Horizons Regional Council

Flood Forecasting System

Manawatu Catchment

Operating Manual

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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 a number of catchments in the council's area. This report presents details of the flood forecasting system developed for the Manawatu Catchment. The system is composed of hydrological and hydraulic models that interact with Horizon's hydrometric database to produce flow and water level forecasts at key locations.

This report is divided into the following sections:

- System Overview – Software components that make up the Manawatu Flood Forecasting System and their interconnections.
- System Installation – Software installation instructions.
- System Operation – Software operation instructions.
- Hydrologic Models – Modelling methodology, setup and calibration details.
- Hydraulic Models – Minor details of the hydraulic models.

2 SYSTEM OVERVIEW

The Horizons Regional Council Flood Forecasting System (HRCFFS) covers a number of catchment within the council's area and will be staged over a number of years. This report covers the Manawatu Catchment portion of this system which will be developed over Stages 1, 2, 3 and 4 of the HRCFFS. For all stages Rainfall-Runoff-Routing Model/s will be developed to forecast flow at various points throughout the catchment for input to the hydraulic models (Mike11). The extents of the Mike11 models for the Manawatu Catchment are shown by the heavy purple line in the Red and Orange catchments on Figure 2-1.

This report will be revised as additional stages are completed. Currently this report covers Stage 1 shown in the red subcatchments (Manawatu R. between Upper Gorge and Teachers College) on Figure 2-1. For the subcatchments of the Manawatu Catchment not covered by Stage 1, measured flow at their outlets will be used as interim inputs to the system.

An overview of the models that make up the flood forecasting system are shown in Figure 2-2. The system can be broken down into the following components;

(1) **Master Model** – This model runs all models in the correct order and if required allows users to change various settings for all sub models such as start and end time of run and the Hilltop file that the outputs are sent to. This model can also be run via a user friendly interface (Manawatu-UserInterfaceV1.xls).

(2) **Rainfall Processing Model** – This model reads actual and forecast rainfall data from the Hilltop database and fills gaps to provide continuous rainfall data as input to the rainfall/runoff/routing model. The Rainfall Processing Model is described in more detail in Section 5.2.2.1

(3) **Rainfall-Runoff-Routing Models** – These models converts rainfall data into flow estimates for key locations which are used as inputs by the Mike11 Models. The Rainfall-Runoff-Routing Models are described in more detail in Section 5.

(4) **MIKE 11 Models** – These models hydraulically route the flow estimates from the Rainfall-Runoff-Routing Models to estimate flow at key downstream locations. The Mike11 are described in more detail in Section 6.

(5) **Transfer Models** – These models transfer results from the Mike11 Models onto the next Mike11 model or into the Hilltop database. These models are quite simple and are best understood by viewing the models directly.

(6) **Hilltop Database** – All input and output data from each model of the system is stored or read from the Hilltop Database. Output data is viewed via Hilltop.

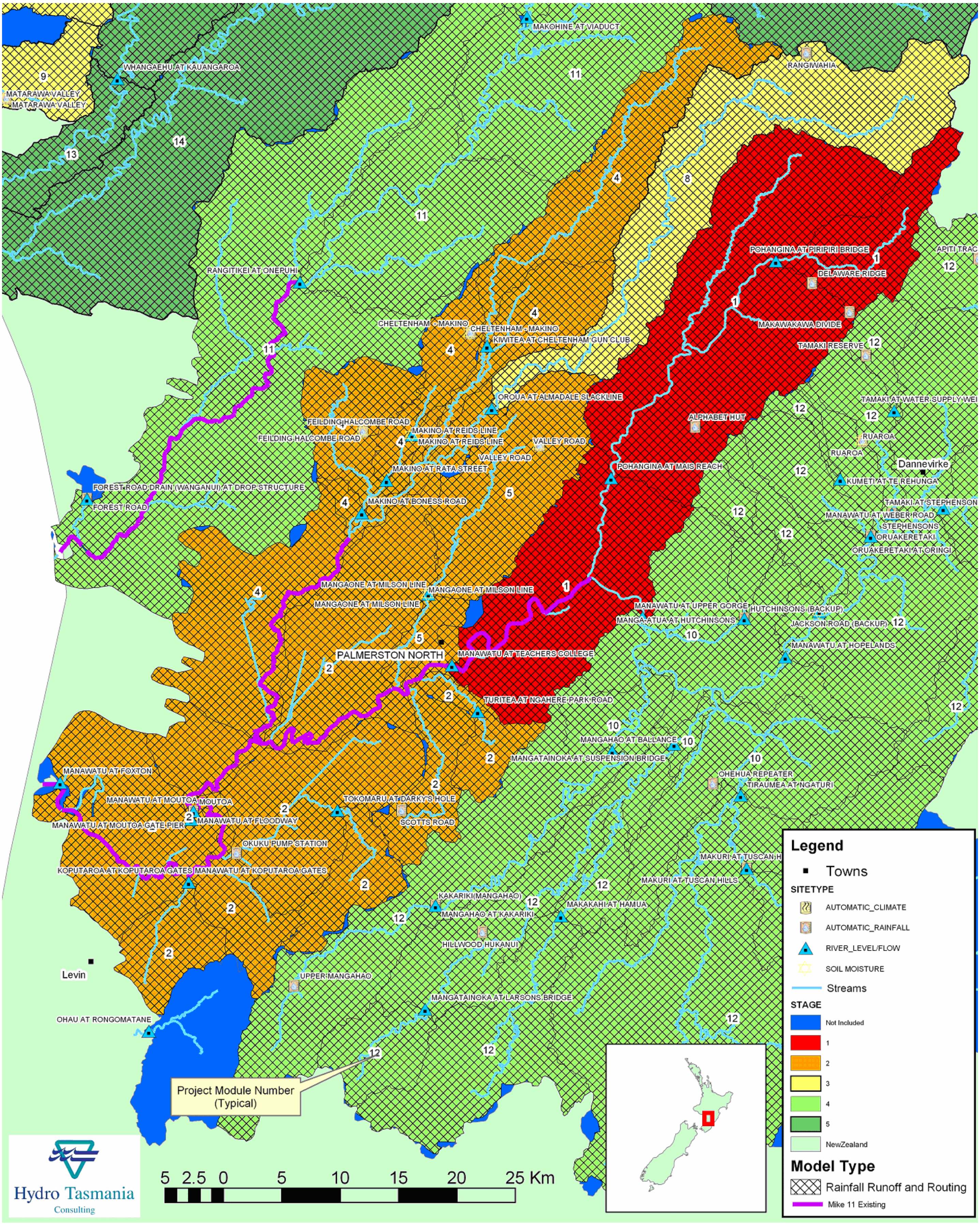


Figure 2-1 Manawatu Catchment

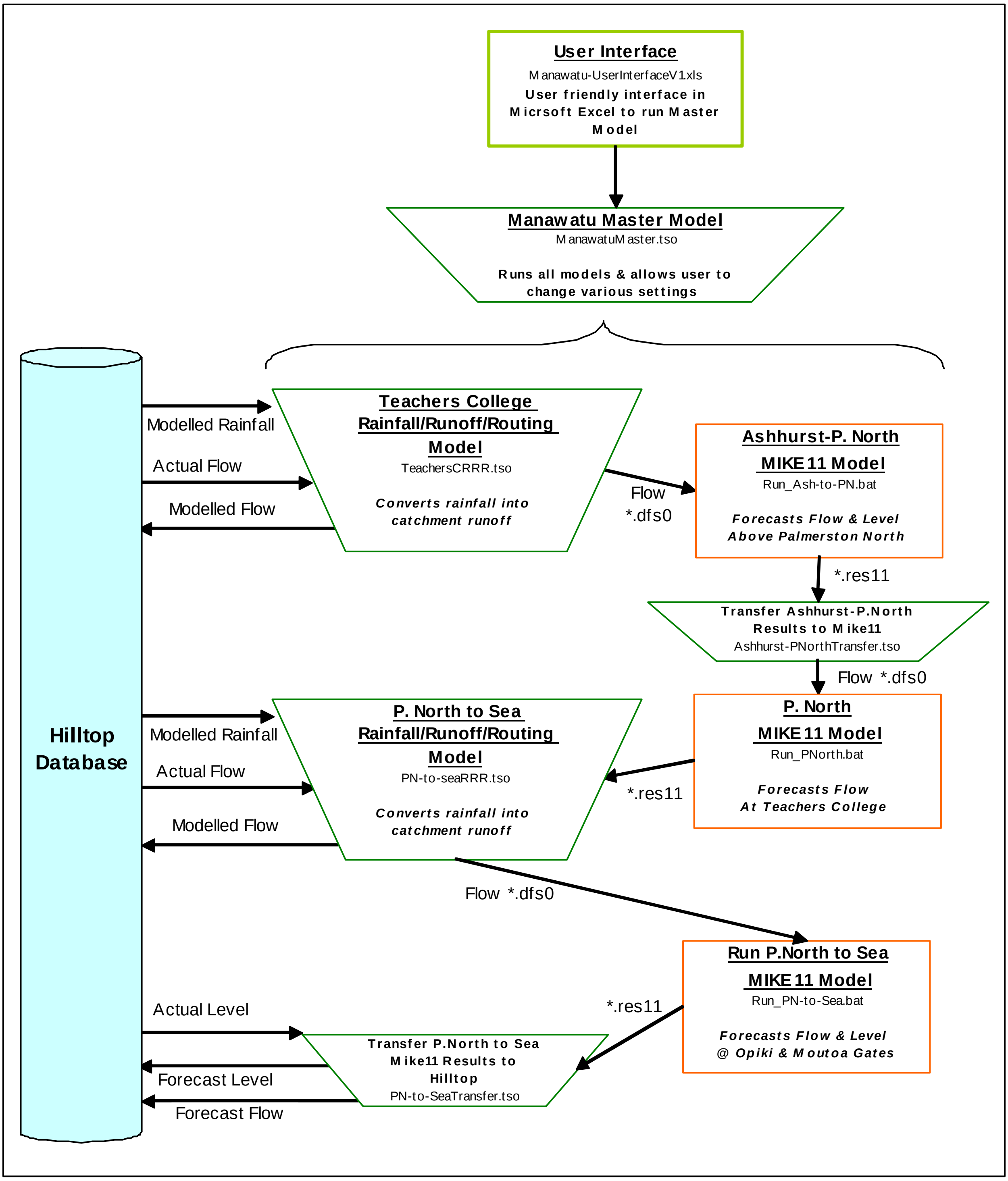


Figure 2-2 System Overview

3 SYSTEM INSTALLATION

Installation of the flood forecasting system onto a local workstation is performed in this way;

(1) Install Hydstra Modelling if it isn't already. Use the default install directory of 'C:\HydstraTSM\'.

(2) Install MIKE11 if it isn't already. Use the default install directory of 'c:\Program Files\DHI\'.

(3) Install Hilltop if it isn't already. Use the default install directory of 'C:\HILLTOP\'.

(4) Install the HRC Flood Forecasting System Models and associated files

   a. Copy the directory from the CD (eg 'D:\HRCFloodFS\...') to 'C:\HRCFloodFS\...'

(5) Setup Hydstra Modelling to read and write hilltop data by:

   a. Open: 'C:\HydstraTSM\Common.ini' in Notepad

   b. Add the following text:

      [Time Series Sources]

      Hilltop=C:\HRCFloodFS\Other\hydrolib.dll

      [Time Series Outputs]

      Hilltop=C:\HRCFloodFS\Other\hydrolib.dll

      Mike11dfs=C:\HRCFloodFS\Other\Mike11.dll

   Note the section headings: [Time Series Sources] and [Time Series Outputs] may already exist and therefore may not need adding.

   c. Save and exit Notepad

(6) Setup Hydstra Modelling to access the modelling library file by:

   a. Open: 'C:\HydstraTSM\Model.ini' in Notepad

   b. Under the '[Libraries]' section add the following text:

      Lib2=C:\HRCFloodFS\Other\Horizons.mlb

   c. Under the '[Setup]' section change the text 'NodeRadius=1.0' to:

      NodeRadius=0.5

   d. Save and exit Notepad

(7) Install Mike11 *.dfs0 output driver to allow Hydstra Modelling to output *.dfs0 files by:

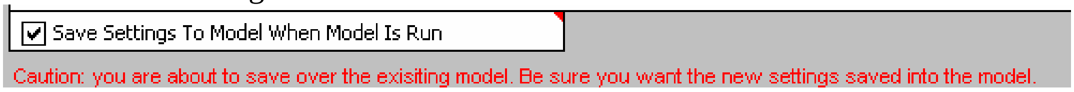
a. Run: ‘C\HRCFloodFS\Setup\MIKEObjectsTS_2004\setup.exe’

b. Use all default settings.

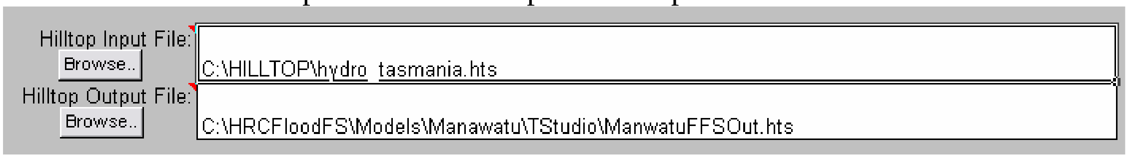
(8) Check that all linkages to the Hilltop database in each of the TimeStudio models to see they are connected to the correct *.hts file. A quick way to change these if required would be to:

a. Open the User Interface (C:\HRCFloodFS\Models\Manawatu\Manawatu-UserInterfaceV1.xls)

b. Check ‘Save Settings To Model When Model Is Run’ check box:



c. Enter the desired Hilltop databases for input and output:



d. Make sure the other model settings are correct as these will be saved into the model/s.

e. Press Run. The models will run and save the settings into the master model (C:\HRCFloodFS\Models\Manawatu\TStudio\ManawatuMaster.tso). Next time the master model is run the same settings will be applied.

(9) Done.

4 SYSTEM OPERATION

4.1 SINGLE RUN - NO INTERFACE

To run the flood forecasting system once, run:

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

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

4.2 SINGLE RUN - USER INTERFACE

The models can also be run via a user friendly interface with the added ability to change settings such as the hilltop file that the outputs are sent to (see Figure 4-1). To do this, open the spreadsheet:

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

Use the comments (red corners in cells) in the spreadsheet to assist in making selections/changes then press the run button to run the model.

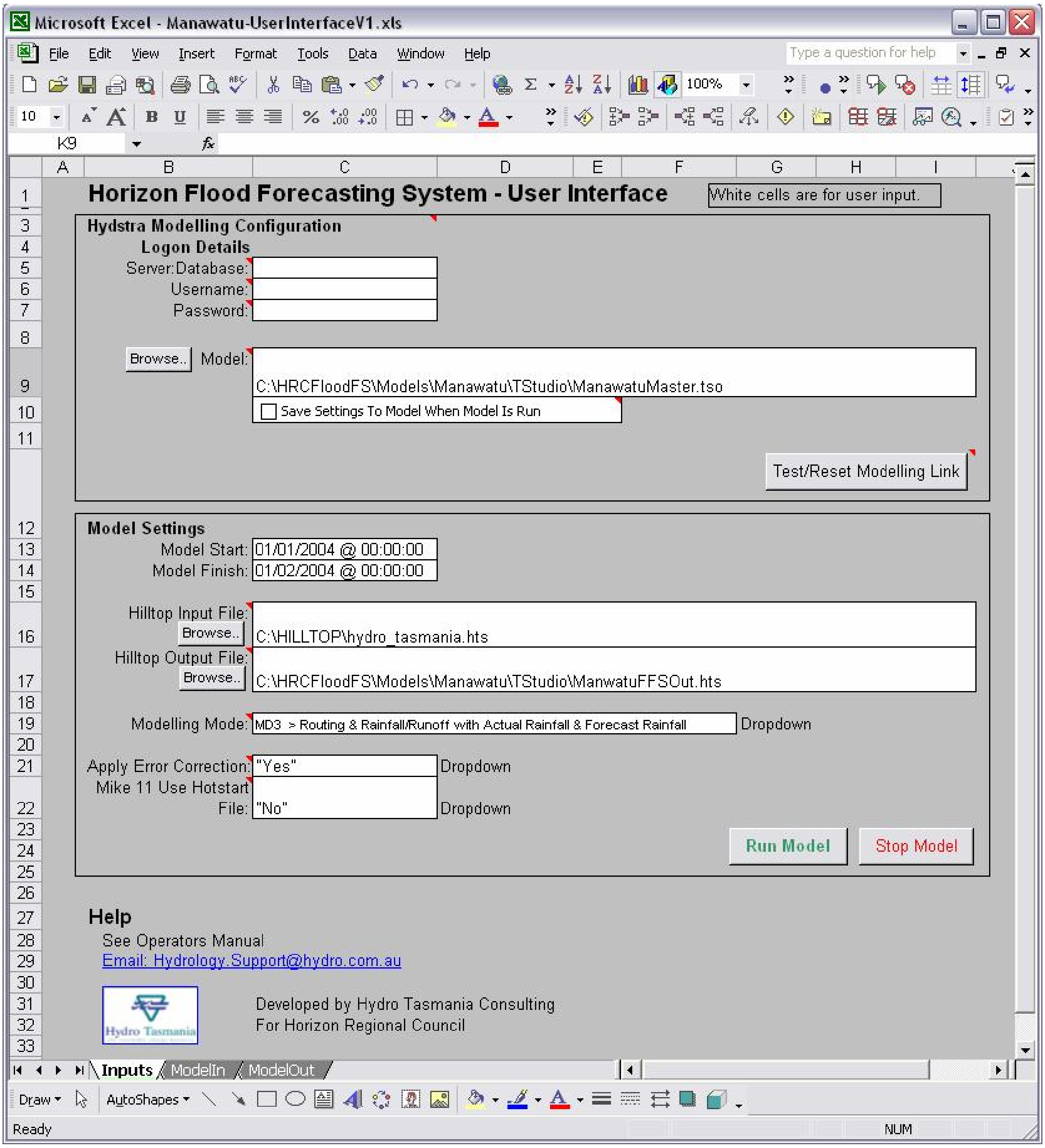


Figure 4-1 Screenshot of Manawatu-UserInterfaceV1.xls.

4.3 SCHEDULED RUNS

The flood forecasting system can be set up to run automatically on cycles using Windows Scheduled Task/s. To do this, copy task schedules from C:\HRCFloodFS\WindowsTaskSchedules\ to **Scheduled Tasks** in **Windows Control Panel.** Adjustments can be made to the scheduled task as desired. Eg run frequency adjusted from 15min.

5 HYDROLOGIC MODELS

5.1 HYDROMETRIC DATA

5.1.1 Evaporation Data.

Monthly Penman evapotranspiration totals were obtained from HRC at the nine sites listed below;

- D05383 Ballantrae, WOODVILLE
- D06212 DANNEVIRKE
- E05231 OHAKEA
- E05343 PALMERSTON N KAIRANG
- E05363 PALMERSTON NORTH
- E0536D Palmerston North EWS
- E05368 PALMERSTON NORTH AWS
- E05622 Levin MAF
- E05620 Levin AWS

Monthly averages were calculated at each site for the period of record and converted to daily values by simply dividing by the number of days in the relevant month. These values were then plotted to provide a representation of spatial variation in evapotranspiration over the catchment.

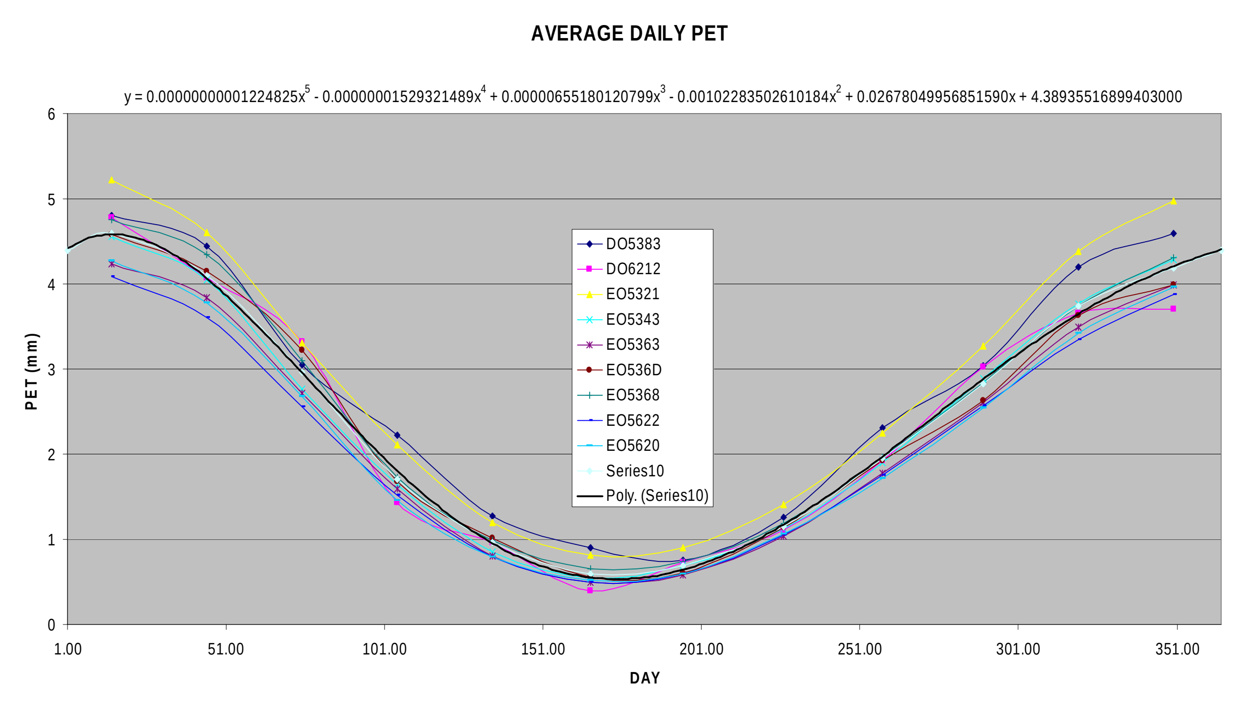


Figure 5-1 Average Potential Evapotranspiration Throughout A Year For Various Sites Around The Catchment

For the Stage 1 and 2 catchment (Manawatu R. between Upper Gorge and Sea) the evaporation of Palmerston North Airport (EO5368) was taken as representative. This is shown below in Table 5-1.

Table 5-1 Evapotranspiration Relationship Used In The Hydrologic Models.

Day of year	Evaporation (mm/d)
0.00000000	4.50
15.00000000	4.75
45.00000000	4.35
75.00000000	3.10
105.0000000	1.72
135.0000000	0.98
166.0000000	0.66
195.0000000	0.74
227.0000000	1.18
258.0000000	1.96
290.0000000	2.84
320.0000000	3.74
350.0000000	4.31
365.0000000	4.50

Note: 0 day and 365 day values are estimated based on the others.

This table is stored in a Hydstra Modelling library: C\HRCFloodFS\Other\Horizons.mlb

5.1.2 Rainfall Data

Rainfall data was provided by Horizons Regional Council (HRC) in a Hilltop Database. For the Stage 1 catchment (Manawatu R. between Upper Gorge and Teachers College) the sites in Table 5-2 were selected to be used in the model. For the Stage 2 catchment (Manawatu R. between Teachers College and Sea) the sites in Table 5-3 were selected to be used in the model.

Table 5-2 Rain Gauges Used In The Upper Gorge To Teachers College Hydrologic Model

Description	Easting (km)	Northing (km)	Mean Annual Rain (mm)
Makawakawa Devide Rain Gauge	2767.10	6119.60	3450.00
Tamaki Reserve Rain Gauge	2763.90	6122.10	2150.00
Alphabet Hut Rain Gauge	2753.90	6109.70	1290.00
Apiti Track Rain Gauge	2778.10	6124.20	1850.00
Delaware Ridge Rain Gauge	2768.50	6115.90	2200.00
Ohehua Repeater Rain Gauge	2758.10	6093.20	1350.00
Scotts Rd Rain Gauge	2728.80	6076.70	1800.00
Mangaone @ Milson L Rain Gauge	2731.10	6095.30	900.00
Valley Road Rain Gauge	2740.60	6108.10	1000.00
Rangiwahia Rain Gauge	2763.40	6141.90	1350.00
Ruaroa Rain Gauge	2768.2	6108.5	1500.00
Hutchinsons Rain Gauge	2758.1	6093.2	1100.00
Cheltenham Rain Gauge	2734.7	6117.8	950.00
Rangitikei Rain Gauge	2770.7	6158.7	1100.00

Table 5-3 Rain Gauges Used In The Teachers College to Sea Hydrologic Model.

Description	Easting (km)	Northing (km)	Mean Annual Rain (mm)
Rangiwahia	2763.4	6141.9	1350
Delaware Ridge	2763.9	6122.1	2200
Scotts Road	2728.8	6076.7	1800
Okuku Pump Track	2714.7	6073.2	900
Mangaone At Milsons Line	2731.1	6095.3	900
Valley Road	2740.6	6108.1	1000
Cheltenham	2734.7	6117.8	950
Feilding Halcombe Rd	2725.5	6109.3	900
Upper Mangahao	2719.6	6061.6	2870
Moutoa	2711	6076.6	900
Alphabet Hut	2753.9	6109.7	1290
Kakariki	2731.7	6068.5	2680
Forest Rd	2701.9	6103.5	900
Rangitikei (New)	2770.725	6158.733	1100

5.1.3 Flow Data

Flow data was provided by Horizons Regional Council (HRC) in a Hilltop Database. Relevant flow data was used to calibrate the hydrologic models. This is discussed in Section 5.2.3 below.

5.2 MODEL DEVELOPMENT

5.2.1 Subcatchment Delineation

Subcatchment delineation was performed using CatchmentSIM GIS software.

CatchmentSIM is a freely available 3D-GIS topographic parameterisation and hydrologic analysis software. The model automatically delineates watershed and subcatchment boundaries, generalises geophysical parameters and provides in-depth analysis tools to examine and compare the hydrologic properties of subcatchments. The model also includes a flexible result export macro language to allow users to fully couple CatchmentSIM with any hydrologic modelling package that is based on subcatchment networks.

The software is tailored towards full coupling with third party hydrologic models by:

- Firstly, CatchmentSIM is used to delineate a catchment, break it up into numerous subcatchments, determine their areas and spatial topographic attributes and analyse each subcatchment's hydrologic characteristics to provide insight into the rainfall response of various catchments and resultant assignment of hydrologic modelling parameters.

- Following this, the derived subcatchments and their attributes may be directly imported into any third party hydrologic model. This is achieved by a flexible result export macro language with specifically developed macro scripts enabling automatic development on input files (text or binary) for other models.

CatchmentSIM can be thought of as a collection of topographic and hydrologic analysis algorithms that have been purpose built for the process of hydrologic analysis and included in a Windows based user-friendly GIS environment. The program has not been intended to be a 'black box' application and as such, all algorithms are described from a conceptual perspective in the user manual.

For more detailed information on CatchmentSIM see the CatchmentSIM Homepage www.toolkit.net.au/catchsim/

The results of the subcatchment delineation for the Stage 1 catchment (Manawatu R. between Upper Gorge and Teachers College), in terms of subcatchment and junctions properties and their linkages, are given in the Appendix.

5.2.2 Hydstra Model

A computer simulation model was developed using Hydstra Modelling. The sub-catchments, described above, were represented by model "nodes" and connected together by "links".

For the Stage 1 catchment (Manawatu R. between Upper Gorge and Teachers College) a schematic of this model is displayed in Figure 5-2. For the Stage 2 catchment (Manawatu R. between Teachers College and Sea) the sites in Table 5-3 were selected to be used in the model.

The rainfall is calculated for each subcatchment by interpolating rainfall from surrounding gauges. The AWBM rainfall/runoff model converts this rainfall to runoff and then this flow is routed through the subcatchment via a catchment routing function and then routed through the rest of the main channel via a channel routing function. This process is discussed in detail in the following sections.

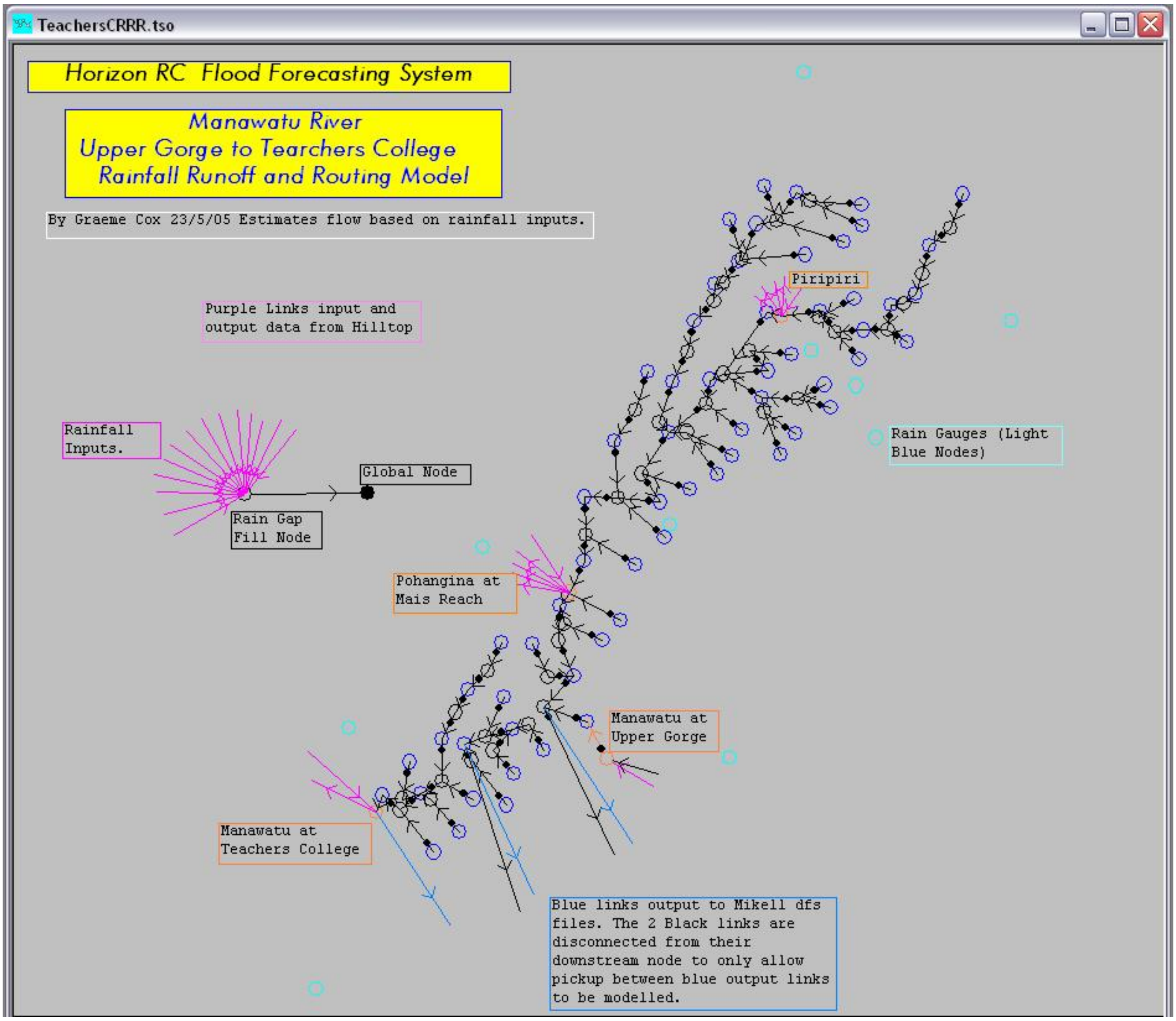


Figure 5-2 Upper Gorge To Teachers College Hydrologic Model Schematic

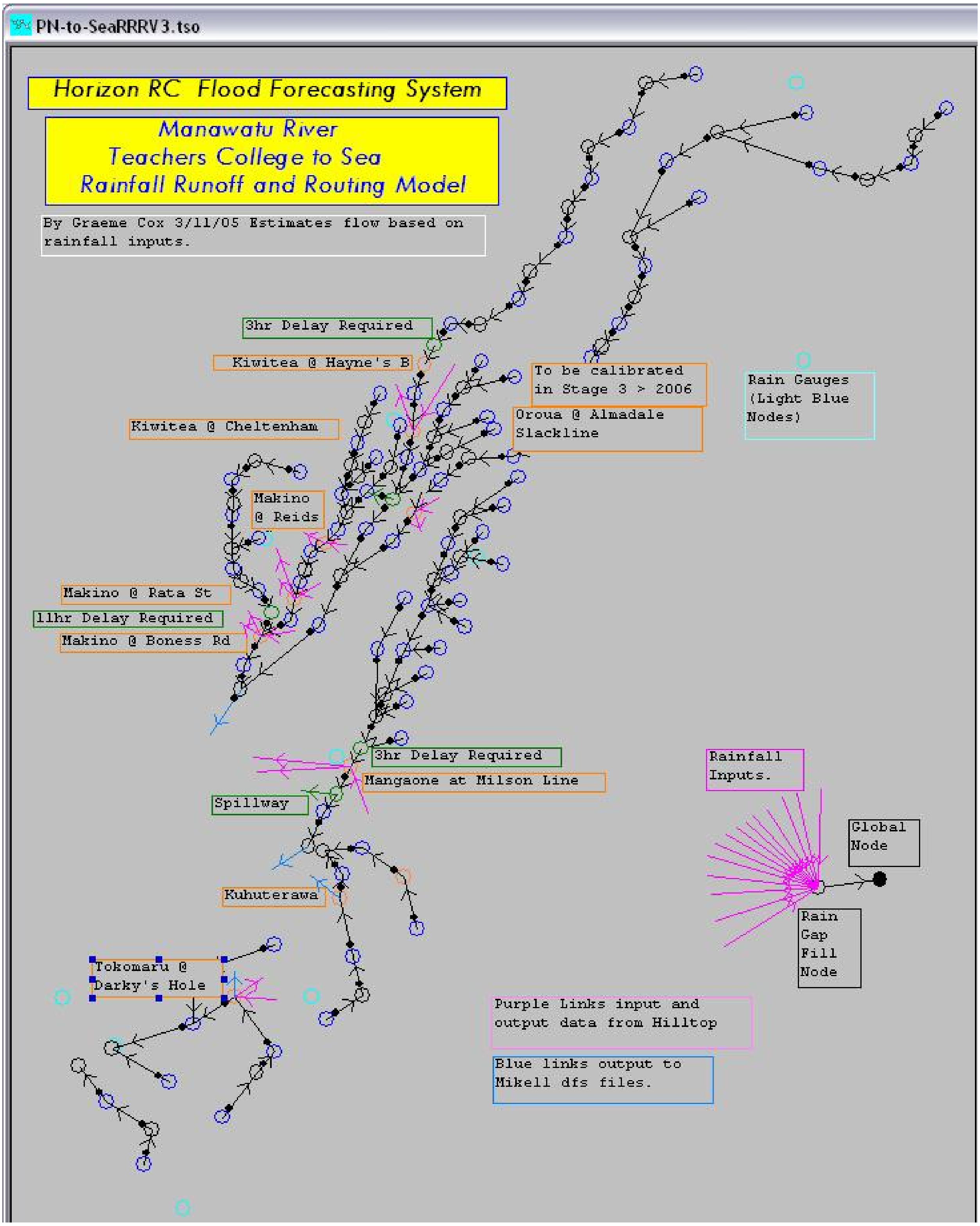


Figure 5-3 Teachers College to Sea Hydrologic Model Schematic

5.2.2.1 Rainfall Gap Filling Algorithm

If rainfall data for one of the input gauges was null (a gap) it was filled using inverse-distance gauge weighting algorithm (FillRain Node). The weighting is computed for each 6 minute time step. A quadrant system is drawn, centred on the gauge Easting and Northing. A weight for the closest gauge in each quadrant that has a rainfall reading is computed as the inverse, squared, distance between the target gauge and weighted gauge. This weight is then adjusted by the fraction of the target gauge mean annual rainfall to the weighted gauge mean annual rainfall, to account for the significant variation in mean annual rainfall across the catchment. See the model node for more details.

A 'Threshold' algorithm was adopted 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.

5.2.2.2 Rainfall Interpolation Algorithm

The rainfall is calculated for each subcatchment using inverse-distance gauge weighting. The gauge weights were automatically calculated at the start of each model run. The weighting is computed for the centroid of the subcatchment. A quadrant system is drawn, centred on the subcatchment centroid. A weight for the closest gauge in each quadrant is computed as the inverse, squared, distance between the gauge and centroid. This weight is then adjusted by the fraction of the subcatchment centroid mean annual rainfall to the gauge mean annual rainfall, to account for the significant variation in mean annual rainfall across the catchment. For each time step and each node, the gauge weights are applied to the incoming rainfall data.

5.2.2.3 Rainfall/Runoff Algorithm

The Australian Water Balance Model (AWBM) was applied to calculate the runoff based on the rainfall inputs. 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.

The AWBM processes are shown schematically in Figure 5-4.

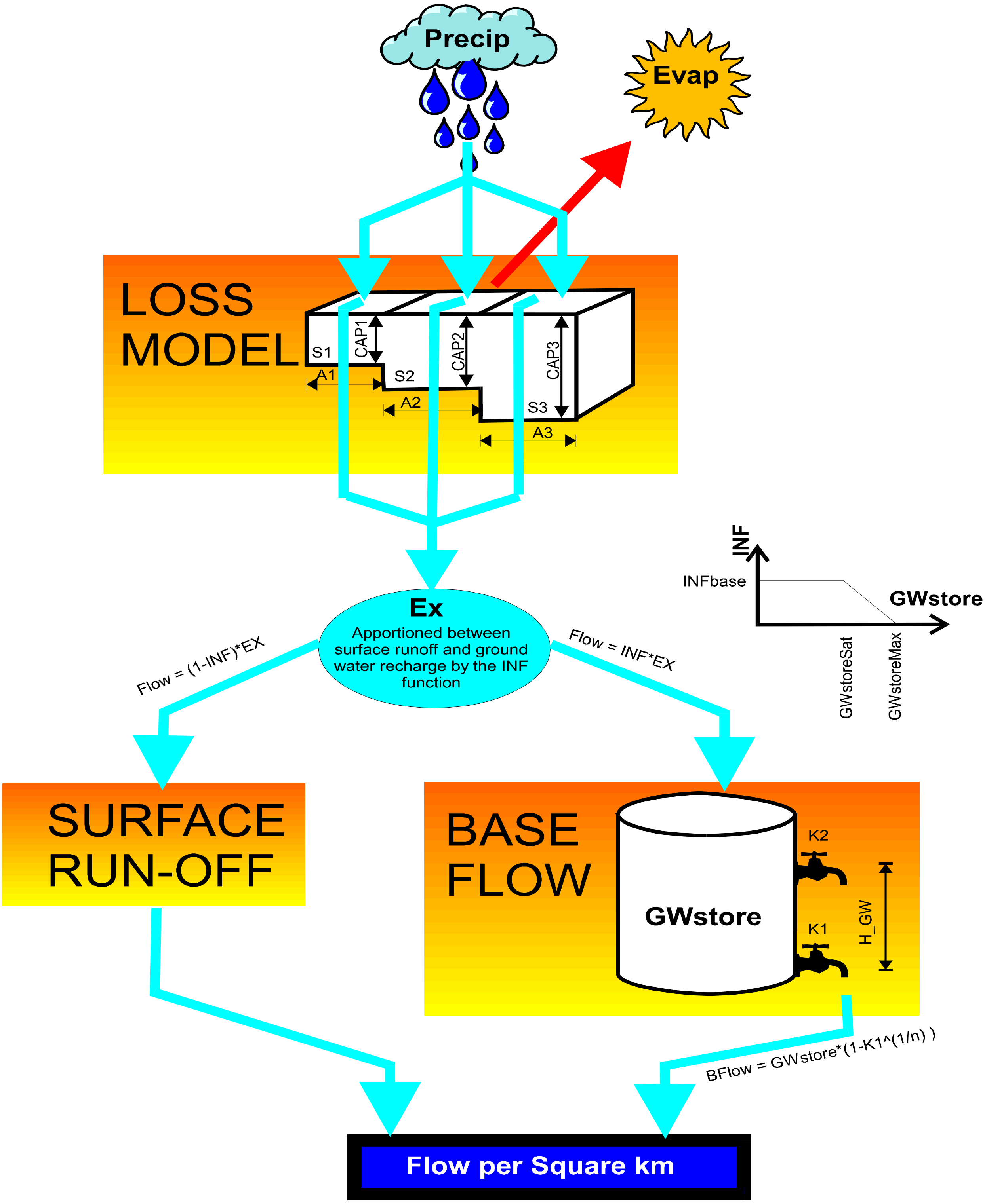


Figure 5-4 Australian Water Balance Model Schematic

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

An AWBM model was coded into each subcatchment separately. This was chosen over the usual method of a single AWBM model for the whole catchment as it more accurately distributes the runoff and base flow spatially over the catchment.

5.2.2.4 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. 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:

$Sc = K.Q^m$ (Pilgrim, 1987)

where:

$K = \beta.A^{0.5}$ (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 *TimeStudio* Modelling and their suggested bounds are:

□	Catchment Lag Parameter	Between 0.0 and 5.0
A	Sub-catchment Area (km2)	Greater than 0.0 (km2)
m	Non-linearity Parameter	Between 0.0 and 1.0

5.2.2.5 Channel Routing Algorithm

A common method employed in nonlinear routing models is a power function storage relation.

$$S = K.Q^n$$

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

$$K = \alpha . L_i$$

and

L_i = Channel length (km)
α = Channel Lag Parameter
n = Non-linearity Parameter
Q = Outflow from Channel Reach (m3/s)

A reach length factor may be used in the declaration of α to account for varying reach lag for individual channel reaches. eg. α.fl where fl is a length factor.
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

5.2.2.6 Soil Moisture Measurement Assimilation

HRC measures soil moisture at a number of gauge stations. They requested HTC make use of this information if it improves the flow forecasting. HTC developed the following procedure to assimilate this data into the models:

1. Import soil moisture, modelled flow and measured flow time series for a particular gauge station into a spreadsheet. Data was aggregated to an hourly time step to keep the number of points manageable.
2. Filter out points which have modelled or measured flow less than a threshold (e.g. $10m^3/s$). This is most of the data. The reason for this is to focus on significant flow events only.
3. Calculate modelled flow error at each time step.
4. Plot soil moisture vs. modelled flow error.
5. If there is an obvious downward trend (i.e. low moisture measurements resulting in higher errors) then it is useful to apply a correction for this.
6. Fit a linear regression equation through soil moisture vs. modelled flow error.
7. Use this fitted equation to correct the modelled flow in real time during flood forecasting. This correction algorithm can be found in the relevant gauge station nodes in the Rainfall-Runoff-Routing model. The actual equations used can be found ‘Section 5.2.3 Model Calibrations’ below.

5.2.2.7 Forecast Error Correction Algorithm

During normal flood forecasting operation the models use an error correction algorithm to adjust the modelled flow to the measured flow at gauge stations. A simple decaying amplitude correction has been adopted for this system. More complicated correction techniques incorporating phase (timing) adjustment and higher order autoregressive (AR) models can be used but experience has shown these add little to forecast accuracy and can in many events reduce accuracy.

Each node in the Rainfall-Runoff-Routing models that corresponds to a gauge station (orange outline) has the algorithm coded into the rule. The node variables below define the potential settings.

Variable	Typical	Comment
ApplyErrorCorr_YN	"Y" or "N"	Allows user to turn error correction off if desired. Eg to test the model performance over an historical event.
StopErrorCorrXHrFromEnd	0	Allows user to test the performance of the models on historical data. Eg set it to 4hrs to see how well the model might predict a certain events with a lead time of 4 hrs. During normal forecasting operation this variable should be set to 0 to allow correction to be right up to the end of the model run (if data is available).
MinErrCorrFlow_cumec	0	Only apply the correction when observed flow is above a set threshold. This is intended for gauges which have unreliable lower end ratings.
ErrorCorrHalflife_hrs	12	Decay rate of error correction. Half the initial error correction magnitude will be applied at x hrs into the future. This is set depending on the autocorrelation of the error.

5.2.3 Model Calibrations

Calibration was achieved by adjusting catchment parameters so that the modelled data replicated the record at gauge stations:

- Pohangina River at Piripiri
- Pohangina River at Mias Reach
- Manawatu River at Teachers College

The results of calibration are shown in the following sections.

The technical performance of the hydrologic models was assessed in accordance with the performance criteria specified in Chinese Standards (2000). This criterion was used as it represents the only known standard method of assessing flood forecasting performance. The two key performance indicators specified in the Chinese Standards are the 'Coefficient of Determination' (CD), which is a measure of the goodness-of-fit between the recorded and predicted discharge time series data, and the 'Qualifying Rates' (QR) of predicted individual flood event peak discharges and volumes. Under this terminology, a forecast peak discharge or flood volume is termed 'qualified' when the difference between the predicted and recorded values is within 20%. 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 5-1.

Table 5-4 Accuracy Grading of Flood Forecast Elements

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.

Note, to calculate these performance indicators, the models were run over the designated analysis period in continuous mode, using all available rainfall records and with error correction turned off. This strictly gives an indication of 'nowcasting' ability without error correction, not forecasting ability because running the models in this fashion assumes complete future knowledge of rain gauge measurements which are not available in real time operation. In real flood forecasting operation the future rainfall is not know and so as the forecasting lead time increases (eg 4hrs, 8hrs, 12hrs out) the accuracy of the forecasts decrease and therefore the performance indicator results also decrease.

To give an indication of lead times for giving reasonable forecasts flood forecast for the Feb 2005 flood were simulated. To do this the model was run for a 4 month warm up period and when the hydrograph was about half way up the rising limb the rainfall and flow inputs were set to null to simulate forecasting into the future with no rainfall or flow information. The time it takes for the modelled hydrograph to peak from this time gives an indication of the catchment response/lag and therefore lead times for giving reasonable forecasts. These simulation results are presented in Figure 5-9, Figure 5-14 and Figure 5-19.

For each calibration point the following results are presented:

- Table of Calibrated Hydrologic Model Parameters,
- Table of Flood Forecasting Performance Indicators,
- Modelled Flow Vs Measured Flow Scatter Plot,
- Modelled Vs Measured hydrographs for the four or five largest flood events, (Rainfall from Makawakawa Divide Gauge is shown for reference - additional rain gauges are used in the modelling),
- Modelled Vs Measured hydrographs for an extended period (6 month). (Rainfall from Makawakawa Divide Gauge is shown for reference - additional rain gauges are used in the modelling),
- Autocorrelation function of discharge error time series to determine suitable value for error correction half life.
- Simulated Flood Forecast for the Feb 2005 flood to give an indication of lead times for giving reasonable forecasts.

5.3.2.1 Pohangina River at Piripiri

As expected the flood forecasting performance indicators for this catchment are not good because:

- It is a relatively small catchment which generally have faster response times and are harder to forecast,
- no rain gauges are within the catchment boundary,
- the flow rating for this site is very approximate, especially below $50m^3/s$ because of large movements of shingle in the river bed.

For the three largest events since 1990 the modelled hydrographs are reasonable.

Based on the autocorrelation plot (Figure 5-8), a suitable setting for the error correction half life at this gauge is 3.5hrs. Also due to the flow rating at this gauge being unreliable below about $50m^3/s$ the MinErrCorrFlow_cumec variable for this gauge node in the model is set to 50.

The simulated flood forecast in Figure 5-9 indicates the forecast hydrograph begins to recede approximately 40min out from when rainfall and flow inputs were set to null. This indicates that the lead time for giving reasonable forecasts is only 40min.

Table 5-5 Calibrated Hydrologic Model Parameters for Pohangina River at Piripiri

Parameter	Setting
CapAve	50
Cap1	0.075 * CapAve
Cap2	0.762 * CapAve
Cap3	1.524 * CapAve
INFbase	0.3
K1	0.9
K2	0.6
H_GW	60
GWstoreSat	40
GWstoreMax	50
GWstoreStart	0
A1	0.134
A2	0.433
A3	0.433
Beta	0.7
m	0.7
Alpha	0.3
n	0.7
EvapScaleF	1
RainScaleF	1

Table 5-6 Flood Forecasting Performance Indicators for Pohangina River at Piripiri

Analysis Start Date:	01/01/1995
Analysis End Date:	01/01/2005
No. Of Events#:	17
No. Of Qualified Events:	2
Qualifying Rate, QR:	12%
QR Accuracy Grading:	Less than C
Coeff. Of Determination, CD:	0.50
CD Accuracy Grading:	C
Lowest Accuracy Grading:	**Less than C**
Recommendation:	**Not recommended for use in flood forecasting**

#Based on Events Greater Than 90 m3/s with a minimum separation of 48hrs.

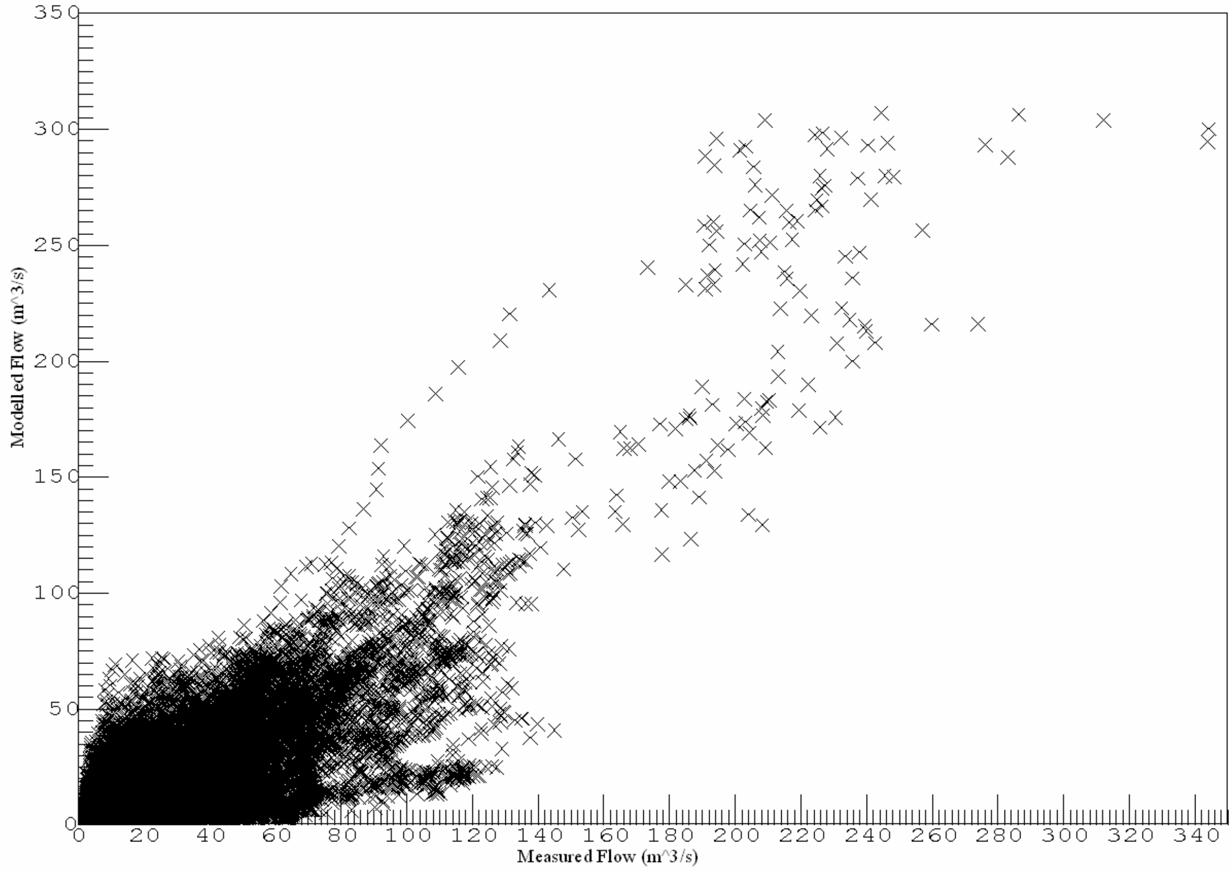
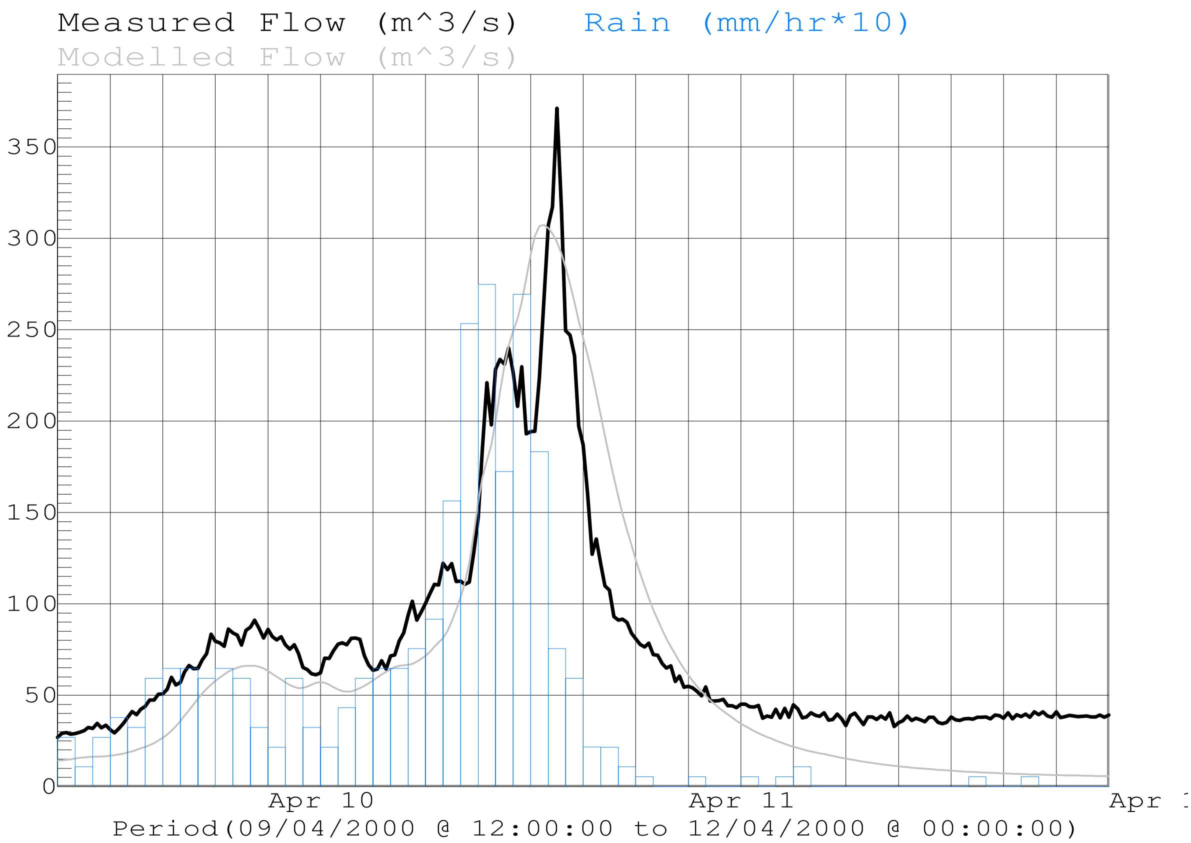
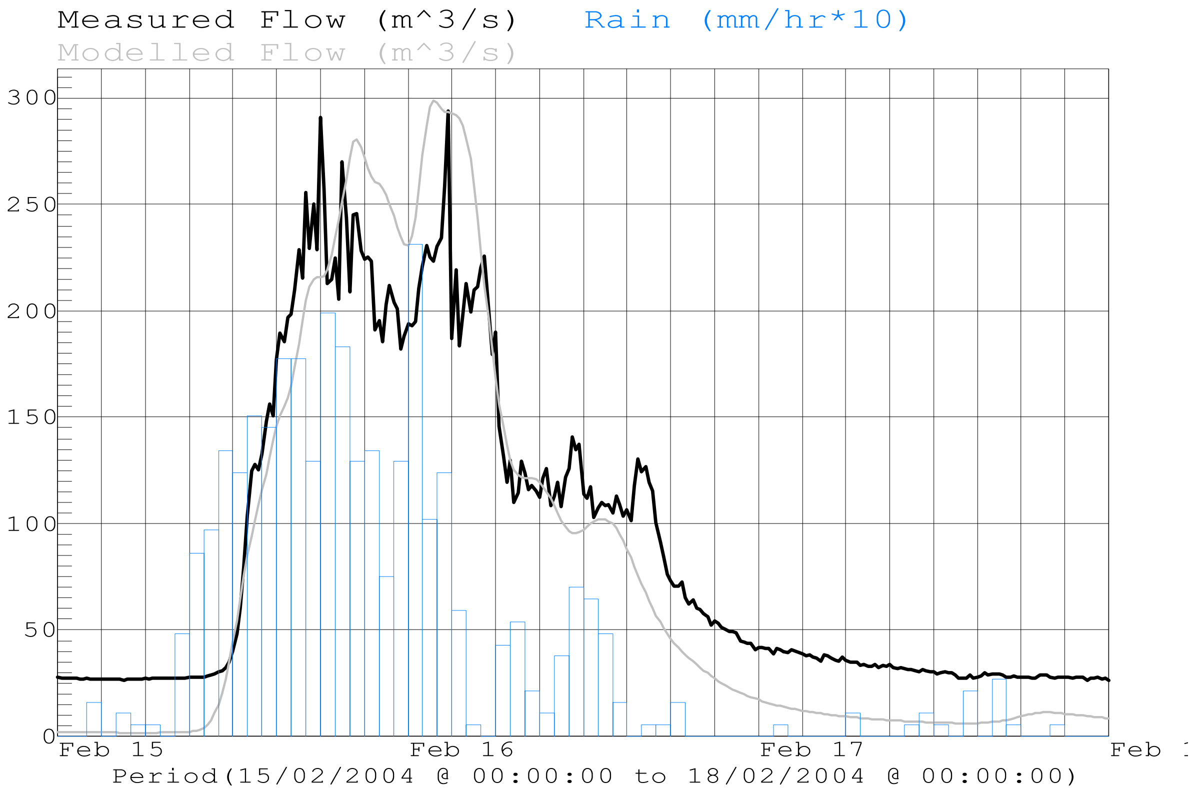
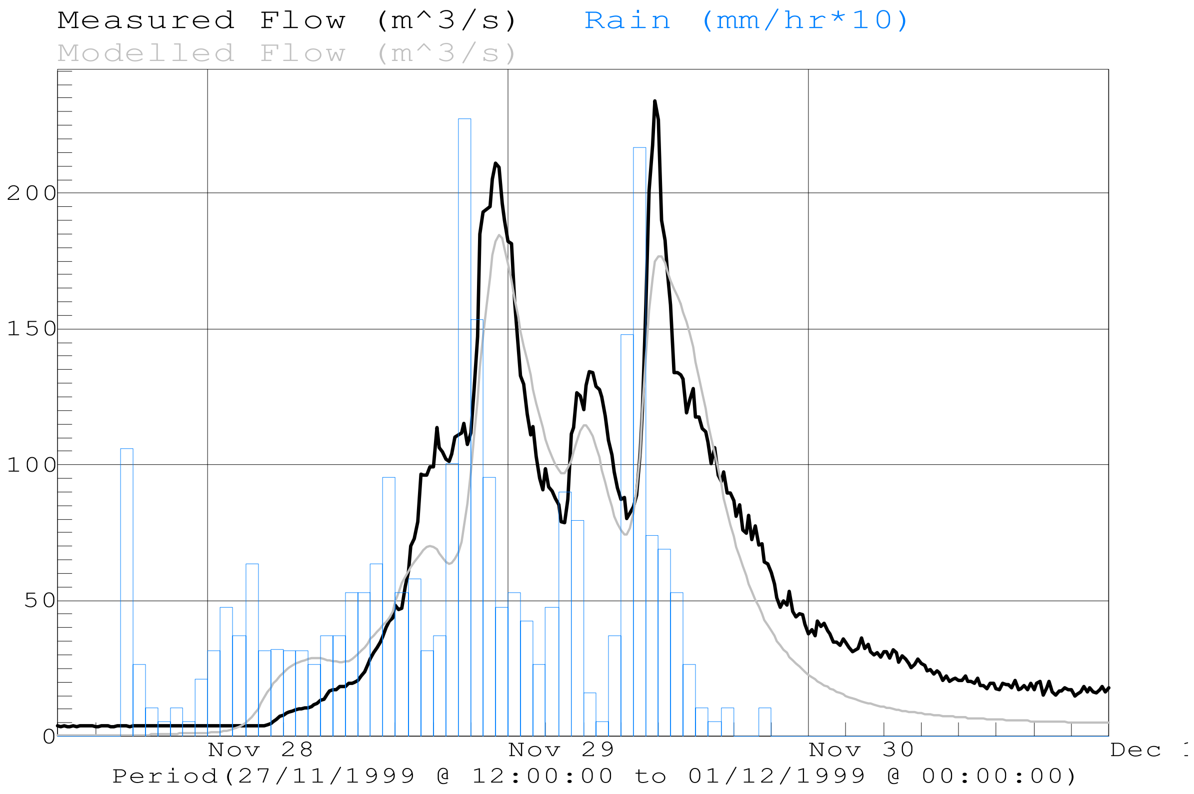
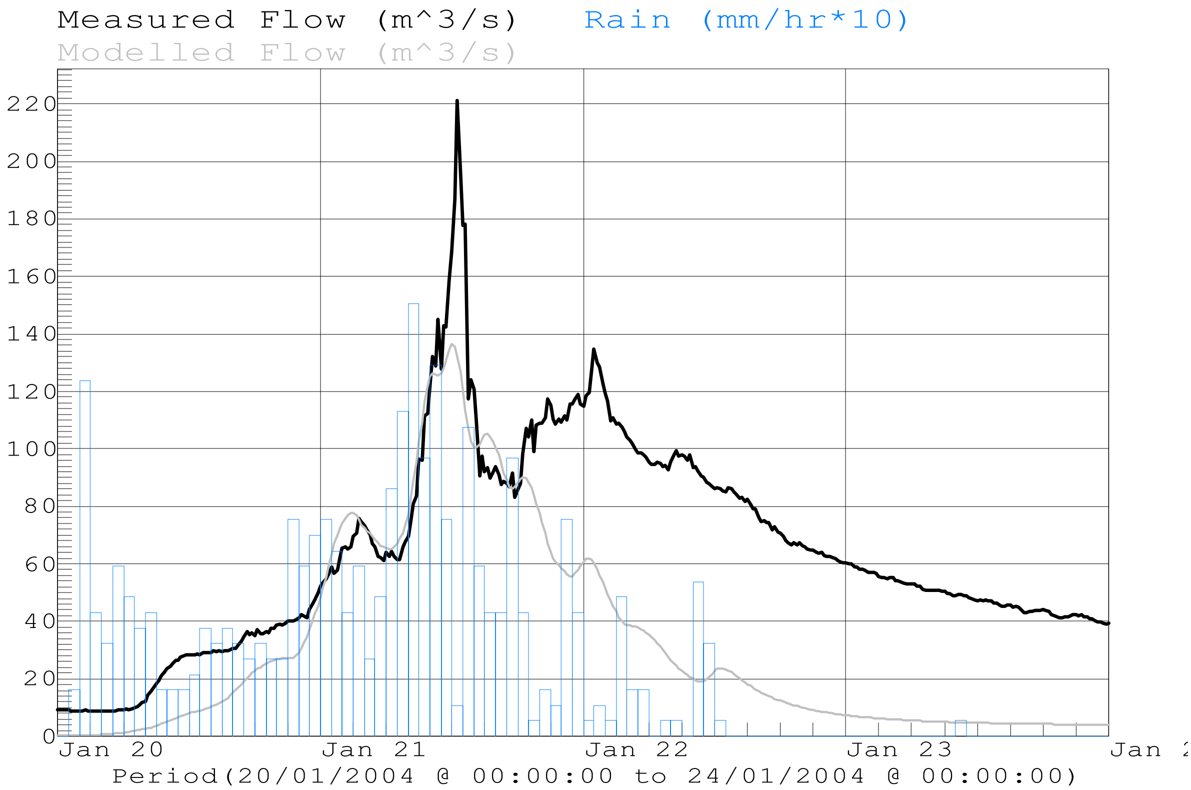


Figure 5-5 Modelled Flow Vs Measured Flow Scatter Plot For Pohangina River at Piripiri (1/1/1995-1/1/2005)




Measured Flow (m^3/s)
Rain (mm/hr*10)
Modelled Flow (m^3/s)
300
250
200
150
100
50
0
Feb 15
Feb 16
Feb 17
Period(15/02/2004 @ 00:00:00 to 18/02/2004 @ 00:00:00)


Measured Flow (m^3/s)
Rain (mm/hr*10)
Modelled Flow (m^3/s)
200
150
100
50
0
Nov 28
Nov 29
Nov 30
Period(27/11/1999 @ 12:00:00 to 01/12/1999 @ 00:00:00)



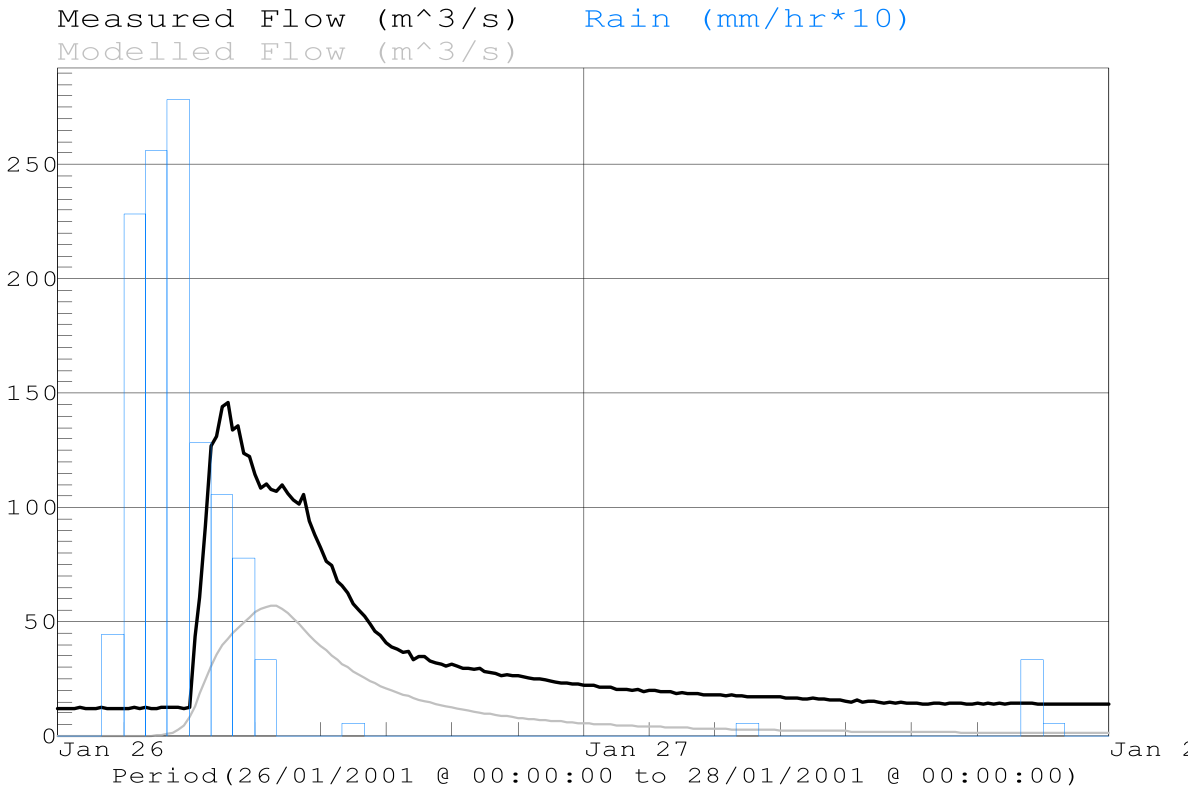


Figure 5-6 Modelled Vs Measured Hydrographs For Pohangina River at Piripiri (5 largest events from 1/1/1995- 1/1/2005).

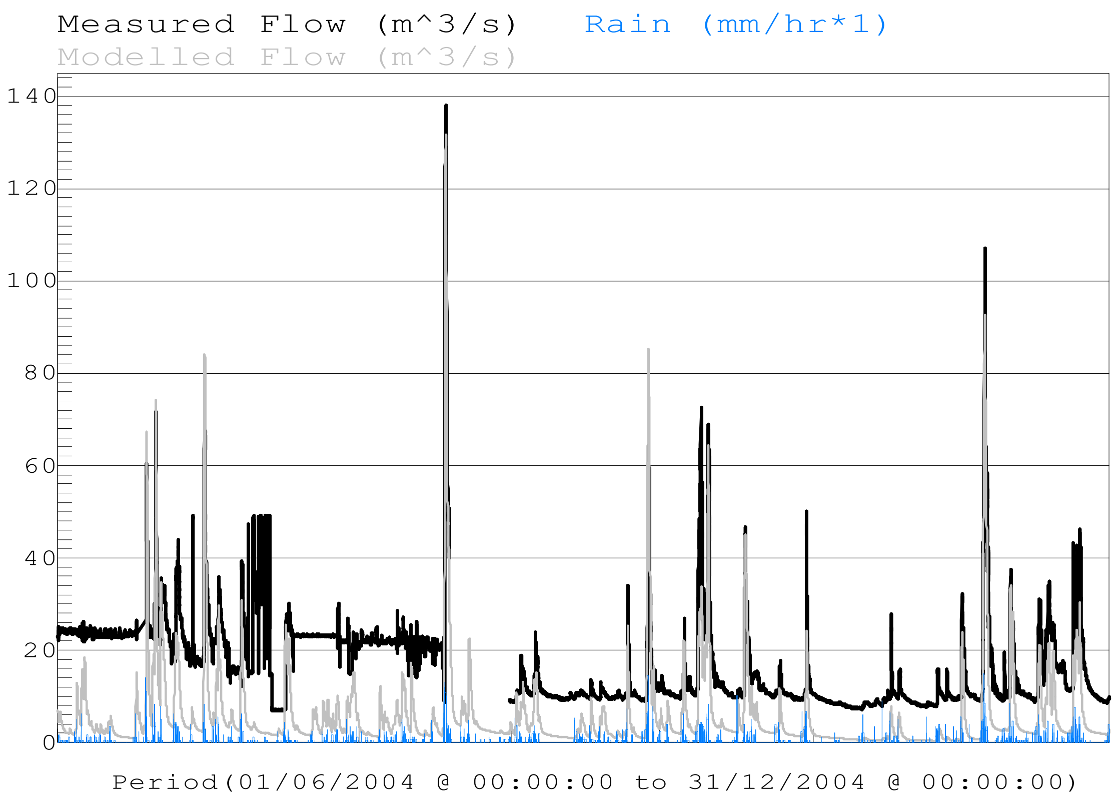


Figure 5-7 Modelled Vs Measured Hydrographs For Pohangina River at Piripiri from 1/6/2004 to 31/12/2004.

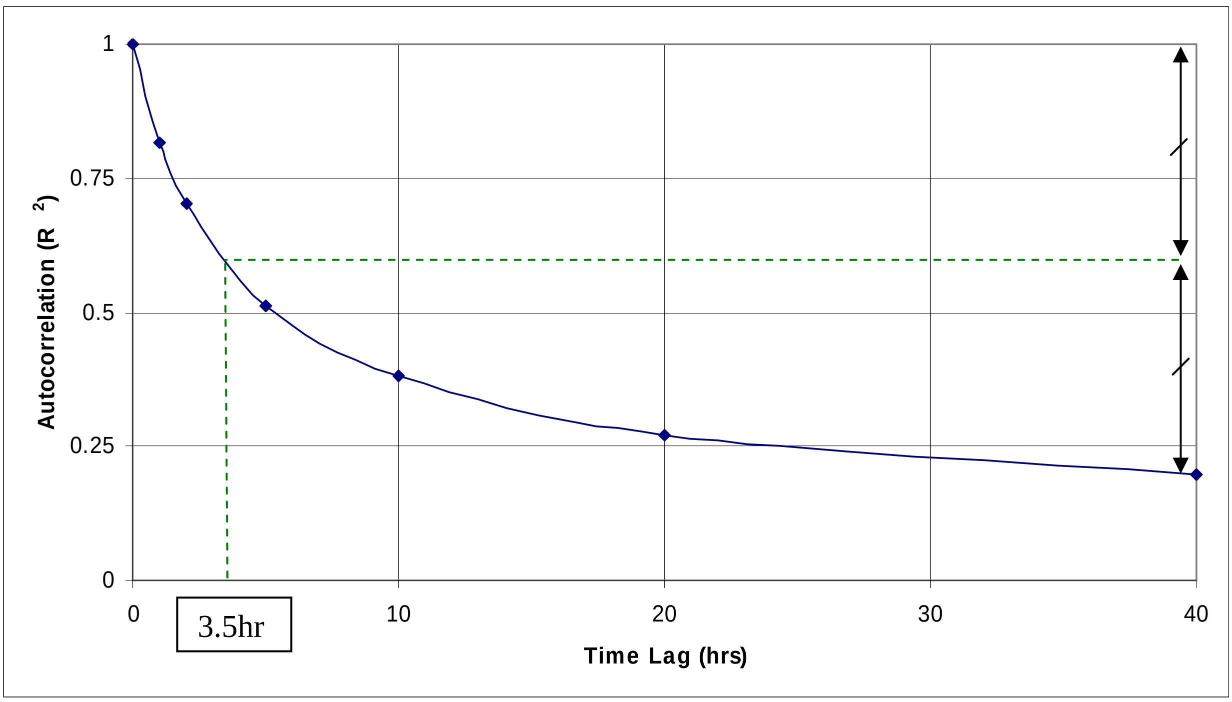


Figure 5-8 Autocorrelation function of the discharge error for Pohangina River at Piripiri from 1/1/1995 to 1/1/2005.

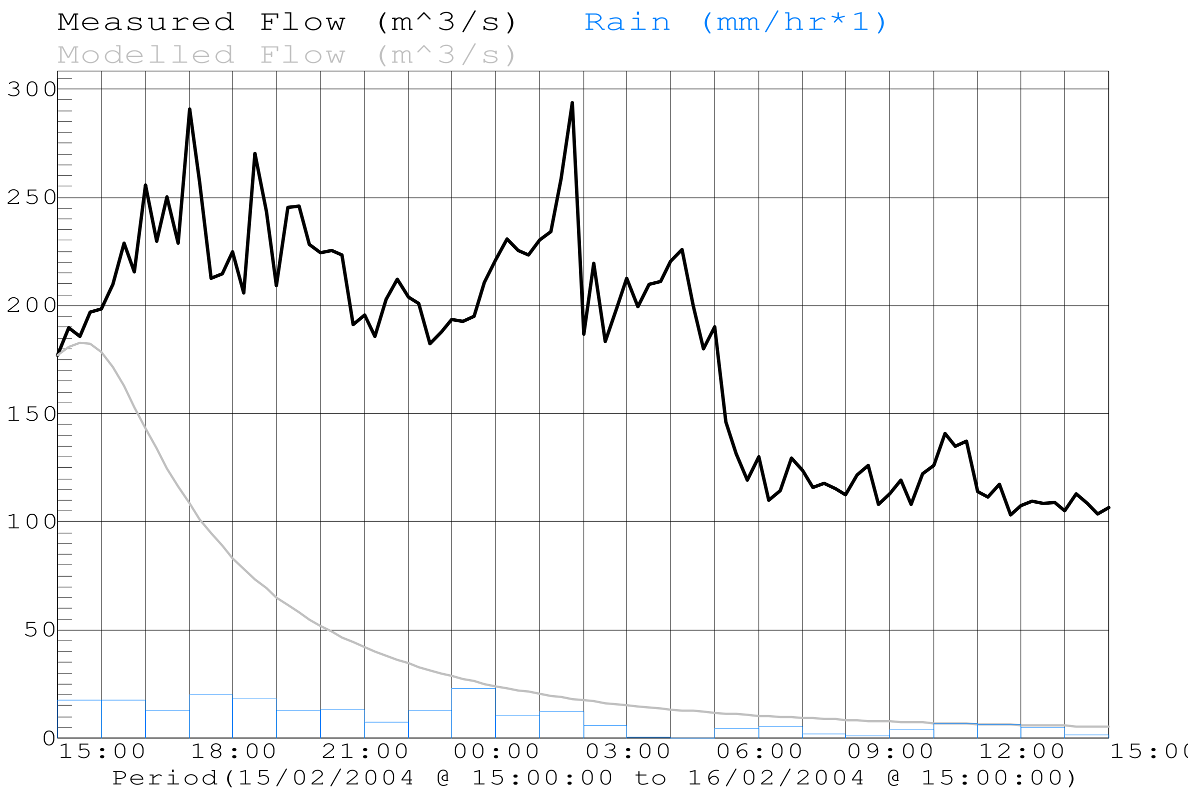


Figure 5-9 Simulated Flood Forecast for Pohangina River at Piripiri at 15:00 15/2/2005.

5.3.2.2 Pohangina River at Mias Reach

The flood forecasting performance indicators for this catchment are reasonably good because:

- it is a reasonable size catchment with significant routing effect,
- good spread of rain gauges within and outside the catchment boundary,
- the flow rating for this site is reasonable although movements of shingle in the river bed can cause significant shifts in the rating.

Based on the autocorrelation plot (Figure 5-13), a suitable setting for the error correction half life is 5hrs.

The simulated flood forecast in Figure 5-14 indicates the forecast hydrograph begins to recede approximately 1.5hrs out from when rainfall and flow inputs were set to null. This indicates that the lead time for giving reasonable forecasts is 1.5hrs.

Table 5-7 Calibrated Hydrologic Model Parameters for Pohangina River at Mias Reach

Parameter	Setting
CapAve	82
Cap1	0.075 * CapAve
Cap2	0.762 * CapAve
Cap3	1.524 * CapAve
INFbase	0.36
K1	0.92
K2	0.8
H_GW	20
GWstoreSat	50
GWstoreMax	70
GWstoreStart	20
A1	0.134
A2	0.433
A3	0.433
Beta	0.6
m	0.8
Alpha	0.5
n	0.7
EvapScaleF	1
RainScaleF	1.1

Table 5-8 Flood Forecasting Performance Indicators for Pohangina River at Mias Reach

Analysis Start Date:	01/01/1990
Analysis End Date:	01/01/2005
No. Of Events#:	17
No. Of Qualified Events:	14
Qualifying Rate, QR:	82%
QR Accuracy Grading:	B
Coeff. Of Determination, CD:	0.84
CD Accuracy Grading:	B
Lowest Accuracy Grading:	**B**
Recommendation:	**Suitable for making official forecasts**

#Based on Events Greater Than 300 m3/s with a minimum separation of 48hrs.

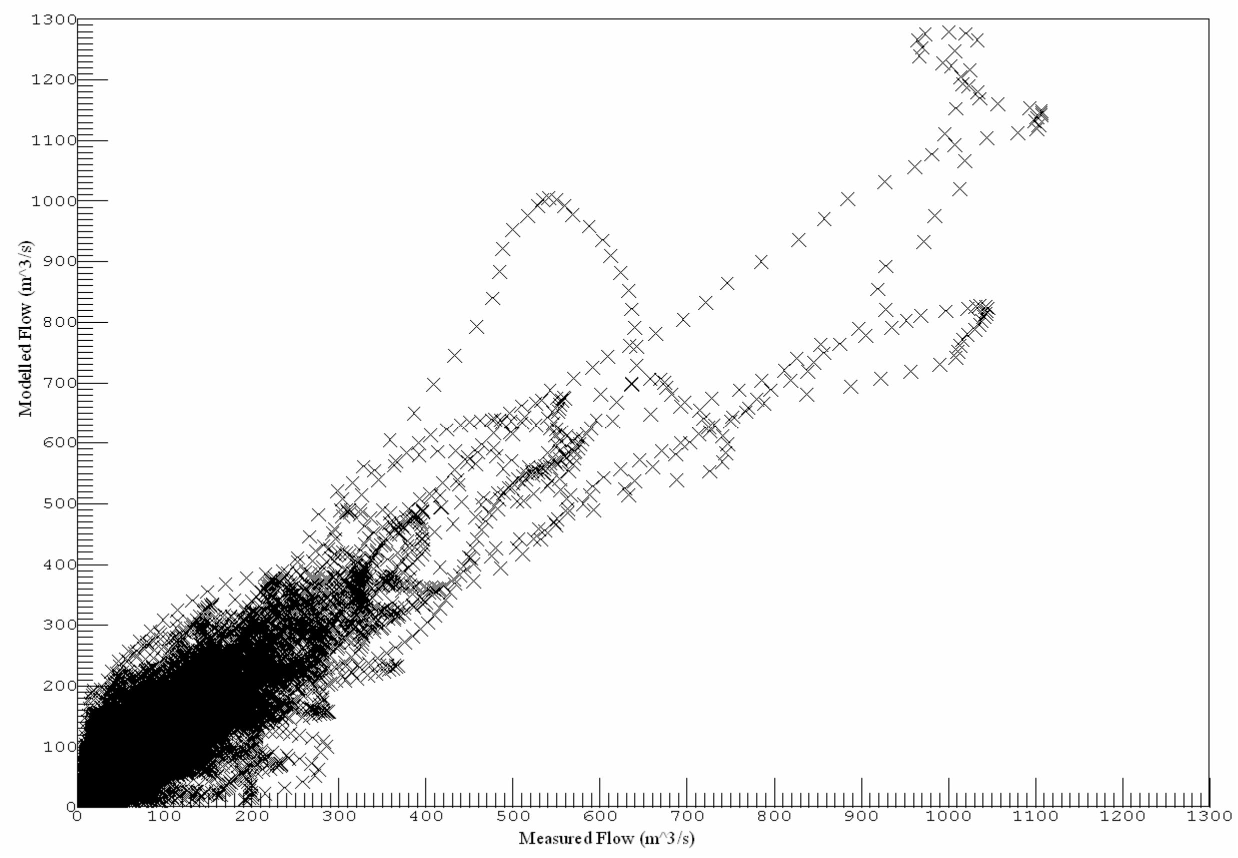
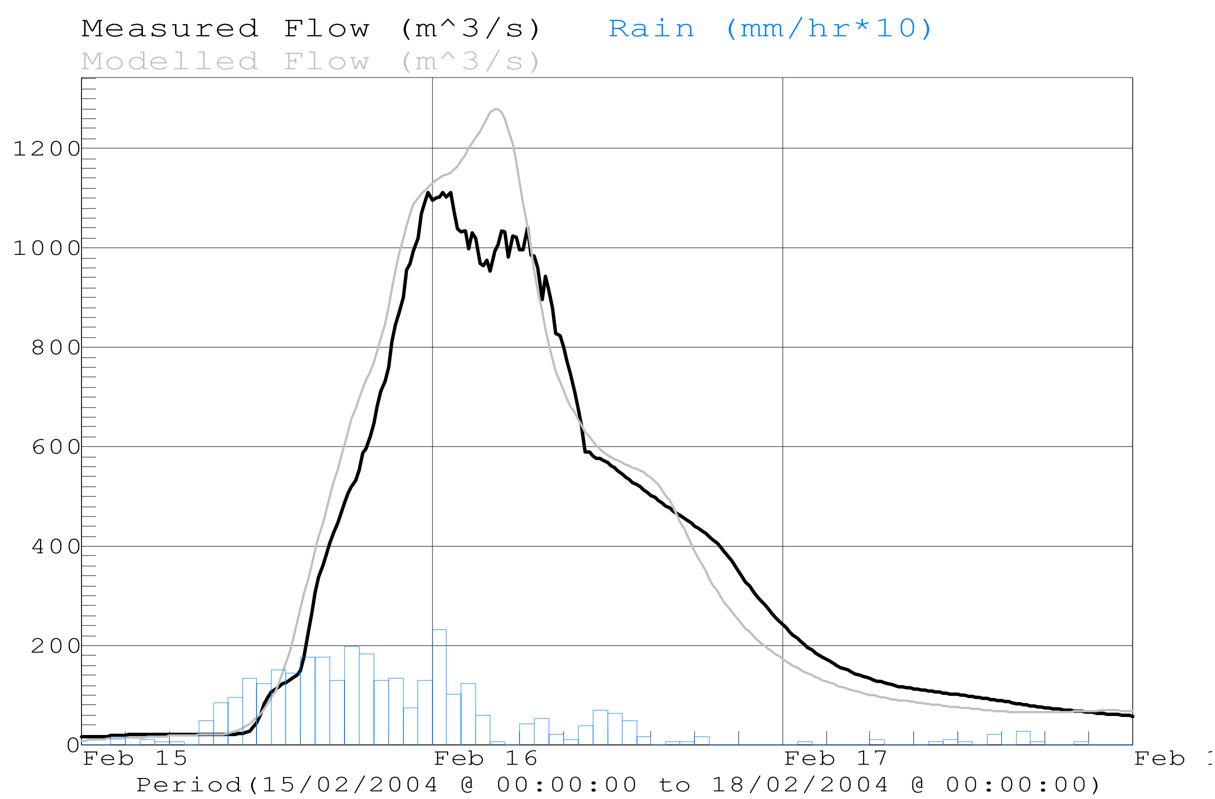
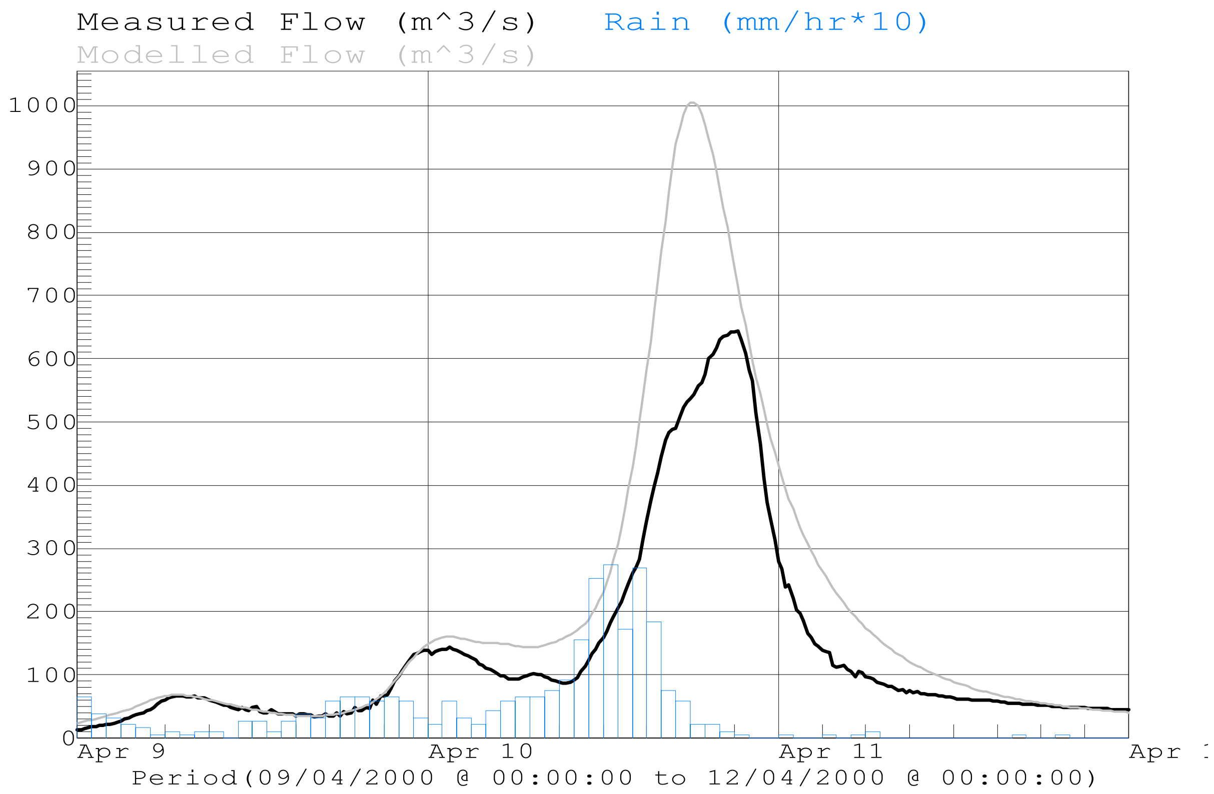
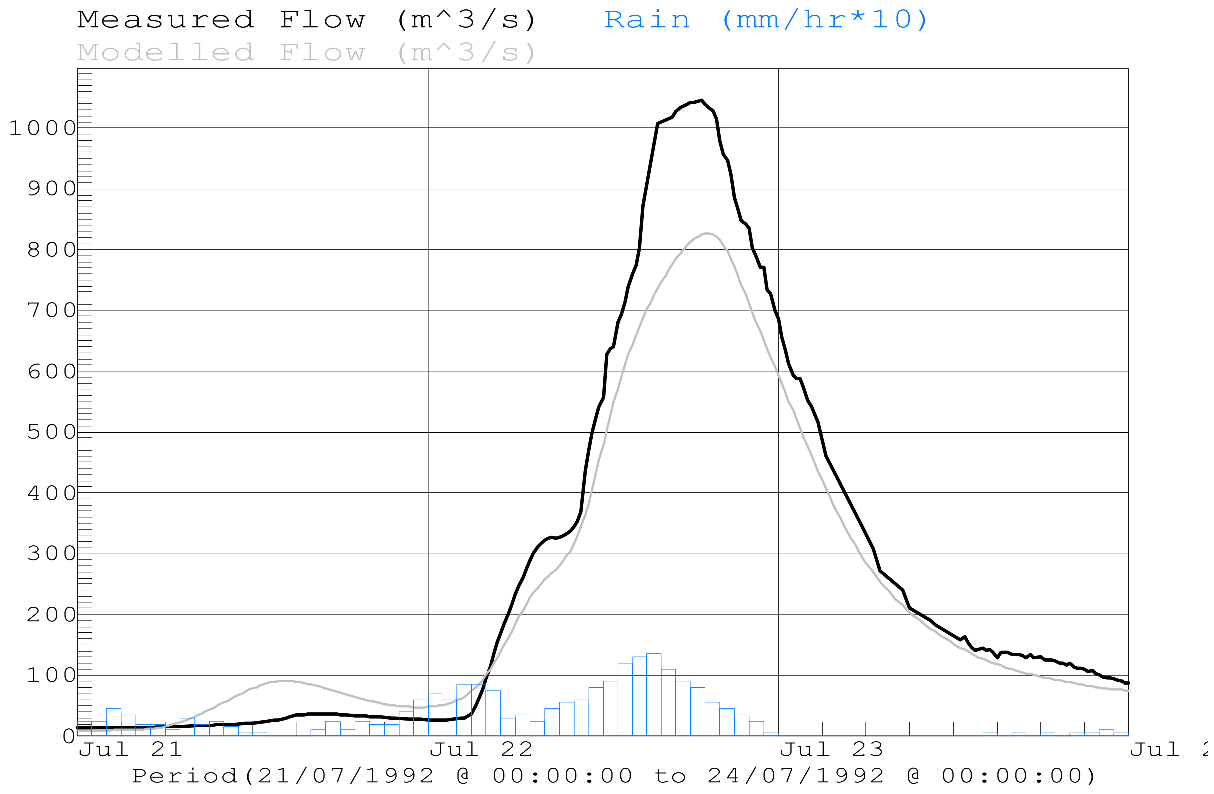
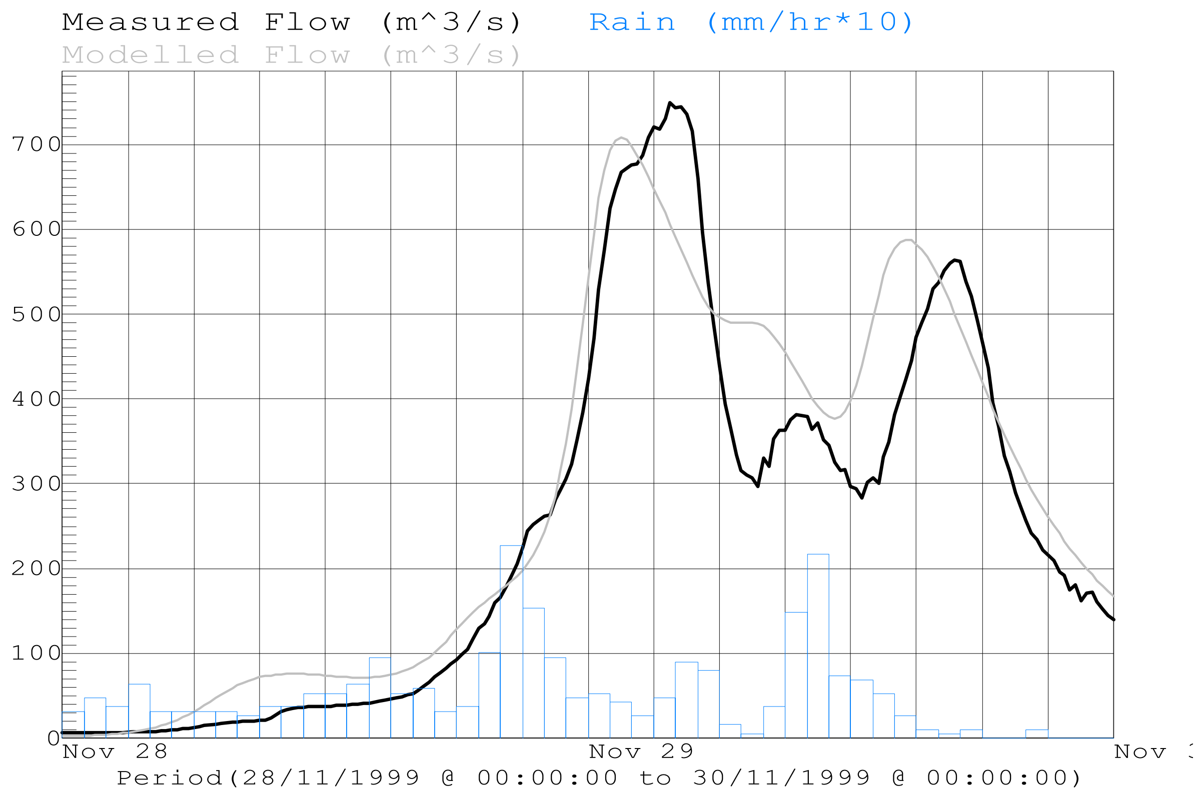


Figure 5-10 Modelled Flow Vs Measured Flow For Pohangina River at Mias Reach (1/1/1990-1/1/2005)




Measured Flow (m^3/s) Rain (mm/hr*10)
Modelled Flow (m^3/s)
1000
900
800
700
600
500
400
300
200
100
0
Apr 9
Apr 10
Apr 11
Period(09/04/2000 @ 00:00:00 to 12/04/2000 @ 00:00:00)


Measured Flow (m^3/s) Rain (mm/hr*10)
Modelled Flow (m^3/s)
1000
900
800
700
600
500
400
300
200
100
0
Jul 21
Jul 22
Jul 23
Period(21/07/1992 @ 00:00:00 to 24/07/1992 @ 00:00:00)



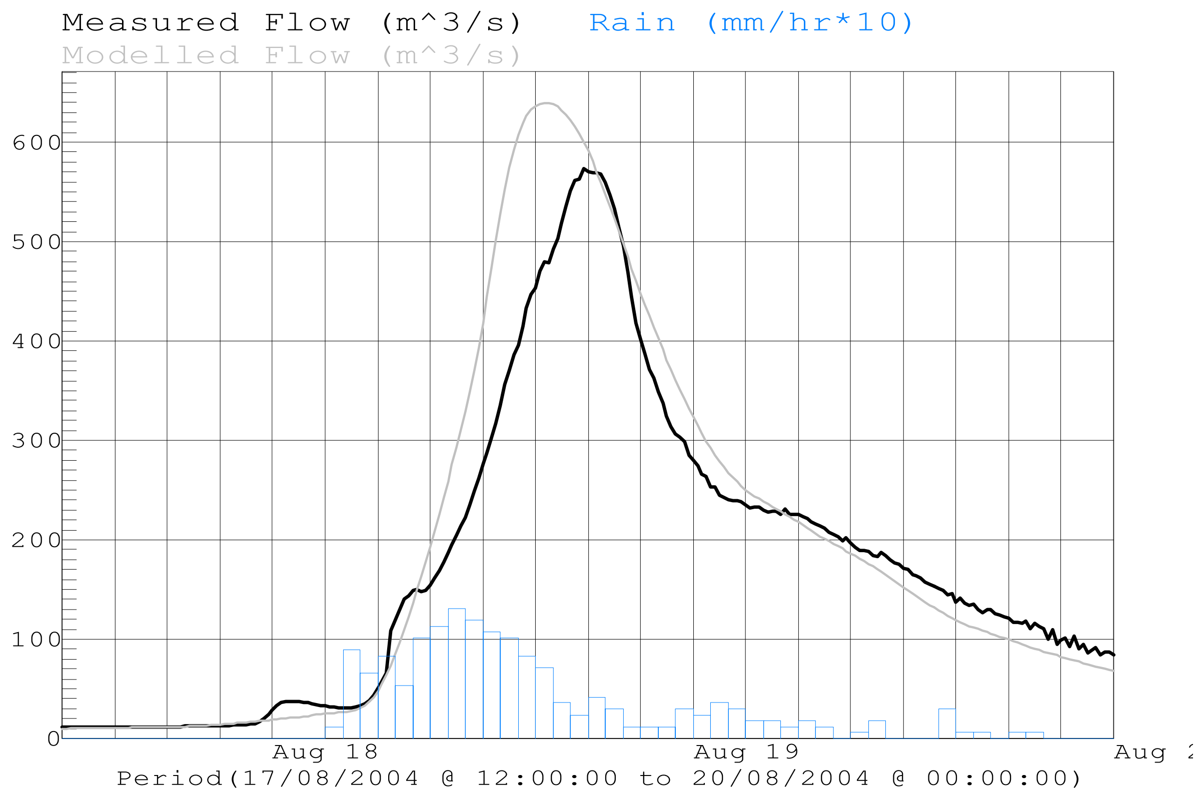


Figure 5-11 Modelled Vs Measured Hydrographs For Pohangina River at Mias Reach (5 largest events from 1/1/1990- 1/1/2005).

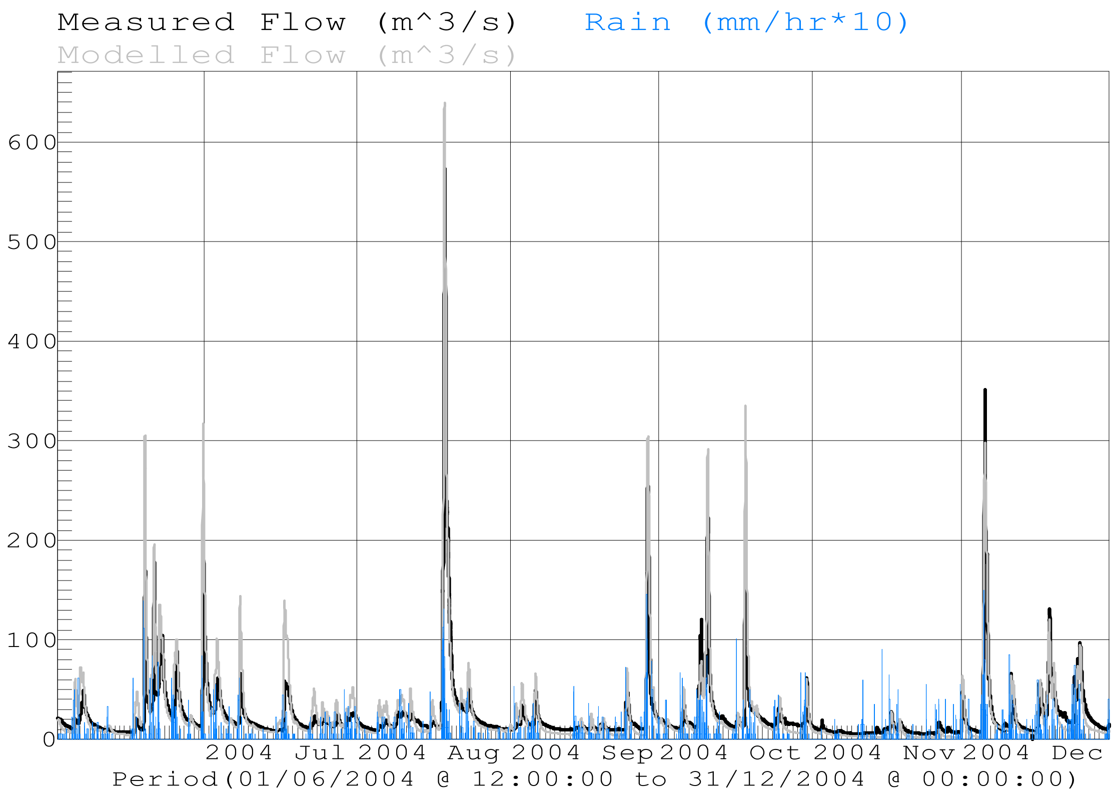


Figure 5-12 Modelled Vs Measured Hydrographs For Pohangina River Mias Reach from 1/6/2004 to 31/12/2004.

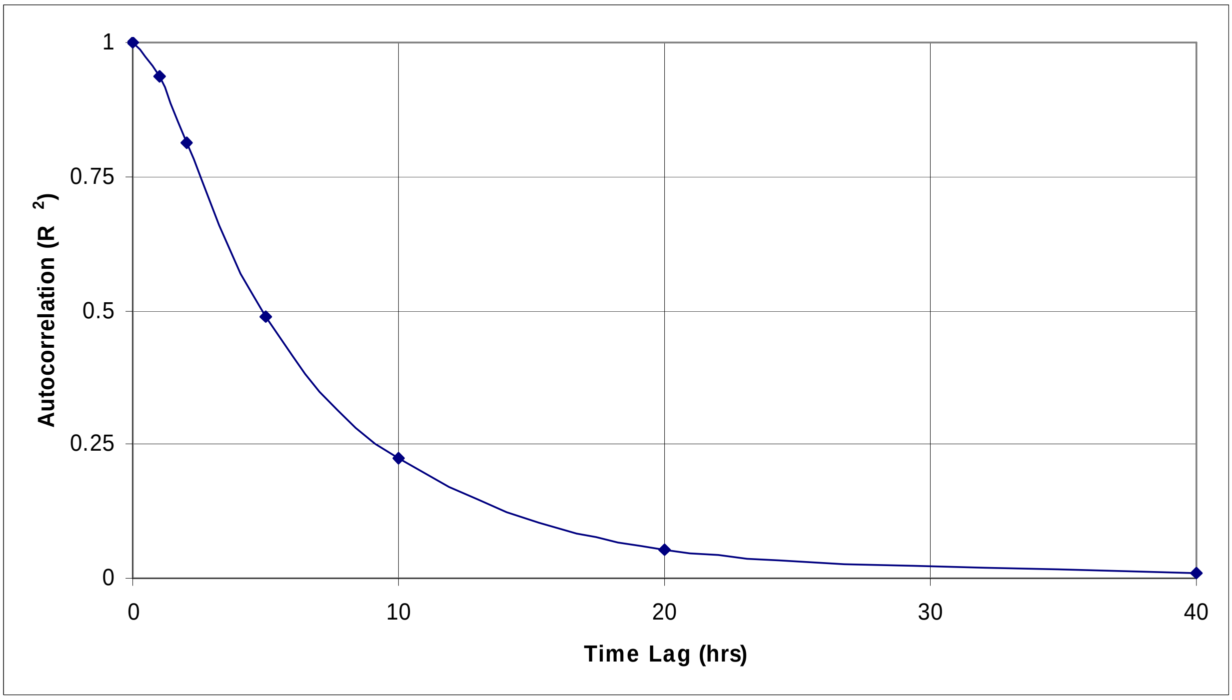


Figure 5-13 Autocorrelation function of the discharge error for Pohangina River Mias Reach from 1/1/1995 to 1/1/2005.

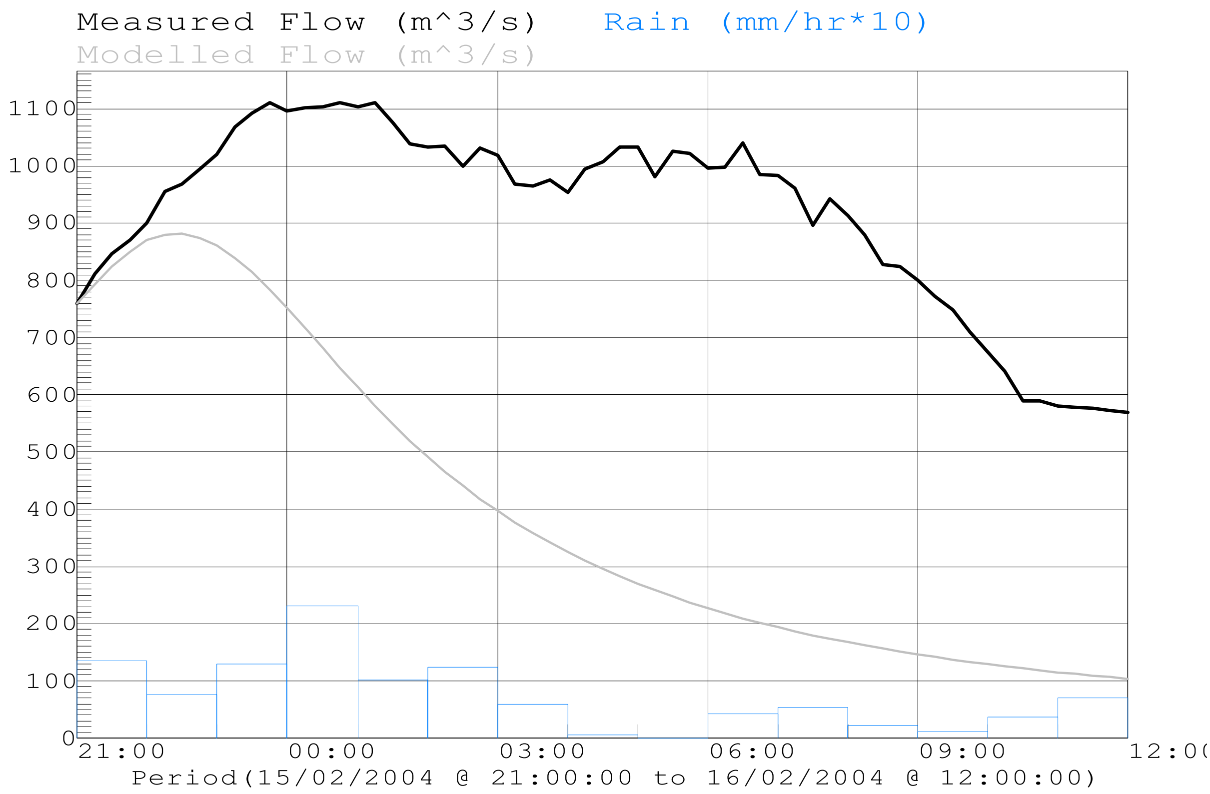


Figure 5-14 Simulated Flood Forecast for Pohangina River Mias Reach at 21:00 15/2/2005.

5.3.2.3 Manawatu River at Teachers College

The flood forecasting performance indicators for this catchment are excellent because:

- The majority of the flow comes from the unmodelled portion of the catchment upstream of Upper Gorge and hence measured flow is used instead. In Stage 4 of this project this catchment will be Rainfall/Runoff modeled.
- The modelled portion of the catchment is modeled with reasonable accuracy as shown by the performance indicators from Pohangina at Mias Reach.

Based on the autocorrelation plot (Figure 5-18), a suitable setting for the error correction half life is 7hrs.

The simulated flood forecast in Figure 5-9 indicates the forecast hydrograph begins to recede approximately 4.5hrs out from when rainfall and flow inputs were set to null. This indicates that the lead time for giving reasonable forecasts is 4.5hrs.

Note these results are from the hydrologic model. In the final implementation of the Flood Forecasting System, Mike11 models are used to route the flow from the confluence of Manawatu and Pohangina Rivers down to Teachers College. Therefore the results from this system would be slightly different.

Table 5-9 Calibrated Hydrologic Model Parameters for Manawatu River at Teachers College

Parameter	Setting
CapAve	82
Cap1	0.075 * CapAve
Cap2	0.762 * CapAve
Cap3	1.524 * CapAve
INFbase	0.36
K1	0.92
K2	0.8
H_GW	20
GWstoreSat	50
GWstoreMax	70
GWstoreStart	20
A1	0.134
A2	0.433
A3	0.433
Beta	0.6
m	0.8
Alpha	0.15
n	1
EvapScaleF	1
RainScaleF	1

Table 5-10 Flood Forecasting Performance Indicators for Manawatu River at Teachers College

Analysis Start Date:	01/01/1990
Analysis End Date:	01/01/2005
No. Of Events#:	17
No. Of Qualified Events:	17
Qualifying Rate, QR:	100%
QR Accuracy Grading:	A
Coeff. Of Determination, CD:	0.98
CD Accuracy Grading:	A
Lowest Accuracy Grading:	**A**
Recommendation:	**Suitable for making official forecasts**

#Based on Events Greater Than 900 m3/s with a minimum separation of 48hrs.

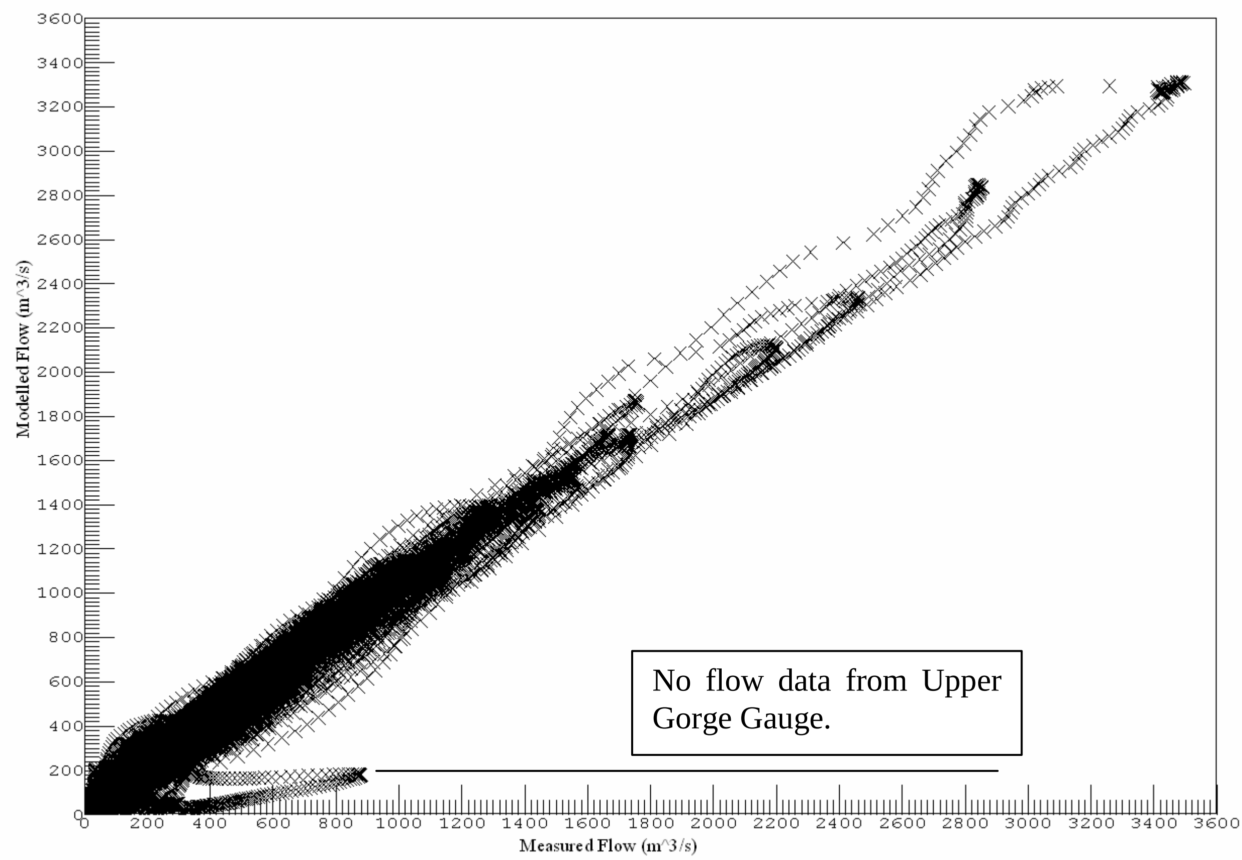
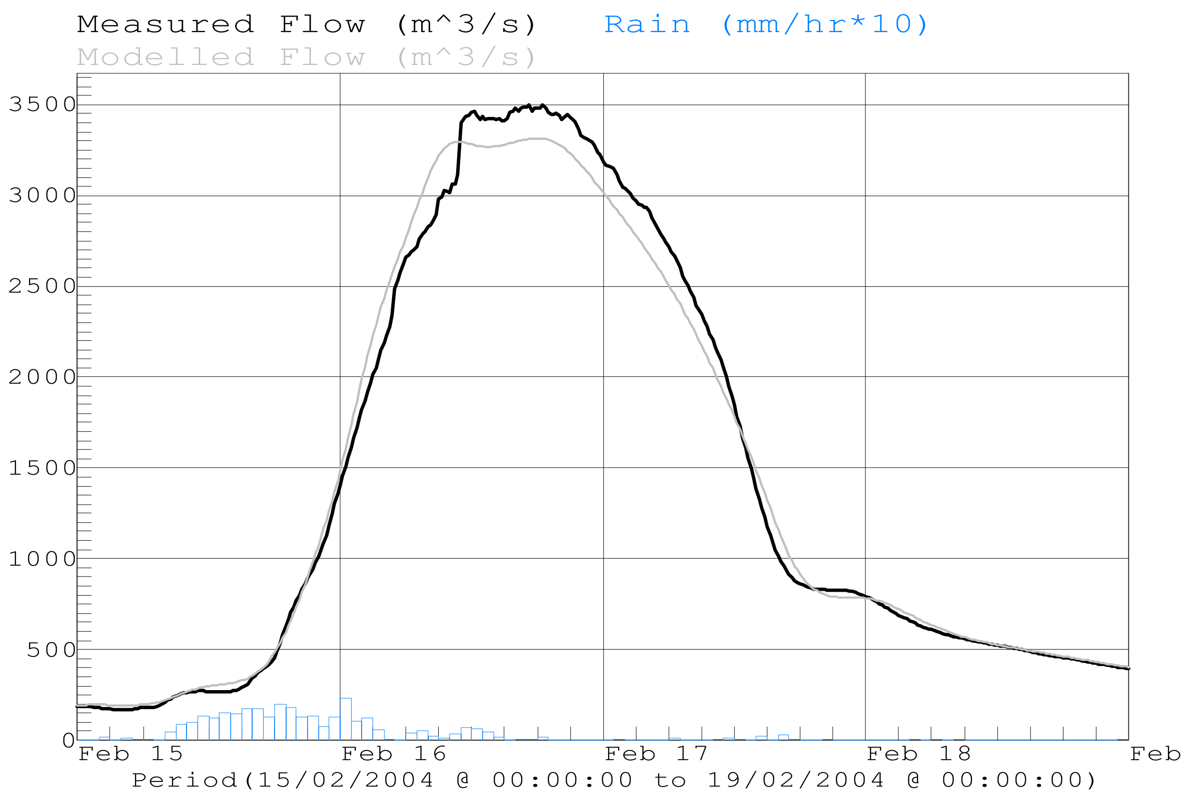
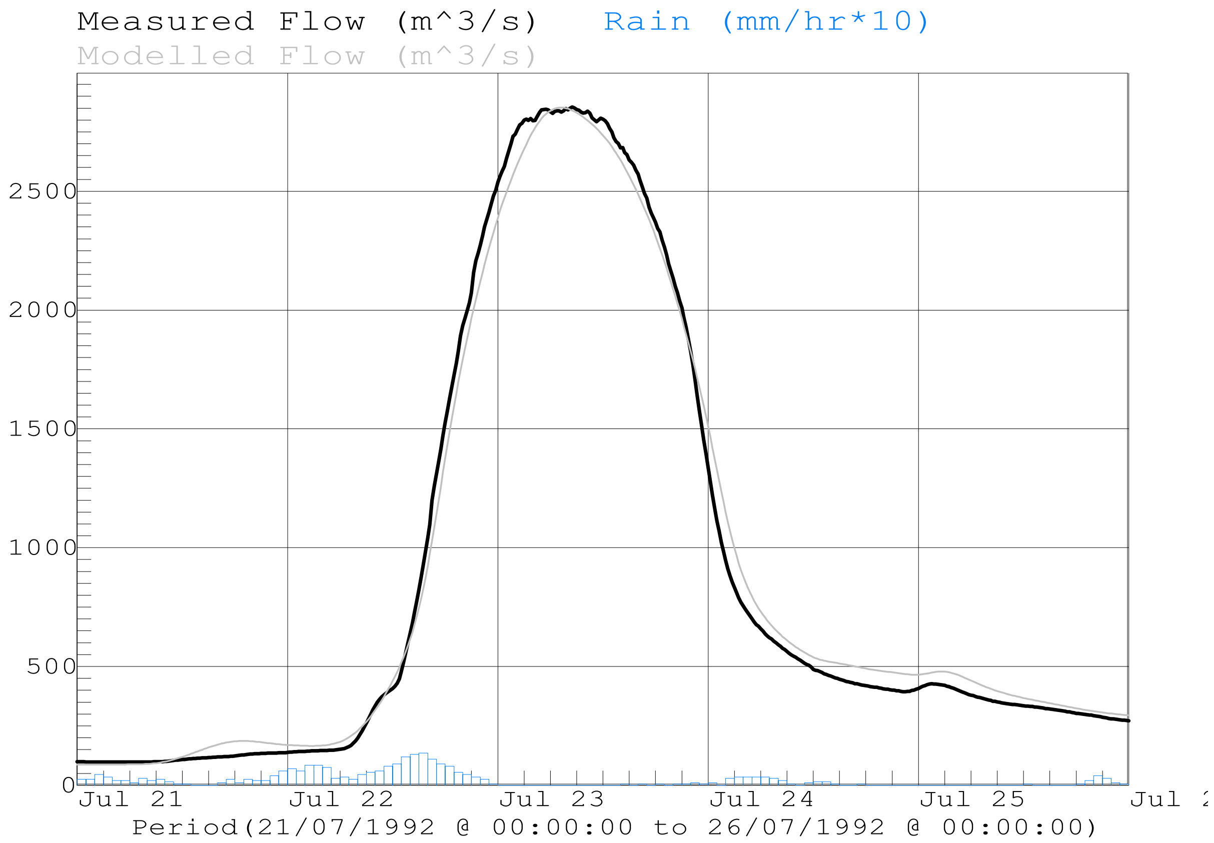
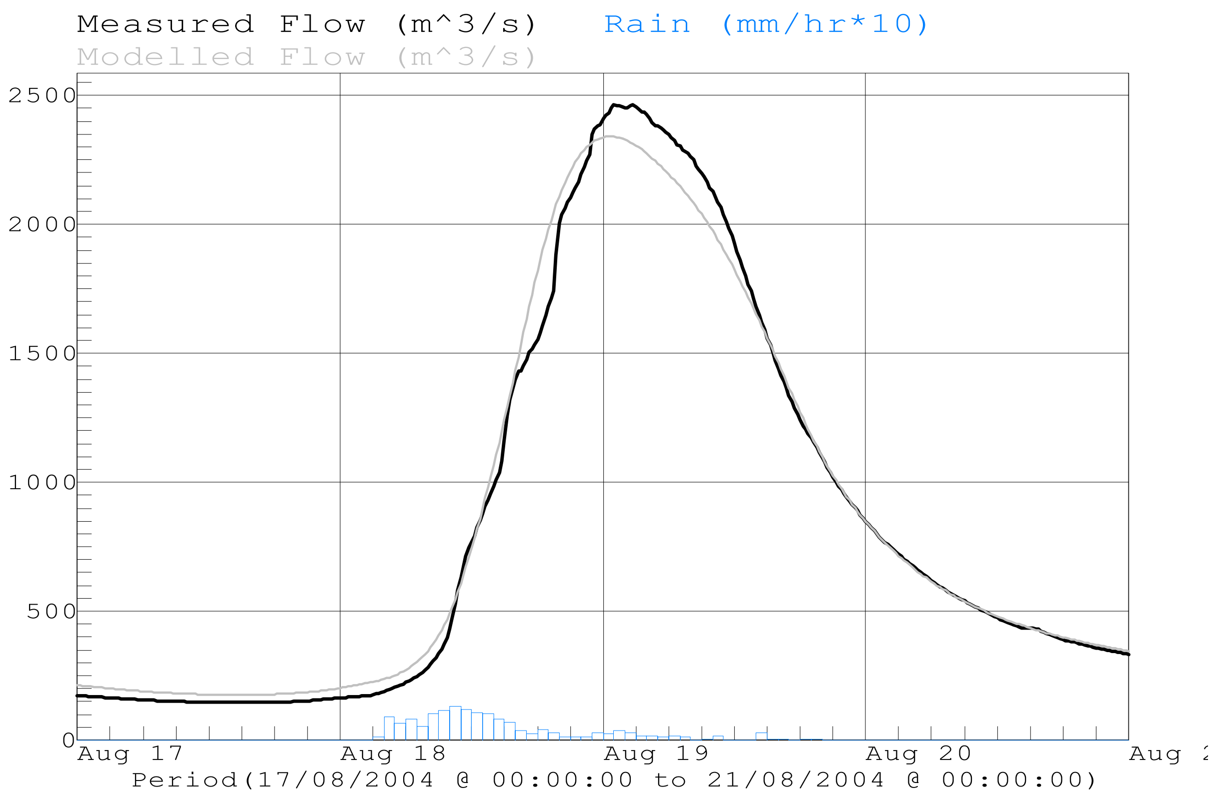
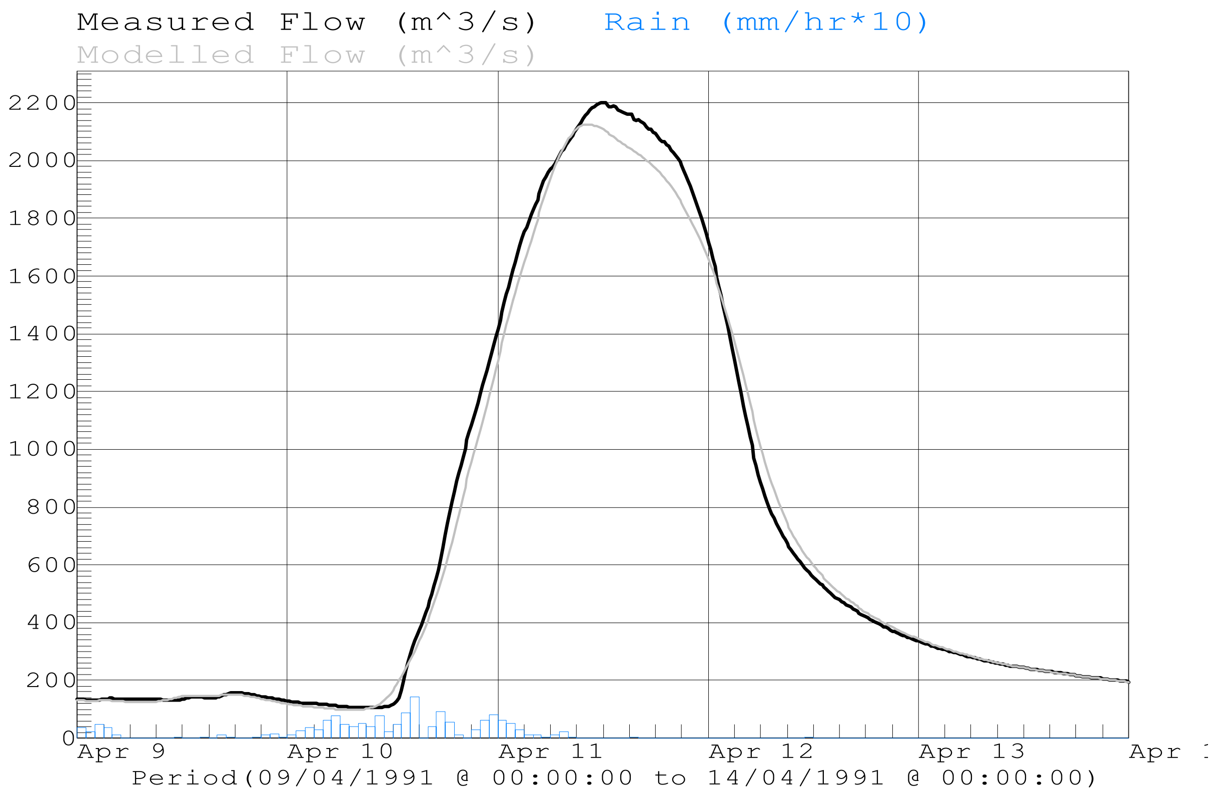


Figure 5-15 Modelled Flow Vs Measure Flow For Manawatu River at Teachers College (1/1/1990-1/1/2005)




Measured Flow (m^3/s)
Rain (mm/hr*10)
Modelled Flow (m^3/s)
2500
2000
1500
1000
500
0
Jul 21
Jul 22
Jul 23
Jul 24
Jul 25
Period(21/07/1992 @ 00:00:00 to 26/07/1992 @ 00:00:00)


Measured Flow (m^3/s)
Rain (mm/hr*10)
Modelled Flow (m^3/s)
2500
2000
1500
1000
500
0
Aug 17
Aug 18
Aug 19
Aug 20
Period(17/08/2004 @ 00:00:00 to 21/08/2004 @ 00:00:00)



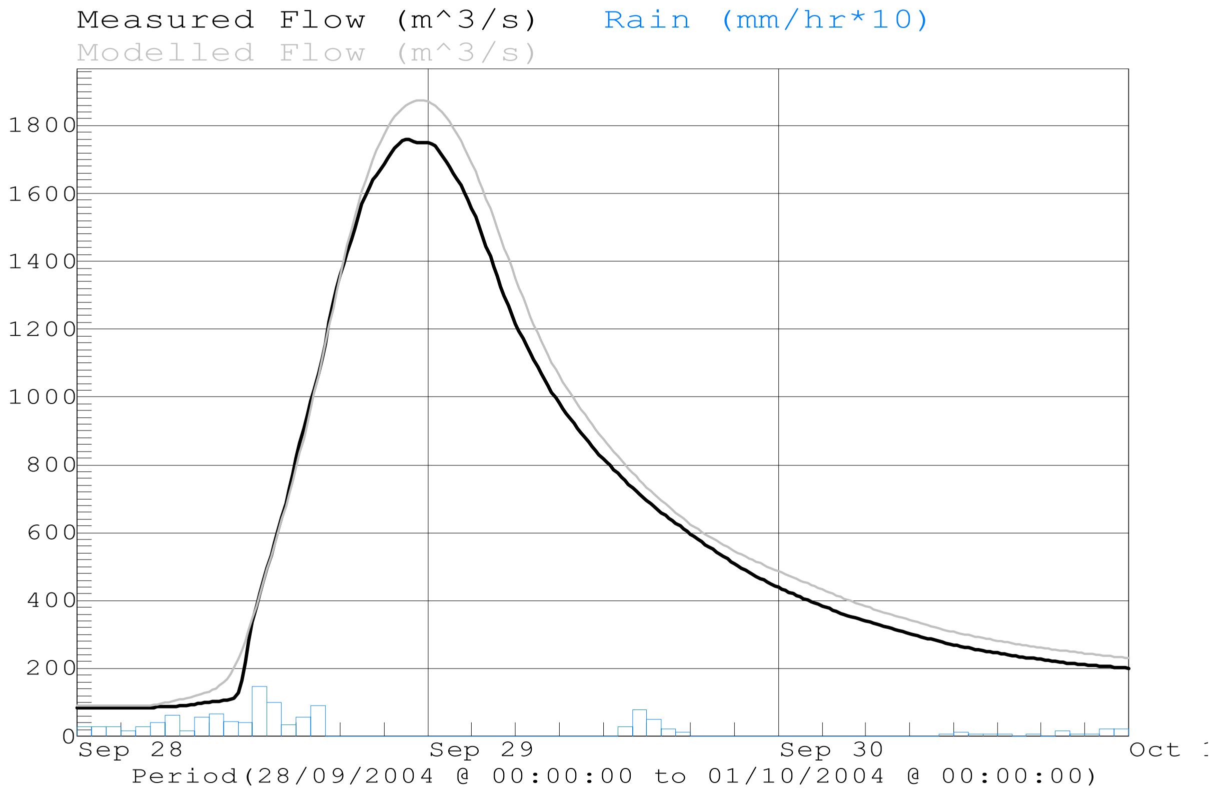


Figure 5-16 Modelled Vs Measured Hydrographs For Manawatu River at Teachers College (5 largest events from 1/1/1990- 1/1/2005).

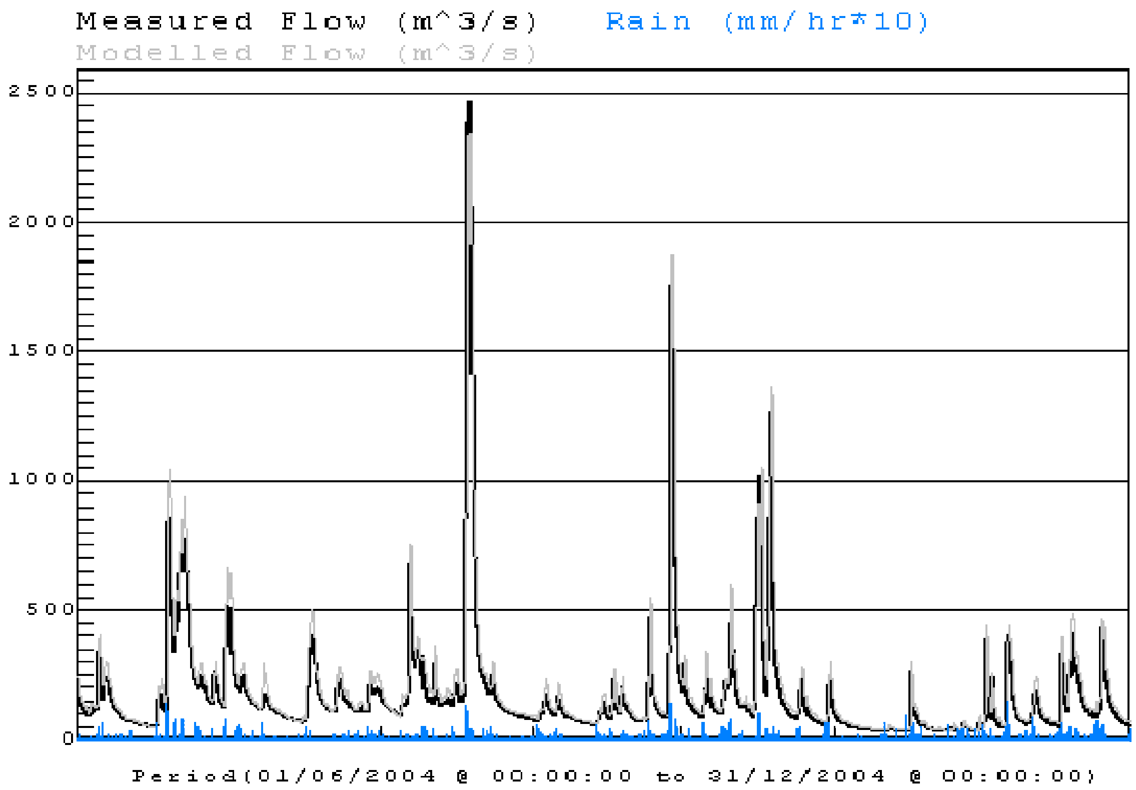


Figure 5-17 Modelled Vs Measured Hydrographs For Manawatu River at Teachers College from 1/6/2004 to 31/12/2004.

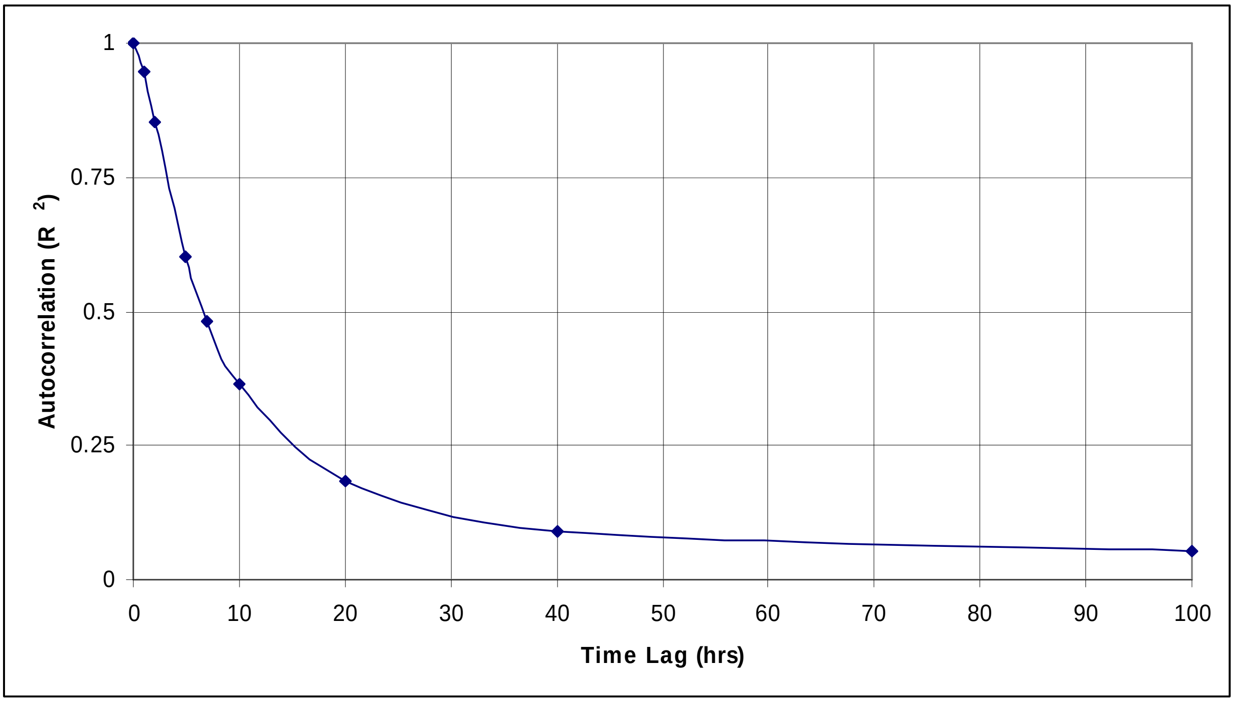


Figure 5-18 Autocorrelation function of the discharge error for Manawatu River at Teachers College from 1/1/1995 to 1/1/2005.

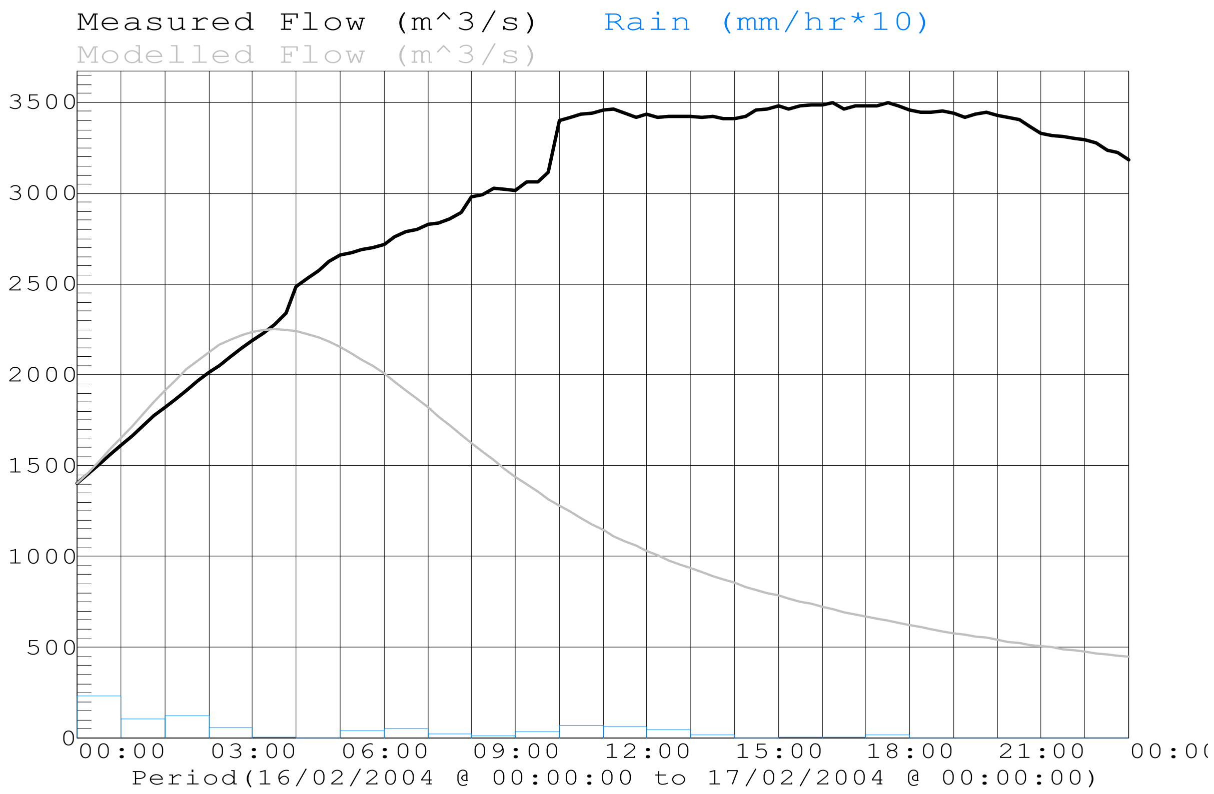


Figure 5-19 Simulated Flood Forecast for Manawatu River at Teachers College at 00:00 16/2/2005.

5.3.2.4 Mangaone Stream at Milsons Line

The flood forecasting performance indicators for this catchment in Table 5-12 are reasonable because there are two rain gauges are within the catchment boundary given reasonable representation of the catchment rainfall.

Based on the autocorrelation plot (Figure 5-23), a suitable setting for the error correction half life at this gauge is 4.5hrs.

To get this catchment to calibrate with any accuracy a constant +3 hour delay was required to be applied to the modelled flow time series. This is a significant time offset for this size catchment. It is difficult to understand hydrologically why this is required. It could be related to the travel time for the runoff to travel overland and enter the watercourses. However it is unusual that it takes 3hrs for **any** runoff to enter a watercourse which appears to be happening.

The simulated flood forecast in Figure 5-24 indicates the forecast hydrograph begins to recede approximately 5 hours out from when rainfall and flow inputs were set to null. This indicates that the lead time for giving reasonable forecasts is 5hrs.

Figure 5-25 shows the relationship between modelled flow error and measured soil moisture at this gauge. Using the linear equation shown in this figure, a real time correction was applied in the model. See Section 5.2.2.6 for more details.

Table 5-11 Calibrated Hydrologic Model Parameters for Mangaone Stream at Milsons Line

Parameter	Setting
Cap1	20
Cap2	60
Cap3	100
INFbase	0.2
K1	0.9
K2	0.1
H_GW	40
GWstoreSat	50
GWstoreMax	70
GWstoreStart	0
A1	0.2
A2	0.4
A3	0.4
Beta	1.5
m	0.8
Alpha	0.5
n	0.81
EvapScaleF	1
RainScaleF	1

Table 5-12 Flood Forecasting Performance Indicators for Mangaone Stream at Milsons Line

Analysis Start Date:	01/01/1990
Analysis End Date:	01/01/2005
No. Of Events#:	17
No. Of Qualified Events:	11
Qualifying Rate, QR:	65%
QR Accuracy Grading:	C
Coeff. Of Determination, CD:	0.72
CD Accuracy Grading:	B
Lowest Accuracy Grading:	C
Recommendation:	Suitable for making reference forecasts

#Based on Events Greater Than 50 m3/s with a minimum separation of 48hrs.

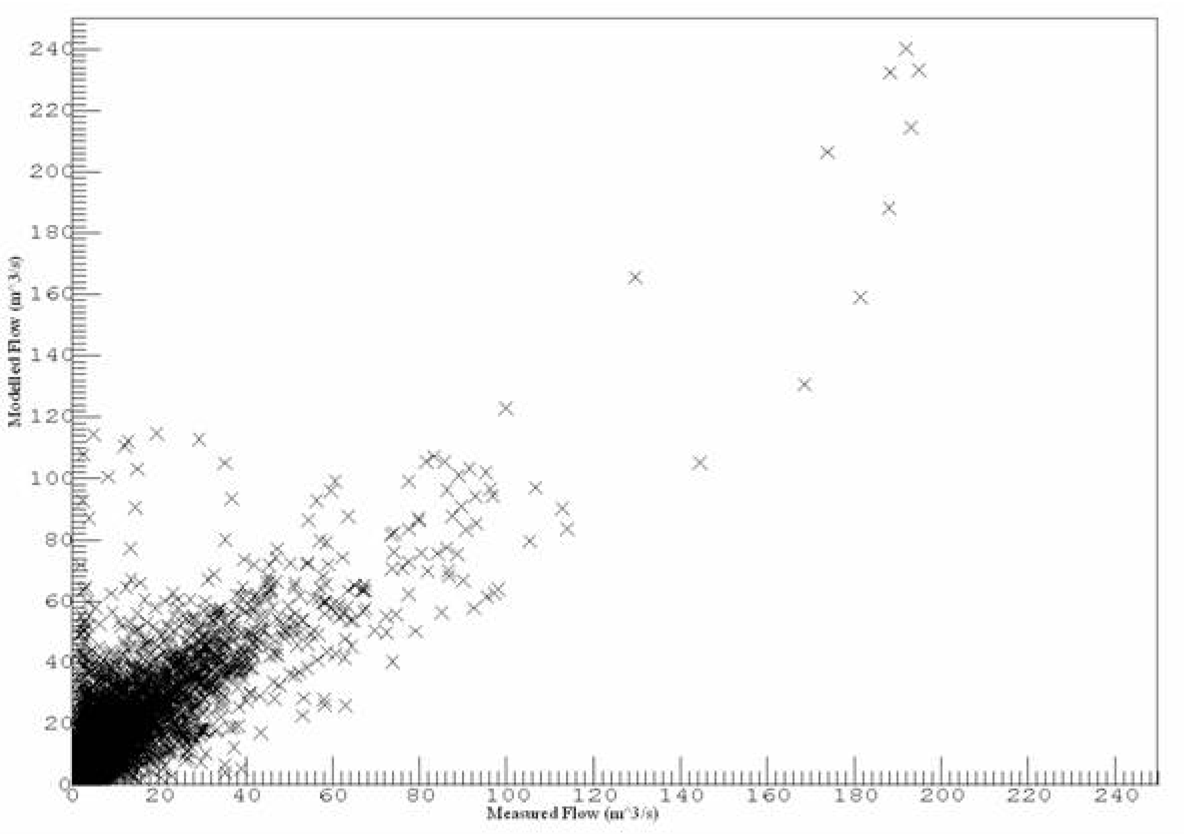


Figure 5-20 Modelled Flow Vs Measure Flow For Mangaone Stream at Milsons Line (1/1/1990-1/1/2005)

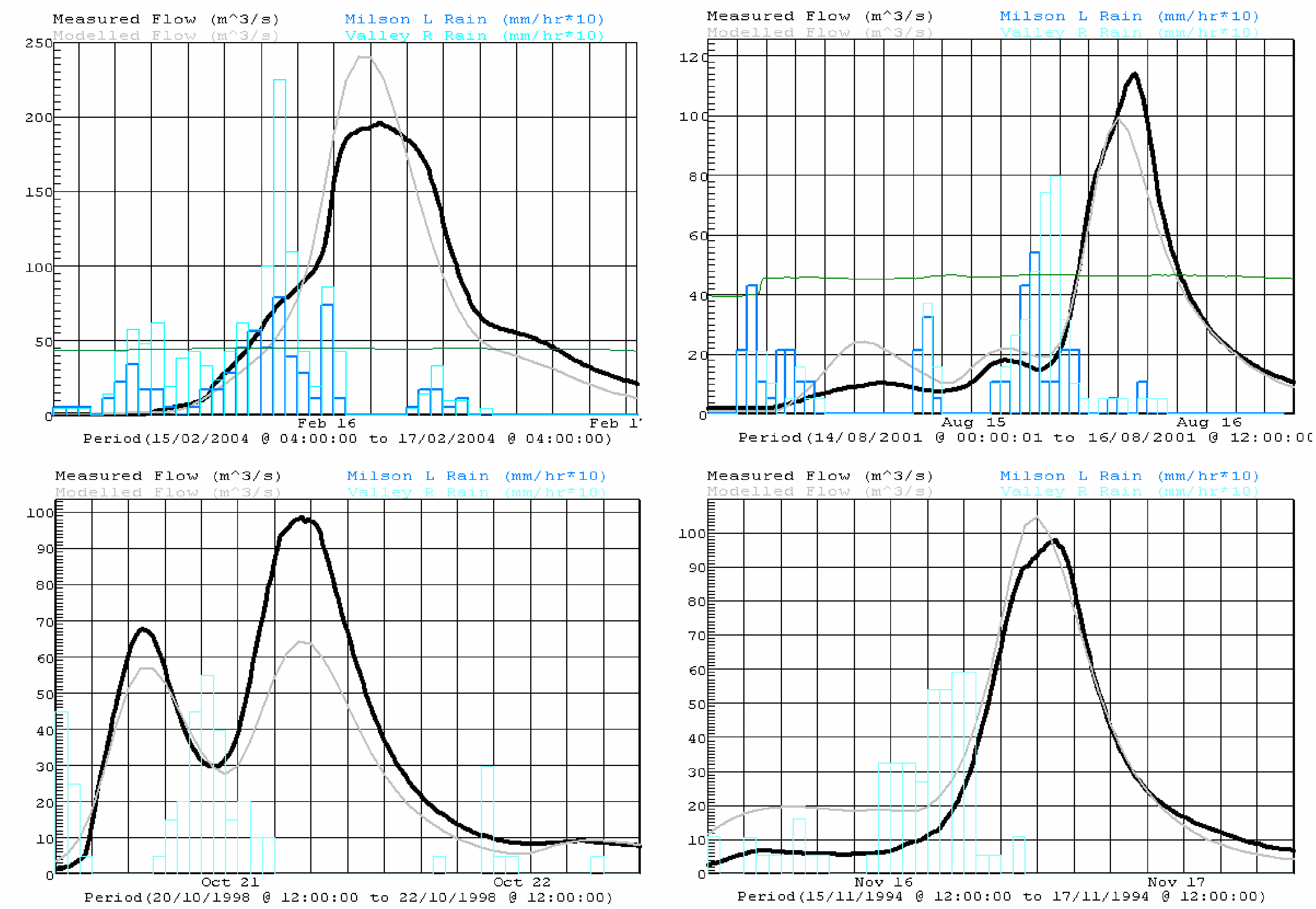


Figure 5-21 Modelled Vs Measured Hydrographs For Mangaone Stream at Milsons Line (4 largest events from 1/1/1990- 1/1/2005).

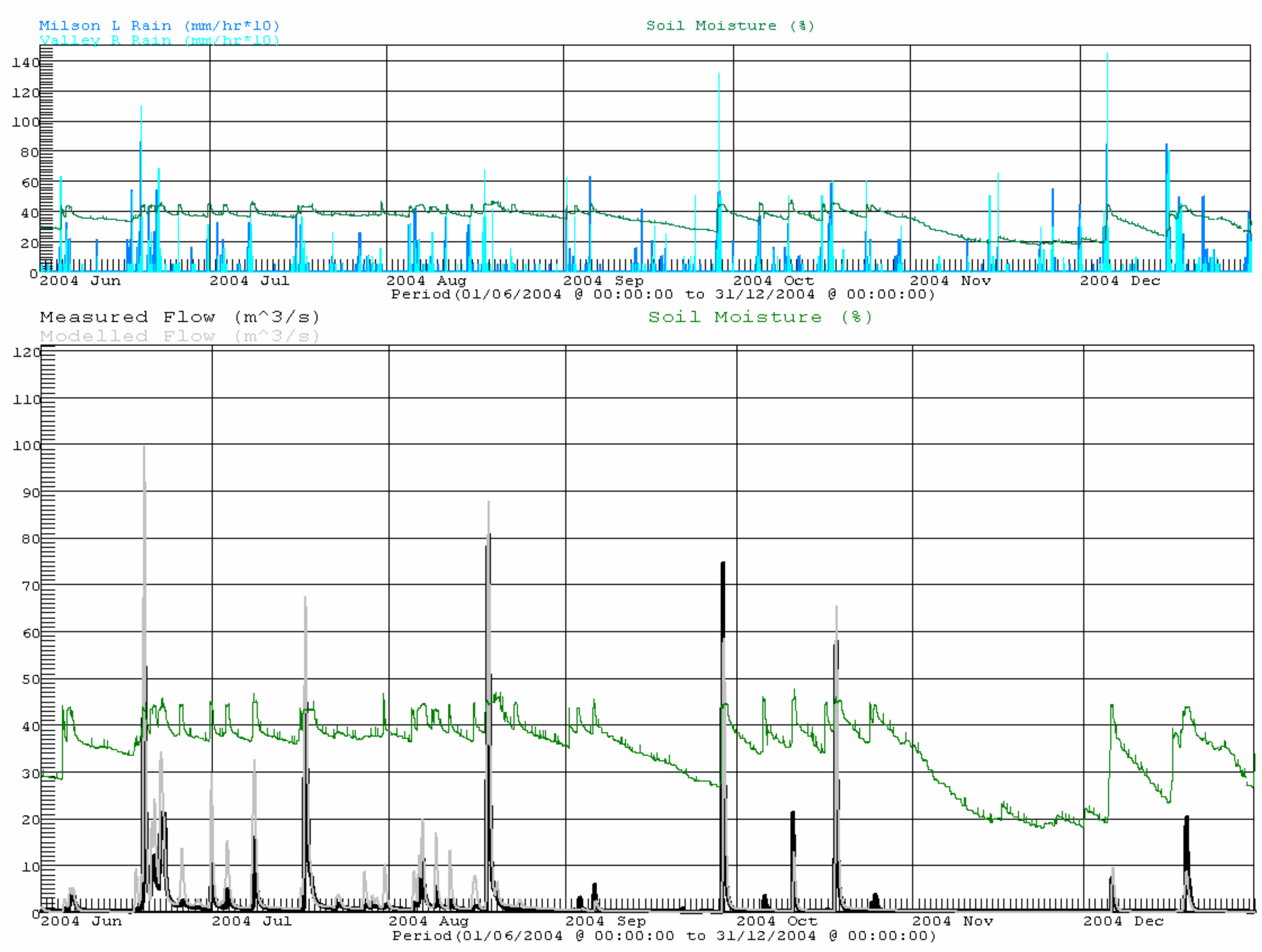


Figure 5-22 Modelled Vs Measured Hydrographs For Mangaone Stream at Milsons Line from 1/6/2004 to 31/12/2004.

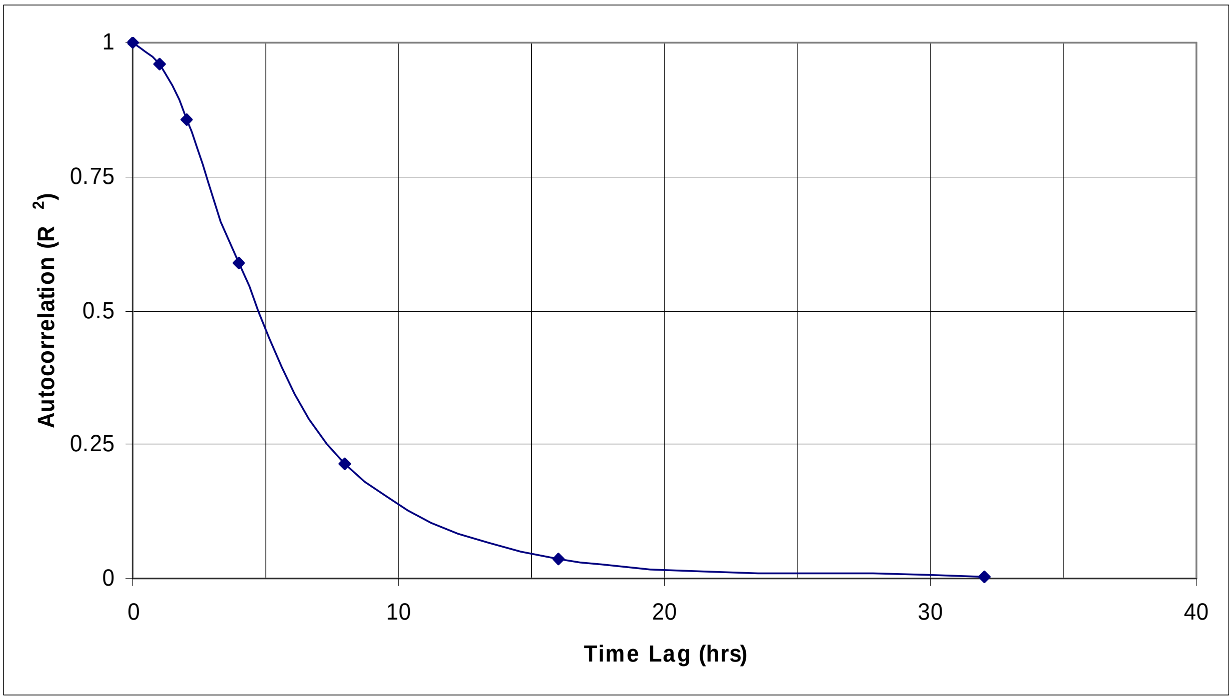


Figure 5-23 Autocorrelation function of the discharge error for Mangaone Stream at Milsons Line from 1/1/1999 to 1/1/2005.

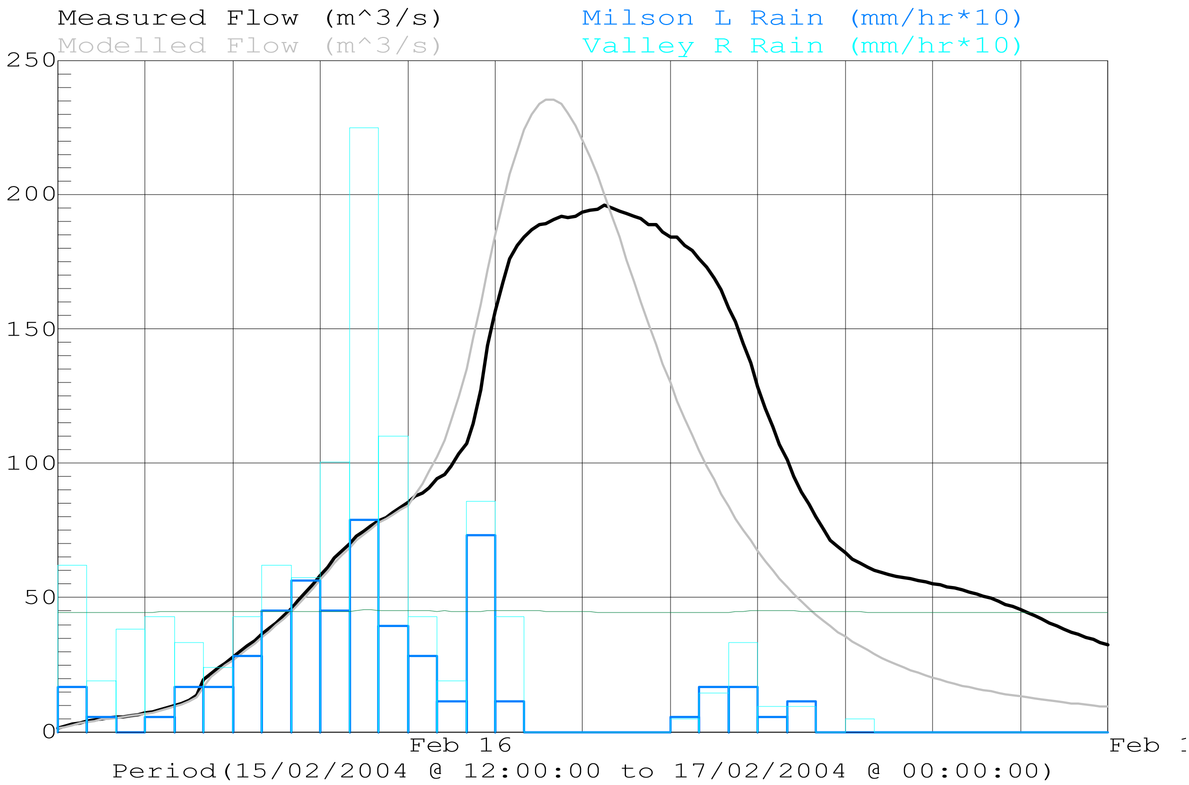


Figure 5-24 Simulated Flood Forecast for Mangaone Stream at Milsons Line at 00:00 16/2/2005.

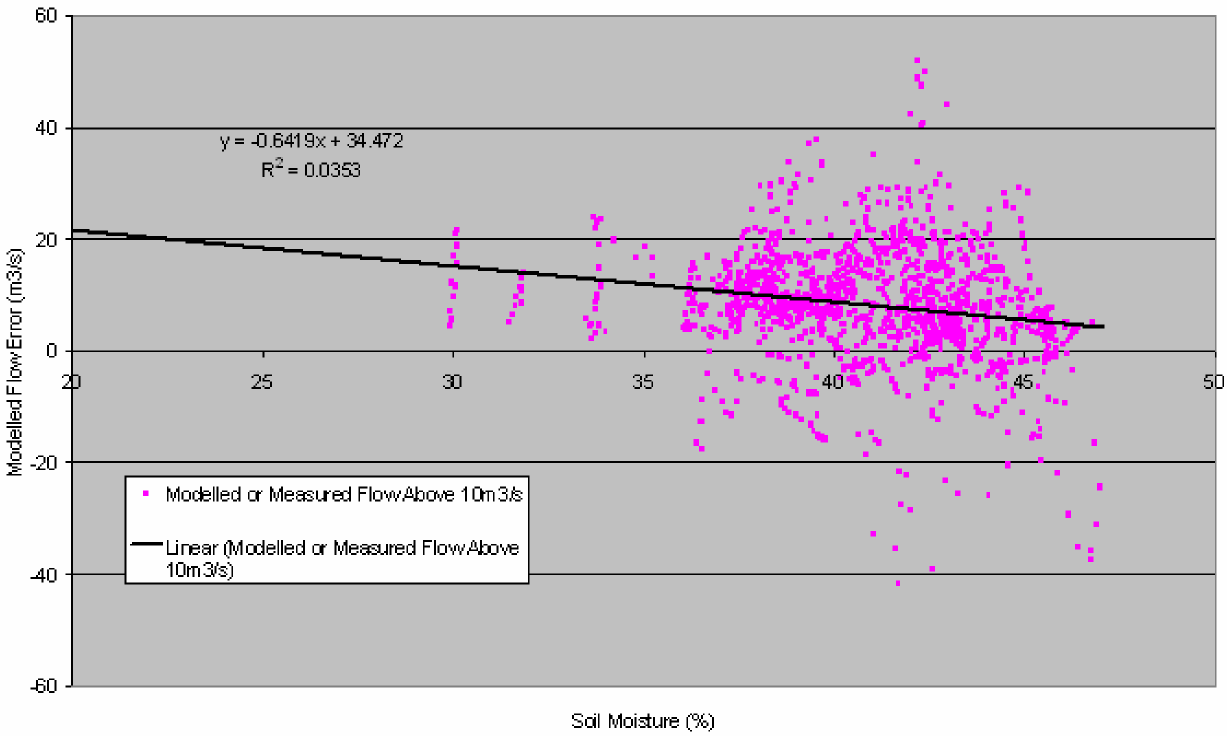


Figure 5-25 Modelled Flow Error Verse Soil Moisture Measurement For Mangaone Stream At Milsons Line For 8/6/2001 to 1/1/2005.

5.3.2.5 Kiwitea Stream at Cheltenham Gun Club

The flood forecasting performance indicators for this catchment are poor probably because:

- no rain gauges are within the catchment boundary (there is one at either end), and
- It is a relatively small catchment which generally have faster response times and are harder to forecast.

For the largest and third largest events since 1999 the modelled hydrographs are reasonable.

Based on the autocorrelation plot (Figure 5-29), a suitable setting for the error correction half life at this gauge is 5hrs.

Like the Mangaone catchment, to get this catchment to calibrate with any accuracy a constant +3 hour delay was required to be applied to the modelled flow time series. This is a significant time offset for this size catchment. It is difficult to understand hydrologically why this is required. It could be related to the travel time for the runoff to travel overland and enter the watercourses. However it is unusual that it takes 3hrs for **any** runoff to enter a watercourse which appears to be happening.

The simulated flood forecast in Figure 5-30 indicates the forecast hydrograph begins to recede approximately 3 hours out from when rainfall and flow inputs were set to null. This indicates that the lead time for giving reasonable forecasts is 3hrs.

A brief review of the Figure 5-28 indicates that the soil moisture measurements are not useful in improving the accuracy of the model because there are a significant number of event that the model over predicts for when soil moisture is high and vice versa. This is similar to the results obtained for Mangaone Stream at Milsons Line.

Table 5-13 Calibrated Hydrologic Model Parameters for Kiwitea Stream at Cheltenham Gun Club

Parameter	Setting
CapAve	40
Cap1	0.075 * CapAve
Cap2	0.762 * CapAve
Cap3	1 * CapAve
INFbase	0.2
K1	0.9
K2	0.1
H_GW	40
GWstoreSat	50
GWstoreMax	70
GWstoreStart	20
A1	0.134
A2	0.433
A3	0.433
Beta	0.15
m	0.81
EvapScaleF	1
RainScaleF	1
AlphaJ_3	0.4
nJ_3	0.78

Table 5-14 Flood Forecasting Performance Indicators for Kiwitea Stream at Cheltenham Gun Club

Analysis Start Date:	01/01/1999
Analysis End Date:	01/01/2005
No. Of Events*:	10
No. Of Qualified Events:	3
Qualifying Rate, QR:	30%
QR Accuracy Grading:	Less than C
Coeff. Of Determination R^2:	0.62
R^2 Accuracy Grading:	C
Lowest Accuracy Grading:	Less than C
Recommendation:	Not recommended for use in flood forecasting

#Based on Events Greater Than 40 m3/s with a minimum separation of 48hrs.

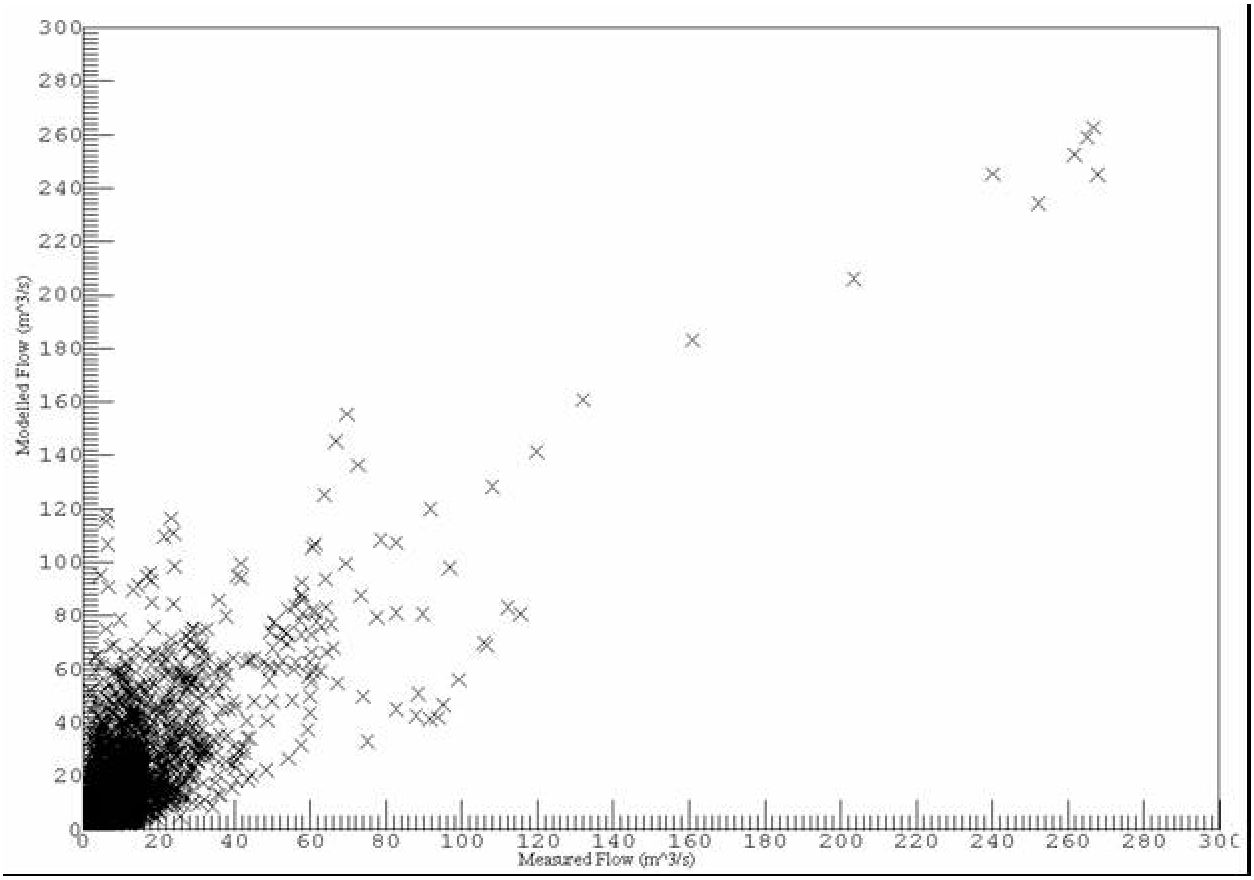


Figure 5-26 Modelled Flow Vs Measure Flow For Kiwitea Stream at Cheltenham Gun Club (1/1/1999-1/1/2005)

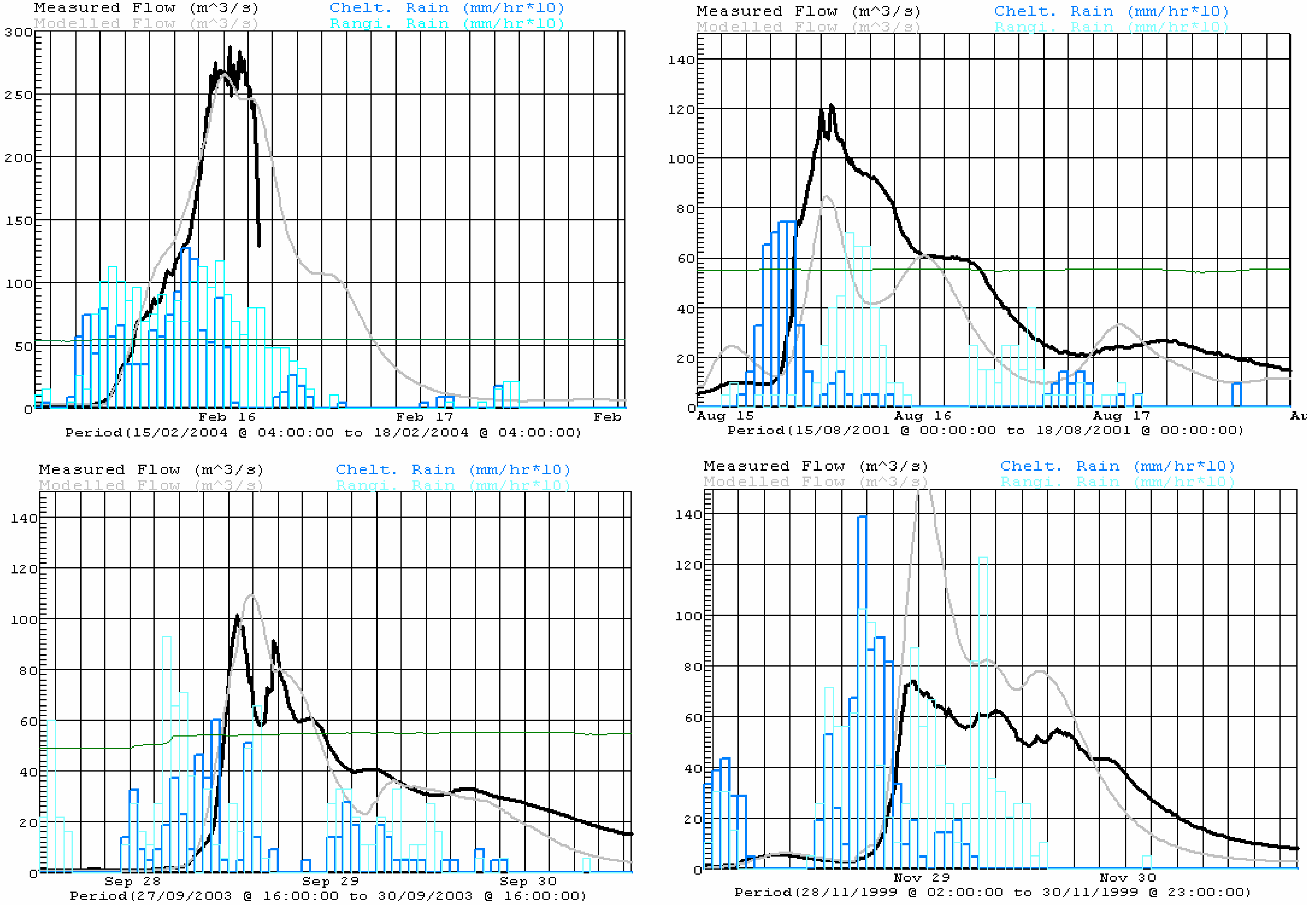


Figure 5-27 Modelled Vs Measured Hydrographs For Kiwitea Stream at Cheltenham Gun Club (4 largest events from 1/1/1999- 1/1/2005).

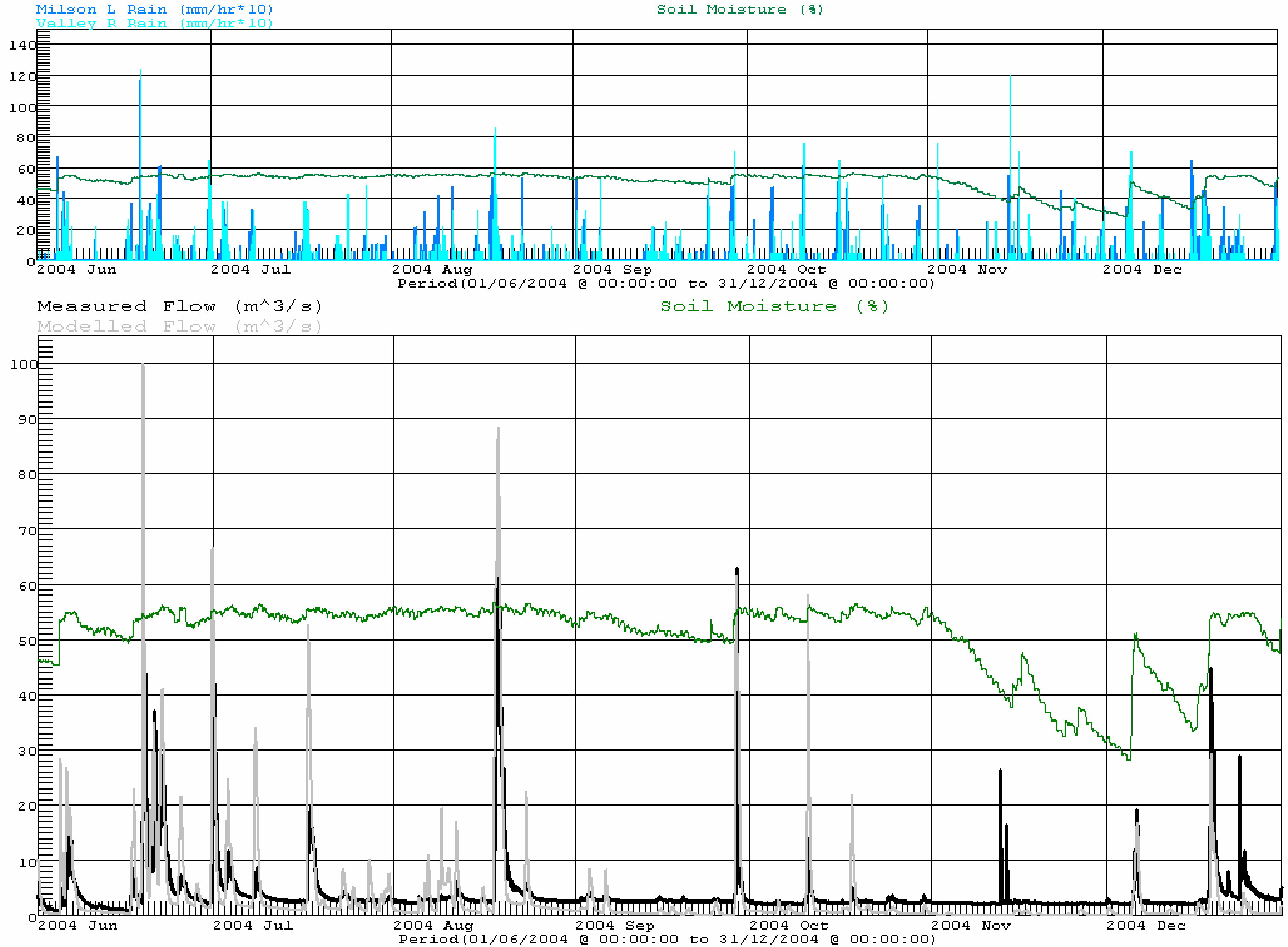


Figure 5-28 Modelled Vs Measured Hydrographs For Kiwitea Stream at Cheltenham Gun Club from 1/6/2004 to 31/12/2004.

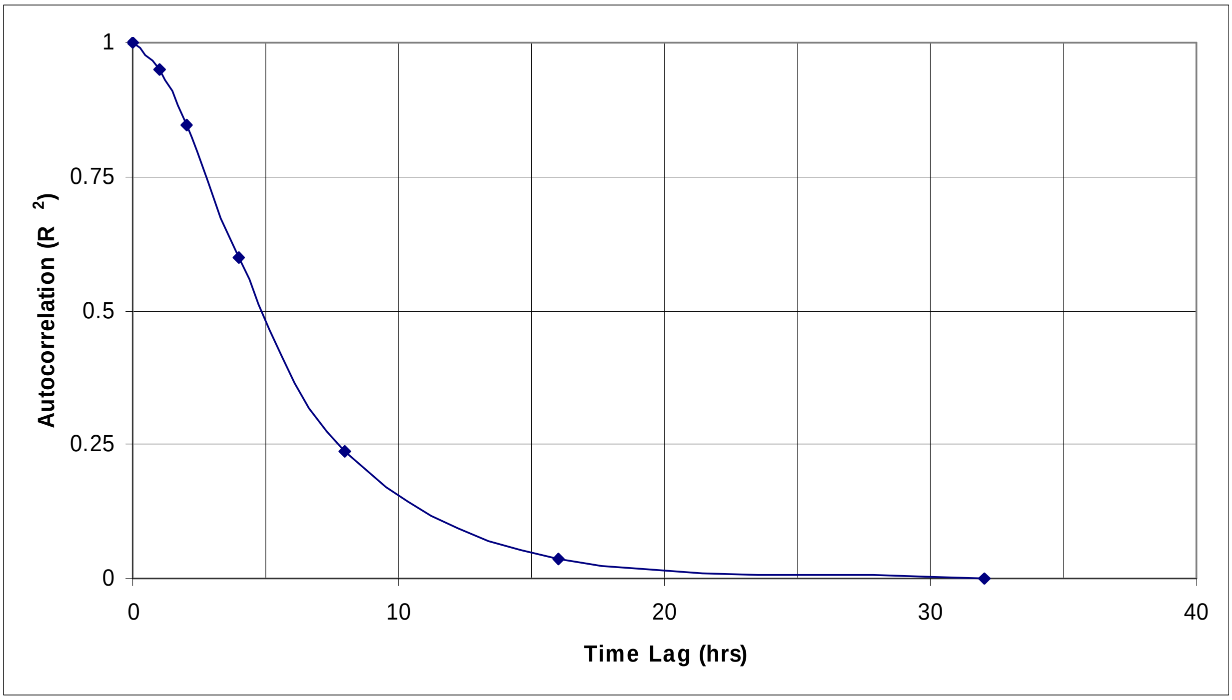


Figure 5-29 Autocorrelation function of the discharge error for Kiwitea Stream at Cheltenham Gun Club from 1/1/1999 to 1/1/2005.

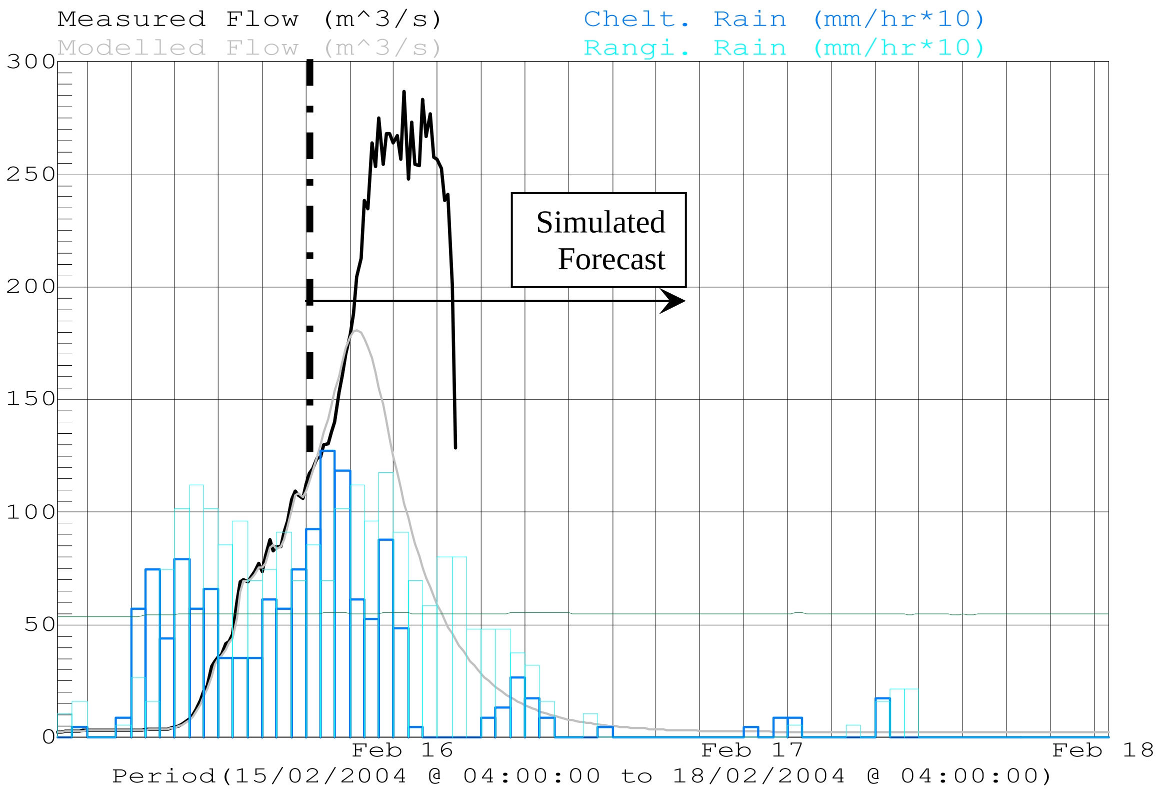


Figure 5-30 Simulated Flood Forecast for Kiwitea Stream at Cheltenham Gun Club at 21:00 15/2/2005.

5.3.2.6 Makino Stream at Reids Line

The flood forecasting performance indicators for this catchment are good with an accuracy grading of ‘B’ shown in Table 5-16. The good level of accuracy is unexpected because small catchments are generally difficult to model and also the rain gauge coverage is not great with gauges at each end of the catchment. However based on the rainfall hyetographs shown in Figure 5-32, it appears the distribution in rainfall across the catchment is somewhat uniform and well represented by the Cheltenham and Halcombe Rain Gauges.

During the February 2004 flood event, it was observed (J.Watson per. comm. 2005) that the Kiwitea Stream broke out when the flow reached 280m^3/s and spilled a significant volume of water into the Makino upstream of the Reids Line Gauge. To model this, a node was added to the Kiwitea stream network to divert all flow above 280m^3/s into the Makino. To get the timing and magnitude of this extra flow to match at Reids Line channel routing and a 3hr time delay was applied to this flow. The implementation of this can be seen in the model.

Based on the autocorrelation plot (Figure 5-34), a suitable setting for the error correction half life at this gauge is 4.5hrs.

The simulated flood forecast in Figure 5-35 indicates the forecast hydrograph begins to recede approximately 1 hour out from when rainfall and flow inputs were set to null. This indicates that the lead time for giving reasonable forecasts is 1hrs.

Figure 5-36 shows the relationship between modelled flow error and measured soil moisture at this gauge. Using the linear equation shown in this figure, a real time correction was applied in the model. See Section 5.2.2.6 for more details.

Table 5-15 Calibrated Hydrologic Model Parameters for Makino Stream at Reids Line

Parameter	Setting
CapAve	70
Cap1	0.075 * CapAve
Cap2	0.762 * CapAve
Cap3	1.024 * CapAve
INFbase	0.2
K1	0.9
K2	0.1
H_GW	5
GWstoreSat	8
GWstoreMax	9
GWstoreStart	5
A1	0.134
A2	0.433
A3	0.433
Beta	2
m	0.4
EvapScaleF	1
RainScaleF	1
AlphaJ_5	0.7
nJ_5	0.8

Table 5-16 Flood Forecasting Performance Indicators for Makino Stream at Reids Line

Analysis Start Date:	01/06/1999
Analysis End Date:	01/01/2005
No. Of Events*:	7
No. Of Qualified Events:	5
Qualifying Rate, QR:	71%
QR Accuracy Grading:	B
Coeff. Of Determination R^2:	0.76
R^2 Accuracy Grading:	B
Lowest Accuracy Grading:	B
Recommendation:	Suitable for making official forecasts

#Based on Events Greater Than 30 m3/s with a minimum separation of 48hrs.

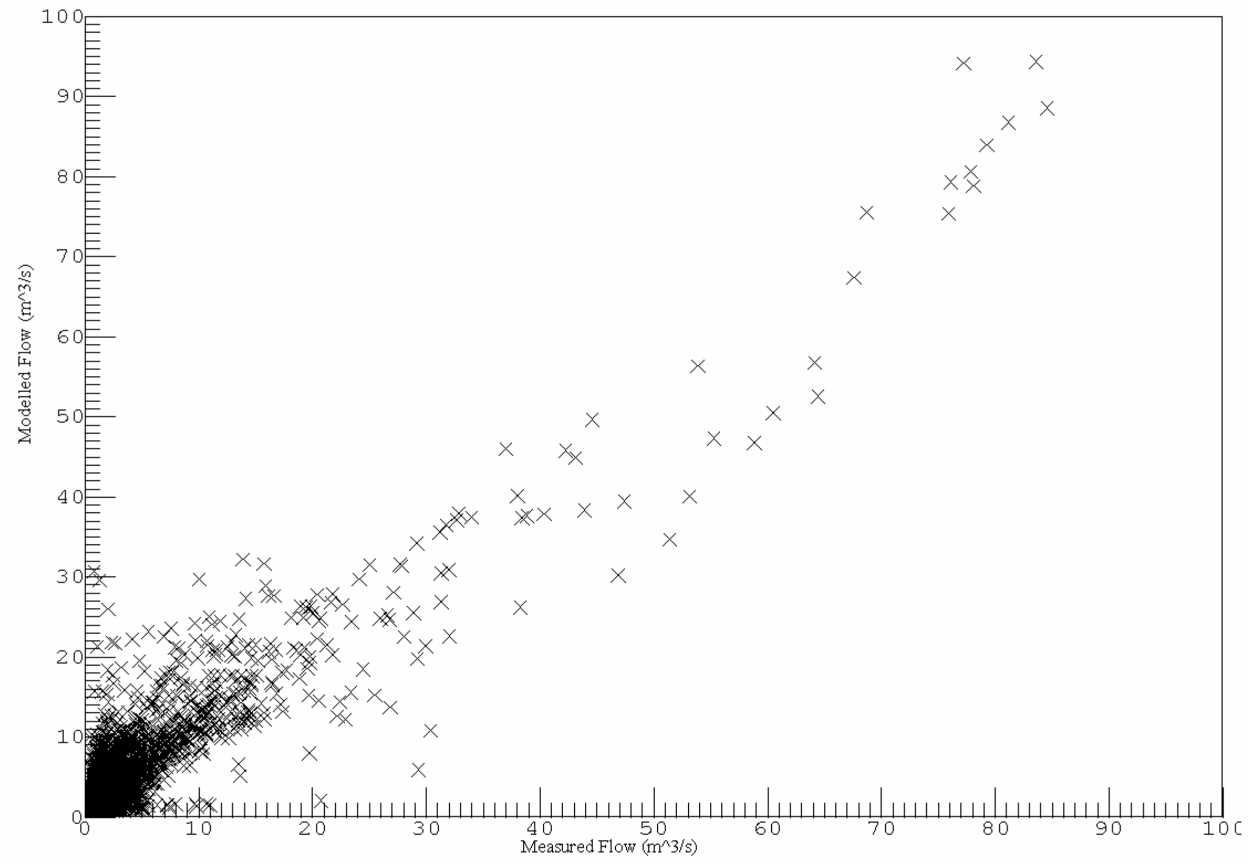


Figure 5-31 Modelled Flow Vs Measure Flow For Makino Stream at Reids Line (1/6/1999-1/1/2005)

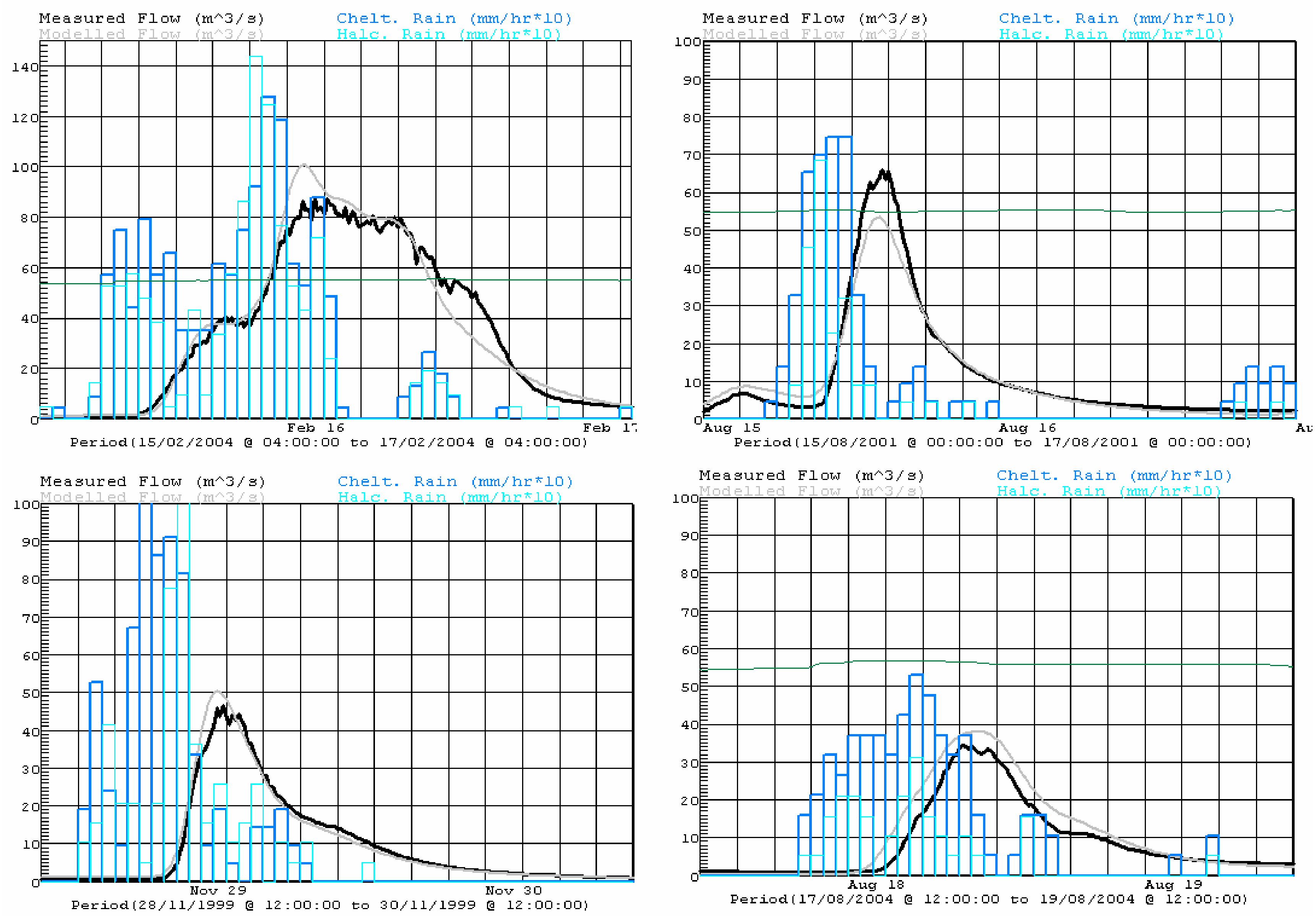


Figure 5-32 Modelled Vs Measured Hydrographs For Makino Stream at Reid's Line (4 largest events from 1/6/1999- 1/1/2005).

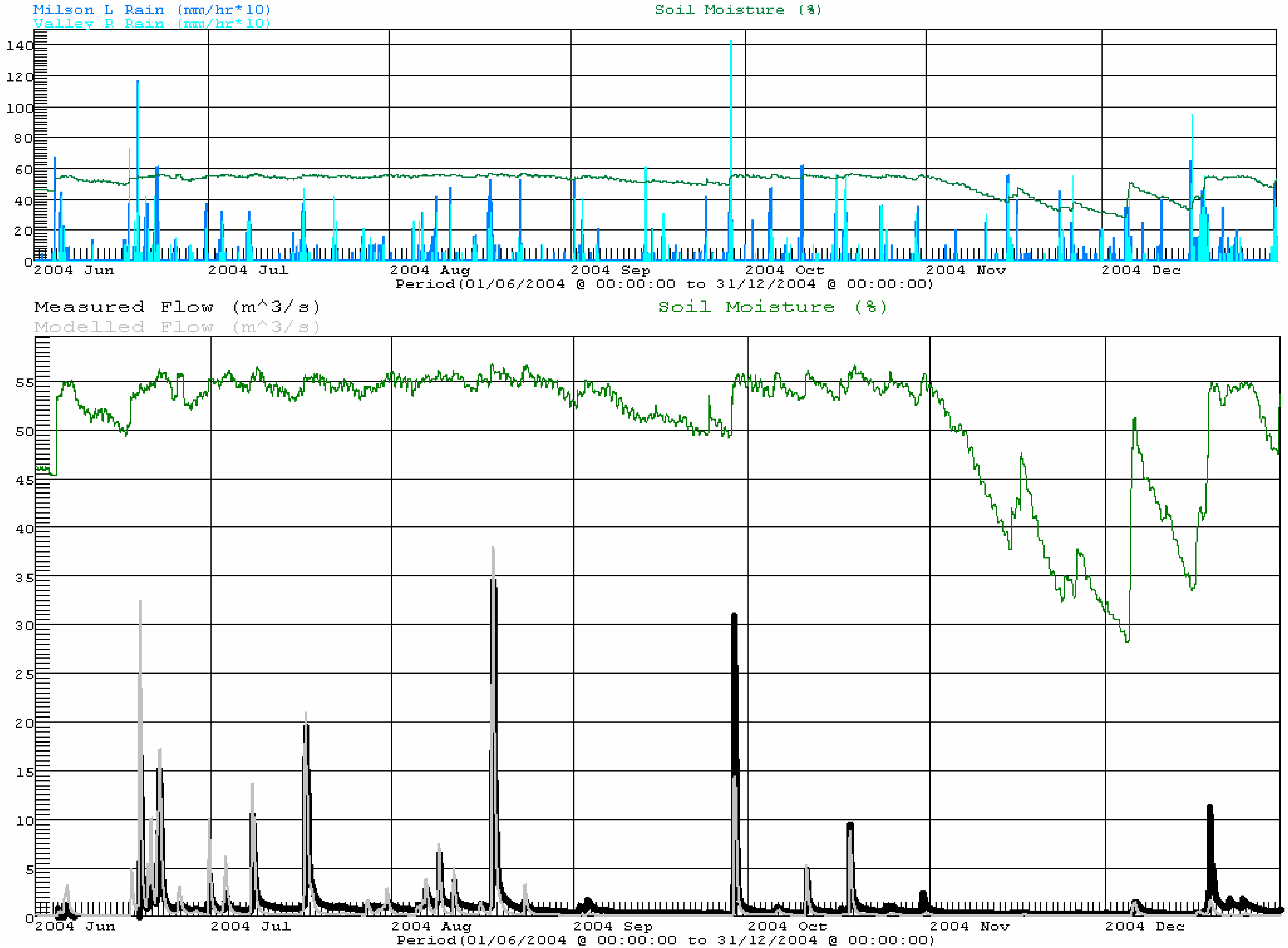


Figure 5-33 Modelled Vs Measured Hydrographs For Makino Stream at Reids Line from 1/6/2004 to 31/12/2004.

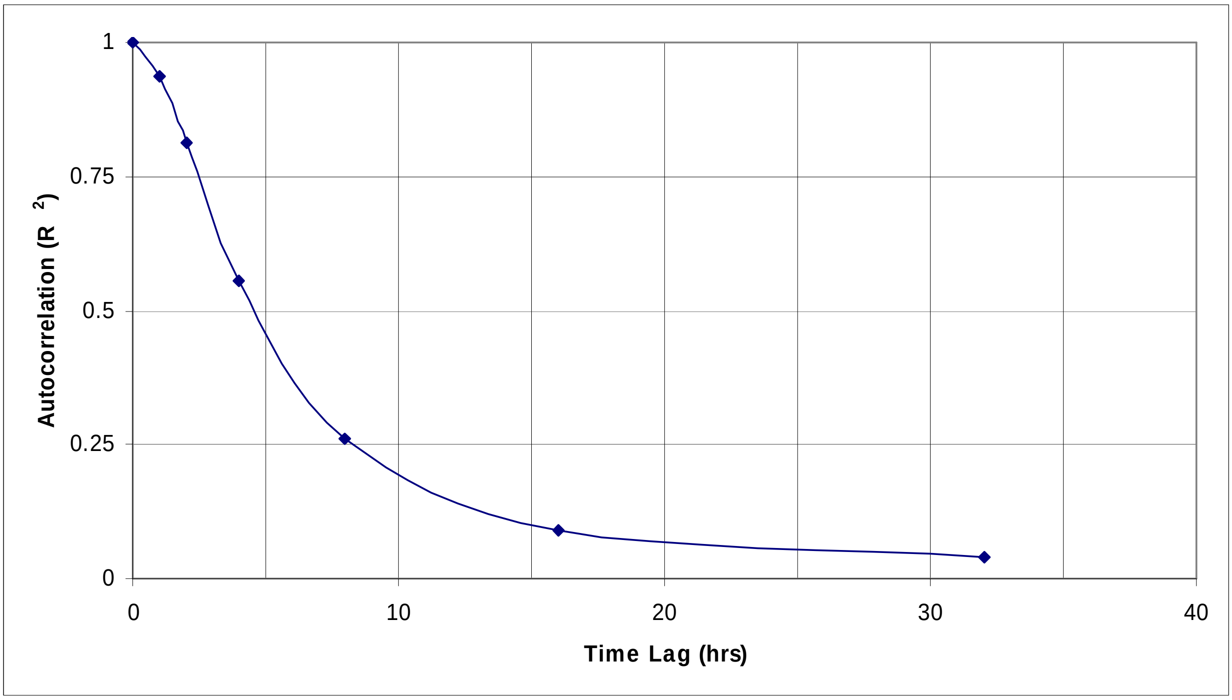


Figure 5-34 Autocorrelation function of the discharge error for Makino Stream at Reids Line from 1/6/1999 to 1/1/2005.

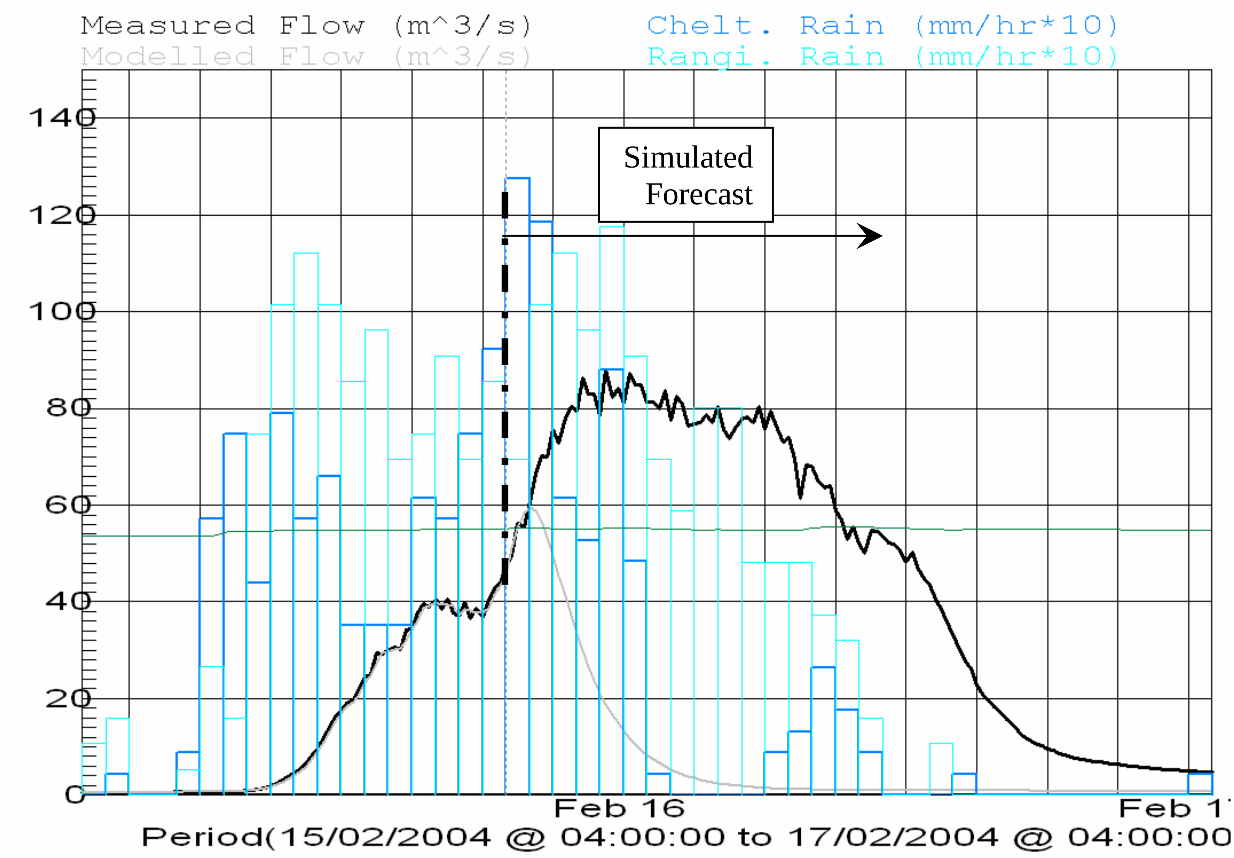


Figure 5-35 Simulated Flood Forecast for Makino Stream at Reids Line at 22:00 15/2/2005.

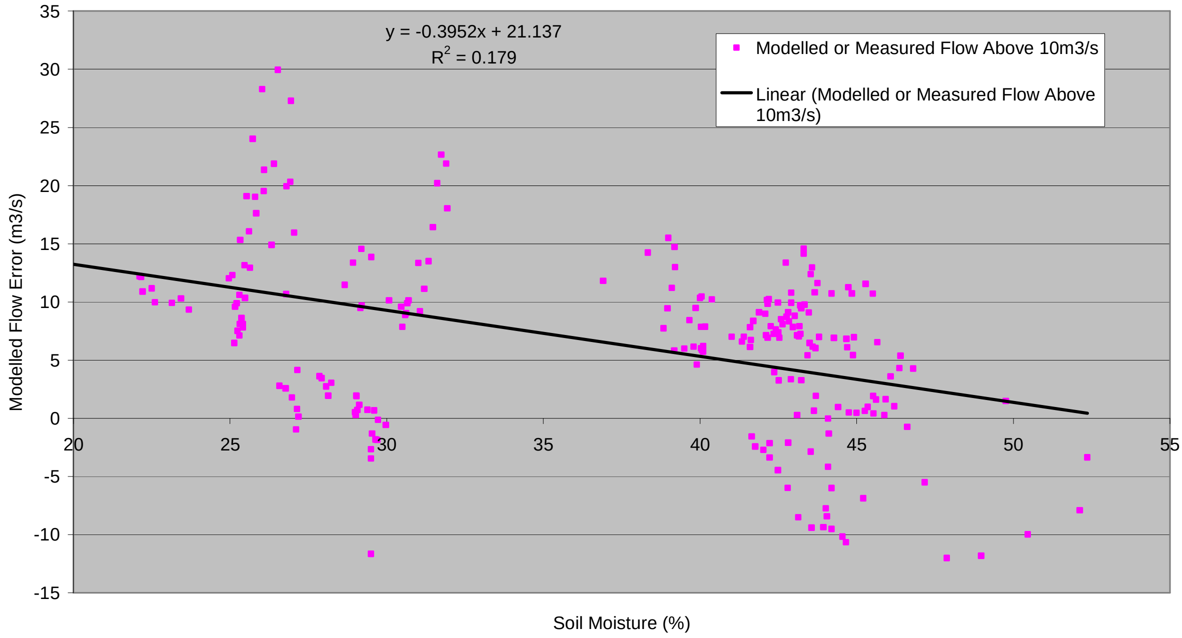


Figure 5-36 Modelled Flow Error vs. Soil Moisture Measurements For Makino Stream at Reids Line, For 1/1/2000 to 1/1/2005.

5.3.2.7 Makino Stream at Rata Street

The flood forecasting performance indicators for this catchment are poor with an accuracy grading of 'Less than C' shown in Table 5-18. This is a large difference to the Makino Stream at Reids Line just upstream which has an accuracy grading of 'B". The downgrade is caused by a large drop in the Qualifying Rate statistic indicating that only 42% of events larger than 30m^3/s can be modelled with less than 20% error. For the largest event in Figure 5-38 (Feb 2004) structures such as bridges that restrict flood flows may have 'clipped' the peak from the event making it difficult to model this event. For the other three event in Figure 5-38, the modelled results are good but the smallest event is underestimated significantly in percentage terms while in absolute terms the error is not that large (10m^3/s). Smaller events down to 30m^3/s were used in the Qualifying Rate calculation and these were not accurately modelled probably due to the limitation of modelling the urban area with limited rain gauge coverage where small localised rainfall events not detected by the Halcombe Rain Gauge could occur over parts of the urban area and generate 30m^3/s.

Based on the autocorrelation plot (Figure 5-40), a suitable setting for the error correction half life at this gauge is 4.0hrs.

The simulated flood forecast in Figure 5-41 indicates the forecast hydrograph begins to recede approximately 2hours out from when rainfall and flow inputs were set to null. This indicates that the lead time for giving reasonable forecasts is 2hrs.

Table 5-17 Calibrated Hydrologic Model Parameters for Makino Stream at Rata Street

Parameter	Setting
Cap1	15
Cap2	40
Cap3	50
INFbase	0.2
K1	0.9
K2	0.1
H_GW	5
GWstoreSat	8
GWstoreMax	9
GWstoreStart	9
A1	0.134
A2	0.433
A3	0.433
Beta	1.5
m	0.8
EvapScaleF	1
RainScaleF	1
AlphaJ_4	0.7
nJ_4	0.8

Table 5-18 Flood Forecasting Performance Indicators for Makino Stream at Rata Street

Analysis Start Date:	01/01/1999
Analysis End Date:	01/01/2005
No. Of Events*:	12
No. Of Qualified Events:	5
Qualifying Rate, QR:	42%
QR Accuracy Grading:	Less than C
Coeff. Of Determination R^2:	0.73
R^2 Accuracy Grading:	B
Lowest Accuracy Grading:	Less than C
Recommendation:	Not recommended for use in flood forecasting

#Based on Events Greater Than 30 m3/s with a minimum separation of 48hrs.

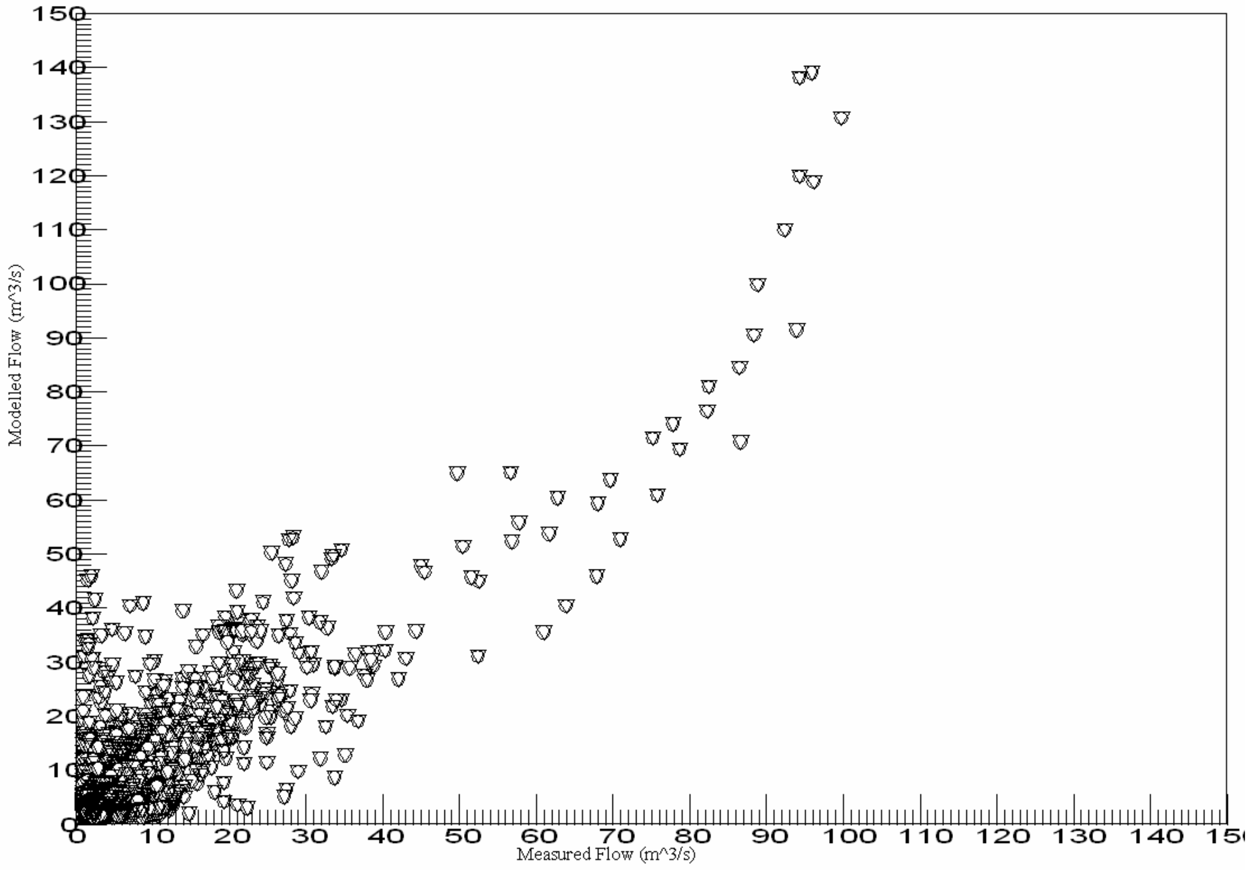


Figure 5-37 Modelled Flow Vs Measure Flow For Makino Stream at Rata Street (1/1/1999-1/1/2005)

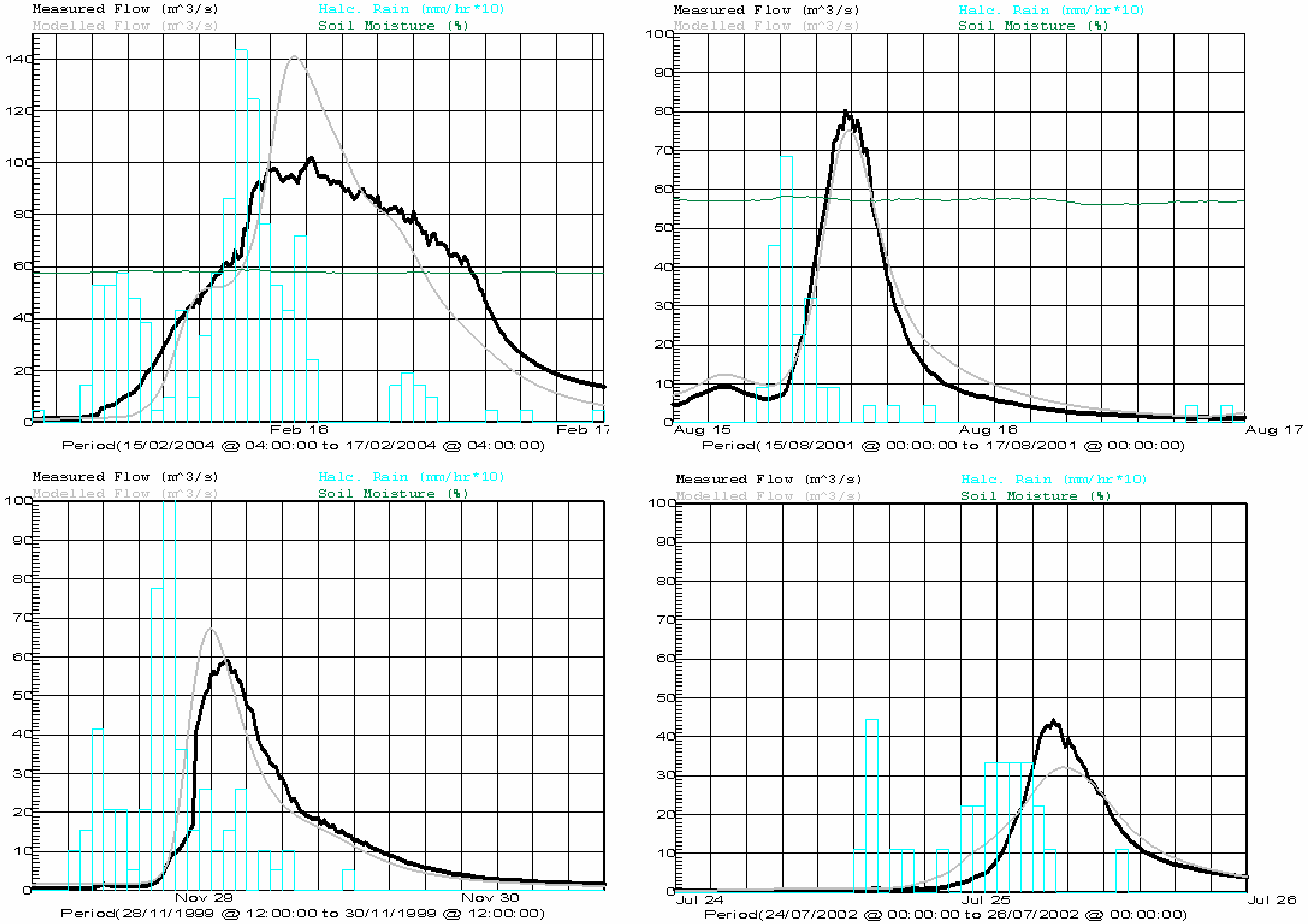


Figure 5-38 Modelled Vs Measured Hydrographs For Makino Stream at Rata Street (4 largest events from 1/1/1999- 1/1/2005).

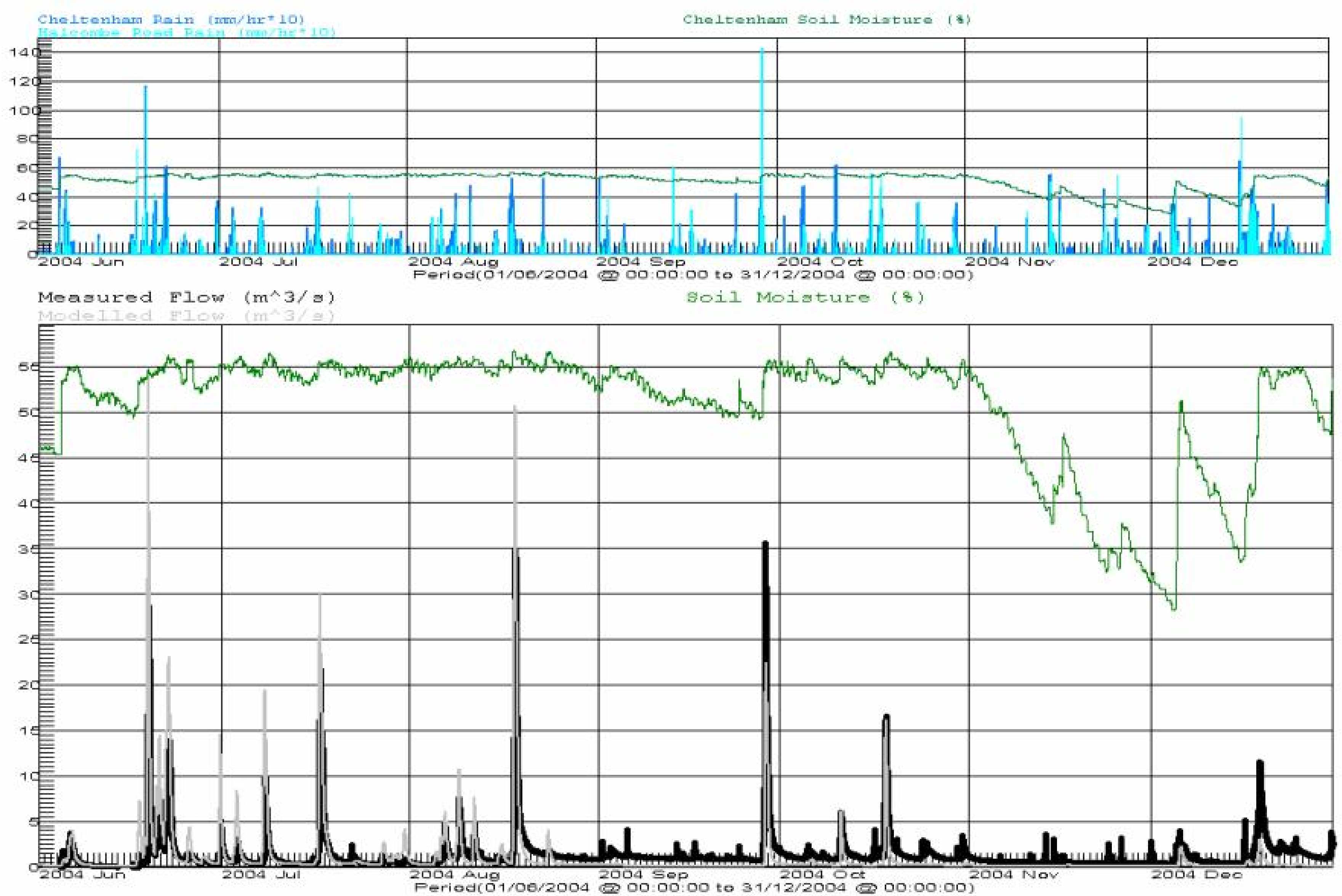


Figure 5-39 Modelled Vs Measured Hydrographs For Makino Stream at Rata Street from 1/6/2004 to 31/12/2004.

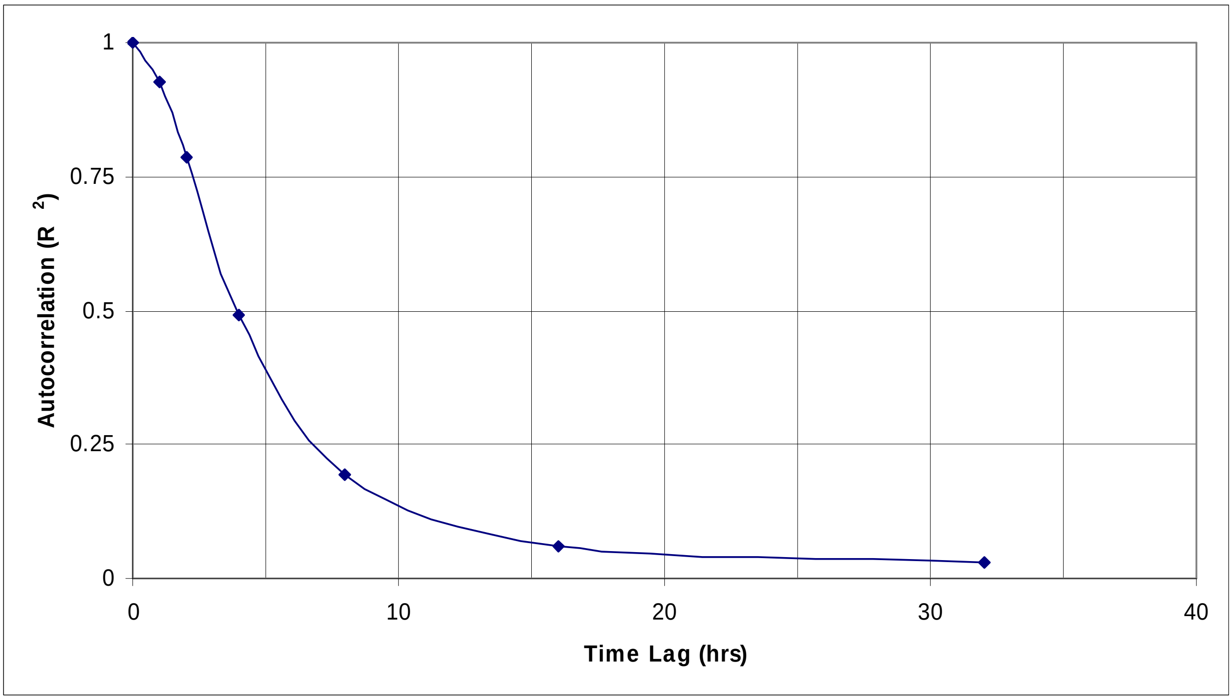


Figure 5-40 Autocorrelation function of the discharge error for Makino Stream at Rata Street from 1/1/1999 to 1/1/2005.

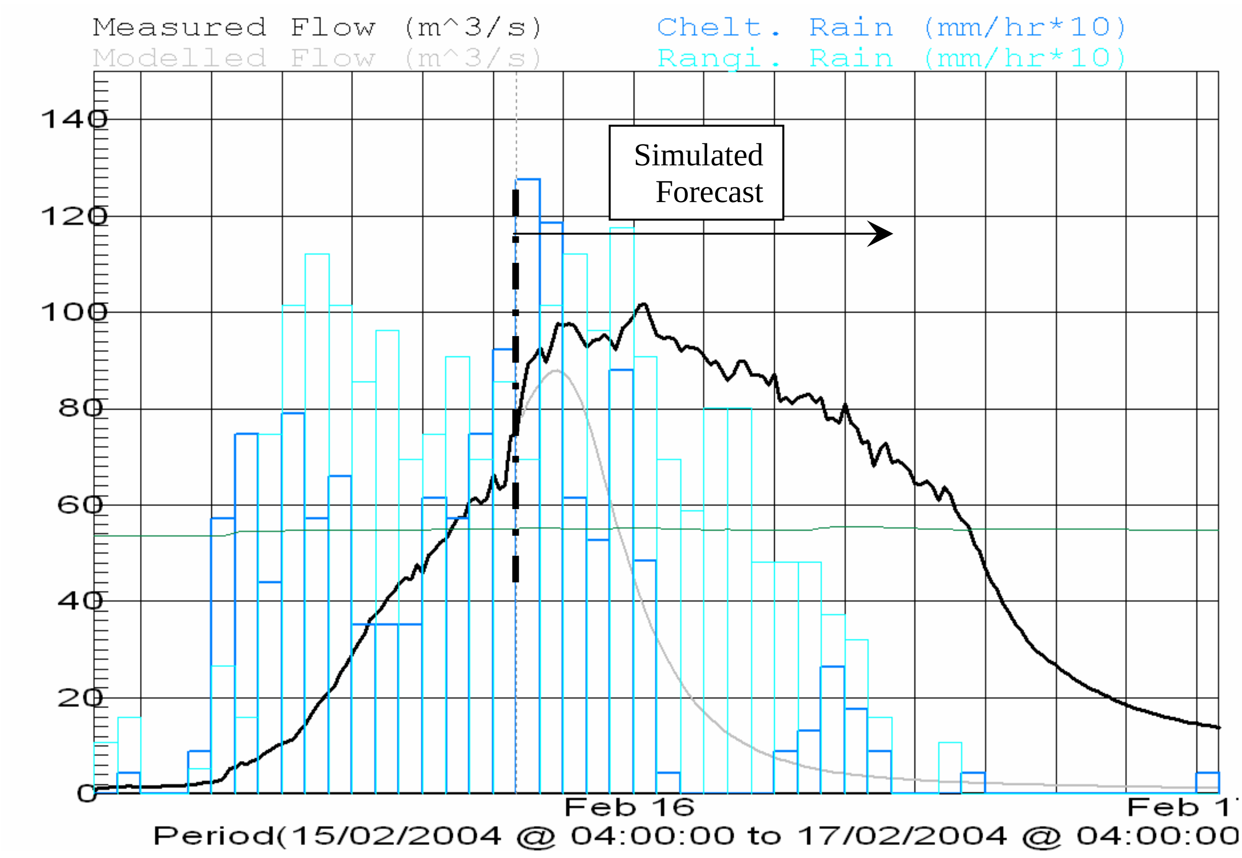


Figure 5-41 Simulated Flood Forecast for Makino Stream at Rata Street at 22:00 15/2/2005.

5.3.2.8 Makino Stream at Boness Road

The flood forecasting performance indicators for this catchment are reasonable with an accuracy grading of 'C' shown in Figure 5-20. Again for the largest event in Figure 5-43 (Feb 2004) structures such as bridges that restrict flood flows may have 'clipped' the peak from the event making it difficult to model this event. For the other three events in Figure 5-43, the modelled results are good.

A peculiar feature of this model was the a very large delay required to be applied to the runoff estimated from the Mangaone West Stream that is a tributary to the Makino just upstream of this gauge. The contribution of the Mangaone West Stream can be seen the 3 smallest events in Figure 5-43. The noticeable bump in the hydrograph tail, well after the peak, is caused by the Mangaone West Stream. To get the rainfall runoff routing model simulate this with any accuracy a 13hr delay was required for all flow out of the Mangaone West Stream. Jeff Watson (per. comm. 2006) has indicated this may be due to unusual limestone caverns in the catchment.

The simulated flood forecast in Figure 5-41 indicates the forecast hydrograph begins to recede approximately 4.5 hours out from when rainfall and flow inputs were set to null. This indicates that the lead time for giving reasonable forecasts is 4.5hrs.

Based on the autocorrelation plot (Figure 5-45), a suitable setting for the error correction half life at this gauge is 6hrs.

Table 5-19 Calibrated Hydrologic Model Parameters for Makino Stream at Boness Road

Parameter	Setting
CapAve	170
Cap1	0.175 * CapAve
Cap2	0.762 * CapAve
Cap3	1.54 * CapAve
INFbase	0.2
K1	0.9
K2	0.1
H_GW	5
GWstoreSat	8
GWstoreMax	9
GWstoreStart	5
A1	0.134
A2	0.433
A3	0.433
Beta	0.5
m	0.8
EvapScaleF	1
RainScaleF	1
AlphaJ_3	1.0
nJ_3	0.8

Table 5-20 Flood Forecasting Performance Indicators for Makino Stream at Boness Road

Analysis Start Date:	01/01/1999
Analysis End Date:	01/01/2005
No. Of Events*:	6
No. Of Qualified Events:	4
Qualifying Rate, QR:	67%
QR Accuracy Grading:	C
Coeff. Of Determination R^2:	0.77
R^2 Accuracy Grading:	B
Lowest Accuracy Grading:	C
Recommendation:	Suitable for making reference forecasts

#Based on Events Greater Than 30 m3/s with a minimum separation of 48hrs.

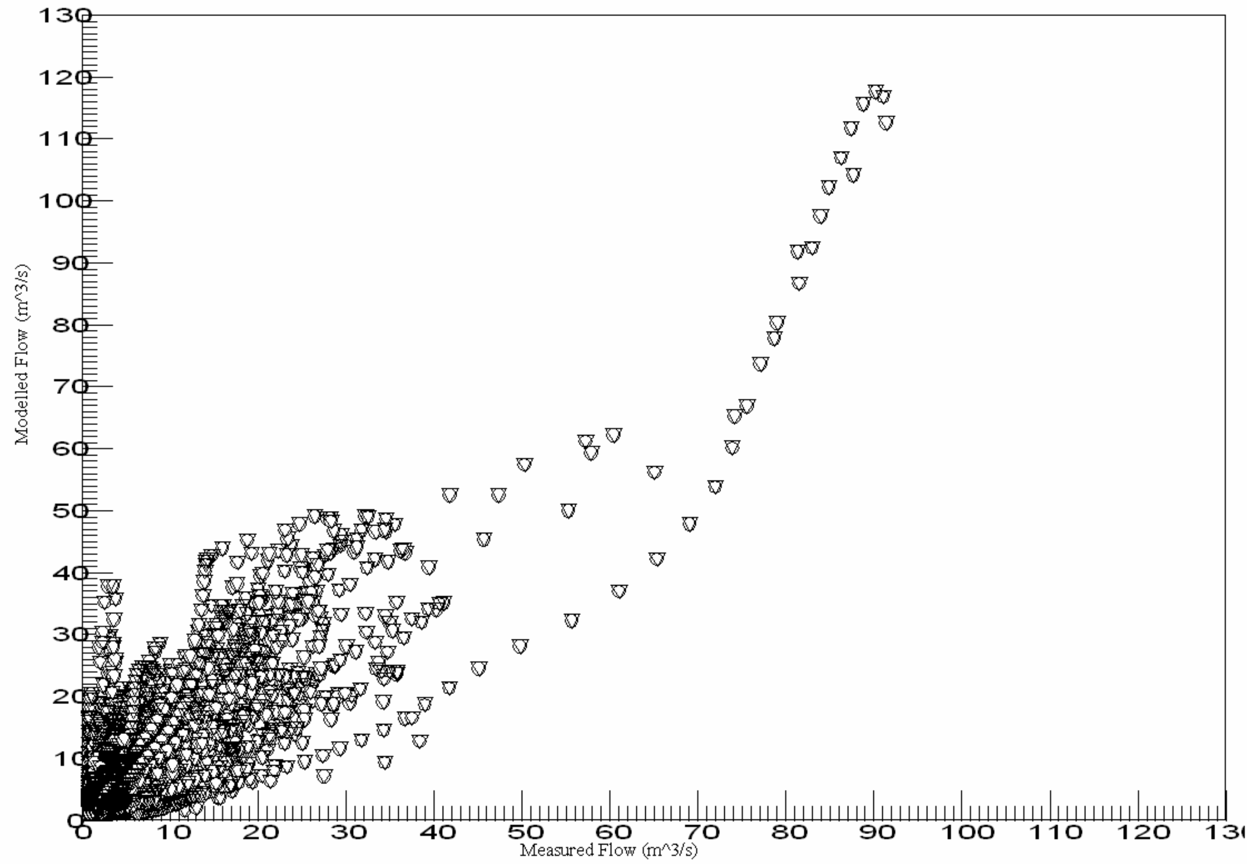


Figure 5-42 Modelled Flow Vs Measure Flow For Makino Stream at Boness Road (1/1/1999-1/1/2005)

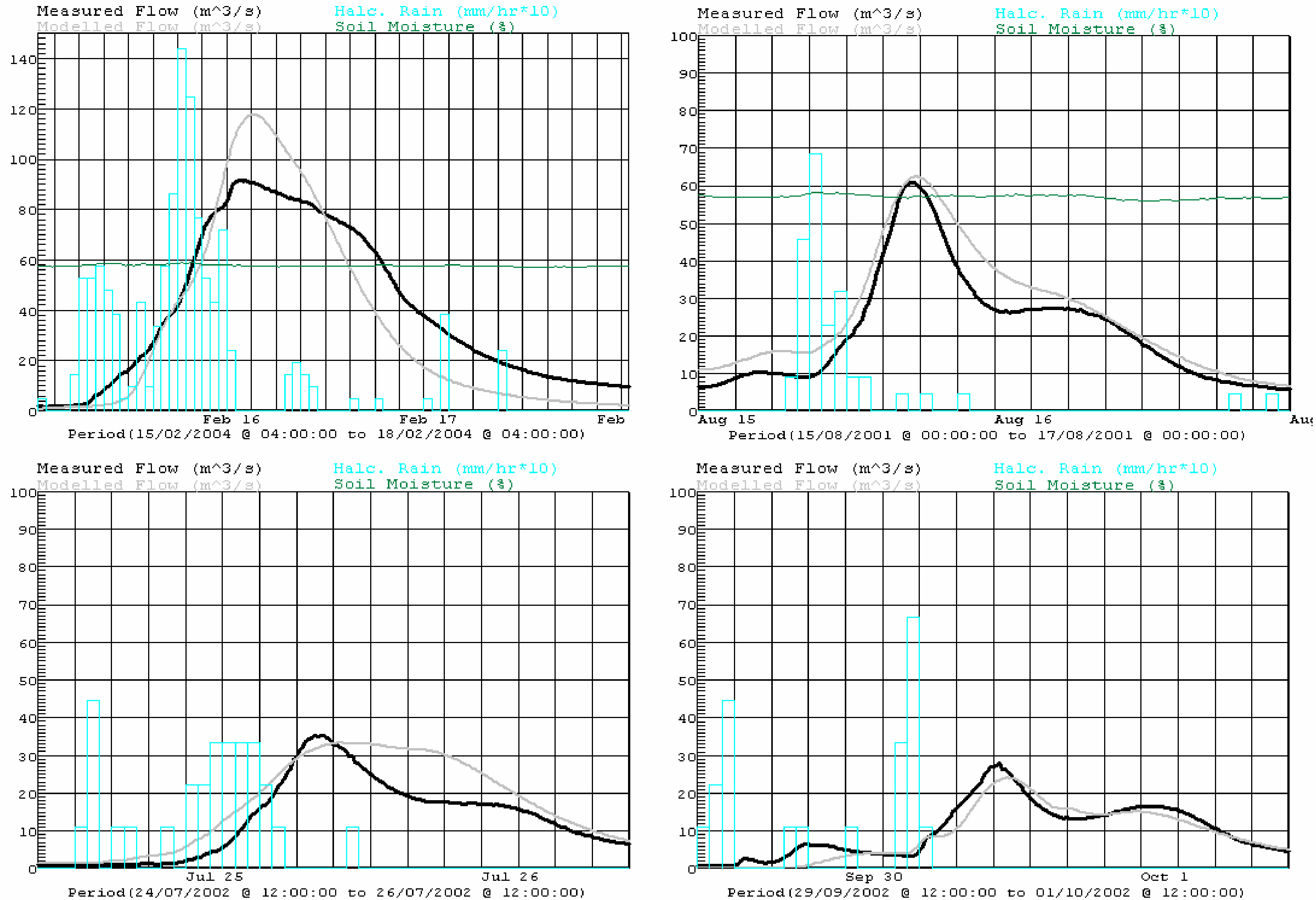


Figure 5-43 Modelled Vs Measured Hydrographs For Makino Stream at Boness Road (4 largest events from 1/1/1999- 1/1/2005).

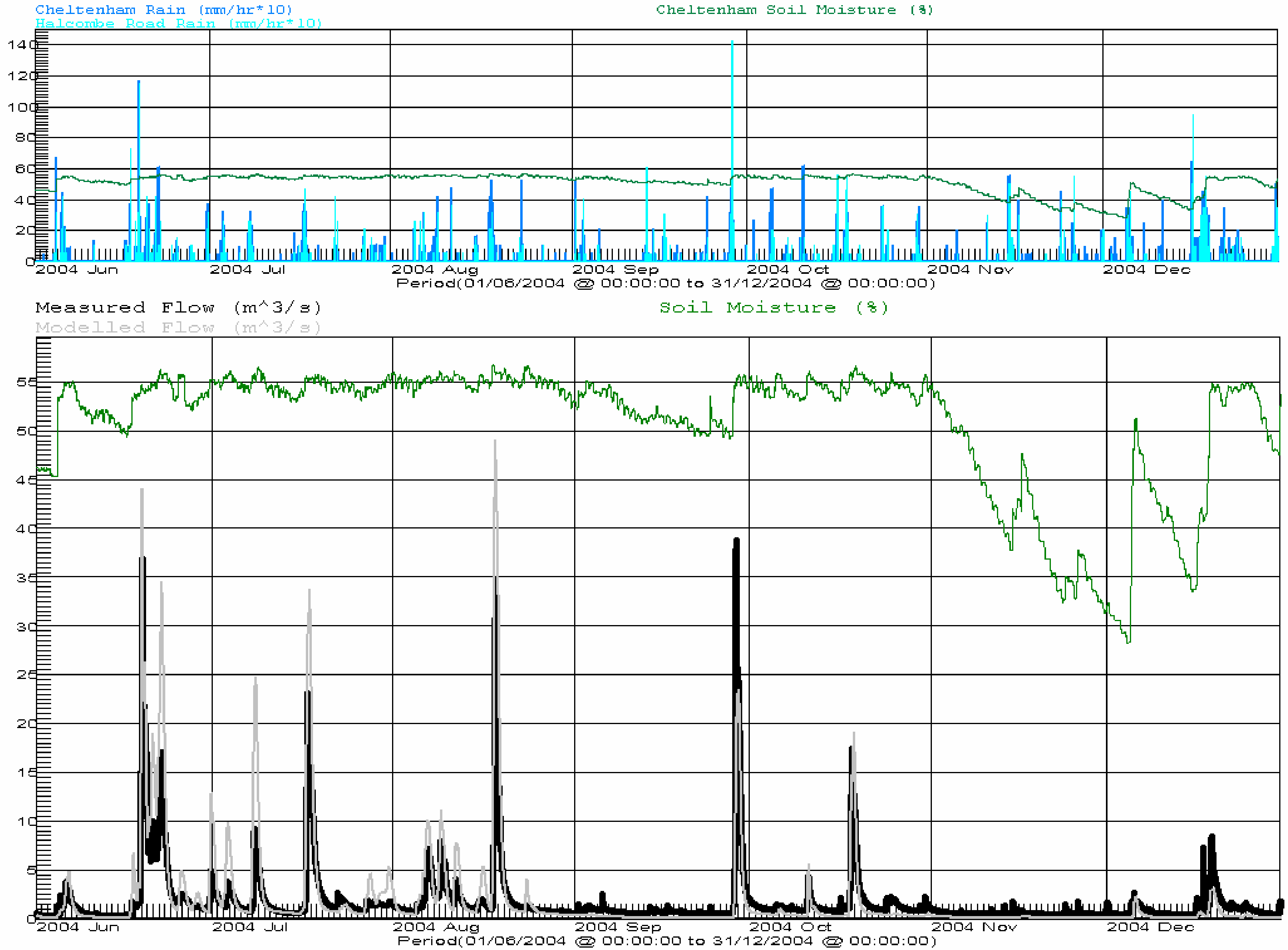


Figure 5-44 Modelled Vs Measured Hydrographs For Makino Stream at Boness Road from 1/6/2004 to 31/12/2004.

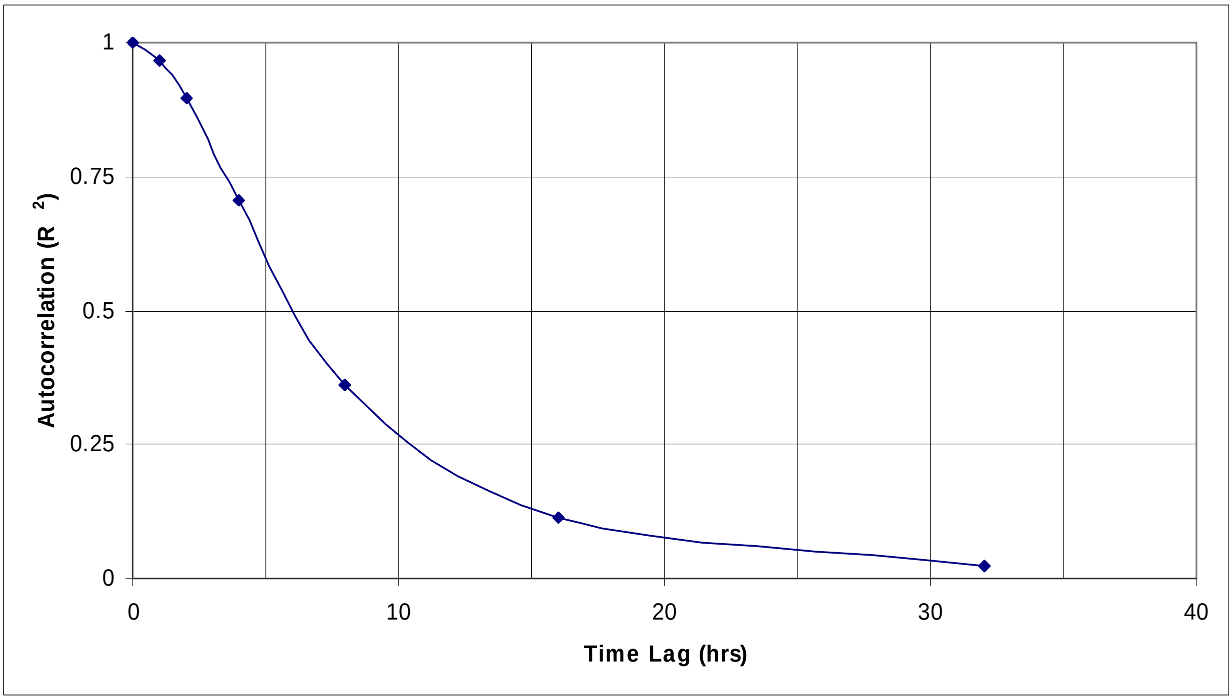


Figure 5-45 Autocorrelation function of the discharge error for Makino Stream at Boness Road from 1/1/1999 to 1/1/2005.

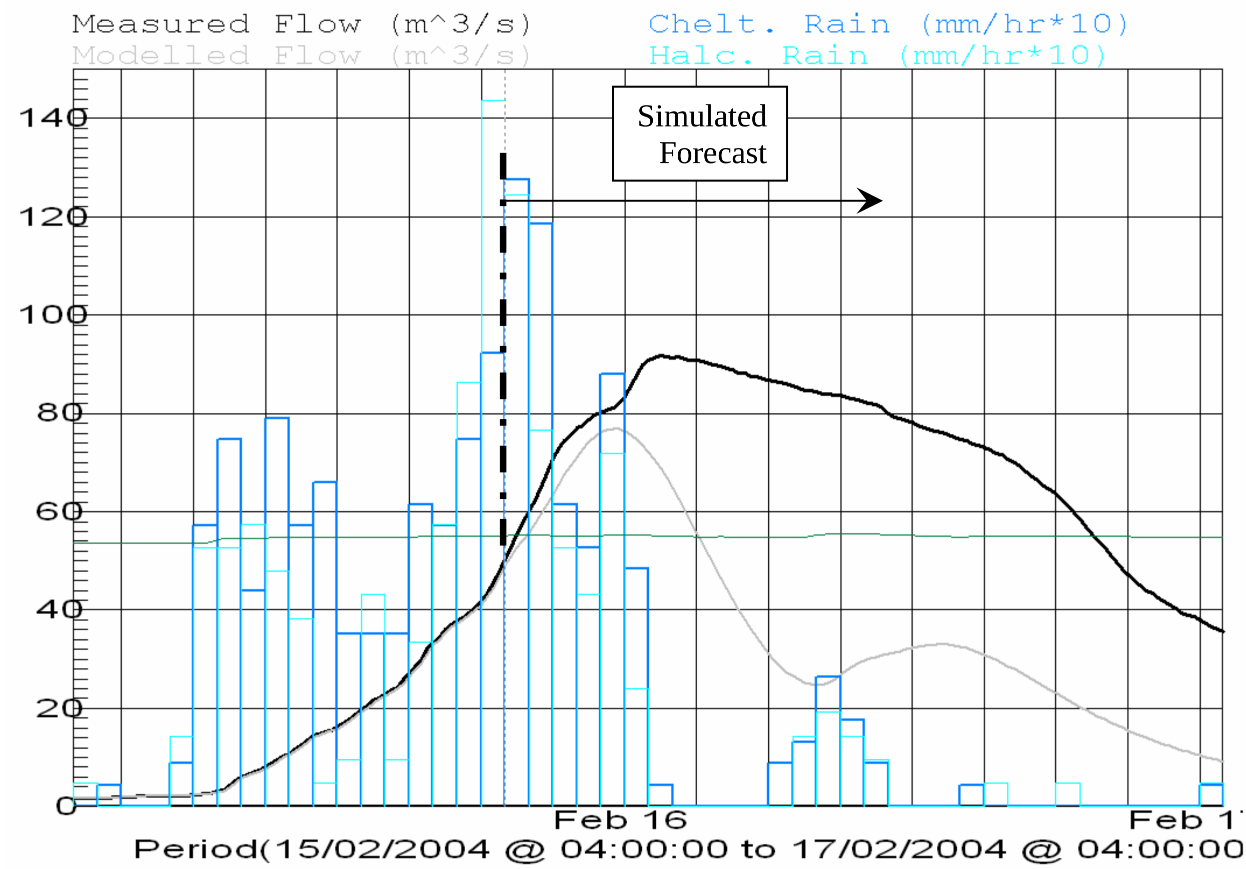


Figure 5-46 Simulated Flood Forecast for Makino Stream at Boness Road at 22:00 15/2/2005.

5.3.2.9 Tokomaru River At Darkys Hole

Attempts to calibrate a rainfall runoff routing model for this catchment produced inconsistent and unreliable results. This is probably due to the relatively small catchment with a large rainfall gradient across it and limited rain gauge coverage. Due to its small size, the lead time for giving reasonable forecasts (for a reasonably calibrated model) would probable be less than an hour in any case. This catchment is a relatively small inflow to the Mike11 model. Based on this it was decided to use the gauge data only as input to the Mike11 model.

5.3.2.10 Turitea Stream At Ngahere Pk Rd

Like the Tokomaru River catchment, an attempted to calibrate a rainfall runoff routing model for this catchment was made but the model produced inconsistent and unreliable results. This is probably due to the relatively small catchment with a large rainfall gradient across it and limited rain gauge coverage. Due to its small size, the lead time for giving reasonable forecasts (for a reasonably calibrated model) would probable be less than an hour in any case. This catchment is a relatively small inflow to the Mike11 model. Based on this it was decided to use the gauge data only as input to the Mike11 model.

5.3 RECOMMENDATIONS FOR IMPROVEMENT

5.3.1 Short Term Rainfall Forecasts

The hyetographs presented in the calibration plots exhibit significant symmetry around the peak. This is due to the ‘persistence’ that rainfall exhibits, meaning rainfall in the near future is probably going to be similar/related to the current rainfall and won’t drop away to zero immediately in the future. The symmetry also indicates if the hyetograph takes a short time to rise then it will probably take a similarly short time to fall and vice versa. This is related to the physical size of the storm and its ground speed.

This characteristic could be used to forecast rainfall in the short term with lead times of 1 to 3hrs. This is expected to improve the lead times for giving reasonable flow forecasts by something less (say 0.5 to 1.5hrs).

This short term rainfall forecasting would still be of benefit even if a longer term rainfall forecast was obtained in the future from a meteorological organisation. This is because the current rainfall is usually a better indicator of near future rainfall than a forecaster can predict.

5.3.2 Additional Rain Gauges

Horizon Regional Council have a good network of flow gauges over the Manawatu Catchment. The rain gauge network is reasonable but biased to higher elevation/rainfall areas. To improve the rainfall distribution measurements over the catchment and hence flood forecasting accuracy, it is recommended that additional rain gauges be placed in lower elevation areas. A cost effective method of achieving this would be to install new rain gauges at existing flow gauge sites (e.g. Mias Reach). This would take advantage of the existing infrastructure (power, telemetry, logger etc) at these sites and significantly reduce the cost of installation and maintenance.

Kiwitea Stream Catchment at Cheltenham Gun Club has a rain gauge just east the northern end of the catchment and one at the southern end. In Figure 5-27 it can be seen that these gauges pickup the rainfall pattern at each end of the catchment but as the rainfall front moves up or down this long catchment these gauges don’t pickup the rainfall falling in the middle. This is why the August 2001 event is underestimated significantly. To capture these events it is recommended a rain gauge be placed in the centre of this catchment.

It is difficult to calibrate the catchment runoff volume into the Makino River between Reids Line and Rata Street flow gauges. This is probably due to the fact that the urban area is very sensitive to rainfall generating runoff and the rain gauge at Halcombe Road may not give the required rainfall sensitivity over this catchment. Based on this and the sensitive issue of flooding in this area it is recommended a rain gauge be added within this catchment.

6 HYDRAULIC MODELS

6.1 MODEL REVIEW

A review of the three Manawatu River MIKE 11 models provided by HRC was carried out by HTC. The main findings of this review and subsequent modifications that were made to the MIKE 11 models are summarized below:

- It is understood that survey of the Manawatu River in the region of Palmerston North has been carried out and that the new river cross-sections were not incorporated into the MIKE 11 models provided to HRC. HTC did not revise the MIKE 11 models to incorporate this new data as it was understood that this would be carried by HRC out at a later date. As a result is was not considered worthwhile to check the model calibration at Teacher's College gauge site as:
    - The existing model has already been calibrated by HRC; and
    - The existing model will need to be recalibrated once the new river cross-sections are incorporated into the model and any calibration/verification carried out at this stage would be become redundant.
- The MIKE 11 cross-section files provided by HRC (MNW2-Ash.xns11 and Manawatu.xns11) did not contain a cross-section at the location of Teachers Crossing gauge site, river chainage 30,500m, which is a critical reporting location for flood forecasting model. As a surveyed cross-section at this location was not available, the cross-section at river chainage 30,440m in the provided files was used for the Teachers College site.
- There are a number of methods that can be selected in MIKE 11 to calculate conveyance for the cross-sections in the hydraulic model. For the three cross-section files provided by HRC both the Resistance Radius and Total Area Hydraulic Radius methods are used, but in an inconsistent way. Typically only one of the two methods should be used on all cross-sections within a branch/model. However, given that the models appear to be stable, no changes to the conveyance calculations were made.
- It was found that many of the conveyance curves in the cross-section files, for all three MIKE 11 models, appear to be roughly defined due to the Level Selection Method that has been adopted to define the cross-section characteristics. Where the conveyance curves appear to be poorly defined, the levels at which the cross-section characteristics are calculated are either not numerous enough or are too far apart. This results in incorrectly interpolated cross-section characteristics for large portions of the cross-section. Given that the current MIKE 11 models have been calibrated with the current conveyance curve definitions, no changes were made to the model. However, it is recommended that all conveyance curves be adjusted when the new river survey above Palmerston North is incorporated into the MIKE 11 model.
- If it is intended to use these MIKE 11 models for flood mapping or engineering design purposes it is recommended that the conveyance curves be revised to ensure correct flood levels are estimated along the full length of each of the models.
- The "trickle" inflow files were removed from the MIKE 11 models for simplification of the models.

When running the provided MIKE 11 models, WARNING messages appear advising that the invert levels of cross-sections in connecting reaches do not match. This can sometimes result in model instability. Based on advice from HRC the invert levels for cross-sections in connecting reaches were not modified to match.

The levee dambreak structures in the MIKE11 model representing the Moutoa Levee break structures were removed for the flood forecast modeling based on advice from HRC.

In the downstream model there are two reporting locations. The flood information at the floodgates is obtained from the GATENTRY 0 cross section. The information relating to Opiki Rd bridge is obtained from the OPIKI-RD 780 cross section.

In order to obtain the discharge for each reporting location, an identical cross section was inserted into the model 10m downstream of the existing cross section. As the MIKE11 results file produces discharge results halfway between each cross section, this enabled accurate discharge results to be extracted for the reporting cross section without altering the accuracy of the model.

Apart from the changes mentioned above, no other modifications were made to the set-up of the MIKE 11 models.

6.2 INCORPORATION INTO FLOOD FORECASTING SYSTEM

The hydraulic modelling component of the Flood Forecasting System consists of three MIKE11 models previously developed by Graham Doull of HRC. The incorporation of these models into the Flood Forecasting System involved:

1. Setup of inflow hydrographs at relevant points,

   - Table 1 below shows the input hydrograph locations for each of the three MIKE 11 models. Also refer to the boundary condition (*.bnd11) files in the directory of each MIKE11 model. eg C:\HRCFloodFS\Models\Manawatu\Mike11\Ashhurst-PNorth\Ash-to-PN.bnd11.

2. Setup of output hydrographs at relevant points,

   - Table 2 below shows output hydrograph (level and discharge) locations for each of the three MIKE 11 models. The output locations are defined in the OutputSpec.txt files in the directory of each MIKE11 model. Eg C:\HRCFloodFS\Models\Manawatu\Mike11 \Ashhurst-PNorth\OutputSpec.txt.

     These text files are used by the res11read.exe program to convert standard MIKE 11 output files (*.res11) into a text format and can be modified to provide output at any location within the MIKE 11 model. Three lots of data are required for these text files:

     - Item Number (eg 1 = water level, 2 = discharge). If unsure of the Item Numbers refer to file C:\Program Files\Common Files\DHI\MIKEZero\eumtype.lan which provides a list MIKE 11 variables. The first variable in the list (usually water level) is equivalent to Item Number 1, the second is Item Number to and so on for the full length of the list.

- The river chainage where the output is required. Note that flood levels and discharges are reported at different river chainages in the MIKE 11 *.res11 output files.
- The river branch name in the MIKE 11 model.

3. Automation of the models.

- For details of how the start time, end time, initial hydrodynamic conditions and hotstart time of the models are updated for each model run, see the Rules of the Run_*sim11 nodes in the Master Model (C: HRCFloodFS\Models\Manawatu\TStudio\ManawatuMaster.tso).
- For details of the DOS commands that are used to run the MIKE11 models, output results to a text file and update the hotstart file see the Run_*.bat file in the directory of each MIKE11 model. (eg C:\HRCFloodFS\Models\Manawatu\Mike11\Run_Ash-to-PN.bat)

Table 6-1 Inflow Locations for MIKE 11 Models

MIKE 11 Branch	Model Chainage (m)	Comment
Ashurst to Palmerston North MIKE 11 Model		
MNW2CHAN	10870	Inflow to top end of model from.
MNW2CHAN	13900	Inflow for pickup between Ashurst and Te Matia Road.
Palmerston North MIKE 11 Model		
MNW2CHAN	22520	Inflow to top end of model from upstream MIKE 11 model.
MNW2CHAN	25680	Inflow for pickup between Te Matia Road and Teachers College.
PIE-TRAK	1000	Constant inflow.
Palmerston North to Sea MIKE 11 Model		
MNW2CHAN	30240	Inflow to top end of model from upstream MIKE 11 model.
OROUA	22500	Inflow from Oroua River
DUMP	445	Inflow from Mangaone River
KEEBLE	1	Inflow from Turitea River
TOKOMARU	0	Inflow from Tokomaru River
Kara-Creek	0	Constant inflow.
Shannon-flud	2800	Constant inflow – $0m^3/s$

Table 6-2 Output Locations for MIKE 11 Models

MIKE 11 Branch	Model Chainage (m)	Comment
Ashurst to Palmerston North MIKE 11 Model		
MNW2CHAN	22520	Flood level output.
MNW2CHAN	22510	Discharge output for input to downstream MIKE 11 model.
Palmerston North MIKE 11 Model		
MNW2CHAN	30240	Flood level output for Teachers College.
MNW2CHAN	30230	Discharge output for input to downstream MIKE 11 model and for Teachers College.
Palmerston North to Sea MIKE 11 Model		
OPIKI-RD	780	Flood level output at Opiki Road
OPIKI-RD	772.5	Flood discharge output at Opiki Road
GATENTRY	0	Flood level output at Muotoa flood gates.
GATENTRY	10	Flood discharge output at Muotoa flood gates.

6.3 MIKE11 HOTSTART VS. PARAMETER FILE

There are two ways to define the initial water level positions in the Mike11 models. These are:

- **Parameter File**: The initial conditions will be taken from the parameter file relevant to the module in question.
- **Hotstart File**: The initial conditions will be loaded from an existing result file.

The hotstart file is more accurate at the start of the run but for this to work the start and end times of the hotstart file must straddle the start time that you wish to run the simulation over. This generally works fine for real-time flood forecasting but the first time the Flood Forecasting System is run it is likely there will be no hotstart file straddling the start time. To generate an approximate hotstart file the parameter file option can be used. This option starts with very rough initial water levels defimed in the parameter file and may take a 1 day of simulation time to settle down before giving good results. It is possible it may not work if stability problems arise.

The option used in the Flood Forecasting System can be changed in the user interface:

.

7 REFERENCES

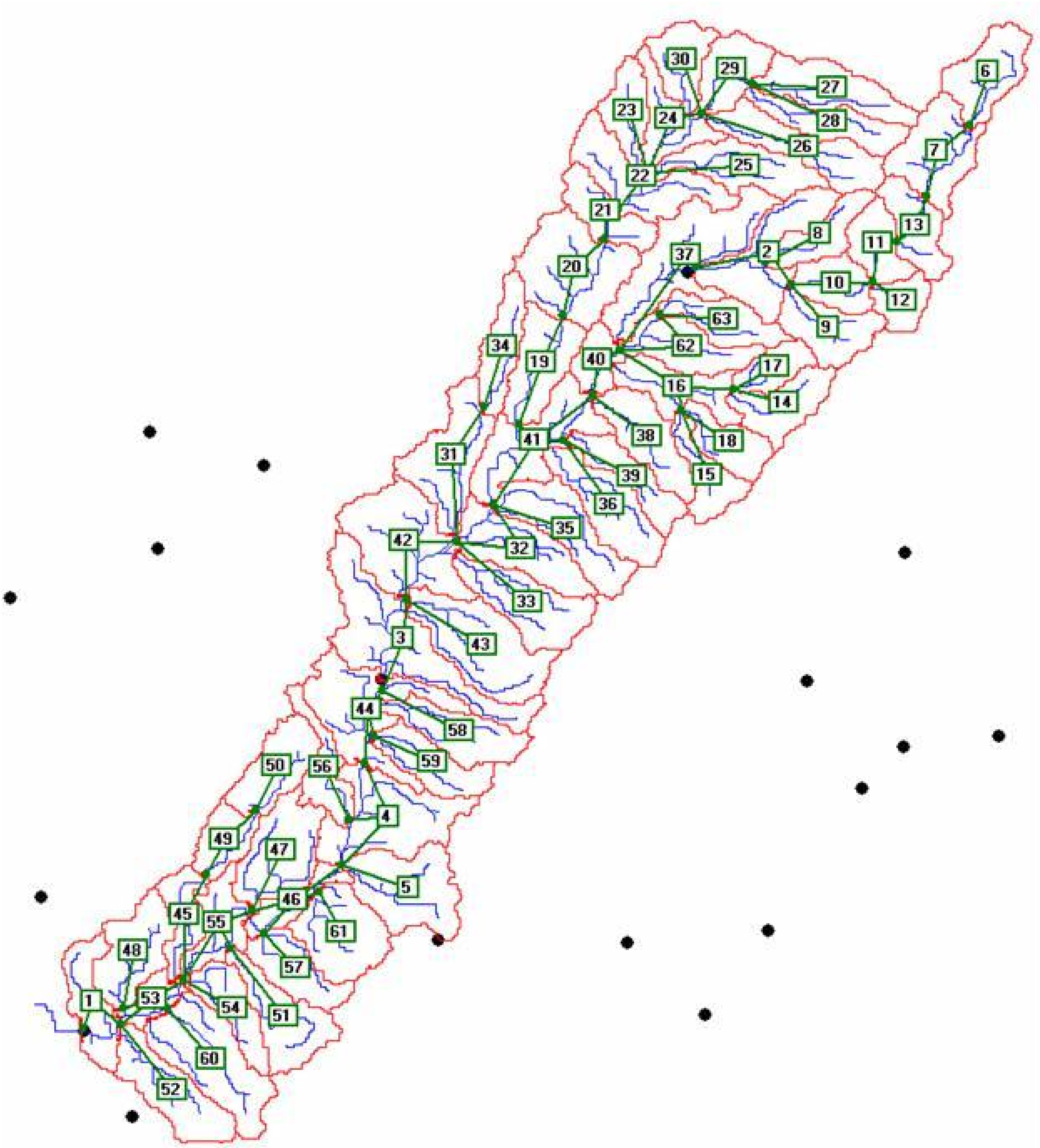
Boughton, W.C. and Chiew, F.,(2003) Calibrations of the AWBM for use on Ungauged Catchments,

CatchmentSIM Homepage www.toolkit.net.au/catchsim/ January 2005.

Chinese Standards (2000), Chinese Standards. (2000). Standard for hydrological information and hydrological forecasting, Chinese Ministry of Water Resources – SL 250-2000.

8 APPENDIX A

8.1 TEACHERS COLLEGE RAINFALL RUNOFF ROUTING MODEL NODE AND LINKAGE DETAILS



SubCatchment Name	Centroid Easting (m)	Centroid Northing (m)	Pickup Area(km^2)	Total Area(km^2)	Mean Annual Rainfall (mm)
SC1	2733484.891	6090493.938	9.4451	719.277	987
SC2	2764560.406	6124932.773	14.8336	85.5746	1880
SC3	2747786.391	6107162.516	24.2786	469.8429	1303

SC4	2747079.266	6098997.375	18.6479	510.5414	1562
SC5	2748015.344	6095754.133	15.9476	15.9476	1427
SC6	2774616.938	6133228.859	10.9224	10.9224	2200
SC7	2772269.5	6129598.375	13.5985	13.5985	2224
SC8	2766938.203	6125804.289	7.4471	7.4471	2310
SC9	2767305.672	6121501.133	9.9657	9.9657	3246
SC10	2767635.969	6123548.281	7.3502	28.8074	2821
SC11	2769569.031	6125354.609	7.4834	16.2019	2570
SC12	2770690.141	6122739.711	5.2553	5.2553	2625
SC13	2771309.375	6126170.938	8.7185	8.7185	2418
SC14	2765269.625	6118038.859	9.3119	9.3119	3137
SC15	2761737.344	6114734.18	7.2775	7.2775	2777
SC16	2760394.516	6118780.469	10.0263	23.2857	1953
SC17	2764841.594	6119686.758	5.6186	5.6186	1931
SC18	2762735.344	6116238.031	7.6408	7.6408	3036
SC19	2754086.313	6119884.938	12.0122	134.2893	2828
SC20	2755608.75	6124231.789	19.3987	122.2771	2030
SC21	2757052.094	6126840.719	8.0888	102.8784	1080
SC22	2758726.734	6128432.805	14.9183	94.7896	1000
SC23	2758120.719	6131442.984	7.5197	7.5197	1034
SC24	2760005.703	6131102.719	8.6095	60.1214	1156
SC25	2763461.844	6128911.727	12.2301	12.2301	1196
SC26	2766183.188	6129824.609	13.1262	13.1262	1286
SC27	2767471.109	6132506.484	12.2786	12.2786	1544
SC28	2767503.422	6130960.672	9.4451	9.4451	1858
SC29	2762868.188	6133346.484	8.5248	8.5248	1878
SC30	2760605.391	6133794.922	8.1373	8.1373	1915
SC31	2749950.156	6115647.164	15.1484	23.77	1499
SC32	2753191.078	6111334.414	13.6711	122.6525	1316
SC33	2753501.094	6108855.344	14.0949	14.0949	1000
SC34	2752324.313	6120633.523	8.6216	8.6216	1156
SC35	2755299.938	6112275.313	14.0949	14.0949	1252
SC36	2757223.313	6113333.047	13.2836	13.2836	1000
SC37	2760774.563	6124811.313	21.881	21.881	1572
SC38	2759000.031	6116466.375	11.4915	11.4915	2146
SC39	2758271.813	6114651.727	8.3673	8.3673	1342
SC40	2756686.547	6120027.414	5.3401	24.2423	2281
SC41	2753815.297	6116322.586	15.6207	34.5229	2219
SC42	2747848.344	6111686.211	20.6338	39.536	1238
SC43	2751414.172	6106903.656	19.5077	19.5077	1307
SC44	2746086.078	6103956.836	18.0183	57.5785	1000
SC45	2737695.547	6094493.172	7.2049	24.6056	1424
SC46	2742706.969	6095173.172	5.2553	75.9963	1429
SC47	2742142.266	6097443.563	14.2766	14.2766	1110
SC48	2735406.25	6092860.32	12.0969	12.0969	1261
SC49	2739554.703	6097974.625	6.6963	17.4007	1236
SC50	2741947.531	6101336.422	10.7044	10.7044	1021
SC51	2742286.625	6089789.914	12.0848	12.0848	1091
SC52	2737139.328	6086445.766	13.0051	13.0051	1226
SC53	2736220.859	6090635.063	4.2139	110.1196	1301
SC54	2739958.984	6090219.852	8.3795	8.3795	1253
SC55	2739287.922	6094119.625	8.0646	78.8056	1092
SC56	2744129.188	6101284.492	7.6529	7.6529	1262
SC57	2742807.984	6092041.852	9.4208	9.4208	1143

SC58	2750374.125	6102947.758	11.0919	11.0919	1358
SC59	2749093.203	6101530.727	9.5661	9.5661	1282
SC60	2738977.063	6087871.828	18.7206	18.7206	1871
SC61	2744947.453	6093699.742	14.107	14.107	1811
SC62	2760831.922	6120650.922	10.2321	18.9022	1290
SC63	2762507.141	6121864.984	8.6701	8.6701	1300

Junction	Easting (m)	Northing (m)	Description
J_1	2733045.156	6089290.539	Manawatu at Teachers College
J_2	2761215.703	6124228.563	Pohangina at Piripiri
J_3	2746759.031	6104820.078	Pohangina at Mais Reach
J_4	2744943.359	6096759.578	
J_5	2773782.406	6130798.008	
J_6	2771779.656	6127529.789	
J_7	2764406.891	6124503.664	
J_8	2765599	6123449.102	
J_9	2769312.891	6123604.992	
J_10	2770459.156	6125439.008	
J_11	2762948.844	6118671.484	
J_12	2760541.688	6117667.359	
J_13	2757682.156	6120462.711	
J_14	2753072.656	6117020.875	
J_15	2755097.406	6122016.734	
J_16	2757012.125	6125582.063	
J_17	2757639.359	6126924.563	
J_18	2758978.188	6128611.859	
J_19	2761454.125	6131326.203	
J_20	2763801.656	6132701.719	
J_21	2750205.469	6111647.203	
J_22	2751435.781	6117859.938	
J_23	2751880.531	6113352.844	
J_24	2755080.906	6116333.125	
J_25	2756474.75	6118350.531	
J_26	2747907.594	6108981	
J_27	2746004.625	6101479.695	
J_28	2737686.75	6091465.383	
J_29	2740775.109	6094679.063	
J_30	2734868.703	6090218.031	
J_31	2738701.266	6096377.18	
J_32	2740968.125	6099304.273	
J_33	2739836.266	6092953.336	
J_34	2734769.125	6089437.266	
J_35	2745237.719	6098886.117	
J_36	2741334.922	6093655.5	
J_37	2746378.484	6102678.867	
J_38	2736947.688	6090174.797	
J_39	2743876.359	6095570.742	
J_40	2759546.734	6122119.445	

Link	Upstream Node	Downstream Node	Flow Length (km)
RJ_2	J_2	SC37	3.3206
RJ_3	J_3	SC44	2.0953
RJ_4	J_4	SC46	3.2533
RJ_5	J_5	SC7	2.4348
RJ_6	J_6	SC13	1.4989
RJ_7	J_7	SC2	1.8622
RJ_8	J_8	SC2	2.8805
RJ_9	J_9	SC10	2.4484
RJ_10	J_10	SC11	1.256
RJ_11	J_11	SC16	3.3396
RJ_12	J_12	SC16	2.3945
RJ_13	J_13	SC40	1.5424
RJ_14	J_14	SC41	2.6994
RJ_15	J_15	SC19	3.3734
RJ_16	J_16	SC20	2.551
RJ_17	J_17	SC21	0.8056
RJ_18	J_18	SC22	1.438
RJ_19	J_19	SC24	2.3173
RJ_20	J_20	SC29	1.934
RJ_21	J_21	SC42	2.1853
RJ_22	J_22	SC31	3.5441
RJ_23	J_23	SC32	1.2727
RJ_24	J_24	SC41	3.8094
RJ_25	J_25	SC41	5.2898
RJ_26	J_26	SC3	2.5087
RJ_27	J_27	SC4	2.6533
RJ_28	J_28	SC53	2.2008
RJ_29	J_29	SC55	3.4895
RJ_30	J_30	SC53	0.2751
RJ_31	J_31	SC45	3.4708
RJ_32	J_32	SC49	2.3926
RJ_33	J_33	SC55	1.9807
RJ_34	J_34	SC1	1.2105
RJ_35	J_35	SC4	1.0604
RJ_36	J_36	SC46	0.5502
RJ_37	J_37	SC44	0.5997
RJ_38	J_38	SC53	0.7153
RJ_39	J_39	SC46	2.0881
RJ_40	J_40	SC62	1.3689
RC_1	SC1	J_1	1.403
RC_2	SC2	J_2	2.9589
RC_3	SC3	J_3	2.615
RC_4	SC4	J_4	2.7261
RC_5	SC5	J_4	4.2863
RC_6	SC6	J_5	3.6669
RC_7	SC7	J_6	2.5173
RC_8	SC8	J_7	3.8931
RC_9	SC9	J_8	3.2766
RC_10	SC10	J_8	2.5585
RC_11	SC11	J_9	1.3386
RC_12	SC12	J_9	2.522

RC_13	SC13	J_10	1.5264
RC_14	SC14	J_11	3.6413
RC_15	SC15	J_12	3.7179
RC_16	SC16	J_13	3.4347
RC_17	SC17	J_11	3.0762
RC_18	SC18	J_12	3.1834
RC_19	SC19	J_14	3.4009
RC_20	SC20	J_15	2.6347
RC_21	SC21	J_16	0.8217
RC_22	SC22	J_17	1.6042
RC_23	SC23	J_18	3.2801
RC_24	SC24	J_18	2.4912
RC_25	SC25	J_18	5.3046
RC_26	SC26	J_19	5.5057
RC_27	SC27	J_20	4.7653
RC_28	SC28	J_20	4.6004
RC_29	SC29	J_19	1.9792
RC_30	SC30	J_19	3.0249
RC_31	SC31	J_21	3.5716
RC_32	SC32	J_21	1.2922
RC_33	SC33	J_21	4.5262
RC_34	SC34	J_22	3.8388
RC_35	SC35	J_23	5.4192
RC_36	SC36	J_24	5.1801
RC_37	SC37	J_13	3.4032
RC_38	SC38	J_25	4.2579
RC_39	SC39	J_24	4.341
RC_40	SC40	J_25	1.7568
RC_41	SC41	J_23	5.3368
RC_42	SC42	J_26	2.2732
RC_43	SC43	J_26	6.1084
RC_44	SC44	J_27	2.463
RC_45	SC45	J_28	3.5533
RC_46	SC46	J_29	3.3346
RC_47	SC47	J_29	4.2609
RC_48	SC48	J_30	3.869
RC_49	SC49	J_31	2.4751
RC_50	SC50	J_32	3.5254
RC_51	SC51	J_33	5.9689
RC_52	SC52	J_34	4.6617
RC_53	SC53	J_34	2.2283
RC_54	SC54	J_28	3.6687
RC_55	SC55	J_28	3.5488
RC_56	SC56	J_35	4.6232
RC_57	SC57	J_36	3.3969
RC_58	SC58	J_3	4.5644
RC_59	SC59	J_37	4.5084
RC_60	SC60	J_38	4.6495
RC_61	SC61	J_39	2.9686
RC_62	SC62	J_13	1.3964
RC_63	SC63	J_40	4.1847

9 APPENDIX B – OROUA R. AT ALMADALE SLACKLINE

9.1 OROUA MODEL DETAILS

As shown in Figure 9-2 below the Oroua catchment has been broken into 13 sub-areas. Almadale Slackline provides a very good calibration point for the river being located near the bottom of the catchment. Many telemetered rainfall gauges surround the catchment but most are located on adjacent ridges and may not be representative of the rainfall in the catchment itself. Of the rainfall gauges shown in the map below, only the rainfall gauges that appear in Figure 9-2 are being currently applied in the model.

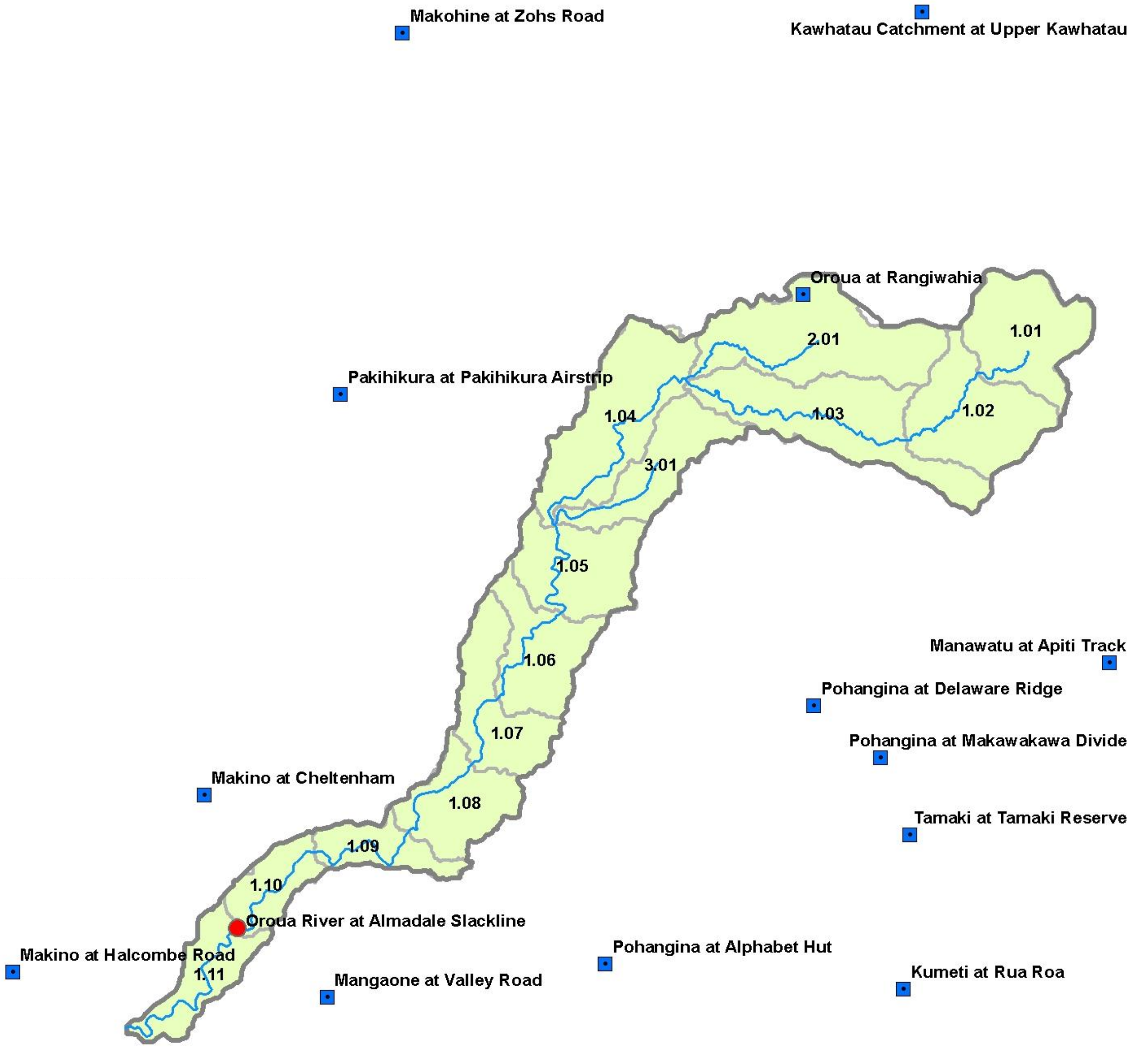


Figure 9-1: Oroua River Subcatchment Breakdown Showing the Network of Available Telmetered Rainfall Gauges

	R1	R2	R5	R6	R7	R8	R10
	Rangiwahia	Delaware Ridge	Mangaone at Milsons Line	Valley Road	Cheltenham	Fielding Halcombe Rd	Motoua
SC101	1.34	0.23	0	0	0	0	0
SC102	1.14	0.28	0	0	0	0	0
SC103	0.90	0.12	0	0	0	0	0
SC104	0.52	0.13	0	0	0.12	0	0.05
SC105	0.22	0.23	0	0	0.21	0	0.05
SC106	0.14	0.22	0	0	0.30	0	0.05
SC107	0.11	0.18	0	0	0.43	0	0.05
SC108	0	0.08	0	0.44	0.40	0	0
SC109	0	0.03	0	0.54	0.42	0	0
SC110	0	0.01	0	0.38	0.50	0.09	0
SC111	0	0	0.09	0.43	0.23	0.22	0
SC201	1.09	0.01	0	0	0	0	0
SC301	0.50	0.18	0	0	0.11	0	0.04
Av Annual Rainfall at Gauge (mm)	1350	2200	900	1000	950	900	900

Figure 9-2: Adopted Rainfall Gauges in Current Model and Their Associated Gauge Weightings and Mean Annual Rainfall Totals.

9.2 OROUA CALIBRATION

The adopted parameter set for the Oroua River is shown below.

Table 9-1: Calibration Parameters – Orua River at Almadale Slackline

Alpha	0.3	INFbase	0.65	A1	0.134
n	0.7	K1	0.895	A2	0.433
CapAve	9	K2	0.99	A3	0.433
Cap1	0.675	H_GW	20	Beta	1
Cap2	0.762	GWstoreSat	90	m	0.7
Cap3	1.524	GWstoreMax	110	EvapScaleF	1
		GWstoreStart	20	RainScaleF	1

Calibration results include:

- Tabulated event statistics comparing peaks and timing. At the base of the table, a rating has been given to the quality of the calibration based on performance criteria specified in Chinese Standards (2000). For more information refer to Section 5.2.3 above.
- Event plots.
- Monthly and seasonal volume balances.
- X-Y plots including correlation coefficients.
- A sample annual time series plot.

Table 9-2: Event Comparison – Oroua River at Almadale Slackline

Event Time	Peak Flow (m^3/s)		% Difference (Mod - Obs)		Timing Difference (Mod - Obs)	
	Observed	Modelled	Actual	Absolute	Actual (hrs)	Absolute (hrs)
29/11/1999 07:00	265.5	228.8	-13.8	13.8	-3.0	3.0
11/04/2000 00:00	193.4	185.3	-4.2	4.2	-2.0	2.0
04/07/2000 19:00	113.5	52.3	-53.9	53.9	-7.0	7.0
25/05/2001 20:00	174.5	149.5	-14.3	14.3	-1.0	1.0
22/07/2001 10:00	106.2	137.3	29.3	29.3	1.0	1.0
13/02/2002 19:00	111.5	158.0	41.7	41.7	-2.0	2.0
11/06/2002 04:00	113.5	94.1	-17.1	17.1	-2.0	2.0
24/07/2002 07:00	144.8	108.0	-25.4	25.4	29.0	29.0
24/08/2003 00:00	161.3	105.9	-34.3	34.3	2.0	2.0
06/09/2003 04:00	121.6	121.4	-0.2	0.2	-1.0	1.0
28/09/2003 18:00	141.8	142.4	0.4	0.4	0.0	0.0
21/01/2004 21:00	117.0	111.5	-4.7	4.7	-5.0	5.0
16/02/2004 06:00	437.0	541.2	23.9	23.9	3	3.0
			Average	**20.2**	**Average**	**4.5**

Chinese Standards Performance Indicators:

QR = 54% CD = 0.63 Accuracy Grading = Less than C

Recommendation: Not suitable for making flood forecasts.

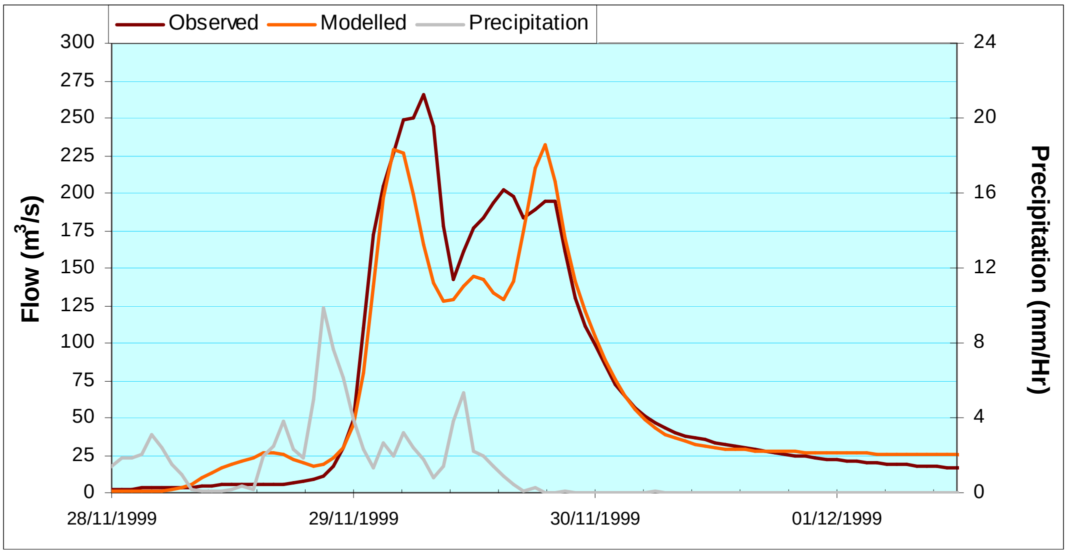


Figure 9-3: November 1999 Event Plot – Oroua River at Almadale Slackline

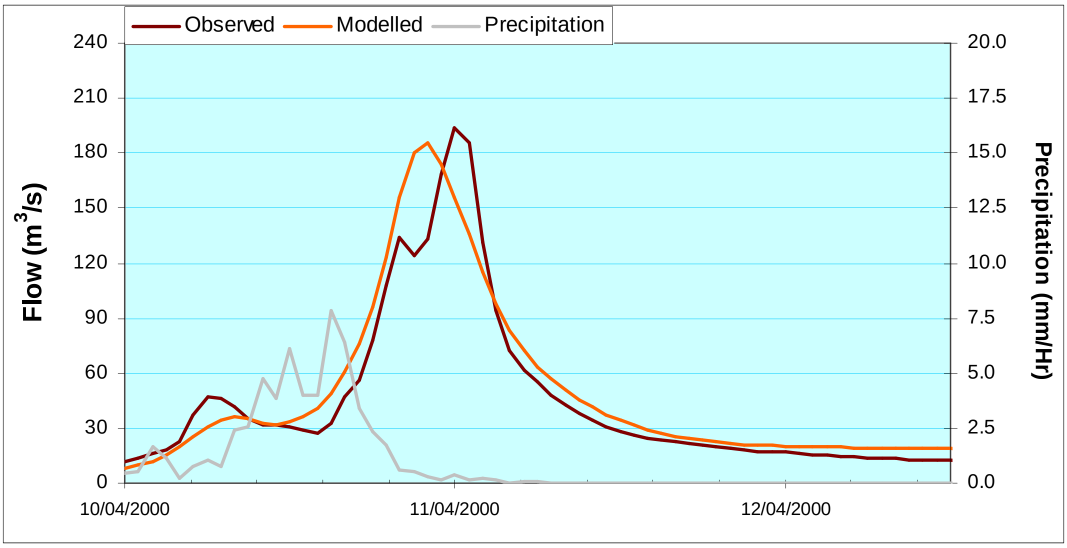


Figure 9-4: April 2000 Event Plot – Oroua River at Almadale Slackline

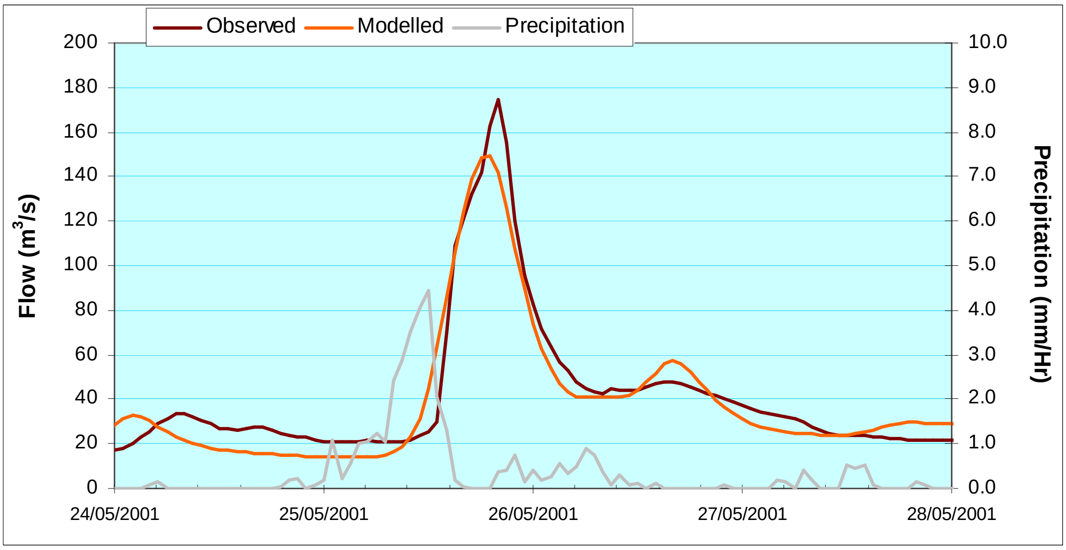


Figure 9-5: May 2001 Event Plot – Oroua River at Almadale Slackline

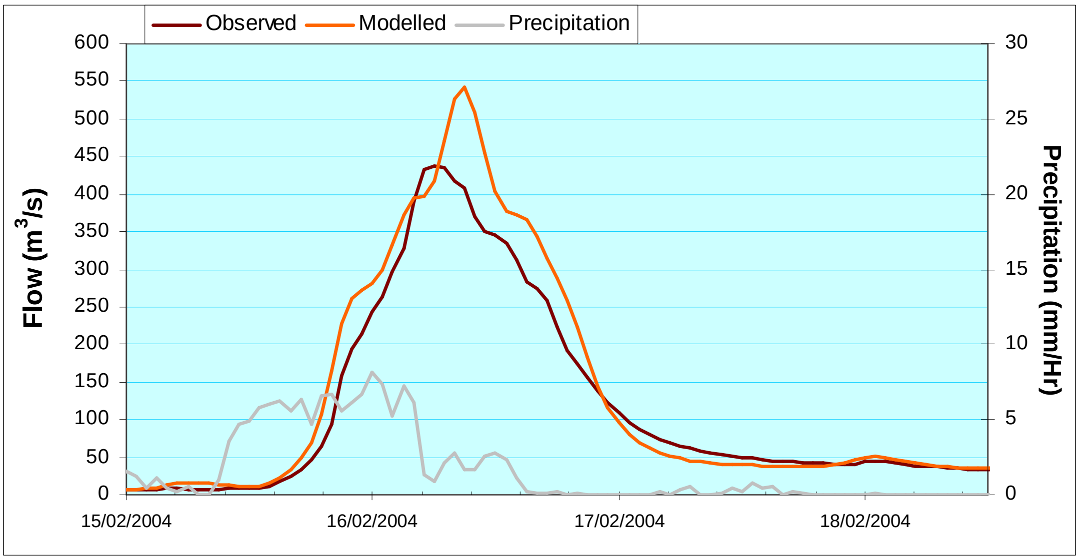


Figure 9-6: February 2004 Event Plot – Oroua River at Almadale Slackline

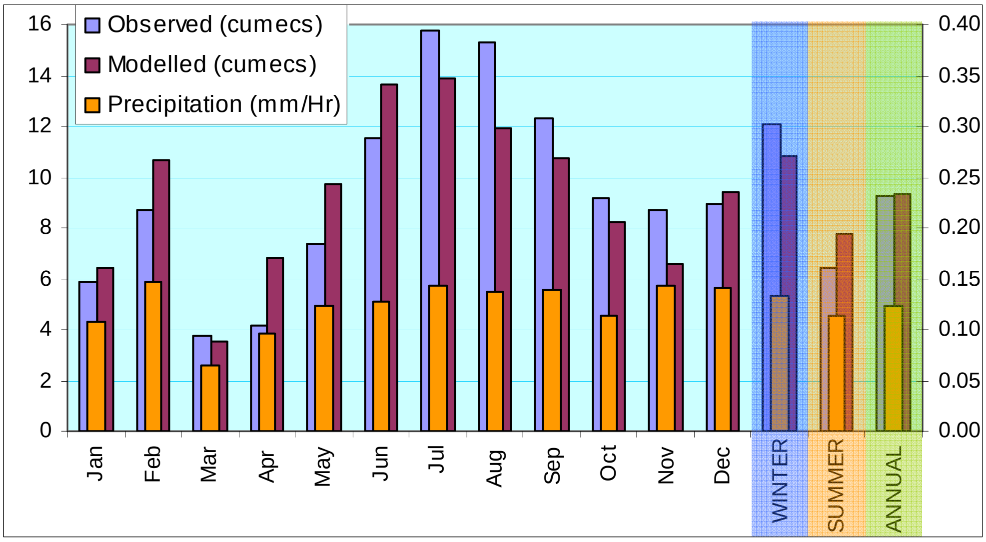


Figure 9-7: Monthly and Seasonal Long Term Volumes – Oroua River at Almadale Slackline

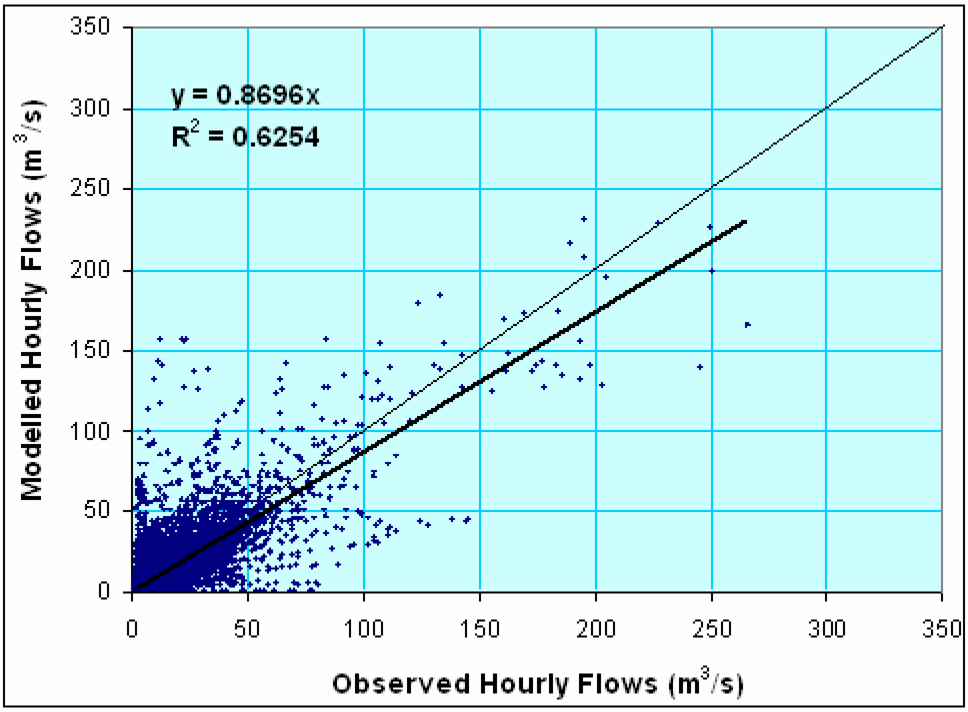


Figure 9-8: Modelled Flows vs Observed Flows – Oroua River at Almadale Slackline

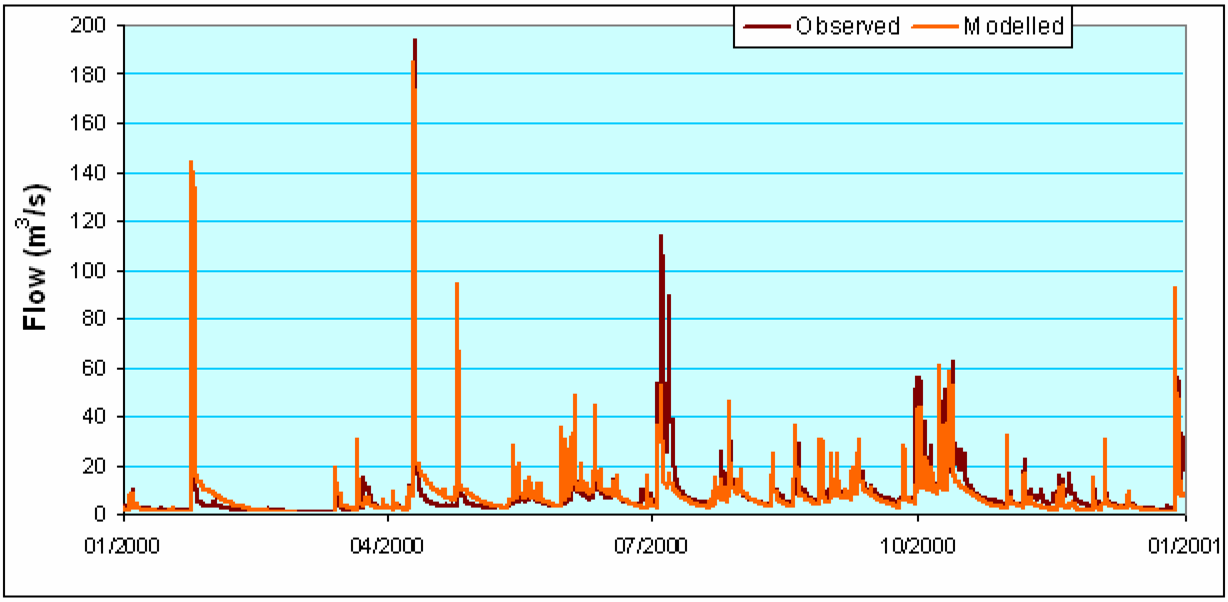


Figure 9-9: Annual Time Series Plot – Oroua River at Almadale Slackline

9.3 DISCUSSION

Calibration results for this catchment are not favourable with the performance criteria indicating that the site is not suitable for forecasting. The time series plot shows that the model is too responsive at lower flows. This suggests that the input rainfall is not high enough during events and the model parameters have been over-modified to best try to represent the largest flood events. The other available rain gauges should be incorporated in the model.

The timing and response issues in the catchment also indicate that some of the fixed components in the model structure may be inconsistent. Further investigation has shown that the model is assuming that the river length is about 15 km longer than the actual length. These components (including areas, reach lengths and Mean Annual Rainfall estimations at catchment centroids) will be reviewed and a recalibration of the model will take place during Stage 4 of the HRCFFS project.

If the model adjustments and recalibration fail to improve the modelled situation in the Oroua River it is recommended that rainfall be recorded from within the catchment. It would probably be best located in the higher rainfall region but still central in the catchment (around sub-area 1.04, 3.01 or 1.05).