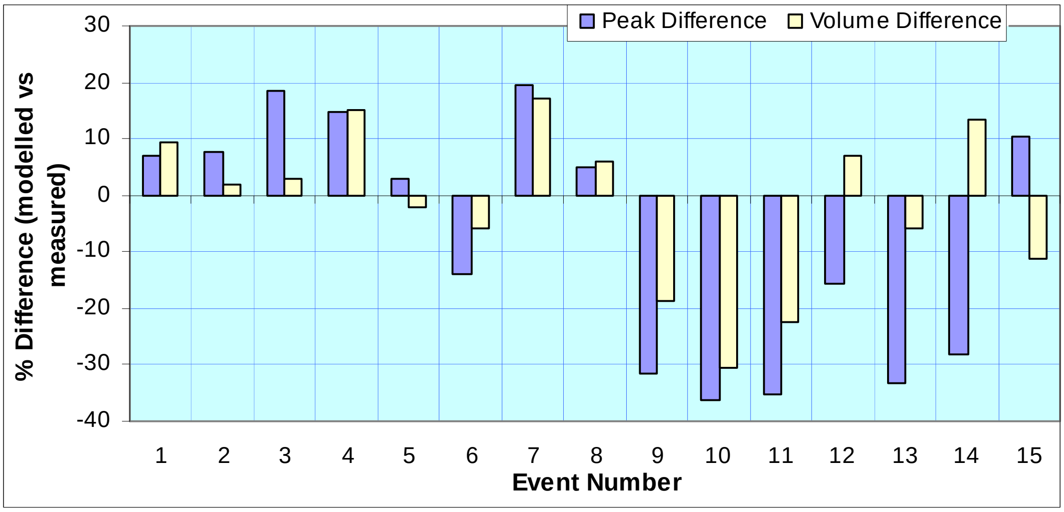


Figure 6-18: Modelled vs Measured Event Differences – Mangahao at Ballance

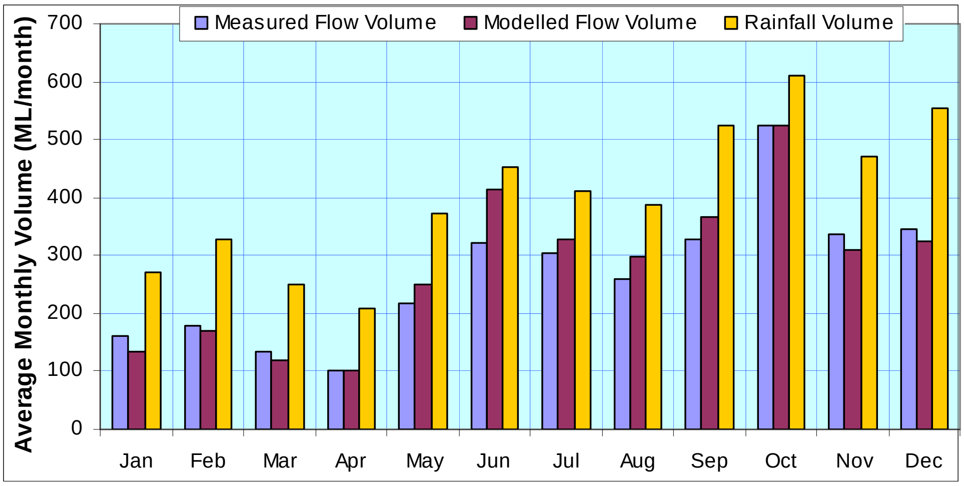
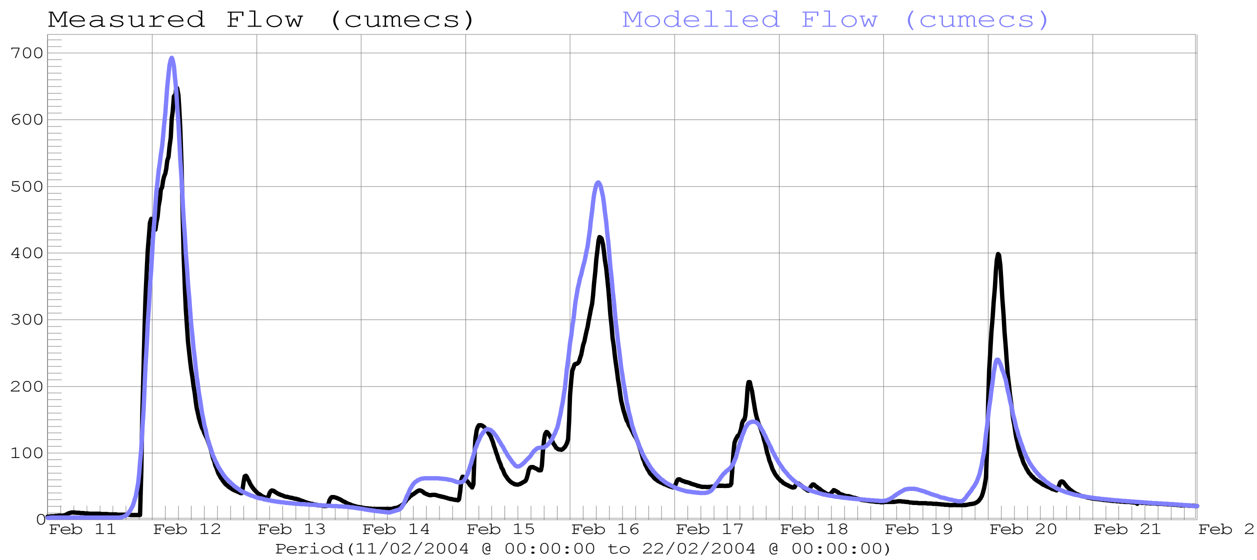
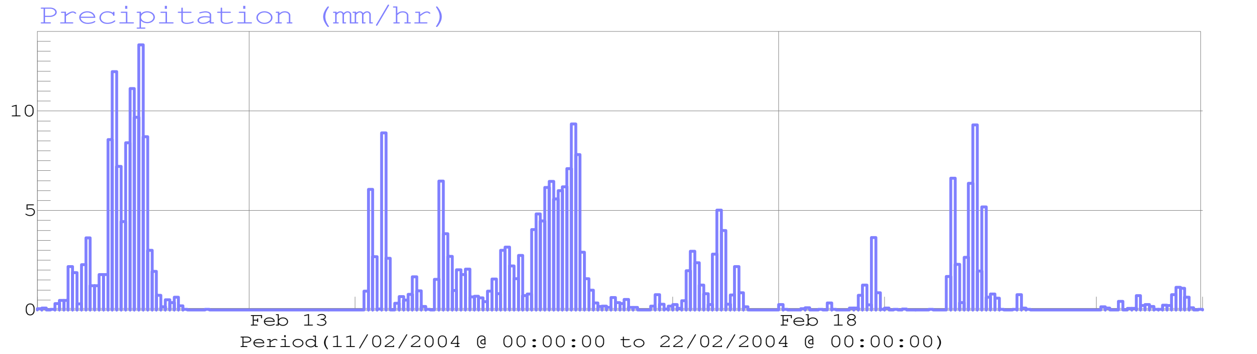
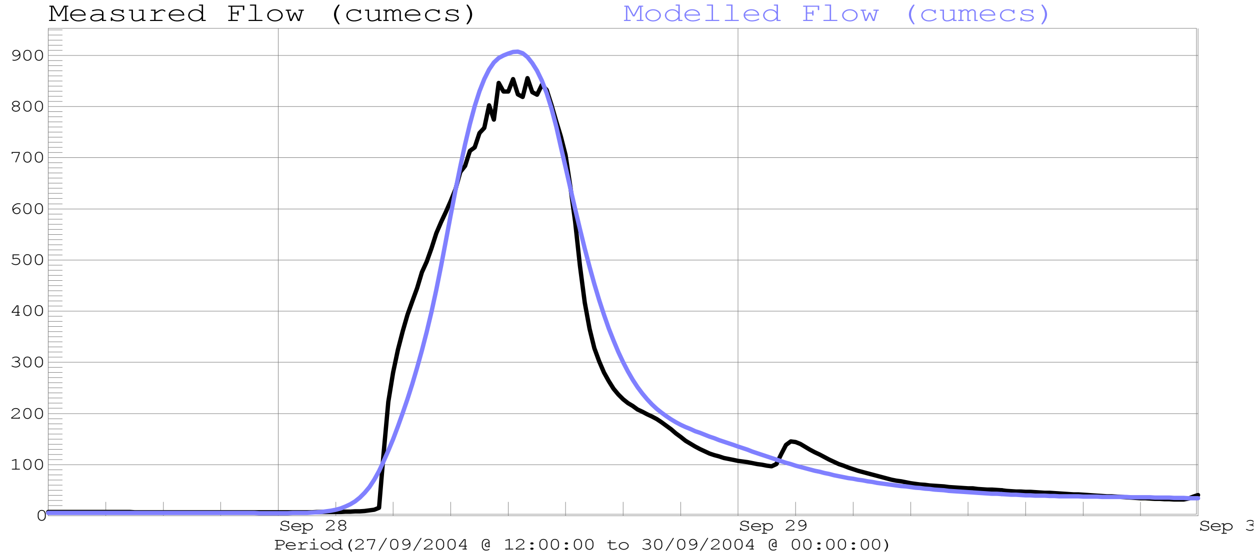


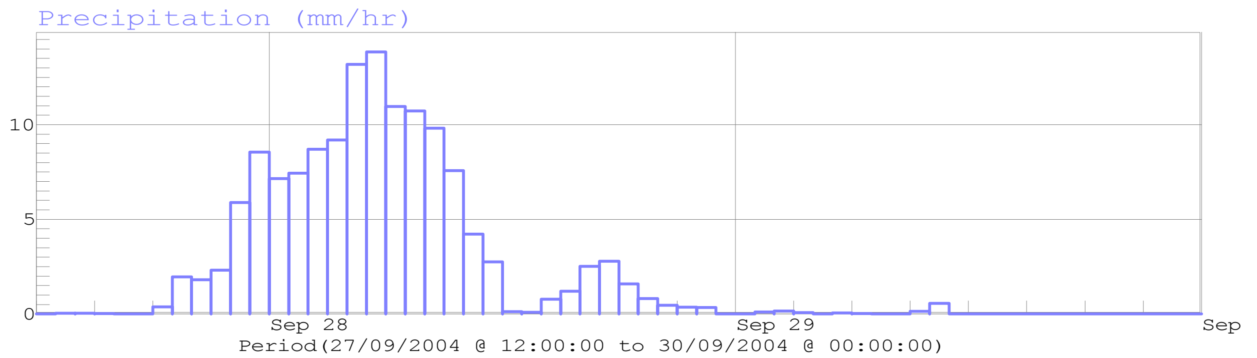
Figure 6-19: Monthly Average Volumes – Mangahao at Ballance

EVENT COMPARISON - MANGAHAO @ BALLANCE

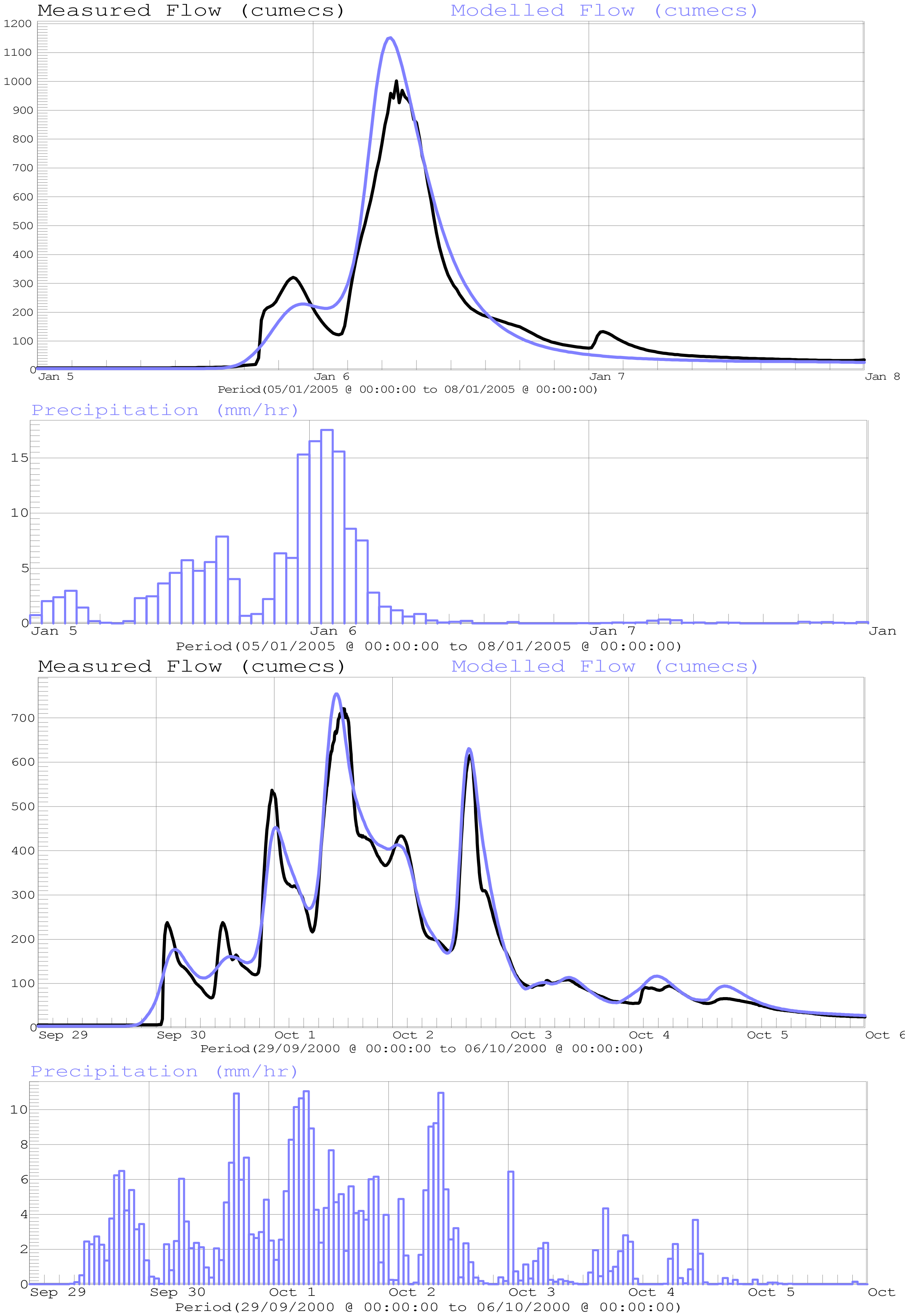


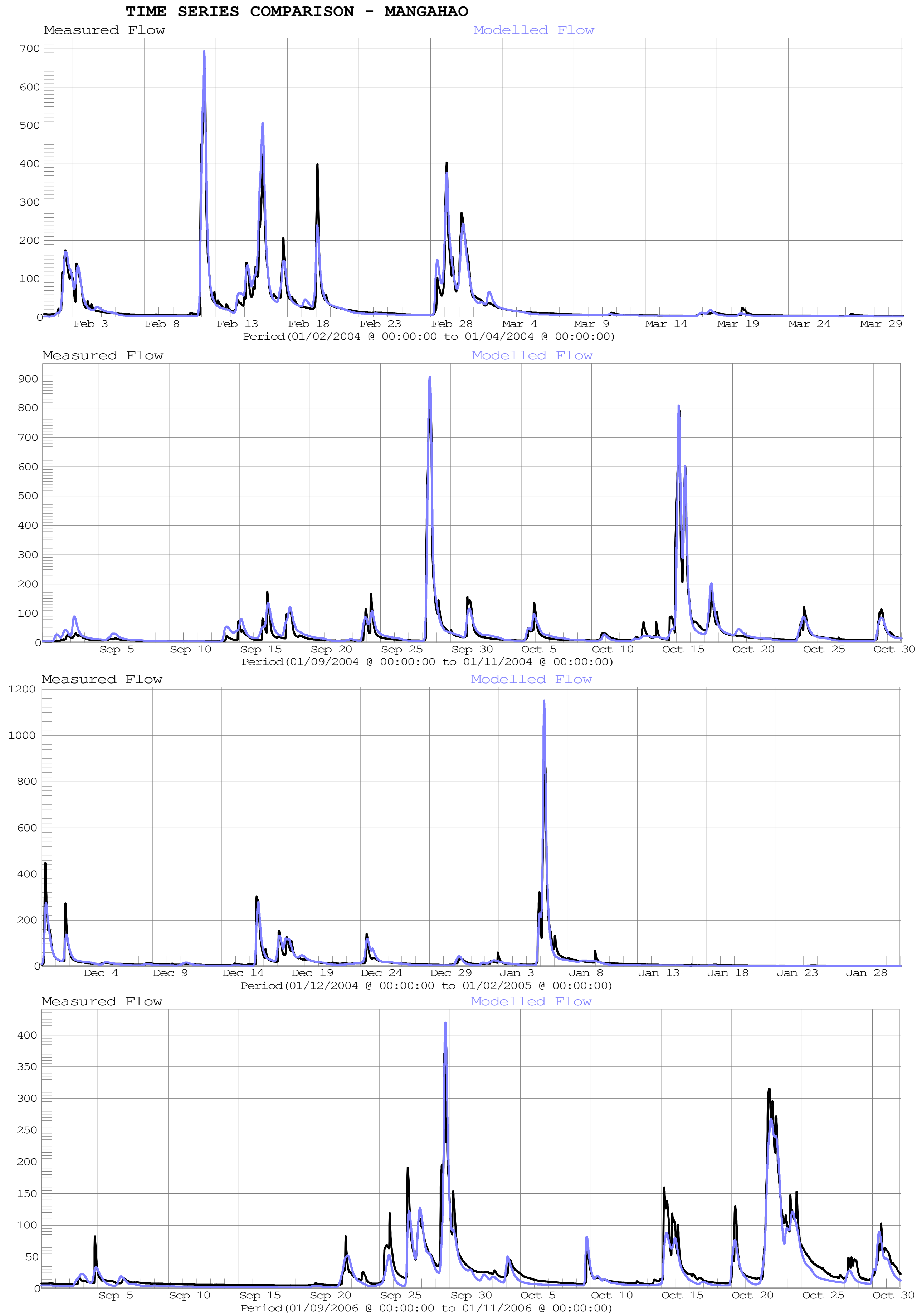






EVENT COMPARISON - MANGAHAO @ BALLANCE




TIME SERIES COMPARISON - MANGAHAO
Measured Flow
Modelled Flow
0 100 200 300 400 500 600 700
Feb 3 Feb 8 Feb 13 Feb 18 Feb 23 Feb 28 Mar 4 Mar 9 Mar 14 Mar 19 Mar 24 Mar 29
Period(01/02/2004 @ 00:00:00 to 01/04/2004 @ 00:00:00)
Measured Flow
Modelled Flow
0 100 200 300 400 500 600 700 800 900
Sep 5 Sep 10 Sep 15 Sep 20 Sep 25 Sep 30 Oct 5 Oct 10 Oct 15 Oct 20 Oct 25 Oct 30
Period(01/09/2004 @ 00:00:00 to 01/11/2004 @ 00:00:00)
Measured Flow
Modelled Flow
0 200 400 600 800 1000 1200
Dec 4 Dec 9 Dec 14 Dec 19 Dec 24 Dec 29 Jan 3 Jan 8 Jan 13 Jan 18 Jan 23 Jan 28
Period(01/12/2004 @ 00:00:00 to 01/02/2005 @ 00:00:00)
Measured Flow
Modelled Flow
0 50 100 150 200 250 300 350 400
Sep 5 Sep 10 Sep 15 Sep 20 Sep 25 Sep 30 Oct 5 Oct 10 Oct 15 Oct 20 Oct 25 Oct 30
Period(01/09/2006 @ 00:00:00 to 01/11/2006 @ 00:00:00)

7 RECOMMENDATIONS FOR FUTURE IMPROVEMENTS

Being a staged project, much is being learnt about the flood forecasting system as it is still being developed. Most of the areas for improvement outlined below are likely to have an effect on the system as a whole, not just the Upper Manawatu catchment.

- **Site information:** There is a good distribution of site information over the Upper Manawatu catchment. The existing site information has resulted in a good calibration at Upper Gorge and the two indicator sites being used in the online flood mapping of the Mangatainoka (Mangatainoka at Larsons and Makakahi at Hamua). If the Mangahao catchment becomes a high priority interest for HRC it may be beneficial to implement a recorder that provides a better understanding of the outflow from the Upper Mangahao Dams.

- **House-keeping/diagnostic archives:** There are a number of house-keeping and monitoring tasks that can be incorporated into the HRCFFS to obtain a better understanding of the real-time performance of the operating system and its components. To begin this process, a moving archive (of possibly 30 days) will be created to keep a record of Mike11 folders for diagnostic purposes. Other components that could make up the complete monitoring system include:

  - An input data timeliness report which will highlight the real-time performance of telemetered data and supplied forecasts.

  - The timeliness report can also create a time-stamped account of every scheduled run which will highlight periods where the FFS goes offline. An additional step could be taken to create a condition monitoring report which provides enough information to identify any of the components that are underperforming including input data timeliness, success/failure of the hydrologic model runs, and success/failure of the hydraulic model runs.

  - Archived custom plots could prove to be useful in capturing each model run prior to data being overwritten in the database.

  Some diagnostic processes were implemented since the completion of Stage 3 but this can be looked into further once all HRC catchments have been modelled.

- **Ongoing Support and Maintenance:** As the project further approaches completion, a support contract should be considered for emergency response to system issues, continual improvement of the system and review of system performance. A support budget is currently in place but it might be worth defining the specific tasks of HTC following the development of all models.

- **Standardisation of Error Correction Techniques.** As mentioned in Section 4 of this report there are numerous methods of real-time model error correction being applied in the HRCFFS models. These include three types of amplitude correction, low flow recession correction and soil moisture corrections. Ongoing review of the live performance has identified that the error correction techniques can sometimes lead to additional errors in the predicted flow. As was the case over this winter period (2008), the impact of these corrections needs to be monitored so that an optimum solution can be achieved. There is the possibility that the optimum solution might be to remove any correction to measured sites (or significantly reduce the impact of measured flows on forecast flows) and adopt a different approach to outputting the modelled results (e.g. over plotting the measured flows with the uncorrected modelled flows). Once the Stage 5 models have been built and implemented, the error correction approach should be standardised across all models.

- **HRCFFS Model Review:** The ongoing review of model performance is essential for maintenance and continual improvement of the model reliability. The review could focus on:
  - Forecast rainfall performance/reliability during flood events
  - Model calibration review especially if some significant floods are experienced in the catchment, or if significant rating adjustments or changes in the catchment appear to be affecting the model performance.
  - Utilising the 6 hr and 12 hr look-ahead model outputs to monitor the models' predictive performance (template plots could be created at high priority sites).
  - General health of the operating system, e.g. monitoring system failures etc.

  Over the recent winter/high flow period HRC have been very effective in monitoring the performance of the modelling system as events occur. By setting up some templates and processes it is possible to maintain an ongoing log of the system's performance.

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