Horizons Regional Council

Flood Forecasting System

Whanganui Catchment

Operating Manual

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

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1 INTRODUCTION

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

Once completed, the Horizons Regional Council Flood Forecasting System (HRCFFS) will cover the majority of catchments that the council is responsible for. It is being completed in a series of 5 stages by HTC. This report has been produced during Stage 3 of the project and covers the flood forecasting system developed for the Whanganui River in detail.

This report is divided into the following sections:

- System Overview – Software components that make up the HRCFFS and their interconnections.
- System Operation.
- Hydrologic Models – Modelling methodology, setup and calibration details.
- Hydraulic Models – Modelling methodology, setup and calibration details.
- Recommendations for Future Improvements.

2 SYSTEM OVERVIEW

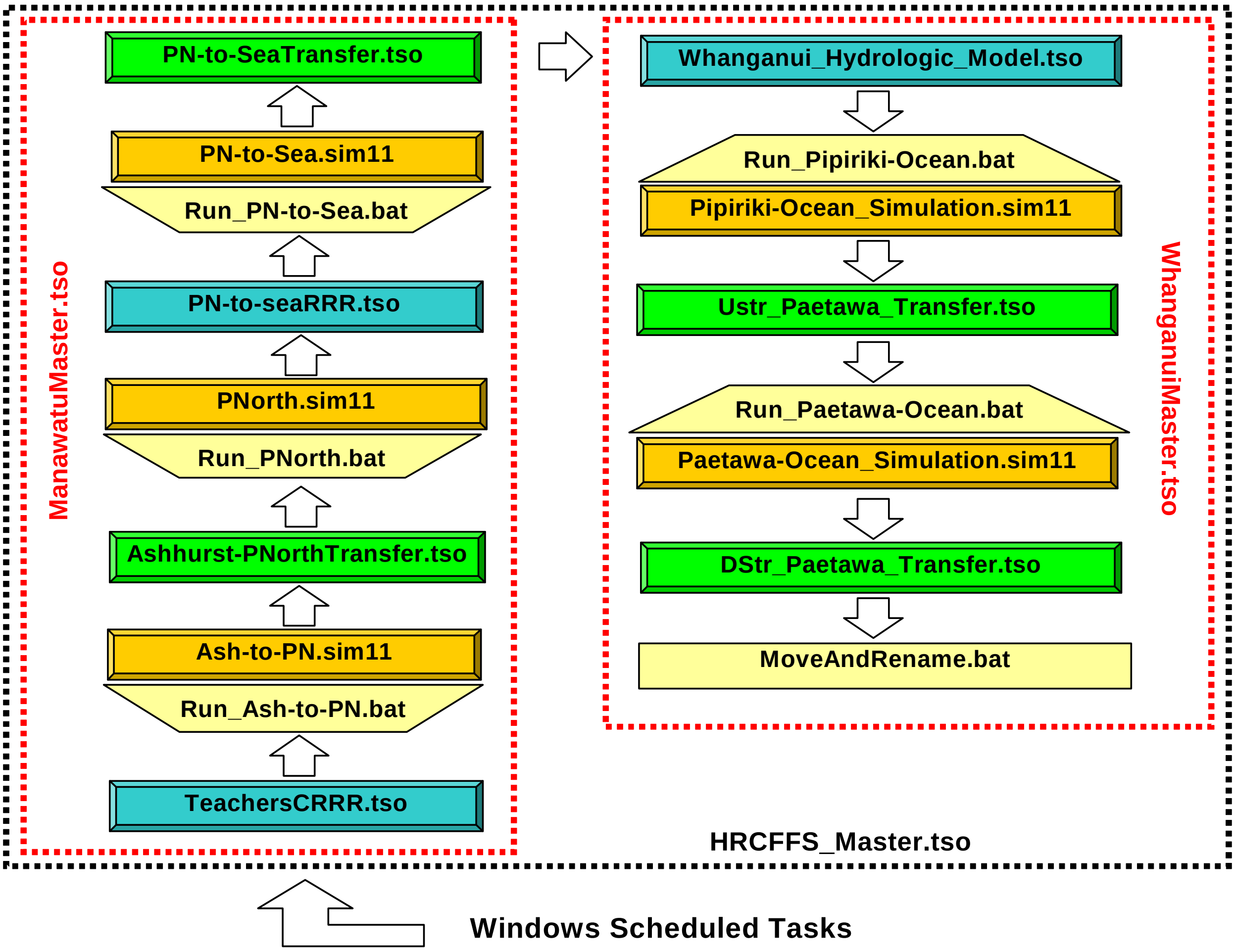


Figure 2-1: Interactions of the Components of the HRCFFS at Completion of Stage 3, representing the Scheduled Real-Time Operating System.

A diagram of the components that make up the HRCFFS is shown in Figure 2-1 above. In general each of the modelled catchments comprise of hydrological rainfall-runoff models to forecast flow at various points throughout the catchment for input to the hydraulic models. 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 is being used as the viewer interface for all output data produced by the HRCFFS.

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 (-24 hrs to +48 hrs). Via an Excel based user-interface or by executing the appropriate batch file, some various settings can be changed such as start/finish dates, the location and name of the Hilltop input and output files and some various run-modes of the hydrologic and hydraulic models (refer to Section 3 for more details). It is the Master Model that applies all these changes to all other models prior to running them. There are master models for the separate Manawatu and Whanganui catchments and also a master model that combines both systems (HRCFFS_Master).

Hydrologic Models

Software: Hydstra Modelling (formerly TimeStudio or Hydrol)
Inputs: Flows, rainfall and forecast rainfalls from Hilltop.
Outputs: Modelled flows for hydraulic model (.dfs0) and archived in Hilltop if outside of the hydraulic model extents.
Comments:
The hydrologic models are discussed in detail in the Manawatu Catchment Operating Manual (Cox, Jul 2006) and Section 4 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 Manawatu Catchment Operating Manual (Cox, Jul 2006) and Section 5 of this report.

Data Transfer Models

Software: Hydstra Modelling

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

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

Comments:

Transfer models are used primarily to change the file format of time series data so that it can be recognised either by Mike11 or Hilltop. Real-time error corrections at flow gauge locations are also performed in these models along with some other basic arithmetic functions (e.g. the preparation of the forecast tide information). The DStr_Paetawa_Transfer.tso model also provides key information (by producing a .xml file) for the web based real-time flood mapping of the lower Whanganui River catchment. Refer to the following report for more information on the web based mapping feature: Whanganui River Flood Forecasting System, Flood Map Preparation and On-Line Real Time Map Presentation, Ludlow, C, 2007.

Housekeeping Executable

Software: MS-DOS batch file

Comments:

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

3 SYSTEM OPERATION

3.1 REAL-TIME OPERATION - SCHEDULED RUNS

In its current set-up (at the completion of Stage3 of the project) the HRCFFS is automated using Windows Scheduled Tasks. A separate task is set up for the Manawatu and Whanganui components of the system (currently enabled) and a third task is available to run the Manawatu and Whanganui combined (currently disabled).

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

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

3.2 SINGLE RUN

Single runs are likely to be performed for two reasons:

1. If the automated system has failed, then a manual initialisation run (rough start) may be required. A rough start will set Mike11 to run from an initial parameter file rather than setting up initial conditions from the outputs of the previous run (hotstart file). This will provide a more stable environment for Mike11 and help get the system back up and running. More details on Hotstart File vs Parameter File are given in Section 5 of this report. It is also the only possible way to restart the system if it has been offline for a long period of time.

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

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

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

   C:\HRCFloodFS\Models\ RunHRCFFS_FloodModels_NoHotstart.bat

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

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

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

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

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

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

Settings that can be changed include:

- Model Start and Finish times. Either generic or fixed dates and times can be used. Generic times state the time with reference to now, for example (-1)/(0)/(0) means one day ago in this month on this year.

- Hilltop input and output file locations. It is recommended that if a scenario run is to be completed, then the output file location/name should be changed to avoid overwriting any existing information.

- Modelling Mode – there are three modes: Mode 1 uses no rainfall inputs in the model, ie it just routes measured flows through the catchment. Mode 2 uses measured rainfall inputs only, no forecast rainfall is used. Mode 3 uses all available input data including forecast rainfalls.

- The option of applying real-time flow error correction or not. This could be useful to perform a historical run with error correction turned off to review the calibration of the hydrological models.

- The option of running Mike11 with a hotstart file or a parameter file. The difference between the two has been discussed in (1) above. Generally for scenario runs, it would be expected that Use Hotstart file will be set to "N", especially if model run times have been adjusted.

- A check box is available to save any changes in settings to the model. Otherwise the settings will only apply to the single run and not to any future runs of the model.

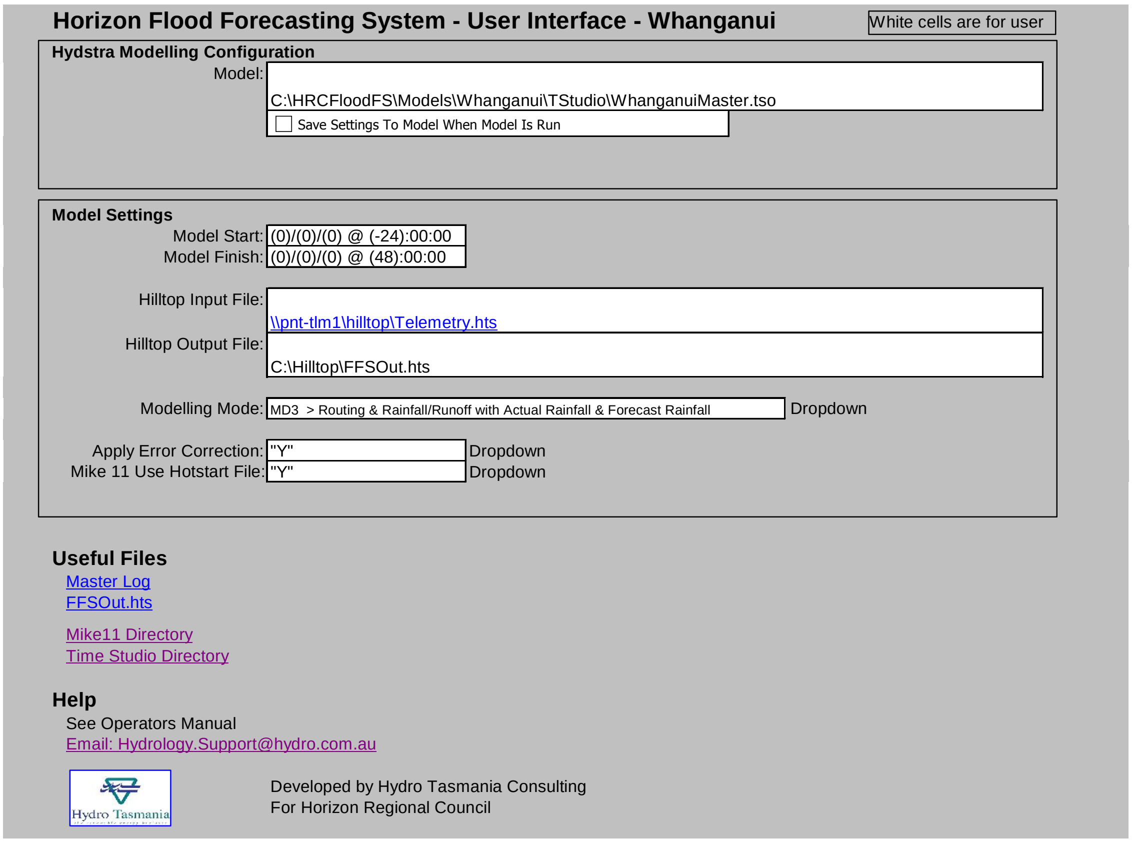
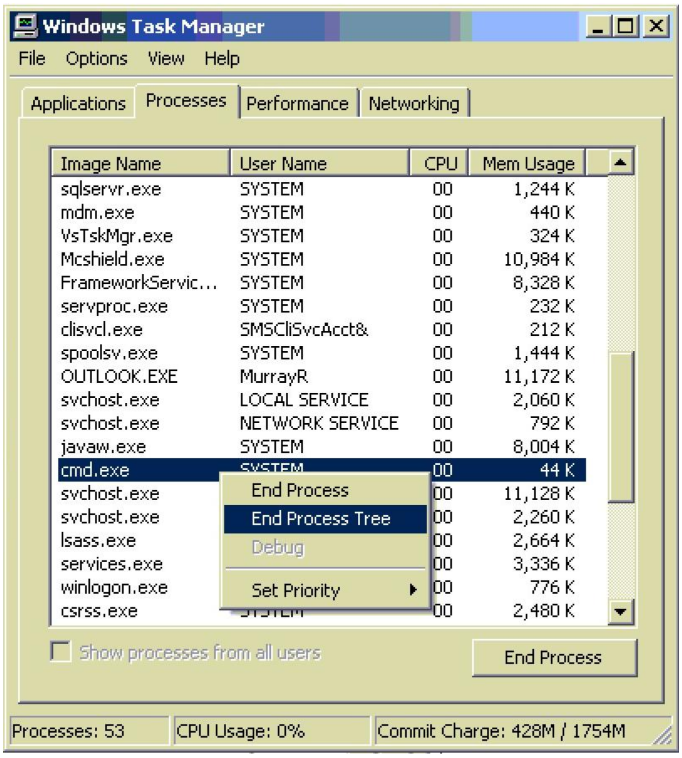


Figure 3-1 Screenshot of Whanganui-UserInterfaceV1.xls.

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 MODELS

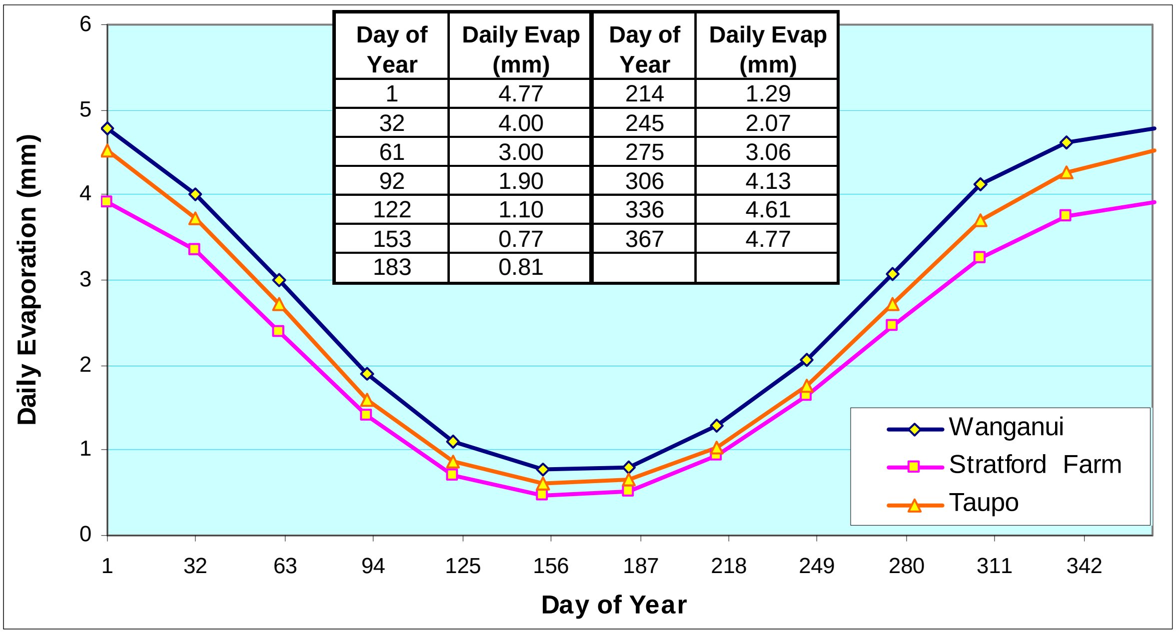
4.1 MEASURED INPUT DATA

4.1.1 Evaporation Data.

Average monthly evaporation data was obtained from HRC at the following locations:

- Wanganui Map Reference R22 850393
- Stratford Demonstration Farm Map Reference Q20 224068
- Taupo Map Reference U18 72759

These values are plotted in Figure 4-1 below to provide a representation of spatial variation in evapotranspiration over the catchment. The monthly average evaporation at Taupo is shown to be a good representation of the average of the three records and this record is adopted in the model. Evaporation values between each month are linearly interpolated.



Day of Year	Daily Evap (mm)	Day of Year	Daily Evap (mm)
1	4.77	214	1.29
32	4.00	245	2.07
61	3.00	275	3.06
92	1.90	306	4.13
122	1.10	336	4.61
153	0.77	367	4.77
183	0.81		

Figure 4-1: Average Potential Evapotranspiration around the Whanganui River Catchment.

4.1.2 Rainfall Data

Rainfall data was provided by Horizons Regional Council (HRC) in a Hilltop Database. The sites in Table 4-1 were considered for use in the model. Figure 4-3 shows the variation of mean annual rainfalls across the catchment at each gauge location. The long-term average measured data at each gauge has been cross-compared to the output from a GIS grid that was developed using the supplied isohyet information for the Horizons Region. The two methods compare well in all regions except for the mountainous region in the Tongariro National Park where the rainfall gauges record much higher annual totals than the supplied isohyet map. The yellow columns on the plot represent the adopted mean annual rainfalls used in the model.

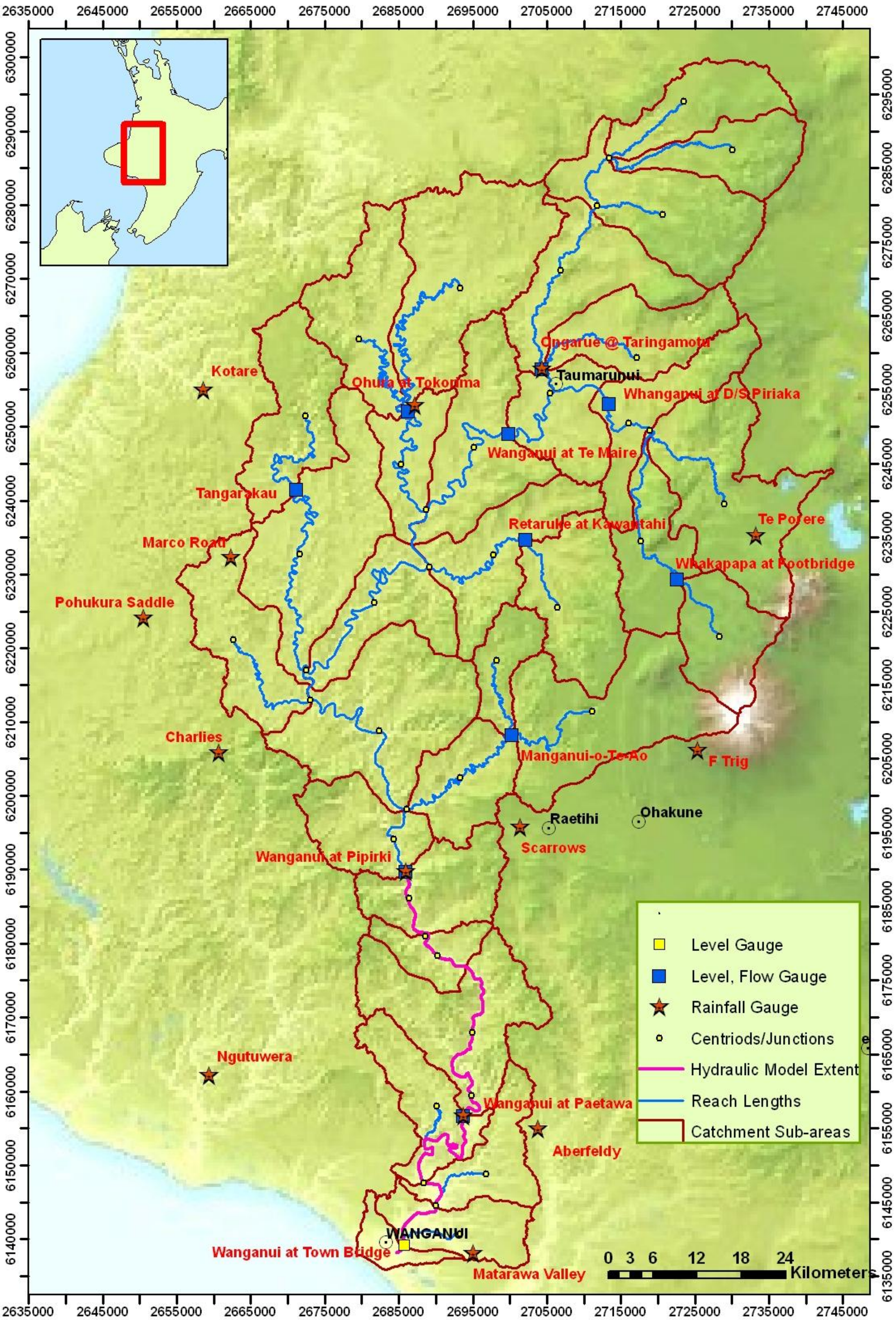


Figure 4-2: Location of Measured Site Information in the Whanganui Catchment

Table 4-1: Rain Gauge Details

Id	Site Name	Ann Rainfall (mm)	Recording Agency	Easting (km)	Northing (km)
Rain1	Matarawa Valley	1000	HRC/WDC	2695	6138
Rain2	Paetawa	1022	NIWA	2693.7	6156.6
Rain3	Pipriki	1275	HRC	2685.9	6189.7
Rain4	Scarrows	1500	HRC	2701.4	6195.7
Rain5	TePorere	2300	HRC	2733.2	6235.2
Rain6	FTrig	2500	NIWA	2725.4	6206.1
Rain7	Ongarue	1460	NIIWA/Genesis	2704.3	6257.8
Rain8	Marco Road	2000	-	2662.3	6232.3
Rain9	Ohura	1717	HRC	2687.1	6252.8
Rain10	Pohukura Saddle	1820	TRC	2650.5	6224.1
Rain11*	Kotare	1950	TRC	2658.5	6254.9
Rain12*	Ngutuwera	1130	TRC	2659.3	6162.1
Rain13	Aberfeldy	1018	HRC	2703.8	6154.8
Excluded*	Charlies	1580	TRC	2660.7	6205.7

* These sites are not being used in the current live model. Charlies has been completely excluded, whereas Kotare and Ngutuwera are coded into the model but have been disabled.

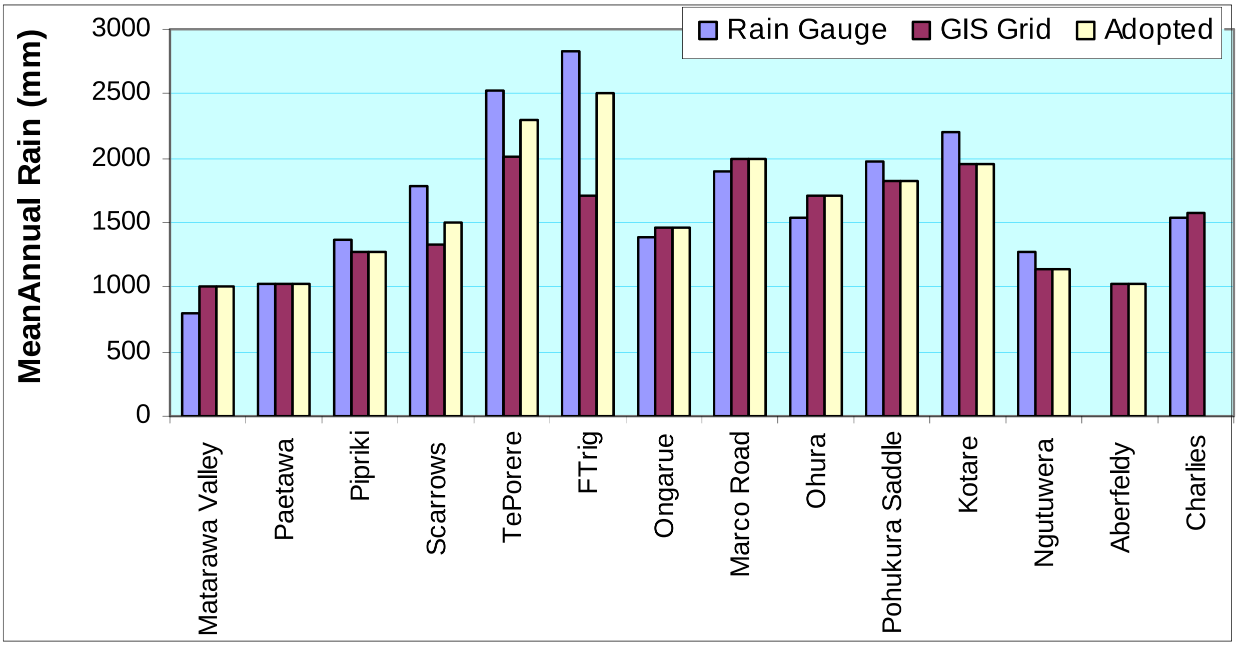


Figure 4-3: Mean Annual Rainfalls at each Gauge

4.1.3 Flow Data

Flow data was provided by Horizons Regional Council (HRC) in a Hilltop Database. Relevant flow data was used to calibrate the hydrologic models. This is discussed in Section 4.4 below.

Table 4-2: Flow Gauge Details

Site	Recording Agency	Map Sheet	Easting	Northing	Comments
Current river level recording sites					
Wanganui at Town Bridge	NIWA/WDC	R22	2685700	6139100	Not used
Current river level & flow recording sites					
Wanganui at Paetawa	NIWA	S22	2693700	6156600	Calibration & correction
Wanganui at Pipirki	HRC	R21	2685900	6189700	Calibration & correction
Wanganui at Te Maire	NIWA/Genesis	S19	2699800	6249000	Calibration & correction
Ongarue at Taringamotu	NIWA/HRC	S18	2704300	6257800	Calibration & correction
Whakapapa at Footbridge	Genesis	S19	2722600	6229300	Not used
Whanganui at downstream Piriaka	Genesis/KCE/NIWA	S18	2713400	6253100	Not used
Closed river level and flow recording sites					
Manganui-o-Te-Ao at Ashworth	NIWA	S20	2700300	6208200	Calibration only
Tangarakau at Tangarakau	NIWA	R19	2671200	6241400	Calibration only
Retaruke at Kawautahi	NIWA	S19	2702200	6234700	Not used
Ohura at Tokorima	HRC	R18	2686300	6252100	Calibration only

4.2 HYDSTRA MODEL PROCESSES AND METHODOLOGY

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

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

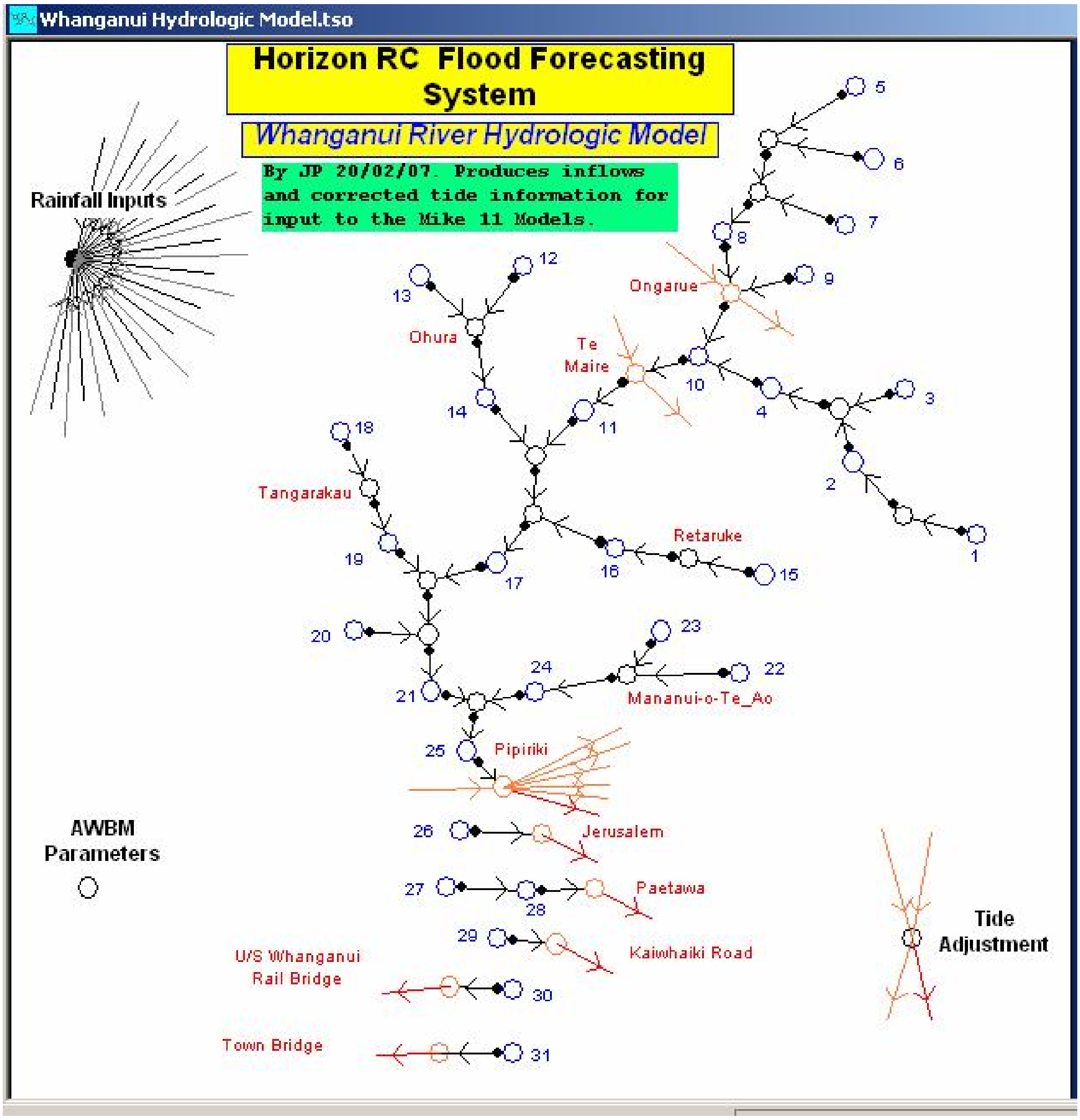


Figure 4-4: Hydstra Model Schematic

4.2.1 Rainfall Gap Filling and Interpolation Algorithm

Figure 4-5 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).

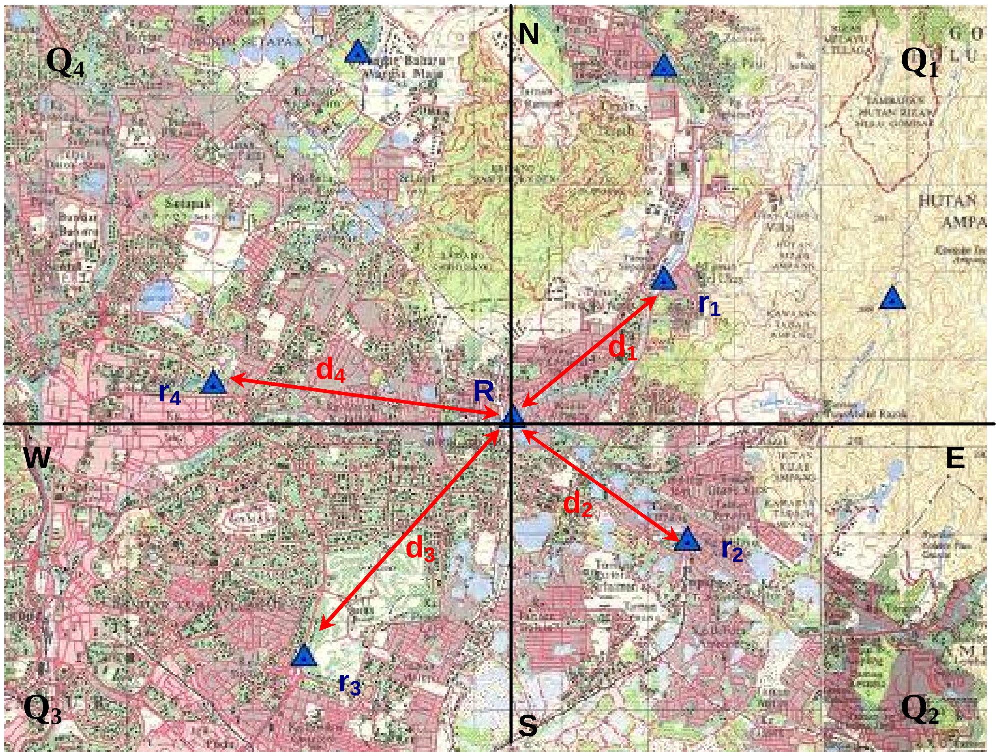


Figure 4-5: Rain Gauge Weighting by Quadrants

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

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

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

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

The inverse distance weighting of the rainfall gauge in each quadrant is determined with the following equation,

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

The actual contribution of rainfall from each gauge is then,

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

where MAR is the mean annual rainfall .

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

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

When there is no measured rainfall data in the catchment then the model will revert to the forecast rainfall algorithm and provide a rainfall estimate at each rain gauge location.

For the infilling of missing rainfall data, this procedure is performed during each time step of the model. When determining the rainfall distribution to each sub catchment in the model, the procedure is performed once at the beginning of the model run.

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

4.2.2 Rainfall/Runoff Algorithm

The Australian Water Balance Model (AWBM) was applied to calculate the runoff based on the rainfall inputs. The AWBM model is a relatively simple water balance model with the following characteristics:

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

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

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

The model parameters are:

Surface Store Parameters:

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

Surface Store Parameters:

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

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

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

The AWBM processes are shown schematically in Figure 4-6.

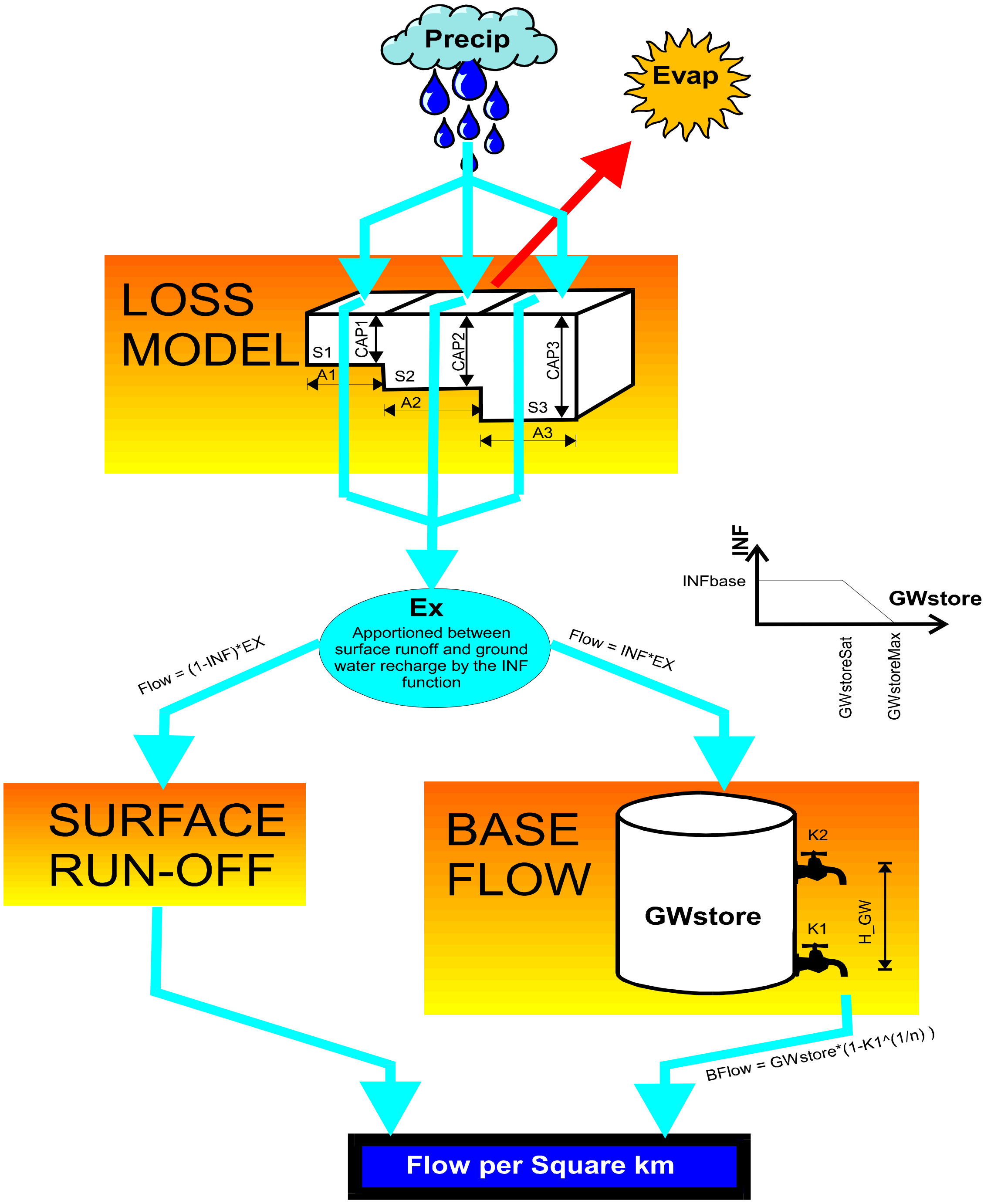


Figure 4-6 Australian Water Balance Model Schematic

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

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

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

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

4.2.3 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. 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

4.2.4 Channel Routing Algorithm

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 (m3/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

4.2.5 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.

The equation parameters have been determined by investigating two observed recession periods at each flow station as shown in the Figures below. This approach has also been applied to some of the rivers in the Manawatu Flood Forecasting System. The recession factors determined below only apply when the model is run on a 15 minute time step.

Two recession equations have been applied at the Oroua River at Almadale Slackline to better fit the two-staged recession slope that is present there.

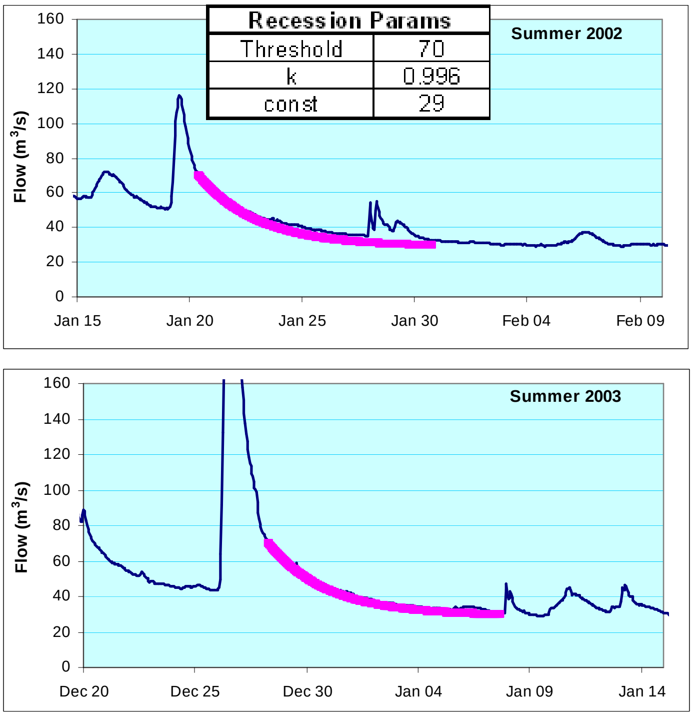


Figure 4-7: Whanganui River at TeMaire - Recession Parameters

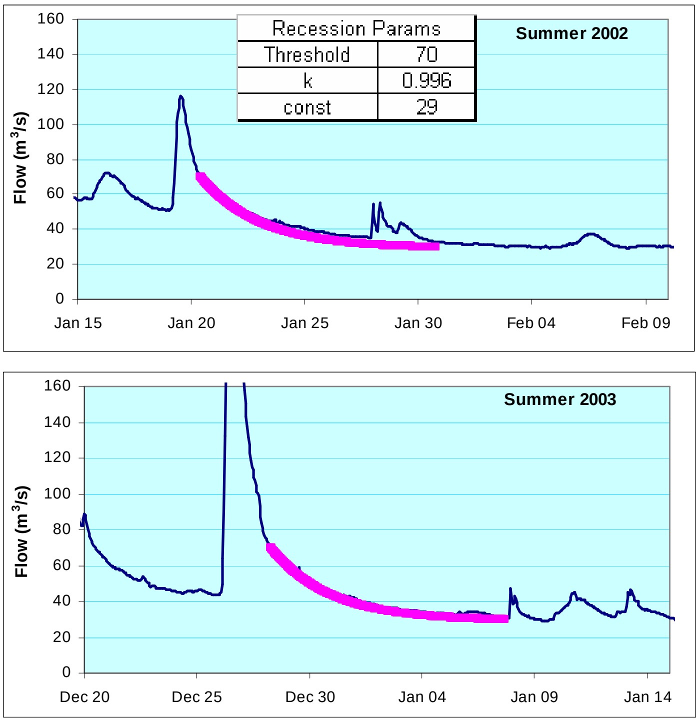


Figure 4-8: Whanganui River at Piriaka – Recession Parameters

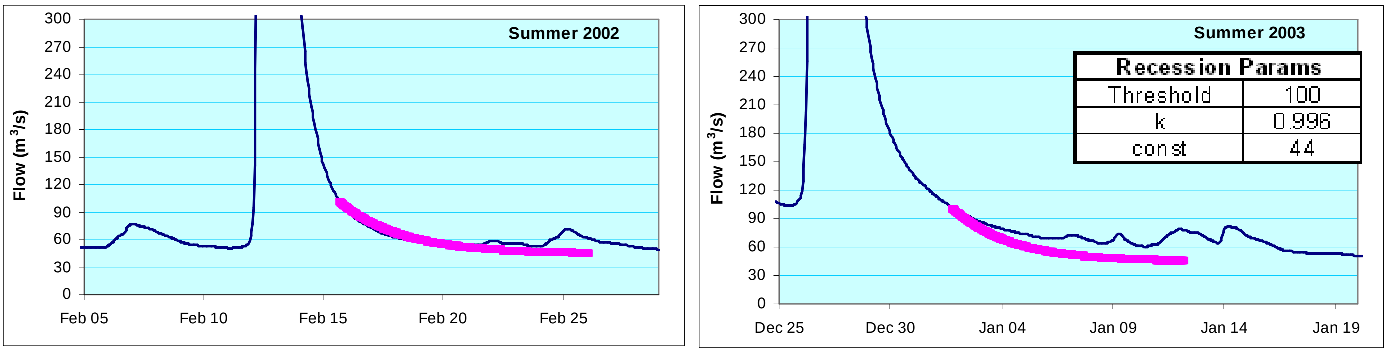


Figure 4-9: Whanganui River at Paetawa – Recession Parameters

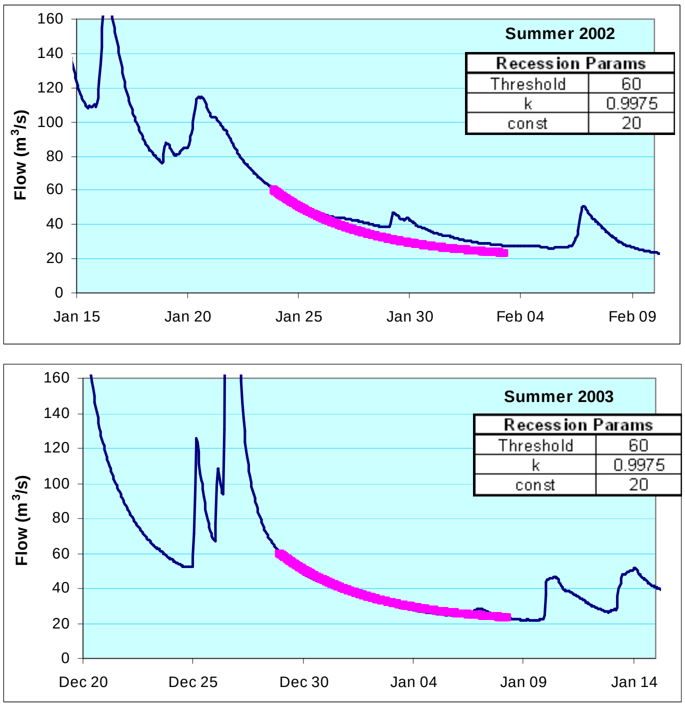


Figure 4-10: Manawatu River at Teachers College – Recession Parameters

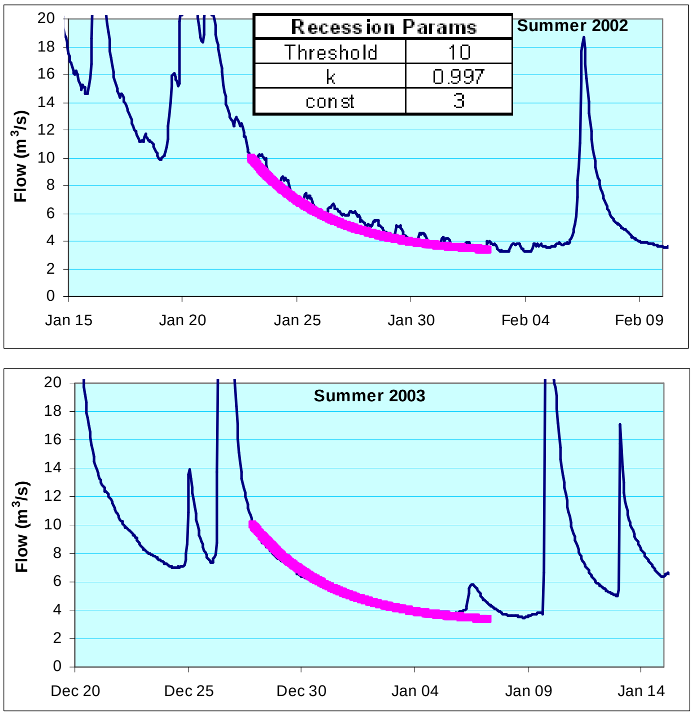


Figure 4-11: Pohangina River at Mais Reach – Recession Parameters

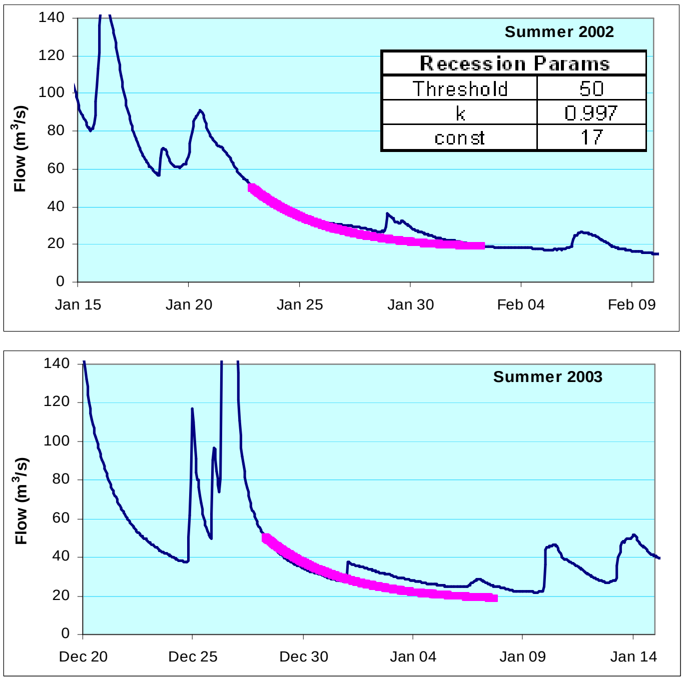


Figure 4-13: Manawatu River at Upper Gorge – Recession Parameters

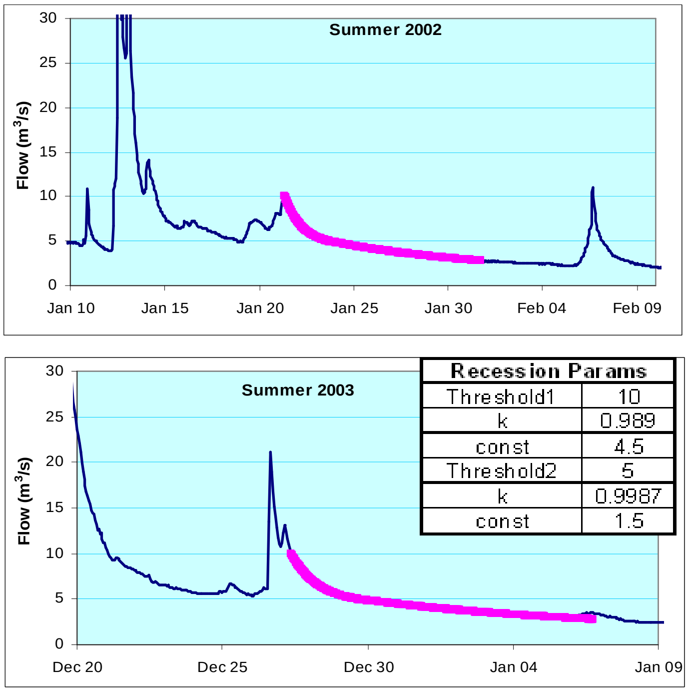


Figure 4-14: Oroua River at Almadale Slackline – Recession Parameters

4.2.6 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 this amplitude correction algorithm differs slightly from the one originally developed for the Manawatu River Flood Forecasting System. All error correction nodes in the Manawatu models have now been replaced with this algorithm and the recession equation algorithm discussed above.

4.3 MODEL DETAILS

4.3.1 Subcatchment Delineation

The Whanganui River catchment has been divided into 31 sub-areas of relatively equal size. The sub-areas have been selected to provide break points at all existing flow gauge locations and to best capture the spatial distribution of the rainfall gauge network around the catchment.

Figure 4-15 shows the sub-catchment breakdown for the Whanganui River Catchment along with the river network and associated identifiers. Table 4-3, Table 4-4 and Table 4-5 list the properties of the catchment components of the rainfall-runoff model structure including the catchment sub-areas, junctions (including locations of flow gauges) and reach (river) lengths.

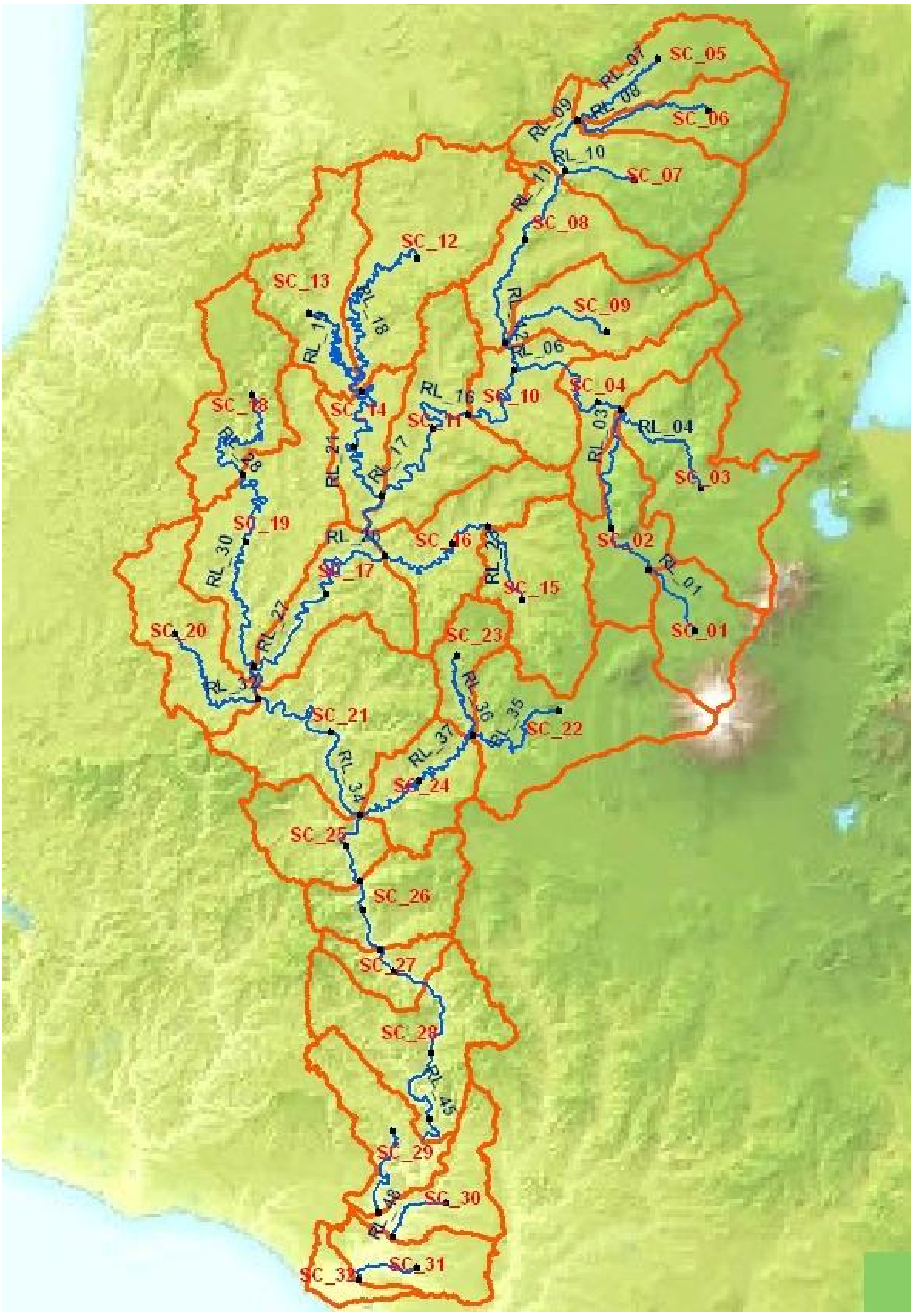


Figure 4-15: Subcatchment Breakdown

Table 4-3: Subcatchment Node Details

Identifier	Centriod Easting	Centroid Northing	Catchment Area (km^2)	Mean Annual Rainfall (mm/Yr)	Calibration Region/River
SC_01	2728285	6221481	173.2	2400	Te Maire / Ongarue
SC_02	2717702	6234483	182.1	1780	Te Maire / Ongarue
SC_03	2728951	6239442	375.9	1880	Te Maire / Ongarue
SC_04	2716029	6250379	190.2	1410	Te Maire / Ongarue
SC_05	2723508	6293990	169.3	1800	Te Maire / Ongarue
SC_06	2730039	6287459	159.8	1669	Te Maire / Ongarue
SC_07	2720605	6278690	298.0	1540	Te Maire / Ongarue
SC_08	2706817	6271131	254.0	1490	Te Maire / Ongarue
SC_09	2717158	6259338	202.0	1400	Te Maire / Ongarue
SC_10	2705486	6254500	174.1	1460	Te Maire / Ongarue
SC_11	2695181	6247184	284.6	1580	Pipiriki / Paetawa
SC_12	2693271	6268712	421.8	1587	Ohura
SC_13	2679603	6261817	236.6	1730	Ohura
SC_14	2685288	6244885	127.8	1750	Ohura
SC_15	2706394	6225412	254.3	1600	Pipiriki / Paetawa
SC_16	2697746	6232608	229.9	1600	Pipiriki / Paetawa
SC_17	2681659	6226137	198.8	1700	Pipiriki / Paetawa
SC_18	2672346	6251416	244.0	1930	Tangarakau
SC_19	2671560	6232729	386.3	1920	Tangarakau
SC_20	2662670	6221057	229.2	1770	Pipiriki / Paetawa
SC_21	2682325	6208660	396.7	1480	Pipiriki / Paetawa
SC_22	2711108	6211387	381.1	1550	Manganui-o-Te-Ao
SC_23	2698229	6218215	97.4	1530	Manganui-o-Te-Ao
SC_24	2693331	6202310	163.7	1370	Manganui-o-Te-Ao
SC_25	2684320	6194086	166.7	1320	Pipiriki / Paetawa
SC_26	2686384	6186054	190.3	1240	Pipiriki / Paetawa
SC_27	2690232	6178270	86.5	1175	Pipiriki / Paetawa
SC_28	2694877	6167864	315.1	1100	Pipiriki / Paetawa
SC_29	2690143	6157962	169.2	1030	Pipiriki / Paetawa
SC_30	2696811	6148665	151.5	1000	Pipiriki / Paetawa
SC_31	2693228	6140656	142.9	1000	Pipiriki / Paetawa

Table 4-4: Junction Node Details

Junction Identifier	Easting	Northing	Comments
JN_01	2722369	6229294	Location of Whakapapa R. at Footbridge. No input in place.
JN_02	2718851	6249481	Standard River Junction
JN_03	2713409	6286310	Standard River Junction
JN_04	2711836	6279839	Standard River Junction
JN_05	2704302	6257995	Location of Ongarue R. at Taringamotu. Error corrections applied.
JN_06	2699706	6248860	Location of Whanganui R. at Te Maire. Error corrections applied.
JN_07	2686099	6251891	Location of Ohura R. at Tokorima. No input in place.
JN_08	2688674	6238656	Standard River Junction
JN_09	2702160	6234714	Location of Retaruke R. flow station. No input in place.
JN_10	2689098	6230915	Standard River Junction
JN_11	2671149	6241384	Location of Tangarakau R. at Tangarakau. No input in place
JN_12	2672467	6216885	Standard River Junction
JN_13	2673072	6212893	Standard River Junction
JN_14	2700165	6208116	Manganui - o - Te Ao at Ashwurst. No input in place.
JN_15	2686074	6198077	Standard River Junction
JN_16	2685910	6189626	Whanganui R. at Pipiriki. Error corrections applied. Flows output for hydraulic model.
JN_17	2688557	6180898	Location of Jerusalem. Flows output for hydraulic model.
JN_18	2694804	6159387	Location of Whanganui R. at Paetawa. Flows output for hydraulic model.
JN_19	2688385	6147507	Location of Kaiwhaiki Road. Flows output for hydraulic model.
JN_20	2689992	6144446	Location of U/S Whanganui Rail Bridge. Flows output for hydraulic model.
JN_21	2685820	6139097	Location of Whanganui R. at Town Bridge. Flows output for hydraulic model.

Table 4-5: Reach Length Details

Reach ID	Length (km)	Reach ID	Length (km)
RL_01	12.23	RL_26	19.68
RL_02	9.84	RL_27	19.02
RL_03	18.94	RL_28	25.45
RL_04	21.00	RL_29	19.71
RL_05	3.34	RL_30	25.37
RL_06	18.07	RL_31	5.59
RL_07	15.69	RL_32	23.32
RL_08	22.75	RL_33	17.37
RL_09	10.02	RL_34	13.97
RL_10	10.82	RL_35	22.48
RL_11	12.46	RL_36	17.27
RL_12	17.90	RL_37	15.77
RL_13	20.76	RL_38	15.42
RL_14	4.66	RL_39	6.26
RL_15	16.78	RL_40	5.33
RL_16	13.18	RL_41	4.12
RL_17	17.15	RL_42	6.51
RL_18	45.84	RL_43	3.88
RL_19	32.84	RL_44	15.76
RL_20	20.66	RL_45	13.04
RL_21	14.80	RL_46	5.48
RL_22	10.46	RL_47	16.91
RL_23	12.02	RL_48	10.89
RL_24	7.16	RL_49	10.05
RL_25	16.63		

Reaches labelled in blue are used in calibration model only

4.3.2 Rainfall Distribution

Table 4-6 below show the rain gauge weighting factors for each sub catchment in the model.

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

The rainfall interpolation applied in the hydrological model (discussed in Section 4.2.1) 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 4-6: Rainfall Gauge Weightings at each Sub Catchment Centroid – all Gauges

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
	Matarawa Valley	Paetawa	Pipriki	Scarrows	TePorere	FTrig	Ongarue	Marco Road	Ohura	Pohukura Saddle	Kotare	Ngutuwera	Aberfeldy
SC_01	0	0	0	0	0.46	0.39	0.24	0	0	0	0	0	0
SC_02	0	0	0	0.18	0.31	0.15	0.28	0	0	0	0	0	0
SC_03	0	0	0	0	0.59	0.10	0.18	0	0	0	0	0	0
SC_04	0	0	0	0.12	0.20	0	0.52	0	0	0	0	0	0
SC_05	0	0	0	0	0.32	0	0.73	0	0	0	0	0	0
SC_06	0	0	0	0	0.31	0	0.65	0	0	0	0	0	0
SC_07	0	0	0	0	0.25	0	0.67	0	0	0	0	0	0
SC_08	0	0	0	0	0.15	0	0.78	0	0	0	0	0	0
SC_09	0	0	0	0	0.19	0	0.66	0	0	0	0	0	0
SC_10	0	0	0	0	0.05	0	0.77	0	0.12	0	0	0	0
SC_11	0	0	0	0	0.08	0	0.34	0.10	0.41	0	0	0	0
SC_12	0	0	0	0	0	0	0.57	0	0.44	0	0	0	0
SC_13	0	0	0	0	0	0	0	0	0.66	0	0.31	0	0
SC_14	0	0	0	0	0.07	0	0	0.15	0.58	0	0.14	0	0
SC_15	0	0	0	0.26	0.18	0.17	0.25	0	0	0	0	0	0
SC_16	0	0	0	0.21	0	0	0.31	0.16	0.30	0	0	0	0
SC_17	0	0	0	0.21	0	0	0	0.29	0.25	0.21	0	0	0
SC_18	0	0	0	0.10	0	0	0	0.22	0.38	0	0.35	0	0
SC_19	0	0	0.16	0	0	0	0	0.50	0.21	0	0.18	0	0
SC_20	0	0	0.23	0	0	0	0	0.50	0.16	0	0	0.17	0
SC_21	0	0	0.48	0	0	0	0	0.19	0.15	0	0	0.20	0
SC_22	0	0	0	0.33	0.12	0.24	0.13	0	0	0	0	0	0
SC_23	0	0	0.30	0.35	0.13	0	0	0	0.19	0	0	0	0
SC_24	0	0	0.34	0.40	0	0.08	0	0.07	0	0	0	0	0
SC_25	0	0	0.69	0.16	0	0	0	0.05	0	0	0	0.09	0
SC_26	0	0.10	0.68	0.12	0	0	0	0	0	0	0	0.08	0
SC_27	0	0.26	0.37	0.19	0	0	0	0	0	0	0	0.15	0
SC_28	0	0.42	0.16	0.11	0	0	0	0	0	0	0	0	0.30
SC_29	0	0.83	0	0.05	0	0	0	0	0	0	0	0.09	0
SC_30	0.29	0.36	0	0	0	0	0	0	0	0	0	0	0.33
SC_31	0.78	0.15	0	0	0	0	0	0	0	0	0	0.06	0

4.4 MODEL CALIBRATIONS

4.4.1 Calibration Methodology and Adopted Parameters

Calibration was achieved by adjusting catchment parameters so that the modelled data best replicated the record at measured flow sites. The calibration process uses all available measured rainfall inputs and no corrections to measured flows in the catchment. This process determines the optimum parameters that allow the model to best represent the catchment and river characteristics given the measured rainfall available. When performing real-time, the model will be forecasting using forecast rainfall inputs which is likely to affect the results shown in the Sections below. For Paetawa, a plot (Figure 4-25) shows the achievable lead-time when rainfall is set to zero over future time-steps for a well calibrated event.

The calibration process was performed in two phases.

In the first phase, the available tributary information from 1965 was used to get a general feel for the varying catchment and river characteristics. Results are shown in Section 4.4.5. Given the limited rainfall data available over this time period, this calibration focussed on investigating and best matching the different responses of each river rather than matching flood peaks.

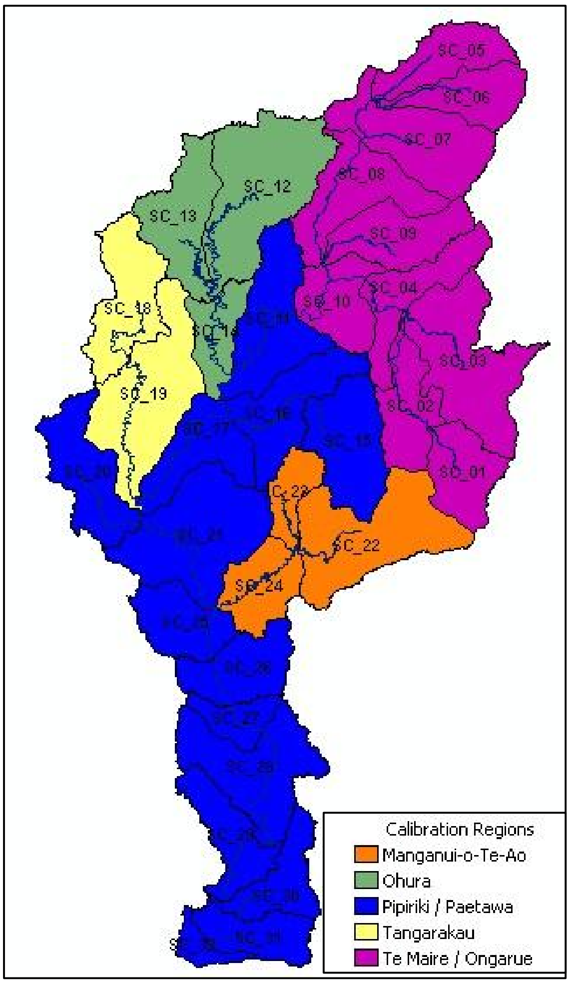
The second phase involved calibrating to the key available sites over the time period where a good representation of the current rainfall gauge network was available. The adopted period was from 1998 to mid 2004, however for Paetawa the March 1990 event plot has been included as a verification of the final adopted parameter set (despite the lack of rainfall information during this period). The top priority of the calibration was to best match the flood events and in some cases the fit of low flows is affected by this.

The adopted AWBM and routing parameters are shown below in Figure 4-16. Calibration results are shown for Whanganui River at Te Maire and Paetawa .

The Te Rewa gauge had only recently been commissioned and was not available for calibration during this study. Calibration results identified an inconsistency between measured flows at Pipiriki and Paetawa and resulted in the Pipiriki rating being reviewed based on the rating at Paetawa. Therefore no results are shown at Pipiriki. Ongarue River at Taringamutu was considered during calibration but parameter adjustments on the Ongarue were only performed to achieve a better fit at Te Maire.

Calibration results include:

- Tabulated event statistics comparing peaks and timing. At the base of the table, a rating has been given to the quality of the calibration based on performance criteria specified in Chinese Standards (2000). Table 4-7 below shows some details on the performance criteria indicated. For more information refer to the hydrological model calibration component of the Manawatu Catchment Operating Manual, Cox G.
- Event plots.
- Monthly and seasonal volume balances.
- X-Y plots including correlation coefficients.
- A sample annual time series plot.



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

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

Figure 4-16: Calibration Parameters – Whanganui River Catchment

Table 4-7: 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 is <= 20%).
Coeff of Determination (CD) = Measure of goodness of fit (R^2).

4.4.2 Paetawa Calibration Results

Table 4-8: Event Comparison – Whanganui River at Paetawa

Event Time	Peak Flow (m^3/s)		% Difference (Mod - Obs)		Timing Difference (Mod - Obs)	
	Observed	Modelled	Actual	Absolute	Actual (hrs)	Absolute (hrs)
03/07/1998 @ 03:00:00	2588.9	2820.3	8.9	8.9	-2.2	2.2
10/07/1998 @ 10:00:00	3337.5	3222.9	-3.4	3.4	0.7	0.7
14/10/1998 @ 04:00:00	2488.0	2439.8	-1.9	1.9	1.8	1.8
21/10/1998 @ 15:00:00	3328.6	3617.9	8.7	8.7	-3.5	3.5
29/10/1998 @ 11:00:00	3814.2	3674.6	-3.7	3.7	1.7	1.7
17/05/1999 @ 09:00:00	2681.1	3492.5	30.3	30.3	-9.3	9.3
03/10/2000 @ 03:00:00	3798.6	3491.7	-8.1	8.1	6.9	6.9
26/05/2001 @ 06:00:00	2198.3	1887.8	-14.1	14.1	-	-
10/12/2001 @ 00:00:00	2479.2	1849.5	-25.4	25.4	-	-
04/10/2003 @ 17:00:00	2478.7	2395.1	-3.4	3.4	3.5	3.5
16/02/2004 @ 10:00:00	3283.9	2535.9	-22.8	22.8	5.9	5.9
29/02/2004 @ 21:00:00	3264.0	3283.5	0.6	0.6	-0.5	0.5
21/06/2004 @ 10:00:00	2292.7	2066.5	-9.9	9.9	5.6	5.6
			Average	**10.9**	**Average**	**3.8**

Chinese Standards Performance Indicators:

QR = 77% CD = 0.89 Accuracy Grading = B

Recommendation: Suitable for making official forecasts.

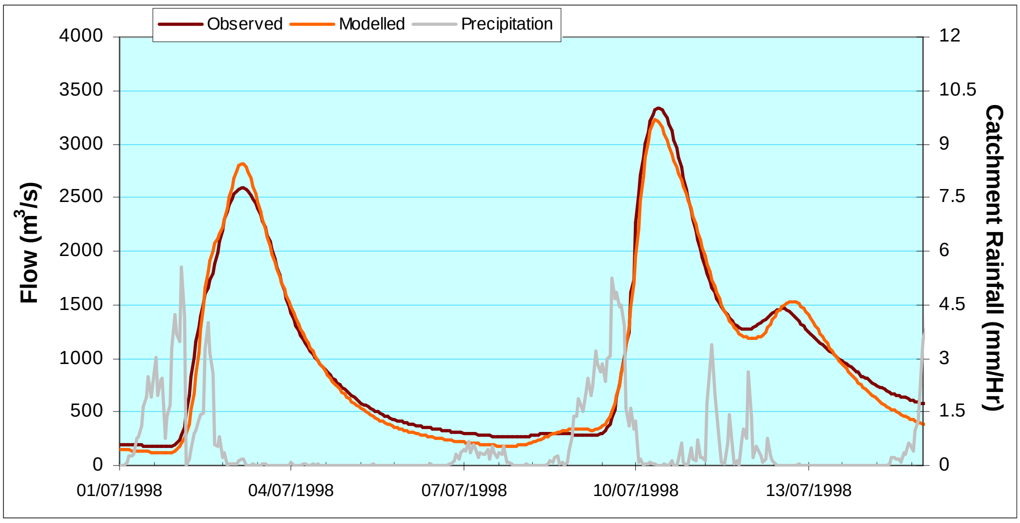


Figure 4-17: July 1998 Event Plot – Whanganui River at Paetawa

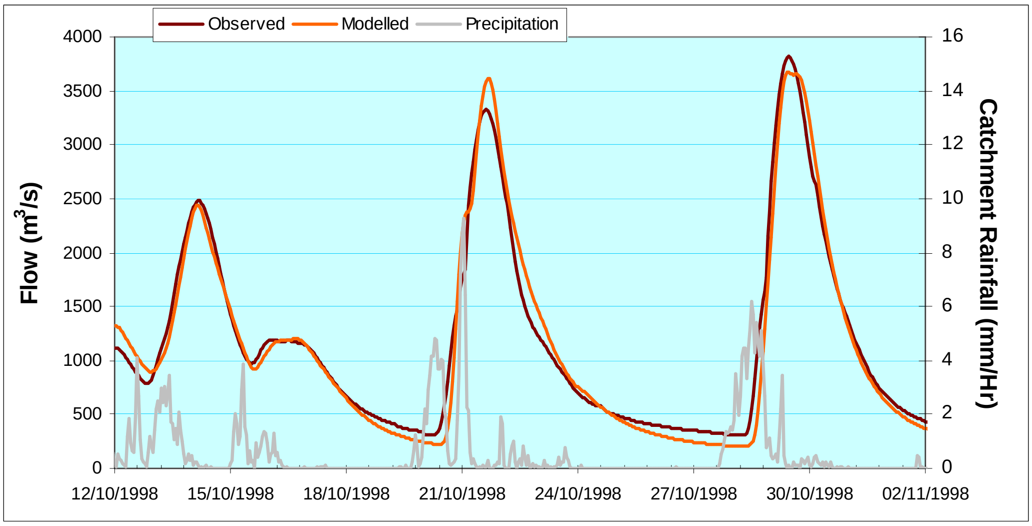


Figure 4-18: October 1998 Event Plot – Whanganui River at Paetawa

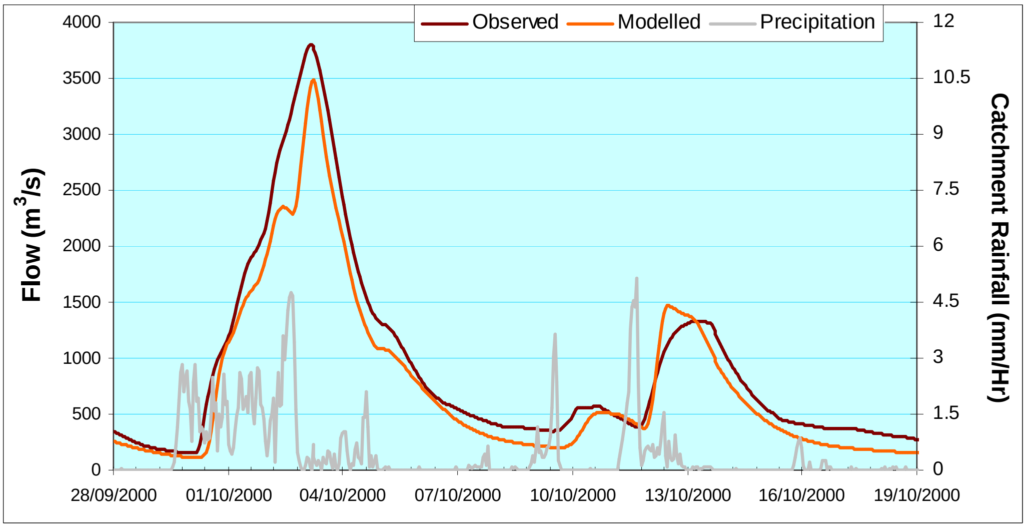


Figure 4-19: October 2000 Event Plot – Whanganui River at Paetawa

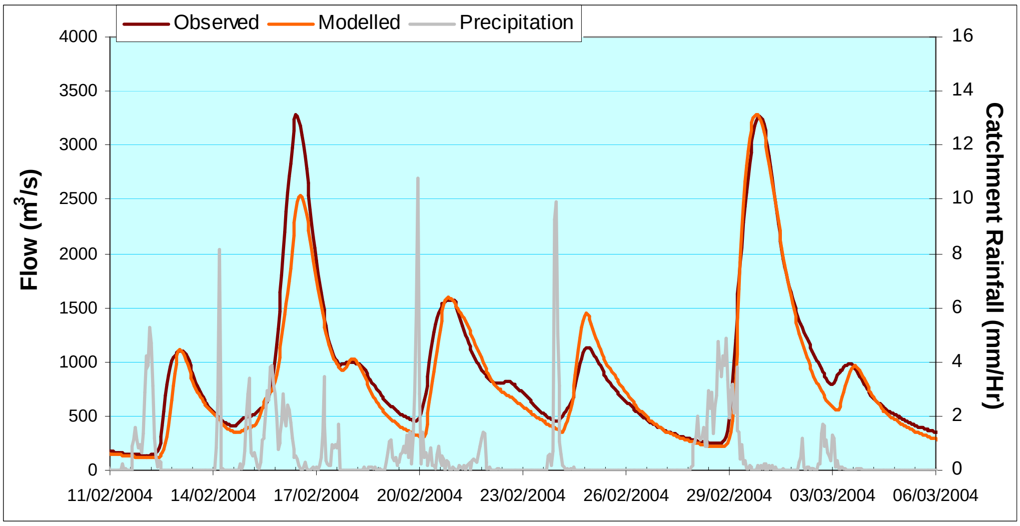


Figure 4-20: February 2004 Events – Whanganui River at Paetawa

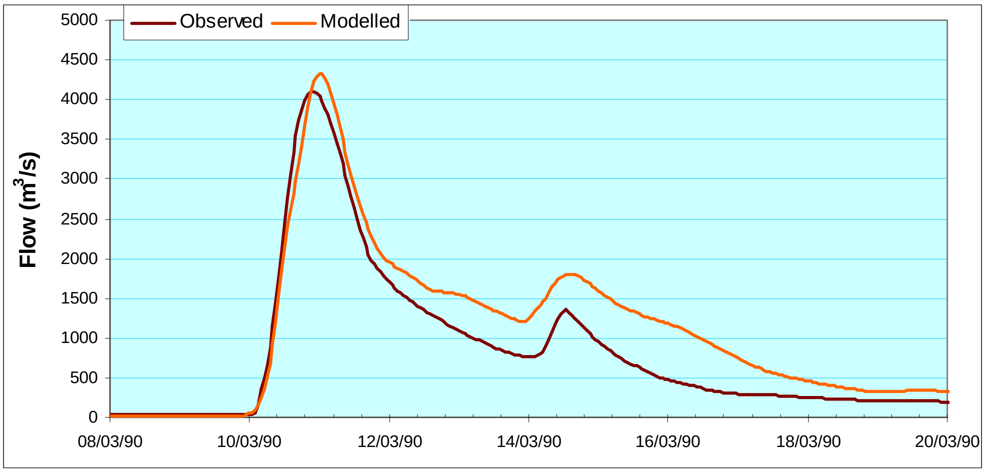


Figure 4-21: March 1990 Event – Whanganui River at Paetawa

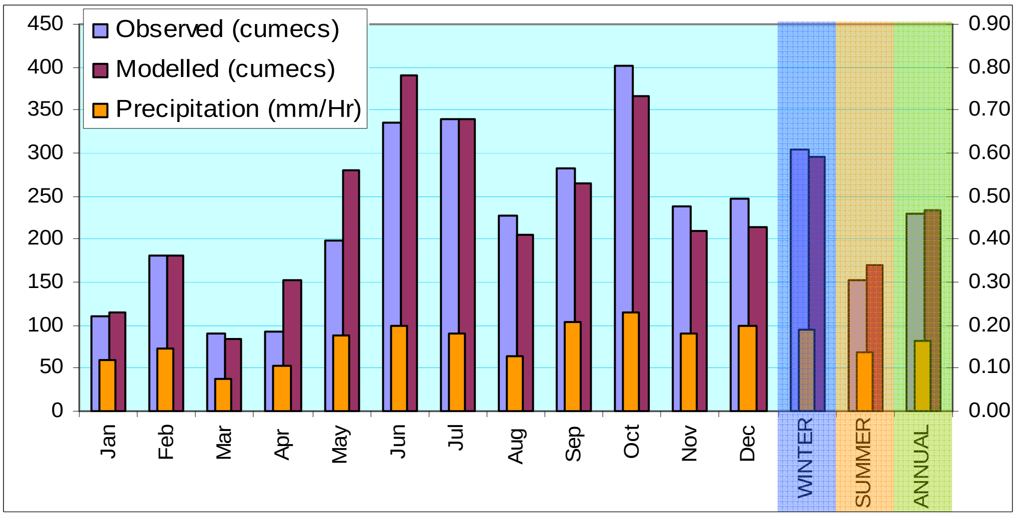


Figure 4-22: Monthly and Seasonal Long Term Volumes – Whanganui River at Paetawa

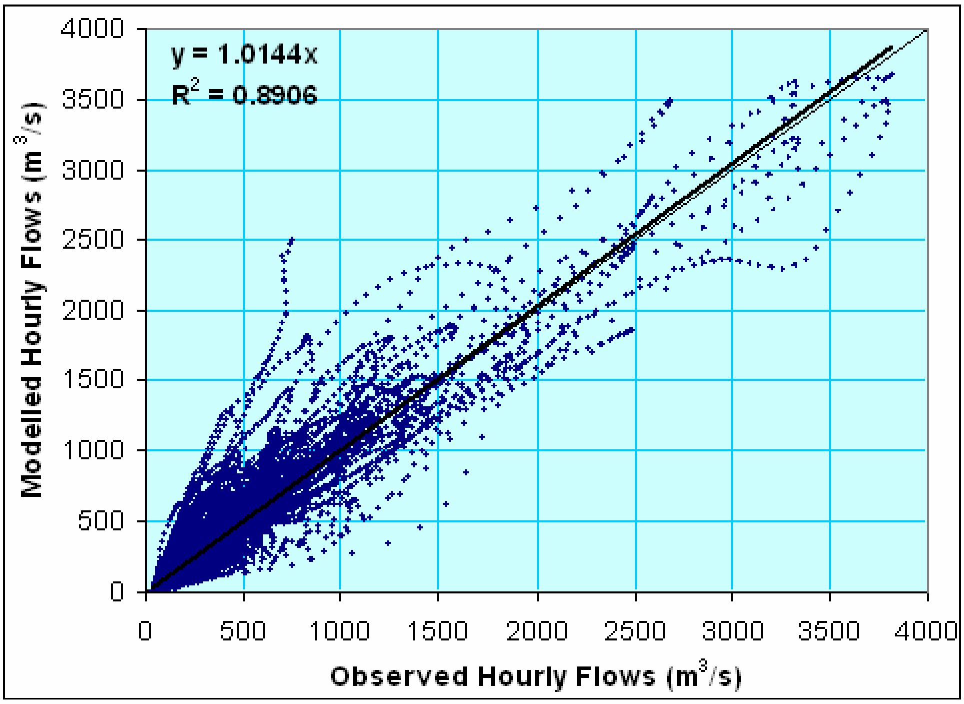


Figure 4-23: Modelled Flows vs Observed Flows - Whanganui River at Paetawa

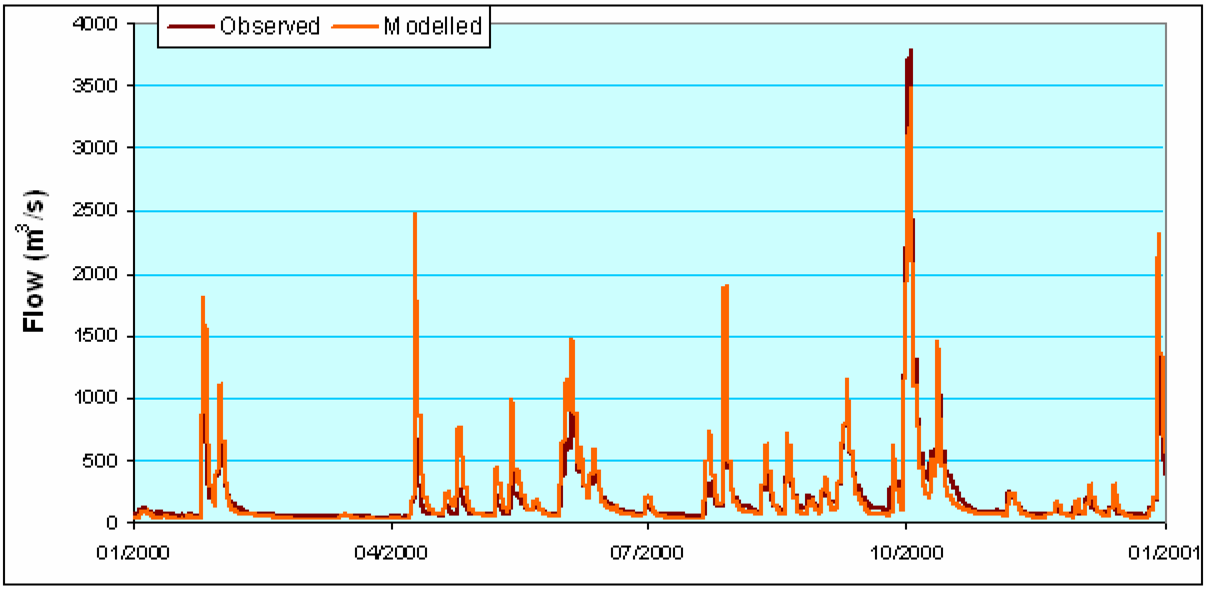


Figure 4-24: Annual Time Series Plot – Whanganui River at Paetawa

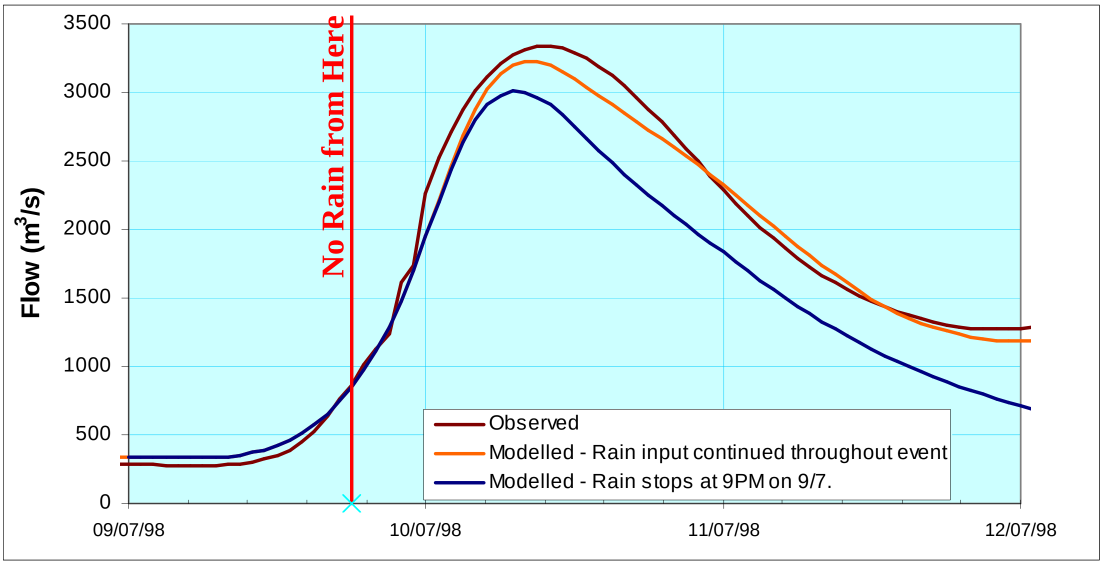


Figure 4-25: Lead Time – Whanganui River at Paetawa

4.4.3 Paetawa Calibration - Effects of no Taranaki Rain Gauges

Table 4-9: Event Comparison – Whanganui River at Paetawa, no Taranaki Rain Inputs

Event Time	Peak Flow (m^3/s)		% Difference (Mod - Obs)		Timing Difference (Mod - Obs)	
	Observed	Modelled	Actual	Absolute	Actual (hrs)	Absolute (hrs)
03/07/1998 @ 03:00:00	2588.9	2930.1	13.2	13.2	-2.6	2.6
10/07/1998 @ 10:00:00	3337.5	3162.0	-5.3	5.3	0.7	0.7
14/10/1998 @ 04:00:00	2488.0	2369.3	-4.8	4.8	1.6	1.6
21/10/1998 @ 15:00:00	3328.6	3568.9	7.2	7.2	-2.0	2.0
29/10/1998 @ 11:00:00	3814.2	3486.8	-8.6	8.6	1.6	1.6
17/05/1999 @ 09:00:00	2681.1	3375.4	25.9	25.9	-9.4	9.4
03/10/2000 @ 03:00:00	3798.6	3406.1	-10.3	10.3	8.8	8.8
26/05/2001 @ 06:00:00	2198.3	1654.3	-24.7	24.7	-	-
10/12/2001 @ 00:00:00	2479.2	1874.8	-24.4	24.4	-	-
04/10/2003 @ 17:00:00	2478.7	2520.5	1.7	1.7	2.9	2.9
16/02/2004 @ 10:00:00	3283.9	2622.7	-20.1	20.1	5.6	5.6
29/02/2004 @ 21:00:00	3264.0	3331.9	2.1	2.1	2.0	2.0
21/06/2004 @ 10:00:00	2292.7	2158.2	-5.9	5.9	3.6	3.6
			Average	**11.9**	**Average**	**3.7**

Chinese Standards Performance Indicators:

QR = 77% CD = 0.89 Accuracy Grading = B

Recommendation: Suitable for making official forecasts.

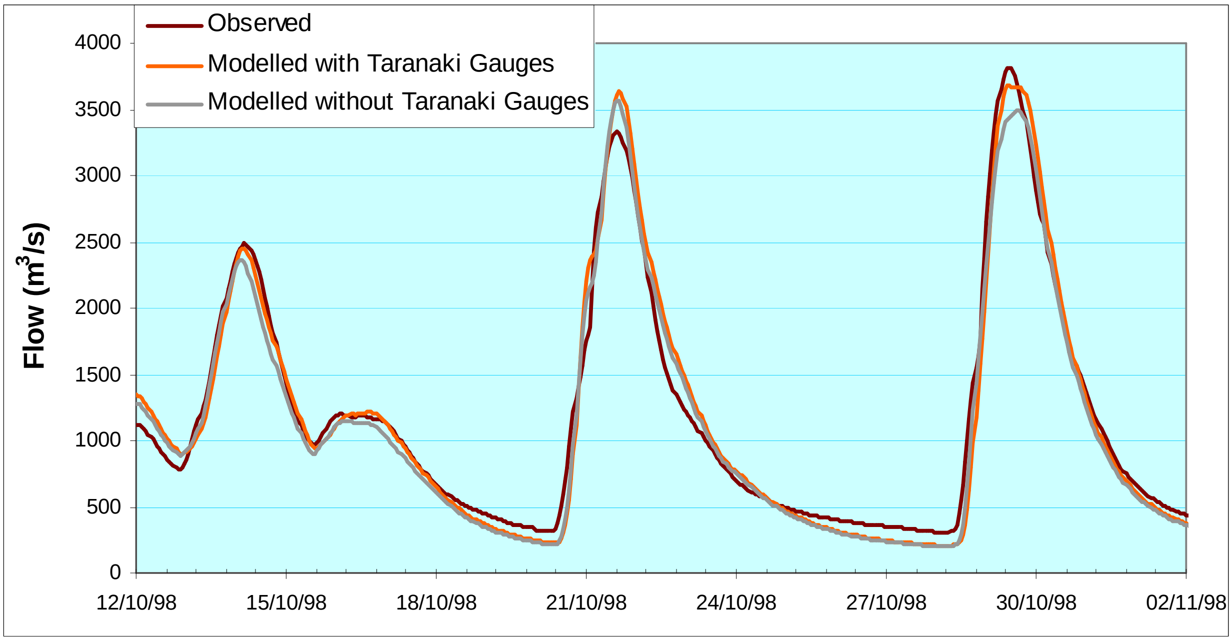


Figure 4-26: October 1998 Event Plot – Whanganui River at Paetawa, no Taranaki Rain Inputs

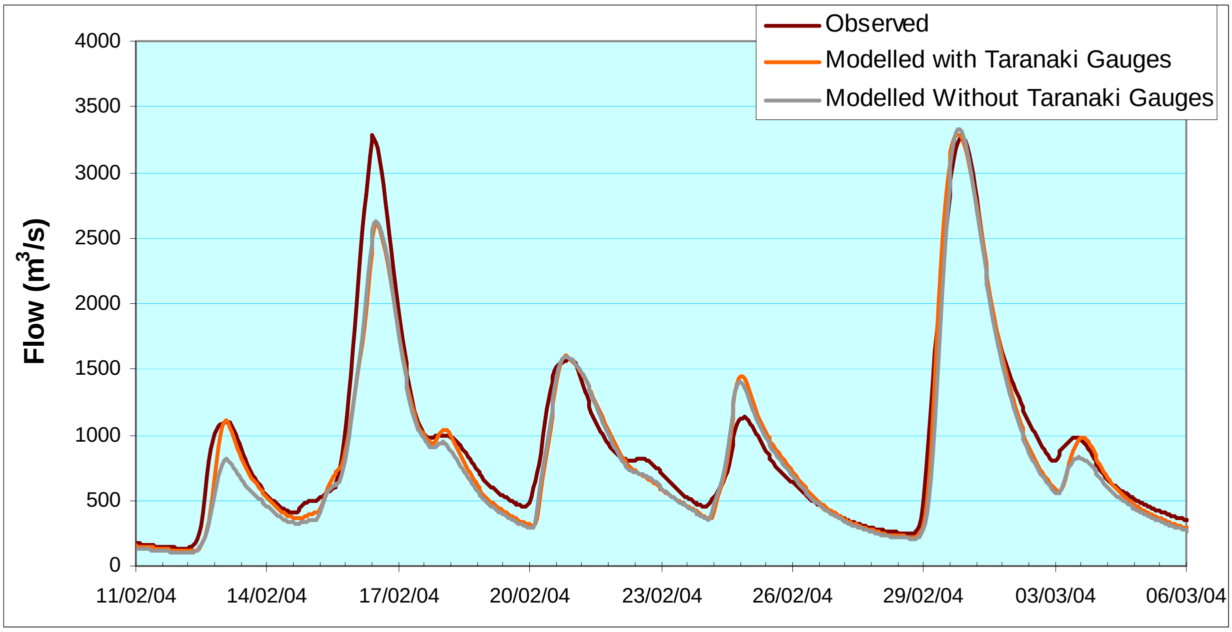


Figure 4-27: February 2004 Event Plot – Whanganui River at Paetawa, no Taranaki Rain Inputs

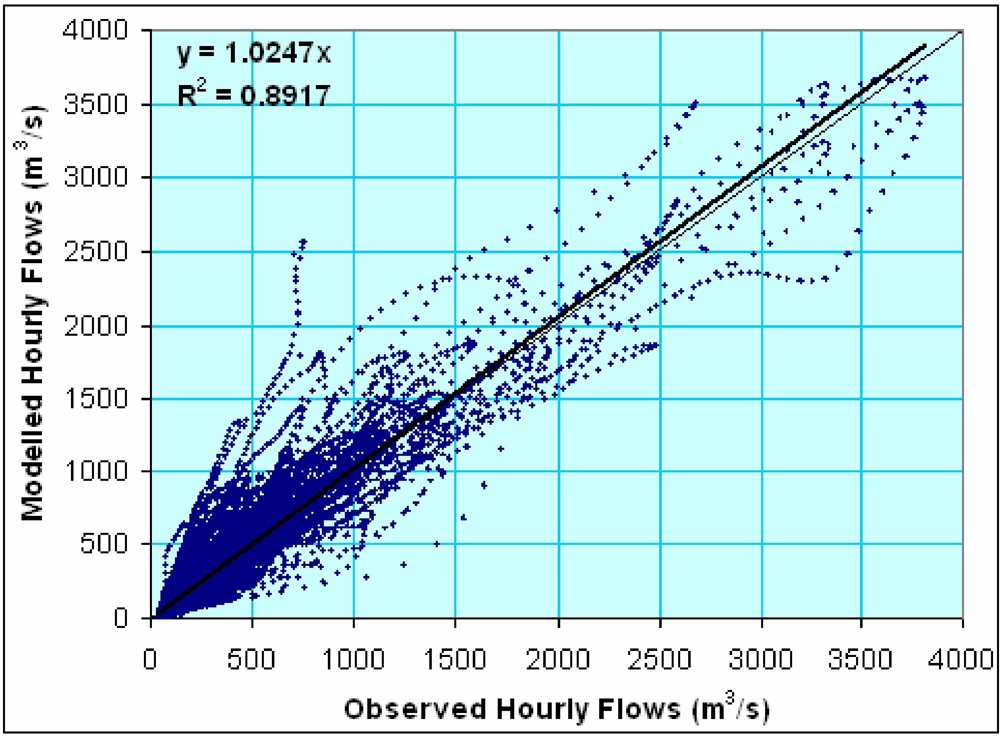


Figure 4-28: Modelled Flows vs Observed Flows - Whanganui River at Paetawa, no Taranaki Rain Inputs

4.4.4 Te Maire Calibration Results

Table 4-10: Event Comparison – Whanganui River at Te Maire

Event Time	Peak Flow (m^3/s)		% Difference (Mod - Obs)		Timing Difference (Mod - Obs)	
	Observed	Modelled	Actual	Absolute	Actual (hrs)	Absolute (hrs)
02/07/1998 @ 09:00:00	1083.4	1022.8	-5.6	5.6	-0.9	0.9
10/07/1998 @ 02:00:00	1371.2	1434.6	4.6	4.6	1.3	1.3
21/10/1998 @ 09:00:00	1345.0	1309.2	-2.7	2.7	-0.8	0.8
28/10/1998 @ 23:00:00	1791.9	1811.0	1.1	1.1	1.8	1.8
17/05/1999 @ 01:00:00	905.5	1169.4	29.1	29.1	-8.2	8.2
03/10/2000 @ 00:00:00	1464.0	1319.1	-9.9	9.9	-5.0	5.0
29/12/2000 @ 12:00:00	619.9	1495.4	141.2	141.2	-	-
25/05/2001 @ 18:00:00	1054.2	579.1	-45.1	45.1	-4.9	4.9
09/12/2001 @ 15:00:00	1013.2	897.1	-11.5	11.5	0.3	0.3
04/10/2003 @ 05:00:00	1247.3	1512.2	21.2	21.2	0.9	0.9
29/02/2004 @ 07:00:00	1390.3	1368.8	-1.5	1.5	1.5	1.5
20/06/2004 @ 23:00:00	914.0	1058.5	15.8	15.8	-0.1	0.1
			Average	**24.1**	**Average**	**2.3**

Chinese Standards Performance Indicators:

QR = 67% CD = 0.8 Accuracy Grading = C

Recommendation: Suitable for making reference forecasts.

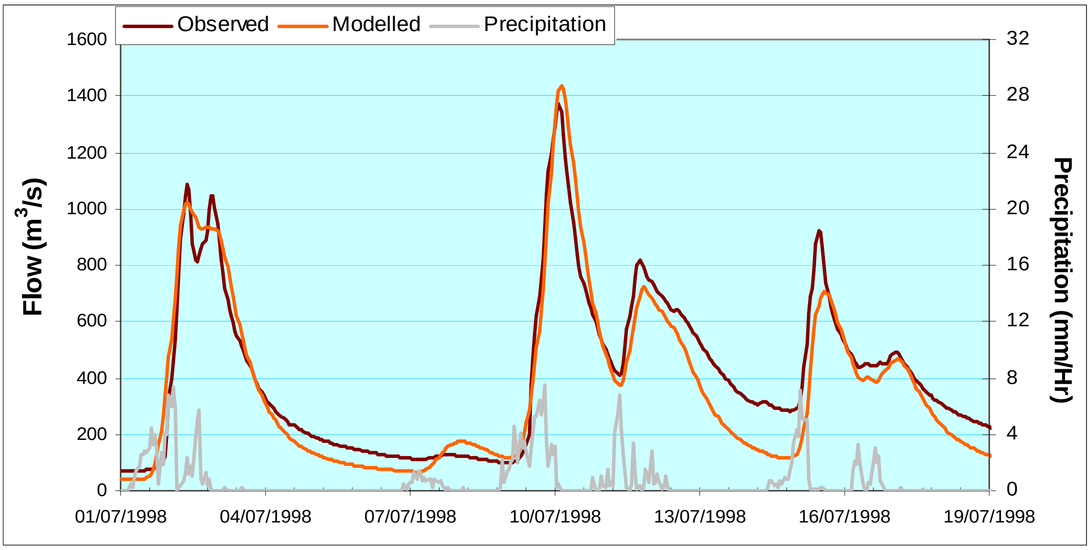


Figure 4-29: July 1998 Event Plot – Whanganui River at Te Maire

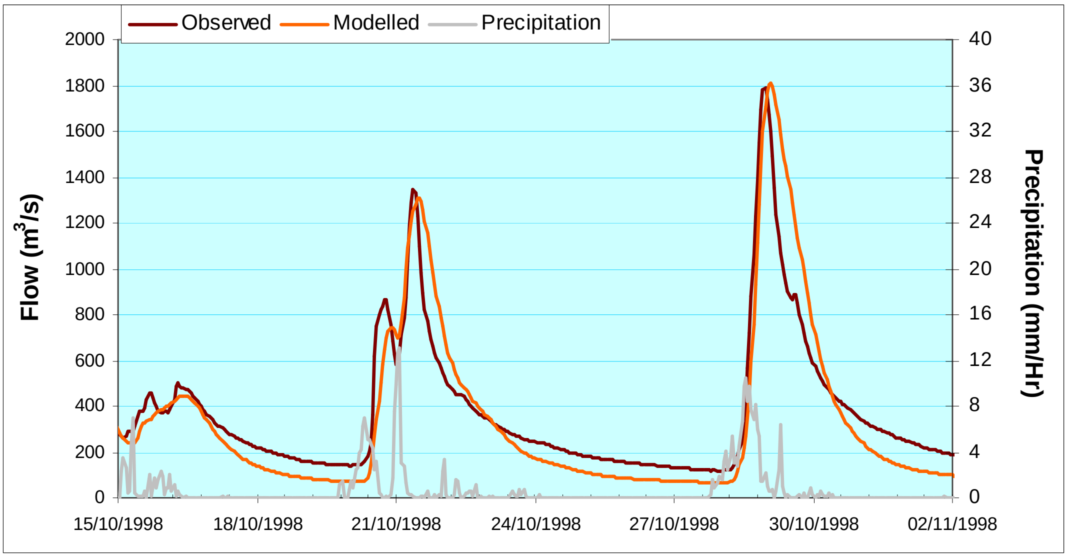


Figure 4-30: October 1998 Event Plot – Whanganui River at Te Maire

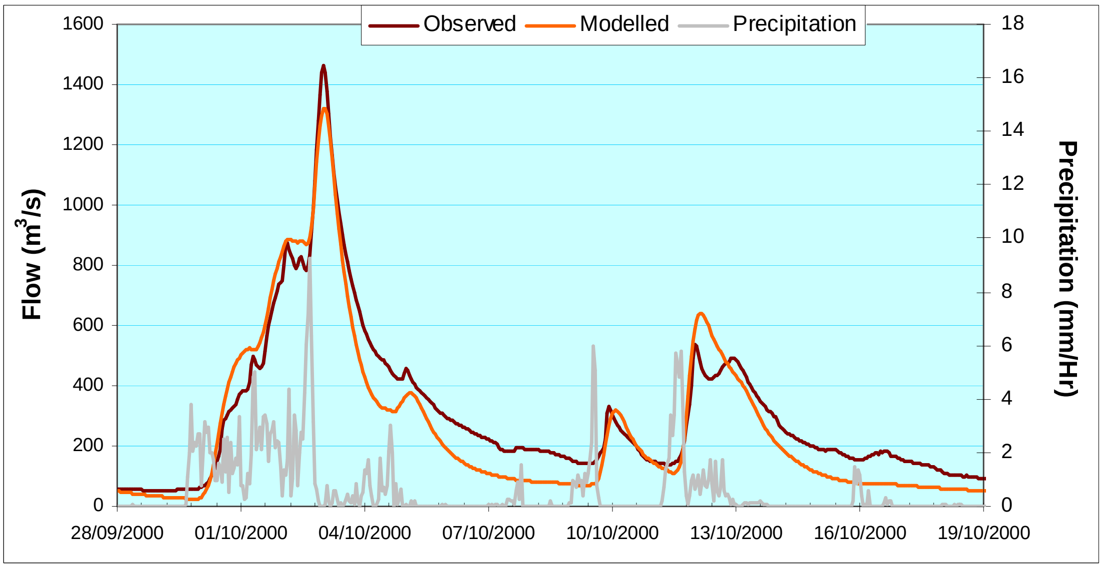


Figure 4-31: October 2000 Event Plot – Whanganui River at Te Maire

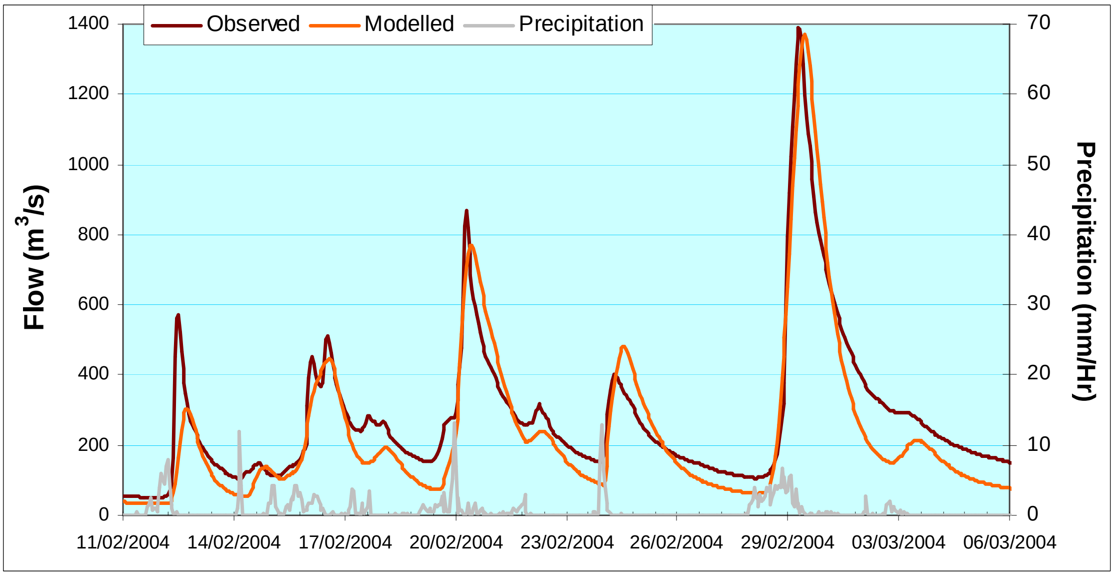


Figure 4-32: Febraury 2004 Event Plot – Whanganui River at Te Maire

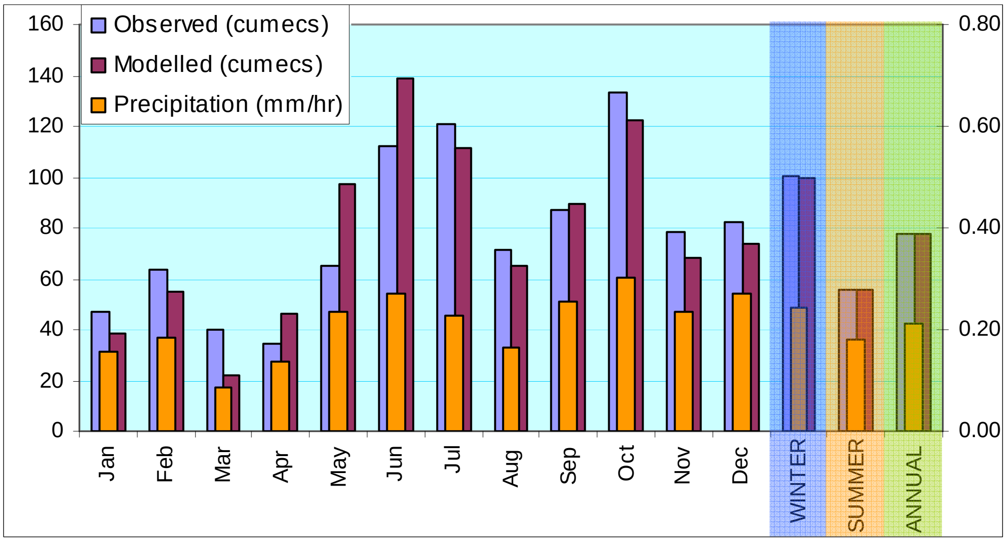


Figure 4-33: Monthly and Seasonal Long Term Volumes – Whanganui River at Te Maire

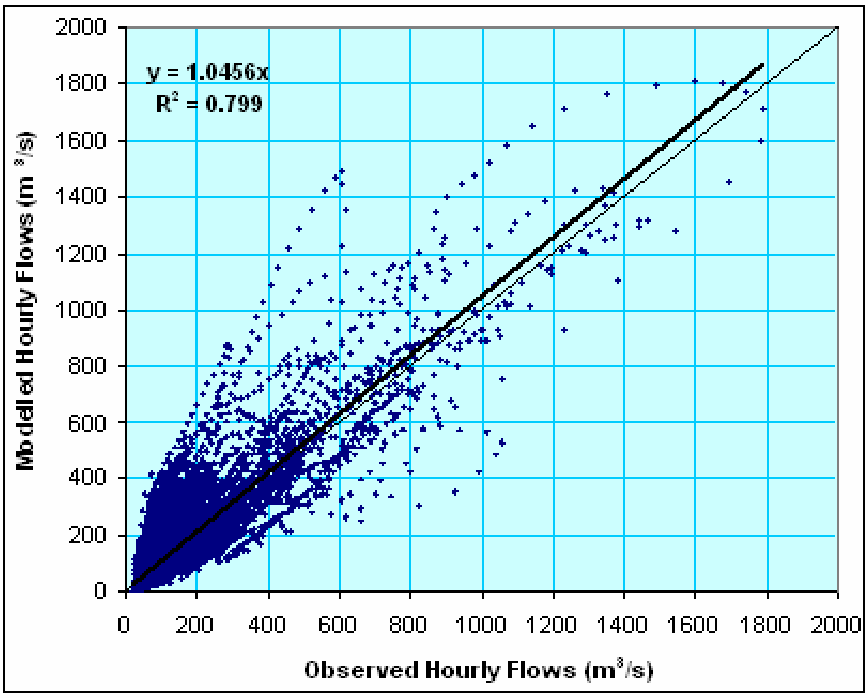


Figure 4-34: Modelled Flows vs Observed Flows - Whanganui River at Te Maire

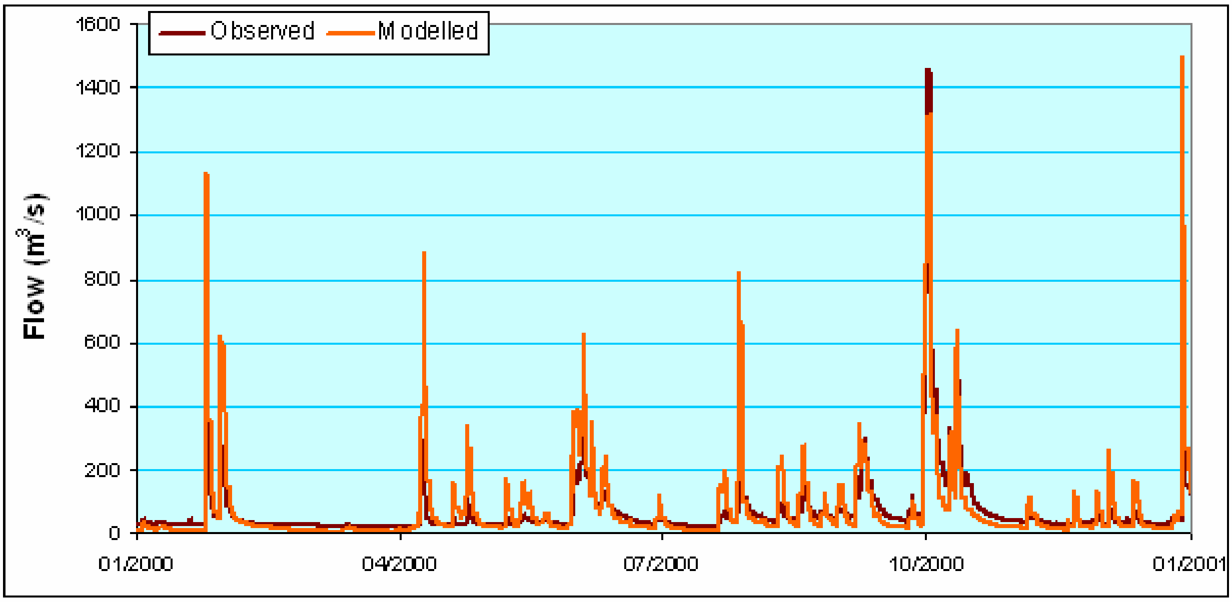


Figure 4-35: Annual Time Series Plot – Whanganui River at Te Maire

4.4.5 Initial Calibration of Tributaries

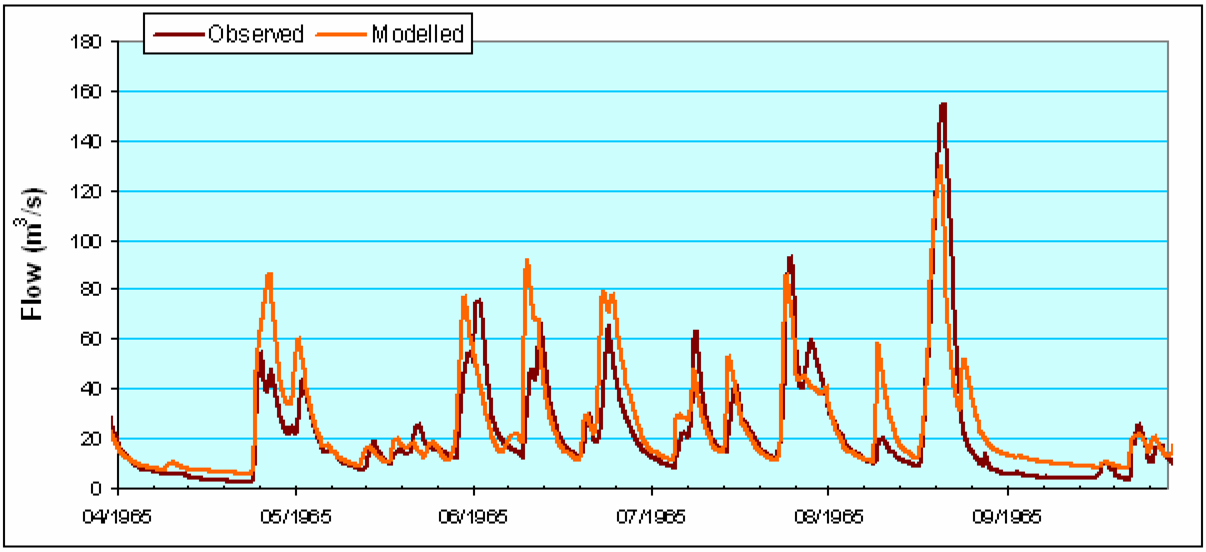


Figure 4-36: Time Series Plot – Ohura River at Tokorima

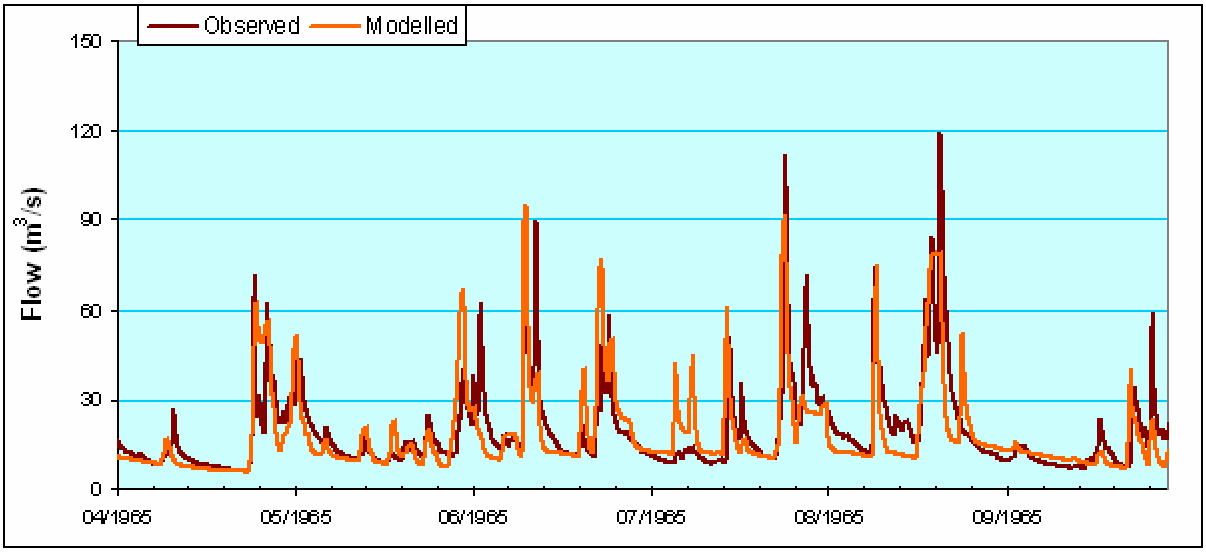


Figure 4-37: Time Series Plot – Manganui-o-Te-Ao at Ashworth

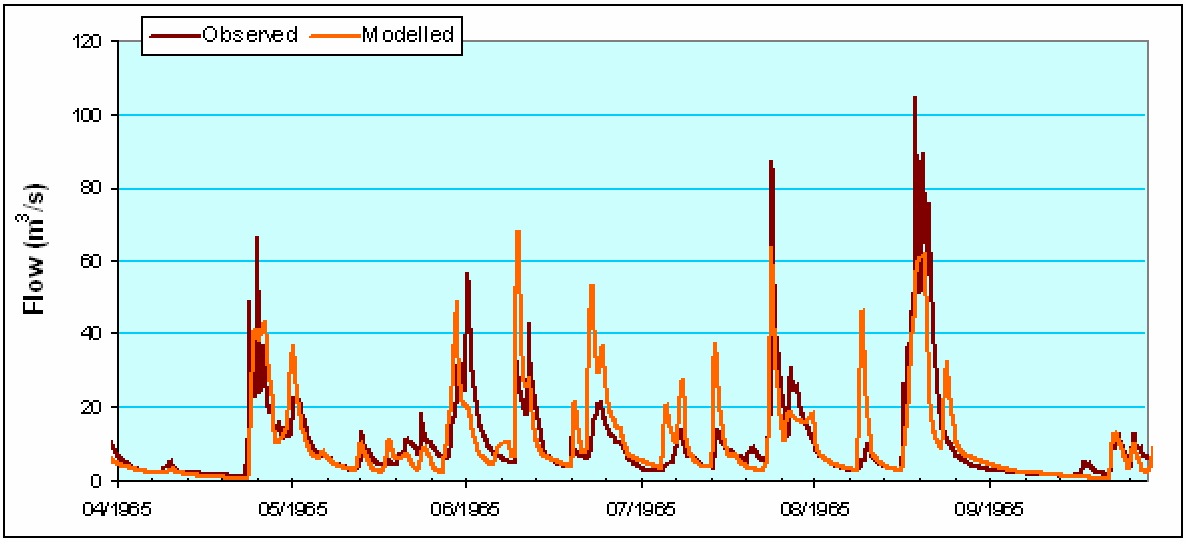


Figure 4-38: Time Series Plot – Tangarakau River at Tangarakau

5 HYDRAULIC MODELS

5.1 INTRODUCTION

A MIKE 11 hydraulic model (Version 3.2) of the Whanganui River, developed by Mr Colin Hovey from Wanganui District Council (Colin Hovey), was provided to HTC for use in the Whanganui flood forecasting model.

The provided model was initially reviewed and then recalibrated where required.

5.2 MODEL REVIEW

A review of the Whanganui River MIKE 11 model provided by Wanganui District Council was carried out by HTC. The main findings of this review and subsequent modifications that were made to the MIKE 11 models are summarized below:

- The MIKE 11 extends from Pipiriki downstream to the ocean.
- Upstream of Wanganui the model cross-sections are at approximately 2-5km spacings while through Wanganui the cross-sections are spaced at approximately 500m intervals. Cross-sections are also incorporated into the model at the Pipiriki and Paetawa river gauge sites.
- It is understood that the original MIKE 11 model was calibrated against a number of storm events such that it provides very good predictions of flood levels through the center of town (Wanganui).
- The bridges over the river have been modelled as cross-sections with the Manning's values adjusted to allow for energy losses through the bridges. Based on discussion with HRC, changes to the bridge modelling approach (ie using bridge headloss routines in MIKE 11) was not made.
- A review of the provided MIKE 11 files was carried out and based on discussions with HRC the following Version 3.2 MIKE 11 files were adopted for the development of the flood forecasting MIKE 11 model:
    - Cross-sections: wha_new2.pst cross-section file was adopted and converted to Version 2005 based on it having the most recent date.
    - Manning's n values: whsym21.ssf parameter file was adopted and converted to Version 2005 based on it having the most recent date.
    - Boundary conditions: New boundary condition files were developed for this study.
    - Model network: New network files were developed for this study as the original network file could not be converted from the earlier version of MIKE 11.
- The original Whanganui River MIKE 11 model was converted into MIKE 11 Version 2005 using information in the files listed above.
- The calibration of the converted model was checked and resulted in a number of changes to the model. Refer to Section 5.5 for details.

- The single MIKE 11 model that was provided was split into two models to facilitate real-time adjustment of flood hydrographs. Refer to Section 6.3 for details of the model split.
- All cross-sections were modified to ensure that cross-section properties were calculated using the Total Area Hydraulic Radius method using 100 equidistant vertical calculation points. This ensures model stability (consistent hydraulic radius method) and minimizes incorrectly interpolated cross-section characteristics (100 equidistant vertical calculation points).

5.3 DATUMS

A large number of datums were referenced as part of the MIKE 11 model set-up and calibration. The number of datums at times resulted in some confusion and misinterpretation of results.

A summary of the datums referenced is provided below for clarification.

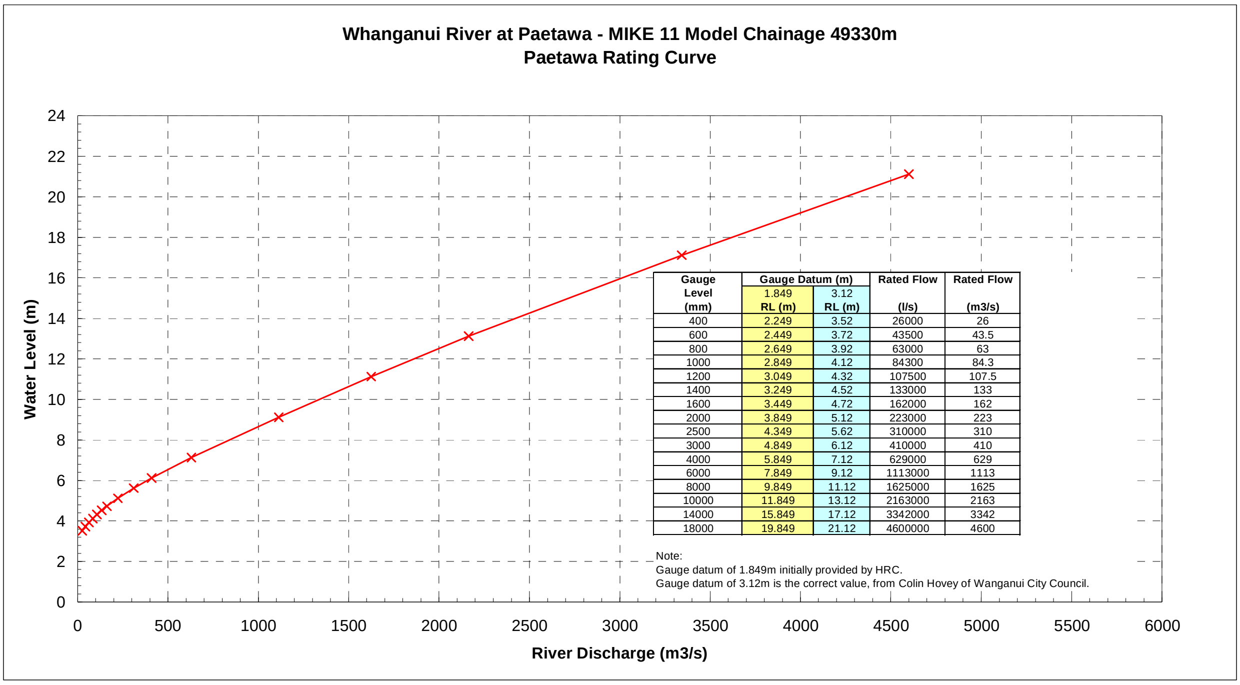
Table 5-1: Datum Summary

Datum Name	Relative to Wanganui Vertical Datum (m)	Comment
Wanganui Vertical Datum	0.0	Datum adopted for MIKE 11 model.
Moturiki Datum	+0.06	Datum for temporary tide level recorder situated at the wharf. 0m gauge at the Wharf is –1.214m Moturiki Datum or –1.154m Wanganui Vertical Datum.
Town Bridge Water Level Recorder Datum	+5.0	Datum for water level recorder at Town Bridge.
Paetawa (Te Rewa) Gauge Datum	-3.12	Datum for water level recorder at Paetawa and Te Rewa.
Pipiriki Gauge Datum	-26.195	Datum for water level recorder at Pipiriki.
Mean Sea Level	+0.113	Datum for synthetic tide data provided by NIWA.

5.4 RATING CURVES

The Paetawa and Pipiriki gauge site rating curves provided by HRC for use in the calibration of the MIKE 11 hydraulic model are provided below.

It should be noted that the rating provided for Pipiriki was adjusted based on the final MIKE 11 model.



Gauge Level (mm)	Gauge Datum (m) 1.849 RL (m)	Gauge Datum (m) 3.12 RL (m)	Rated Flow (l/s)	Rated Flow (m3/s)
400	2.249	3.52	26000	26
600	2.449	3.72	43500	43.5
800	2.649	3.92	63000	63
1000	2.849	4.12	84300	84.3
1200	3.049	4.32	107500	107.5
1400	3.249	4.52	133000	133
1600	3.449	4.72	162000	162
2000	3.849	5.12	223000	223
2500	4.349	5.62	310000	310
3000	4.849	6.12	410000	410
4000	5.849	7.12	629000	629
6000	7.849	9.12	1113000	1113
8000	9.849	11.12	1625000	1625
10000	11.849	13.12	2163000	2163
14000	15.849	17.12	3342000	3342
18000	19.849	21.12	4600000	4600

Figure 5-1: Paetawa Rating Curve

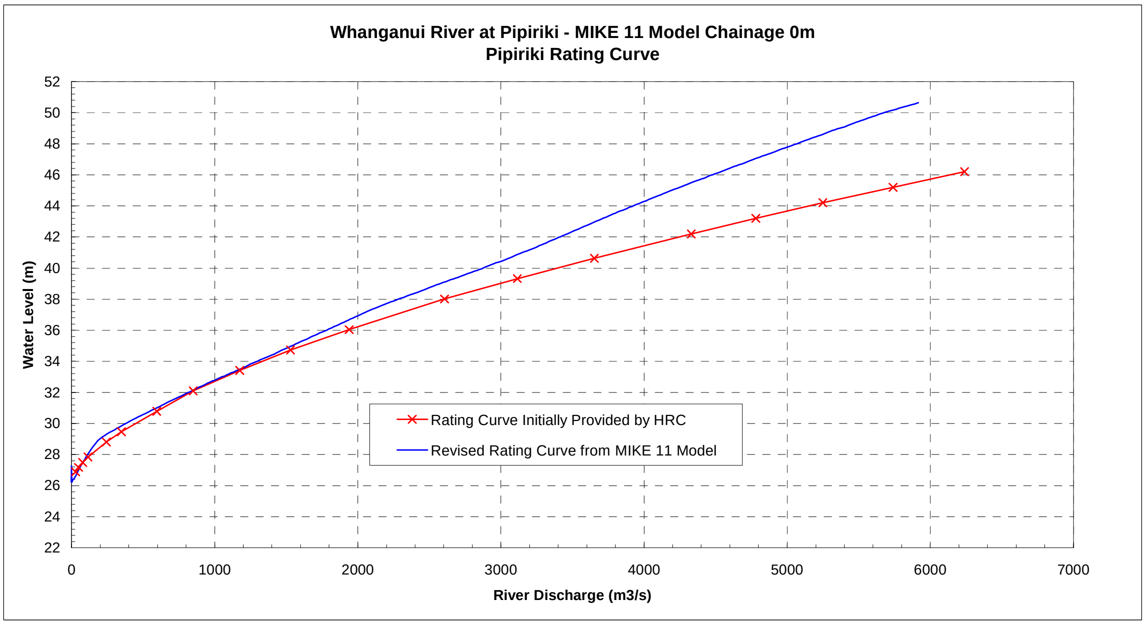


Figure 5-2: Pipiriki Rating Curve

5.5 MODEL RE-CALIBRATION

As stated in Section 5.2, the Whanganui River MIKE 11 model (set-up in version 3.2 of the software), was previously calibrated by Colin Hovey.

The model was re-calibrated in four stages on advice from Horizons Regional Council:

- **Stage 1:** The calibration of the model at Paetawa and Pipiriki was carried out using a dummy flow hydrograph and comparing the predicted model results against the provided rating curves for the two locations. This was done prior to recorded flood levels and flow from past flood events being available.

- **Stage 2:** The lower section of the river was calibrated to recorded flood levels at Town Bridge for the following flood events:

    - 8 March 1990.
    - 10 July 1998.
    - 29 October 1998.
    - 29 September 2000.
    - 14 February 2004.
    - 28 February 2004.

  The modelled results for these flood events was also checked against the rating at Paetawa.

- **Stage 3:** The re-calibration of the lower section of the model was revised to achieve a match between surveyed maximum flood levels rather than recorded levels at Town Bridge. Typically the surveyed peak levels are higher than the peak recorded levels at Town Bridge. Also the datum for the Paetawa rating was revised and the modelled results at Paetawa were re-checked. The Stage 3 calibration was carried out for the following flood events:

    - 8 March 1990.
    - 29 October 1998.

- **Stage 4:** The model was checked and revised to achieve a better match to tidal oscillations.

The final results of the model calibration (Stage 3 and Stage 4 calibration results) along with a summary of the model changes are provided below.

5.5.1 Calibration Results

Figures 5.3 to 5.6 show the calibration results for 8 March 1990 flood event. The MIKE 11 model typically predicted peak flood levels within ±300mm of the maximum surveyed levels which is considered to be acceptable.

Figures 5.7 to 5.10 show the calibration results for the 29 October 1998 flood event. Like the 8 March 1990 event the MIKE 11 model typically predicted peak flood levels within ±300mm of the maximum surveyed levels which is considered to be a good calibration.

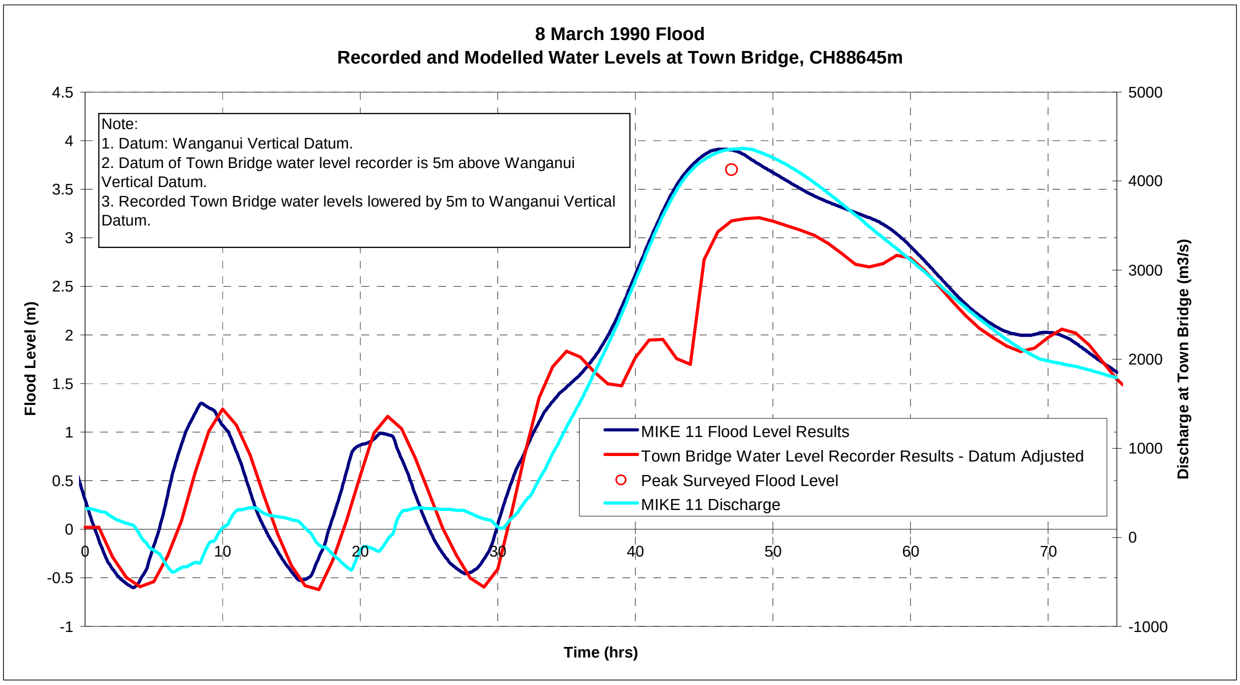


Figure 5-3: 8 March 1990 Calibration at Town Bridge

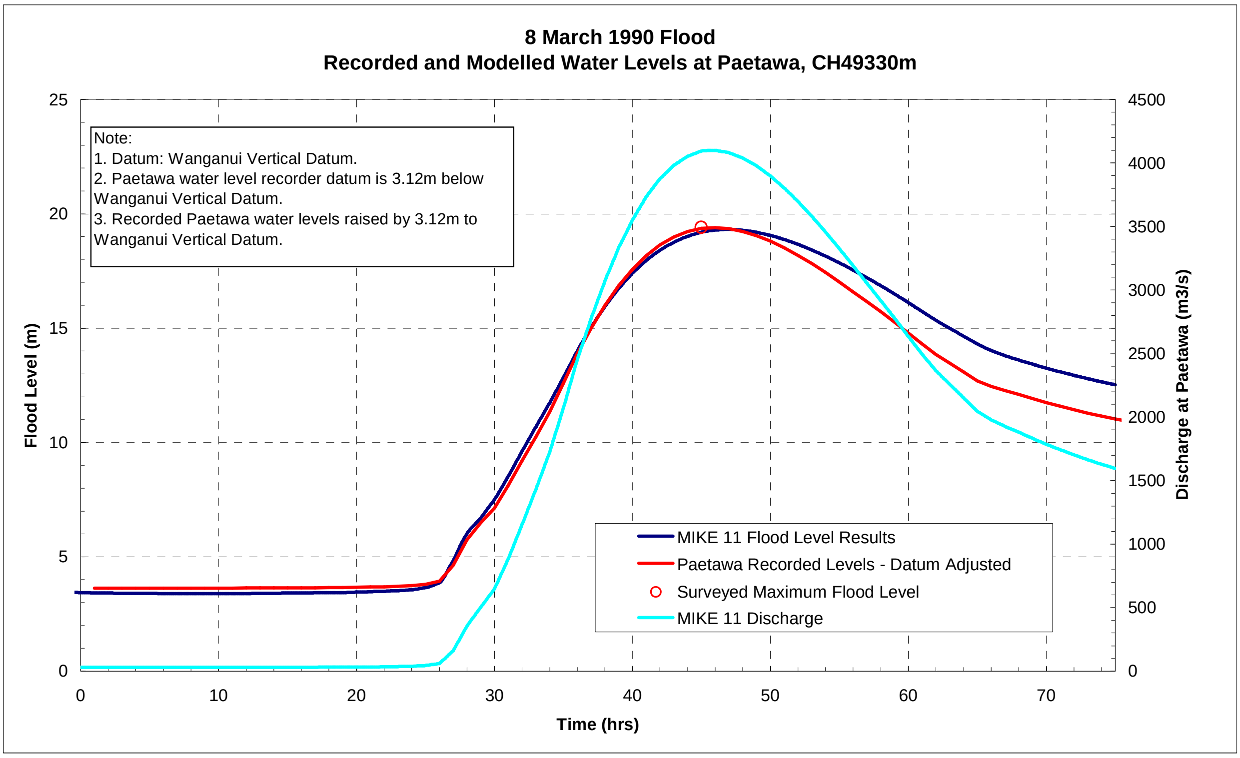


Figure 5-4: 8 March 1990 Calibration at Paetawa

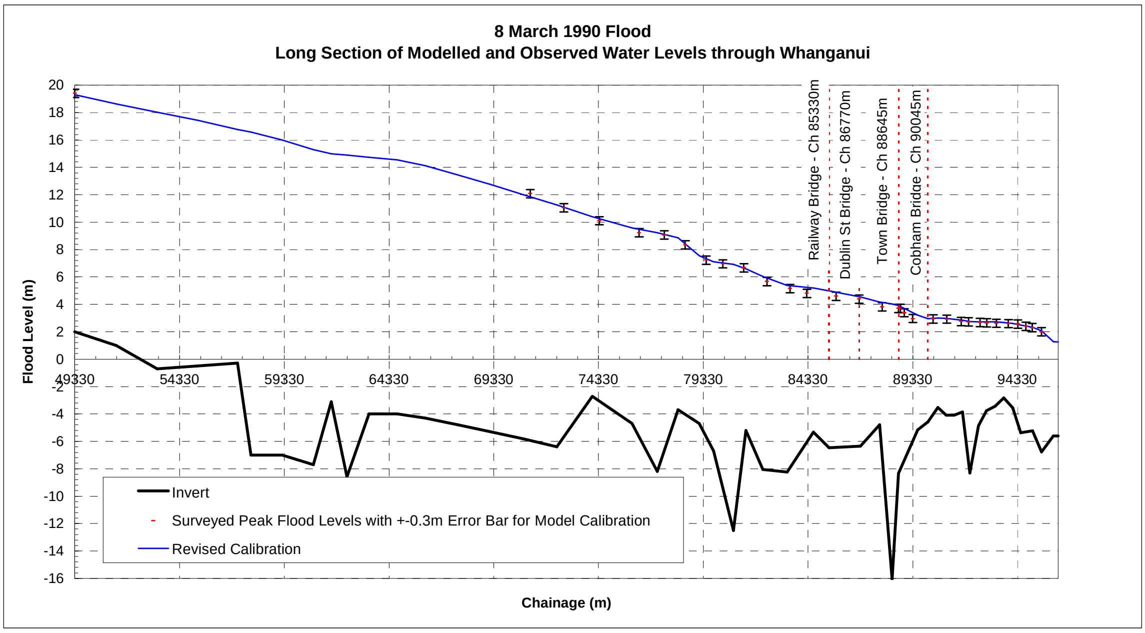


Figure 5-5: 8 March 1990 Calibration Long Section from Paetawa to Ocean

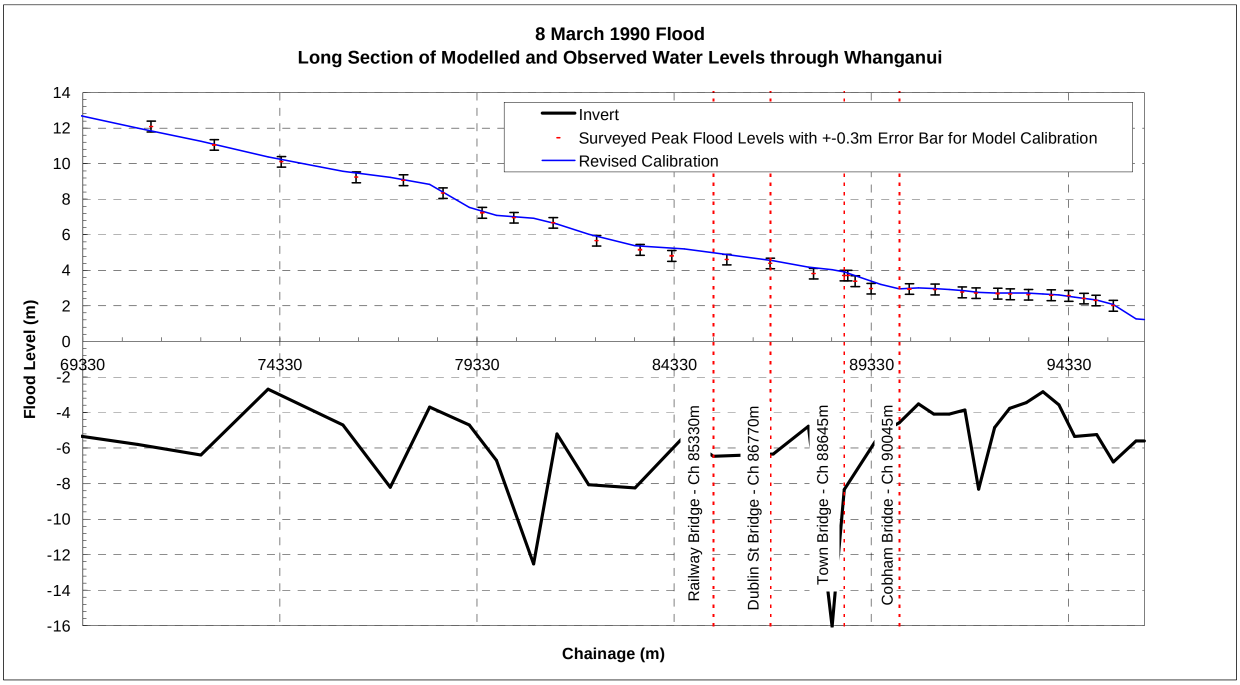


Figure 5-6: 8 March 1990 Calibration Long Section through Wanganui

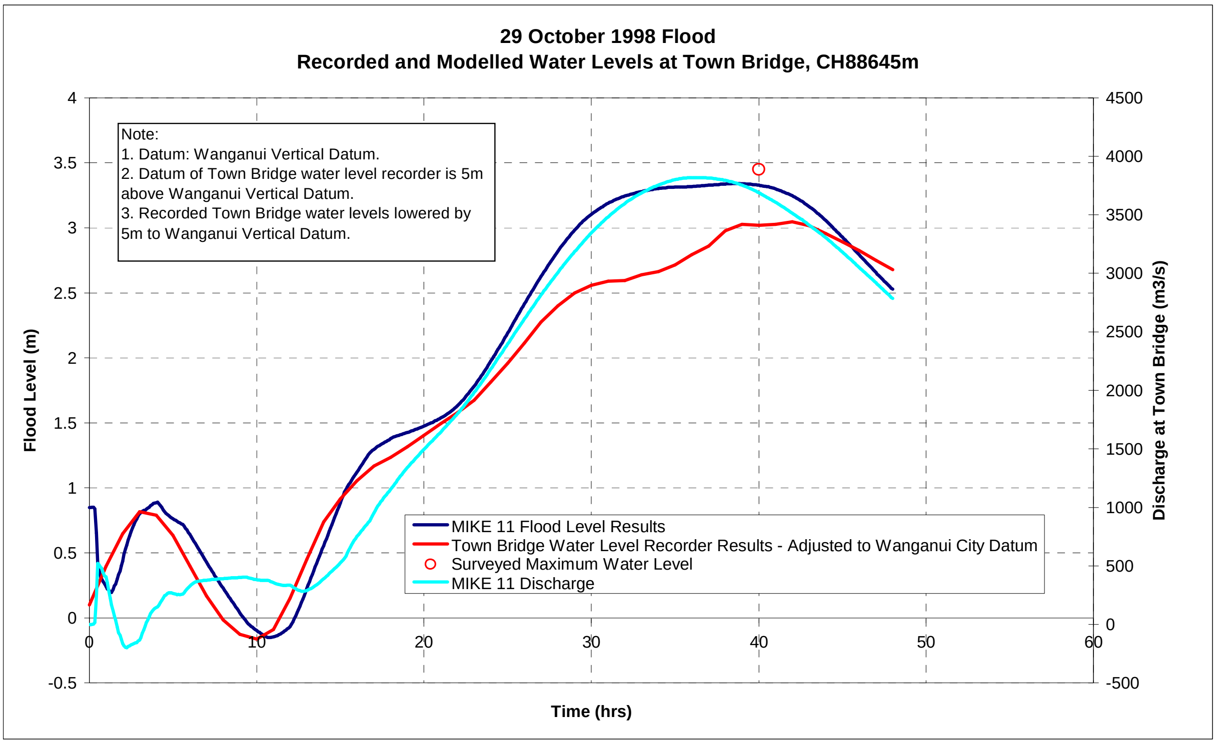


Figure 5-7: 29 October 1998 Calibration at Town Bridge

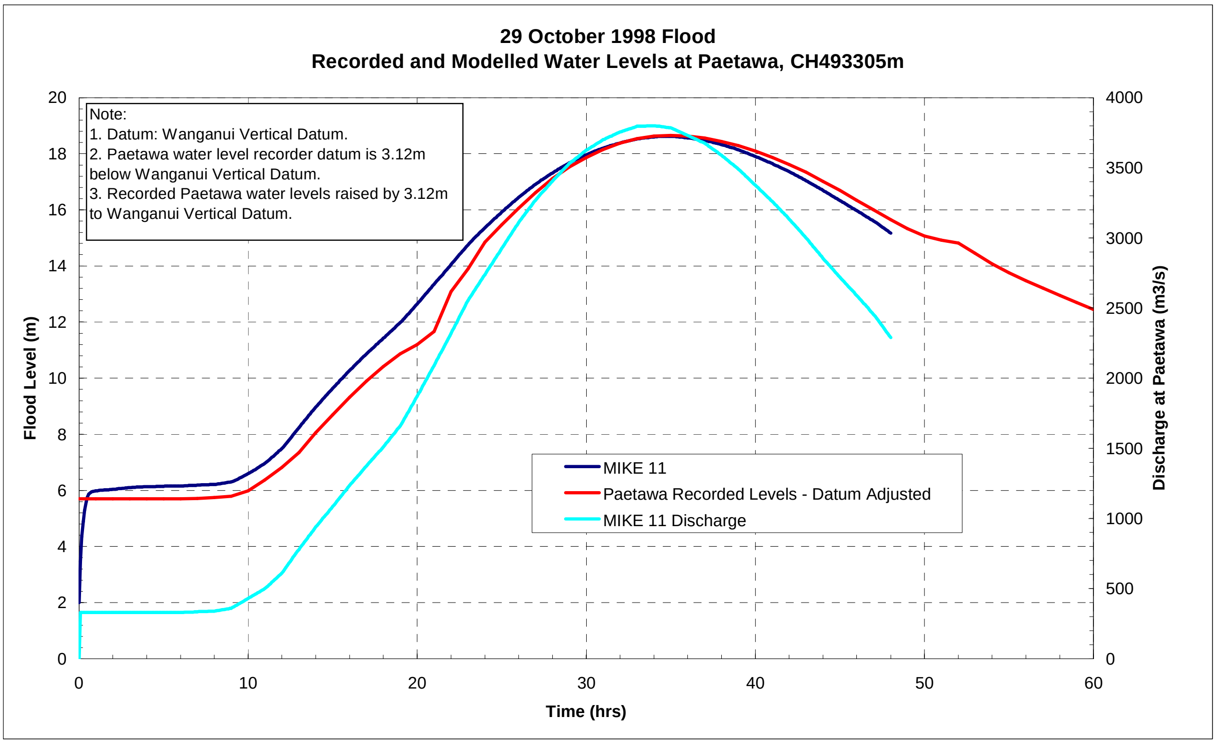


Figure 5-8: 29 October 1998 Calibration at Paetawa

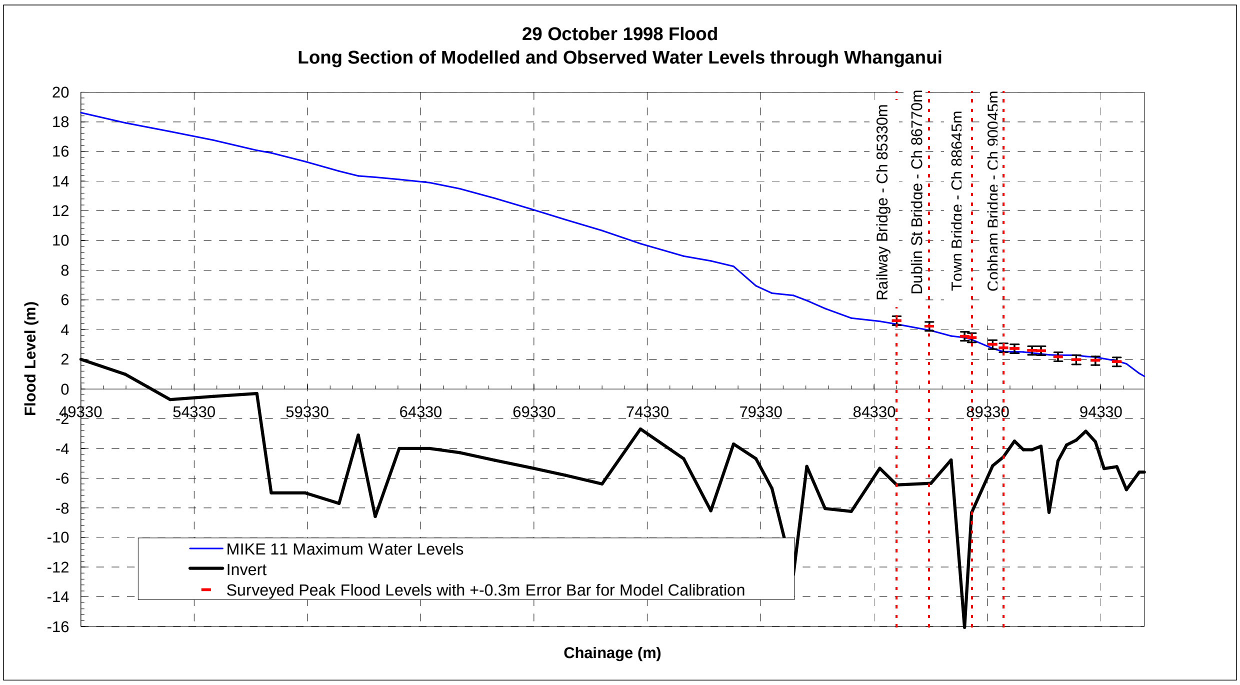


Figure 5-9: 29 October 1998 Calibration Long Section from Paetawa to Ocean

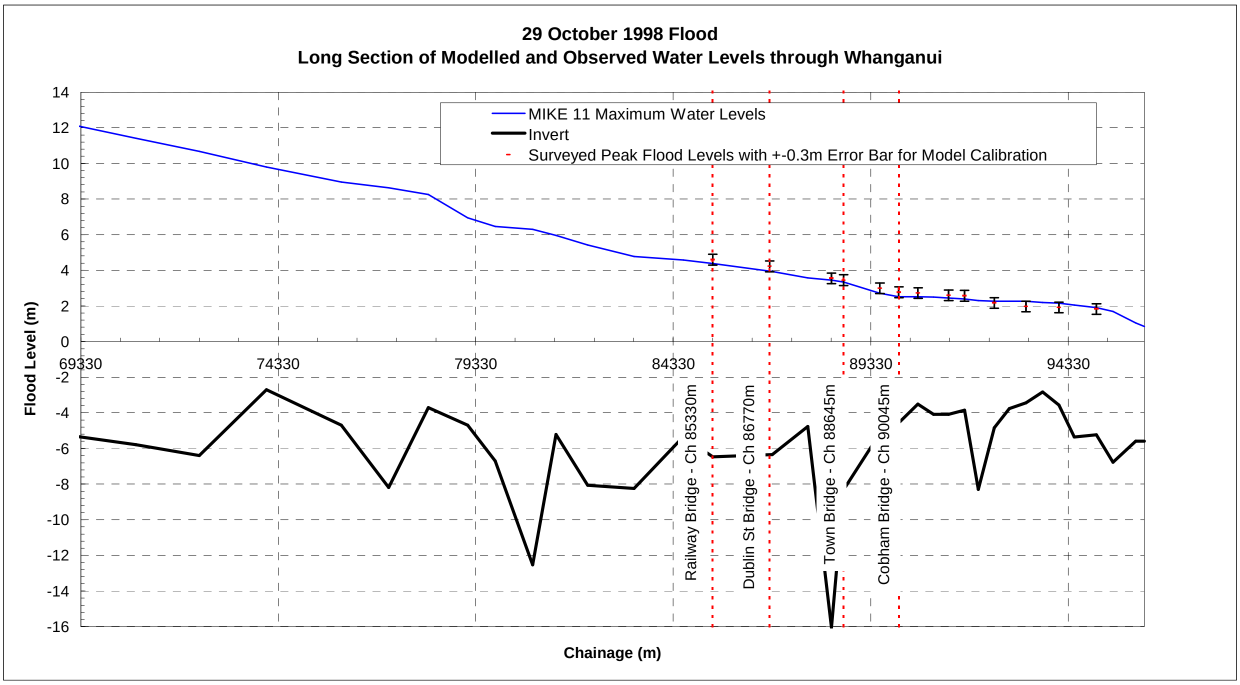


Figure 5-10: 29 October 1998 Calibration Long Section through Wanganui

Figure 5-9 shows the recorded and modelled water levels at Town Bridge for the period between 7 August and 9 August 2007. The MIKE 11 modelling was carried out using the measured tide levels at Whanganui River at Castlecliff Wharf. The synthetic tide data (used for the real-time modelling) is provided for information only.

There is a good match between the recorded and modelling water levels in both amplitude and frequency, with about a constant 0.2m offset.

This indicates that MIKE 11 is providing a good prediction of the tidal movements in non-flood situations.

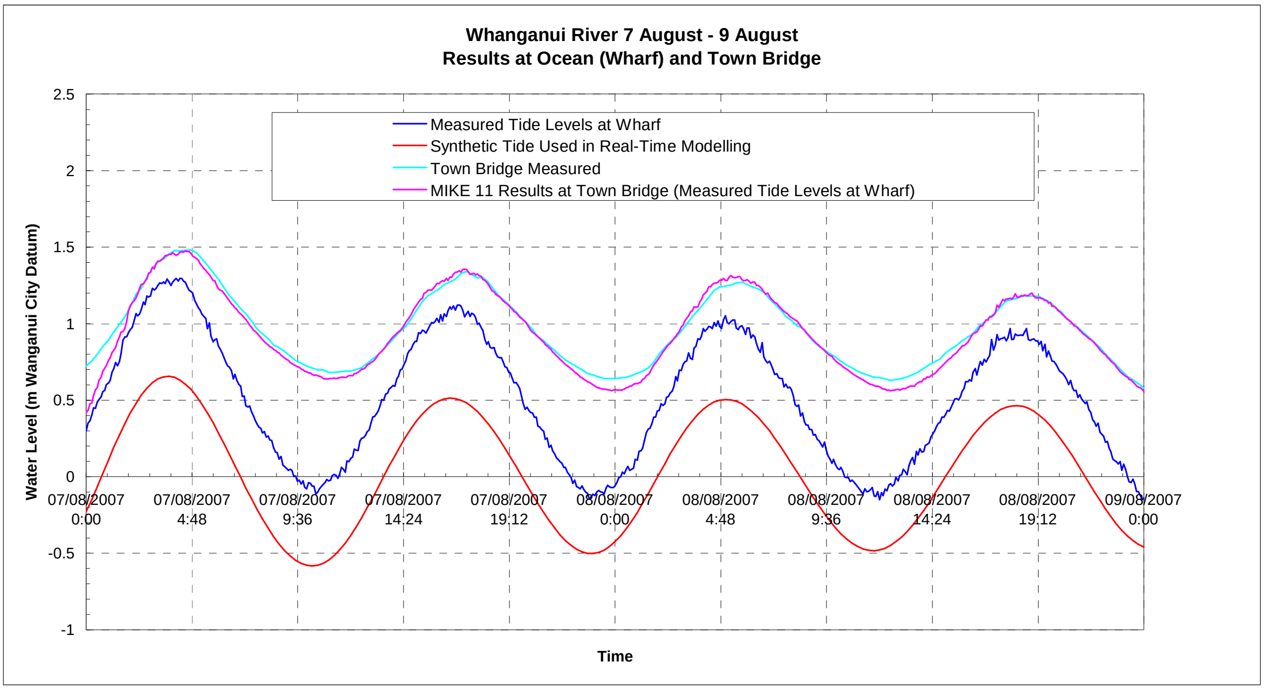


Figure 5-11: 7 August to 9 August Results at Town Bridge

5.6 MODEL CHANGES FOR CALIBRATION

It was found that the cross-section at the location of the Pipiriki gauge site was was 4m too low in the MIKE 11 model and was subsequently corrected.

The re-calibration of the MIKE 11 was achieved by modifing the Manning's n values in two separate ways:

1. Changing the Manning's value adopted for a particular section.
2. Providing a vertical variation in Manning's for particular cross-sections.

The vertical variation in Manning's n values for the cross-section from Pipiriki to 20km downstream of Paetawa was defined to represent large areas of no flow (in times of flood and high water levels) on the river overbanks caused by the formation of large eddies (as witnessed by HRC personnel).

Table 5.2 shows the changes made to the Manning's values for each of the cross-sections.

Table 5-2: Changes to Manning's Values

Cross Section Chainage (m)	Original Manning's	Revised Manning's	Reason for Change
95465	0.038	0.033	Lowered to match tidal amplitude and period. Original Manning's too high causing a choking effect at river mouth.
95045	0.036	0.025	
94485	0.03	0.025	
94095	0.018	0.018	--
93680	0.018	0.018	--
93260	0.018	0.018	--
92840	0.018	0.018	--
92460	0.018	0.018	--
92055	0.02	0.017	Lowered/raised to match peak recorded flood levels.
91705	0.02	0.017	
91305	0.02	0.017	
90920	0.02	0.017	
90530	0.02	0.02	
90045	0.026	0.025	
89565	0.027	0.025	
88645	0.027	0.04	
88335	0.032	0.02	
88130	0.032	0.02	
87740	0.031	0.027	
86840	0.028	0.027	
85330	0.025	0.027	
84590	0.025	0.02	
83335	0.025	0.025	--
82165	0.025	0.045	
81362	0.028	0.04	Lowered/raised to match peak recorded flood levels.
80767	0.03	0.035	
79827	0.03	0.035	
79130	0.03	0.05	
78130	0.03	0.055	
77130	0.035	0.025	
75930	0.03	0.045	
74030	0.035	0.047	
72330	0.033	0.047	
70730	0.073	0.06	
66046	0.057	0.057	
63384	0.03	0.03	
62319	0.038	0.038	
61574	0.038	0.038	
60722	0.03	0.05	Manning's raised and vertical variation applied to match Paetawa rating curve.
57741	0.03	0.05	
57102	0.03	0.05	
53269	0.03	0.05	
49330	0.03	0.05	
45910	0.045	0.045	Vetical variation used to match to Paetawa rating curve also applied to these sections. No change to base Manning's values.
43280	0.045	0.045	
40430	0.042	0.042	
36730	0.05	0.05	
31480	0.05	0.05	
29380	0.042	0.042	
24590	0.042	0.042	
19270	0.045	0.045	
15370	0.047	0.047	
10220	0.047	0.047	
5000	0.03	0.03	
3550	0.05	0.05	
300	0.03	0.03	
0	0.047	0.047	

5.7 MODEL SPLIT

A single MIKE 11 model was provided for the Whanganui River. This single model was split into two to facilitate realtime adjustment of the flood hydrograph at Te Rewa using the following methodology:

- The hydrologic model will predict flows at Pipiriki.
- The hydrograph predicted at Pipiriki will then be adjusted to match the recorded flood hydrograph at Pipiriki.
- The adjusted Piripiki hydrograph will be put in at the top end of the top MIKE 11 model and routed to Te Rewa (along with any pickup hydrographs). Between these two locations there are a few road closure sites where the peak forecast flood levels will be extracted from the MIKE 11 modelling results.
- The routed hydrograph at Te Rewa will be exported from the hydraulic model and adjusted based on recorded flows at Te Rewa.
- The adjusted Te Rewa hydrograph will then be put into the downstream MIKE 11 model along with any flow pickup hydrographs from intermediate catchments. Results at the critical road closure locations and Town Bridge will be extracted from the MIKE 11 modelling results.

The single model was split into the following two models:

- **Pipiriki-Ocean:** This is the full model that runs from Pipiriki to the Ocean. There were no real benefits identified in cutting the model off downstream of Paetawa.
- **Te_Rewa-Ocean:** This model runs from Te Rewa to the Ocean with the model being cut at the location of the Te Rewa gauge.

A check of the consistency between the two models at Paetawa was carried out prior to the model split being changed to Te Rewa. This check involved:

- Running a dummy hydrograph through the Pipiriki-Ocean model and extracting the routed hydrograph at Paetawa.
- Using the extracted Paetawa hydrograph as the inflow to the Paetawa-Ocean model.

The predicted water level results from the two models are provided in Figure 5-12 below and show that there is a good match of predicted water levels at Paetawa between the two models.

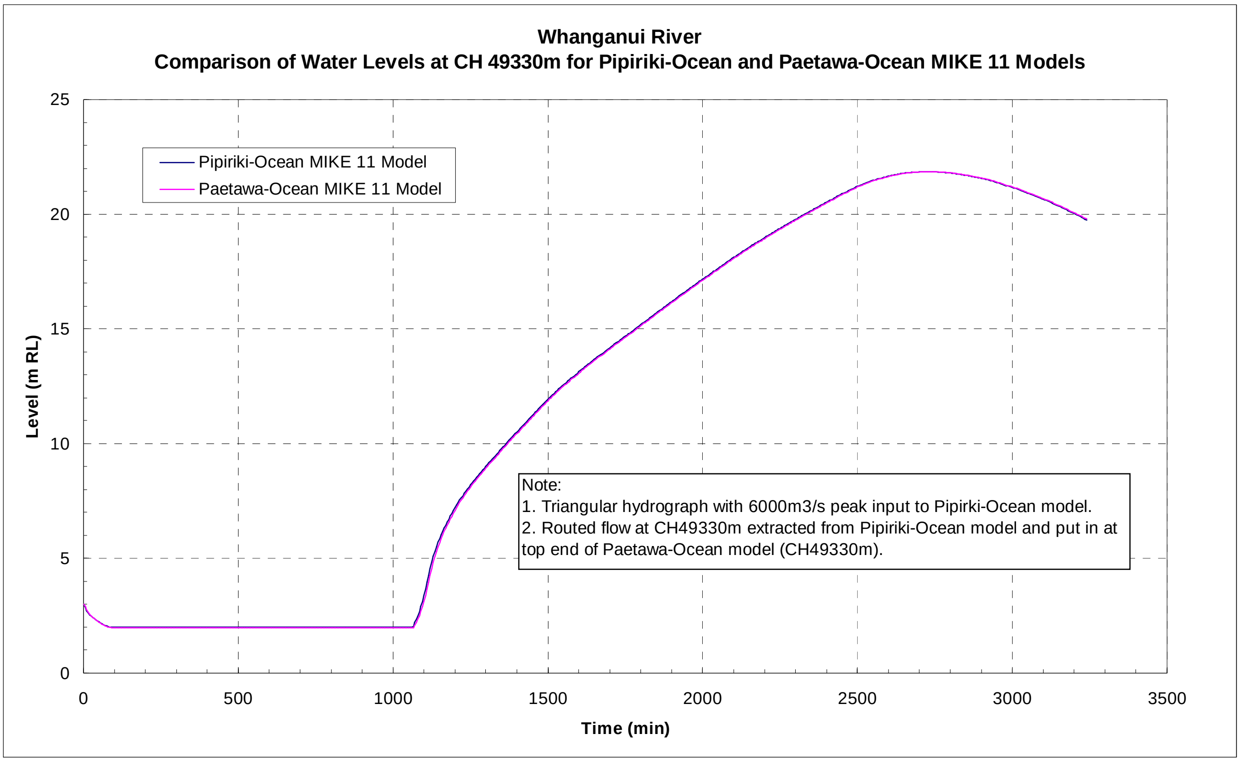


Figure 5-12: Comparison of Water Levels at Paetawa

5.8 OCEAN WATER LEVELS (DOWNSTREAM MODEL BOUNDARY)

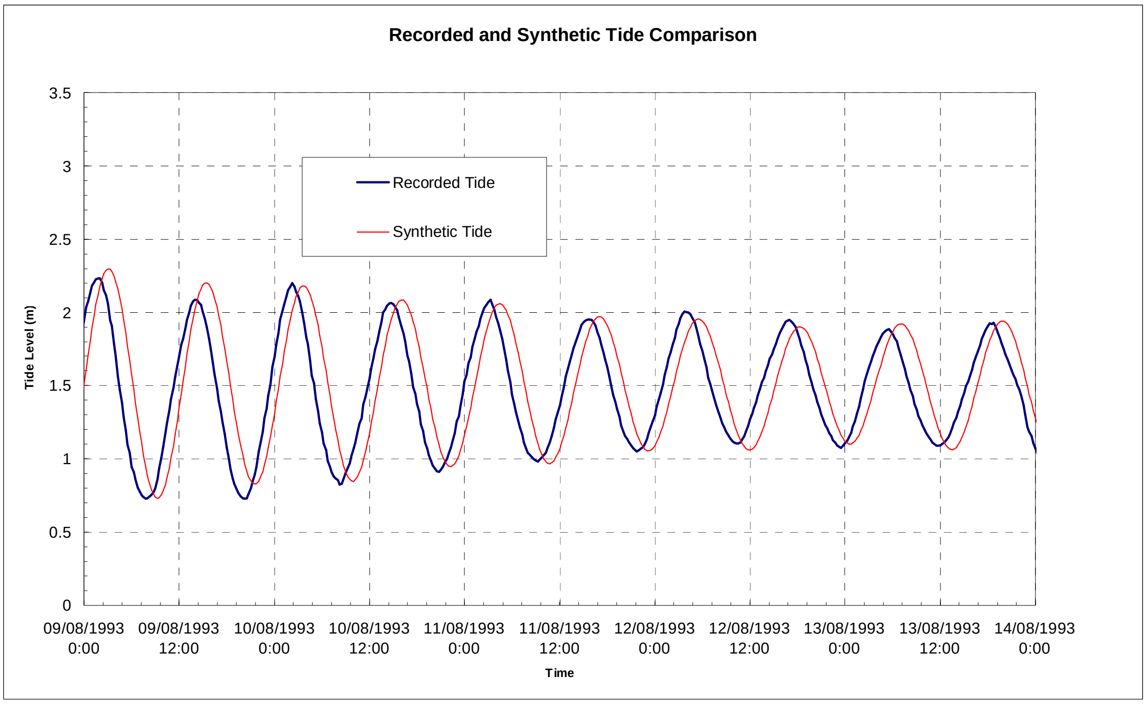
The lower reaches of the Whanganui River are tidal. To accurately predict real-time flood levels along the tidal reaches of the river, an accurate estimation of forecast tidal levels (incorporating storm surge) is required to be incorporated into the hydraulic model.

NIWA developed a synthetic tide series at the Whanganui River mouth, however this series does not allow for storm surge. Two methods to incorporate storm surge into the synthetic tide series for forecast model runs were investigated.

The first method involved adjusting the synthetic tide series based on measured atmospheric pressure. The NIWA report (*Meteorological Hazards and Climate Change Report*, February 2005) provides a general "rule of thumb" whereby the inverted barometer measurement contributes to half of the set-up in ocean storm surge while the other half comes from wind set-up etc. Using this rule of thumb, the ocean rise based on measured and forecast atmospheric pressure at Manawatu at Foxton would be multiplied by 2 and this increase would be applied to the long term tidal forecast for each particular model run.

The second method was based on adjusting the synthetic tide series based on real-time comparison between measured tide levels (which include storm surge) and the synthetic tide data. The difference between the two values at a particular point in time should be approximately equal to the storm surge. This was the preferred method of adjusting the synthetic data as it is based on measured tide levels at the Whanganui River mouth while the first method is based on an indirect rule of thumb. A check was carried out for this method where hindcast synthetic tide data was compared with measured tide levels at Whanganui River mouth and it was found that there is a slight difference in timing between the synthetic and measured tide data and that this timing difference constantly changes. Figure 5-13 shows that the difference in timing causes a mismatch in tidal peaks between the two sets of data. This mismatch in timing also prevents the difference between the two sets of data from being just the storm surge. Due to the timing difference between the recorded and synthetic data this method of synthetic tide data adjustment was not adopted. The first method was therefore adopted for adjusting the synthetic tide data to account for storm surge.

Figure 5-13: Recorded and Synthetic Tide Data Comparison



5.9 SIMULATION PARAMETERS

A model calculation timestep of 10seconds has been adopted for the hydraulic model. The adopted timestep has a direct effect on the model run time with a larger timestep resulting in faster model runs.

Model results are stored at 5 minute intervals.

5.10 LINKS BETWEEN HYDRAULIC MODEL AND THE FLOOD-FORECASTING SYSTEM

5.10.1 Inflow Hydrographs

Table 5-3 shows the locations for inflow hydrographs for the two MIKE 11 hydraulic models. The inflow hydrographs generated from the hydrologic model are converted to a MIKE 11 timeseries format (*.dsf0) by the UStr_Paetawa_Transfer.tso transfer model. The adjusted inflow hydrograph at Te Rewa for the **Te_Rewa_Ocean** model is converted to a MIKE 11 timeseries format (*.dsf0) using the UStr_Paetawa_Transfer.tso transfer model.

Table 5-3 Inflow Locations for MIKE 11 Models

MIKE 11 Branch	Model Chainage (m)	Comment
Pipiriki to Ocean MIKE 11 Model		
Whanganui	0	Inflow to top end of model.
Whanganui	10220	Sub-catchment inflow at Jerusalem.
Whanganui	40430	Sub-catchment inflow at Athens.
Whanganui	77130	Sub-catchment inflow at Kaiwhaiki Rd.
Whanganui	85330	Sub-catchment inflow upstream of the rail bridge.
Whanganui	88645	Sub-catchment inflow at Town Bridge.
Te Rewa to Ocean MIKE 11 Model		
Whanganui	47050	Inflow to top end of model - adjusted outflow hydrograph from the Hindcast hydraulic model run.
Whanganui	77130	Sub-catchment inflow at Kaiwhaiki Rd.
Whanganui	85330	Sub-catchment inflow upstream of the rail bridge.
Whanganui	88645	Sub-catchment inflow at Town Bridge.

5.10.2 Output Locations

Table 5-4 shows the locations where predicted flood level/flow data is extracted from the two hydraulic models. The UStr_Paetawa_Transfer.tso transfer model extracts the data from the **Pipiriki_Ocean** MIKE 11 results file and converts it into Hilltop format while the DStr_Paetawa_Transfer.tso transfer model extracts and converts the results from the **Te_Rewa_Ocean** results file.

Table 5-4 Output Locations for MIKE 11 Models

MIKE 11 Branch	Model Chainage (m)	Comment
Pipiriki to Ocean MIKE 11 Model		
Whanganui	10220	Forecast levels and flows at Jerusalem.
Whanganui	40430	Forecast levels and flows at Athens.
Whanganui	46770	Forecast levels and flows at Oyster Bluff. No cross-section at this location in the model - interpolate between forecast results at cross-sections 49330 and 53269.
Whanganui	47050	Forecast flows at Te Rewa extracted for comparison to measured flows.
Te Rewa to Ocean MIKE 11 Model		
Whanganui	46050	Forecast levels and flows at Te Rewa.
Whanganui	49330	Forecast levels and flows at Paetawa.
Whanganui	51490	Forecast levels and flows at Parakino. No cross-section at this location in the model - interpolate between forecast results at cross-sections 49330 and 53269.
Whanganui	53110	Forecast levels and flows at Patapa. No cross-section at this location in the model - interpolate between forecast results at cross-sections 49330 and 53269.
Whanganui	77130	Forecast levels and flows at Kaiwhaiki Rd.
Whanganui	85330	Forecast levels and flows upstream of Rail Bridge.
Whanganui	88645	Forecast levels and flows at Town Bridge.

5.11 AUTOMATION OF THE HYDRAULIC MODELS

The hydraulic models are automatically run from within the WhanganuiMaster.tso via Windows Scheduler. Details on the components of the automated system and the automated process can be found in Sections 2 and 3 of this report.

For details (code) of how the start time, end time, initial hydrodynamic conditions and hotstart time of the models are updated for each model run, see the Rules of the Run_*sim11 nodes in the Master Model (C: HRCFloodFS\Models\Whanganui\TStudio\WhanganuiMaster.tso).

For details of the DOS commands that are used to run the MIKE11 models, output results to a text file and update the hotstart file see the Run_*.bat file in the directory of each MIKE11 model. (eg C:\HRCFloodFS\Models\Whanganui\Mike11\Run_Pipiriki-Ocean.bat)

5.12 STARTING THE HYDRAULIC MODEL – HOTSTART VS. PARAMETER FILE

For each MIKE 11 hydraulic model run a set of "initial conditions" is required for the model to start. These initial conditions are the water levels and discharges at the model cross-sections and represent the starting point for the model run.

There are a number of ways that the initial conditions for a particular model run can be defined. Two of the options are:

Parameter File: The initial conditions are set up manually and are contained the in hydrodynamic parameter (*.HD11) file used for the model run. These initial conditions can be either set up by:

- Entering water level and discharges for each cross-section (or a number of cross-sections) within the model.
- Providing a global set of initial conditions (ie starting water depth of 1m and starting flow of 5m^3/s) that apply over the whole model.

Hotstart File: The initial conditions for the model run are taken from the MIKE 11 result file (*.res11) that has been previously run.

When in real-time operation the flood-forecasting system will use the **Hotstart File** method to generate the initial conditions for each model run. The following is an example of how the Hotstart file method will be used during one cycle of the flood-forecasting model run:

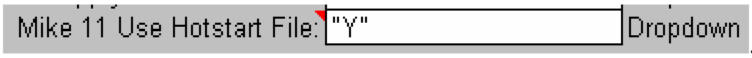
1. The previous flood-forecasting model run will have generated two sets of MIKE 11 results files. One set for the Pipiriki-Ocean model and the second set for the Te_Rewa-Ocean model.
2. For the current flood-forecasting model run the Pipiriki-Ocean hydraulic model is run first. The results 15minutes into the previous model run result file are referenced as the initial conditions for the current Pipiriki-Ocean model run. The results, 15min into the results file produced by the current model run will then be used as the initial conditions for the Pipiriki-Ocean in the next flood-forecasting cycle.
3. Similiarly for the Te_Rewa-Ocean hydraulic model.

For the **Hotstart File** method to work the starting time for the next model run must lie within the timeframe contained in the hotstart file that is being referenced. For example:

> If a flood forecasting model, which is predicting results 3 days into the future, crashes and is restarted in a weeks time the hotstart file generated by the previous model run will have an end time of approximately 4 days ago when the model is restarted. The "now time" initial conditions do not lie within the hotstart file time frame and the hydraulic model will come up with an error and will not operate.

For cases when downtime causes the hotstart file timeframe to become out of date the **Parameter File** method should be used to restart both the Pipiriki-Ocean and Te_Rewa-Ocean models. Rough initial water levels and flows have been set up in the Whanganui_Parameter.HD11 file. When starting with this option it may take a 1 day of simulation time to settle down before giving good results. It is possible it may not work if stability problems arise.

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



.

If Y is selected then the **Hotstart File** method is used.

If N is selected then the **Parameter File** method is used. Using this method, the Pipiriki-Ocean and Te_Rewa-Ocean will both be run once to create Hotstart File for use in subsequent automated model runs.

5.13 SUMMARY OF MIKE 11 MODEL FILES

MIKE 11 File Name	Description
Data Files Pipiriki-Ocean Model	
Pipiriki-Ocean.nwk11	Contains model network layout.
Whanganui_Cross-Sections.xns11	Contains cross-section data. Common file for both Pipiriki-Ocean and Te_Rewa-Ocean models.
Pipiriki-Ocean_Boundary.bnd11	Contains data relating to hydraulic model boundaries and defines inflow hydrograph locations.
Whanganui_Parameters.HD11	Contains Manning's n values to be applied to cross-sections. Common file for both Pipiriki-Ocean and Te_Rewa-Ocean models.
Pipiriki-Ocean.sim11	Links all relevant files required for the model simulation. Contains model start and end times and model timestep.
Pipiriki.dsf0	Timeseries file containing inflow hydrograph for Pipiriki.
Jerusalem.dsf0	Timeseries file containing inflow hydrograph for pickup between Pipiriki and Jerusalem.
Paetawa Local.dsf0	Timeseries file containing inflow hydrograph for pickup between Jerusalem and Paetawa.
Kaiwhaiki Road.dsf0	Timeseries file containing inflow hydrograph for pickup between Paetawa and Kaiwhaiki. Common file for both Pipiriki-Ocean and Te_Rewa-Ocean models.
Whanganui Rail.dsf0	Timeseries file containing inflow hydrograph for pickup between Kaiwhaiki and the rail bridge. Common file for both Pipiriki-Ocean and Te_Rewa-Ocean models.
Town Bridge.dsf0	Timeseries file containing inflow hydrograph for pickup between the rail bridge and Town Bridge. Common file for both Pipiriki-Ocean and Te_Rewa-Ocean models.
Pipiriki-Ocean_HS.res11	HOTSTART initial conditions file copied from the output file (Pipiriki-Ocean.res11) from the previous model run.
Pipiriki-OceanHDAdd_HS.res11	HOTSTART initial conditions file copied from the output file (Pipiriki-OceanHDAdd.res11) from the previous

MIKE 11 File Name	Description
	model run.
Data Files Te_Rewa-Ocean Model	
Te_Rewa-Ocean.nwk11	Contains model network layout.
Whanganui_Cross-Sections.xns11	Contains cross-section data. Common file for both Pipiriki-Ocean and Te_Rewa-Ocean models.
Te_Rewa-Ocean_Boundary.bnd11	Contains data relating to hydraulic model boundaries and defines inflow hydrograph locations.
Whanganui_Parameters.HD11	Contains Manning's n values to be applied to cross-sections. Common file for both Pipiriki-Ocean and Paetawa-Ocean models.
Te_Rewa-Ocean.sim11	Links all relevant files required for the model simulation. Contains model start and end times and model timestep.
Te_Rewa Adjusted Total.dsf0	Timsereis file containing the adjusted hydrograph at Te Rewa for input to the top end of the Te_Rewa-Ocean model.
Kaiwhaiki Road.dsf0	Timeseries file containing inflow hydrograph for pickup between Paetawa and Kaiwhaiki. Common file for both Pipiriki-Ocean and Te_Rewa-Ocean models.
Whanganui Rail.dsf0	Timeseries file containing inflow hydrograph for pickup between Kaiwhaiki and the rail bridge. Common file for both Pipiriki-Ocean and Te_Rewa-Ocean models.
Town Bridge.dsf0	Timeseries file containing inflow hydrograph for pickup between the rail bridge and Town Bridge. Common file for both Pipiriki-Ocean and Paetawa-Ocean models.
Te_Rewa-Ocean_HS.res11	HOTSTART initial conditions file copied from the output file (Te_Rewa-Ocean.res11) from the previous model run.
Te_Rewa-OceanHDAdd_HS.res11	HOTSTART initial conditions file copied from the output file (Te_Rewa-OceanHDAdd.res11) from the previous model run.
Output Files Pipiriki-Ocean Model	
Pipiriki-Ocean.res11	Results file containing water level results at cross-section locations (h-points) and discharge results at intermediate locations (q-points). Results file name is specified in the *.sim11 file.
Pipiriki-OceanHDAdd.res11	Results file containing discharge results at cross-section locations (q-points). Results file name is specified in the *.sim11 file.
Pipiriki-Ocean_Simulation.Log	Contains initial WARNINGS and ERRORS prior to a model run. Automatically generated.
Pipiriki-Ocean_Simulation-Info.Log	Contains WARNGINGS and ERRORS that occur during a model run. Automatically generated.
Pipiriki-Ocean_Simulation-SimStat.Log	Contains simulation start and end time (modelling time). Automatically generated.
Output Files Pipiriki-Ocean Model	
Te_Rewa-Ocean.res11	Results file containing water level results at cross-section locations (h-points) and discharge results at intermediate locations (q-points). Results file name is specified in the *.sim11 file.
Te_Rewa-OceanHDAdd.res11	Results file containing discharge results at cross-section locations (q-points). Results file name is specified in the

MIKE 11 File Name	Description
	*.sim11 file.
Te_Rewa-Ocean_Simulation.Log	Contains initial WARNINGS and ERRORS prior to a model run. Automatically generated.
Te_Rewa-Ocean_Simulation-Info.Log	Contains WARNGINGS and ERRORS that occur during a model run. Automatically generated.
Te_Rewa-Ocean_Simulation-SimStat.Log	Contains simulation start and end time (modelling time). Automatically generated.
Automation Files	
Run Pipiriki-Ocean.bat	Contains the commands to run the Pipiriki-Ocean hydraulic model simulation, convert the MIKE 11 results to text files and to copy the Pipiriki-Ocean.res11 and Pipiriki-OceanHDAdd.res11 to Pipiriki-Ocean_HS.res11 and Pipiriki-OceanHDAdd_HS.res11.
Run Te_Rewa-Ocean.bat	Contains the commands to run the Te_Rewa-Ocean hydraulic model simulation, convert the MIKE 11 results to text files and to copy the Paetawa-Ocean.res11 and Paetawa-OceanHDAdd.res11 to Paetawa-Ocean_HS.res11 and Paetawa-OceanHDAdd_HS.res11.

6 RECOMMENDATIONS FOR FUTURE IMPROVEMENTS

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

Some areas of improvement identified at the completion of Stage 3 of the project are:

- **Site information:** As shown in the calibration section of the hydrological model (particularly Section 4.4.3) there was little effect on the calibration performance when excluding the Taranaki rainfall gauges from the analysis. It is likely then that the existing rainfall network is ok. The emphasis now should be on identifying the most crucial gauges to the system (se figs on page 28) and ensuring that the polling of data from these sites is always up to date.

  Reinstating the flow gauges at the existing tributary locations in the Whanganui catchment could benefit to the model performance both by providing additional flow correction points and a means to gain a better understanding of the variation of catchment conditions during future calibrations. These include the Ohura, Manganui-o-Te-Ao and Tangarakau Rivers. It is not recommended that flow sites be installed in any new locations until a future review of the model calibration has been undertaken.

- **House-keeping/diagnostic archives:** As discussed in Section 2 and also during the September site visit, there are a number of house-keeping and monitoring tasks that can be incorporated into the HRCFFS to obtain a better understanding of the real-time performance of the operating system and its components. To begin this process, a moving archive (of possibly 30 days) will be created to keep a record of Mike11 folders for diagnostic purposes. Other components that could make up the complete monitoring system include:

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

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

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

- **Review of Forecast Rainfalls and Predictive Reliability:** HTC have not reviewed any of the forecast rainfall inputs for their real-time performance. Next to the calibration, the forecast rainfalls are critical to the reliability of the HRCFFS. By constructing useful plots for the diagnostic archive (mentioned in the point above), the forecast verses measured rainfall could be captured as the models progress through flood events. This could simplify manual review procedures of predictive analyses. A measure of the uncertainty of forecast rainfall estimates will be beneficial to the FFS.

- **Ongoing Support and Maintenance:** As the project further approaches completion, a support contract should be considered for emergency response to system issues, continual improvement of the system and review of system performance.

- **Nominating a System Administrator:** A member (or possibly two) of Horizons Regional Council should be appointed as an administrator of the HRCFFS. Specific training can be provided to the administrator/s to transfer knowledge on how to troubleshoot system issues, make minor changes to the models (adding/removing gauges or performing model recalibrations), and to undertake an annual review of the system performance. The September site visit revealed that there are a number of capable personnel for the job; it is just whether it is worth allocating some time to a HRC staff member or to outsource all review and troubleshooting tasks to HTC.

- **Flood Event Follow-up Procedures and Annual Review:** Already highlighted above, this point deserves a double mention. It is not worth installing new sites unless the performance of the modelling system can be adequately quantified. Following any significant flood event, sufficient information should be collated (e.g. moving appropriate files out of the moving archive if automated house-keeping and maintenance procedures are adopted) and there should be a review process, either annual or bi-annual, to quantify the performance of the modelling system. It is recommended that this review process includes model recalibrations if it is warranted. These processes could be undertaken by the system administrator or HTC or a combination of both.