Horizons Regional Council

Flood Forecasting System

Whangaehu, Turakina and Rangitikei Catchments

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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 5 of the project and covers the flood forecasting system developed for the Whangaehu, Turakina and Rangitikei Rivers. Two separate models have been developed: one for the Whangaehu and Turakina Rivers, and the other for the Rangitikei River. A re-calibration of the Whanganui hydrologic model is documented in Appendix D (Section 12) of this report. This report is the fourth in a suite of documents covering the methodology, assumptions and performance of each model that makes up the HRCFFS. The other three reports are referenced in Section 8.

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, just upstream of the confluence of the Mangatainoka and Makakahi Rivers and on the Manawatu River at Upper Gorge. The reports relating to these projects are referenced in Section 8 of this report.

Note that the information provided in this report documents the status of the Whangaehu, Turakina and Rangitikei models (named "Whangaehu_Turakina_Hydrologic_Model.tso" and "Rangitikei_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 future documentation or amendments related to the HRCFFS should remain collated with the original documentation to maintain a single point of reference.

A calibration results summary for all key catchments in the HRCFFS is provided over the page. It provides a clear comparison between all calibration sites in each of the catchments. Initially it can be seen that the Lower Manawatu and Rangitikei catchments are among the worst performing catchments. The recent calibration review of the Whanganui improved the general model fit of the upper catchments (as shown by the increase in R^2), but the fit of flood events was still not improved enough for them to achieve a C rating. The period investigated can also be monitored in this table to determine when there might be a suitable amount of additional record to review the calibration.

Table 1-1: Calibration Results Summary for the HRCFFS

Stream Gauge	Coefficient of Determination, R^2	Event Qualifying Rate	Chinese Standards Ranking	Long Term Volume Comparison Mm^3			Average Event Peak Difference	Av Event Volume Difference	Period Investigated	
				Measured	Modelled	Rainfall			Start	Finish
UPPER MANAWATU CATCHMENT										
Manawatu at Upper Gorge	0.93	80%	B	48,906	47,530	77,984	10.2%	9.8%	1991	2006
Manawatu at Upper Gorge (from 2000) *	0.94	92%	A	19,736	19,282	31,020	7.7%	8.4%	2000	2006
Manawatu at Hopelands	0.85	73%	B	14,019	14,759	31,399	13.7%	13.9%	1991	2006
Manawatu at Hopelands (from 2000)	0.87	100%	B	6,284	6,384	12,974	7.4%	5.1%	2000	2006
Manawatu at Weber Rd	0.87	100%	B	2,183	2,422	4,365	7.0%	11.3%	2004	2006
Tiraumea at Ngaturi	0.77	60%	C	9,502	8,613	15,440	22.0%	18.6%	1991	2006
Tiraumea at Ngaturi (from 2000)	0.74	67%	C	4,104	3,754	6,378	21.4%	16.2%	2000	2006
Makakahi at Hamua	0.88	80%	B	3,654	3,792	4,973	18.1%	5.4%	1991	2006
Makakahi at Hamua (from 2000)	0.90	85%	A	1,450	1,503	1,941	15.4%	5.9%	2000	2006
Mangatainoka at Larsons Rd	0.81	73%	B	2,920	3,011		15.8%	7.4%	1991	2006
Mangatainoka at Larsons Rd (from 2000)	0.84	77%	B	1,130	1,178	1,271	13.9%	7.9%	2000	2006
Mangatainoka at Pahiatua	0.89	53%	<C	10,365	11,470		18.6%	9.2%	1991	2006
Mangatainoka at Pahiatua (from 2000)	0.90	62%	C	4,101	4,537	5,377	15.5%	8.5%	2000	2006
Mangahao at Balance	0.89	67%	C	3,208	3,342		18.6%	11.2%	2000	2006
LOWER MANAWATU CATCHMENT										
Manawatu at Teachers College**	0.98	100%	A	-	-	-	-	-	1990	2005
Pohangina at Mais Reach	0.84	82%	B	-	-	-	-	-	1990	2004
Pohangina at Piripiri	0.50	12%	< C	-	-	-	-	-	1995	2004
Mangaone Stream at Milson Line	0.72	65%	C	-	-	-	-	-	1995	2004
Kiwitea Stream at Cheltenham	0.62	30%	< C	-	-	-	-	-	1995	2004
Makino Stream at Reids Line	0.76	71%	B	-	-	-	-	-	1999	2004
Makino Stream at Rata Street	0.73	42%	< C	-	-	-	-	-	1999	2004
Makino Stream at Boness Road	0.77	67%	C	-	-	-	-	-	1999	2004
Tokomaru at Darkys Hole	-	-	-	-	-	-	-	-	-	-
Turitea at Ngahere Park Road	-	-	-	-	-	-	-	-	-	-
WHANGANUI CATCHMENT										
Whanganui at Te Rewa	0.86	70%	B	104,707	102,386	170,553	12.8%	13.1%	1994	2008
Whanganui at Te Rewa (2009 Recalibration)***	0.86	80%	B	104,707	103,777	170,553	13.4%	11.7%	1994	2008
Whanganui at Pipiriki	0.87	75%	B	95,528	93,173	154,905	10.9%	12.4%	1994	2008
Whanganui at Pipiriki (2009 Recalibration)	0.88	85%	B	95,528	93,173	154,905	12.2%	12.2%	1994	2008
Whanganui at Te Maire (2009 Recalibration)	0.77	40%	< C	36,864	38,059	75,685	17.7%	11.8%	1994	2008
Whanganui at Te Maire	0.83	47%	< C	36,864	39,865	75,685	24.4%	14.9%	1994	2008
Ongarue at Taringamotu	0.70	13%	< C	17,576	16,717	23,995	37.8%	14.9%	1994	2008
Ongarue at Taringamotu (2009 Recalibration)	0.82	40%	< C	17,576	18,362	23,995	35.2%	15.5%	1994	2008
Ohura at Tokorima	0.70	-	-	5,727	4,761	7,136	-	-	2006	2008
Ohura at Tokorima (2009 Recalibration)	0.83	-	-	5,727	5,011	7,136	-	-	2006	2008
WHANGAEHU, TURAKINA and RANGITIKEI CATCHMENTS										
Whangaehu at Kauangaroa	0.82	92%	B	4,955	5,180	7,803	10.6%	12.0%	2005	2008
Whangaehu at Aranui	0.74	75%	B	1,320	1,409	1,526	14.2%	14.4%	2005	2008
Mangawhero at Raupio Rd	0.82	80%	B	2,091	2,183	3,394	9.7%	13.4%	2005	2008
Mangawhero at Ore Ore	0.73	56%	C	1,825	1,843	2,994	18.2%	17.4%	2005	2008
Turakina at Oneills Bridge	0.88	67%	C	1,060	1,162	2,635	16.9%	8.6%	2005	2008
Turakina at Otairi	0.78	73%	B	775	832	1,587	19.0%	12.2%	2005	2008
Rangitikei at Mangaweka****	0.90	83%	B	8,759	9,531	11,456	14.3%	7.0%	2005	2008
Hautapu at Alabasters	0.78	34%	< C	636	674	1,024	22.9%	16.6%	2005	2008
Rangitikei at Pukeokahu	0.67	11%	< C	2,782	3,526	3,612	41.8%	38.3%	2005	2008
Moawhango at Moawhango	0.48	-	-	786	827	2,128	-	-	2005	2008
Makohine at Viaduct	0.64	-	-	126	134	365	-	-	2005	2008

* Upper Manawatu catchments consistently showed a better calibration fit to recent events (post 2000) compared to earlier flood events.

** Lower Manawatu results have been extracted from original report. Note that Teachers College results were determined by inputting measured flows at Upper Gorge. A calibration review is required to accurately determine all model peformance measures shown here.

*** 2009 Recalibration results were the result of the January 2009 recalibration attempt. The original parameters are still adopted in the live model.

**** Mangaweka results have been obtained when measured flows are input at upstream gauges (Pukeokahu, Moawhango and Hautapu at Alabasters).

2 SYSTEM OVERVIEW

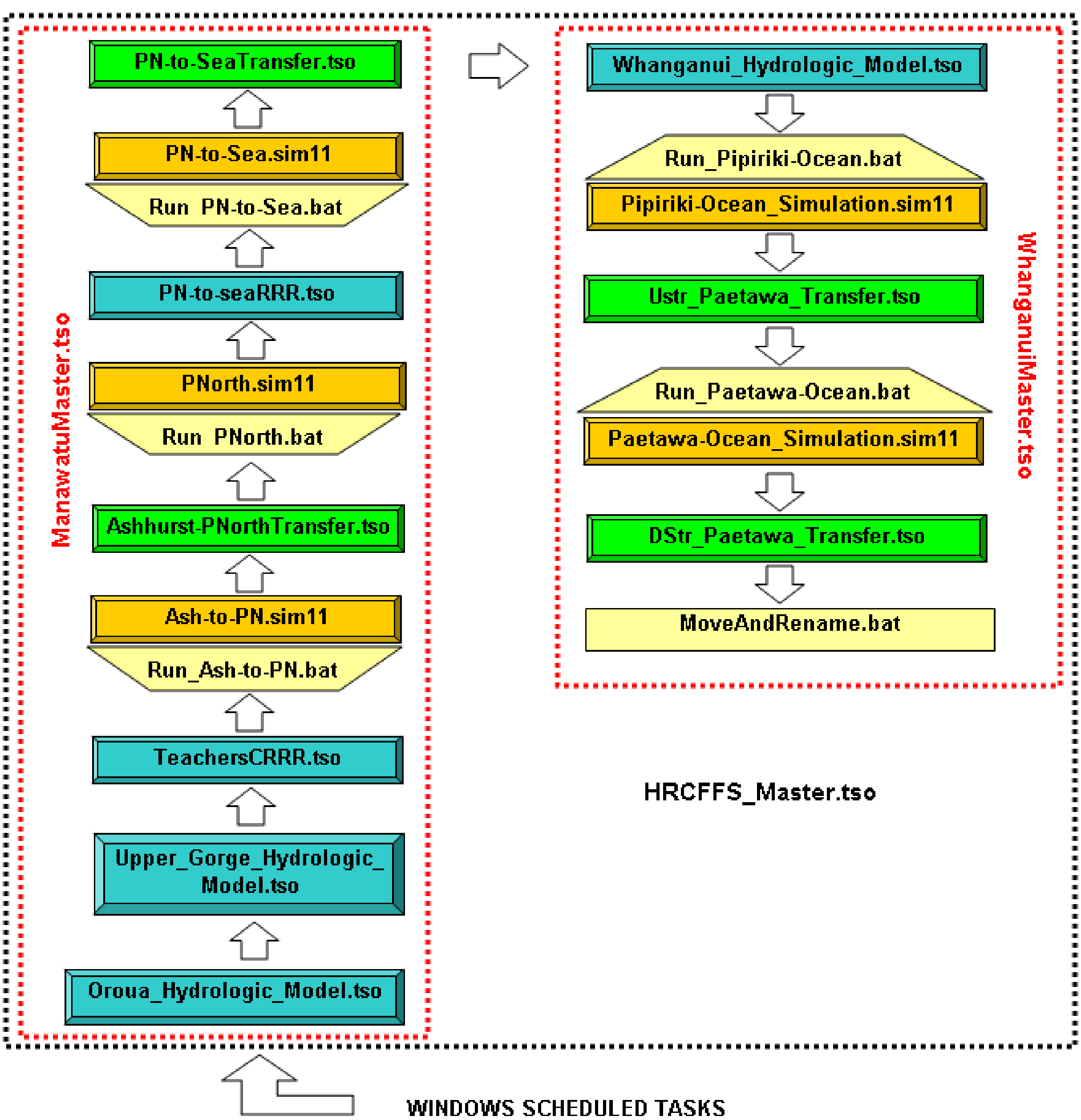


Figure 2-1: Interactions of the components of the HRCFFS at completion of Stage 5, representing the scheduled real-time operating system.

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 Whangaehu-Turakina and Rangitikei hydrologic models are executed within the Whanganui 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 a 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 directly archived in Hilltop if outside of the hydraulic model extents.
Comments:
The Whangaehu-Turakina and Rangitikei hydrologic models are 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). The UpperGorge_Hydrologic_Model.tso model also provides key information (by producing a .xml file) for the web based real-time flood mapping of the lower Mangatainoka and Makakahi Rivers, and the flood restriction at the Upper Gorge. References to the flood inundation mapping reports are given in the Introduction section of 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 an .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.

Condition Monitor

Software: Hydstra Modelling, MS-DOS batch files

Comments:

This model and associated files performs some diagnostics run on 5 or 6 of the highest priority outputs from each modelled catchment. The model outputs are written to a date and time stamped .csv file each model cycle to provide an archive of model outputs that are not progressively overwritten. If any of the interrogated outputs contain missing data or values outside of defined thresholds then a log file is updated specifying the issue. This log file can potentially be linked to an automatic alarming process in the future or manually reviewed on a regular basis. The MIKE11 run details log file for each hydraulic model is also checked to ensure that the model ran successfully. If not, the failure is also recorded in the log file and a roughstart of the modelling system is automatically executed.

3 SYSTEM OPERATION

3.1 REAL-TIME OPERATION - SCHEDULED RUNS

In its current set-up (at the completion of Stage 5 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). At the time of writing this report it is assumed that the combined task will probably not be re-instated as the two split tasks are currently working well. If the combined task is to be re-enabled, some minor review of this task and its respective commands will be required prior to putting the task live.

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. Presently the Whangaehu-Turakins and Rangitikei hydrologic models are running on a 30 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. Note that the Whangaehu, Turakina and Rangitikei models are included in the Whanganui system. 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. Note that a historical run can only be successfully performed if the input data is available over the entire historical run period.

- 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.

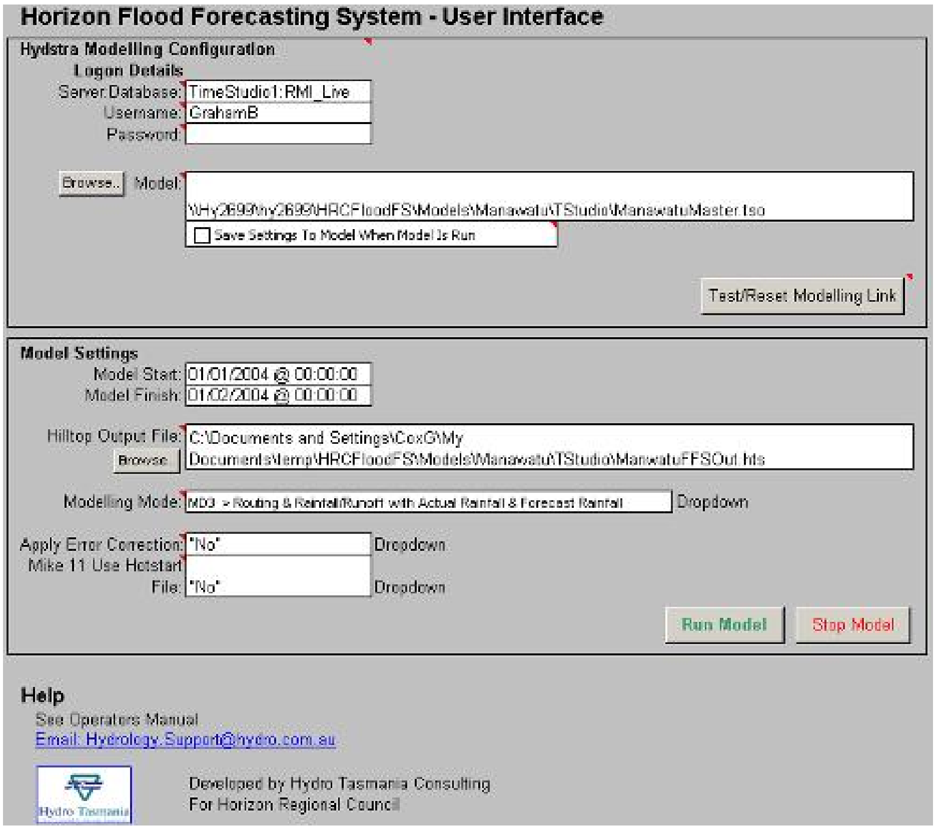
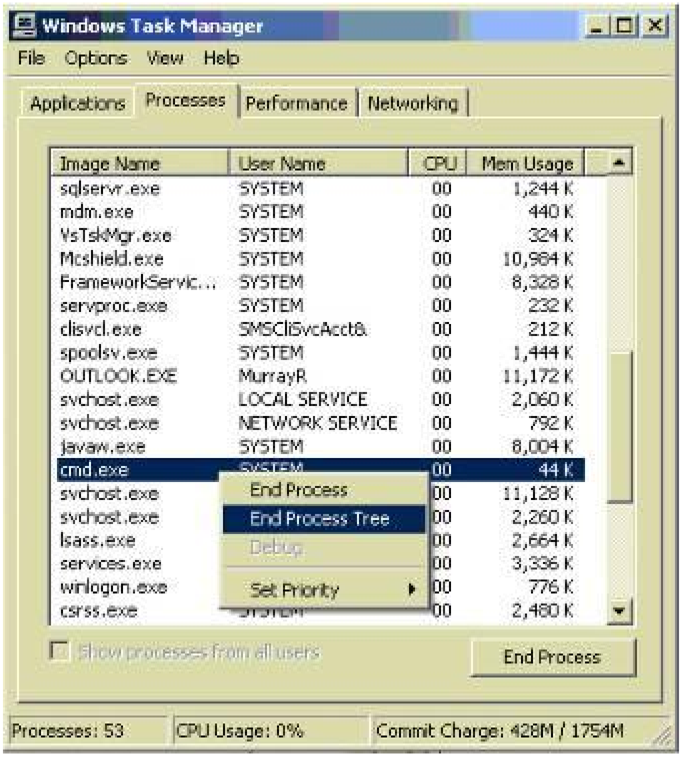


Figure 3-1 Screenshot of Manawatu-UserInterfaceV1.xls.

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

Two computer simulation models have been developed using Hydstra Modelling, one covering the Whangaehu and Turakina Rivers, and the other for the Rangitikei River. The sub-catchments, as shown in the Model Details section below, are represented by model "nodes" and connected together by "links". The schematics of both models are displayed in Figure 4-1 and Figure 4-2.

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.

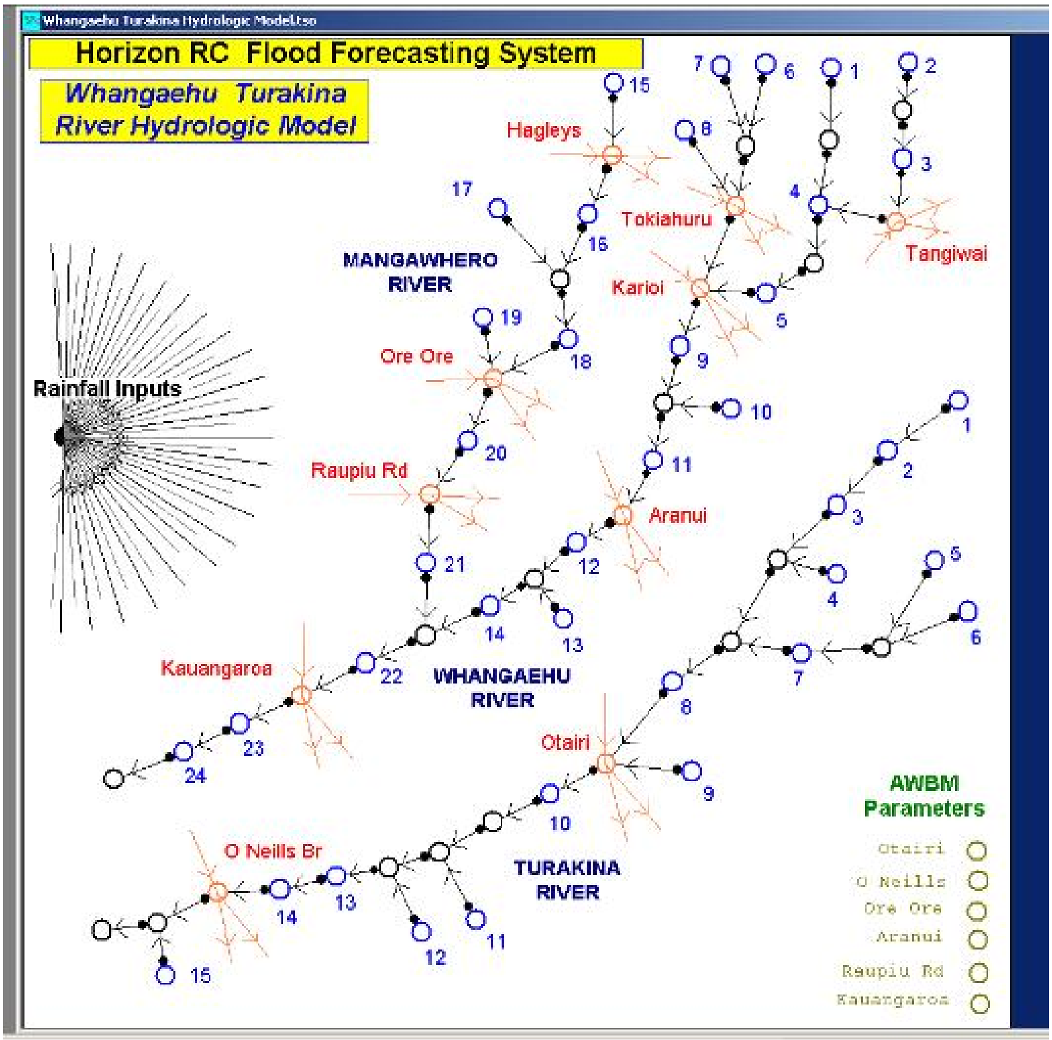


Figure 4-1: Whangaehu Turakina Hydstra Model schematic

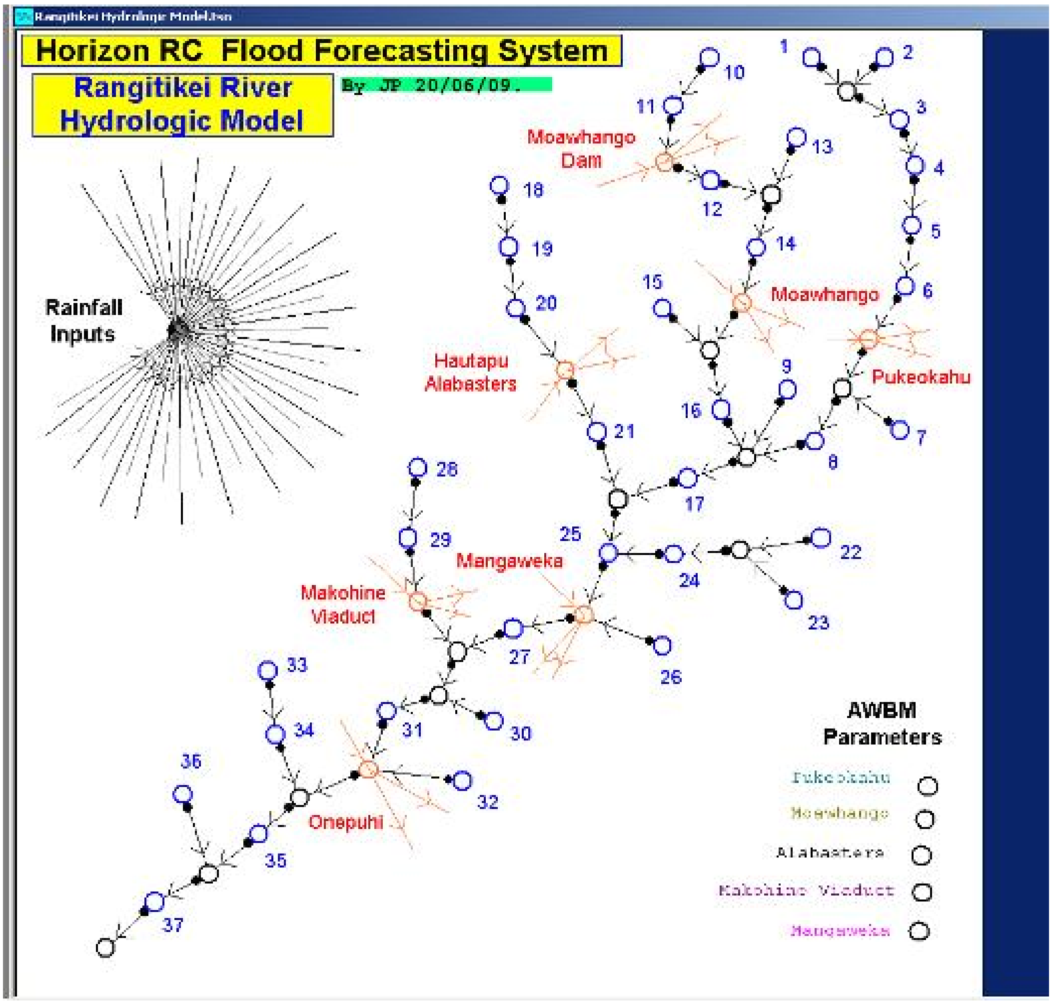


Figure 4-2: Rangitikei Hydstra Model schematic

4.1 RAINFALL GAP FILLING AND INTERPOLATION ALGORITHM

Figure 4-3 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).

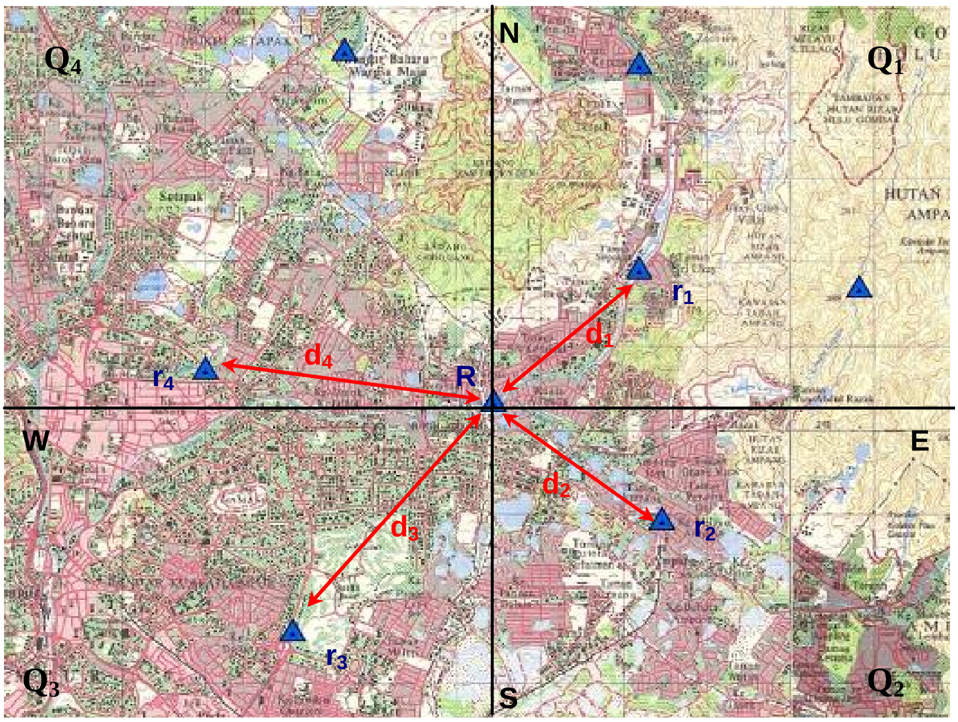


Figure 4-3: Rain gauge weighting by quadrants

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,

$$\textbf{Total Weighting, } T_W = \frac{1}{d_1^2} + \frac{1}{d_2^2} + \frac{1}{d_3^2} + \frac{1}{d_4^2}$$

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 is 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,

$$\textbf{Weighting per Quadrant, } W_Q = \frac{1}{d_Q^2} \times \frac{1}{T_W}$$

The actual contribution of rainfall from each gauge is then,

$$\textbf{Rainfall Contribution per Quadrant, } RC_Q = W_Q \times \frac{MAR_R}{\sum_{Q=1}^{4}\left(MAR_Q \times W_Q\right)} \times r_Q$$

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,

$$\textbf{Total In-filled Rainfall, } \mathbf{R} = \sum \mathbf{RC_Q}$$

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 is still operating correctly. 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. If the interpolated rainfall is below the threshold the gauge is assumed to be working correctly 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. It should be set low (e.g. less than 1 mm/hr) otherwise there is the potential for this algorithm to remove critical amounts of catchment rainfall, particularly during events with consistent low intensity rainfall.

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 AWBM 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. (2^{nd} 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 4-4.

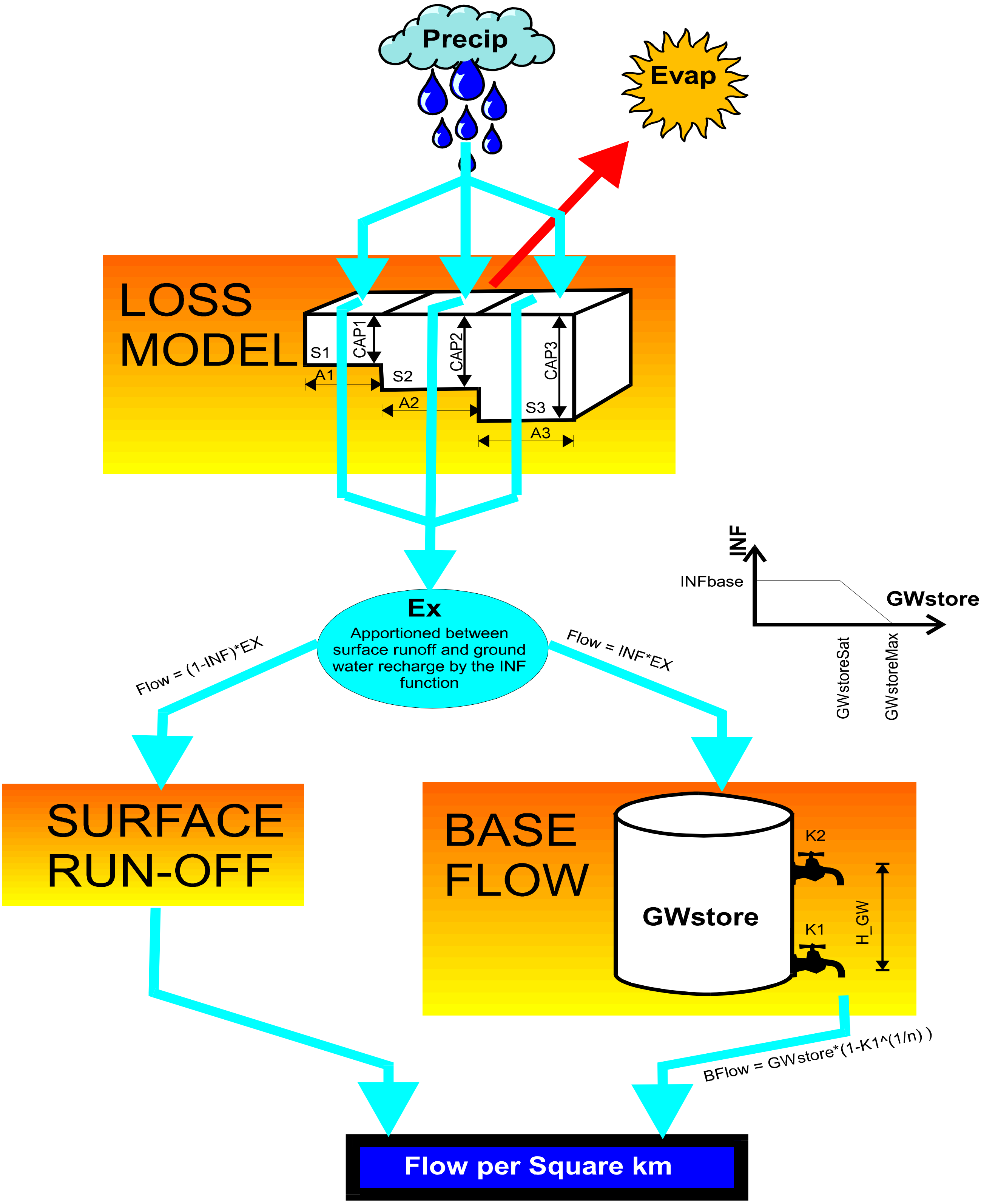


Figure 4-4 Australian Water Balance Model schematic

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.

$$S = K.Q^n$$

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.

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

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.

An example of the parameter values and resultant recession are shown in Figure 4-5 below. All the functionality is available in the Whangaehu-Turakina and Rangitikei models to apply the low flow recession correction algorithm at the location of each major river gauge. But at this stage the code is not being utilised as the calibration results showed reasonable low flow fits at most sites.

If the summer period reveals an issue with the modelled low flows, then little effort is required to develop and implement these recession equations.

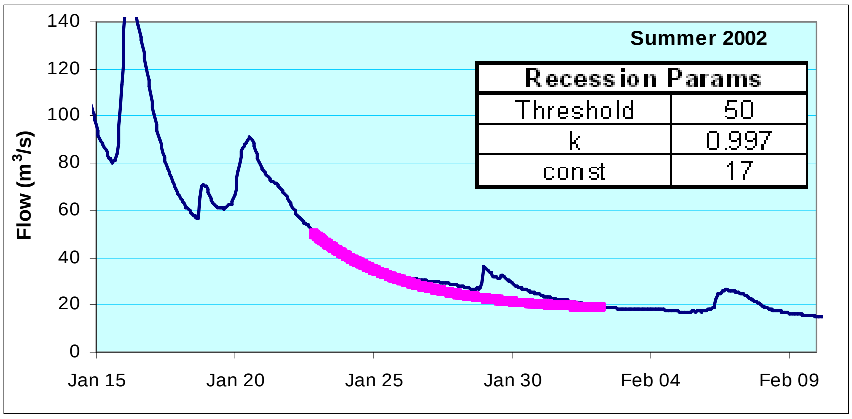


Figure 4-5: Example - Low flow recession equation at Manawatu River at Upper Gorge

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.

Currently the Upper Manawatu model and the recent Whangaehu – Turakina and Rangitikei models are adopting the original error correction algorithm as defined in the 3 step description made above.

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 OPERATING ASSUMPTIONS OF THE UPPER WHANGAEHU AND MOAWHANGO CATCHMENTS

At this stage the assumptions based around the controlled regions of each catchment have been kept simple.

Two nodes have been placed in the model at the location of the diversion on the southern foothills of Mt Ruapehu that feeds Mangaio Tunnel. But at this stage no allowance has been made for diverted flows in this part of the catchment. Natural flow conditions have been assumed as it has little impact on the flood flows in the lower reaches of the Whangaehu River.

It has been assumed that all the catchment upstream of Moawhango Dam does not contribute at all to the flows downstream of Moawhango Dam. Apparently Moawhango Dam spills very infrequently and without a gauge at the dam site, the regular flushing flow released cannot be measured until the Moawhango River at Moawhango gauge. Currently it is recommended that the Rangitikei model feeds in measured flows from Moawhango River at Moawhango and only utilises the rainfall runoff model downstream of this site.

5 HYDROLOGIC MODEL DETAILS

5.1 EVAPORATION INPUT DATA

Monthly average evaporation values from Taupo have been used in the model. This is consistent with the monthly average evaporations being used in the Whanganui model. The values are linearly smoothed in between months.

Some adjustment factors have been applied to the evaporation to improve the calibration results including a set of monthly variable evaporation adjustment factors in the Turakina River catchment. These adjustments are documented in the Model Calibration section later in the report.

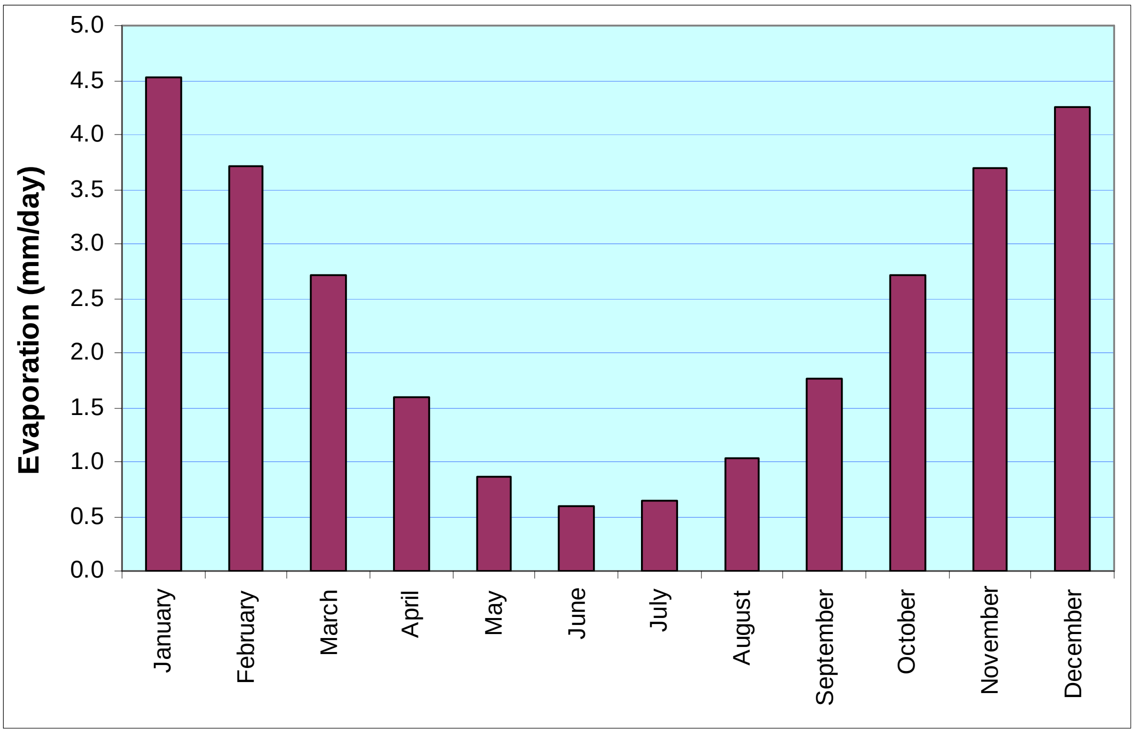


Figure 5-1: Average potential evapotranspiration adopted in the Whangaehu Turakina and Rangitikei models.

5.2 MEASURED RAINFALL INPUT DATA

All measured rainfall data was provided by Horizons Regional Council (HRC) in a Hilltop Database. Around the northern and eastern boundaries of the catchment, some Genesis Energy and Hawkes Bay Regional Council gauges have been utilized. The supplied data has been assumed to be of a suitable quality for use in the model for historical calibration and real-time operation. A map of the rainfall sites used to develop the Upper Manawatu model is shown in Figure 5-2 over the page.

The rainfall gauge distribution over the Whangaehu, Turakina and lower Rangitikei catchments is first class. Even though the gauges from other agencies have improved the distribution in the upper and eastern Rangitikei catchment, the Genesis Energy gauges do not seem to be completely representative of the northern catchment and the Hawkes Bay Regional Council gauges are located on the eastern side of the Ruahine Ranges. Further discussion on the upper Rangitikei rainfall distribution can be found in the Model Calibration section later in the report.

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 plotted on the catchment map along with the isohyets in Figure 5-3. The mean annual rainfall distribution is relatively uniform over the majority of the catchments except for the far north and eastern ranges. In the high rainfall regions in both catchments the rainfall isohets do not compare well with the gauge information. In general the gauge information has been used in preference to the isohyets.

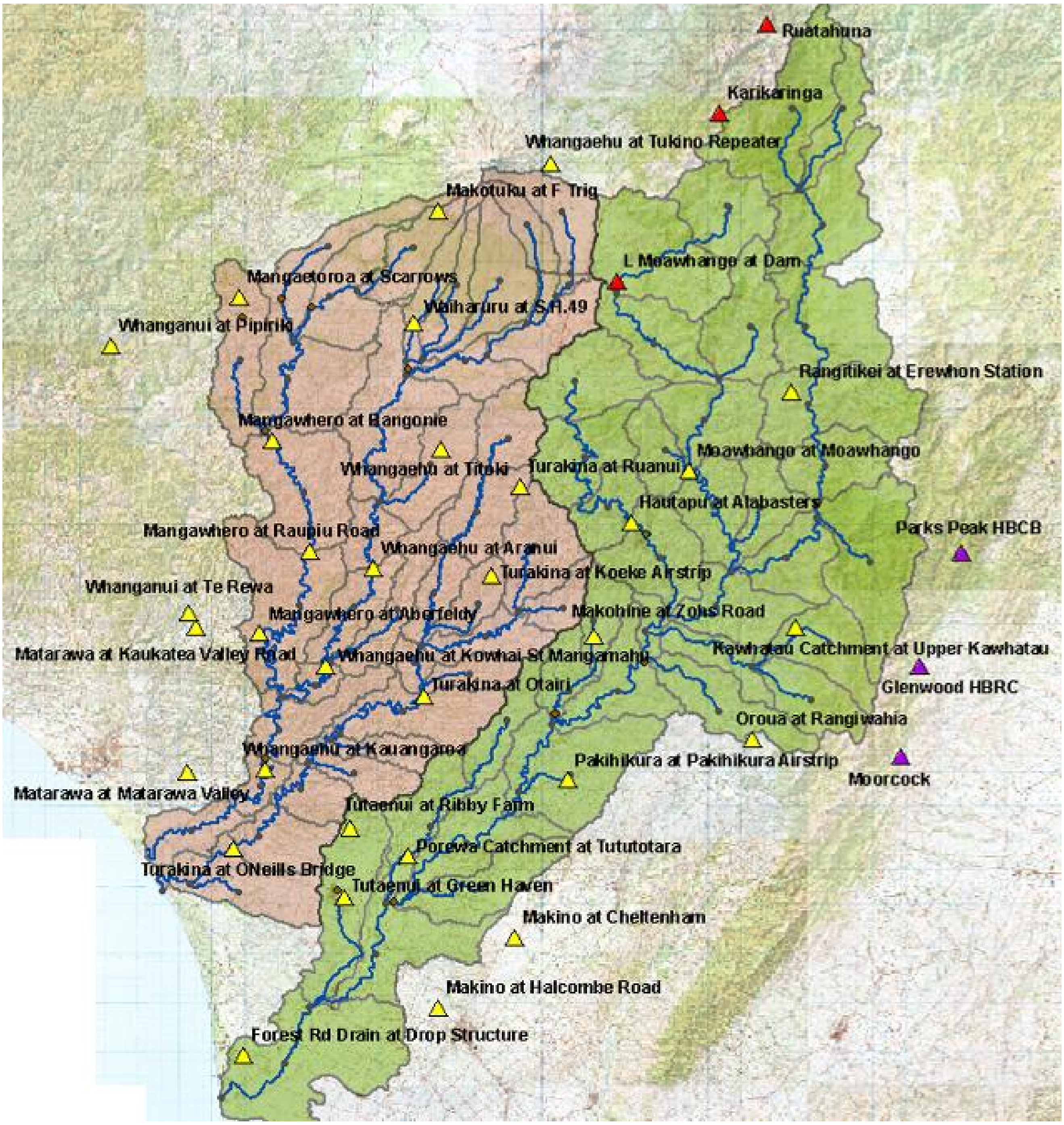


Figure 5-2: Rainfall gauges used in the Whangaehu -Turakina and Rangitikei models. Red gauges belong to Genesis Energy and pink gauges belong to Hawkes Bay Regional Council.

Table 5-1: Rain gauge details

Site Name	Easting	Northing	Record Begins	Record Ends	Period Years	Months Missing	Total Rainfall	MAR (Gauge Info)	MAR (Isohyets)	Adopted Rainfall
Forest Rd Drain at Drop Structure	2701900	6103500	15/08/2003	01/11/2008	5.2	0	4700	901	900	**900**
Hautapu at Alabasters	2748800	6168200	01/04/2005	01/01/2009	3.8	0	3250	866	1000	**939**
Kawhatau Catchment at Upper Kawhatau	2768700	6155500	01/04/2005	01/01/2009	3.8	0	4700	1252	1150	**1250**
Makino at Cheltenham	2734700	6117800	01/01/1998	01/09/2008	10.7	0	11200	1050	950	**1025**
Makino at Halcombe Road	2725500	6109300	12/12/1998	01/11/2008	9.9	0	9200	930	900	**930**
Makohine at Zohs Road	2744200	6154500	15/06/2005	01/01/2009	3.5	0	4000	1127	1040	**1100**
Makotuku at F Trig	2725400	6206100	01/01/1998	01/01/2009	11.0	0	30600	2782	1700	**2800**
Mangaetoroa at Scarrows	2701400	6195700	01/01/1998	01/11/2008	10.8	3	17100	1616	1330	**1616**
Mangawhero at Aberfeldy	2703800	6154800	01/12/2004	01/11/2008	3.9	0	4000	1021	1010	**1020**
Mangawhero at Bangonie	2705400	6178300	01/12/2004	01/11/2008	3.9	0	4600	1174	1190	**1180**
Mangawhero at Raupiu Road	2709900	6164800	01/12/2004	01/01/2009	4.1	0	4900	1200	1100	**1200**
Matarawa at Matarawa Valley	2695000	6138000	01/11/1998	01/11/2008	10.0	0	8300	830	950	**940**
Moawhango at Moawhango	2755700	6174500	01/06/2002	01/01/2009	6.6	0.5	5100	779	900	**920**
Oroua at Rangiwahia	2763400	6141900	01/01/1998	01/01/2009	11.0	0	16100	1464	1400	**1450**
Pakihikura at Pakihikura Airstrip	2741200	6137100	01/04/2005	01/11/2008	3.6	0	2950	823	980	**985**
Porewa Catchment at Tututotara	2721700	6127800	01/02/2005	01/01/2009	3.9	0	3500	894	1000	**950**
Rangitikei at Erewhon Station	2768200	6184200	01/04/2005	01/01/2009	3.8	0	3500	932	900	**930**
Turakina at Koeke Airstrip	2731809	6161844	01/02/2005	01/11/2008	3.7	0	3350	894	1050	**920**
Turakina at ONeills Bridge	2700600	6128700	01/05/2005	01/11/2008	3.5	0	3600	1027	970	**1000**
Turakina at Otairi	2723600	6147100	01/02/2005	01/11/2008	3.7	0	3800	1014	1040	**1020**
Turakina at Ruanui	2735300	6172700	01/02/2005	01/11/2008	3.7	0	3800	1014	1020	**1015**
Tutaenui at Green Haven	2714100	6122700	15/06/2007	01/11/2008	1.4	0	1350	976	1000	**980**
Tutaenui at Ribby Farm	2714777	6131057	01/06/2007	01/11/2008	1.4	0	1600	1126	1010	**1025**
Waiharuru at S.H.49	2722500	6192500	01/06/2006	01/11/2008	2.4	0	3450	1425	1300	**1395**
Whangaehu at Aranui	2717500	6162700	01/01/2007	01/01/2009	2.0	0	1950	974	1080	**1000**
Whangaehu at Kauangaroa	2704459	6138291	01/05/2005	01/11/2008	3.5	0	3520	1004	980	**1000**
Whangaehu at Kowhai St Mangamahu	2711849	6150874	01/05/2005	01/11/2008	3.5	0	3800	1084	1000	**1080**
Whangaehu at Titoki	2725728	6177109	15/02/2005	01/11/2008	3.7	0	3700	997	1080	**1000**
Whangaehu at Tukino Repeater	2739000	6211800	01/01/1998	01/11/2008	10.8	1	12000	1116	2300	**1150**
Whanganui at Pipiriki	2685900	6189700	-	-	8.9	-	-	1362	1280	**1275**
Whanganui at Te Rewa (Paetawa)	2695200	6157300	-	-	5.0	-	-	1032	1010	**1030**
Karikaringa	2759400	6218000	01/07/2001	01/01/2009	7.5	11.4	11950	1823	2400	**1820**
Ruatahuna	2765100	6228700	01/07/2001	02/01/2009	7.5	1.5	13400	1815	2250	**1815**
L Moawhango at Dam	2747000	6197600	15/11/2001	03/01/2009	7.1	5.5	5600	839	1500	**840**
Matarawa at Kaukatea Valley Road	2696200	6141900	17/11/1998	25/06/2003	4.6	0	4460	969	950	**950**
Glenwood HBRC	2783663	6150847	01/01/1998	01/11/2008	10.8	3	21807	2060	1450	**2270**
Parks Peak HBCB	2788792	6164632	01/01/1999	01/11/2008	9.8	1	26619	2730	1200	**2615**
Moorcock	2781400	6139900	01/01/1998	01/11/2008	10.8	5	27077	2599	1620	**2620**

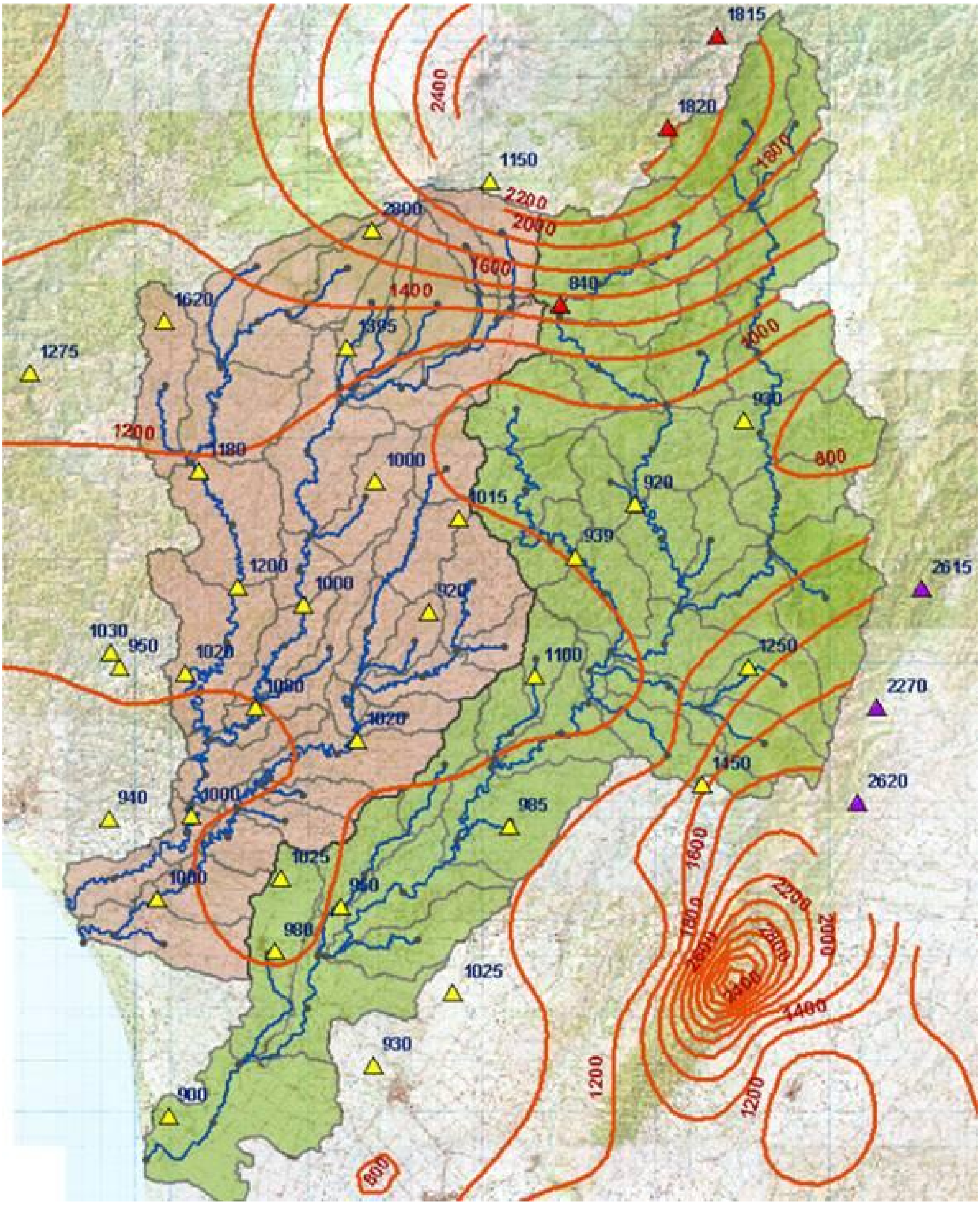


Figure 5-3: Rainfall distribution map showing MAR isohyets and adopted MAR (mm) at each gauge

5.3 MEASURED FLOW INPUT DATA

Figure 5-5 over the page shows the locations of flow gauges in the Whangaehu, Turakina and Rangitikei catchments. The gauges indicated by a red square have been used for calibration and have the option to apply real-time error correction.

Model nodes have also been put in place at the following gauge locations and could be utilised either to correct modelled data or output flows if required in the future:

- Two reach locations on the Mangaio Tunnel diversion.
- Waiharuru at S.H.49
- Tokiahuru at Junction
- Moawhango Dam

The error correction and calibration review algorithms have also been added to the model at the location of the Rangitikei at Onepuhi gauge. Although the site is primarily located at the lower reaches of the Rangitikei River, the flow rating not of a suitable quality to correct modeled flows or calibrate. Figure 5-4 shows that during the high flow period in July 2006 the flows at Mangaweka are consistently much larger despite Onepuhi being located downstream. It was agreed that Mangaweka is the reliable site and the rating that results in the highest flows (green trace on the plot) has been adopted.

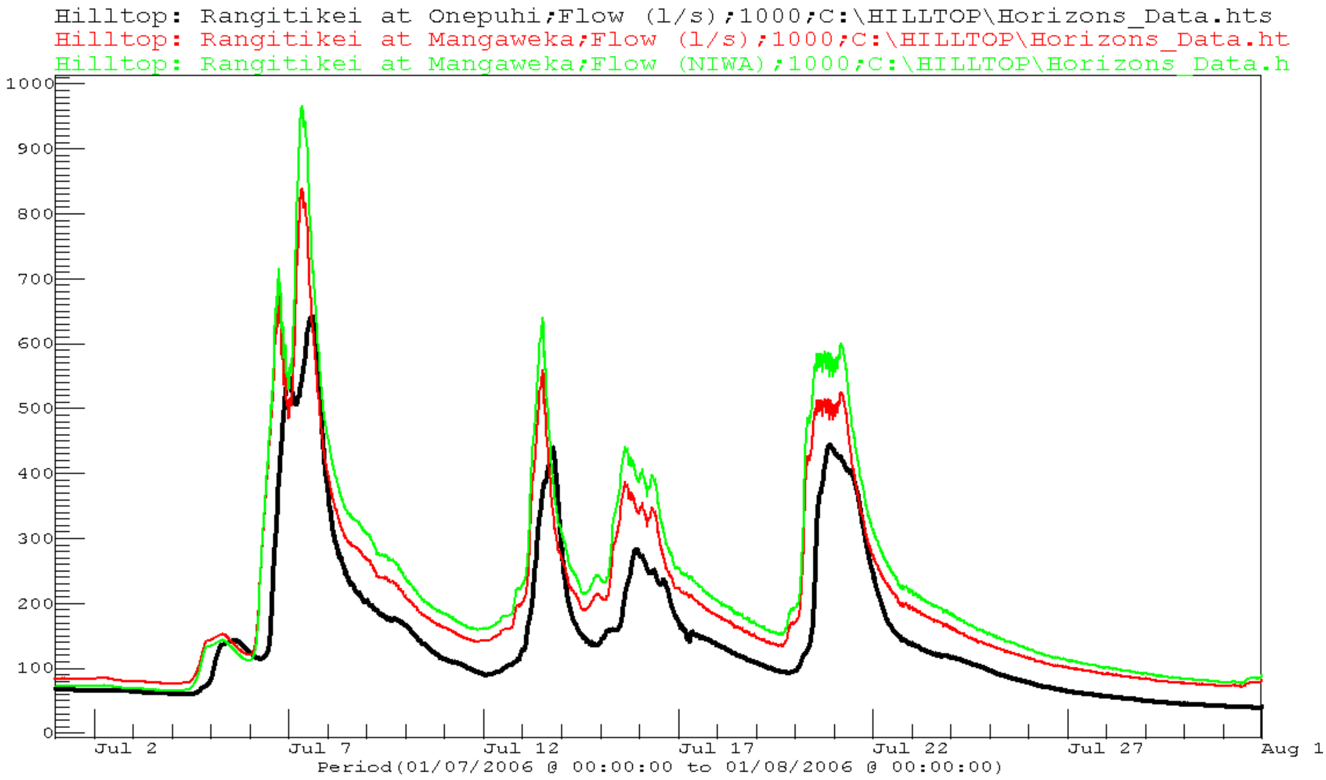


Figure 5-4: Difference between measured Rangitikei flows at Onepuhi and Mangaweka during July 2006

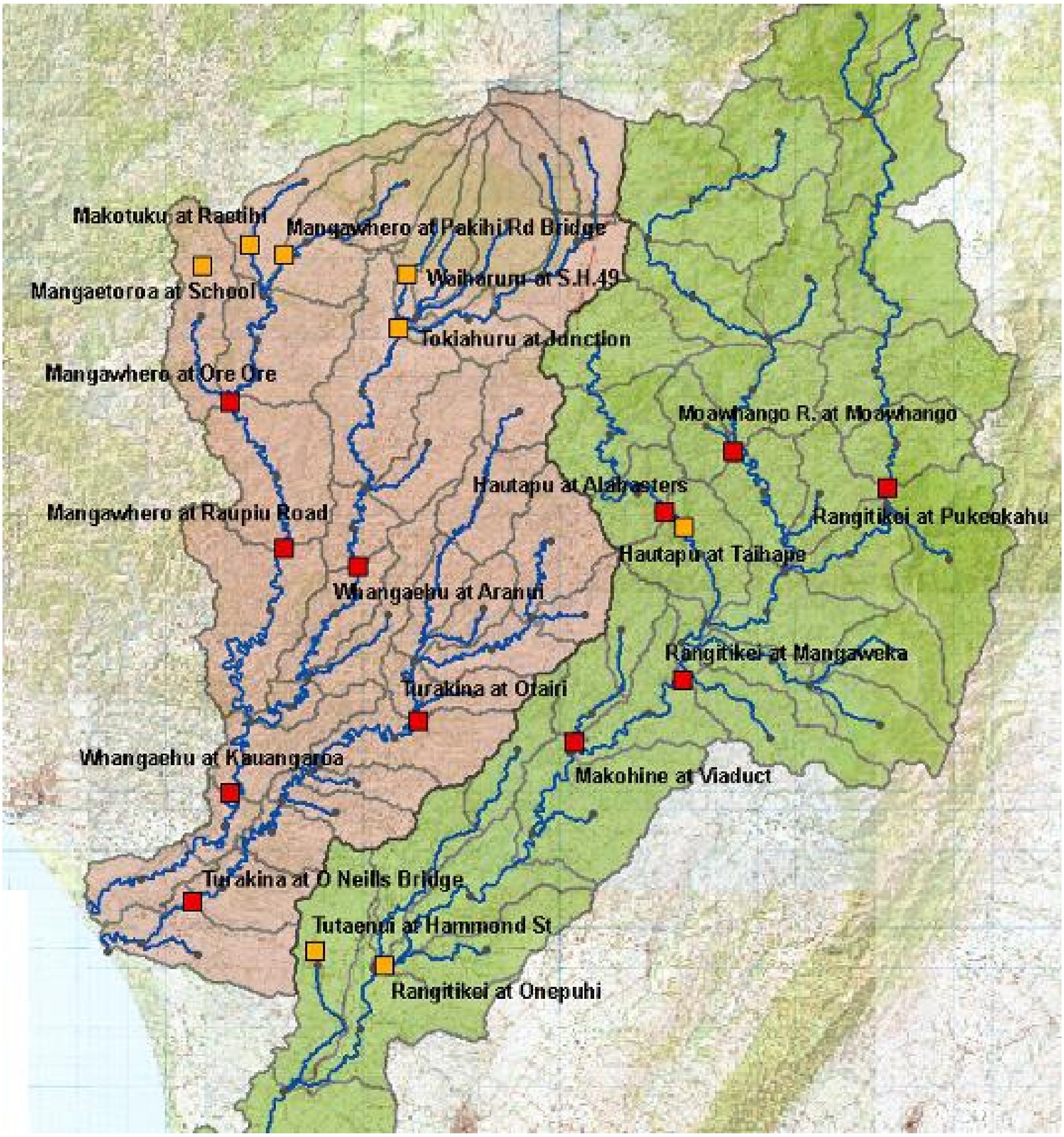


Figure 5-5: Flow gauges used in the Whangaehu -Turakina and Rangitikei models. Red gauges have been used during calibration while orange gauges have not.

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 flood 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 up or down. This is not accounted for in the weightings shown in the table over the page, or in the calculated runoff coefficients that are displayed in the results file spreadsheets and in the calibration results section later in the report.

Table 5-2: Catchment area and rainfall gauge weightings at each measured flow gauge

Flow Site ID	Catcment Area (km^2)	Whangaehu Tukino Repeater	Makotuku F Trig	Mangaetoroa Scarrows	Moawhango Dam	Waiharuru SH49	Turakina Ruanui	Mangawhero RaupiuRd	Whangaehu Aranui	Turakina Koeke Airstrip	Mangawhero Aberfeldy	Makohine Zohs Rd	Whangaehu Kowhai St Mangamahu	Turakina Otairi	Whangaehu Kauangaroa	Matarawa Valley	Tutaenui Ribby Farm	Turakina Oneills Bridge	Tutaenui Green Haven	Mangawhero Bangonie	Whangaehu Titoki
Turakina at O Neills Bridge	843	0.00	0.00	0.00	0.01	0.01	0.13	0.00	0.05	0.22	0.00	0.06	0.03	0.24	0.06	0.01	0.07	0.07	0.00	0.00	0.05
Turakina at Otairi	510	0.00	0.00	0.00	0.01	0.01	0.22	0.00	0.08	0.36	0.00	0.09	0.01	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Tokiahuru at Junction	210	0.08	0.25	0.00	0.07	0.34	0.01	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	0.01
Mangawhero at Ore Ore	511	0.00	0.18	0.34	0.00	0.21	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	0.22	0.02
Whangaehu at Aranui	790	0.12	0.08	0.01	0.11	0.21	0.01	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.25
Mangawhero at Raupiu Road	667	0.00	0.14	0.26	0.00	0.16	0.00	0.10	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.03
Mangawhero at Hagleys	70.9	0.00	0.69	0.00	0.03	0.21	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	0.00	0.00
Whangaehu at Tangiwai	84.8	0.68	0.00	0.00	0.27	0.05	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	0.00	0.00
Whangaehu at Karioi	482	0.19	0.13	0.00	0.17	0.28	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Whangaehu at Kauangaroa	1894	0.05	0.08	0.10	0.05	0.14	0.01	0.08	0.07	0.01	0.05	0.00	0.05	0.01	0.03	0.00	0.00	0.00	0.00	0.12	0.11

Flow Site ID	Catcment Area (km^2)	Ruatahuna	Karikaringa	Moawhango Dam	Erewhon Stn	Turakina Ruanui	Moawhango	Hautapu Alabasters	Makohine Zohs Rd	Upper Kawhatau	Oroua Rangiwahia	Pakihikura Airstrip	Porewa Tututotara	Tutaenui Green Haven	Makino Cheltenham	Makino Halcombe Rd	Forest Rd Drain	Glenwood	Parks Peak	Moorcock
Rangitikei at Onepuhi	3259.1	0.04	0.08	0.10	0.16	0.03	0.10	0.07	0.06	0.10	0.06	0.08	0.03	0.00	0.02	0.00	0.00	0.02	0.03	0.00
Rangitikei at Mangaweka	2672.9	0.05	0.10	0.13	0.20	0.04	0.12	0.09	0.02	0.13	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.01
Rangitikei at Pukeokahu	768.2	0.14	0.25	0.02	0.47	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Moawhango at Dam	275.1	0.05	0.22	0.64	0.07	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	0.00	0.00
Moawhango at Moawhango	324.2	0.01	0.02	0.28	0.30	0.00	0.32	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hautapu at Alabasters	276.3	0.00	0.00	0.21	0.00	0.36	0.12	0.32	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Makohine at Viaduct	97.9	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.77	0.00	0.03	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

5.4 SUBCATCHMENT DELINEATION

The Whangaehu and Turakina catchment model and the Rangitikei model both have been divided into 37 sub-areas. The sub-areas have been selected to provide break points at all existing flow gauge locations and significant hydraulic structures, and to best capture the spatial distribution of the rainfall gauge network around the catchment. The following figures and tables show the sub-catchment de-lineation and reach lengths for the each model, and display their identifiers and properties.

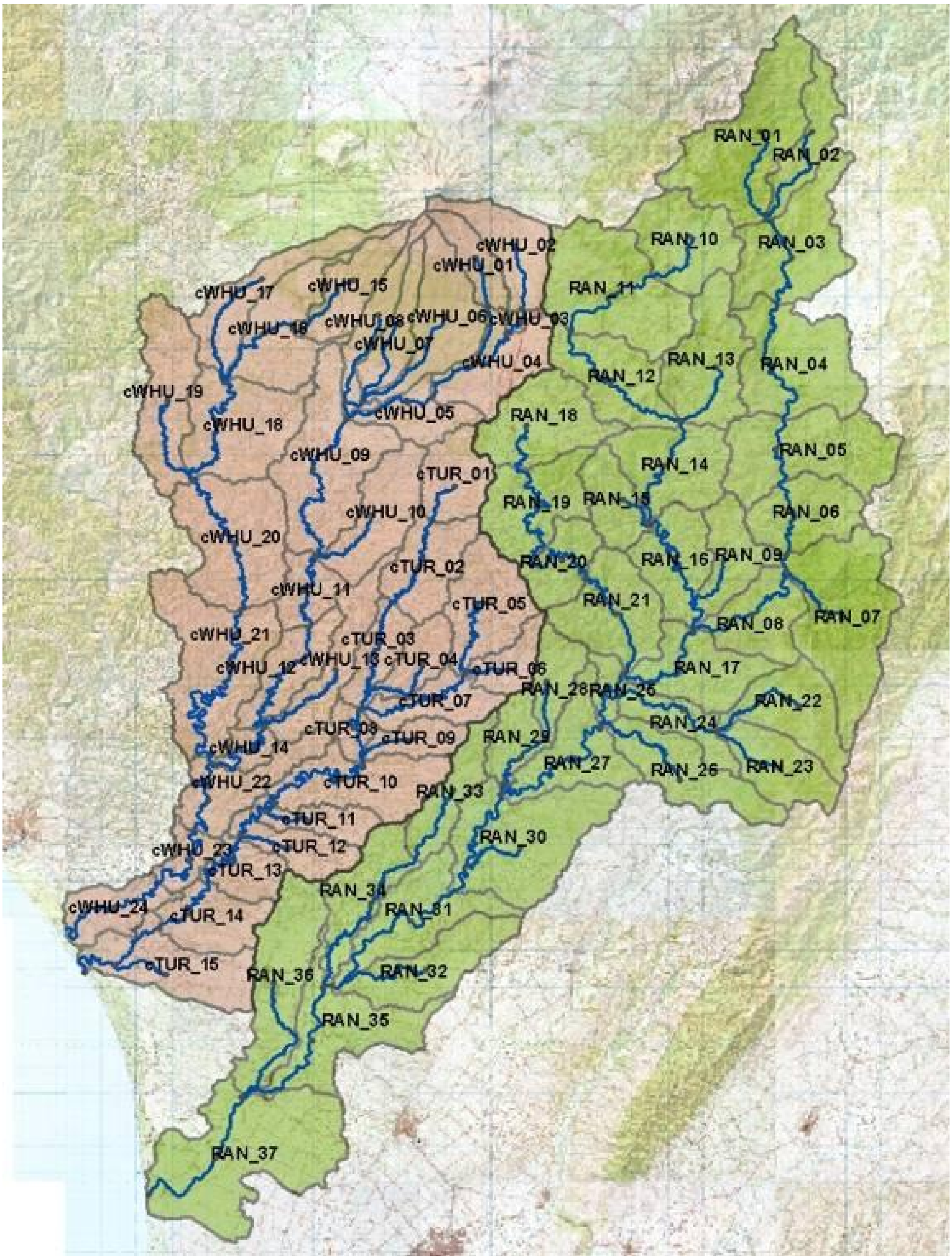


Figure 5-6: Subcatchment breakdown showing subcatchment ID's

Table 5-3: Subcatchment node details

SubArea ID	Easting	Northing	Area (km^2)	Mean Annual Rainfall (mm)	SubArea ID	Easting	Northing	Area (km^2)	Mean Annual Rainfall (mm)
RAN_01	2768407	6218722	182.56	1800	cTUR_01	2734028	6178550	66.89	1010
RAN_02	2774340	6218656	61.52	1750	cTUR_02	2730057	6169672	83.61	990
RAN_03	2772019	6204484	135.06	1400	cTUR_03	2724852	6159798	47.73	990
RAN_04	2769887	6192134	148.30	1000	cTUR_04	2730321	6158558	47.44	950
RAN_05	2770201	6182730	153.56	900	cTUR_05	2737126	6165458	100.80	950
RAN_06	2772269	6175270	87.20	900	cTUR_06	2740656	6157922	40.61	1050
RAN_07	2777724	6163626	184.42	1800	cTUR_07	2731212	6154456	60.21	1000
RAN_08	2767651	6164151	81.31	1000	cTUR_08	2722594	6151276	22.95	1020
RAN_09	2764404	6170262	68.00	950	cTUR_09	2729240	6150004	39.68	1020
RAN_10	2760394	6206878	102.15	1400	cTUR_10	2721323	6145489	111.67	1020
RAN_11	2751658	6200051	172.95	900	cTUR_11	2717475	6140783	43.84	1020
RAN_12	2751610	6190073	100.96	900	cTUR_12	2715281	6137857	55.89	1010
RAN_13	2763306	6192078	115.99	920	cTUR_13	2708858	6135949	49.30	1000
RAN_14	2757673	6180812	107.21	920	cTUR_14	2703770	6130321	72.61	1000
RAN_15	2752947	6177088	56.52	950	cTUR_15	2701353	6123453	113.50	990
RAN_16	2758806	6170497	83.37	930	cWHU_01	2736271	6204482	43.37	1200
RAN_17	2759128	6158225	95.20	1050	cWHU_02	2740383	6206071	78.07	1100
RAN_18	2742023	6185481	112.60	950	cWHU_03	2741364	6197193	6.70	900
RAN_19	2743178	6176244	104.70	980	cWHU_04	2736271	6192474	89.12	950
RAN_20	2746051	6170255	59.03	950	cWHU_05	2728748	6187988	53.66	1100
RAN_21	2752308	6164133	110.15	1000	cWHU_06	2732860	6197800	104.35	1250
RAN_22	2772904	6153687	95.02	1950	cWHU_07	2727627	6197146	52.70	1400
RAN_23	2770595	6146812	78.12	2100	cWHU_08	2725384	6197894	54.30	1450
RAN_24	2759639	6153338	54.20	1050	cWHU_09	2717955	6180652	166.48	1100
RAN_25	2750509	6155164	23.19	1050	cWHU_10	2724637	6175419	94.36	1000
RAN_26	2759451	6145389	99.62	1950	cWHU_11	2717002	6166686	47.44	1050
RAN_27	2747152	6147905	96.86	1000	cWHU_12	2715301	6158099	68.58	1040
RAN_28	2744288	6156498	50.07	1100	cWHU_13	2720572	6157851	84.03	1020
RAN_29	2741316	6147940	47.80	1000	cWHU_14	2710619	6148552	24.71	1050
RAN_30	2741423	6137772	179.35	980	cWHU_15	2722534	6201819	70.90	2250
RAN_31	2728963	6129465	112.33	950	cWHU_16	2712301	6195744	103.87	1500
RAN_32	2730682	6123916	99.73	980	cWHU_17	2712161	6202006	90.23	2000
RAN_33	2733869	6144324	63.25	1000	cWHU_18	2707255	6185699	132.97	1350
RAN_34	2724488	6131506	87.45	950	cWHU_19	2701554	6188222	113.17	1450
RAN_35	2717864	6116003	127.14	950	cWHU_20	2709264	6172008	155.87	1200
RAN_36	2713508	6122448	135.73	980	cWHU_21	2708602	6158380	177.00	1050
RAN_37	2707015	6102779	245.21	910	cWHU_22	2706180	6143179	82.19	1000
					cWHU_23	2703946	6136350	32.76	1000
					cWHU_24	2695548	6131027	60.79	980

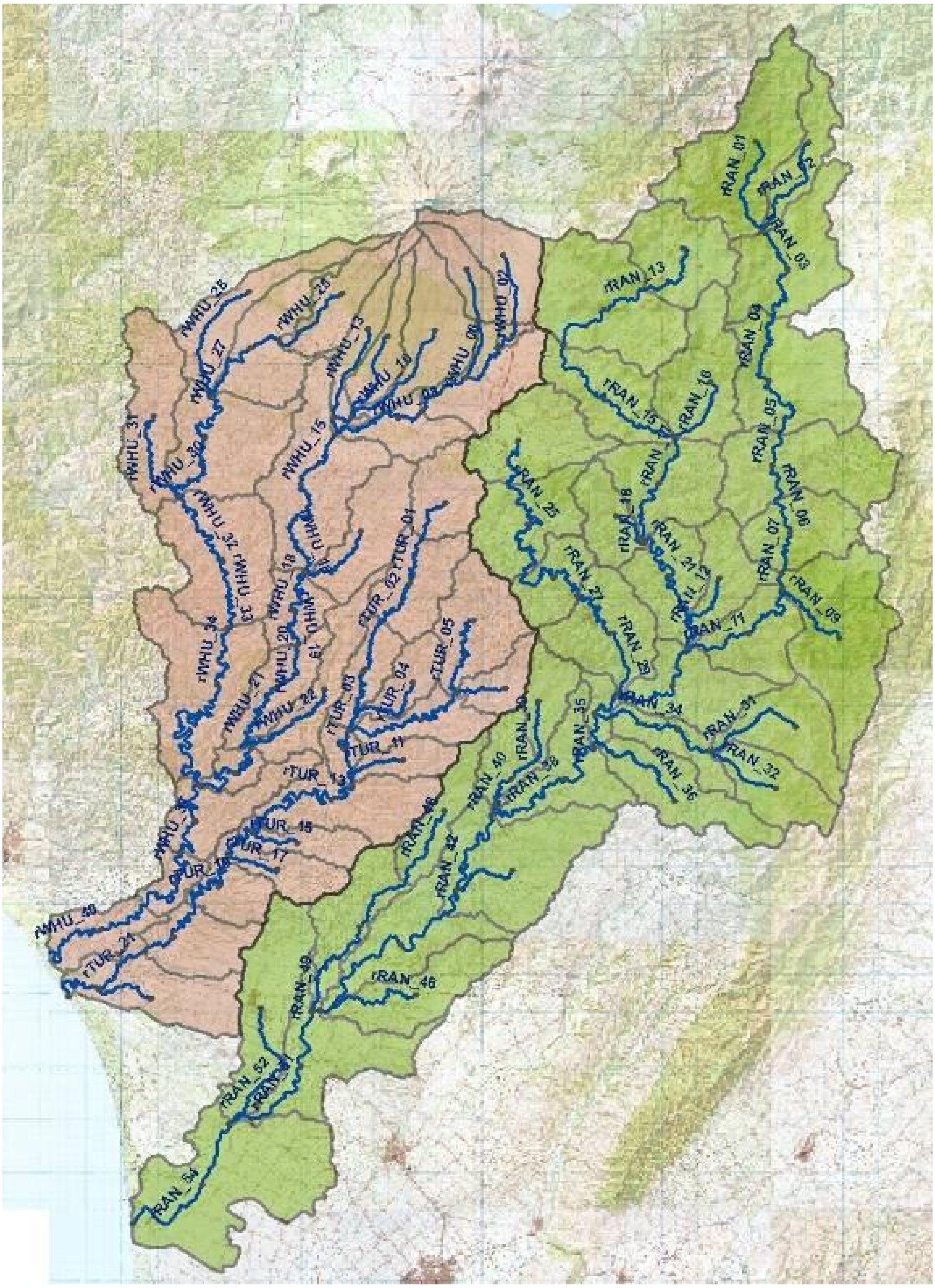


Figure 5-7: Location of reach identifiers

Table 5-4: Reach length details

Reach ID	Length (km)	Reach ID	Length (km)	Reach ID	Length (km)	Reach ID	Length (km)	Reach ID	Length (km)
rRAN_01	13.93	rRAN_27	7.60	rTUR_01	14.92	rWHU_01	6.21	rWHU_21	17.64
rRAN_02	15.54	rRAN_28	10.29	rTUR_02	18.35	rWHU_02	8.36	rWHU_22	16.88
rRAN_03	6.12	rRAN_29	8.47	rTUR_03	11.50	rWHU_03	1.71	rWHU_23	7.65
rRAN_04	19.71	rRAN_30	4.89	rTUR_04	15.50	rWHU_04	3.02	rWHU_24	10.55
rRAN_05	14.20	rRAN_31	14.39	rTUR_05	16.05	rWHU_05	7.50	rWHU_25	11.39
rRAN_06	10.23	rRAN_32	9.28	rTUR_06	7.53	rWHU_06	7.54	rWHU_26	4.62
rRAN_07	6.29	rRAN_33	6.50	rTUR_07	9.76	rWHU_07	7.44	rWHU_27	10.33
rRAN_08	2.18	rRAN_34	12.28	rTUR_08	12.76	rWHU_08	3.86	rWHU_28	18.00
rRAN_09	10.53	rRAN_35	5.14	rTUR_09	5.19	rWHU_09	11.33	rWHU_29	11.52
rRAN_10	10.35	rRAN_36	17.46	rTUR_10	5.44	rWHU_10	16.74	rWHU_30	14.17
rRAN_11	8.68	rRAN_37	8.94	rTUR_11	9.32	rWHU_11	12.45	rWHU_31	14.83
rRAN_12	13.14	rRAN_38	14.98	rTUR_12	5.96	rWHU_12	2.81	rWHU_32	15.24
rRAN_13	16.95	rRAN_39	13.92	rTUR_13	20.80	rWHU_13	12.53	rWHU_33	11.03
rRAN_13a	8.33	rRAN_40	6.78	rTUR_14	3.52	rWHU_14	2.33	rWHU_34	9.94
rRAN_14	11.52	rRAN_41	1.24	rTUR_15	7.46	rWHU_15	10.02	rWHU_35	34.18
rRAN_15	11.23	rRAN_42	14.98	rTUR_16	9.74	rWHU_16	19.90	rWHU_36	8.96
rRAN_16	9.92	rRAN_43	10.99	rTUR_17	7.89	rWHU_17	11.83	rWHU_37	7.91
rRAN_17	6.16	rRAN_44	13.87	rTUR_18	5.49	rWHU_18	9.91	rWHU_38	7.03
rRAN_18	9.53	rRAN_45	16.04	rTUR_19	18.33	rWHU_19	7.41	rWHU_39	18.28
rRAN_19	0.52	rRAN_46	16.02	rTUR_20	4.86	rWHU_20	7.67	rWHU_40	11.23
rRAN_20	5.87	rRAN_47	1.14	rTUR_21	8.45				
rRAN_21	11.11	rRAN_48	20.67	rTUR_22	8.52				
rRAN_22	13.70	rRAN_49	16.74	rTUR_23	8.75				
rRAN_23	5.89	rRAN_50	7.75						
rRAN_24	9.38	rRAN_51	13.51						
rRAN_25	19.66	rRAN_52	19.42						
rRAN_26	21.20	rRAN_53	8.39						
		rRAN_54	12.00						

5.5 RAINFALL DISTRIBUTION

Table 5-5and Table 5-6 show the rain gauge weighting factors for each sub catchment in both models.

These tables 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.

Table 5-5: Rain gauge weightings to each catchment sub-area – Whangaehu, Turakina catchments

Sub Catchment ID	Catcment Area (km^2)	Whangaehu Tukino Repeater	Makotuku F Trig	Mangaetoroa Scarrows	Moawhango Dam	Waiharuru SH49	Turakina Ruanui	Mangawhero RaupiuRd	Whangaehu Aranui	Turakina Koeke Airstrip	Mangawhero Aberfeldy	Makohine Zohs Rd	Whangaehu Kowhai St Mangamahu	Turakina Otairi	Whangaehu Kauangaroa	Matarawa Valley	Tutaenui Ribby Farm	Turakina Oneills Bridge	Tutaenui Green Haven	Mangawhero Bangonie	Whangaehu Titoki
cTUR_01	66.89	0.00	0.00	0.00	0.04	0.06	0.58	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	0.29
cTUR_02	83.61	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.08	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
cTUR_03	47.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.44	0.00	0.06	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cTUR_04	47.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.84	0.00	0.05	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cTUR_05	100.8	0.00	0.00	0.00	0.02	0.00	0.36	0.00	0.00	0.48	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cTUR_06	40.61	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.19	0.00	0.74	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cTUR_07	60.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.61	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cTUR_08	22.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.07	0.00	0.00	0.12	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cTUR_09	39.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cTUR_10	111.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.91	0.00	0.00	0.03	0.00	0.00	0.00	0.00
cTUR_11	43.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.42	0.00	0.00	0.32	0.00	0.00	0.00	0.00
cTUR_12	55.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.23	0.00	0.58	0.00	0.00	0.00	0.00
cTUR_13	49.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.57	0.00	0.24	0.12	0.00	0.00	0.00
cTUR_14	72.61	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	0.15	0.07	0.00	0.73	0.06	0.00	0.00
cTUR_15	113.5	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	0.09	0.00	0.00	0.77	0.13	0.00	0.00
cWHU_01	43.37	0.38	0.19	0.00	0.14	0.07	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	0.00	0.00
cWHU_02	78.07	0.73	0.00	0.00	0.22	0.05	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	0.00	0.00
cWHU_03	6.7	0.11	0.00	0.00	0.79	0.07	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cWHU_04	89.12	0.00	0.00	0.00	0.40	0.30	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
cWHU_05	53.66	0.00	0.00	0.00	0.07	0.50	0.11	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	0.23
cWHU_06	104.35	0.13	0.24	0.00	0.15	0.22	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	0.00	0.00
cWHU_07	52.7	0.06	0.25	0.00	0.00	0.44	0.03	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	0.00
cWHU_08	54.3	0.00	0.27	0.00	0.00	0.48	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	0.00	0.04
cWHU_09	166.48	0.00	0.00	0.07	0.00	0.21	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	0.21	0.46
cWHU_10	94.36	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93
cWHU_11	47.44	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.91	0.00	0.00	0.00	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cWHU_12	68.58	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.52	0.00	0.00	0.00	0.21	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cWHU_13	84.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.13	0.00	0.00	0.15	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cWHU_14	24.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.84	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.00
cWHU_15	70.9	0.00	0.69	0.00	0.03	0.21	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	0.00	0.00
cWHU_16	103.87	0.00	0.15	0.35	0.00	0.37	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	0.00	0.00
cWHU_17	90.23	0.00	0.32	0.40	0.00	0.32	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	0.00	0.00
cWHU_18	132.97	0.00	0.00	0.25	0.00	0.12	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	0.58	0.08
cWHU_19	113.17	0.00	0.00	0.61	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.30	0.00
cWHU_20	155.87	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.08
cWHU_21	177	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.39	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
cWHU_22	82.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.18	0.00	0.61	0.00	0.07	0.00	0.00	0.00	0.00
cWHU_23	32.76	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	0.88	0.04	0.02	0.05	0.00	0.00	0.00
cWHU_24	60.79	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	0.13	0.34	0.00	0.54	0.00	0.00	0.00
Count Subareas		**5**	**7**	**5**	**10**	**16**	**6**	**4**	**10**	**9**	**4**	**6**	**10**	**13**	**8**	**4**	**6**	**5**	**2**	**5**	**9**
Average Contribution		**0.28**	**0.30**	**0.34**	**0.19**	**0.22**	**0.26**	**0.26**	**0.28**	**0.36**	**0.16**	**0.17**	**0.21**	**0.29**	**0.34**	**0.12**	**0.21**	**0.44**	**0.09**	**0.31**	**0.28**

Table 5-6: Rain gauge weightings to each catchment sub-area – Rangitikei catchment

Sub Catchment ID	Catcment Area (km^2)	Ruatahuna	Karikaringa	Moawhango Dam	Erewhon Stn	Turakina Ruanui	Moawhango	Hautapu Alabasters	Makohine Zohs Rd	Upper Kawhatau	Oroua Rangiwahia	Pakihikura Airstrip	Porewa Tututotara	Tutaenui Green Haven	Makino Cheltenham	Makino Halcombe Rd	Forest Rd Drain	Glenwood	Parks Peak	Moorcock
cRAN_01	182.6	0.41	0.56	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	0.00	0.00	0.01	0.00
cRAN_02	61.5	0.50	0.42	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	0.00	0.00	0.03	0.00
cRAN_03	135.1	0.00	0.46	0.00	0.37	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	0.08	0.00
cRAN_04	148.3	0.00	0.00	0.10	0.84	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	0.05	0.00
cRAN_05	153.6	0.00	0.00	0.00	0.92	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
cRAN_06	87.2	0.00	0.00	0.00	0.47	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00
cRAN_07	184.4	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.34	0.00
cRAN_08	81.3	0.00	0.00	0.00	0.10	0.00	0.16	0.00	0.00	0.52	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_09	68.0	0.00	0.00	0.00	0.19	0.00	0.43	0.16	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_10	102.2	0.12	0.49	0.23	0.11	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	0.00	0.00
cRAN_11	173.0	0.00	0.06	0.88	0.05	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	0.00	0.00
cRAN_12	101.0	0.00	0.06	0.63	0.00	0.00	0.19	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_13	116.0	0.04	0.00	0.18	0.61	0.00	0.14	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
cRAN_14	107.2	0.00	0.00	0.07	0.23	0.00	0.65	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_15	56.5	0.00	0.00	0.03	0.04	0.00	0.84	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_16	83.4	0.00	0.00	0.00	0.06	0.00	0.70	0.17	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_17	95.2	0.00	0.00	0.00	0.06	0.00	0.00	0.22	0.19	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_18	112.6	0.00	0.00	0.43	0.00	0.36	0.24	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
cRAN_19	104.7	0.00	0.00	0.08	0.00	0.52	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_20	59.0	0.00	0.00	0.00	0.00	0.08	0.08	0.80	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_21	110.2	0.00	0.00	0.00	0.00	0.00	0.17	0.68	0.12	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_22	95.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.02	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.06	0.00
cRAN_23	78.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.20
cRAN_24	54.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.40	0.24	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_25	23.2	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.64	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_26	99.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.16	1.08	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_27	96.9	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.55	0.00	0.10	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_28	50.1	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.96	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_29	47.8	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.57	0.00	0.06	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_30	179.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_31	112.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.61	0.00	0.20	0.00	0.00	0.00	0.00	0.00
cRAN_32	99.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.28	0.00	0.50	0.11	0.00	0.00	0.00	0.00
cRAN_33	63.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.56	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_34	87.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.87	0.00	0.06	0.00	0.00	0.00	0.00	0.00
cRAN_35	127.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.47	0.00	0.27	0.07	0.00	0.00	0.00
cRAN_36	135.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
cRAN_37	245.2	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	0.00	0.07	0.94	0.00	0.00	0.00
Count Subareas		**4**	**6**	**9**	**14**	**6**	**12**	**11**	**11**	**12**	**9**	**9**	**5**	**2**	**3**	**4**	**3**	**3**	**8**	**1**
Average Contribution		**0.27**	**0.34**	**0.29**	**0.30**	**0.17**	**0.32**	**0.26**	**0.33**	**0.31**	**0.24**	**0.27**	**0.42**	**0.74**	**0.26**	**0.11**	**0.34**	**0.19**	**0.09**	**0.20**

5.6 MODEL OUTPUTS

The model writes outputs back to Hilltop at each of the primary flow locations.

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.

6 MODEL CALIBRATION

6.1 CALIBRATION METHODOLOGY

Model calibration involves adjusting the catchment parameters so that the modelled data best replicates the record at measured flow sites. The calibration process uses all available measured rainfall inputs and usually no corrections are made using 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. 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. As mentioned above the accuracy grading is determined over a historical time period using measured rainfalls. It does not directly measure the model's predictive reliability (i.e. in future time steps) or take into account the uncertainty of the forecast rainfall inputs.

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).

The period considered for calibration is from 01/01/2005 to 01/11/2008. The selected calibration period is relatively short due to the inclusion of the majority of rainfall gauges and some stream flow gauges following the February 2004 floods. Many of these sites were not instated until late 2004 or early 2005. As the calibration period is short there will be benefits in monitoring the model performance of these catchments and conducting a calibration review when more data becomes available.

Adopted parameters and results summary are provided in the following sections and more detailed results at each site are documented in the Appendices (Sections 9 – 11).

In addition to comparative time series plots, a results summary file has been produced for each model (Results_File_WhangaehuTurakina.xls, and Results_File_Rangitikei.xls). The model outputs a .csv summary file which can be pasted directly into each spreadsheet to present the following results at each primary site:

- A summary of the Chinese Standards performance indicators (CD and QR), and a long-term flow volume comparison (01/01/2005 – 01/10/2008).

- 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 can be selected for all tributary and upstream sites and up to 20 events can be selected at the major downstream gauges. At this stage around 10 – 12 events have been selected for comparison at each site due to the limited time frame.
- A plot of the peak and volume errors for each event.
- Monthly and seasonal volume balances.

Due to the issues experienced when trying to calibrate the Rangitikei catchment, the calibration at Mangaweka allows the input of measured flows from the three available upstream flow gauges: Moawhango River at Moawhango, Rangitikei at Pukeokahu and Hautapu at Alabasters. The calibration difficulties of the Rangitikei catchment are discussed further in the Calibration Summary section below.

6.2 ADOPTED CALIBRATION PARAMETERS

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 five separate regions for each model. Varying regions were mostly defined for the catchment area upstream of a particular calibration gauge. Parameters were derived for each region independently.
- The channel and catchment routing parameters (Alpha and Beta). These parameters generally vary according to each of the calibration regions. In the Hautapu catchment the catchment routing parameter, Beta has been increased significantly in the upper catchment to better represent the slower response in that region due to the flat, marshy terrain.
- 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. This is mostly noticeable at downstream sites (particularly Kauangaroa and Oneills Bridge) where the measured upstream hydrographs appear to show little or no flow attenuation when they reach the downstream site. A combination of a very low Alpha value and a delay at the downstream site would allow the model to best replicate this phenomenon.
- Rainfall scaling factors have been applied at many of calibration regions. Mostly fixed but a seasonally variable scaling factor has been applied in the Aranui calibration region. These factors apply to all catchment sub-areas in the specific region. Rainfall scaling has generally been applied to either reduce overall volumes (if the factor is <1) or to increase the magnitude of the models' event peaks or volumes (if the factor is >1).
- Evaporation scaling factors have been applied at many of the calibration regions. Mostly a reduction of evaporation has been applied. The evaporation scaling factors were applied to minimise the impacts of under-estimating event peaks while over-estimating the overall volume of water in the catchment, which was a common issue for these catchments. In the Turakina catchment the evaporation scaling factors were varied monthly. The application of rainfall and evaporation scaling factors is considered as a last resort and has been done in order to achieve a better fit of flood events.

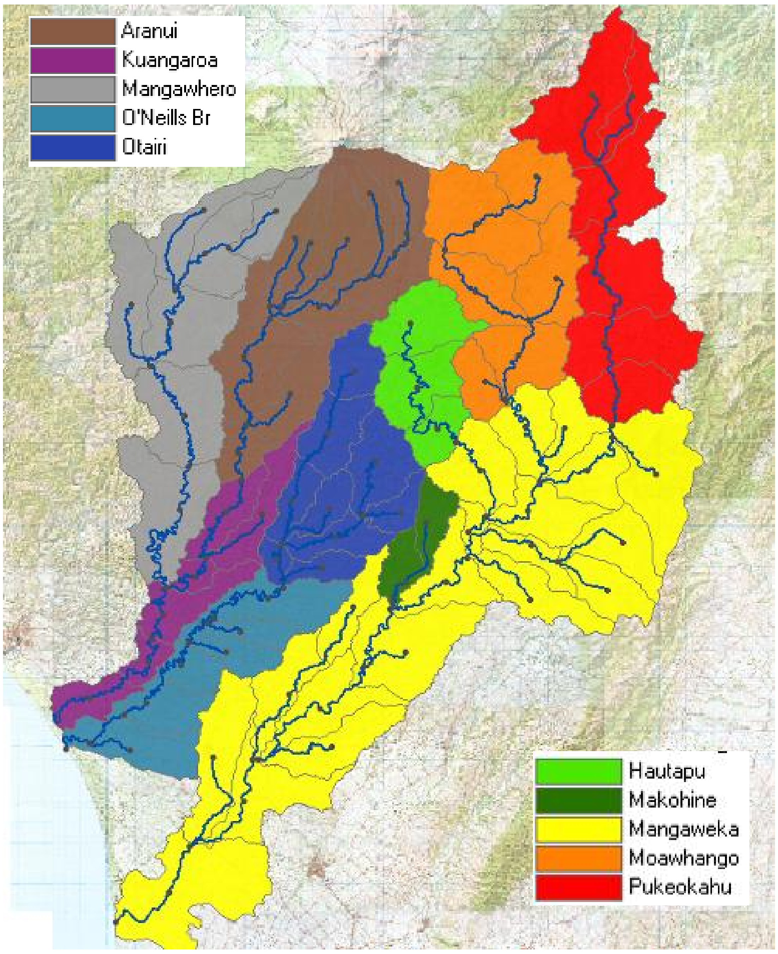


Figure 6-1: Calibration regions

Table 6-2: Adopted calibration parameters

	WHANGAEHU, TURAKINA					RANGITIKEI				
	Mangawhero	Aranui	Kauangaroa	Otairi	Oneills Br	Pukeokahu	Moawhango	Hautapu	Makohine	Mangaweka
Alpha	1	1	0.4	0.68	0.38	1	1.3	1	1	1
CapAve	100	20	30	85	100	80	30	140	90	80
INFbase	0.45	0.55	0.3	0.45	0.38	0.6	0.92	0.8	0.5	0.6
K1	0.82	0.98	0.96	0.83	0.95	0.97	0.95	0.97	0.6	0.97
K2	0.999	0.99	0.999	0.999	0.99	0.9	0.97	0.96	0.99	0.98
H_GW	15	60	40	5	5	50	40	50	20	60
GWstoreSat	45	110	80	9	40	120	80	80	80	180
GWstoreMax	50	135	100	25	45	150	120	120	120	200
Beta	0.3	1	1	0.6	1.5	0.5	0.5	3 ***	0.5	0.5
RainScaleF	0.96	**	0.8	1	0.85	1.6	1.2	1.25	1	1.3
EvapScaleF	0.7	1	1	*	*	1	0.7	0.6	1	0.6

Site	Delay (hrs)
Whangaehu at Kauangaroa	6
Turakina at Otairi	1.5
Turakina at Oneills Bridge	6.5

** Aranui Variable Rain Scaling Factor

Period	Factor
March - August	1.37
September - February	1.7

*** Beta parameter for the two highest subcatchments in Hautapu is 6.

* Monthly Variable Evaporation Scaling Factor

Month	Otairi	Oneills Br
January	0.8	1
February	0.9	1
March	0.97	1
April	1.05	1.1
May	1.05	1.1
June	1.05	1.1
July	0.9	1.1
August	0.675	0.8
September	0.65	0.8
October	0.6	0.75
November	0.47	0.7
December	0.5	0.9

6.3 SUMMARY OF CALIBRATION RESULTS

Table 6-3 summarises the calibration results for each site in the three river catchments. More detailed calibration results for each site are displayed in the appendices at the end of this report.

Table 6-3: Summary of calibration results

Stream Gauge	Coefficient of Determination, R^2	Event Qualifying Rate (QR)	Chinese Standards Ranking	Measured Flow Volume (Mm^3)	Modelled Flow Volume (Mm^3)	Rainfall Volume (Mm^3)	Average Event Peak Difference	Average Event Volume Difference
Whangaehu at Kauangaroa	0.82	92%	B	4,955	5,180	7,803	10.6%	12.0%
Whangaehu at Aranui	0.74	75%	B	1,320	1,409	1,526	14.2%	14.4%
Mangawhero at Raupio Rd	0.82	80%	B	2,091	2,183	3,394	9.7%	13.4%
Mangawhero at Ore Ore	0.73	56%	C	1,825	1,843	2,994	18.2%	17.4%
Turakina at Oneills Bridge	0.88	67%	C	1,060	1,162	2,635	16.9%	8.6%
Turakina at Otairi	0.78	73%	B	775	832	1,587	19.0%	12.2%
Rangitikei at Mangaweka	0.90	83%	B	8,759	9,531	11,456	14.3%	7.0%
Hautapu at Alabasters	0.78	34%	< C	636	674	1,024	22.9%	16.6%
Rangitikei at Pukeokahu	0.67	11%	< C	2,782	3,526	3,612	41.8%	38.3%
Moawhango at Moawhango	0.48	-	-	786	827	2,128	-	-
Makohine at Viaduct	0.64	-	-	126	134	365	-	-

DISCUSSION OF RESULTS - WHANGAEHU/TURAKINA CATCHMENT:

The Whangaehu and Turakina catchments calibrated well with most sites achieving a B ranking making them suitable for official forecasts. But even better results were anticipated given the dense distribution of rainfall gauges over these catchments.

In the Whangaehu catchment the model only misses an A rating at Kauangaroa due to a low R^2 (CD) value of 0.82. This value was dragged down from 0.87 by including 2005 in the analysis period (i.e. if the model is run from 2006 the R^2 is 0.87). Therefore the overall model performance (and possibly the ranking) of the model should improve if 2005 was uncharacteristic.

The low R^2 at Aranui is affected by the complex hydrological conditions of Mt Ruapehu. Significant rainfall scaling was required here to match the flow volumes and reach the event peaks. In the Mangawhero River a single set of parameters was selected based on the fit at Raupio Rd. When trying to optimise the calibration fit at Ore Ore, the results were negatively impacted at Raupio Rd. Therefore better results at Ore Ore were sacrificed to obtain good results at Raupio Rd.

In the Turakina River a similar situation occurred between the two measured flow sites as witnessed in the Mangawhero River. Achieving a good fit at Otairi appeared to have a negative impact on Oneills Bridge. When using a single parameter set for the whole Turakina River the event qualifying rate (QR) at Oneills Bridge could be improved to 75% but the results at Otairi are significantly impacted (R^2 = 0.69, QR = 45%). Despite the C ranking at Oneills Bridge, the rankings do not clearly reflect the performance at this site, as 10 out of 12 events are within 25% and the general fit (according to R^2) is very good.

In both the Whangaehu and Turakina Rivers the lower reaches appear to cause little or no attenuating effects on the flows from upstream. To account for this in the model, some significant delays have been applied at the downstream sites and very low channel routing parameters (Alpha) have been adopted to reduce the impact of the non-linear channel routing equations.

DISCUSSION OF RESULTS - RANGITIKEI CATCHMENT:

Calibration of the Rangitikei model proved to be very difficult. Surprisingly the Rangitikei catchment appears to possess much more complex groundwater conditions and significant baseflows compared to the Whangaehu catchment despite the Whangaehu River's origin at the peak of Mt Ruapehu. In addition to the significant baseflows, the rainfall inputs in all upstream catchments appear to often be unrepresentative with little rainfall recorded during significant flow events and at other times large rainfalls causing almost no flood rise. Significant factoring of the rainfalls proved fruitless with some events still not being reaches with other events over-estimating by a considerable margin.

Investigations and discussions found that the impacts of the Ruahine Range are significant on the eastern side of the Rangitikei catchment. In addition the rain shadow cast across the south east of Mt Ruapehu and apparent under-estimation of the Genesis Energy gauges in the upper catchment added considerable uncertainty to the rainfall distribution in these regions. Hawkes Bay Regional Council gauges were introduced to better represent the influence of the Ruahine Range on the rainfall into the eastern Rangitikei catchment.

Given the difficulties in achieving satisfactory results in the upper reaches of the Rangitikei, it was agreed that measured flows be input at Rangitikei at Pukeokahu, Moawhango at Moawhango, and Hautapu at Alabasters. The rainfall-runoff portion of the model between these sites and Mangaweka was then calibrated to achieve a best fit at the Mangaweka gauge. When using measured flow inputs upstream, a very good fit was achieved at Mangaweka which just misses an A rating by a single event (QR = 83%). These results rely on the inclusion of the Hawkes Bay rainfall gauges. Without them the performance of the model reduces (R^2 reduces from 0.9 to 0.86, and QR reduces from 83% to 58%).

The Rangitikei model relies on real-time flow data being available at each of the three upstream sites mentioned above. Although calibration results for these sites have been presented in this report it is recommended that forecast flows are not fed through the model from these sites and only measured flows are used. This will have an impact on the forecast lead-time that can be achieved by the Rangitikei model (example shown in the following section).

A sample time series is presented in Appendix C showing the flow comparison at Onepuhi. This has been included to check the timing of modelled events. When the modelled flows are factored down by 0.7 there is a reasonably close agreement between modelled and measured.

6.4 MODELLED FLOW RESPONSE WITH ZERO RAINFALL INPUT

A well calibrated event was selected for the flow site at the base of the three rivers and the rainfall was stopped at various time intervals through the event to investigate the models' flow response if zero rainfall is input. This gives an indication of the achievable lead-time of the catchment with no forecast rainfalls input to the models. Both the Whangaehu and Turakina models can achieve from 6-9 hours of lead-time if no forecast rain is input, particularly once the peak of the rainfall event has occurred.

At Mangaweka the measured flows from upstream sites are also set to zero at the same time as the rainfalls and the impact is obvious both on lead-time (~ 3 hours) and also in the fast rate of recession.

These lead-times are likely to vary for each event. In practice the models receive forecast rainfall inputs which will increase the lead-time, but also increase the uncertainty in the model forecasts depending on the accuracy of the supplied forecast rainfalls.

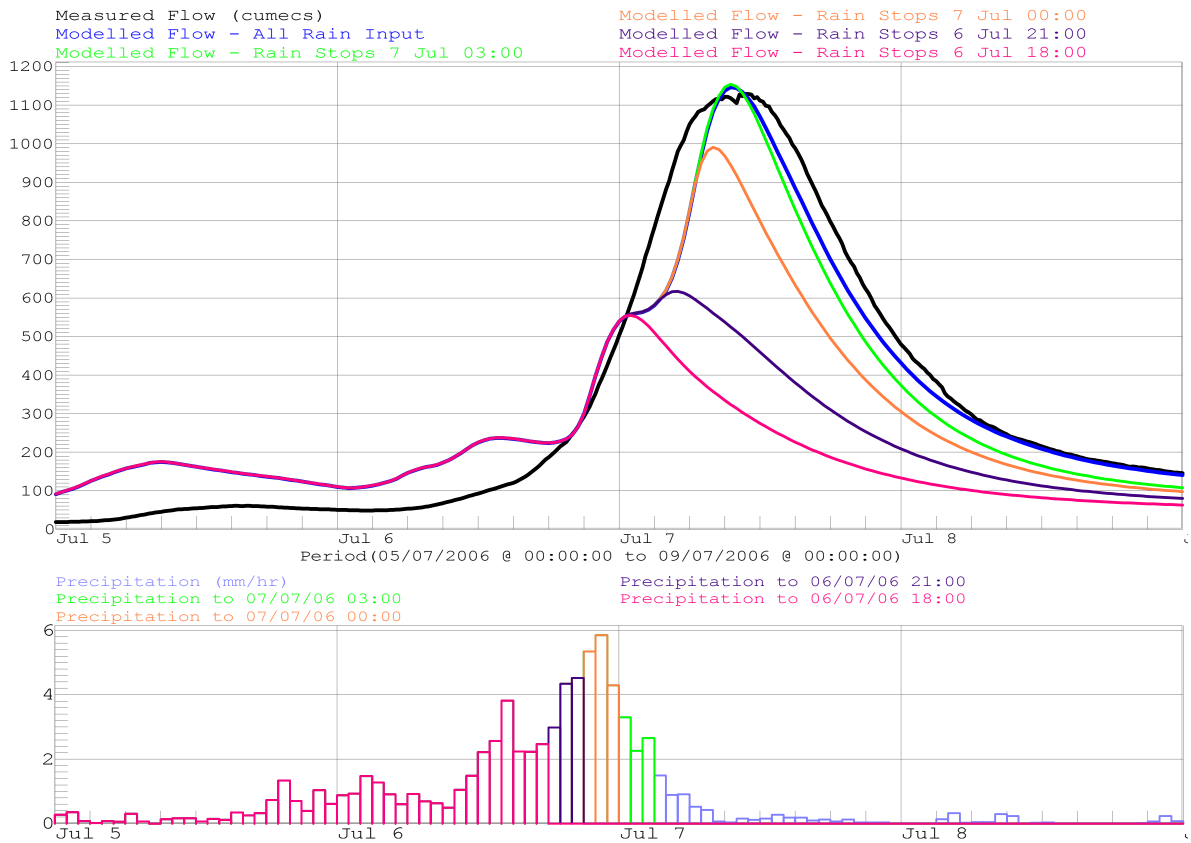


Figure 6-2: Model response if rainfall is set to zero – Whangaehu at Kauangaroa

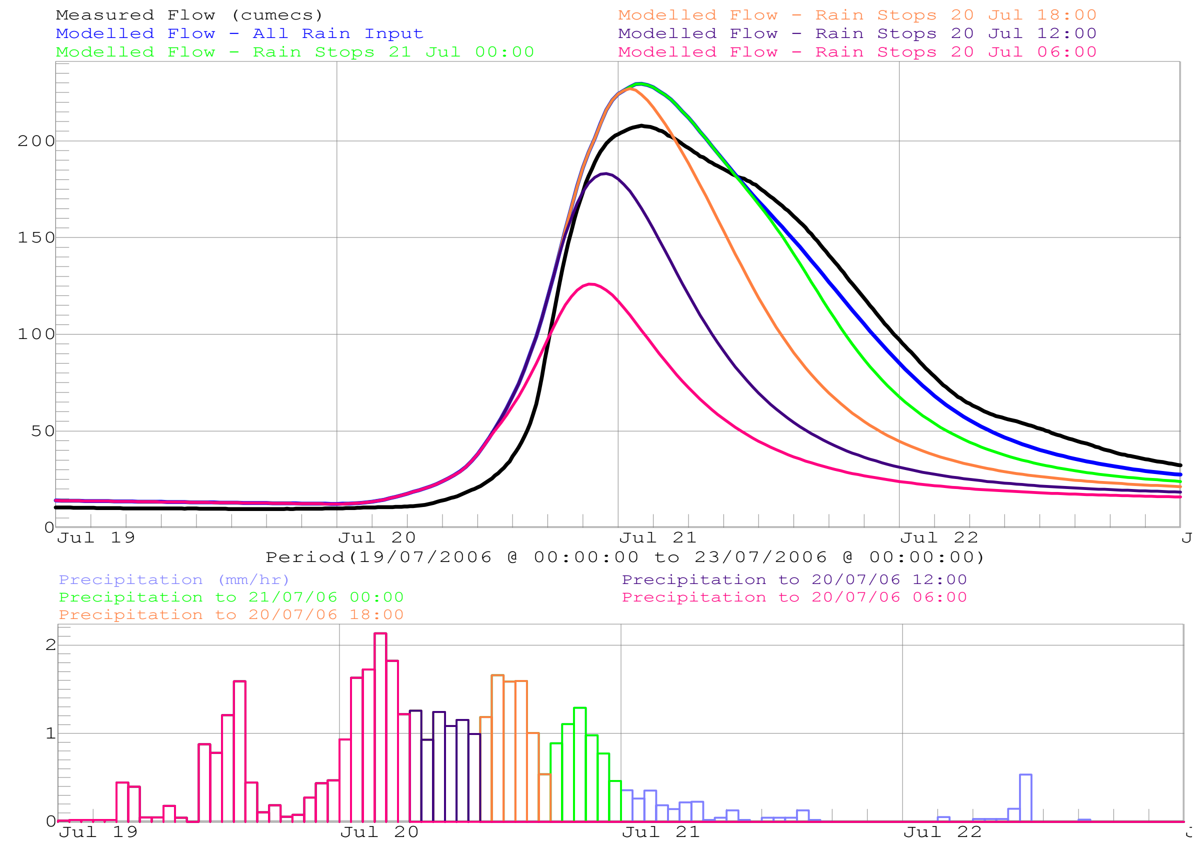


Figure 6-3: Model response if rainfall is set to zero – Turakina at Oneills Bridge

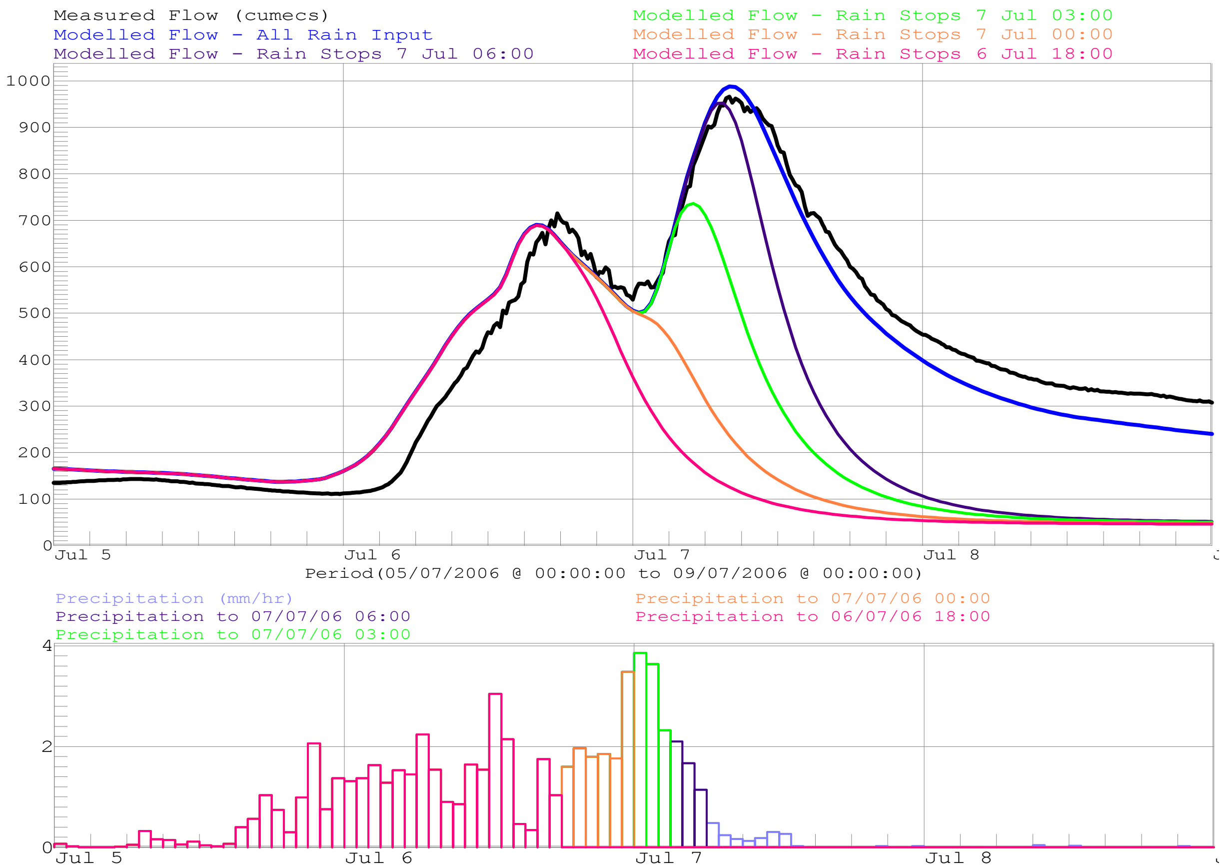


Figure 6-4: Model response if rainfall and upstream flows are set to zero – Rangitikei at Mangaweka

7 RECOMMENDATIONS FOR FUTURE IMPROVEMENTS

The recommendations below are targeted towards improvements of both the catchment models that were developed in this stage as well as the system as a whole.

- **Site information:** It is essential for the reliability of Rangitikei model forecasts that the following flow sites are providing up-to-date flow data of good quality:

    - Rangitikei River at Pukeokahu
    - Moawhango River at Moawhango
    - Hautapu River at Alabasters.

  It will be of benefit to the Rangitikei and Oroua models to develop a better understanding of the rainfall both along the Ruahine Range and also to the east and south east of Mt Ruapehu.

- **House-keeping/diagnostic archives:** A condition monitoring process has been implemented for the modelling system during the development of Stage 5. At this point in time, .csv files of the model output are archived during every cycle and no process is in place to remove them after a period of time. Something may need to be implemented to keep this archive at a manageable size. Alternatively, they could be archived based on conditions such as if questionable data exists or if there is a flood event occurring. If not in place in other HRC processes, an input data timeliness report could be produced which will measure the timeliness of telemetered data and supplied forecasts.

- **Ongoing Support and Maintenance:** Now that the five development stages have been completed, 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.

- **Improvement 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 in future time steps) and adopt a different approach to outputting the modelled results (e.g. over plotting the measured flows with the uncorrected modelled flows).

- **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. Model calibration is usually limited by the time made available to calibrate and often the optimum outcome is not achieved. Despite failed initial efforts during this study, there is potential to greatly improve the calibration results at many locations in the Rangitikei catchment. This may also be applicable to parts of the

Lower Manawatu catchment where a suitable result was not achieved. As this takes time and is often benefited by understanding the local conditions, it is a task that could be undertaken by HRC personnel which will also help develop an understanding of the software.

- 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 times 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.

- **Further Knowledge Transfer:** Continue to improve the skills and understanding of the components of the HRCFFS and the software used among some key staff members. Ideally one or two staff members would take on a chief administrator role with the system and be able to pass their knowledge on to other staff members of HRC.
- **Catchment Average Rainfall Output to Hilltop:** Currently most hydrologic models in the system are calculating the catchment average rainfall during each model time step at the location of major flow gauges. This data is not being archived but could be useful information for HRC for a number of hydrology related investigations. If new measurements are set up in Hilltop then these catchment average rainfalls can be output from the models.

8 REFERENCES

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9 APPENDIX A - WHANGAEHU RIVER CALIBRATION RESULTS

9.1 WHANGAEHU AT KAUANGAROA:

R Squared	0.82	a	5.04	b	0.84
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	4,955	Modelled Flow Volume (Mm3)	5,180	Event Qualifying Rate	92%

Table 9-1: Calibration Event Details – Whangaehu at Kauangaroa

	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	03/07/2006 @ 18:00	11/07/2006 @ 12:00	1127.82	1146.40	1.65	134.71	141.93	5.36	179.26	0.75	0.79
2	11/07/2006 @ 12:00	18/07/2006 @ 00:00	505.82	527.72	4.33	75.65	89.35	18.11	84.85	0.89	1.05
3	19/07/2006 @ 06:00	25/07/2006 @ 00:00	497.74	570.34	14.59	78.99	83.03	5.11	81.85	0.97	1.01
4	21/10/2006 @ 12:00	27/10/2006 @ 18:00	557.05	487.43	-12.50	54.39	45.98	-15.46	84.82	0.64	0.54
5	30/11/2006 @ 00:00	03/12/2006 @ 00:00	355.33	375.21	5.59	26.38	31.56	19.64	67.15	0.39	0.47
6	27/06/2007 @ 09:00	10/07/2007 @ 00:00	359.68	411.78	14.49	90.71	108.13	19.20	123.92	0.73	0.87
7	10/08/2007 @ 12:00	16/08/2007 @ 00:00	324.23	317.56	-2.06	53.42	52.45	-1.80	58.18	0.92	0.90
8	10/10/2007 @ 12:00	23/10/2007 @ 00:00	493.86	418.62	-15.23	154.54	115.27	-25.41	161.29	0.96	0.71
9	22/06/2008 @ 00:00	03/07/2008 @ 00:00	412.67	339.57	-17.71	142.84	150.86	5.61	221.09	0.65	0.68
10	11/07/2008 @ 00:00	17/07/2008 @ 00:00	385.03	322.29	-16.29	53.75	48.67	-9.46	50.88	1.06	0.96
11	12/08/2008 @ 00:00	23/08/2008 @ 00:00	319.50	292.72	-8.38	118.59	100.65	-15.13	110.33	1.07	0.91
12	09/09/2008 @ 00:00	18/09/2008 @ 00:00	359.79	419.56	16.61	75.44	68.77	-8.84	98.15	0.77	0.70
13	04/10/2008 @ 06:00	13/10/2008 @ 00:00	533.40	487.56	-8.59	99.99	92.64	-7.35	133.97	0.75	0.69
14	14/02/2004 @ 18:00	19/02/2004 @ 18:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				***9.86***			***11.18***		***0.75***	***0.74***

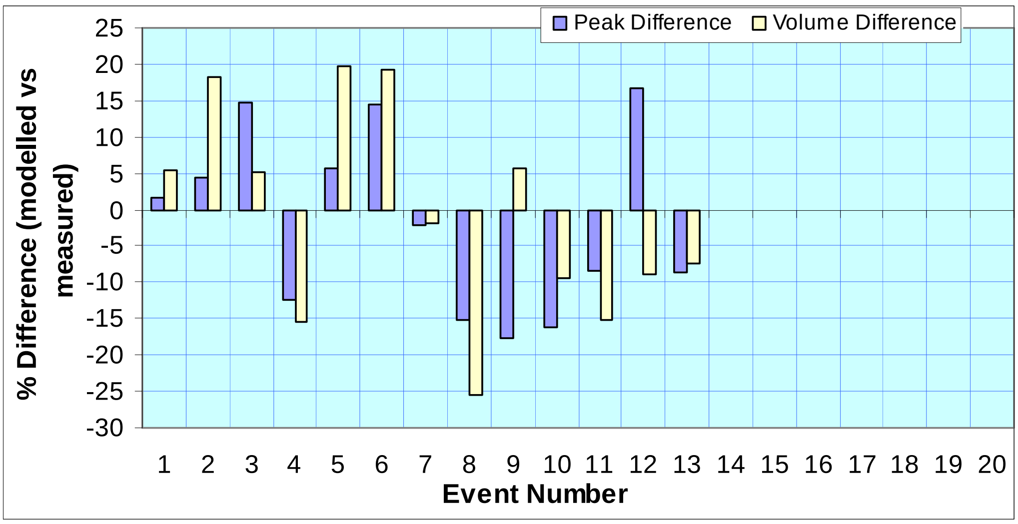


Figure 9-1: Modelled vs Measured Event Differences – Whangaehu at Kauangaroa

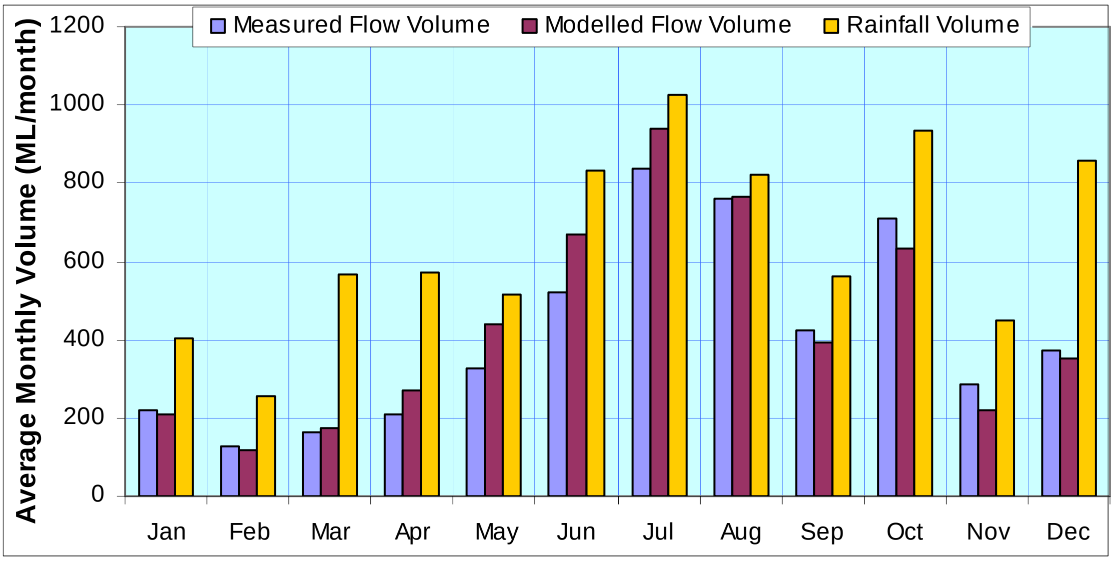


Figure 9-2: Monthly Average Volumes – Whangaehu at Kauangaroa

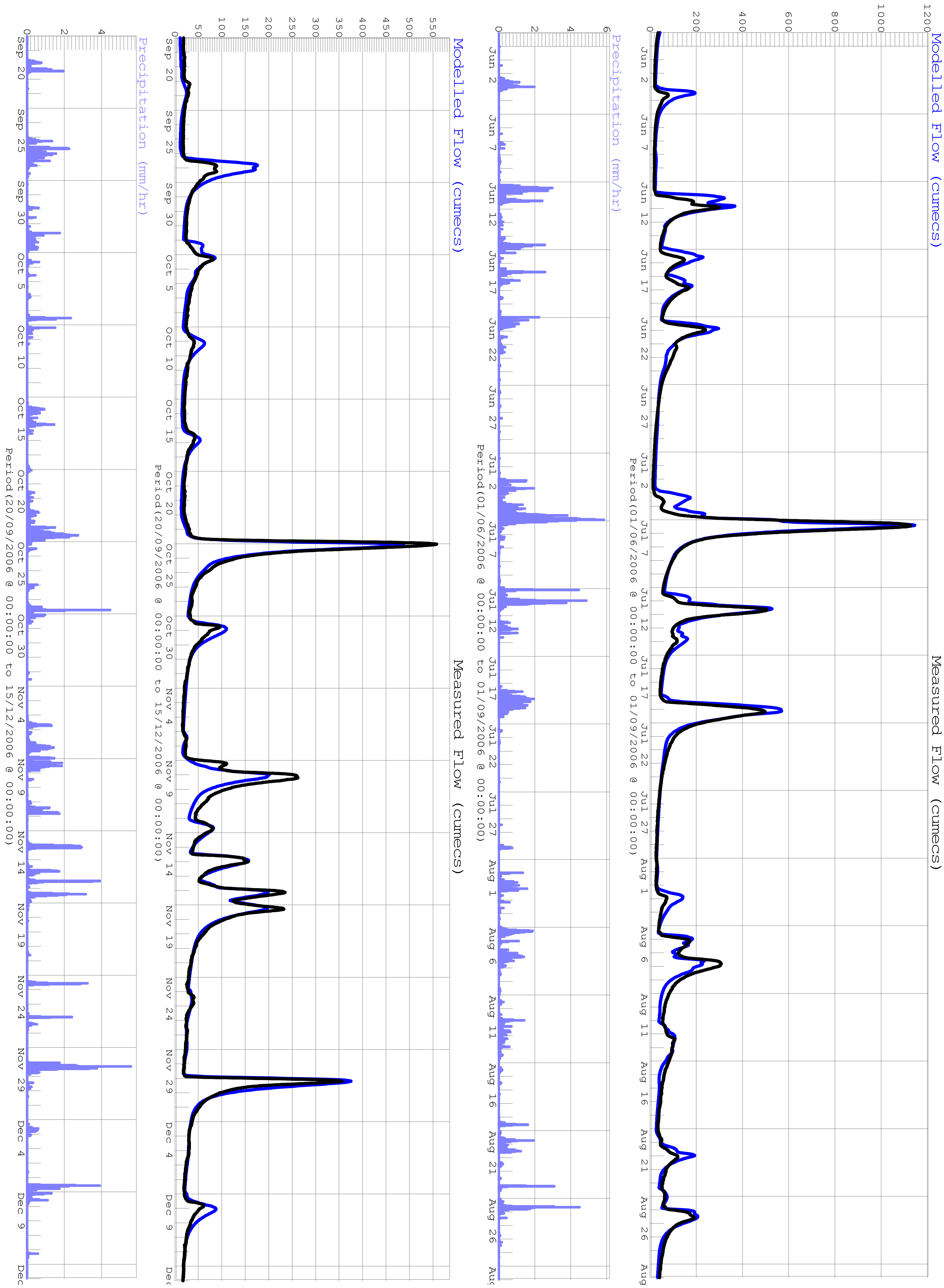


Figure 9-3: Time Series Comparison – Whangaehu at Kauangaroa (1)

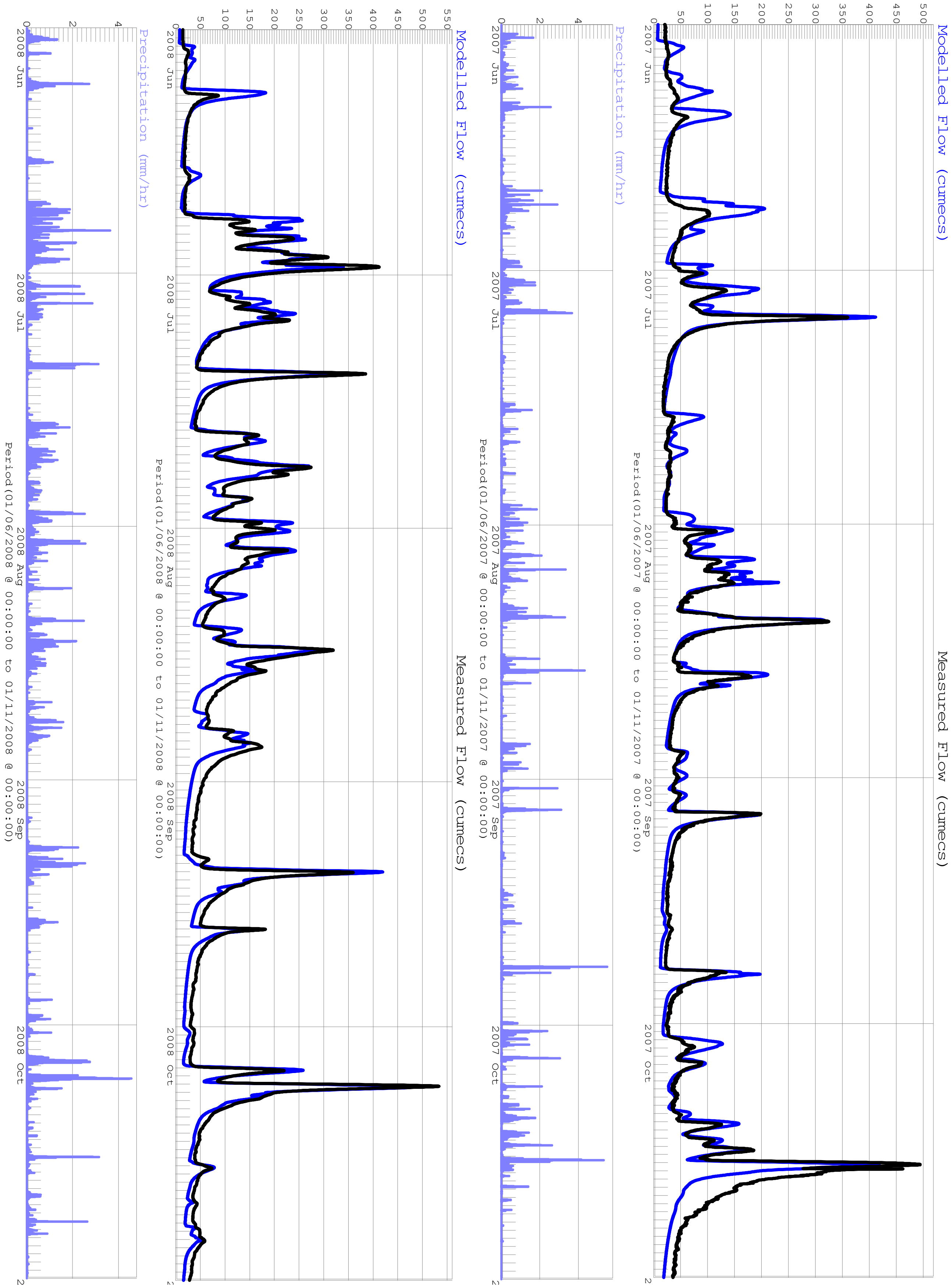


Figure 9-4: Time Series Comparison – Whangaehu at Kauangaroa (2)

9.2 WHANGAEHU AT ARANUI:

R Squared	0.74	a	1.21	b	0.87
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	1,320	Modelled Flow Volume (Mm3)	1,409	Event Qualifying Rate	75%

Table 9-2: Calibration Event Details – Whangaehu at Aranui

	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	04/07/2006 @ 00:00	12/07/2006 @ 00:00	565.49	433.32	-23.37	60.58	48.99	-19.13	56.96	1.06	0.86
2	12/07/2006 @ 00:00	19/07/2006 @ 00:00	204.45	210.80	3.10	36.00	32.17	-10.65	26.78	1.34	1.20
3	19/07/2006 @ 00:00	26/07/2006 @ 00:00	186.97	220.78	18.08	39.94	34.96	-12.46	24.90	1.60	1.40
4	29/11/2006 @ 00:00	04/12/2006 @ 00:00	178.73	163.04	-8.78	15.09	16.85	11.66	25.95	0.58	0.65
5	04/10/2008 @ 12:00	13/10/2008 @ 00:00	244.91	251.73	2.79	34.63	40.01	15.56	47.24	0.73	0.85
6	24/10/2006 @ 00:00	28/10/2006 @ 00:00	146.11	133.77	-8.44	16.97	14.22	-16.18	13.43	1.26	1.06
7	11/07/2008 @ 12:00	16/07/2008 @ 00:00	170.68	95.94	-43.79	16.43	13.43	-18.26	16.78	0.98	0.80
8	11/09/2008 @ 00:00	17/09/2008 @ 00:00	146.40	153.81	5.06	21.77	24.27	11.51	18.80	1.16	1.29
9	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				*10.76*			*14.27*		*1.10*	*1.00*

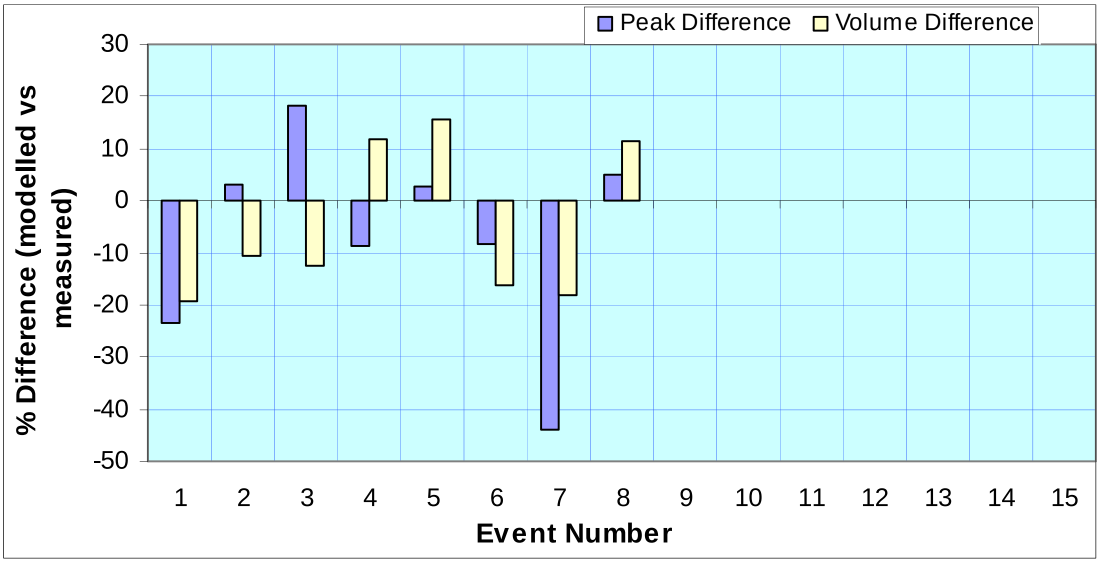


Figure 9-5: Modelled vs Measured Event Differences – Whangaehu at Aranui

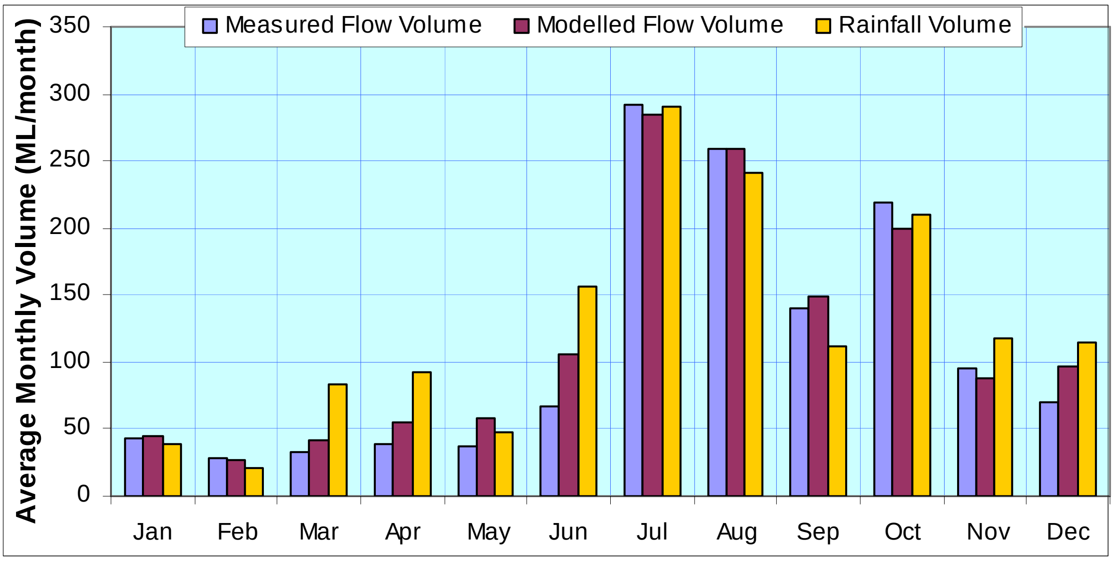


Figure 9-6: Monthly Average Volumes – Whangaehu at Aranui

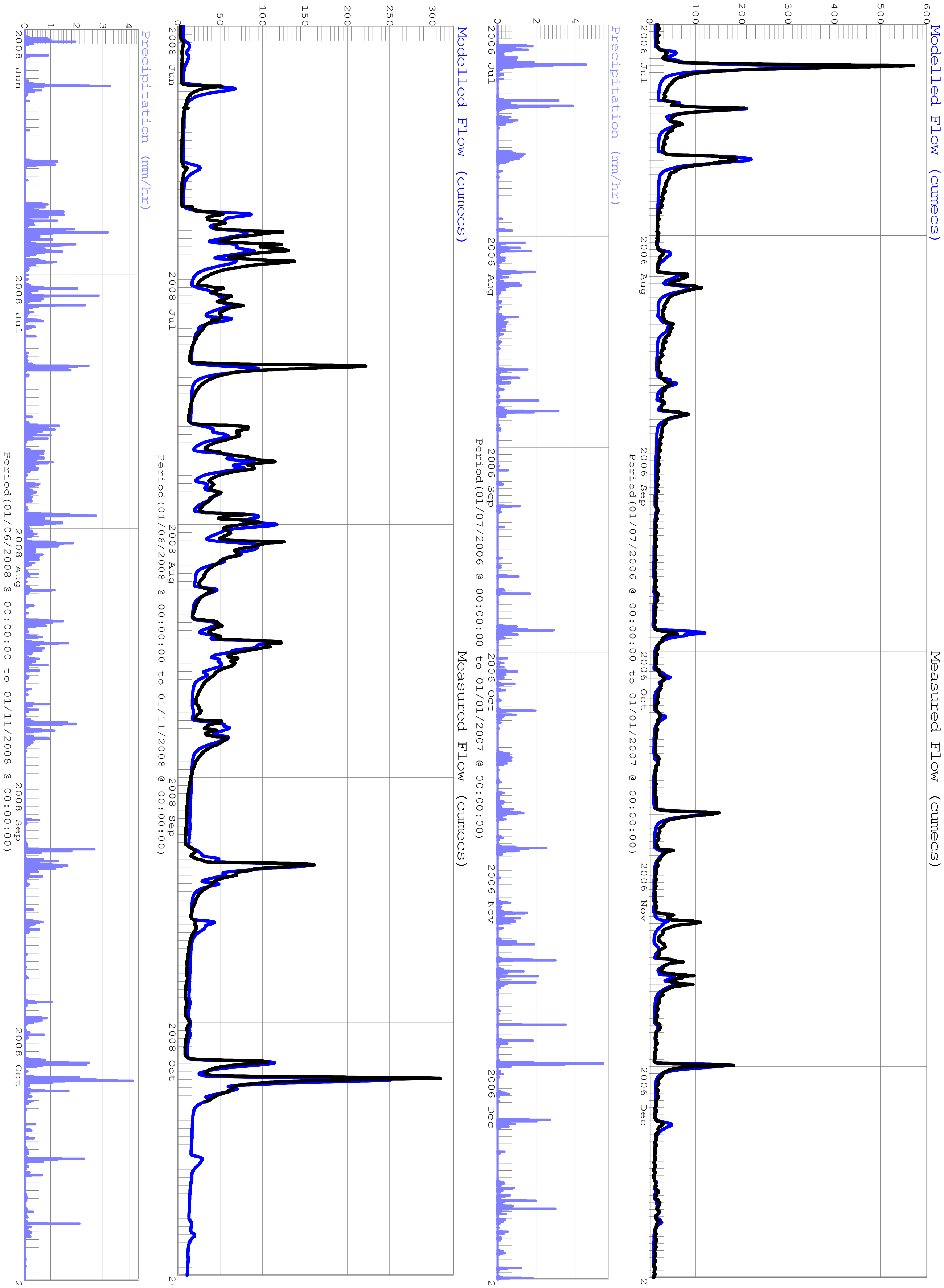


Figure 9-7: Time Series Comparison – Whangaehu at Aranui

9.3 MANGAWHERO AT RAUPIO RD:

R Squared	0.82	a	3.63	b	0.77
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	2,091	Modelled Flow Volume (Mm3)	2,183	Event Qualifying Rate	80%

Table 9-3: Calibration Event Details – Mangawhero at Raupio 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	30/04/2005 @ 00:00	07/05/2005 @ 00:00	189.13	200.62	6.07	26.31	28.59	8.67	40.65	0.65	0.70
2	03/07/2006 @ 18:00	11/07/2006 @ 00:00	427.37	471.68	10.37	56.36	63.16	12.07	81.92	0.69	0.77
3	11/07/2006 @ 18:00	17/07/2006 @ 00:00	220.31	253.20	14.93	32.91	38.82	17.96	40.25	0.82	0.96
4	30/11/2006 @ 00:00	03/12/2006 @ 00:00	228.06	234.22	2.70	16.63	17.39	4.57	34.76	0.48	0.50
5	17/03/2007 @ 12:00	22/03/2007 @ 00:00	183.33	179.46	-2.11	12.69	17.59	38.60	28.71	0.44	0.61
6	05/07/2007 @ 06:00	09/07/2007 @ 00:00	190.99	240.51	25.93	22.61	26.01	15.05	22.88	0.99	1.14
7	10/08/2007 @ 12:00	16/08/2007 @ 00:00	158.53	151.35	-4.53	27.90	24.93	-10.65	25.84	1.08	0.96
8	17/10/2007 @ 00:00	20/10/2007 @ 12:00	230.06	206.77	-10.12	29.90	24.18	-19.13	30.55	0.98	0.79
9	11/07/2008 @ 12:00	15/07/2008 @ 00:00	202.26	222.23	9.87	21.65	22.05	1.82	26.98	0.80	0.82
10	04/10/2008 @ 12:00	12/10/2008 @ 00:00	295.15	263.93	-10.58	42.85	45.12	5.30	67.67	0.63	0.67
11	15/02/2004 @ 00:00	19/02/2004 @ 12:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				*9.72*			*13.38*		*0.76*	*0.79*

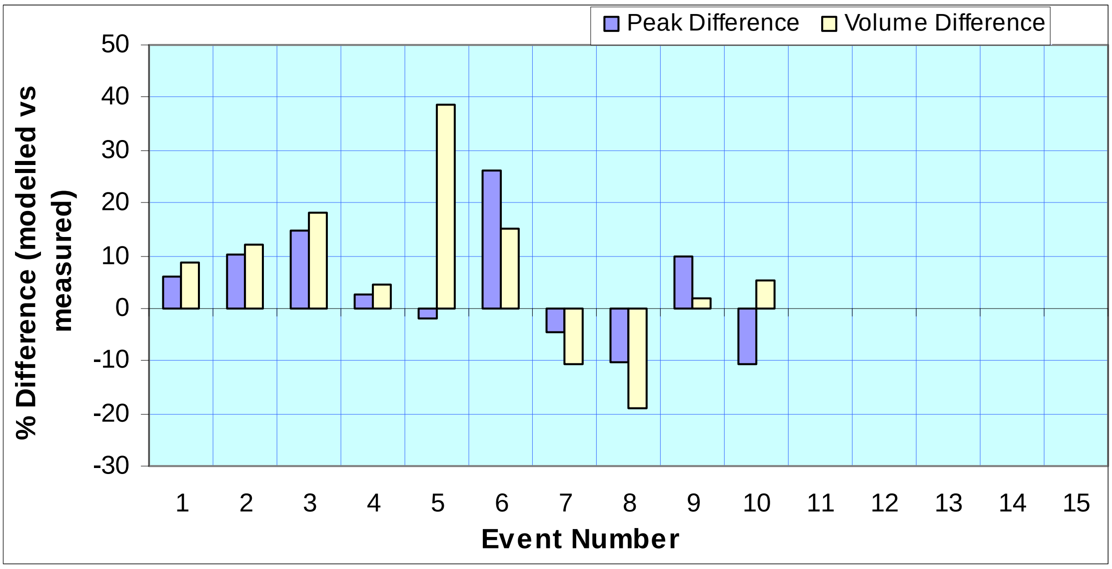


Figure 9-8: Modelled vs Measured Event Differences – Mangawhero at Raupio Rd

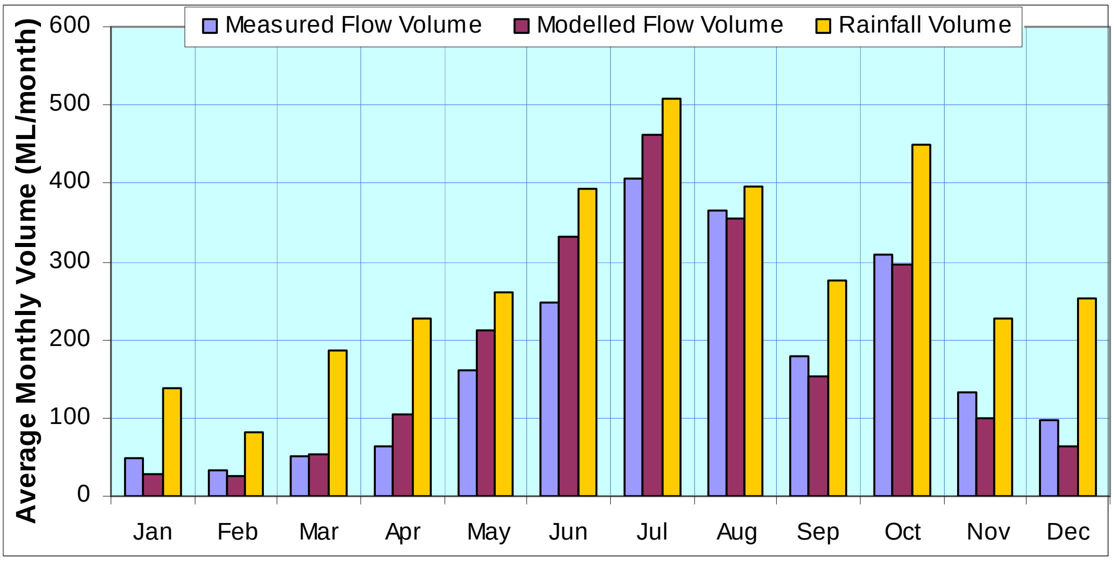


Figure 9-9: Monthly Average Volumes – Mangawhero at Raupio Rd

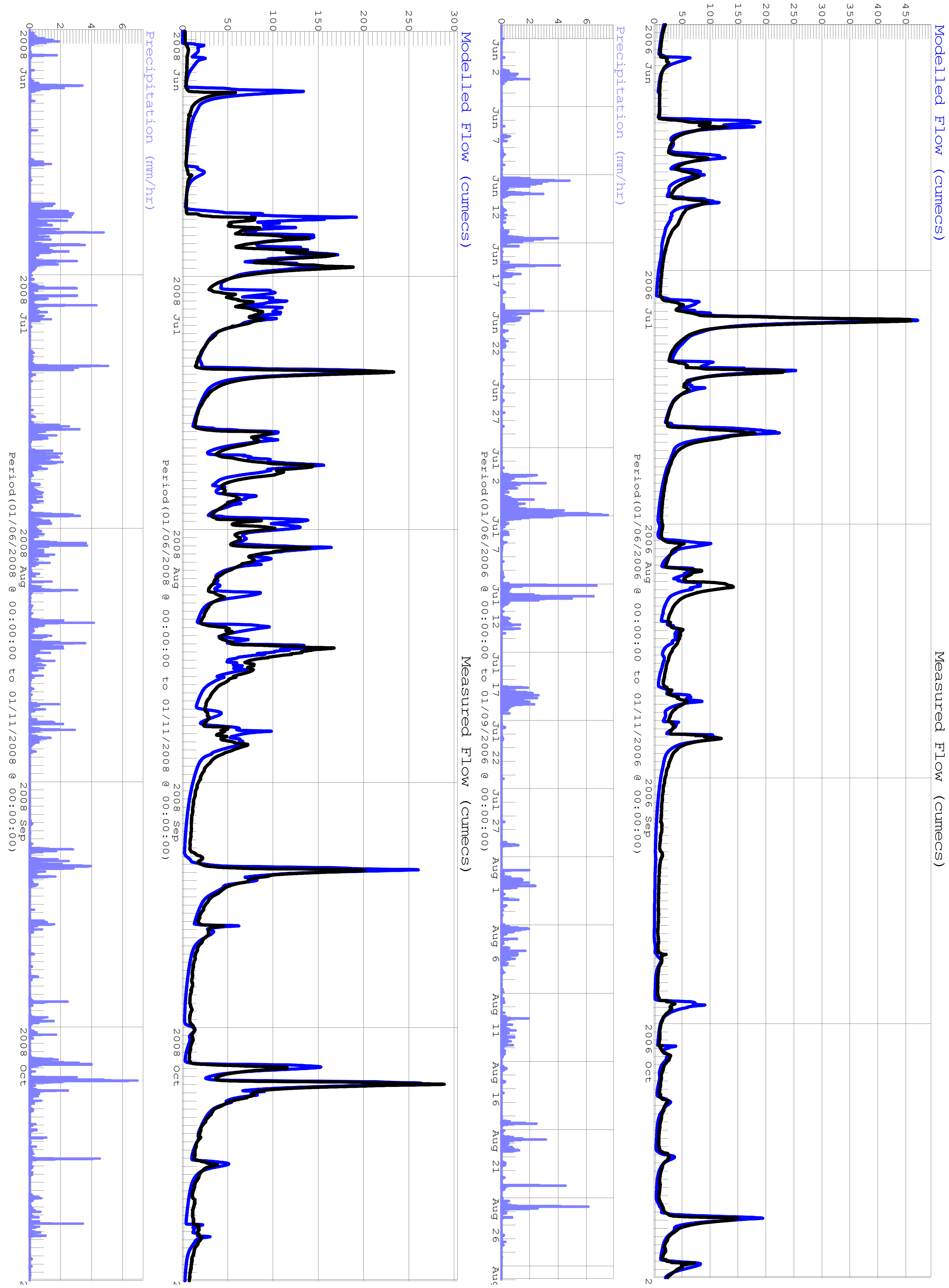


Figure 9-10: Time Series Comparison – Mangawhero at Raupio Rd

9.4 MANGAWHERO AT ORE ORE:

R Squared	0.73	a	4.09	b	0.72
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	1,825	Modelled Flow Volume (Mm3)	1,843	Event Qualifying Rate	56%

Table 9-4: Calibration Event Details – Mangawhero at Ore Ore

	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	30/04/2005 @ 00:00	06/05/2005 @ 00:00	145.50	232.63	59.89	15.33	25.19	64.29	35.00	0.44	0.72
2	03/07/2006 @ 18:00	11/07/2006 @ 00:00	425.65	382.32	-10.18	44.57	47.83	7.32	63.89	0.70	0.75
3	11/07/2006 @ 18:00	17/07/2006 @ 00:00	212.87	220.68	3.67	26.92	29.81	10.73	32.07	0.84	0.93
4	30/11/2006 @ 00:00	03/12/2006 @ 00:00	251.90	258.77	2.72	16.30	16.29	-0.07	30.50	0.53	0.53
5	17/03/2007 @ 12:00	22/03/2007 @ 00:00	176.80	207.04	17.11	11.96	15.56	30.10	22.67	0.53	0.69
6	05/07/2007 @ 06:00	09/07/2007 @ 00:00	194.92	250.45	28.48	19.06	20.78	9.02	18.98	1.00	1.09
7	17/10/2007 @ 00:00	20/10/2007 @ 00:00	290.62	215.49	-25.85	25.93	18.94	-26.94	25.97	1.00	0.73
8	11/07/2008 @ 12:00	15/07/2008 @ 00:00	221.02	214.71	-2.85	19.74	18.19	-7.86	22.57	0.87	0.81
9	04/10/2008 @ 12:00	11/10/2008 @ 00:00	308.26	268.97	-12.75	35.71	35.89	0.50	55.73	0.64	0.64
10	15/02/2004 @ 00:00	19/02/2004 @ 12:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				*18.17*			*17.42*		*0.73*	*0.77*

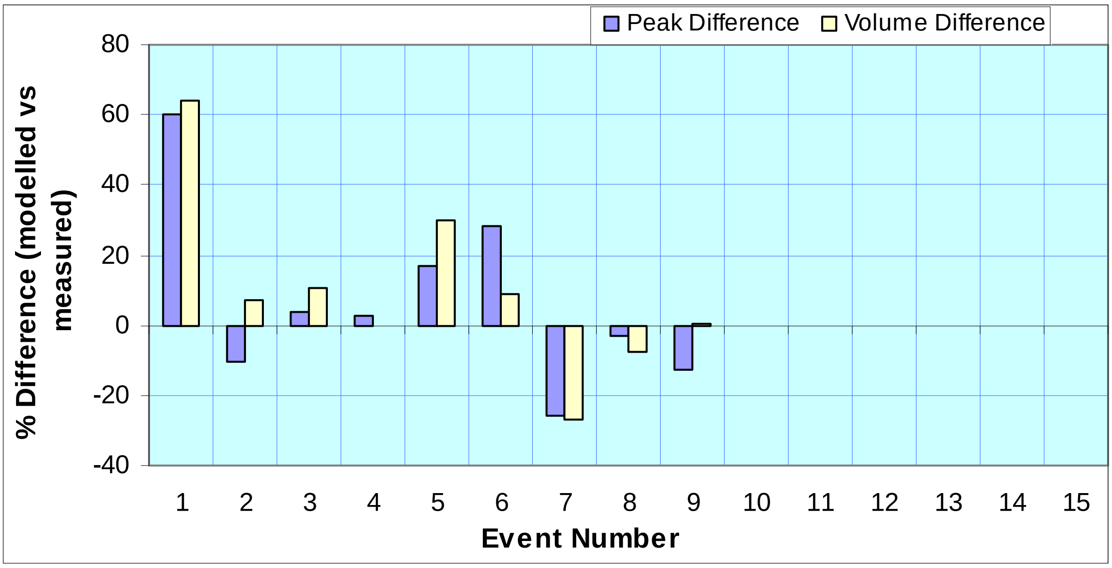


Figure 9-11: Modelled vs Measured Event Differences – Mangawhero at Ore Ore

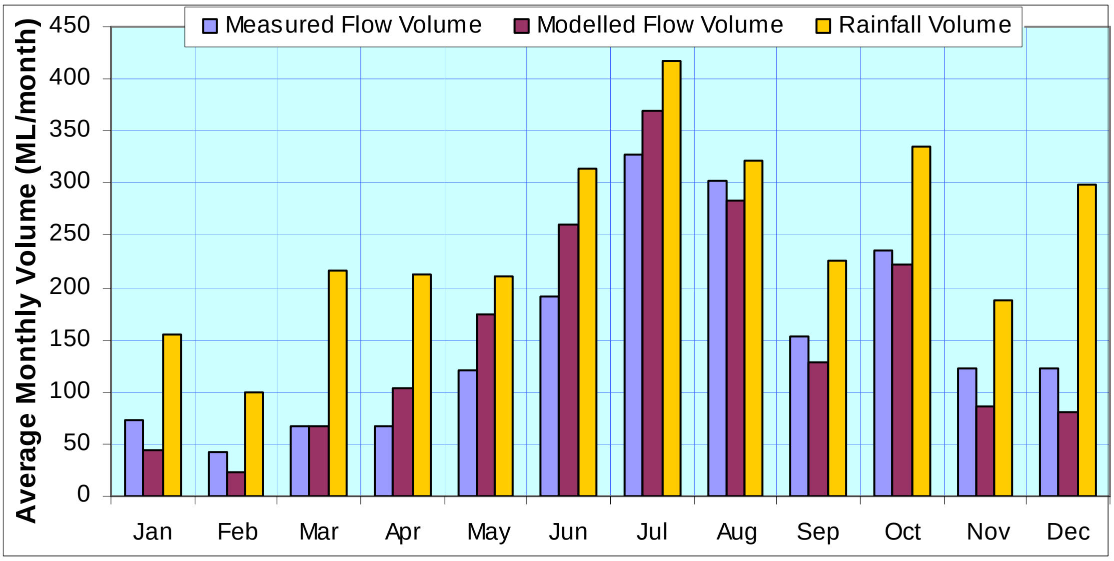


Figure 9-12: Monthly Average Volumes – Mangawhero at Ore Ore

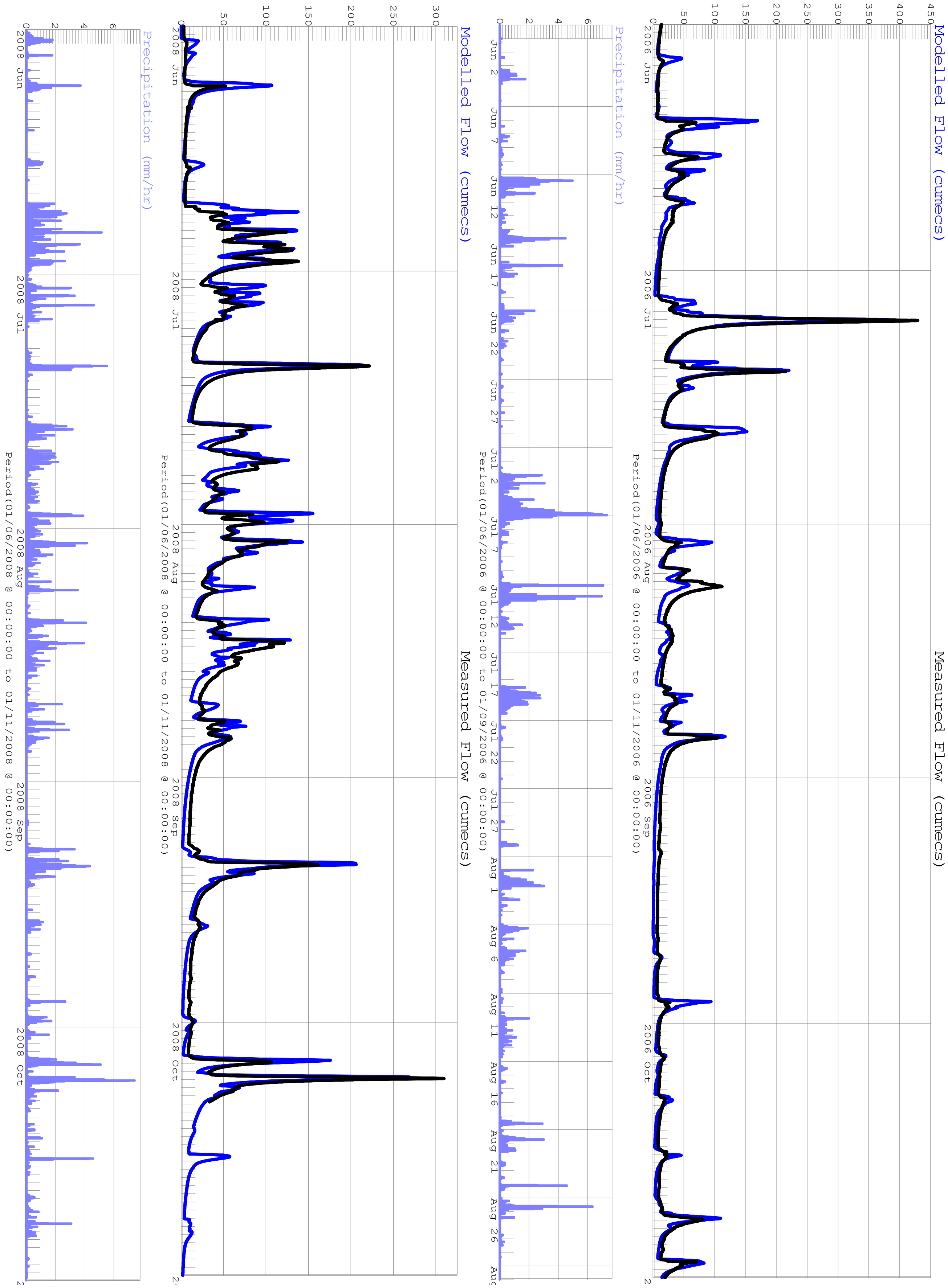


Figure 9-13: Time Series Comparison – Mangawhero at Ore Ore

10 APPENDIX B - TURAKINA RIVER CALIBRATION RESULTS

10.1 TURAKINA AT ONEILLS BRIDGE:

R Squared	0.88	a	0.73	b	0.84
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	1,060	Modelled Flow Volume (Mm3)	1,162	Event Qualifying Rate	67%

Table 10-1: Calibration Event Details – Turakina at Oneills Bridge

	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	19/10/2005 @ 12:00	25/10/2005 @ 00:00	115.78	107.86	-6.84	15.40	16.00	3.91	31.33	0.49	0.51
2	04/07/2006 @ 00:00	11/07/2006 @ 00:00	333.76	434.24	30.11	42.83	44.85	4.71	58.64	0.73	0.76
3	11/07/2006 @ 12:00	18/07/2006 @ 00:00	190.78	203.46	6.65	22.83	26.41	15.68	28.63	0.80	0.92
4	19/07/2006 @ 00:00	25/07/2006 @ 00:00	207.45	229.57	10.66	28.64	29.67	3.60	33.84	0.85	0.88
5	22/10/2006 @ 12:00	29/10/2006 @ 00:00	206.78	247.67	19.78	21.11	20.44	-3.14	42.01	0.50	0.49
6	06/11/2006 @ 06:00	13/11/2006 @ 00:00	158.38	129.24	-18.40	18.41	15.52	-15.73	41.55	0.44	0.37
7	05/07/2007 @ 00:00	11/07/2007 @ 00:00	107.56	134.58	25.12	12.44	14.88	19.56	16.59	0.75	0.90
8	11/08/2007 @ 00:00	16/08/2007 @ 12:00	115.91	118.85	2.53	16.47	16.15	-1.95	16.47	1.00	0.98
9	13/10/2007 @ 18:00	24/10/2007 @ 00:00	182.07	135.97	-25.32	28.72	25.91	-9.80	42.56	0.67	0.61
10	23/06/2008 @ 00:00	02/07/2008 @ 12:00	185.56	129.73	-30.09	42.55	36.13	-15.08	60.59	0.70	0.60
11	14/08/2008 @ 00:00	22/08/2008 @ 00:00	110.45	103.67	-6.14	27.82	29.01	4.29	35.56	0.78	0.82
12	04/10/2008 @ 00:00	14/10/2008 @ 00:00	115.11	91.04	-20.91	23.60	22.13	-6.23	45.31	0.52	0.49
13	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				*16.88*			*8.64*		*0.69*	*0.69*

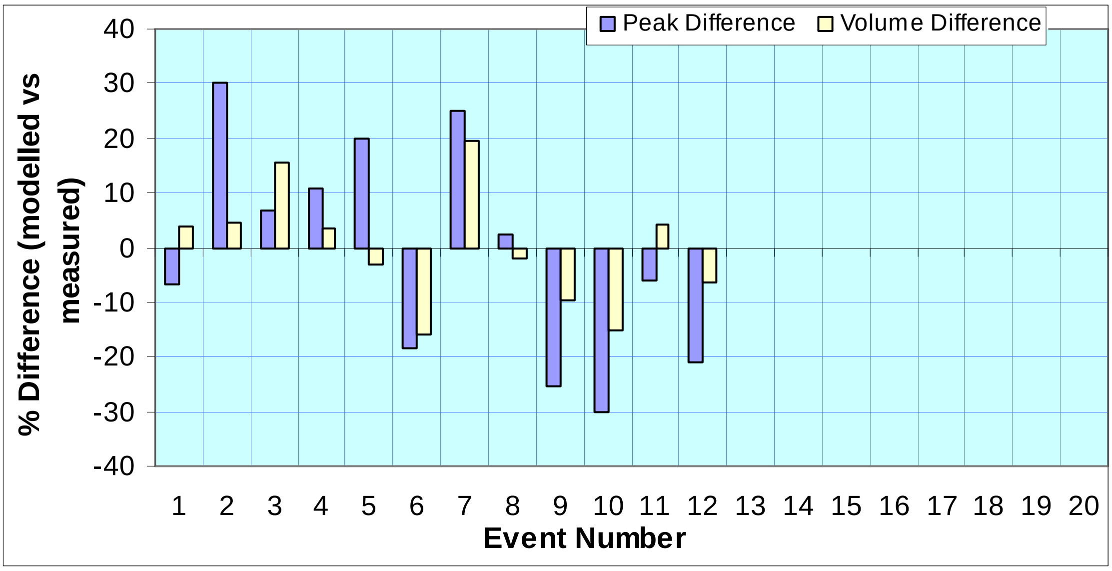


Figure 10-1: Modelled vs Measured Event Differences – Turakina at Oneills Bridge

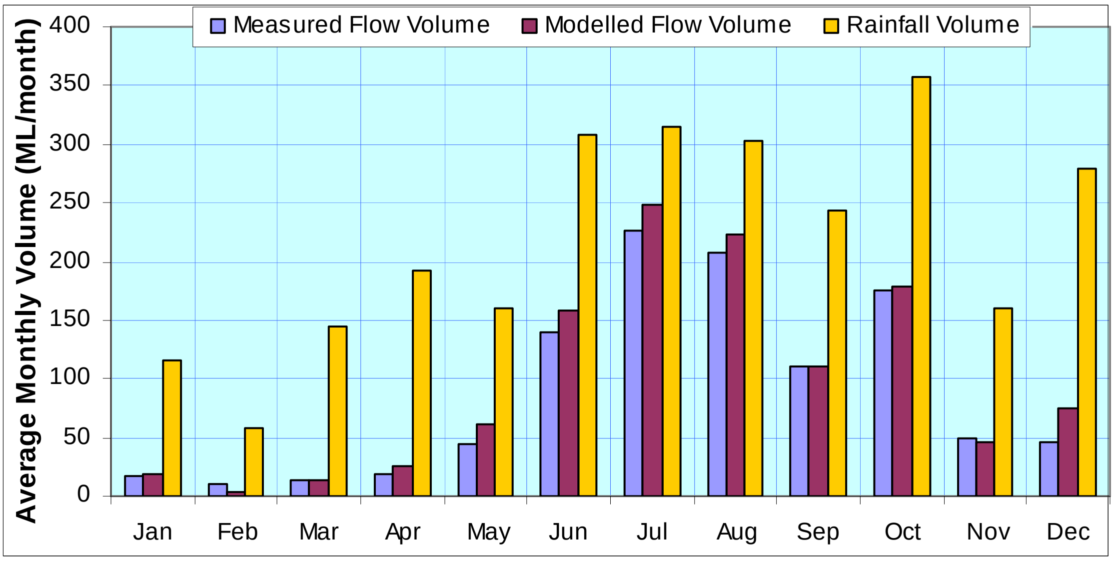


Figure 10-2: Monthly Average Volumes – Turakina at Oneills Bridge

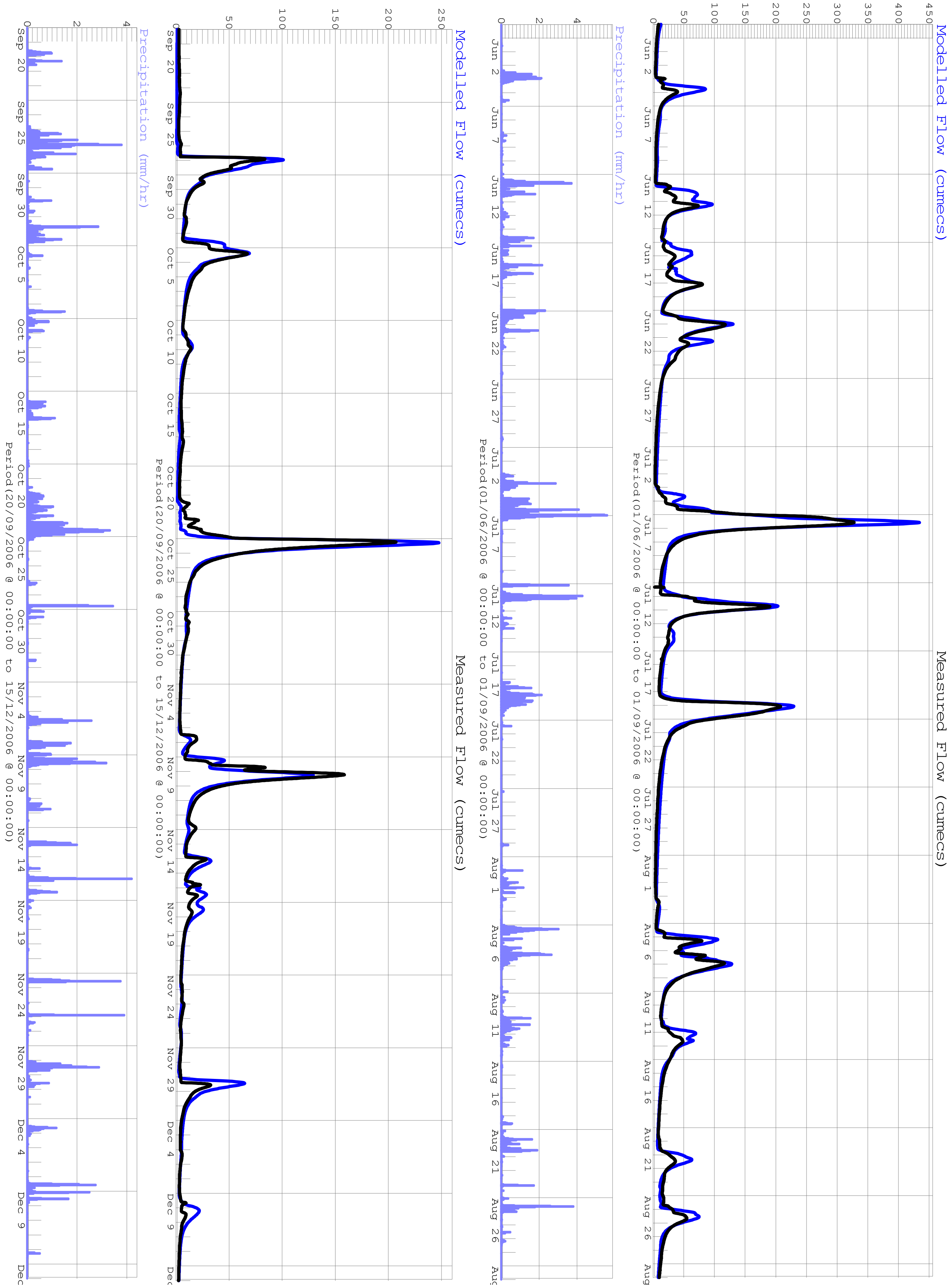


Figure 10-3: Time Series Comparison – Turakina at Oneills Bridge (1)

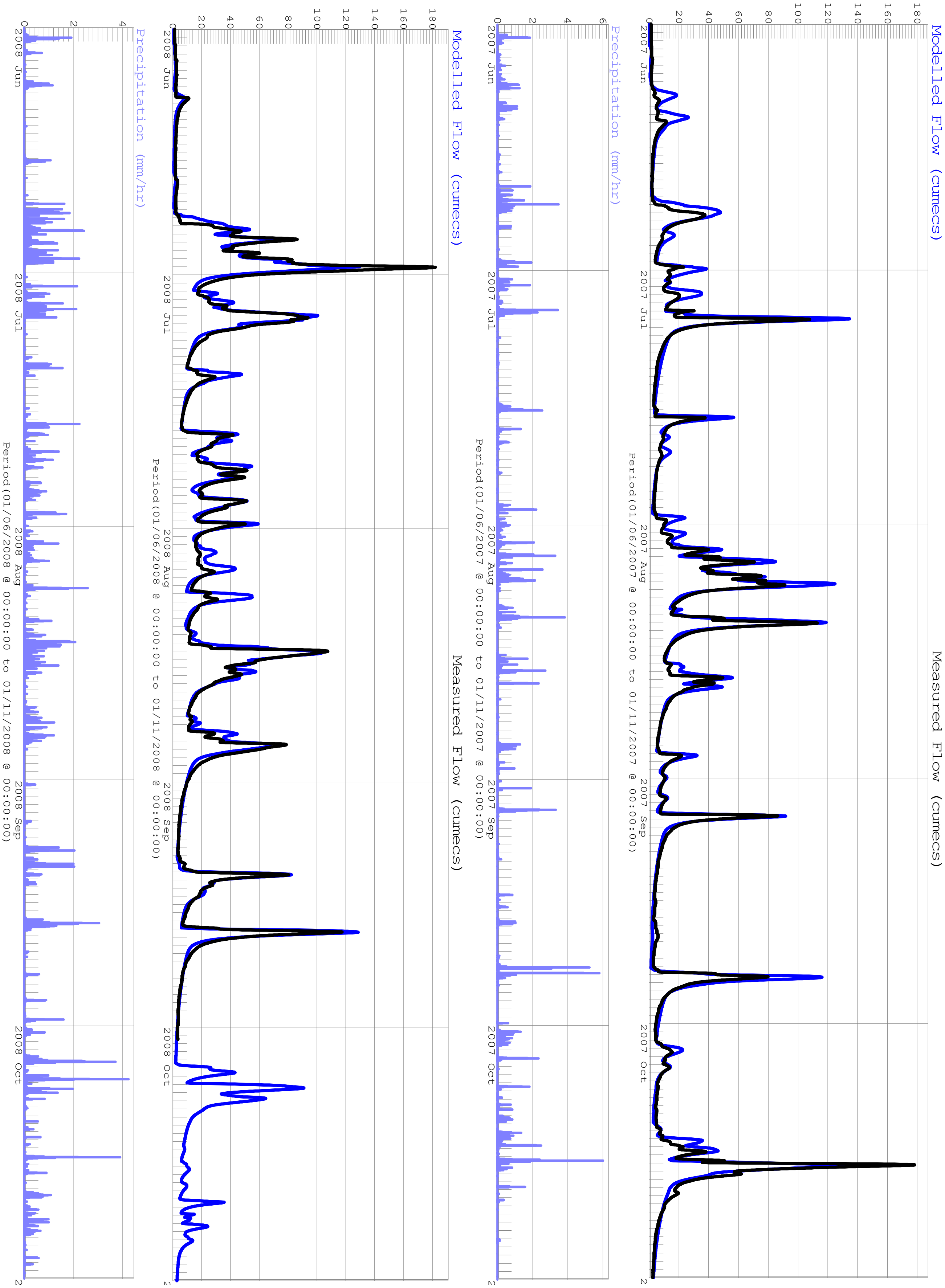


Figure 10-4: Time Series Comparison – Turakina at Oneills Bridge (2)

10.2 TURAKINA AT OTAIRI:

R Squared	0.78	a	0.63	b	0.84
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	775	Modelled Flow Volume (Mm3)	832	Event Qualifying Rate	73%

Table 10-2: Calibration Event Details – Turakina at Otairi

	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	19/10/2005 @ 12:00	25/10/2005 @ 00:00	96.05	78.74	-18.03	11.18	9.86	-11.74	15.66	0.71	0.63
2	04/07/2006 @ 00:00	11/07/2006 @ 00:00	297.43	351.89	18.31	26.58	30.72	15.57	32.78	0.81	0.94
3	11/07/2006 @ 12:00	18/07/2006 @ 00:00	157.14	156.66	-0.31	15.72	17.29	10.01	15.81	0.99	1.09
4	19/07/2006 @ 00:00	25/07/2006 @ 00:00	140.68	154.17	9.59	21.32	21.69	1.78	22.18	0.96	0.98
5	22/10/2006 @ 12:00	29/10/2006 @ 00:00	166.97	196.91	17.93	13.69	15.73	14.94	24.08	0.57	0.65
6	06/11/2006 @ 06:00	13/11/2006 @ 00:00	144.96	116.85	-19.39	13.83	13.47	-2.63	26.49	0.52	0.51
7	05/07/2007 @ 00:00	11/07/2007 @ 00:00	103.04	130.91	27.05	9.26	12.15	31.17	11.34	0.82	1.07
8	11/08/2007 @ 00:00	16/08/2007 @ 12:00	99.76	93.51	-6.27	11.67	11.20	-4.05	9.46	1.23	1.18
9	13/10/2007 @ 18:00	24/10/2007 @ 00:00	166.46	121.64	-26.93	21.08	18.80	-10.82	24.25	0.87	0.78
10	23/06/2008 @ 00:00	02/07/2008 @ 12:00	150.58	72.95	-51.55	32.04	24.70	-22.91	33.35	0.96	0.74
11	14/08/2008 @ 00:00	22/08/2008 @ 00:00	88.45	76.03	-14.05	20.91	19.20	-8.16	19.95	1.05	0.96
12	04/10/2008 @ 00:00	14/10/2008 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				*19.04*			*12.16*		*0.86*	*0.87*

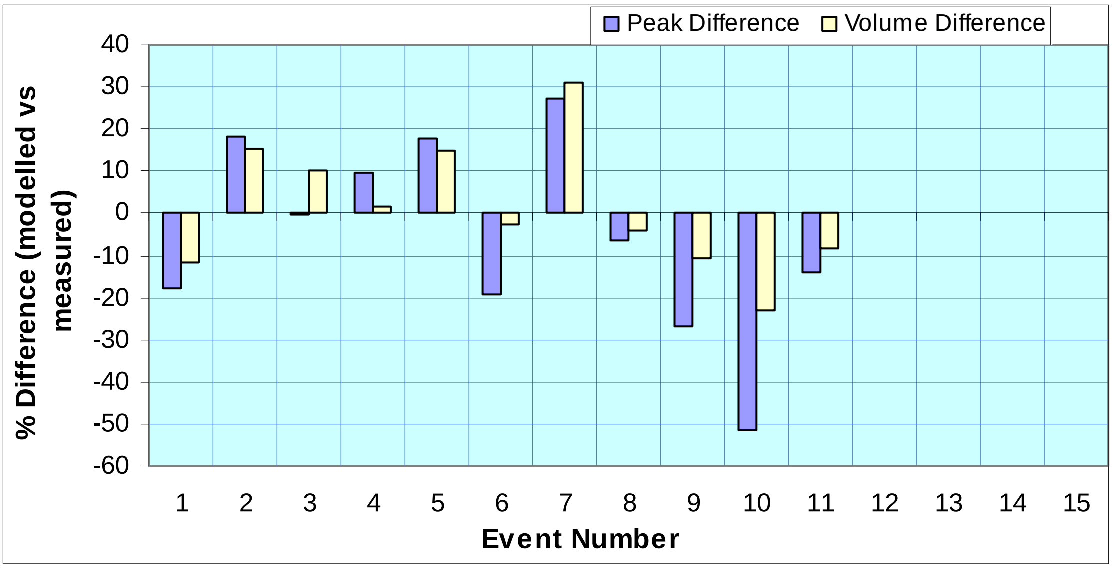


Figure 10-5: Modelled vs Measured Event Differences – Turakina at Otairi

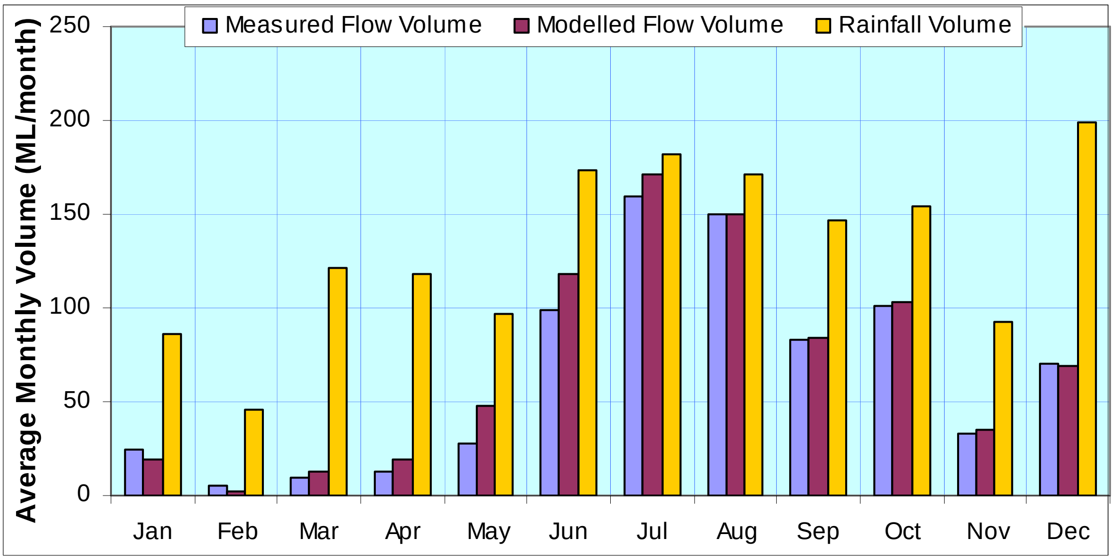


Figure 10-6: Monthly Average Volumes – Turakina at Otairi

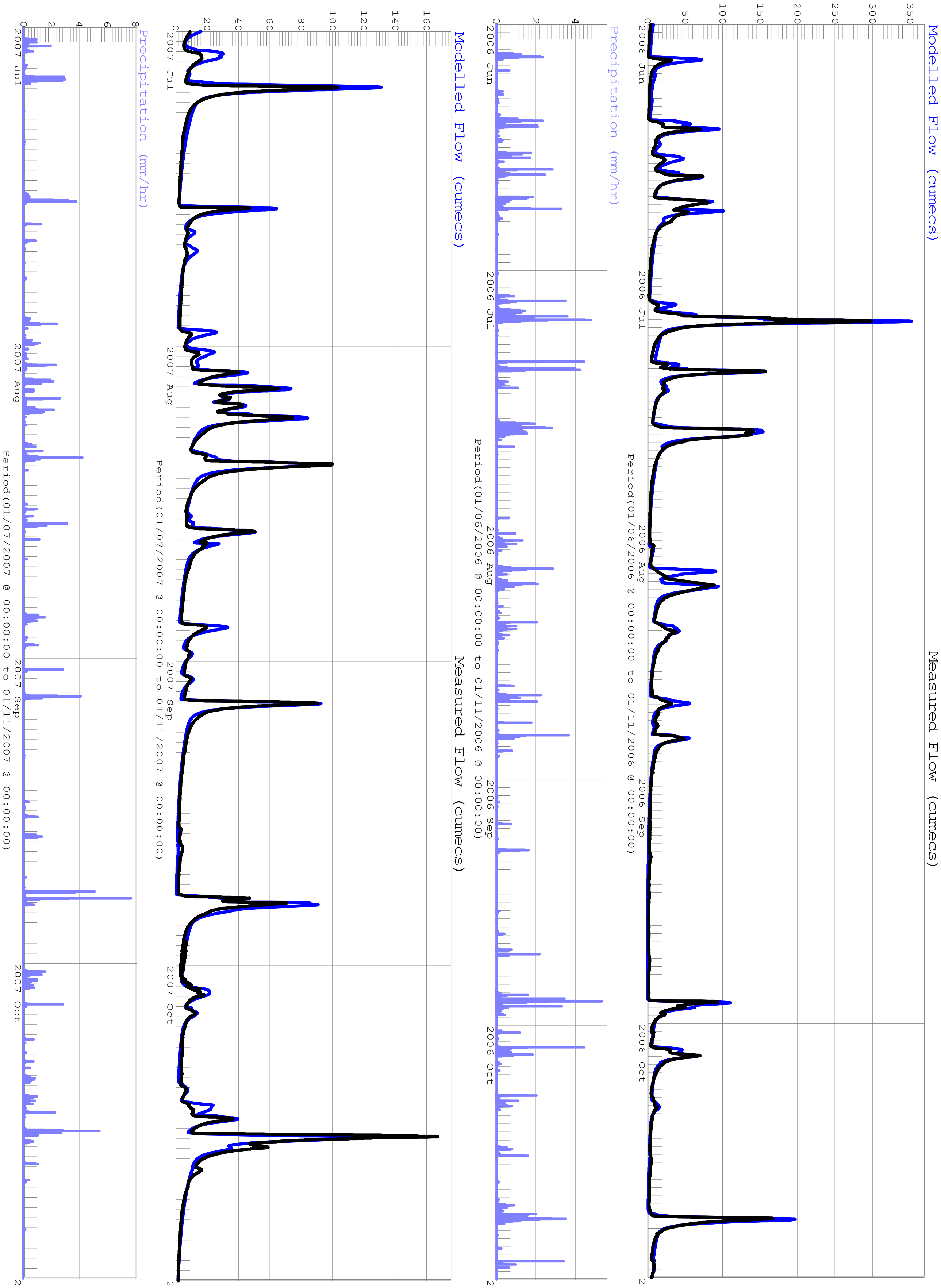


Figure 10-7: Time Series Comparison – Turakina at Otairi

11 APPENDIX C - RANGITIKEI RIVER CALIBRATION RESULTS

11.1 RANGITIKEI AT MANGAWEKA:

R Squared	0.90	a	3.17	b	0.88
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	8,759	Modelled Flow Volume (Mm3)	9,531	Event Qualifying Rate	83%

Table 11-1: Calibration Event Details – Rangitikei at Mangaweka

	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	19/10/2005 @ 12:00	28/10/2005 @ 00:00	544.59	437.35	-19.69	107.97	108.60	0.58	122.92	0.88	0.88
2	28/04/2006 @ 06:00	05/05/2006 @ 00:00	711.69	675.59	-5.07	157.75	171.34	8.61	173.33	0.91	0.99
3	03/06/2006 @ 18:00	11/07/2006 @ 18:00	834.34	893.61	7.10	449.65	511.98	13.86	516.64	0.87	0.99
4	11/07/2006 @ 18:00	19/07/2006 @ 00:00	557.13	598.10	7.35	151.41	162.95	7.62	106.86	1.42	1.52
5	19/07/2006 @ 00:00	28/07/2006 @ 00:00	524.14	588.88	12.35	159.34	178.38	11.94	137.22	1.16	1.30
6	30/11/2006 @ 00:00	03/12/2006 @ 00:00	514.50	320.01	-37.80	34.60	33.82	-2.23	77.96	0.44	0.43
7	05/07/2007 @ 00:00	10/07/2007 @ 00:00	531.01	510.36	-3.89	79.43	75.80	-4.58	78.49	1.01	0.97
8	17/10/2007 @ 00:00	22/10/2007 @ 00:00	475.31	527.38	10.95	91.50	85.32	-6.75	85.73	1.07	1.00
9	14/04/2008 @ 12:00	20/04/2008 @ 00:00	536.38	457.94	-14.62	46.51	49.77	6.99	241.96	0.19	0.21
10	12/07/2008 @ 00:00	16/07/2008 @ 00:00	611.95	497.75	-18.66	71.84	65.27	-9.14	42.03	1.71	1.55
11	29/07/2008 @ 18:00	02/08/2008 @ 18:00	1232.52	1325.59	7.55	172.01	164.86	-4.16	145.35	1.18	1.13
12	06/10/2008 @ 00:00	10/10/2008 @ 12:00	700.94	514.77	-26.56	71.43	76.78	7.49	105.30	0.68	0.73
13	15/02/2004 @ 00:00	19/02/2004 @ 12:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				***14.30***			***7.00***		***0.96***	***0.98***

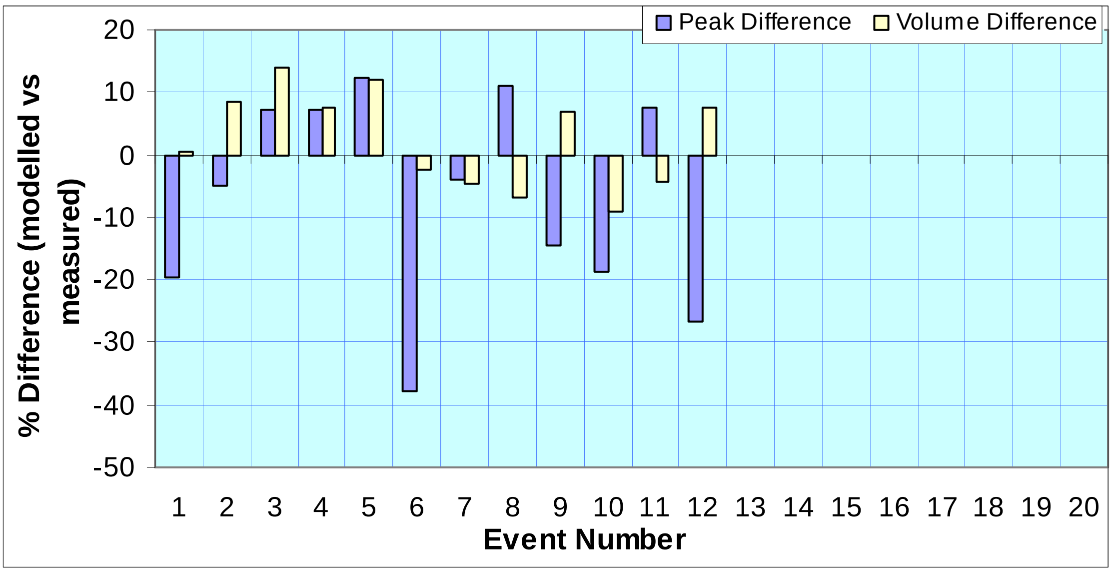


Figure 11-1: Modelled vs Measured Event Differences – Rangitikei at Mangaweka

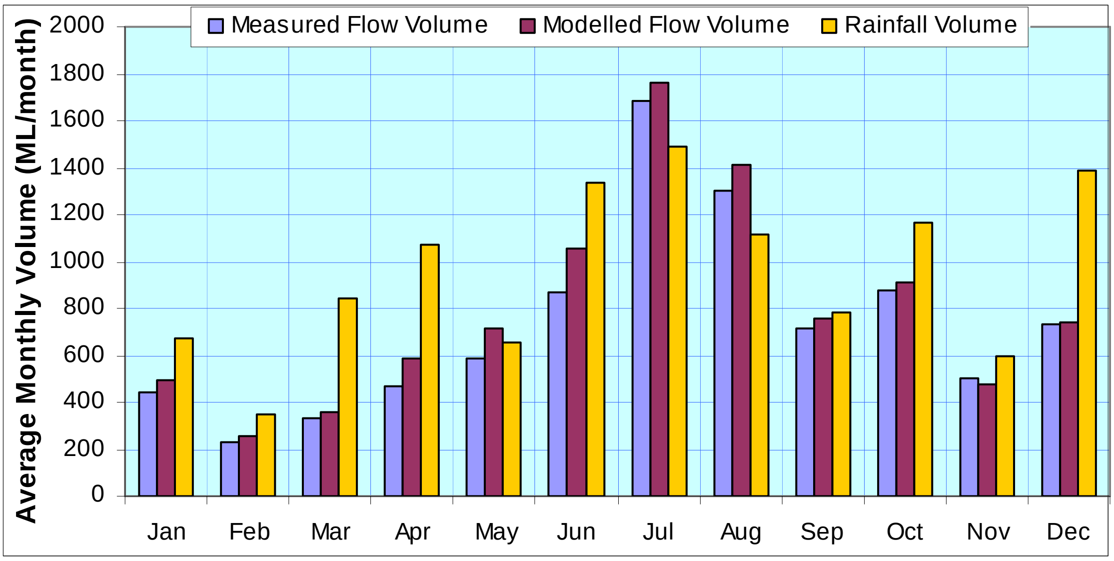


Figure 11-2: Monthly Average Volumes – Rangitikei at Mangaweka

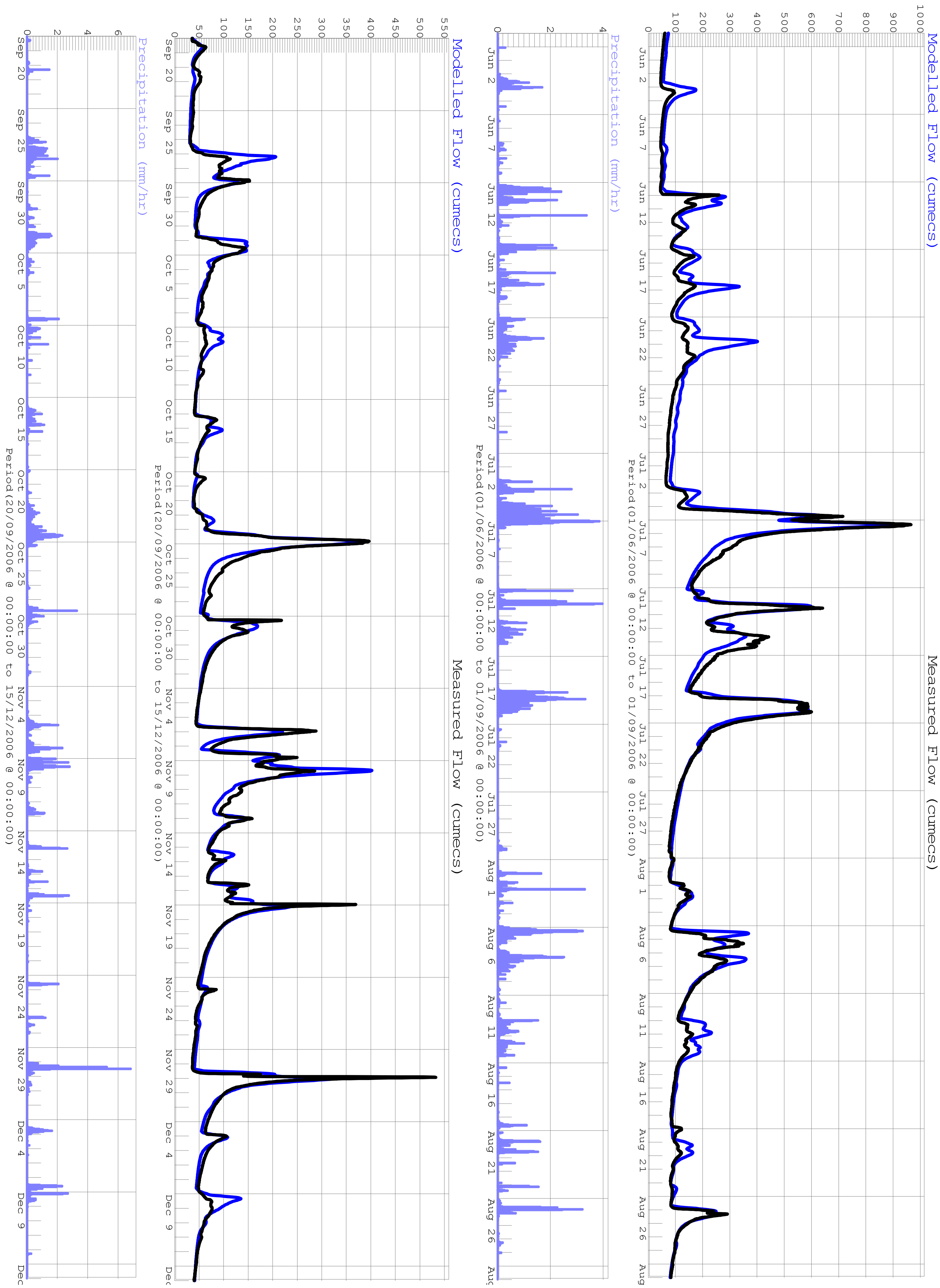


Figure 11-3: Time Series Comparison – Rangitikei at Mangaweka (1)

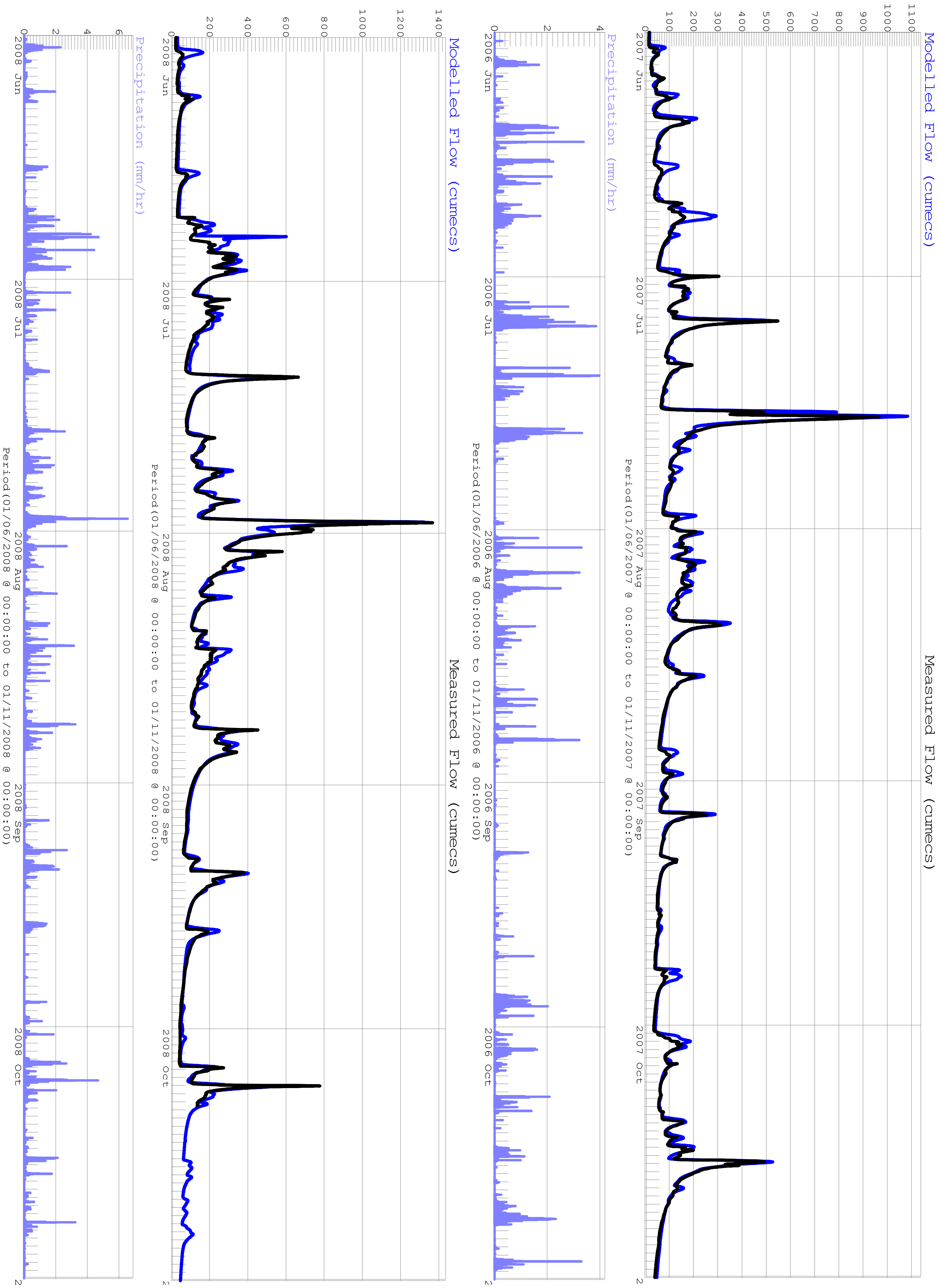


Figure 11-4: Time Series Comparison – Rangitikei at Mangaweka (2)

11.2 RANGITIKEI AT PUKEOKAHU:

R Squared	0.67	a	6.25	b	0.58
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	2,782	Modelled Flow Volume (Mm3)	3,526	Event Qualifying Rate	11%

Table 11-2: Calibration Event Details – Rangitikei at Pukeokahu

	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	12/06/2006 @ 00:00	15/06/2006 @ 00:00	252.73	187.46	-25.83	14.16	21.73	53.47	29.47	0.48	0.74
2	12/07/2006 @ 00:00	14/07/2006 @ 18:00	310.26	261.46	-15.73	27.52	23.64	-14.09	23.34	1.18	1.01
3	16/11/2006 @ 12:00	22/11/2006 @ 00:00	256.36	108.37	-57.73	28.88	18.15	-37.14	18.86	1.53	0.96
4	30/11/2006 @ 00:00	03/12/2006 @ 00:00	341.79	122.24	-64.24	14.91	10.32	-30.83	26.69	0.56	0.39
5	14/04/2008 @ 00:00	17/04/2008 @ 12:00	316.69	608.34	92.09	11.87	31.90	168.68	83.77	0.14	0.38
6	11/07/2008 @ 00:00	16/07/2008 @ 00:00	371.97	238.02	-36.01	36.81	31.54	-14.32	24.86	1.48	1.27
7	27/07/2008 @ 12:00	02/08/2008 @ 12:00	374.59	459.59	22.69	72.15	73.73	2.20	62.39	1.16	1.18
8	02/08/2008 @ 12:00	05/08/2008 @ 00:00	314.15	213.34	-32.09	32.89	30.71	-6.63	18.78	1.75	1.64
9	04/10/2008 @ 18:00	11/10/2008 @ 00:00	449.19	316.68	-29.50	33.54	39.22	16.92	56.44	0.59	0.69
10	28/02/2004 @ 00:00	05/03/2004 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				***41.77***			***38.25***		***0.99***	***0.92***

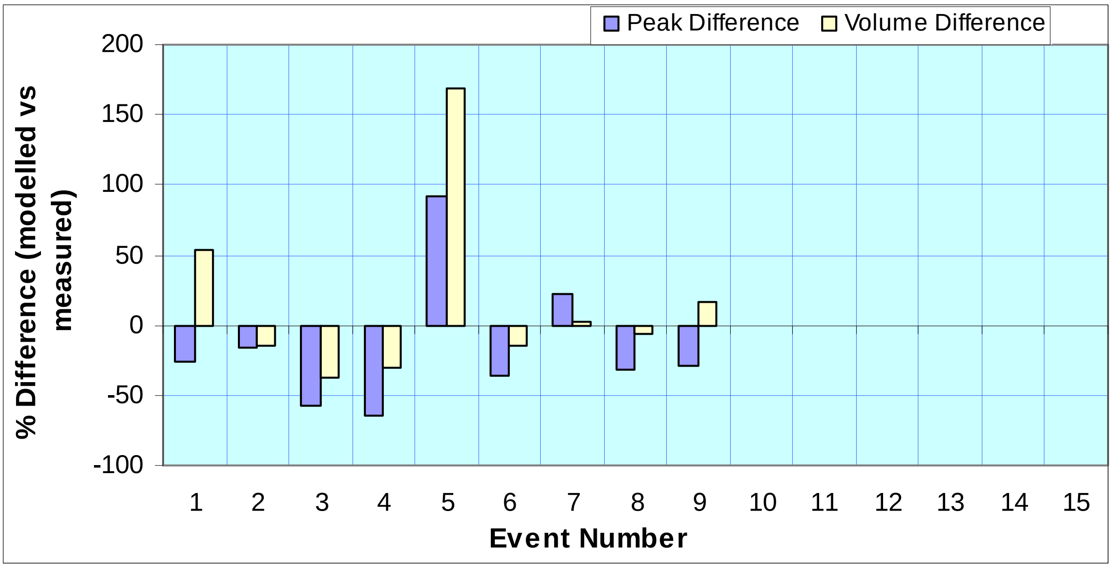


Figure 11-5: Modelled vs Measured Event Differences –Rangitikei at Pukeokahu

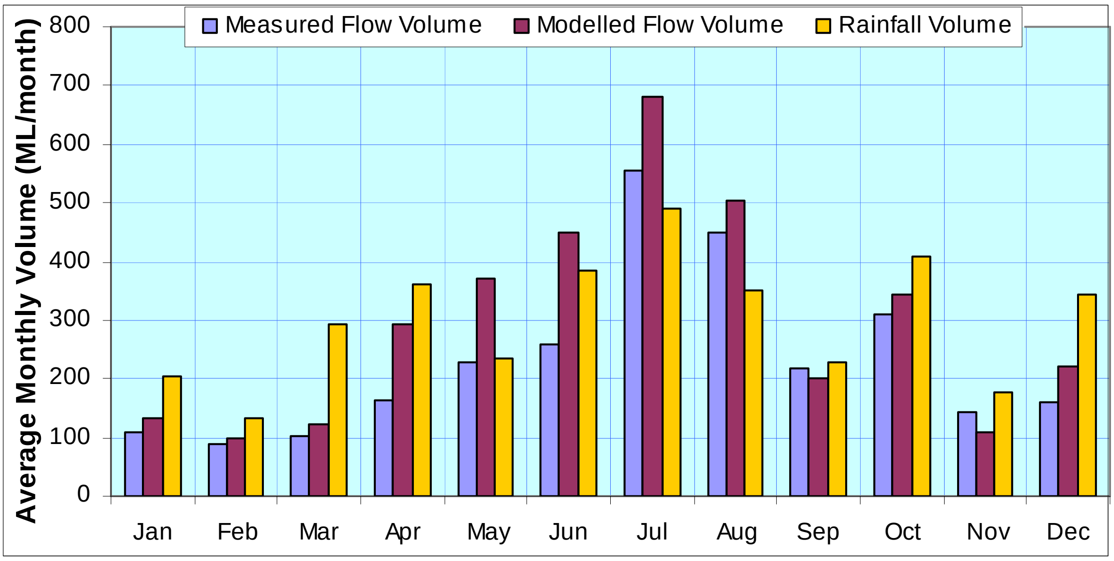


Figure 11-6: Monthly Average Volumes –Rangitikei at Pukeokahu

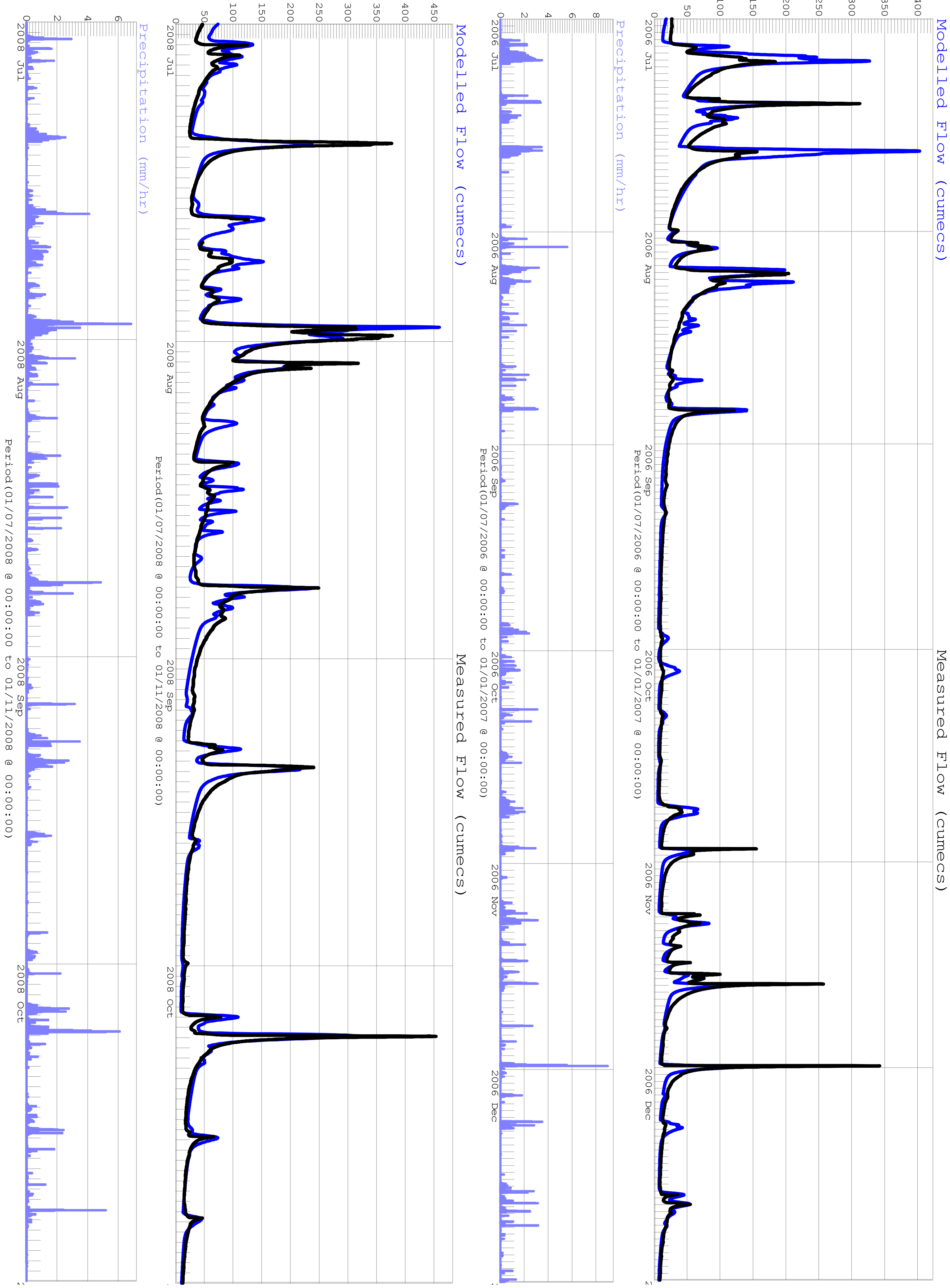


Figure 11-7: Time Series Comparison – Rangitikei at Pukeokahu

11.3 HAUTAPU AT ALABASTERS:

R Squared	0.78	a	0.61	b	0.83
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	636	Modelled Flow Volume (Mm3)	674	Event Qualifying Rate	38%

Table 11-3: Calibration Event Details – Hautapu at Alabasters

	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	03/07/2006 @ 12:00	12/07/2006 @ 00:00	123.25	125.76	2.04	24.84	22.20	-10.61	19.63	1.27	1.13
2	12/07/2006 @ 00:00	19/07/2006 @ 00:00	74.19	38.21	-48.50	13.86	13.04	-5.87	9.31	1.49	1.40
3	19/07/2006 @ 00:00	27/07/2006 @ 00:00	64.94	73.93	13.85	19.68	19.13	-2.81	13.05	1.51	1.47
4	08/11/2006 @ 00:00	15/11/2006 @ 00:00	39.55	16.54	-58.19	6.59	5.64	-14.42	13.37	0.49	0.42
5	05/07/2007 @ 12:00	11/07/2007 @ 00:00	39.43	49.66	25.92	6.81	11.40	67.51	8.38	0.81	1.36
6	17/10/2007 @ 00:00	22/10/2007 @ 00:00	81.88	32.57	-60.22	15.63	8.88	-43.19	10.60	1.47	0.84
7	23/06/2008 @ 00:00	11/07/2008 @ 00:00	63.32	81.30	28.40	36.30	47.96	32.12	39.46	0.92	1.22
8	30/07/2008 @ 00:00	08/08/2008 @ 00:00	41.24	35.23	-14.57	16.31	17.36	6.41	13.74	1.19	1.26
9	15/02/2004 @ 00:00	19/02/2004 @ 12:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	01/01/2100 @ 00:00	01/01/2100 @ 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average				***22.88***			***16.63***		***0.83***	***0.83***

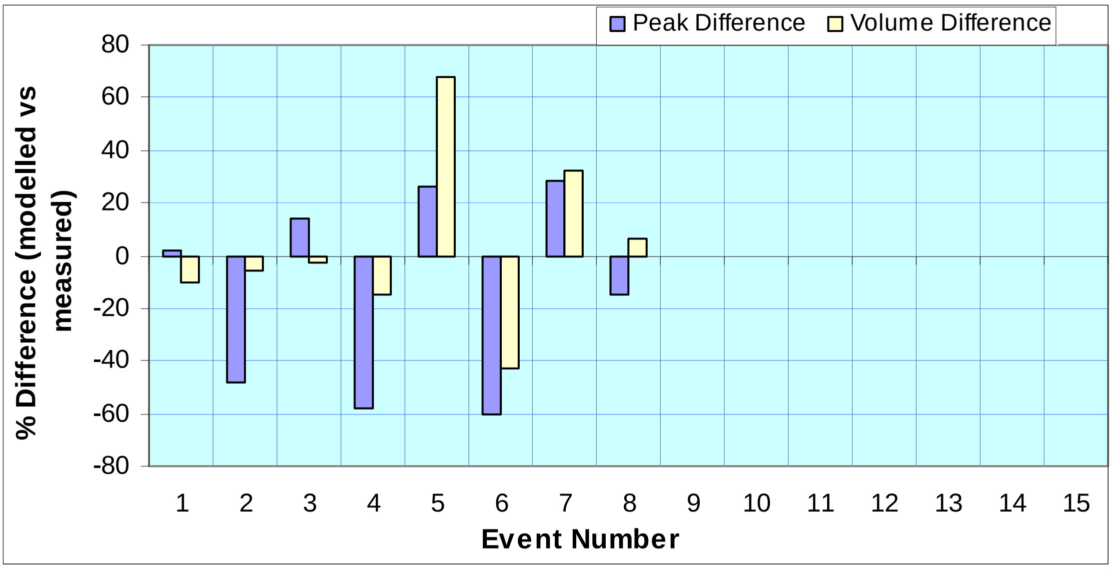


Figure 11-8: Modelled vs Measured Event Differences – Hautapu at Alabasters

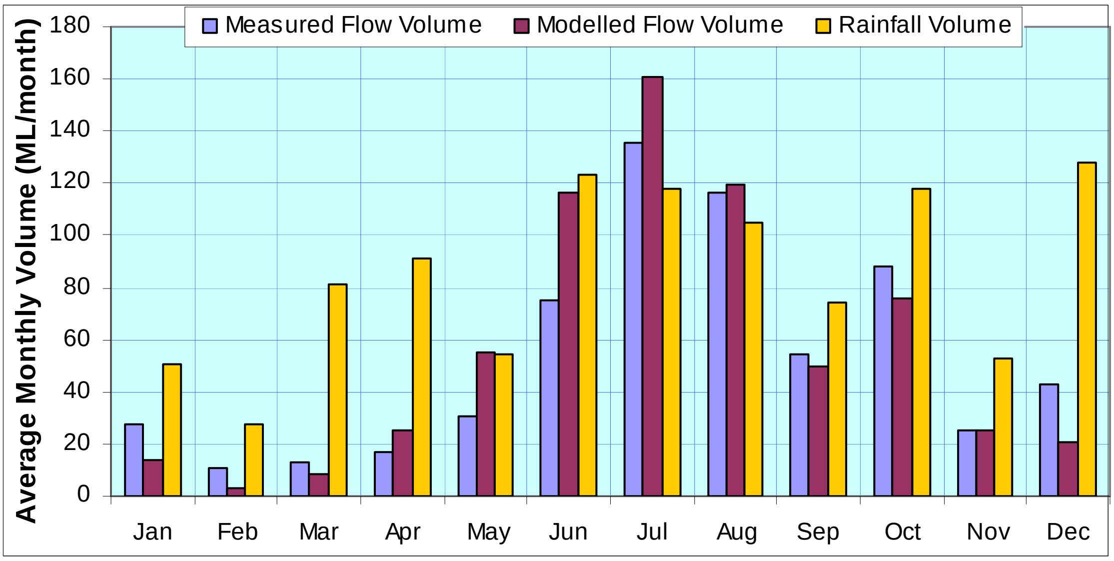


Figure 11-9: Monthly Average Volumes – Hautapu at Alabasters

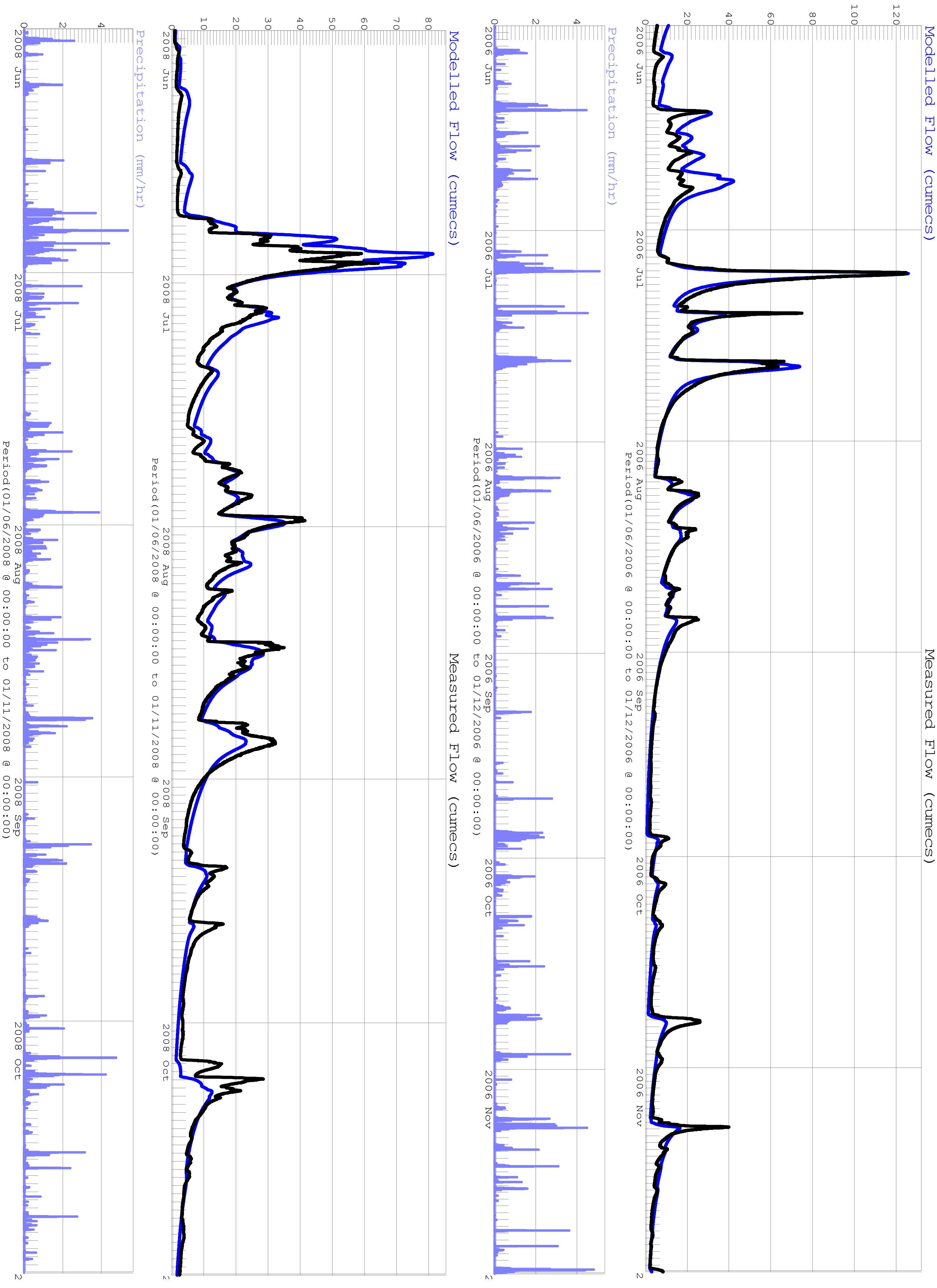


Figure 11-10: Time Series Comparison – Hautapu at Alabasters

11.4 MOAWHANGO AT MOAWHANGO:

R Squared	0.48	a	0.05	b	0.94
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	786	**Modelled Flow Volume (Mm3)**	827	**Event Qualifying Rate**	N/A

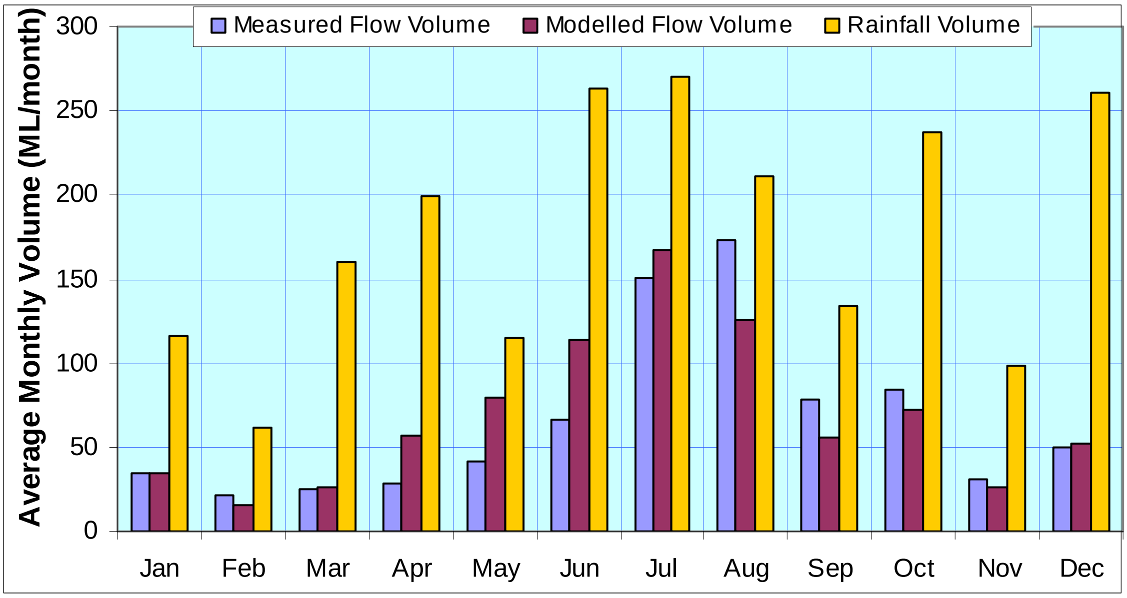


Figure 11-11: Monthly Average Volumes – Moawhango at Moawhango

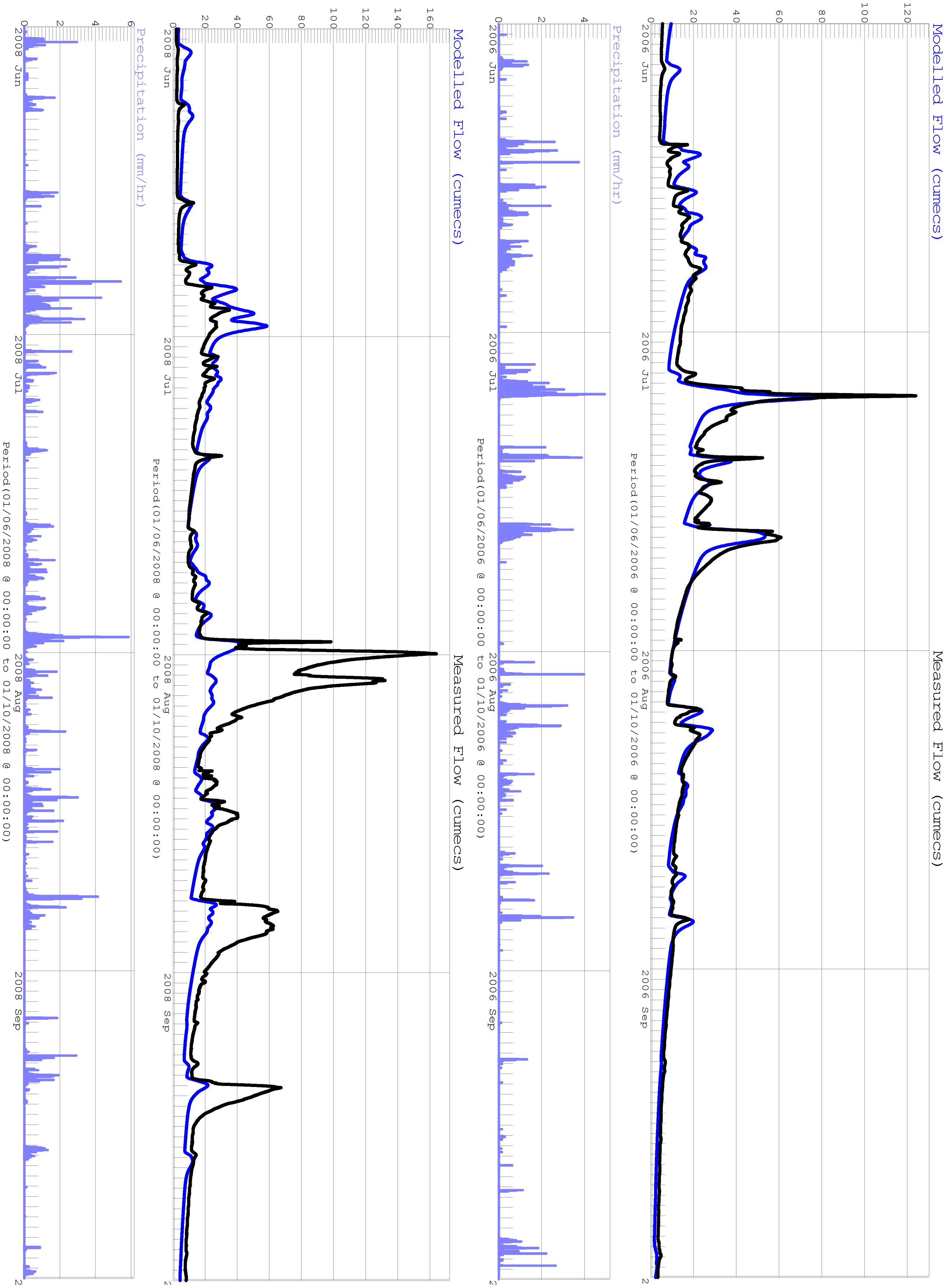


Figure 11-12: Time Series Comparison – Moawhango at Moawhango

11.5 MAKOHINE AT VIADUCT:

R Squared	0.64	a	0.23	b	0.75
Where Line of best fit = a + bX					
Measured Flow Volume (Mm3)	126	**Modelled Flow Volume (Mm3)**	134	**Event Qualifying Rate**	N/A

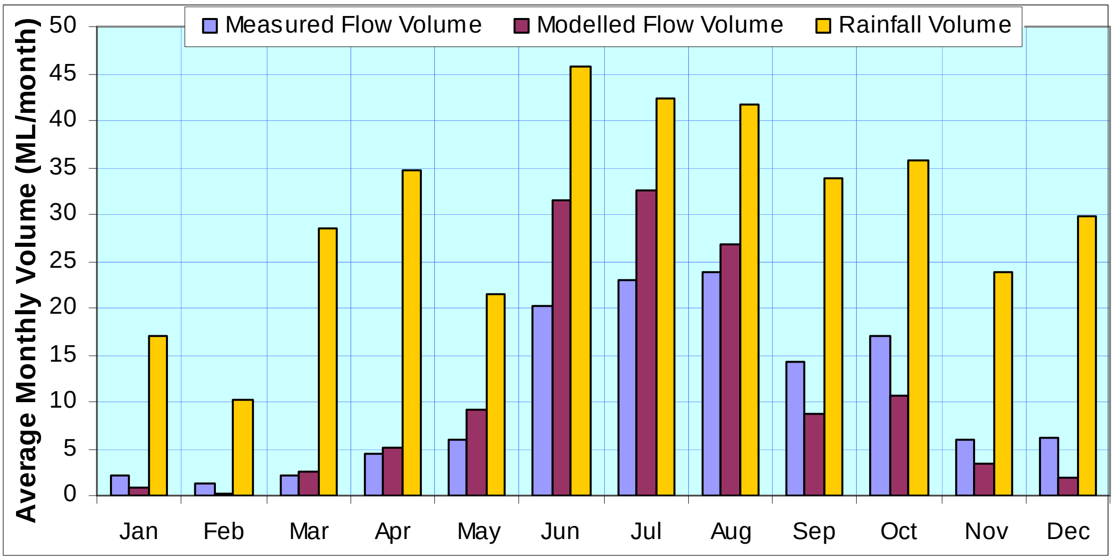


Figure 11-13: Monthly Average Volumes – Makohine at Viaduct

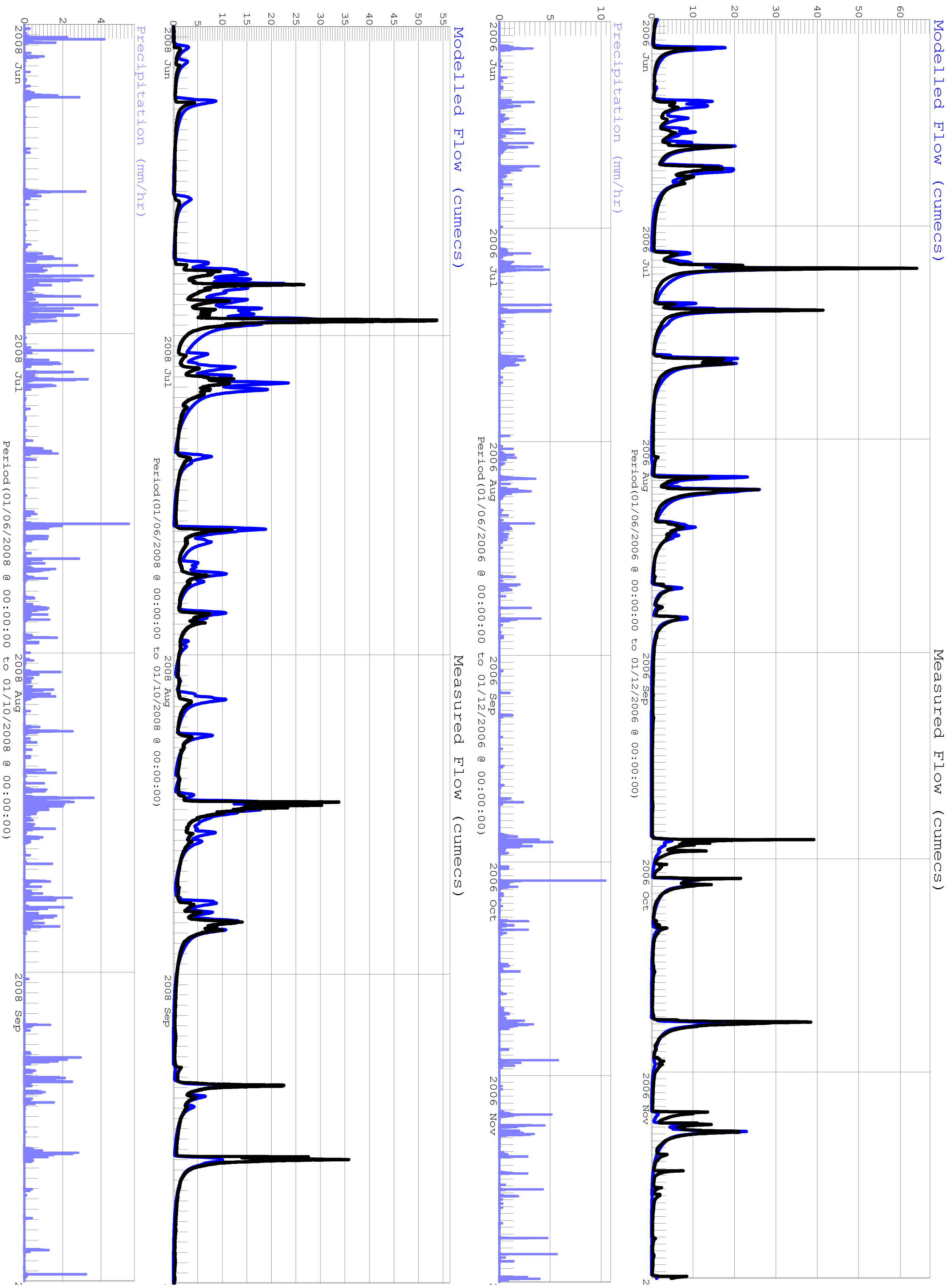


Figure 11-14: Time Series Comparison – Makohine at Viaduct

11.6 RANGITIKEI AT ONEPUHI

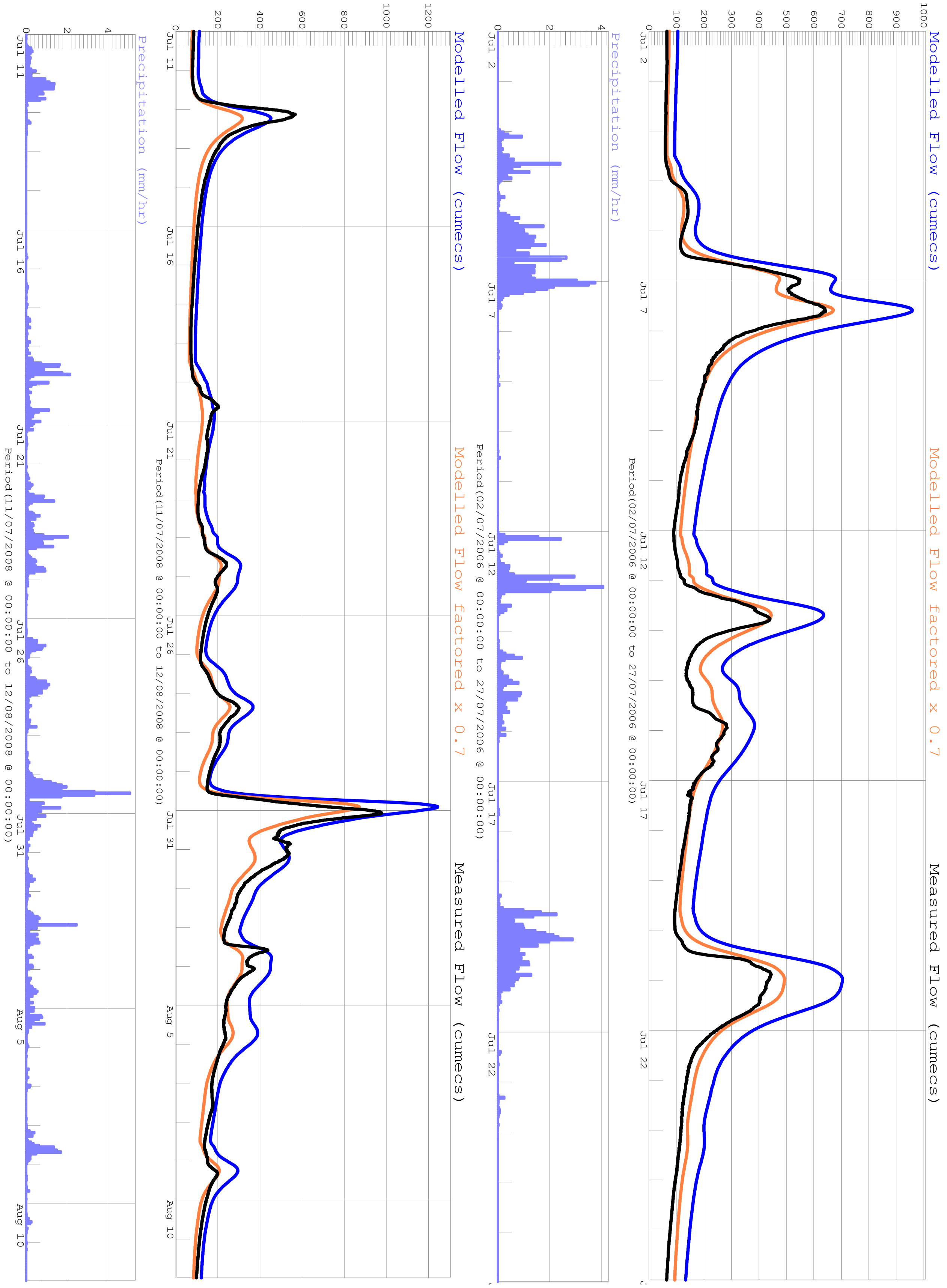


Figure 11-15: Time Series Comparison – Rangitikei at Onepuhi

12 APPENDIX D - WHANGANUI RECALIBRATION

During the 2008 winter the Whanganui flood model was showing consistent signs of under-estimating the measured floods. This prompted a model re-calibration.

It was found during the re-calibration that a model rainfall parameter "Interpolation Threshold" was causing the issue. This threshold defines a quantity of hourly rainfall that must be exceeded at nearby gauges before assuming that any missing data points at a SCADA event-based rainfall gauge are actually missing and not just a period of no rain (due to the event-based polling of that data). This value was set to 5mm/hr which is significant enough to cause the reduction in modelled flow events shown in the red trace in Figure 12-1 below. This value was reduced significantly to 0.5 mm/hr and the improvement can be seen in the blue modelled trace.

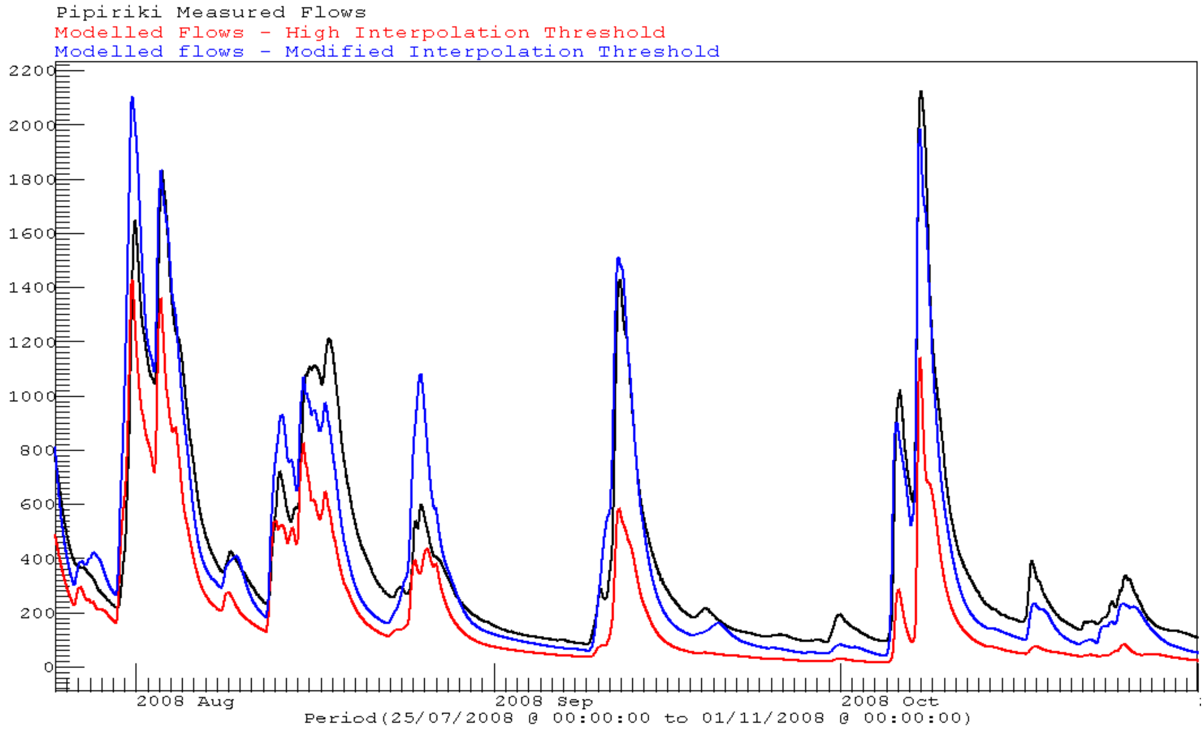


Figure 12-1: Impact of "Interpolation Thresold" Model Parameter on Model Performance during 2008 winter

A re-calibration was still undertaken for the Whanganui catchment, mostly concentrating on the sites in the upper catchment (especially Ongarue and Ohura). Although some noticeable improvements were made at these sites, it resulted in very little improvement at the downstream sites. In all cases the R^2 and qualifying rate have been improved but in some cases the average event errors (peak and volume) have increased.

Due to the marginal improvements, the original model parameters are still in use for the Whanganui model but the modified "Interpolation Threshold" value was applied across all models in the HRCFFS.

If the results below appear to be convincing enough for the model parameters to be updated, then it will take little time to modify the live model.

Region-specific Calibration Parameters					
Calibration Region	Pipiriki / Paetawa	Te Maire / Ongarue	Ohura	Tangarakau	Manganui-o-Te-Ao
Region Acronym	(none) / Pae	Tem / Ong	Ohu	Tan	Man
Alpha	1.15 Pae = 1.2	Tem = 1.15 Ong = 2.6	2.2	0.8	1.15
n	0.7	0.7	0.7	0.7	0.7
CapAve	16	15	10	30	6
INFbase	0.2	0.28	0.28	0.28	0.2
K1	0.999	0.999	0.975	0.9	0.975
K2	0.91	0.91	0.91	0.85	0.91

General Calibration Parameters			
A1	0.2	H_GW	80
A2	0.4	GWstoreSat	110
A3	0.4	GWstoreMax	150
Cap1	0.075 x CapAve	EvapScaleF	1
Cap2	0.762 x CapAve	RainScaleF	1
Cap3	1.524 x CapAve	Beta	1
		m	0.7

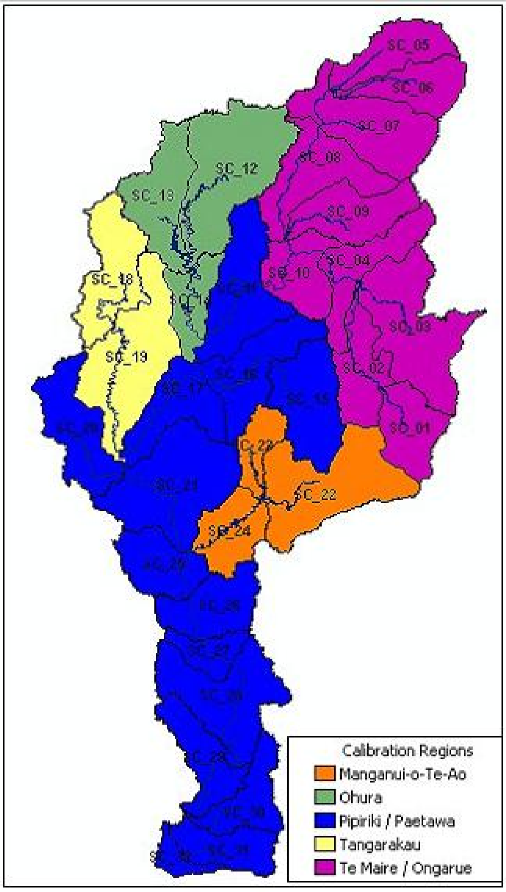


Figure 12-2: Whanganui Hydrologic Model – Original Calibration Parameters (2007)

Region-specific Calibration Parameters					
Calibration Region	Pipiriki	Paetawa	Ohura	Ongarue	Te Maire
Acronym	(none)	Pae	Ohu	Ong	Tem
Alpha	1.5	2.2	4.5	2.2	0.8
CapAve	75	50	35	6	15
INFbase	0.8	0.9	0.11	0.78	0.78
K1	0.99	0.99	0.975	0.965	0.93
K2	0.99	0.99	0.91	0.945	0.92
H_GW	68	68	50	80	80
GWstoreSat	80	80	110	110	90
GWstoreMax	90	90	150	150	110
RainScaleF	1.1	1	1	1	1
Beta	1	1	1	1.3	0.6

General Calibration Parameters	
A1	0.2
A2	0.4
A3	0.4
Cap1	0.075 x CapAve
Cap2	0.762 x CapAve
Cap3	1.524 x CapAve
EvapScaleF	1
m,n	0.7

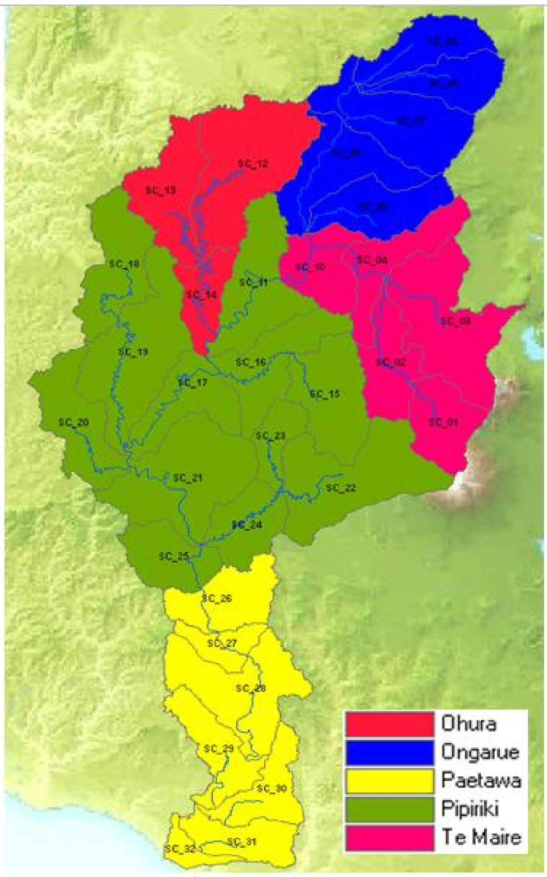


Figure 12-3: Whanganui Hydrologic Model – Original Calibration Parameters (2007)

Table 12-1: Calibration Results Summary

Stream Gauge	Coefficient of Determination, R^2	Event Qualifying Rate	Chinese Standards Ranking	Long Term Volume Comparison Mm^3			Average Event Peak Difference	Av Event Volume Difference	Period Investigated	
				Measured	Modelled	Rainfall			Start	Finish
Whanganui at Te Rewa	0.86	70%	B	104,707	102,386	170,553	12.8%	13.1%	1994	2008
Whanganui at Te Rewa (2009 Recalibration)***	0.86	80%	B	104,707	103,777	170,553	13.4%	11.7%	1994	2008
Whanganui at Pipiriki	0.87	75%	B	95,528	93,173	154,905	10.9%	12.4%	1994	2008
Whanganui at Pipiriki (2009 Recalibration)	0.88	85%	B	95,528	93,173	154,905	12.2%	12.2%	1994	2008
Whanganui at Te Maire (2009 Recalibration)	0.77	40%	< C	36,864	38,059	75,685	17.7%	11.8%	1994	2008
Whanganui at Te Maire	0.83	47%	< C	36,864	39,865	75,685	24.4%	14.9%	1994	2008
Ongarue at Taringamotu	0.70	13%	< C	17,576	16,717	23,995	37.8%	14.9%	1994	2008
Ongarue at Taringamotu (2009 Recalibration)	0.82	40%	< C	17,576	18,362	23,995	35.2%	15.5%	1994	2008
Ohura at Tokorima	0.70	-	-	5,727	4,761	7,136	-	-	2006	2008
Ohura at Tokorima (2009 Recalibration)	0.83	-	-	5,727	5,011	7,136	-	-	2006	2008

Whanganui at Te Rewa

Original Parameters (2007 Calibration)

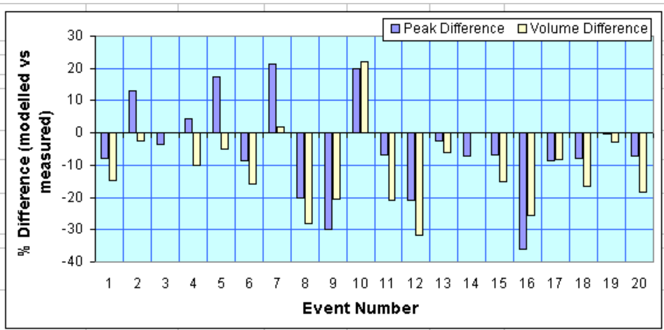
Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

R Squared	0.86	a	34.86	b	0.87

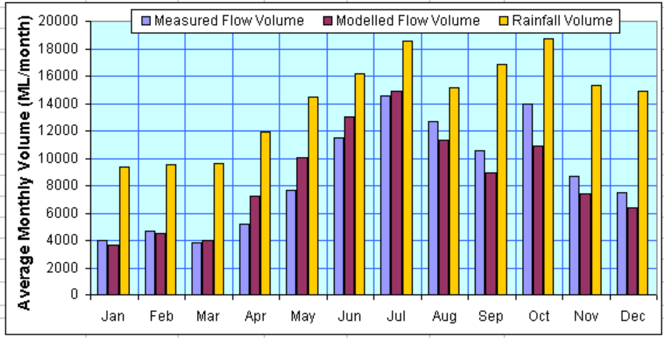
Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	104,707	Modelled Flow Volume (Mm3)	102,386



Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	4003.42	3623.52	9357.15
February	4720.68	4517.97	9552.02
March	3862.97	3992.36	9596.70
April	5166.93	7214.95	11916.97
May	7617.54	10068.70	14455.85
June	11489.44	13053.15	16180.79
July	14537.96	14903.39	18545.18
August	12643.91	11339.57	15145.57
September	10582.48	8964.91	16879.63
October	13931.83	10911.86	18744.06
Novermber	8674.18	7373.24	15323.57
December	7475.44	6422.49	14855.27
Annual	104,707	102,386	170,553
Runoff Coeff	***0.61***	***0.60***	



Event Statistics:

	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	27/02/2004 @ 12:00	05/03/2004 @ 00:00	3323.07	3059.62	-7.93	659.92	561.53	-14.91	818.19	0.81	0.69
2	01/07/1998 @ 00:00	06/07/1998 @ 18:00	2656.04	3000.06	12.95	491.12	478.37	-2.60	647.55	0.76	0.74
3	08/07/1998 @ 18:00	14/07/1998 @ 00:00	3400.47	3284.24	-3.42	671.99	671.29	-0.11	899.64	0.75	0.75
4	14/07/1998 @ 00:00	21/07/1998 @ 00:00	1990.31	2077.84	4.40	513.33	461.32	-10.13	429.37	1.20	1.07
5	19/10/1998 @ 12:00	27/10/1998 @ 00:00	3381.67	3968.65	17.36	698.38	662.70	-5.11	877.73	0.80	0.76
6	27/10/1998 @ 06:00	02/11/1998 @ 12:00	3852.75	3515.74	-8.75	727.23	612.15	-15.82	833.10	0.87	0.73
7	06/11/1994 @ 06:00	14/11/1994 @ 00:00	3072.47	3731.16	21.44	744.73	757.64	1.73	1206.62	0.62	0.63
8	04/09/1995 @ 12:00	13/09/1995 @ 00:00	2823.48	2251.41	-20.26	611.70	439.11	-28.21	659.19	0.93	0.67
9	29/11/1996 @ 00:00	08/12/1996 @ 00:00	2585.58	1812.97	-29.88	563.05	446.76	-20.65	773.79	0.73	0.58
10	14/05/1999 @ 00:00	22/05/1999 @ 00:00	2729.30	3271.11	19.85	511.39	624.30	22.08	876.59	0.58	0.71
11	29/09/2000 @ 00:00	09/10/2000 @ 00:00	3839.24	3576.82	-6.84	1166.95	921.63	-21.02	1323.31	0.88	0.70
12	06/12/2001 @ 12:00	16/12/2001 @ 00:00	2530.56	2000.61	-20.94	705.61	480.92	-31.84	924.77	0.76	0.52
13	27/09/2003 @ 12:00	10/10/2003 @ 00:00	2530.12	2469.75	-2.39	1035.14	973.75	-5.93	1369.77	0.76	0.71
14	16/06/2004 @ 00:00	27/06/2004 @ 12:00	2347.50	2179.56	-7.15	920.32	921.04	0.08	1213.11	0.76	0.76
15	14/11/1994 @ 12:00	21/11/1994 @ 18:00	2579.12	2405.41	-6.74	549.78	466.72	-15.11	651.71	0.84	0.72
16	14/02/2004 @ 12:00	19/02/2004 @ 00:00	3342.73	2134.55	-36.14	504.05	374.65	-25.67	576.27	0.87	0.65
17	09/10/1998 @ 00:00	19/10/1998 @ 12:00	2545.32	2325.62	-8.63	883.53	811.01	-8.21	1198.40	0.74	0.68
18	27/02/2004 @ 00:00	07/03/2004 @ 00:00	3323.07	3059.62	-7.93	740.30	619.10	-16.37	818.19	0.90	0.76
19	11/07/2008 @ 18:00	19/07/2008 @ 00:00	2305.17	2299.69	-0.24	410.93	399.41	-2.80	445.79	0.92	0.90
20	04/10/2008 @ 18:00	15/10/2008 @ 00:00	2369.54	2198.57	-7.22	649.17	530.07	-18.35	882.85	0.74	0.60
	Average				***12.80***			***13.07***		***0.81***	***0.72***

Whanganui at Te Rewa — Updated Parameters (2009 Calibration)

Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

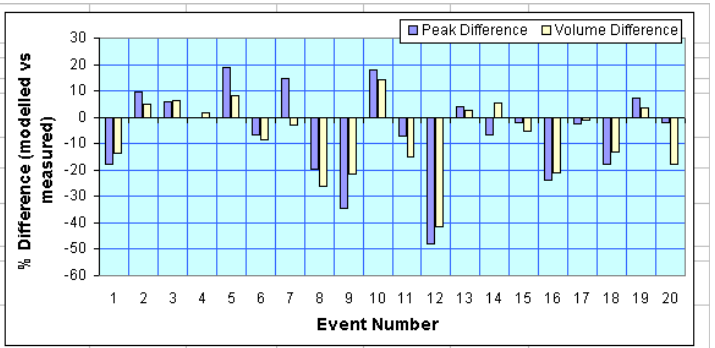
R Squared	0.86	a	8.44	b	0.97

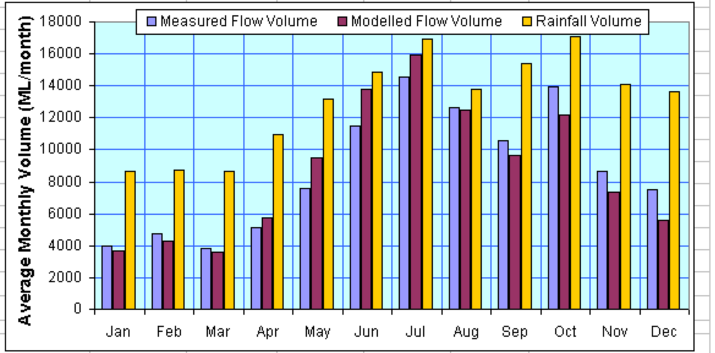
Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	104,707	Modelled Flow Volume (Mm3)	103,777

Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	4003.42	3702.37	8640.84
February	4720.68	4317.14	8751.97
March	3862.97	3562.99	8657.07
April	5166.93	5710.44	10938.94
May	7617.54	9475.63	13209.38
June	11489.44	13798.79	14854.44
July	14537.96	15914.27	16961.67
August	12643.91	12503.56	13776.90
September	10582.48	9684.47	15396.24
October	13931.83	12196.01	17103.47
Novermber	8674.18	7331.98	14063.72
December	7475.44	5579.06	13672.12
Annual	104,707	103,777	156,027
Runoff Coeff	***0.67***	***0.67***	





Event Statistics:

	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	27/02/2004 @ 12:00	05/03/2004 @ 00:00	3323.07	2738.21	-17.60	659.92	571.54	-13.39	739.64	0.89	0.77
2	01/07/1998 @ 00:00	06/07/1998 @ 18:00	2656.04	2905.37	9.39	491.12	514.33	4.72	586.37	0.84	0.88
3	08/07/1998 @ 18:00	14/07/1998 @ 00:00	3400.47	3595.77	5.74	671.99	713.94	6.24	795.89	0.84	0.90
4	14/07/1998 @ 00:00	21/07/1998 @ 00:00	1990.31	1986.12	-0.21	513.33	523.23	1.93	406.09	1.26	1.29
5	19/10/1998 @ 12:00	27/10/1998 @ 00:00	3381.67	4027.21	19.09	698.38	755.10	8.12	824.94	0.85	0.92
6	27/10/1998 @ 06:00	02/11/1998 @ 12:00	3852.75	3594.86	-6.69	727.23	664.12	-8.68	790.47	0.92	0.84
7	06/11/1994 @ 06:00	14/11/1994 @ 00:00	3072.47	3528.96	14.86	744.73	722.09	-3.04	1120.54	0.66	0.64
8	04/09/1995 @ 12:00	13/09/1995 @ 00:00	2823.48	2273.54	-19.48	611.70	451.88	-26.13	564.38	1.08	0.80
9	29/11/1996 @ 00:00	08/12/1996 @ 00:00	2585.58	1690.74	-34.61	563.05	441.74	-21.54	712.87	0.79	0.62
10	14/05/1999 @ 00:00	22/05/1999 @ 00:00	2729.30	3223.23	18.10	511.39	584.42	14.28	807.35	0.63	0.72
11	29/09/2000 @ 00:00	09/10/2000 @ 00:00	3839.24	3562.71	-7.20	1166.95	994.33	-14.79	1217.38	0.96	0.82
12	06/12/2001 @ 12:00	16/12/2001 @ 00:00	2530.56	1321.05	-47.80	705.61	413.78	-41.36	835.51	0.84	0.50
13	27/09/2003 @ 12:00	10/10/2003 @ 00:00	2530.12	2635.15	4.15	1035.14	1063.89	2.78	1260.74	0.82	0.84
14	16/06/2004 @ 00:00	27/06/2004 @ 12:00	2347.50	2193.38	-6.57	920.32	969.54	5.35	1112.41	0.83	0.87
15	14/11/1994 @ 12:00	21/11/1994 @ 18:00	2579.12	2528.23	-1.97	549.78	520.19	-5.38	589.09	0.93	0.88
16	14/02/2004 @ 12:00	19/02/2004 @ 00:00	3342.73	2542.69	-23.93	504.05	398.04	-21.03	493.30	1.02	0.81
17	09/10/1998 @ 00:00	19/10/1998 @ 12:00	2545.32	2485.11	-2.37	883.53	873.58	-1.13	1116.76	0.79	0.78
18	27/02/2004 @ 00:00	07/03/2004 @ 00:00	3323.07	2738.21	-17.60	740.30	644.46	-12.95	739.64	1.00	0.87
19	11/07/2008 @ 18:00	19/07/2008 @ 00:00	2305.17	2475.44	7.39	410.93	425.48	3.54	415.68	0.99	1.02
20	04/10/2008 @ 18:00	15/10/2008 @ 00:00	2369.54	2318.04	-2.17	649.17	532.67	-17.95	807.52	0.80	0.66
	Average				***13.35***			***11.72***		***0.89***	***0.82***

Whanganui at Pipiriki

Original Parameters (2007 Calibration)

Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

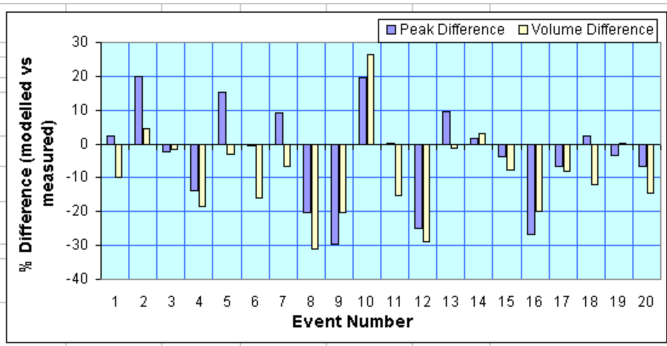
R Squared	0.87	a	36.63	b	0.85

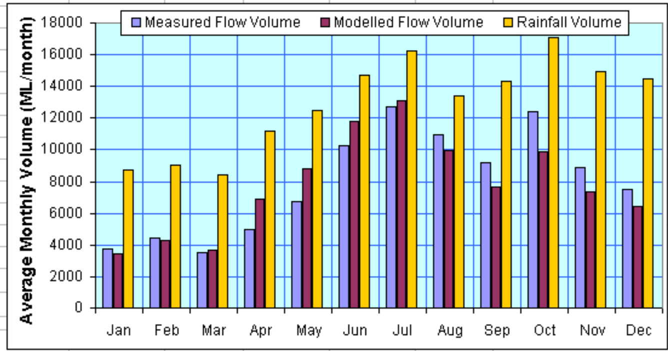
Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	95,528	Modelled Flow Volume (Mm3)	93,173

Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	3784.88	3425.72	8697.99
February	4452.03	4291.26	9004.36
March	3550.84	3639.39	8421.88
April	4965.09	6875.60	11184.29
May	6773.57	8792.84	12480.96
June	10278.42	11775.68	14672.93
July	12700.28	13091.23	16269.91
August	10930.48	9942.79	13409.90
September	9228.61	7696.26	14293.52
October	12420.56	9851.79	17055.11
Novermber	8909.40	7321.52	14924.61
December	7533.88	6468.77	14489.91
Annual	95,528	93,173	154,905
Runoff Coeff	***0.62***	***0.60***	





Event Statistics:

	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	27/02/2004 @ 12:00	05/03/2004 @ 00:00	2948.05	3015.53	2.29	596.56	537.13	-9.96	774.17	0.77	0.69
2	01/07/1998 @ 00:00	06/07/1998 @ 18:00	2310.98	2768.54	19.80	430.73	450.80	4.66	608.38	0.71	0.74
3	08/07/1998 @ 18:00	14/07/1998 @ 00:00	3032.86	2967.95	-2.14	654.71	644.05	-1.63	852.61	0.77	0.76
4	14/07/1998 @ 00:00	21/07/1998 @ 00:00	1991.49	1718.32	-13.72	522.57	425.29	-18.62	397.83	1.31	1.07
5	19/10/1998 @ 12:00	27/10/1998 @ 00:00	2975.86	3426.07	15.13	631.64	613.42	-2.89	815.65	0.77	0.75
6	27/10/1998 @ 06:00	02/11/1998 @ 12:00	3450.09	3431.18	-0.55	697.16	585.73	-15.98	789.73	0.88	0.74
7	06/11/1994 @ 06:00	14/11/1994 @ 00:00	3120.12	3402.30	9.04	770.12	720.13	-6.49	1138.41	0.68	0.63
8	04/09/1995 @ 12:00	13/09/1995 @ 00:00	2775.65	2210.61	-20.36	620.83	427.78	-31.10	629.83	0.99	0.68
9	29/11/1996 @ 00:00	08/12/1996 @ 00:00	2428.50	1710.79	-29.55	535.17	426.80	-20.25	729.99	0.73	0.58
10	14/05/1999 @ 00:00	22/05/1999 @ 00:00	2495.71	2987.34	19.70	472.84	597.97	26.46	836.47	0.57	0.71
11	29/09/2000 @ 00:00	09/10/2000 @ 00:00	3285.55	3292.54	0.21	1034.15	877.02	-15.19	1259.97	0.82	0.70
12	06/12/2001 @ 12:00	16/12/2001 @ 00:00	2245.86	1689.61	-24.77	645.97	460.49	-28.71	874.38	0.74	0.53
13	27/09/2003 @ 12:00	10/10/2003 @ 00:00	2201.00	2409.36	9.47	923.75	910.73	-1.41	1290.68	0.72	0.71
14	16/06/2004 @ 00:00	27/06/2004 @ 12:00	2087.80	2119.11	1.50	846.63	871.97	2.99	1144.82	0.74	0.76
15	14/11/1994 @ 12:00	21/11/1994 @ 18:00	2310.17	2225.79	-3.65	476.92	439.94	-7.76	613.41	0.78	0.72
16	14/02/2004 @ 12:00	19/02/2004 @ 00:00	2298.06	1682.63	-26.78	400.48	320.78	-19.90	512.88	0.78	0.63
17	09/10/1998 @ 00:00	19/10/1998 @ 12:00	2395.56	2236.31	-6.65	839.40	772.65	-7.95	1133.35	0.74	0.68
18	27/02/2004 @ 00:00	07/03/2004 @ 00:00	2948.05	3015.53	2.29	669.81	588.27	-12.17	774.17	0.87	0.76
19	11/07/2008 @ 18:00	19/07/2008 @ 00:00	2118.51	2047.16	-3.37	378.85	378.95	0.03	425.62	0.89	0.89
20	04/10/2008 @ 18:00	15/10/2008 @ 00:00	2124.21	1985.34	-6.54	596.58	510.75	-14.39	837.89	0.71	0.61
	Average				***10.87***			***12.43***		***0.80***	***0.72***

Whanganui at Pipiriki **Updated Parameters (2009 Calibration)**

Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

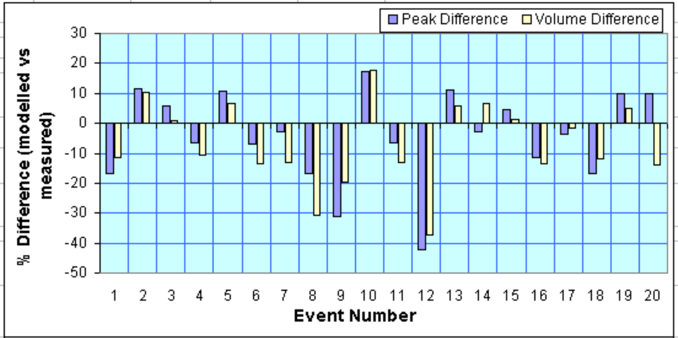
R Squared	0.88	a	8.53	b	0.97

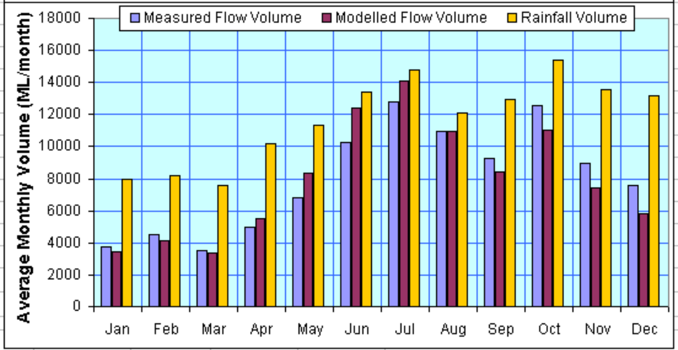
Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	95,862	Modelled Flow Volume (Mm3)	95,050

Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	3782.77	3474.43	7979.96
February	4485.95	4163.37	8166.87
March	3551.61	3381.80	7551.98
April	4959.80	5544.33	10174.52
May	6783.91	8372.39	11311.00
June	10273.06	12416.65	13417.88
July	12759.99	14093.94	14812.86
August	10923.75	10922.85	12133.17
September	9256.85	8449.60	12955.34
October	12571.79	10995.82	15423.98
Novermber	8962.27	7439.23	13528.91
December	7550.29	5795.39	13190.97
Annual	95,862	95,050	140,647
Runoff Coeff	*0.68*	*0.68*	





Event Statistics:

	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	27/02/2004 @ 12:00	05/03/2004 @ 00:00	3281.78	2736.22	-16.62	622.72	551.53	-11.43	696.65	0.89	0.79
2	01/07/1998 @ 00:00	06/07/1998 @ 18:00	2478.38	2765.88	11.60	444.00	489.93	10.35	547.87	0.81	0.89
3	08/07/1998 @ 18:00	14/07/1998 @ 00:00	3393.24	3590.89	5.82	688.49	695.90	1.08	758.16	0.91	0.92
4	14/07/1998 @ 00:00	21/07/1998 @ 00:00	2096.80	1961.31	-6.46	531.31	475.50	-10.50	371.48	1.43	1.28
5	19/10/1998 @ 12:00	27/10/1998 @ 00:00	3318.22	3667.42	10.52	656.74	699.53	6.52	751.19	0.87	0.93
6	27/10/1998 @ 06:00	02/11/1998 @ 12:00	3956.93	3689.26	-6.76	740.59	641.67	-13.36	742.02	1.00	0.86
7	06/11/1994 @ 06:00	14/11/1994 @ 00:00	3509.02	3403.76	-3.00	811.79	705.31	-13.12	1049.66	0.77	0.67
8	04/09/1995 @ 12:00	13/09/1995 @ 00:00	3058.48	2549.30	-16.65	643.01	445.82	-30.67	549.05	1.17	0.81
9	29/11/1996 @ 00:00	08/12/1996 @ 00:00	2622.08	1801.55	-31.29	546.31	438.25	-19.78	665.32	0.82	0.66
10	14/05/1999 @ 00:00	22/05/1999 @ 00:00	2705.19	3172.63	17.28	487.55	574.40	17.81	762.35	0.64	0.75
11	29/09/2000 @ 00:00	09/10/2000 @ 00:00	3731.58	3491.34	-6.44	1093.54	952.01	-12.94	1146.55	0.95	0.83
12	06/12/2001 @ 12:00	16/12/2001 @ 00:00	2399.48	1388.28	-42.14	658.93	412.53	-37.39	779.57	0.85	0.53
13	27/09/2003 @ 12:00	10/10/2003 @ 00:00	2345.25	2603.26	11.00	944.51	1000.17	5.89	1164.76	0.81	0.86
14	16/06/2004 @ 00:00	27/06/2004 @ 12:00	2210.02	2144.95	-2.94	867.39	926.37	6.80	1042.42	0.83	0.89
15	14/11/1994 @ 12:00	21/11/1994 @ 18:00	2477.40	2588.61	4.49	487.79	493.96	1.26	546.79	0.89	0.90
16	14/02/2004 @ 12:00	19/02/2004 @ 00:00	2462.71	2181.83	-11.41	411.34	356.31	-13.38	418.48	0.98	0.85
17	09/10/1998 @ 00:00	19/10/1998 @ 12:00	2581.60	2487.37	-3.65	858.89	844.03	-1.73	1043.38	0.82	0.81
18	27/02/2004 @ 00:00	07/03/2004 @ 00:00	3281.78	2736.22	-16.62	695.08	613.70	-11.71	696.65	1.00	0.88
19	11/07/2008 @ 18:00	19/07/2008 @ 00:00	2246.47	2465.08	9.73	386.41	405.79	5.02	390.17	0.99	1.04
20	04/10/2008 @ 18:00	15/10/2008 @ 00:00	2253.26	2480.48	10.08	607.18	522.49	-13.95	761.40	0.80	0.69
	Average				*12.23*			*12.23*		*0.91*	*0.84*

Whanganui at Te Maire

Original Parameters (2007 Calibration)

Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

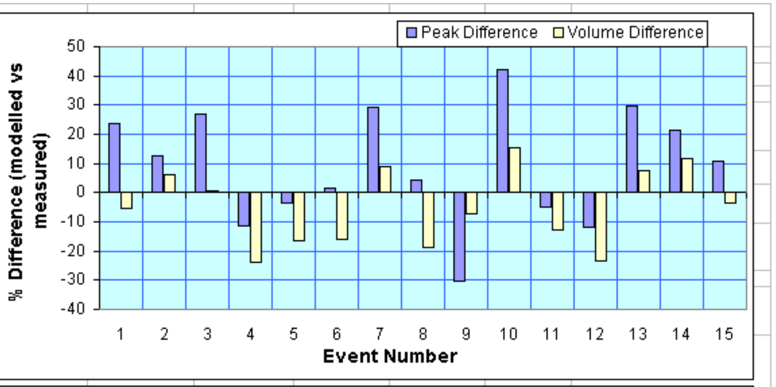
R Squared	0.77	a	27.58	b	0.63

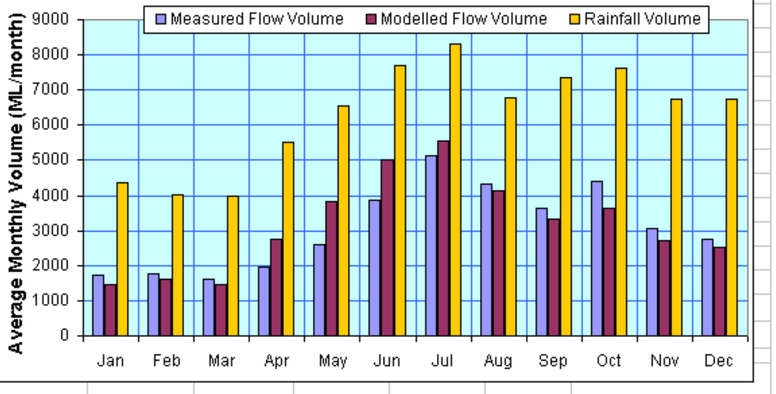
Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	36,864	Modelled Flow Volume (Mm3)	38,059

Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	1739.10	1446.50	4364.09
February	1770.38	1627.28	4021.81
March	1614.23	1452.97	3998.33
April	1954.56	2743.60	5525.50
May	2619.45	3845.39	6545.06
June	3866.33	5012.34	7695.37
July	5116.58	5548.93	8323.19
August	4330.99	4138.54	6787.13
September	3622.31	3330.61	7337.79
October	4408.92	3651.55	7613.18
Novermber	3073.69	2736.57	6734.08
December	2747.79	2524.72	6739.54
Annual	36,864	38,059	75,685
Runoff Coeff	***0.49***	***0.50***	





Event Statistics:

	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	27/02/2004 @ 12:00	05/03/2004 @ 00:00	1393.32	1723.82	23.72	227.19	214.73	-5.49	371.65	0.61	0.58
2	01/07/1998 @ 00:00	06/07/1998 @ 18:00	1088.04	1226.44	12.72	172.40	182.79	6.03	288.93	0.60	0.63
3	08/07/1998 @ 18:00	14/07/1998 @ 00:00	1373.67	1742.02	26.81	264.27	265.52	0.47	421.47	0.63	0.63
4	14/07/1998 @ 00:00	20/07/1998 @ 00:00	929.83	822.89	-11.50	194.52	148.28	-23.77	181.71	1.07	0.82
5	19/10/1998 @ 12:00	27/10/1998 @ 00:00	1354.02	1307.06	-3.47	227.07	190.02	-16.31	329.56	0.69	0.58
6	27/10/1998 @ 12:00	01/11/1998 @ 18:00	1800.80	1829.08	1.57	226.99	190.77	-15.96	349.09	0.65	0.55
7	06/11/1994 @ 00:00	14/11/1994 @ 00:00	951.05	1231.00	29.44	245.55	267.49	8.93	536.96	0.46	0.50
8	04/09/1995 @ 12:00	13/09/1995 @ 00:00	1132.69	1183.90	4.52	227.23	184.86	-18.65	314.22	0.72	0.59
9	29/11/1996 @ 00:00	08/12/1996 @ 00:00	1139.88	795.16	-30.24	157.59	145.90	-7.42	311.01	0.51	0.47
10	29/07/2008 @ 12:00	08/08/2008 @ 00:00	767.73	1090.30	42.02	326.01	375.50	15.18	561.00	0.58	0.67
11	29/09/2000 @ 00:00	09/10/2000 @ 00:00	1464.37	1393.17	-4.86	356.66	311.90	-12.55	555.88	0.64	0.56
12	06/12/2001 @ 12:00	16/12/2001 @ 00:00	1015.04	895.75	-11.75	274.48	210.62	-23.27	444.76	0.62	0.47
13	27/09/2003 @ 12:00	10/10/2003 @ 00:00	1251.95	1621.33	29.50	330.22	355.78	7.74	620.31	0.53	0.57
14	16/06/2004 @ 00:00	27/06/2004 @ 12:00	945.22	1148.71	21.53	311.94	348.25	11.64	554.94	0.56	0.63
15	14/11/1994 @ 12:00	21/11/1994 @ 18:00	911.27	1009.53	10.78	139.23	133.99	-3.76	231.56	0.60	0.58
	Average				***17.63***			***11.81***		***0.63***	***0.59***

Whanganui at Te Maire Updated Parameters (2009 Calibration)

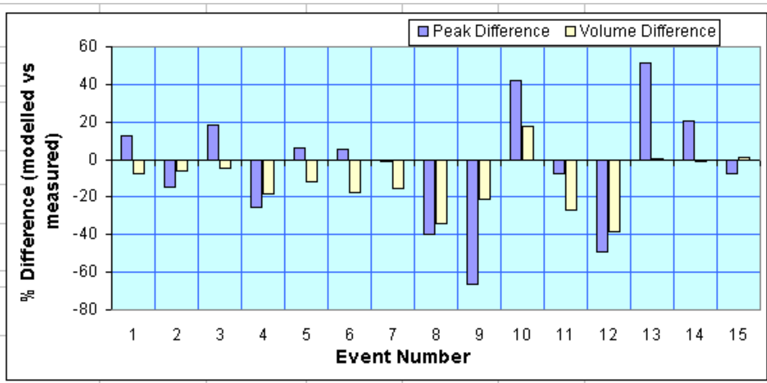
Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

R Squared	0.83	a	-9.48	b	1.03

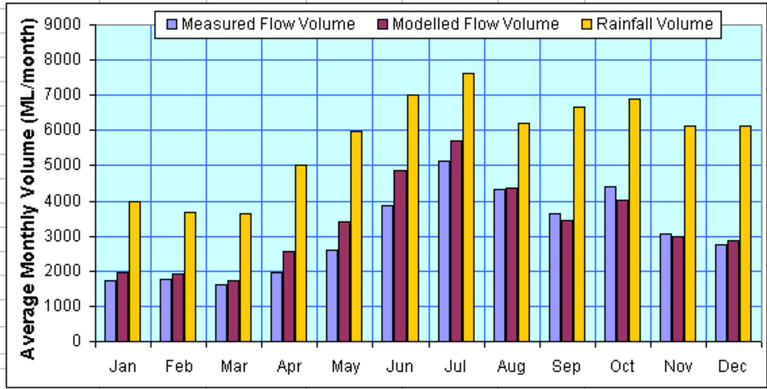
Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	36,864	Modelled Flow Volume (Mm3)	39,865



Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	1739.10	1955.26	3972.58
February	1770.38	1921.27	3691.72
March	1614.23	1742.20	3647.54
April	1954.56	2578.97	5026.62
May	2619.45	3419.05	5989.61
June	3866.33	4849.60	6993.51
July	5116.58	5689.26	7636.20
August	4330.99	4376.51	6190.73
September	3622.31	3450.02	6660.59
October	4408.92	4022.52	6897.44
Novermber	3073.69	3002.98	6127.18
December	2747.79	2857.43	6145.70
Annual	36,864	39,865	68,979
Runoff Coeff	*0.53*	*0.58*	



Event Statistics:

	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	27/02/2004 @ 12:00	05/03/2004 @ 00:00	1393.32	1564.98	12.32	227.19	210.00	-7.57	341.01	0.67	0.62
2	01/07/1998 @ 00:00	06/07/1998 @ 18:00	1088.04	929.88	-14.54	172.40	162.17	-5.93	269.81	0.64	0.60
3	08/07/1998 @ 18:00	14/07/1998 @ 00:00	1373.67	1627.84	18.50	264.27	251.22	-4.94	381.41	0.69	0.66
4	14/07/1998 @ 00:00	20/07/1998 @ 00:00	929.83	692.30	-25.55	194.52	158.52	-18.51	166.92	1.17	0.95
5	19/10/1998 @ 12:00	27/10/1998 @ 00:00	1354.02	1434.94	5.98	227.07	199.54	-12.12	295.52	0.77	0.68
6	27/10/1998 @ 12:00	01/11/1998 @ 18:00	1800.80	1893.70	5.16	226.99	187.82	-17.26	311.24	0.73	0.60
7	06/11/1994 @ 00:00	14/11/1994 @ 00:00	951.05	939.82	-1.18	245.55	207.87	-15.35	477.73	0.51	0.44
8	04/09/1995 @ 12:00	13/09/1995 @ 00:00	1132.69	684.49	-39.57	227.23	149.61	-34.16	288.55	0.79	0.52
9	29/11/1996 @ 00:00	08/12/1996 @ 00:00	1139.88	386.96	-66.05	157.59	123.97	-21.33	281.78	0.56	0.44
10	29/07/2008 @ 12:00	08/08/2008 @ 00:00	767.73	1088.34	41.76	326.01	382.86	17.44	508.85	0.64	0.75
11	29/09/2000 @ 00:00	09/10/2000 @ 00:00	1464.37	1352.73	-7.62	356.66	260.71	-26.90	507.98	0.70	0.51
12	06/12/2001 @ 12:00	16/12/2001 @ 00:00	1015.04	518.34	-48.93	274.48	168.42	-38.64	400.21	0.69	0.42
13	27/09/2003 @ 12:00	10/10/2003 @ 00:00	1251.95	1890.99	51.04	330.22	331.16	0.28	558.72	0.59	0.59
14	16/06/2004 @ 00:00	27/06/2004 @ 12:00	945.22	1142.27	20.85	311.94	308.79	-1.01	505.78	0.62	0.61
15	14/11/1994 @ 12:00	21/11/1994 @ 18:00	911.27	843.34	-7.45	139.23	141.17	1.39	208.19	0.67	0.68
	Average				*24.43*			*14.86*		*0.70*	*0.60*

Ongarue at Taringamotu — Original Parameters (2007 Calibration)

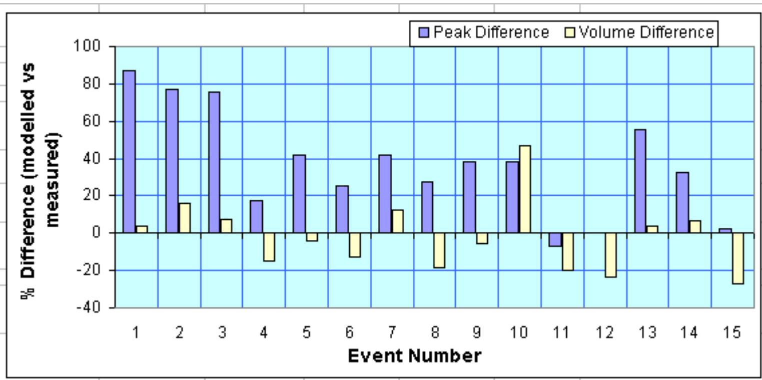
Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

R Squared	0.70	a	15.83	b	0.61

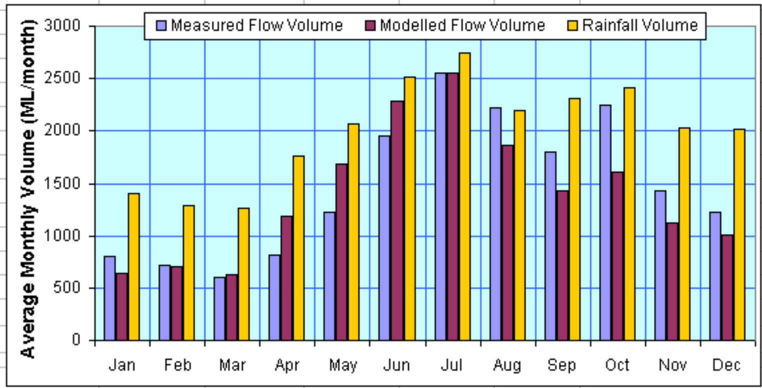
Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	17,576	Modelled Flow Volume (Mm3)	16,717



Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	799.47	632.23	1398.48
February	714.19	708.14	1290.49
March	605.54	629.48	1267.44
April	815.24	1189.52	1756.56
May	1220.80	1684.53	2065.76
June	1948.40	2282.72	2509.53
July	2552.63	2554.83	2750.34
August	2216.50	1860.33	2190.59
September	1800.40	1430.36	2307.53
October	2241.45	1609.40	2412.71
Novermber	1434.41	1126.75	2035.04
December	1226.74	1008.39	2010.67
Annual	17,576	16,717	23,995
Runoff Coeff	***0.73***	***0.70***	



Event Statistics:

	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	27/02/2004 @ 00:00	05/03/2004 @ 00:00	448.95	840.35	87.18	104.15	108.43	4.11	141.06	0.74	0.77
2	01/07/1998 @ 00:00	06/07/1998 @ 18:00	324.64	573.87	76.77	74.93	86.66	15.66	99.82	0.75	0.87
3	08/07/1998 @ 18:00	14/07/1998 @ 00:00	403.20	706.68	75.27	120.06	128.58	7.10	154.25	0.78	0.83
4	14/07/1998 @ 00:00	20/07/1998 @ 00:00	287.63	338.67	17.74	86.85	73.95	-14.86	68.42	1.27	1.08
5	19/10/1998 @ 12:00	27/10/1998 @ 00:00	309.28	437.88	41.58	81.07	77.68	-4.18	99.18	0.82	0.78
6	27/10/1998 @ 12:00	06/11/1998 @ 00:00	412.72	515.81	24.98	106.22	92.73	-12.70	123.97	0.86	0.75
7	06/11/1994 @ 00:00	14/11/1994 @ 00:00	339.14	482.04	42.14	103.57	116.39	12.38	172.00	0.60	0.68
8	04/09/1995 @ 00:00	13/09/1995 @ 00:00	359.23	459.08	27.80	105.99	86.32	-18.56	103.73	1.02	0.83
9	29/07/2008 @ 18:00	11/08/2008 @ 00:00	365.11	504.87	38.28	203.19	192.38	-5.32	201.22	1.01	0.96
10	14/05/1999 @ 00:00	22/05/1999 @ 00:00	299.50	414.58	38.42	64.81	95.28	47.01	119.85	0.54	0.80
11	29/09/2000 @ 00:00	09/10/2000 @ 00:00	553.98	514.68	-7.09	164.05	131.34	-19.94	163.42	1.00	0.80
12	06/12/2001 @ 12:00	16/12/2001 @ 00:00	359.49	359.32	-0.05	120.51	92.04	-23.62	141.59	0.85	0.65
13	27/09/2003 @ 12:00	10/10/2003 @ 00:00	352.45	547.43	55.32	144.56	150.41	4.05	190.27	0.76	0.79
14	16/06/2004 @ 00:00	27/06/2004 @ 12:00	367.31	486.76	32.52	149.06	159.30	6.87	183.49	0.81	0.87
15	04/10/2008 @ 18:00	15/10/2008 @ 00:00	384.70	393.38	2.26	115.86	84.35	-27.20	126.31	0.92	0.67
	Average				***37.83***			***14.90***		***0.85***	***0.81***

Ongarue at Taringamotu — Updated Parameters (2009 Calibration)

Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

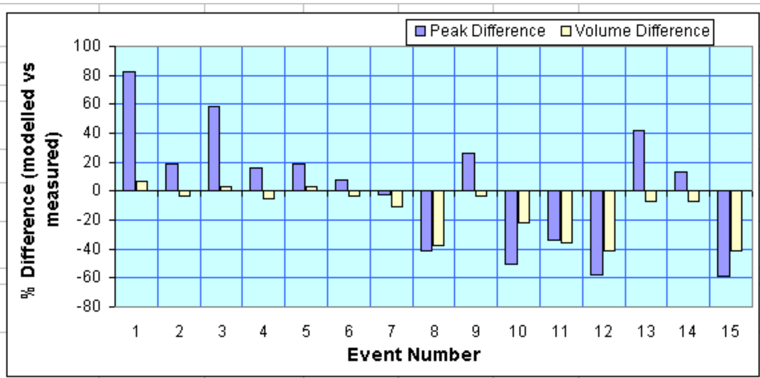
R Squared	0.82	a	-4.29	b	1.07

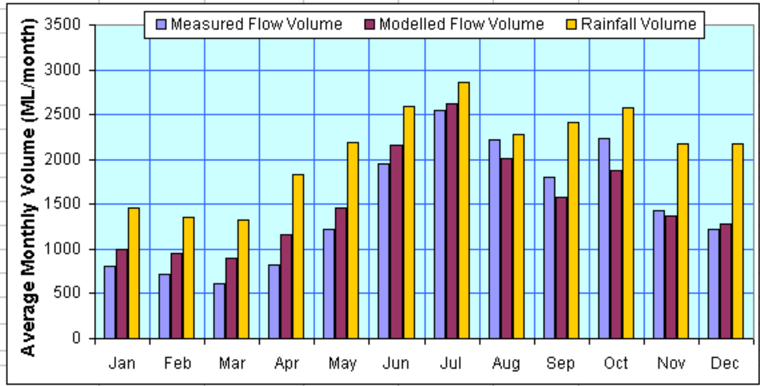
Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	17,576	Modelled Flow Volume (Mm3)	18,362

Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	799.47	995.39	1459.12
February	714.19	950.45	1354.75
March	605.54	889.11	1326.25
April	815.24	1164.74	1833.26
May	1220.80	1465.06	2182.74
June	1948.40	2154.80	2592.92
July	2552.63	2625.19	2866.46
August	2216.50	2013.44	2284.49
September	1800.40	1580.63	2412.48
October	2241.45	1879.19	2571.50
Novermber	1434.41	1365.74	2169.16
December	1226.74	1278.20	2169.80
Annual	17,576	18,362	25,223
Runoff Coeff	*0.70*	*0.73*	





Event Statistics:

	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	27/02/2004 @ 00:00	05/03/2004 @ 00:00	448.95	819.18	82.46	104.15	111.45	7.02	139.15	0.75	0.80
2	01/07/1998 @ 00:00	06/07/1998 @ 18:00	324.64	386.43	19.03	74.93	72.12	-3.75	104.77	0.72	0.69
3	08/07/1998 @ 18:00	14/07/1998 @ 00:00	403.20	640.39	58.83	120.06	123.64	2.98	152.18	0.79	0.81
4	14/07/1998 @ 00:00	20/07/1998 @ 00:00	287.63	334.60	16.33	86.85	82.15	-5.41	66.73	1.30	1.23
5	19/10/1998 @ 12:00	27/10/1998 @ 00:00	309.28	366.28	18.43	81.07	83.40	2.87	102.35	0.79	0.81
6	27/10/1998 @ 12:00	06/11/1998 @ 00:00	412.72	444.07	7.60	106.22	102.76	-3.25	130.84	0.81	0.79
7	06/11/1994 @ 00:00	14/11/1994 @ 00:00	339.14	331.36	-2.30	103.57	92.25	-10.94	173.61	0.60	0.53
8	04/09/1995 @ 00:00	13/09/1995 @ 00:00	359.23	212.69	-40.79	105.99	66.18	-37.56	108.88	0.97	0.61
9	29/07/2008 @ 18:00	11/08/2008 @ 00:00	365.11	459.57	25.87	203.19	195.95	-3.56	206.55	0.98	0.95
10	14/05/1999 @ 00:00	22/05/1999 @ 00:00	299.50	147.63	-50.71	64.81	50.71	-21.76	122.81	0.53	0.41
11	29/09/2000 @ 00:00	09/10/2000 @ 00:00	553.98	364.16	-34.27	164.05	105.41	-35.75	177.45	0.92	0.59
12	06/12/2001 @ 12:00	16/12/2001 @ 00:00	359.49	151.94	-57.74	120.51	70.73	-41.30	147.02	0.82	0.48
13	27/09/2003 @ 12:00	10/10/2003 @ 00:00	352.45	500.54	42.02	144.56	134.47	-6.98	198.82	0.73	0.68
14	16/06/2004 @ 00:00	27/06/2004 @ 12:00	367.31	416.36	13.35	149.06	138.24	-7.26	189.32	0.79	0.73
15	04/10/2008 @ 18:00	15/10/2008 @ 00:00	384.70	159.92	-58.43	115.86	67.95	-41.36	127.43	0.91	0.53
	Average				*35.21*			*15.45*		*0.83*	*0.71*

Ohura at Tokorima — Original Parameters (2007 Calibration)

Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

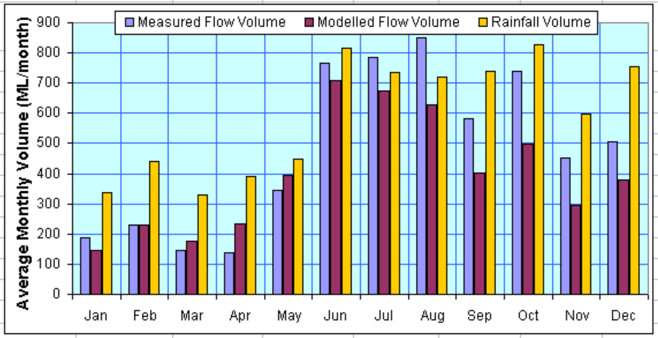
R Squared	0.70	a	4.81	b	0.97

Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	5,727	Modelled Flow Volume (Mm3)	4,761

Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	189.06	147.03	336.05
February	230.93	228.02	441.36
March	145.04	174.68	327.92
April	136.25	232.92	390.81
May	346.42	393.97	448.65
June	764.27	708.75	816.30
July	786.70	673.16	733.79
August	849.75	628.17	719.66
September	581.48	404.01	738.58
October	740.96	498.27	827.66
Novermber	451.23	293.95	599.29
December	505.32	378.50	755.84
Annual	5,727	4,761	7,136
Runoff Coeff	***0.80***	***0.67***	



Ohura at Tokorima — Updated Parameters (2009 Calibration)

Model run time from 01/01/1994 @ 00:00 to 01/11/2008 @ 00:00

For Measured flows above a threshold of 0 cumecs:

R Squared	0.83	a	3.12	b	1.00

Where Line of best fit = a + bX

Measured Flow Volume (Mm3)	5,727	Modelled Flow Volume (Mm3)	5,011

Monthly and Annual Volumes (Mm3) - All flow magnitudes:

Month	Measured Flow Volume	Modelled Flow Volume	Rainfall Volume
January	189.06	75.51	374.04
February	230.93	148.27	470.76
March	145.04	119.70	371.42
April	136.25	139.85	418.48
May	346.42	393.99	494.27
June	764.27	841.65	847.20
July	786.70	775.63	789.58
August	849.75	783.23	760.44
September	581.48	499.37	761.46
October	740.96	648.95	865.83
Novermber	451.23	351.46	636.90
December	505.32	233.75	803.46
Annual	5,727	5,011	7,594
Runoff Coeff	***0.75***	***0.66***