Department of Science, Information Technology and Innovation

Paroo River Catchment IQQM Calibration

Headwaters to GS424001 Paroo River at Wannaring GS424001 (NSW)

January 2016

Queensland Government

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Executive Summary

A daily flow model of the Paroo River catchment to GS424001 Wanaaring has been developed using Version 6.75.32 of the Integrated Quantity-Quality Model (IQQM) developed by the Department of Land and Water Conservation in New South Wales. The IQQM model is a hydrological system simulation model that operates on a daily time step. A full description of the model can be found in the IQQM Manual (DLWC, 1996).

The model was developed for the Water Resource (Warrego, Paroo, Bulloo and Nebine Catchments) Plan Review 1, the 10 year review of the *Water Resource (Warrego, Paroo, Bulloo and Nebine Catchments) Plan 2003*. This report describes the process and results of the system calibration undertaken.

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1. Introduction

A daily flow model was developed for the Paroo River catchment. The catchment was divided into reaches, based on the location of major gauging stations. The reach from Wanaaring to the Darling River was not considered. The reaches included in the model are:

- Reach 1 – Upstream Of Yarronvale
- Reach 2 – Yarronvale to Caiwarro
- Reach 5 – Caiwarro to Willara Crossing (NSW)
- Reach 6 – Willara Crossing to Wanaaring (NSW)

This report contains the details for the whole of catchment model to Wanaaring. The model was developed as part of the Water Resource (Warrego, Paroo, Bulloo and Nebine Catchments) Plan Review 1 study. This model extends and refines the model prepared for the *Water Resource (Warrego, Paroo, Bulloo and Nebine Catchments) Plan 2003.*

Version 6.75.32 of the Integrated Quantity and Quality Model (IQQM), developed by the Department of Land and Water Conservation in New South Wales, was used for the development of the model. A full description of the IQQM model can be found in the IQQM Manual (DLWC, 1996). A map of the catchment is shown in Figure 1.1. It shows the Paroo River to the Darling River however the model finished at Wanaaring which is the most downstream location where flows are recorded.

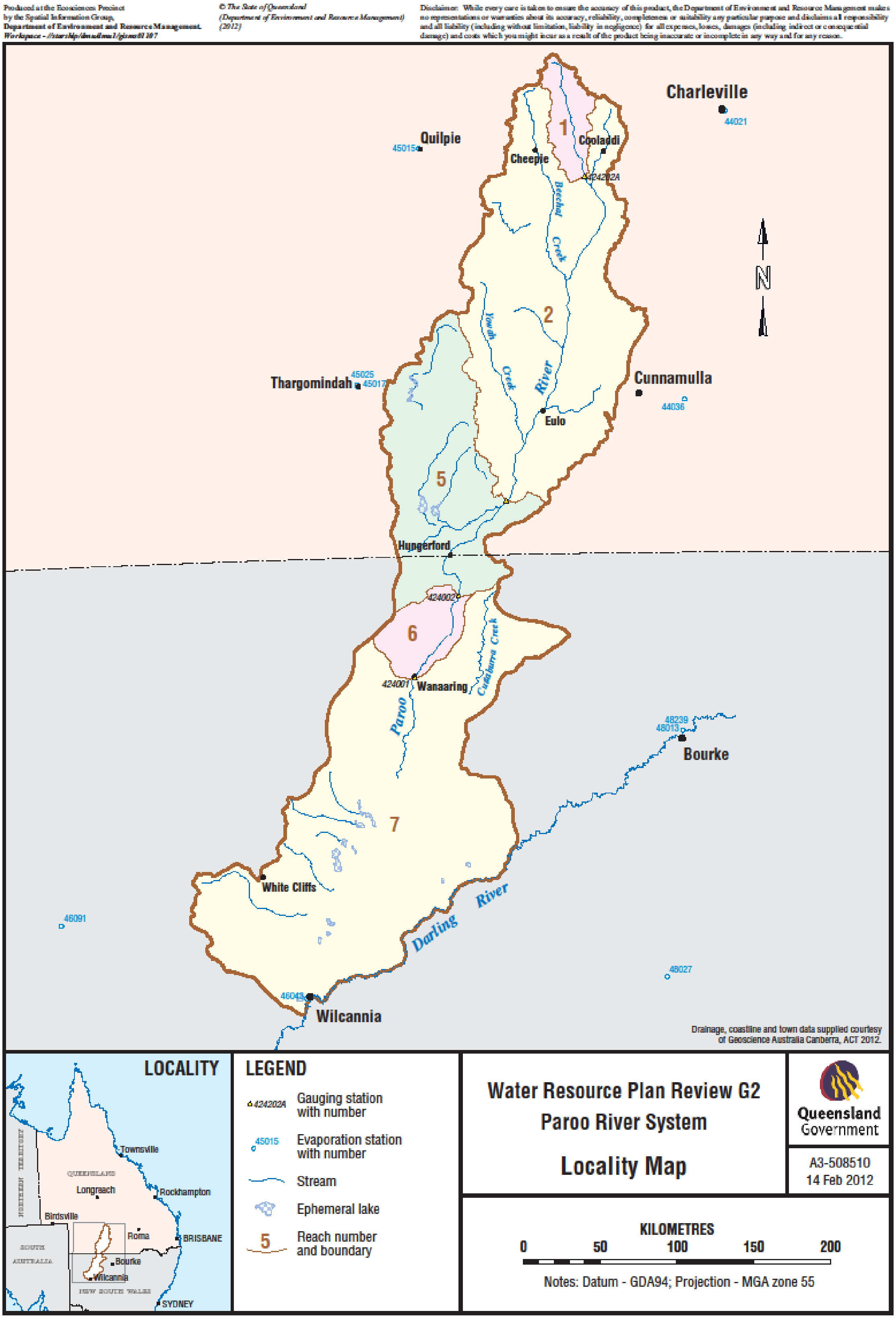


Figure 1.1: Paroo Catchment Map

2. Previous Hydrology

The Paroo WRP Review model is extensively based on the model developed for the *Water Resource (Warrego, Paroo, Bulloo and Nebine Catchments) Plan 2003*. Details of that model can be found in the IQQM calibration report, *Paroo River System Hydrology Volume 1 – Calibration of Daily Flow Simulation Model from upstream of Yarronvale (QLD AMTD 303.7 km) to Darling River/Paroo River Confluence (NSW AMTD 0.0 km).* (Qld DNRM, 2003). In this new report the earlier study and the IQQM model developed in it will be referred to as the 2003 study or 2003 IQQM model.

3. Paroo Basin Description

3.1 Plan Area

The Paroo component of the Water Resource (Warrego, Paroo, Bulloo and Nebine Catchments) Plan Review 1 study area is located in South Western Queensland. It includes the Paroo River Basin to Wanaaring. The total area to Wanaaring is 34,486 square kilometres. The model was developed for the area that contributes runoff, which to Wanaaring is 26,530 square kilometres. This excludes areas draining to ephemeral lakes which do not feed the main river. The reach from Wanaaring to the Darling River was not considered. The catchment is shown in Figure 1.1.

3.2 Basin Description

The Paroo River headwaters are situated in the Warrego and Wallaroo Ranges. The river flows southwest through Queensland and into New South Wales where it discharges into a complex flood plain south of Wanaaring, as it approaches the Darling River between Tilpa and Wilcannia.

Flows in the basin are erratic, with long periods of no flow. Average annual rainfall varies from about 275 mm/a near Wanaaring up to approximately 400 mm/a in the headwaters of the basin.

The Paroo is a fairly linear system with many smaller creeks feeding into the main stream.

4. Model Development Methodology

This section describes the development methodology for the Paroo Basin IQQM model and the development of the full system model. Figure 4.1 summarises the process. The IQQM model is described in Appendix A1.

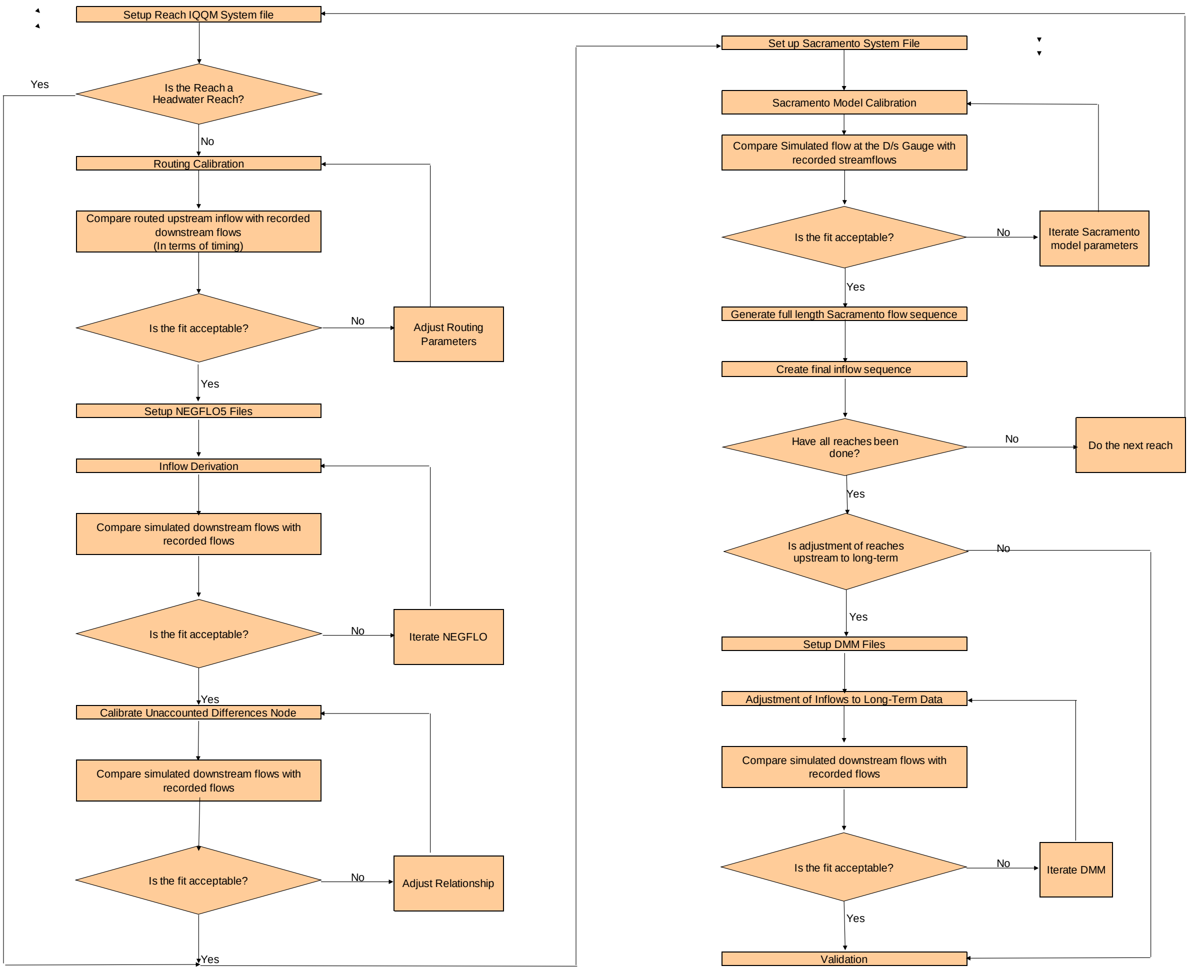


Figure 4.1: Model Development Flow Chart

4.1 Summary of the Model Calibration Process

The catchment model for the Paroo was developed following a series of steps:

- Data collection and preparation
- Reach calibration and record based inflow sequence derivation
- Sacramento model calibration
- Full length inflow sequence derivation
- Final inflow sequence derivation.

The following sections describe these steps in more detail.

4.1.1 Data Collection and Preparation

The initial stage of model development is the acquisition and collation of data required for the hydrological representation of the catchment. This stage includes the derivation of historical stream flows, and groundwater aquifer characteristics and water use behaviour if they are required.

4.1.2 Reach Calibration and Record Based Inflow Sequence

Discrete reach models are defined by locations with recorded stream flow data (gauging stations), and are either “headwater reaches” defined by a gauging station with no further upstream gauging station, or “residual reaches” defined by a gauging station and its nearest upstream gauging station(s). These discrete reach models form the basis of the final aggregated catchment model.

For headwater reaches, reach inflows were based on the recorded data at the stream flow gauge. The process for deriving a residual reach inflow via calibrating a residual reach is described below.

1. An IQQM model was set up for a reach including recorded inflows from upstream catchments and inflows from subareas in the reach (initially set to zero). To obtain a continuous upstream data sequence missing data was infilled with 0 values.

2. Lag and routing parameters were then calibrated to give the best overall reproduction of flows at the downstream gauge. Flows from the upstream gauges were routed and compared with recorded events at the downstream gauge. The non-linear lag and route procedure was used for the routing applied at the links between nodes. Routing is performed upstream of any residual inflows, such that when the residuals are calculated and put back into the model, no routing occurred on these flows to lessen the peaks downstream. Routing should remain the same over the whole period of record, barring major changes to the system such as infrastructure. The model routing parameters were adjusted until there was a reasonable correspondence between the time of arrival and the shape of the hydrographs. Special attention was placed on the flood events where the recorded downstream hydrograph was less than or comparable with the upstream hydrograph.

3. Following the calibration of the routing parameters the model is run and the record based local catchment inflow is estimated by subtracting the model outflows from the downstream gauge flows. The negatives caused by routing differences and data errors are smoothed. This sequence is adopted as the estimated pre-development inflow for the reach. If the upstream or downstream gauge records are missing, the record based residual inflows will have missing values on those missing days. The record based inflow sequence was then added to the model.

4. Estimates of the stream unaccounted differences along a reach are made. The unaccounted differences represent the loss factor relationship commonly used in the calibration of reaches to account for the average difference in flows at the downstream gauge over the calibration period. They are developed using a reach model that includes the calculated residual inflow. The relationship is built up from low to high flows so that the exceedance curves align well for the downstream gauge. The changed mean flow of the modelled data compared to the recorded data is also reviewed as you develop the relationship to ensure an acceptable volume balance is maintained. The relationship remains constant for the whole period of simulation in scenario runs.

   A waterhole was sometimes trialled to account for the antecedent conditions in the catchment. The waterhole volume and surface area were adjusted until simulated peaks which occurred prior to recorded events were removed. The waterhole was included after the record based inflow sequence was added to the IQQM model but prior to the unaccounted difference estimation.

4.1.3 Sacramento Model Calibration

A Sacramento rainfall-runoff model calibration against estimated record based pre-development inflows is then undertaken for the reach for the purposes of infilling periods of missing record and/or extending available inflow data beyond historically recorded periods. The Sacramento model is described in detail in Appendix A2.

The Sacramento model parameters were calibrated by comparing the derived flow with the calibration inflow sequence. The parameters were adjusted until an acceptable calibration was achieved for the whole period of record. The process involved obtaining visual matches between the modelled and recorded flows over the full flow range on daily flow plots, flow duration curves, cumulative mass and residual mass curves as well as checking the match between statistics associated with daily flows and the peak flow discharges in the recorded and calculated flow sequences. The adopted Sacramento parameters were those that provided the best statistical and visual match of the flow characteristics of the reach.

4.1.4 Full Length Inflow Sequence

The calibrated Sacramento model was used to generate flows for the full IQQM model period 01/01/1889–30/06/2011. This data was used to infill and extend the record based pre-development flows to produce the full length residual reach inflow sequence.

4.1.5 Final Inflow Sequence

Once all the full length inflow sequences for the whole model were available, then further adjustments were made to the Sacramento portions of these to obtain a better match between the model and the long term recorded flow data across the catchment. The adjustments were made using DMM.

DMM is an adjustment process applied across multiple reaches. It is used to adjust Sacramento data in multiple reaches upstream of a long term gauge, to bring the modelled and recorded flows into alignment. Recorded head water inflows and calculated residual inflows are not adjusted.

DMM first calculates the difference between modelled and recorded flows at the downstream gauge being adjusted to. The differences are caused by inaccuracies in Sacramento inflows due to things like inaccurate spatial and temporal rainfall and evaporation representation, and also by the averaging of lag and routing, and averaging of losses. DMM adjusts the Sacramento parts of the inflow sequences to get sequences that when put with the calibrated models assumptions will result in better alignment of the modelled and gauge flows at the long term gauge. It does multiple iterations to converge towards a best set of adjusted inflows and then the user decides which iteration’s inflows give the best result overall. The DMM process multiplies the inflows by the ratio of the measured flow to the modelled flow at the downstream gauge. When the modelled flow is zero and the measured flow is non-zero, the DMM program adds the flow back into the inflows. The DMM program uses pre-defined factors to spread this extra inflow amongst the sub-catchments upstream. These factors are usually based on the catchment areas of the upstream sub-catchments.. The DMM flow adjustment programs are outlined in Appendix B.

DMM can be applied to align the model to multiple long term gauges. In this case a DMM is done to the 1st gauge you want to DMM to then the inflow data adjusted to it is excluded from adjustments when the DMM to the 2nd gauge further downstream is done.

The final residual reach inflows are what was used in the model validation and will be used in future model simulations.

4.2 Model Validation

As the last step in the process, a validation model was prepared to confirm the performance and accuracy of the model run as a complete system. Results were reported at each gauge to validate behaviour of the full Paroo model that combined all reach models.

5. Data

This section outlines the data used in the IQQM models. The types of data used include:

- basin division
- stream flow data
- rainfall data
- evaporation data
- groundwater data
- water infrastructure
- historical surface water extraction data.

5.1 Basin Division

The total catchment area of the Paroo Basin to Wanaaring is 34 486 km^2 however the model has been developed for the area contributing to runoff, which to Wanaaring is 26,530 square kilometres. This excludes areas draining to ephemeral lakes which do not feed the main river. For modelling, the Paroo River system to Wanaaring was split into four reaches defined based on the location of major stream gauging sites. The reaches used in the model are identified in Table 5.1 and can be seen on Figure 1.1. Reach 7 on Figure 1.1 is shown for completeness of the basin but has not been modelled. This report will use the name of the station only to refer to the gauge being discussed.

Table 5.1: Paroo Basin Division

Reach	Upstream Gauge	Downstream Gauge	Total Catchment Area (km2)	Contributing Catchment Area (km2)
1		Yarronvale GS424202a	1,819	1,819
2	Yarronvale GS424202a	Caiwarro GS424201a	19,627	19,627
5	Caiwarro GS424201a	Willara Crossing GS424002	10,748	2,792
6	Willara Crossing GS424002	Wanaaring Gs424001	2,292	2,292
Total			**34,486**	**26,530**

5.2 Stream flow

Stream flow records from four mainstream gauges along the Paroo River were used. These gauges were chosen because of the reliability and quality of records.

Stream flow data for the QLD gauges was obtained from HYDSTRA (Kisters Pty. Ltd, 2010), while NSW stream gauging station data was obtained from the Department of Primary Industries Office of Water of New South Wales. Table 5.2 shows summary data for these gauges and missing periods of record are listed in Table 5.3 and Table 5.4 shows the water balance prepared using the recorded stream flow data.

For QLD gauge sites, the data required for IQQM modeling was readily accessible from HYDSTRA. This data was not available for the New South Wales (NSW) gauges at the time of modelling. Therefore it was necessary to obtain streamflow data via public access of the NSW Government Department of Primary Industries Office of Water website. Not all categories and formats of the data requested were available from this source.

Table 5.2: Paroo River Stream flow Gauges – Summary

Station		Period of Record		AMTD	Contributing C.A.	Control	Highest Gauged Flow(1)			Highest Recorded Flow(2)			% Rated(3)
#	Name	Start	End	(km)	(km2)		Date	Height (m)	Flow (m3/s)	Date	Height (m)	Flow (m3/s)	
424202a	Yarronvale	27/10/1967	29/09/1988	306.9 Qld.	1,819	-	24/05/1990	3.57	76	09/01/1974	5.65	1,327	6
424201a	Caiwarro	19/04/1967	Date	57.3 Qld.	21,446	Causeway	17/05/1968	4.61	1,137	08/03/2010	4.98	1,801	63
424002	Willara Crossing	25/11/1975	Date	0.0 Qld/ 290.4 NSW	24,238	-							
424001	Wanaaring	02/01/1968	31/12/1983	228.0 NSW	26,530	-							

(1) This is the largest flood measured by a physically measured reading or gauging (discharge actually measured)

(2)This is the largest flood recorded by the automatic recorder (height reading only converted to a flow by use of the rating table)

(3) Percentage rated refers how close the largest measured discharge (gauging) corresponds to the highest recorded flood height (from automatic recorder)

Table 5.3: Paroo River Stream Flow Gauges – Missing Data

Station Number	Station Name	Missing Data
424202a	Yarronvale	15/09/1971–16/09/1971 28/12/1977–30/12/1977 13/12/1980–14/05/1981 13/05/1982–14/05/1982 14/05/1987–26/11/1987 01/02/1988–19/05/1988
424201a	Caiwarro	17/05/1988–05/11/1988 18/05/1989–12/06/1989
424002	Willara Crossing	22/03/1987–01/06/1987
424001	Wanaaring	19/08/1971–31/08/1971 01/12/1971–14/12/1971 18/01/1973–23/01/1973

Table 5.4: Paroo River Recorded Data Water Balance

Station #	Station Name	Contributing Catchment Area (km^2)	Period of Record	July to June			
				Mean Annual Flow (ML/a)	Mean Annual Flow (mm/a)	MARF (mm/a)	% RO Coeff
424202A	Yarronvale	1,819	27/10/1967–29/09/1988	69,851	38.40	384	10%
424201A	Caiwarro	21,446	19/04/1967–30/06/2011	554,517	25.86	385	7%
424002	Willara Crossing	24,238	25/11/1975–30/06/2011	363,992	15.02	372	4%
424001	Wanaaring	26,530	02/01/1968–31/12/1983	394,899	14.88	361	4%

5.3 Rainfall

For modelling purposes, daily rainfall data for the period 01/01/1889 to 30/06/2011 was obtained from the meteorological data stored in the SILO datasets (https://www.longpaddock.qld.gov.au/silo/).

The SILO datasets use the rainfall observations from selected Bureau of Meteorology (BoM) rain gauges as well as estimates made using the recorded data to generate rasters of estimated daily rainfall. Each raster contains an estimate of the rainfall at every 0.05 degrees across Australia. A description of the methods used to generate these rasters is documented in Jeffrey et al (2001).

The accuracy of the SILO database is highly dependent on the station coverage as well as the length and quality of the data. In the western areas the distribution of stations is limited and the storm rainfall patterns and large distances mean that often events are not captured. Also, generally, the accuracy will be less the further back in time you go.

From the datasets, rainfall can be determined for either a point (e.g. town, climate station, storage) or as an average of a number of points (e.g. catchment). When data is extracted for a rainfall station held in the patched point dataset it will include the recorded data infilled and extended using the SILO estimated data for that location. For this study station point data was extracted from the patched point data set. Table 5.1 shows summary information on the rainfall stations used in this study. These stations were tested to identify any trending and were found to have no significant trends. The station locations can be seen on the Reach Maps in Section 6.

Stations were selected based on the length of record. It can be seen from Table 5.5 that there are a significant number of rainfall stations in the catchment with record as far back as the late 1800s.

For the Sacramento models point data from multiple stations was used. Table 5.6 shows the model rainfall data used for the Sacramento models. Initially the weights were based on the catchment areas they were assumed to represent but in some cases these were adjusted to give a better match between the actual rainfall and flow patterns.

Table 5.5: Paroo Rainfall Stations

Station Number	Rainfall Station	Lat.	Long.	Period of Record	Mean SILO Rainfall July to June 1889–2011 (mm/a)
44004	Beechal	-27.1383	144.7392	01/07/1873–date	357
44007	Bierbank	-26.7756	145.0708	01/01/1888–date	389
44012	Boorara	-28.6575	144.3808	01/01/1885–30/06/2008	291
44025	Cowley Station	-26.9044	144.8272	01/01/1884–date	378
44026	Cunnamulla Post Office	-28.0706	145.6808	01/12/1879–date	368
44031	Dynevor Downs	-28.0911	144.3586	01/01/1880–date	293
44040	Gumnardo	-26.1108	144.8728	01/01/1885–date	428
44064	Spring Creek	-27.2694	145.3803	01/01/1927–date	370
44072	Werrina	-26.8842	145.8992	01/05/1908–30/11/2006	402
44129	Pingine	-26.4214	144.9992	01/03/1920–date	411
44181	Hungerford	-28.9972	144.4094	01/01/1884–date	291
45017	Thargominda Post Office	-27.9978	143.8197	01/12/1879–31/03/2005	273
48079	Wanaaring Post Office	-29.7028	144.1482	01/10/1884–date	262
48087	Yantabulla Station	-29.3423	145.0032	01/11/1892–30/11/2008	277

Table 5.6: Paroo Model Rainfall

Reach	Rainfall Station Number	Mean Annual Rainfall July to June mm/a	Sacramento Proportion	Mean Catchment Rainfall July to June mm/a	Sacramento Catchment Rainfall Adjustment Factor (RFADJ)
1	44129	386	0.164	390	1
	44007	392	0.314		
	44040	412	0.072		
	Total		1.00		
2	44129	386	0.072	365	1
	44025	378	0.08		
	44072	416	0.028		
	44004	358	0.188		
	44064	371	0.232		
	44026	373	0.304		
	44012	293	0.096		
	Total		1.00		
5	44031	299	0.336	296	1
	45017	285	0.027		
	44012	293	0.336		
	44181	298	0.291		
	48087	295	0.01		
	Total		1.00		
6	44181	298	0.095	277	1
	48079	275	0.905		
	Total		1.00		

5.4 Evaporation

For modelling purposes, daily climate data for the period 01/01/1889 to 30/06/2011 was obtained from the meteorological data stored in the SILO data drill dataset (https://www.longpaddock.qld.gov.au/silo/).

The accuracy of the SILO database is highly dependent on the station coverage as well as the length and quality of the data. In general the accuracy will be less the further back in time you go. For evaporation the station coverage is sparse and the length of records is generally short. In this catchment, the nearest representative evaporation station was the Hermitage site in Warwick. This station is located outside of the Basin, to the east.

Daily PET and Lake Evaporation was extracted for the period 01/01/1889 to 30/06/2011. Table 5.7 summarises the evaporation data used in the model. The data was tested and found to show no significant trends.

Table 5.7: Paroo Model Evaporation

Station Number	Station Name	Lat.	Long.	Period of Record	Missing Record	Mean SILO PET Evap. July to June (mm/a)	Mean SILO Lake Evap. July to June (mm/a)
41044	Hermitage, Warwick	-28.2061	152.1	August 1969–June 2000	n/a	1,742	1,436

5.5 Groundwater Data

Using the current recorded stream flow data it is not possible to identify any groundwater inflows into the Paroo catchment that have any significant effect on the surface water on a catchment scale. On this basis groundwater interaction has been ignored in this study.

5.6 Natural Lakes

There are natural ephemeral lakes within the Paroo River Catchment which capture flow from parts of the catchment. These have not been modelled and their catchment areas are excluded from the runoff contributing catchment areas discussed in this report.

5.7 Water Infrastructure

There is no water infrastructure of note in the catchment.

5.8 Historical Surface Water Extraction Data

There is little recorded information on historical diversions so it was decided to be conservative and assume that no historical diversions occurred. Real diversions are not large so this is an acceptable assumption.

6. Reach Model Calibrations

6.1 Overview

The following sections describe how the methods outlined in Section 4 were used with the data from Section 5 to derive inflows and model parameters for each Reach.

6.2 Reach 1 – Upstream of Yarronvale

6.2.1 Description

The location of Reach 1 is shown on Figure 1.1 and more detail is provided by Figure 6.1.

This headwater reach ends at Yarronvale and is in the far north of the system. It is bound to the north by the Warrego and Wallaroo Ranges, which separate the Paroo River System from the adjoining river basins. Elevations in the reach range from 250 m at Yarronvale up to 500 m in the ranges.

Tributaries of the Paroo River within this reach include Stockade Creek and Cattle Creek.

The average annual rainfall for the stations used in this study range from 389 to 412 millimetres per annum.

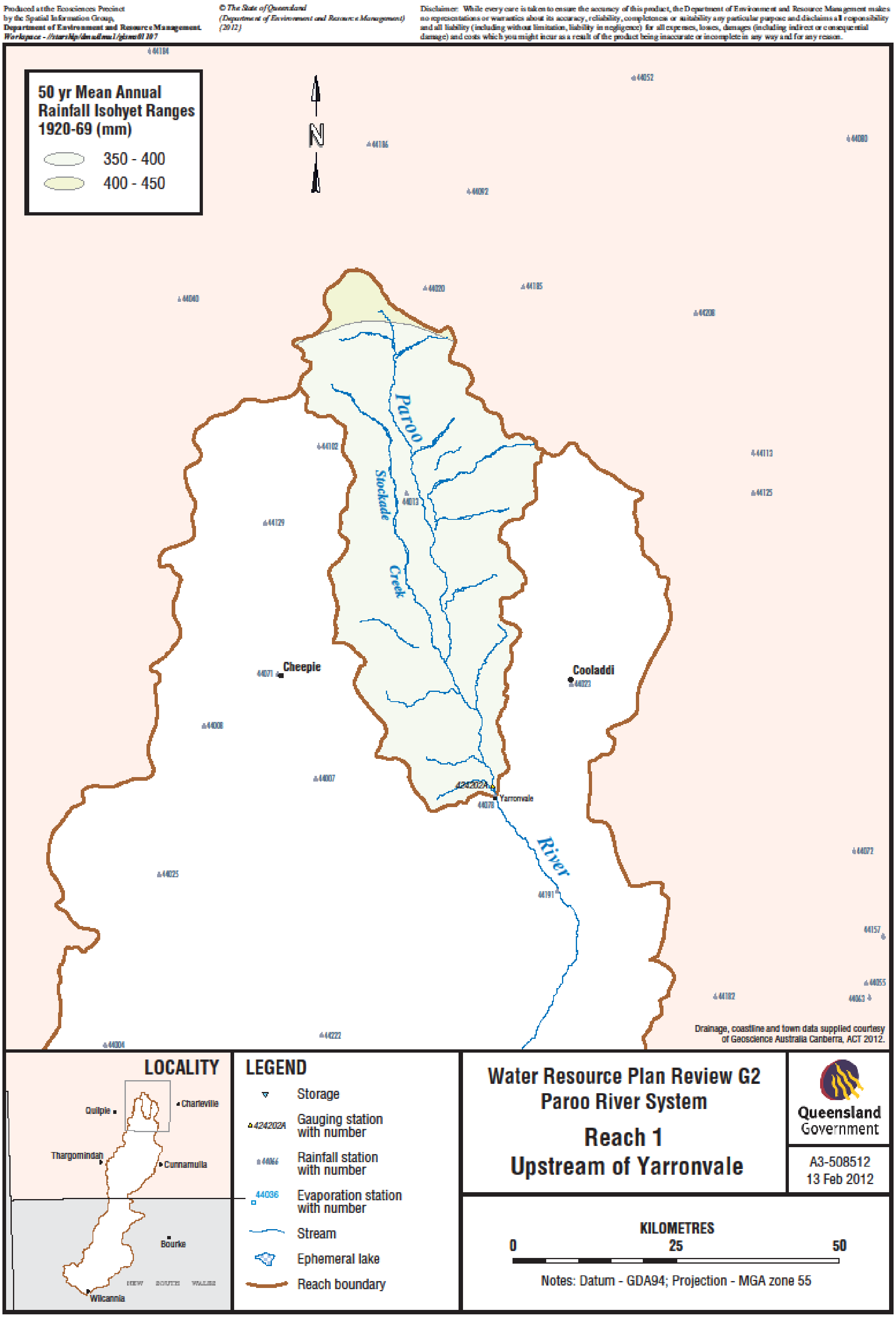


Figure 6.1: Map of Reach 1 – Upstream of Yarronvale

6.2.2 Data

6.2.2.1 Flow Data

Gauge data from Yarronvale was used for Reach 1. The stream flow data used for calibration can be viewed in Table 6.1.

Table 6.1: Reach 1 – Flow Data

Location	Station	Period
Downstream	424202a	27/10/1967 to 29/09/1988

6.2.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 1.

6.2.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 1.

6.2.3 Reach Calibration and Record Based Inflow Sequence

Measured flows at Yarronvale for the period of record 27/10/1967 to 29/09/1988 were used as the recorded Reach 1 inflow sequence for model calibration. As this is a headwater catchment the routing and transmission losses for the reach are inherent in the recorded flow sequence.

6.2.4 Sacramento Model Calibration

The Sacramento model was calibrated to the record based inflow sequence.

6.2.4.1 Time Period

The calibration period for the reach Sacramento was 27/10/1967 to 29/09/1988, the period of available stream flow record. No data was ignored during the calibration.

Validation periods were defined by dividing the gauge record in half.

6.2.4.2 Unit Hydrograph

Table 6.2 shows the unit hydrograph adopted for calibration. The unit hydrograph was developed by trial and error. The unit hydrograph was adjusted during the calibration process in order to improve the timing and width of flow events at the Yarronvale gauge.

Table 6.2: Reach 1 – Unit Hydrograph

1	2	3	4
0.45	0.35	0.15	0.05

6.2.4.3 Catchment Area

The total and the contributing catchment area of Reach 1 is 1,819 square kilometres. All of the subarea catchment is assumed to contribute to runoff (100%).

6.2.4.4 Sacramento Model Parameters

Table 6.3 shows the Sacramento model parameters for the reach. These are the parameters that provided the best statistical and visual match of the flow characteristics of the reach.

Table 6.3: Reach 1 – Sacramento Model Parameters

Parameter	Adopted Value	Initial Volume
LZTWM	410	0
UZFWM	10.33817	0
UZK	0.18	
REXP	2.898092	
UZTWM	44.485	0
PFREE	0.265	
ZPERC	12.93995	
LZFPM	5	0
SIDE	0.002	
LZSK	0.76	
PCTIM	0.29998	
LZFSM	8	0
SARVA	0	
LZPK	0.5	
ADIMP	0.245156	
SSOUT	0.002	
RSERV	0.3	
RFADJ	1	

6.2.4.5 Sacramento Model Calibration Results

Table 6.4, Table 6.5 and Table 6.6 show the flow statistics for the recorded and calculated data for the calibration period and the two validation periods. Figure 6.2, Figure 6.3 and Figure 6.4 show the Report Cards. Appendix C1 includes daily plots of the data. The statistics and figures have been compiled by excluding data for the periods where there is missing data in the recorded flow sequence.

Table 6.4: Reach 1 – Sacramento Calibration Statistics

Location		Daily Recorded	Daily Simulated
Yarronvale 27/10/1967–29/09/1988 Calibration	Mean (ML/d)	165	165
	Standard Deviation (ML/d)	1,446	1,368
	Skew	27.56	26.62
	Maximum Flow (ML/d)	76,281	65,097
	Volume Change (%)		100
	Coefficient of Determination		0.7331
	Coefficient of Efficiency		0.7251

Table 6.5: Reach 1 – Sacramento Validation 1 Statistics

Location		Daily Recorded	Daily Simulated
Yarronvale 27/10/1967–30/06/1978 Validation 1	Mean (ML/d)	222	222
	Standard Deviation (ML/d)	1,849	1,777
	Skew	23.47	21.94
	Maximum Flow (ML/d)	76,281	65,097
	Volume Change (%)		99.6
	Coefficient of Determination		0.7808
	Coefficient of Efficiency		0.7749

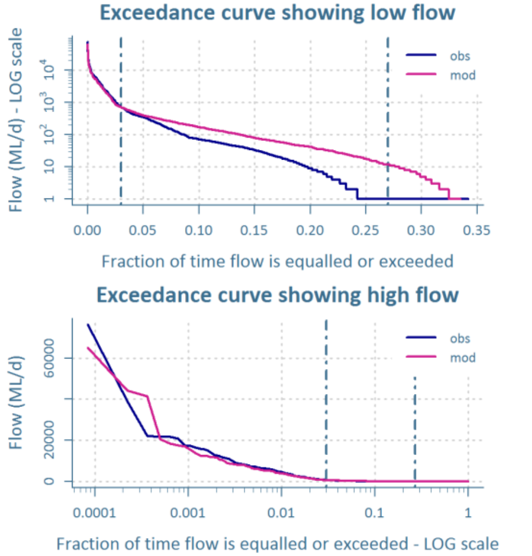
Table 6.6: Reach 1 – Sacramento Validation 2 Statistics

Location		Daily Recorded	Daily Simulated
Yarronvale 01/07/1978–29/09/1988 Validation 2	Mean (ML/d)	96	97
	Standard Deviation (ML/d)	714	560
	Skew	15.91	12.10
	Maximum Flow (ML/d)	17,387	12,467
	Volume Change (%)		101
	Coefficient of Determination		0.3673
	Coefficient of Efficiency		0.3245

Reach 1-Yarronvale Sacramento Calibration

Period of analysis: 27/10/1967 to 29/9/1988

(observed flow is available for 93.9% of days in this period)



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,182,004	0.0%	★★★★★
Total Low Flow Volume (ML)*	517	378.9%	★☆☆☆☆
Total Medium Flow Volume (ML)*	157,230	58.7%	★☆☆☆☆
Total High Flow Volume (ML)*	1,024,257	-9.2%	★★★☆☆
Mean Flow Volume (ML/d)	165	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	105	-37.5%	★☆☆☆☆
Zero Flow Days (%)+	65.8%	0.7%^	★★★★☆
Standard Deviation (ML/d)	1,446	-5.4%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.73	★★★☆☆
Non-matching Zero Flow Days	30.7%	★★☆☆☆

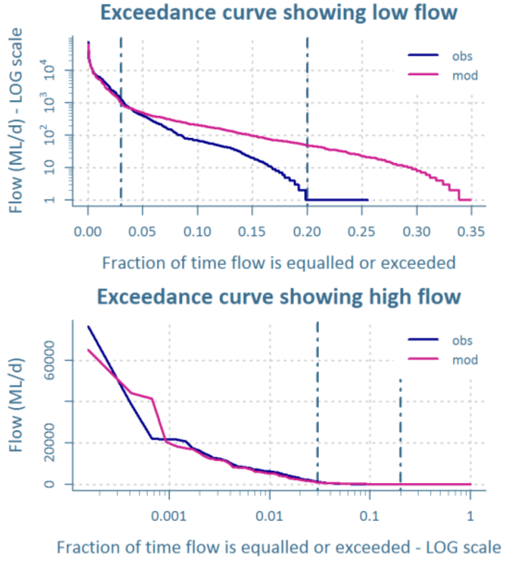
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.27 to 1 exceedance probability range
* Medium flow = flow in the 0.03 to 0.27 exceedance probability range
* High flow = flow in the 0 to 0.03 exceedance probability range
\+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

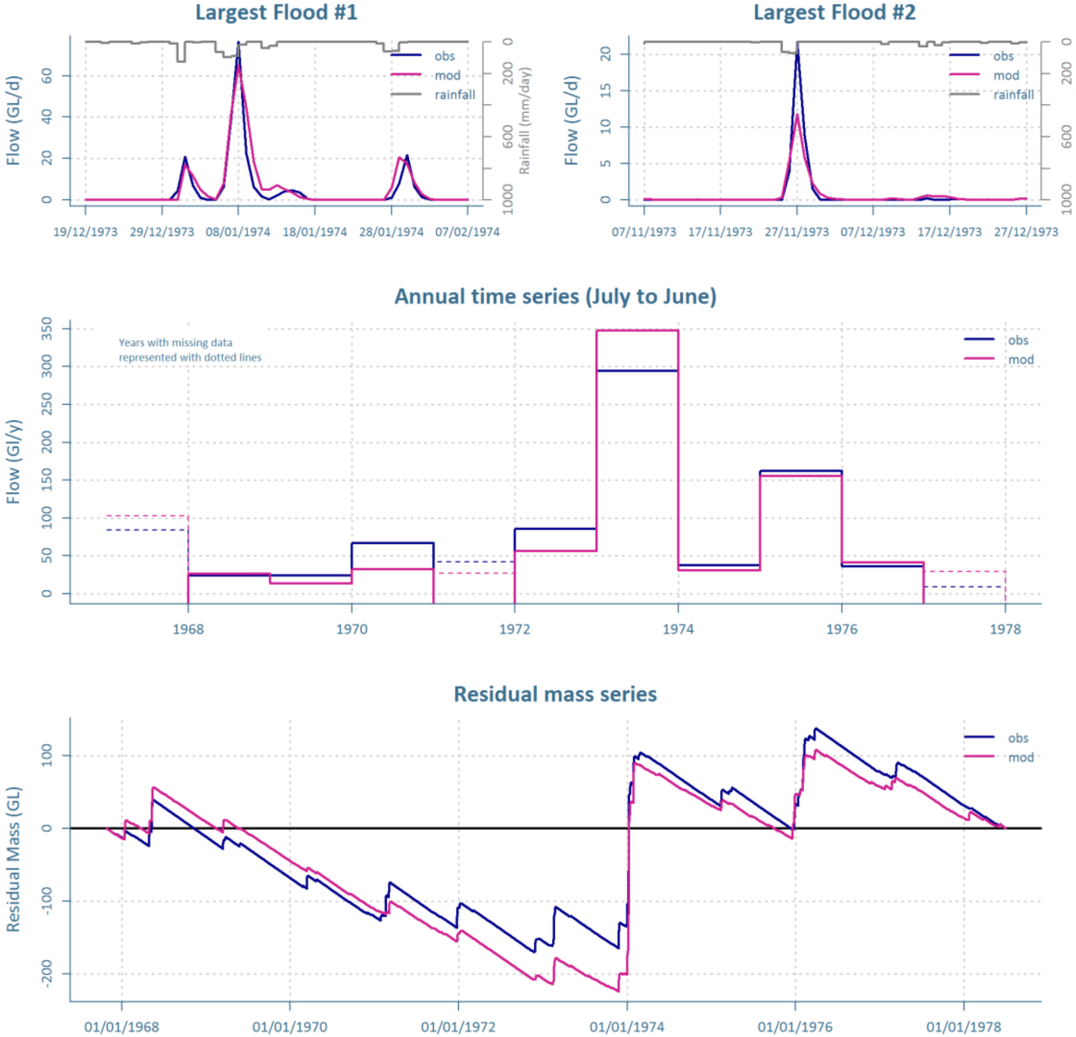
Figure 6.2: Reach 1 – Sacramento Calibration Report Card

Reach 1-Yarronvale Sacramento Validation 1

Period of analysis: 27/10/1967 to 30/6/1978

(observed flow is available for 99.9% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	866,458	-0.4%	★★★★☆
Total Low Flow Volume (ML)*	214	4862.6%	★☆☆☆☆
Total Medium Flow Volume (ML)*	97,742	59.6%	★☆☆☆☆
Total High Flow Volume (ML)*	768,502	-9.4%	★★★☆☆
Mean Flow Volume (ML/d)	222	-0.4%	★★★★☆
Driest 3 Year Mean (ML/d)	105	-37.5%	★☆☆☆☆
Zero Flow Days (%)+	74.5%	9.4%^	★★☆☆☆
Standard Deviation (ML/d)	1,849	-3.9%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.77	★★★★☆
Non-matching Zero Flow Days	24.9%	★★★☆☆

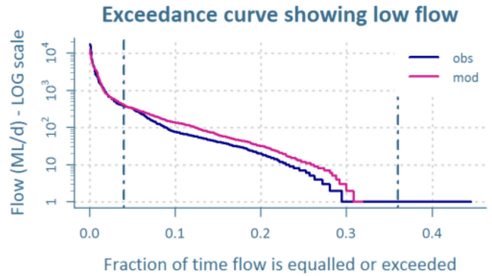
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.2 to 1 exceedance probability range
* Medium flow = flow in the 0.03 to 0.2 exceedance probability range
* High flow = flow in the 0 to 0.03 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

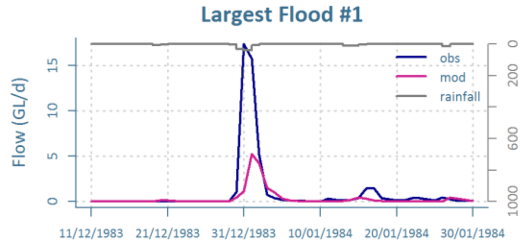
Figure 6.3: Reach 1 – Sacramento Validation 1 Report Card

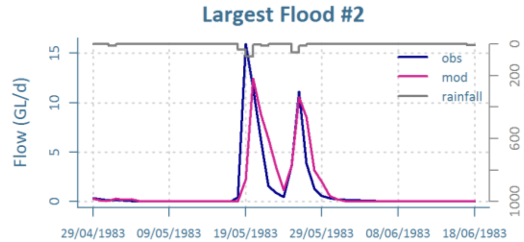
Reach 1-Yarronvale Sacramento Validation 2

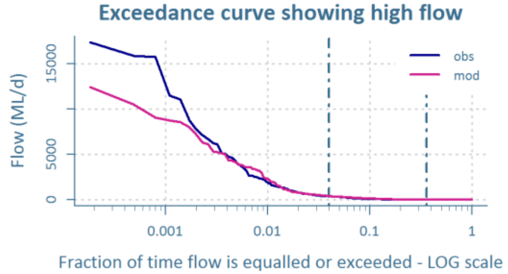
Period of analysis: 1/7/1978 to 29/9/1988

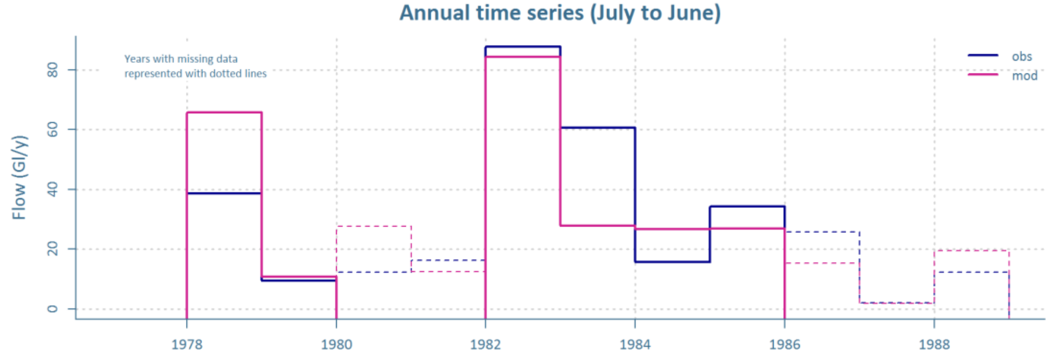
(observed flow is available for 87.7% of days in this period)











Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	315,546	1.2%	★★★☆☆
Total Low Flow Volume (ML)*	280	-100.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	55,460	35.3%	★☆☆☆☆
Total High Flow Volume (ML)*	259,806	-6.0%	★★★☆☆
Mean Flow Volume (ML/d)	96	1.2%	★★★☆☆
Driest 3 Year Mean (ML/d)	79	-29.3%	★☆☆☆☆
Zero Flow Days (%)+	55.5%	12.7%^	★☆☆☆☆
Standard Deviation (ML/d)	714	-18.7%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.32	★★☆☆☆
Non-matching Zero Flow Days	37.7%	★★☆☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.36 to 1 exceedance probability range
* Medium flow = flow in the 0.04 to 0.36 exceedance probability range
* High flow = flow in the 0 to 0.04 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

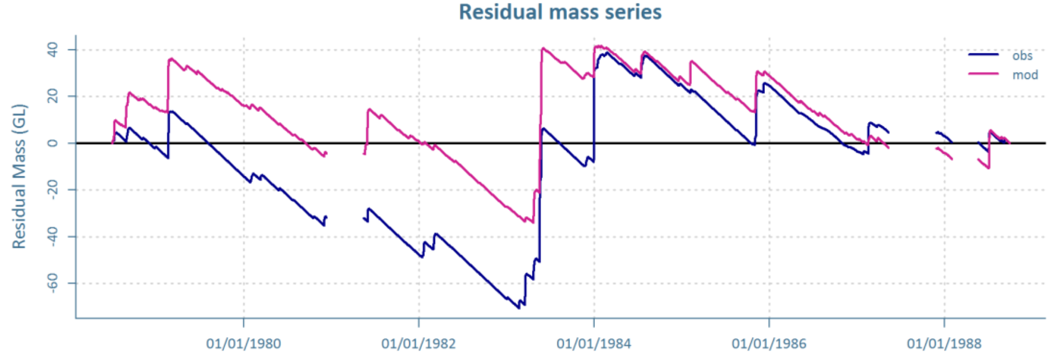


Figure 6.4: Reach 1 – Sacramento Validation 2 Report Card

6.2.4.6 Discussion

Over the full period of calibration and the validation periods a volume balance was achieved.

Over the full period of calibration the model reproduced the high and medium flows reasonably well as shown by the calibration flow duration curve. The validation plots show that the model matched better to the later validation period data.

For large recorded events there were over and under estimations. This is likely to be due to inaccuracies in rainfall as the limited number of stations used will not capture all rainfall variability. The rainfall stations that were adopted for calibration were chosen on the basis of their length of record and location, and are the best combination of available data.

In some cases, the simulated events occurred a few days earlier than the observed events. This is caused by the average lag function in the model not truly representing the natural variability in lags.

The model has difficulty in dry times. Small and medium events are produced that were not in the recorded flow data. Some of this can be accounted for by rainfall not being representative while others are related to the effects on flows of the variable antecedent condition of the catchment.

The residual mass curves show a good reproduction of the pattern of flow over time but you can see, especially in the 2nd validation period, where larger events have not been reproduced well.

The resulting calibration is the best compromise that could be made between maintaining the magnitude of flow events and balancing low flow events and maintaining an overall volume match.

The resulting model is acceptable for converting rainfall into stream flow for this catchment.

6.2.5 Full Length Inflow Sequence

The calibrated Sacramento model was used to generate inflows for the full IQQM model period 01/01/1889–30/06/2011. This data was used to infill and extend the record based pre-development inflows to produce the full length residual reach inflow sequence.

6.2.6 Final Inflow Sequence

For this reach the full length inflow sequence was adjusted using DMM for missing periods of record. Adjustments to the Reach1 and 2 flows were made to align the model flows to the flow record at Caiwarro. Table 6.7 and Figure 6.5 show the composition of the final inflow sequence for Reach 1. The mean daily inflow is 148 ML/day and the mean annual inflow 54,197 megalitres per annum.

Table 6.7: Reach 1 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–18/04/1967	Sacramento		
19/04/1967–26/10/1967	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a
27/10/1967–14/09/1971	Gauge	424202a	
15/09/1971–16/09/1971	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a.
17/09/1971–27/12/1977	Gauge	424202a	
28/12/1977–30/12/1977	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a.
01/01/1978–12/12/1980	Gauge	424202a	
13/12/1980–14/05/1981	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a.
15/05/1981–12/05/1982	Gauge	424202a	
13/05/1982–14/05/1982	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a.
15/05/1982–13/05/1987	Gauge	424202a	
14/05/1987–26/11/1987	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a.
27/11/1987–31/12/1987	Gauge	424202a	
01/02/1988–19/05/1988	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a.
20/05/1988–29/09/1988	Gauge	424202a	
30/09/1988–30/06/2011	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a.

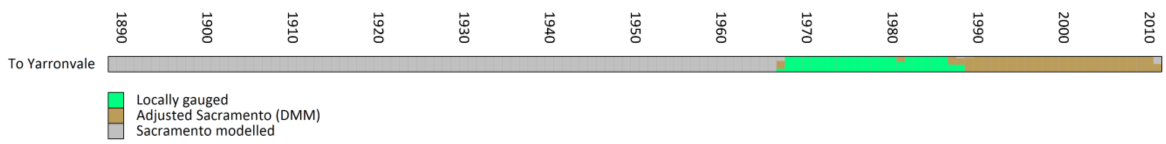


Figure 6.5: Reach 1 – Composition of Final Inflow Sequence

6.3 Reach 2 - Yarronvale to Caiwarro

6.3.1 Description

The location of Reach 2 can be seen on Figure 1.1, with more detail shown on Figure 6.6.

The Paroo River reach between Yarronvale and Caiwarro is in the central part of the basin catchment. The reach is bound to the west by the Bulloo River System between Quilpie and Autumnvale and to the east by the Warrego River System, between Charleville and Cunnamulla.

The catchment is reasonably flat with elevations ranging from around 140 m above sea level at Caiwarro to around 300 m above sea level in the north of the catchment. Mt Prara is the highest point in the catchment at 309 m above sea level.

Tributaries of the Paroo River within this reach include Middle Creek, Quilbery Creek, Eugood Creek, Yali Creek, Beechal Creek, Yerral Creek, Nammon Creek, Yowah Creek and Cookarra Creek all of which flow from the western side of the catchment into the Paroo River.

The average annual rainfall from the seven stations used in this study range from 293 to 416 millimetres per annum.

6.3.2 Data

6.3.2.1 Flow Data

The stream flow data used for calibration can be viewed in Table 6.8.

Table 6.8: Reach 2 – Flow Data

Location	Station	Period
Upstream	424202a	27/10/1967–29/09/1988
Downstream	424201a	19/04/19672date

6.3.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 2.

6.3.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 2.

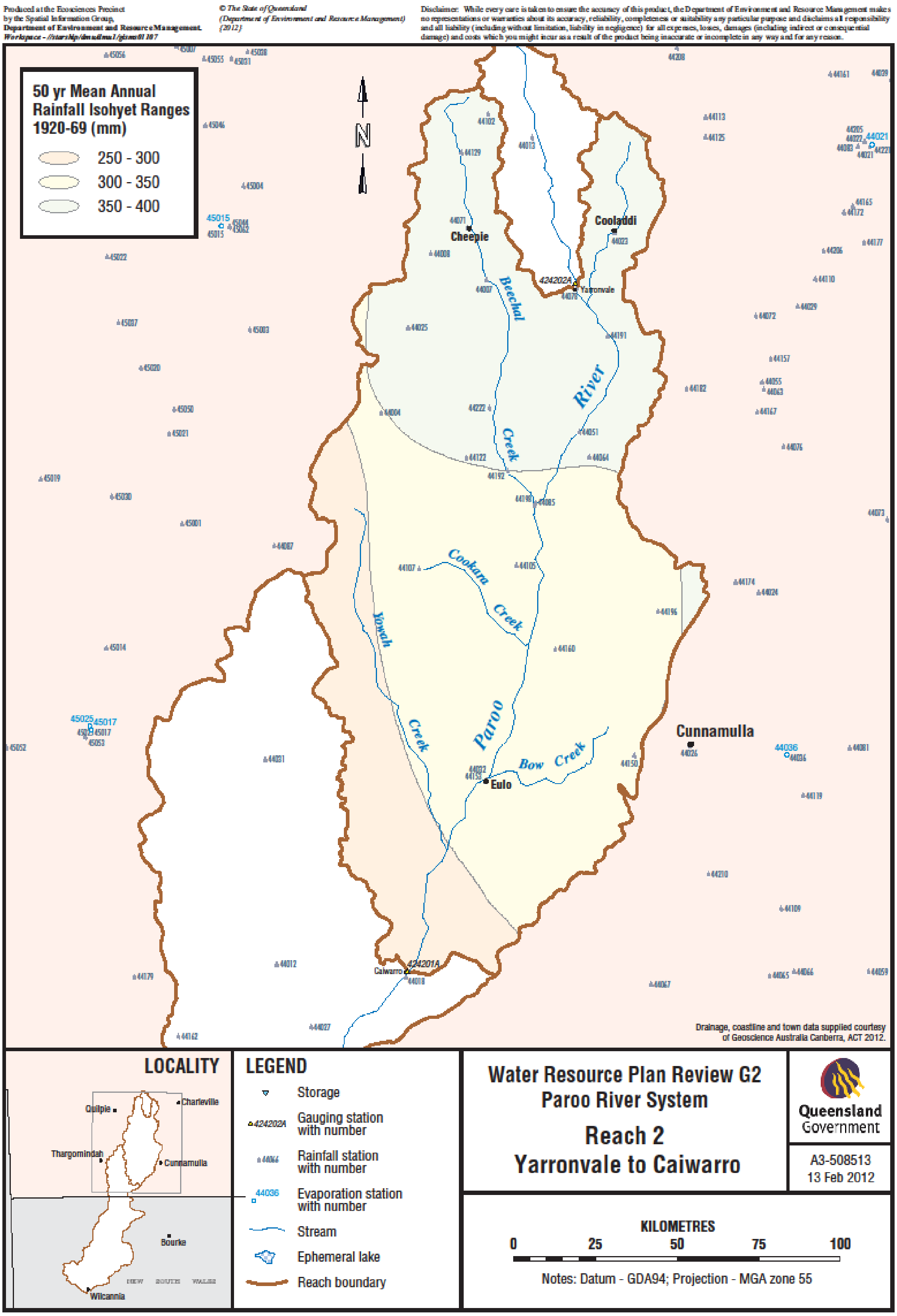


Figure 6.6: Map of Reach 2 – Yarronvale to Caiwarro

6.3.3 Reach Calibration and Record Based Inflow Sequence

6.3.3.1 Record Based Inflow Sequence

The reach calibration and derivation of the record based inflow sequence for Reach 2 was completed according to the methods outlined in Section 4.1. Only one model was required to calculate the residual inflow for Reach 2 due to there being no change in the infrastructure layout of the catchment.

The residual flow was not derived during periods of missing data at either gauge.

6.3.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations, 04/11/1967 to 08/02/1988.

Residual flow during periods of missing data was estimated using the Sacramento model. Note that missing days at the Yarronvale Gauge (424202A) were added back into the residual eight days late to account for lag.

The residual end date was limited by the Yarronvale gauge being closed in 1988.

6.3.3.3 Routing Parameters

The routing parameters were determined using trial and error. Recorded flows from the upstream gauge were routed and compared with suitable recorded events at the downstream gauge. Events were chosen which had negligible reach runoff. This was achieved by selecting events from upstream which showed up as smaller at the Caiwarro gauge during periods of low or no rainfall.

The non-linear lag and route procedure was used for the routing that was applied at the most upstream link in the reach. The calibrated lag and routing parameters used for the reach are listed in Table 6.9.

Table 6.9: Reach 2 – Lag and Routing Parameters

Reach Length (km)	Lag Time (days)	k	m
248.6	8	0.3	0.8

6.3.3.4 Unaccounted Difference

A derived unaccounted difference relationship was added at the end of the reach. It is shown in Table 6.10. A waterhole was not required.

For the unaccounted difference node, the mean annual river flow during the period of calibration was 497,776 ML/a, with mean annual unaccounted difference 1,073 megalitres per annum. The unaccounted difference was 0.22 per cent.

Table 6.10: Reach 2 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
5	5
100	5
1,000,000	5

6.3.4 Sacramento Model Calibration

The Sacramento model was calibrated to the record based inflow sequence.

6.3.4.1 Time Period

The calibration period for the reach Sacramento was 04/11/1967 to 08/02/1988, the period a residual could be derived for. Data that was missing at either gauge was excluded from the calibration. The validation periods were defined by dividing the recorded flow data in half.

6.3.4.2 Unit Hydrograph

Table 6.11 shows the unit hydrograph adopted for calibration. The unit hydrograph was adjusted during the calibration process in order to improve the timing and width of flow events.

Table 6.11: Reach 2 – Unit Hydrograph

1	2	3
0.1	0.8	0.1

6.3.4.3 Catchment Area

The total and contributing catchment area of Reach 2 is 19,627 square kilometres. All of the reach catchment is assumed to contribute to runoff (100%).

6.3.4.4 Adjustment for In River Routing

River routing on upstream inflows is accounted for in the derived residual. The Sacramento model, however, does not account for in river routing of local inflows in large linear catchments where much of the local inflow is upstream. Such a situation occurs in this reach and to account for it a three day lag was applied to the Sacramento model flows prior to the output being compared to the recorded data. Three days lag was also applied to the final Sacramento data prior to it being combined with the derived residual.

6.3.4.5 Sacramento Model Parameters

Table 6.12 shows the Sacramento Model parameters for the reach. These are the parameters that provided the best statistical and visual match of the flow characteristics of the reach.

Table 6.12: Reach 2 – Sacramento Parameters

Parameter	Adopted Value	Initial Volume
LZTWM	388.119	0
UZFWM	28.81	0
UZK	0.787	
REXP	1.988	
UZTWM	38.474	0
PFREE	0.360	
ZPERC	50	
LZFPM	99.999	0
SIDE	1.00E-04	
LZSK	0.999	
PCTIM	9.63E-03	
LZFSM	8	0
SARVA	3.00E-03	
LZPK	0.208	
ADIMP	1.084E-05	
SSOUT	3.00E-04	
RSERV	0.3	
RFADJ	1	

6.3.4.6 Sacramento Model Calibration Results

Table 6.13, Table 6.14, and Table 6.15 show the flow statistics for the recorded and calculated data for the calibration period and the two validation periods. Figure 6.8, Figure 6.8 and Figure 6.9 present the Report Cards. Appendix C2 includes daily plots of the data. The statistics and figures have been compiled by excluding data for the periods where there is missing data in the residual flow sequence.

Table 6.13: Reach 2 – Sacramento Calibration Statistics

Location		Daily Recorded	Daily Simulated
Yarronvale to Caiwarro 04/11/1967 to 08/02/1988 Calibration	Mean (ML/d)	1,329	1,329
	Standard Deviation (ML/d)	7,000	7,236
	Skew	8.50	9.26
	Maximum Flow (ML/d)	103,045	134,334
	Volume Change (%)		100
	Coefficient of Determination		0.65
	Coefficient of Efficiency		0.59

Table 6.14: Reach 2 – Sacramento Validation 1 Statistics

Location		Daily Recorded	Daily Simulated
Yarronvale to Caiwarro 04/11/1967 to 30/06/1978 Validation 1	Mean (ML/d)	1,682	1,755
	Standard Deviation (ML/d)	8,046	8,650
	Skew	7.50	8.10
	Maximum Flow (ML/d)	103,045	134,334
	Volume Change (%)		104
	Coefficient of Determination		0.64
	Coefficient of Efficiency		0.56

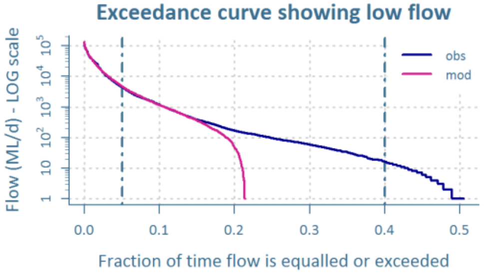
Table 6.15: Reach 2 – Sacramento Validation 2 Statistics

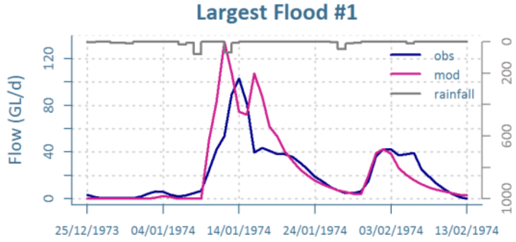
Location		Daily Recorded	Daily Simulated
Yarronvale to Caiwarro 01/07/1978 to 08/02/1988 Validation 2	Mean (ML/d)	894	803
	Standard Deviation (ML/d)	5,414	4,910
	Skew	10.39	10.85
	Maximum Flow (ML/d)	89,480	89,619
	Volume Change (%)		89.8
	Coefficient of Determination		0.68
	Coefficient of Efficiency		0.67

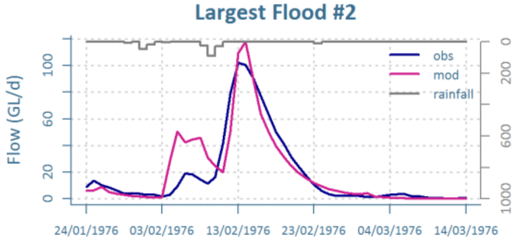
Reach 2-Yarronvale to Caiwarro Sacramento Calibration

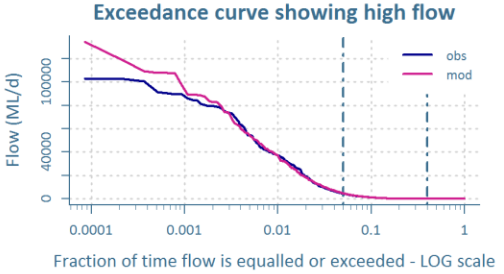
Period of analysis: 4/11/1967 to 8/2/1988

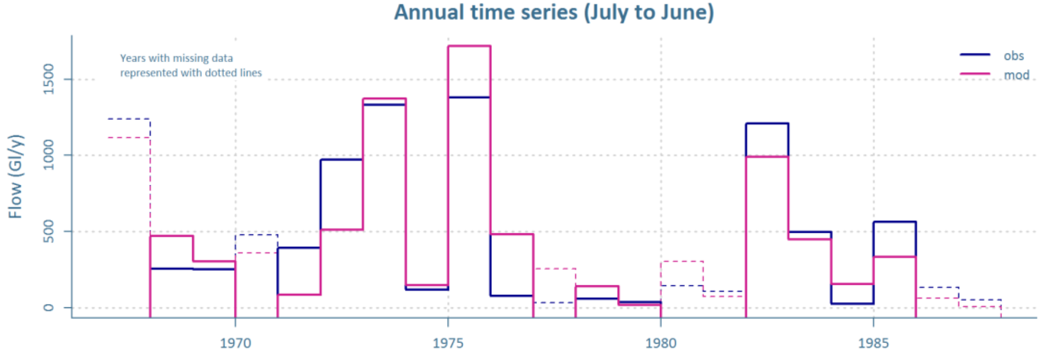
(observed flow is available for 95.2% of days in this period)











Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	9,359,720	0.1%	★★★★★
Total Low Flow Volume (ML)*	4,959	-100.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	1,246,172	-7.0%	★★★☆☆
Total High Flow Volume (ML)*	8,108,589	1.2%	★★★★☆
Mean Flow Volume (ML/d)	1,329	0.1%	★★★★★
Driest 3 Year Mean (ML/d)	119	219.4%	★☆☆☆☆
Zero Flow Days (%)+	49.5%	29.1%^	★☆☆☆☆
Standard Deviation (ML/d)	7,000	3.4%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.59	★★★☆☆
Non-matching Zero Flow Days	38.3%	★★☆☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.4 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.4 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
\+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

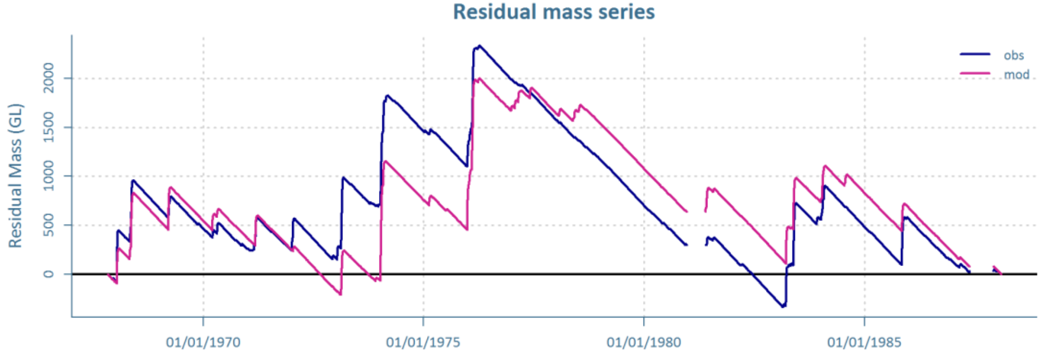
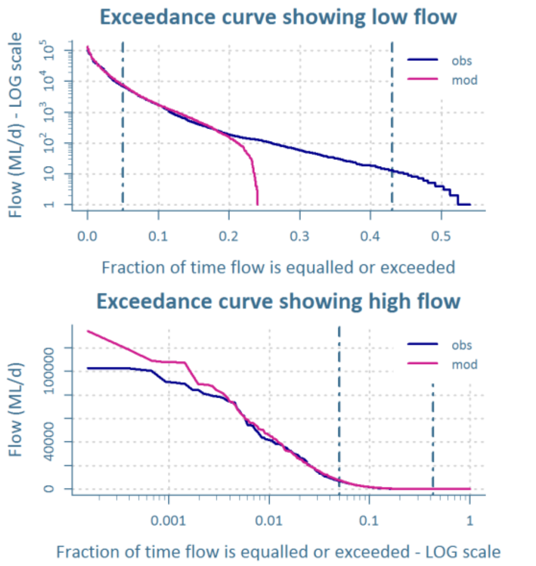


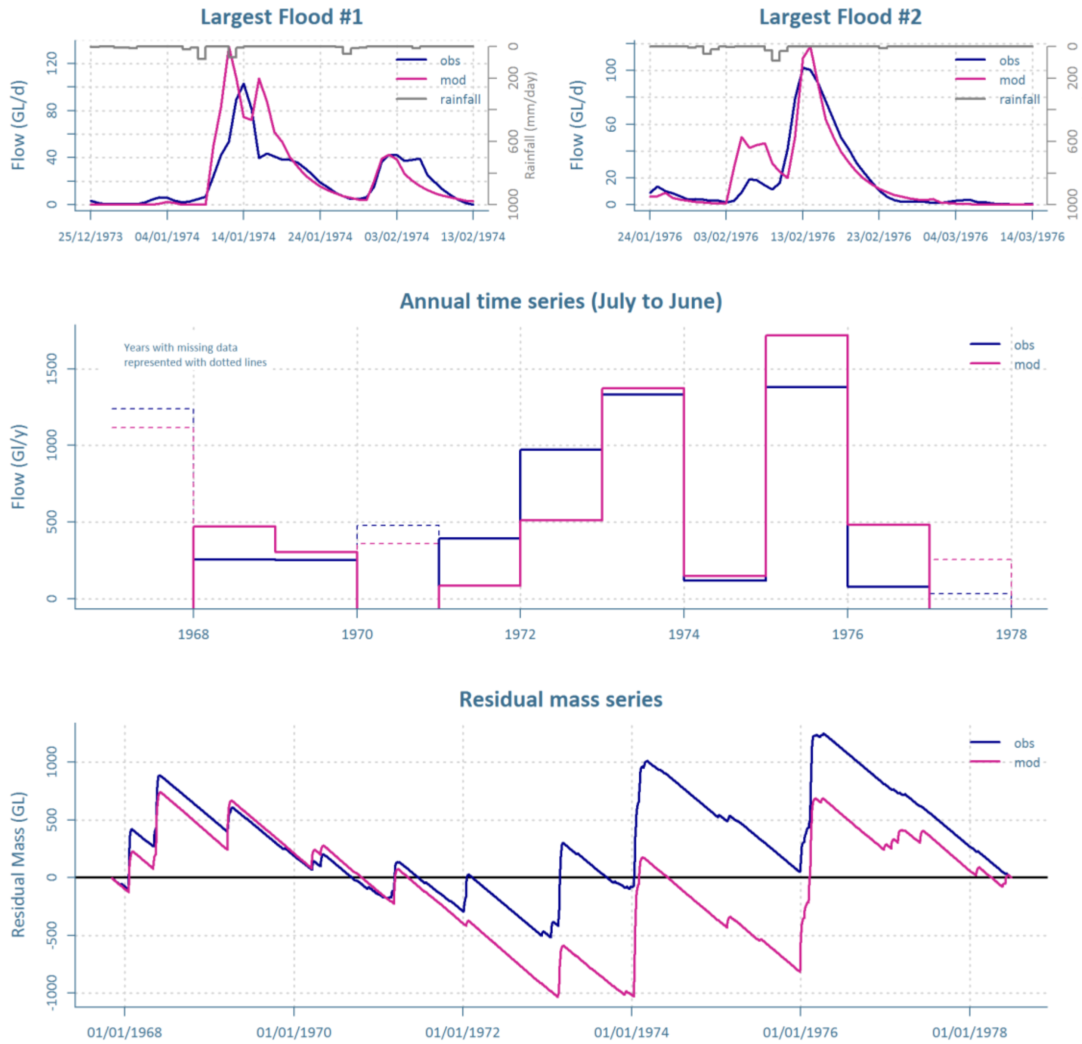
Figure 6.7: Reach 2 – Sacramento Calibration Report Card

Reach 2-Yarronvale to Caiwarro Sacramento Validation 1

Period of analysis: 4/11/1967 to 30/6/1978

(observed flow is available for 99.9% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	6,536,577	4.5%	★★★☆☆
Total Low Flow Volume (ML)*	2,451	-100.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	1,002,255	1.3%	★★★★☆
Total High Flow Volume (ML)*	5,531,871	5.1%	★★★☆☆
Mean Flow Volume (ML/d)	1,682	4.5%	★★★☆☆
Driest 3 Year Mean (ML/d)	1,688	-48.1%	★☆☆☆☆
Zero Flow Days (%)+	46.0%	30.0%^	★☆☆☆☆
Standard Deviation (ML/d)	8,045	7.6%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.56	★★★☆☆
Non-matching Zero Flow Days	39.1%	★★☆☆☆

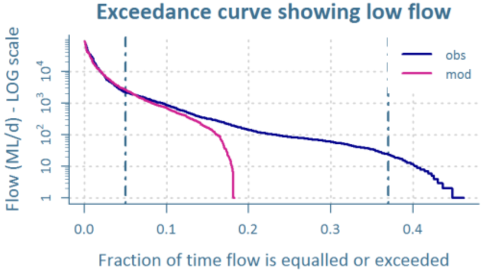
\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.43 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.43 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
\+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

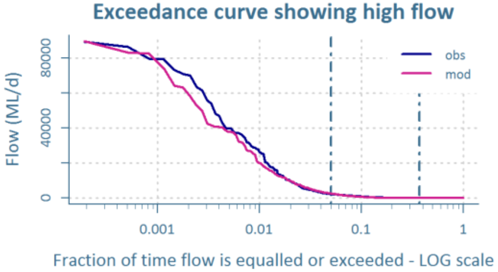
Figure 6.8: Reach 2 – Sacramento Validation 1 Report Card

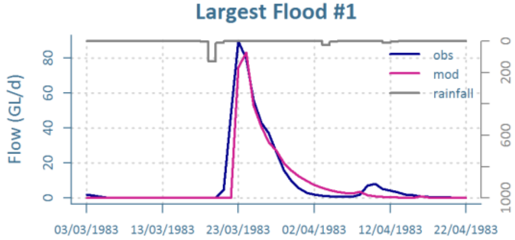
Reach 2-Yarronvale to Caiwarro Sacramento Validation 2

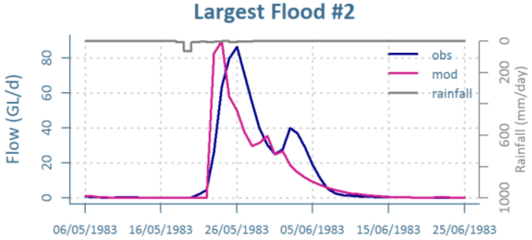
Period of analysis: 1/7/1978 to 8/2/1988

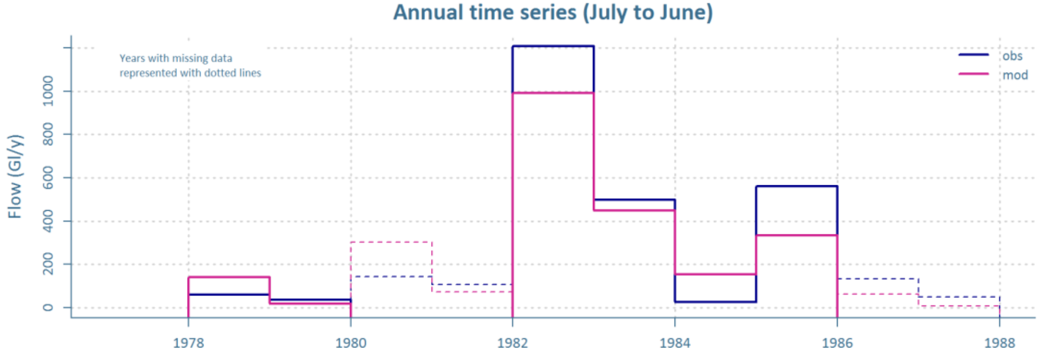
(observed flow is available for 90% of days in this period)











Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	2,823,143	-10.2%	★☆☆☆☆
Total Low Flow Volume (ML)*	2,501	-100.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	385,537	-26.8%	★☆☆☆☆
Total High Flow Volume (ML)*	2,435,105	-7.4%	★★★☆☆
Mean Flow Volume (ML/d)	894	-10.2%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	683	-10.9%	★★☆☆☆
Zero Flow Days (%)+	53.8%	28.0%^	★☆☆☆☆
Standard Deviation (ML/d)	5,413	-9.3%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.67	★★★☆☆
Non-matching Zero Flow Days	37.2%	★★☆☆☆

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.37 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.37 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
\+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

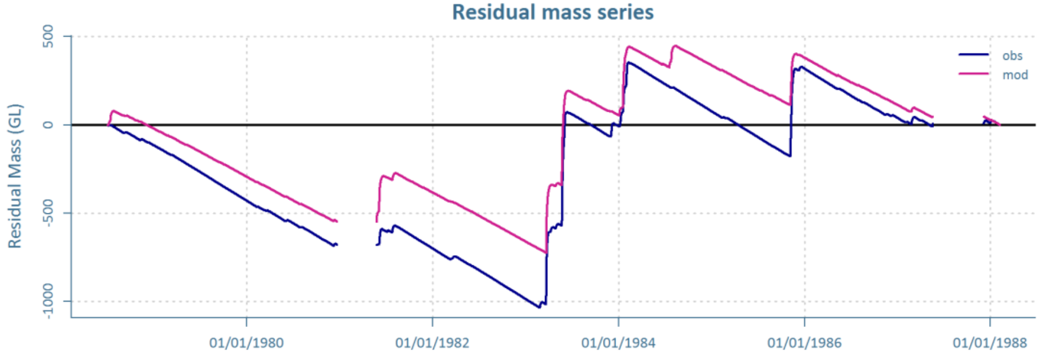


Figure 6.9: Reach 2 – Sacramento Validation 2 Report Card

6.3.4.7 Discussion

Over the full period of calibration a volume balance was achieved.

Over the full period of calibration the model reproduced the high and medium flows well. The validation plots of flow duration show that the model matched better to the earlier validation period data.

Reach 2 is a residual catchment, and the quality of the Sacramento calibration can be affected by the quality of the derived residual. The derived residual is dependent on the accuracy of the lag and routing parameters, the flow data, and the consistency of the ratings at the flow measurement sites. The use of an average lag and routing hinders the accuracy of the residual. This is not a huge problem in this catchment as the upstream flow is small compared to the downstream flow so mismatches caused by the model tend to disappear into the residual. However, the derivation of low flows is affected and this will help explain the inability to model to reproduce low flows well.

In this reach the length of the river in the reach also introduces the complication of in stream routing of local inflows which cannot be handled in the Sacramento model. As discussed earlier it has been addressed by applying a lag to the Sacramento flows.

All these issues contribute to inaccuracies in the flow sequence (especially in the low flows) that the Sacramento model is being calibrated to and hence contribute to the model being less accurate in the low flow regime.

As with the Yarronvale calibration some extra small events were produced in drier periods, which were not in the residual. Some of this can be accounted for by rainfall not being representative while others are related to the effects on flows of the variable antecedent condition of the catchment.

The resulting calibration is the best compromise that could be made between maintaining the magnitude of flow events and balancing low flow events and maintaining an overall volume match.

The resulting model is acceptable for converting rainfall into stream flow for this catchment.

6.3.5 Full Length Inflow Sequence

The calibrated Sacramento model was used to generate inflows for the full IQQM model period 01/01/1889–30/06/2011. The Sacramento data was lagged by three days to account for in river routing of local reach inflows. This data was used to infill and extend the record based pre-development inflows to produce the full length residual reach inflow sequence.

6.3.6 Final Inflow Sequence

For this reach the full length inflow sequence was adjusted using DMM for the periods where there was missing record at the Yarronvale gauge. Adjustments to the Reach 1 and 2 flows were made to align the model flows to the flow record at Caiwarro.

Table 6.16 and Figure 6.10 show the composition of the final residual inflow sequence for Reach 2. The mean daily inflow is 1,272 ML/day and the mean annual inflow is 464,291 megalitres per annum.

Table 6.16: Reach 2 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–03/11/1967	Sacramento		
04/11/1967–22/09/1971	Calculated residual	424201a	
23/09/1971–24/09/1971	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a. Factor 0.9
25/09/1971–04/01/1978	Calculated residual	424201a	
05/01/1978–06/01/1978	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a. Factor 0.9
07/01/1978–20/12/1980	Calculated residual	424201a	
21/12/1980–22/05/1981	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a. Factor 0.9
23/05/1981–20/05/1982	Calculated residual	424201a	
21/05/1982–22/05/1982	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a. Factor 0.9
23/05/1982–21/05/1987	Calculated residual	424201a	
22/05/1987–04/12/1987	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a. Factor 0.9
05/12/1987–08/02/1988	Calculated residual	424201a	
09/02/1988–30/06/2011	Sacramento adjusted	424201a	Reaches 1 & 2 adj. to 424201a. Factor 0.9

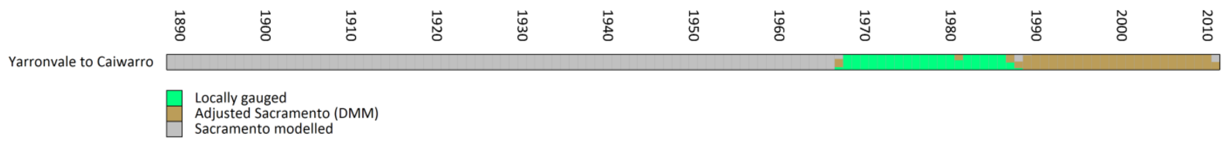


Figure 6.10: Reach 2 – Composition of Final Inflow Sequence

6.4 Reach 5 – Caiwarro to Willara Crossing

6.4.1 Description

The location of Reach 5 is illustrated on Figure 1.1 and is shown in more detail on Figure 6.11.

The Paroo River reach between Caiwarro and Willara Crossing includes the Queensland - New South Wales border. The river crosses the border at Hungerford.

Adjoining this reach is a network of lakes that in times of floods and high flows generally take flow from the Paroo River System. They include: Lake Numulla, Lake Wyarra, Bindegolly, Hutchinson, and Tomaroo. Lakes Hutchinson, Bindegolly and Tomaroo are fed by Bundilia Creek. These have a large catchment area of their own within the Paroo catchment, but like the Paroo River are often dry.

Two main tributaries join the Paroo River between Caiwarro and Willara Crossing; Caiwarro Creek and Barton’s Creek. There are many areas that in times of flood will act as flood plains and channel water to the Paroo River, but there are really no other actual creeks on this reach.

The catchment is very flat with its highest point being less than 200 m above sea level.

The average annual rainfall from the five stations used in this study range from 285 to 299 millimetres per annum.

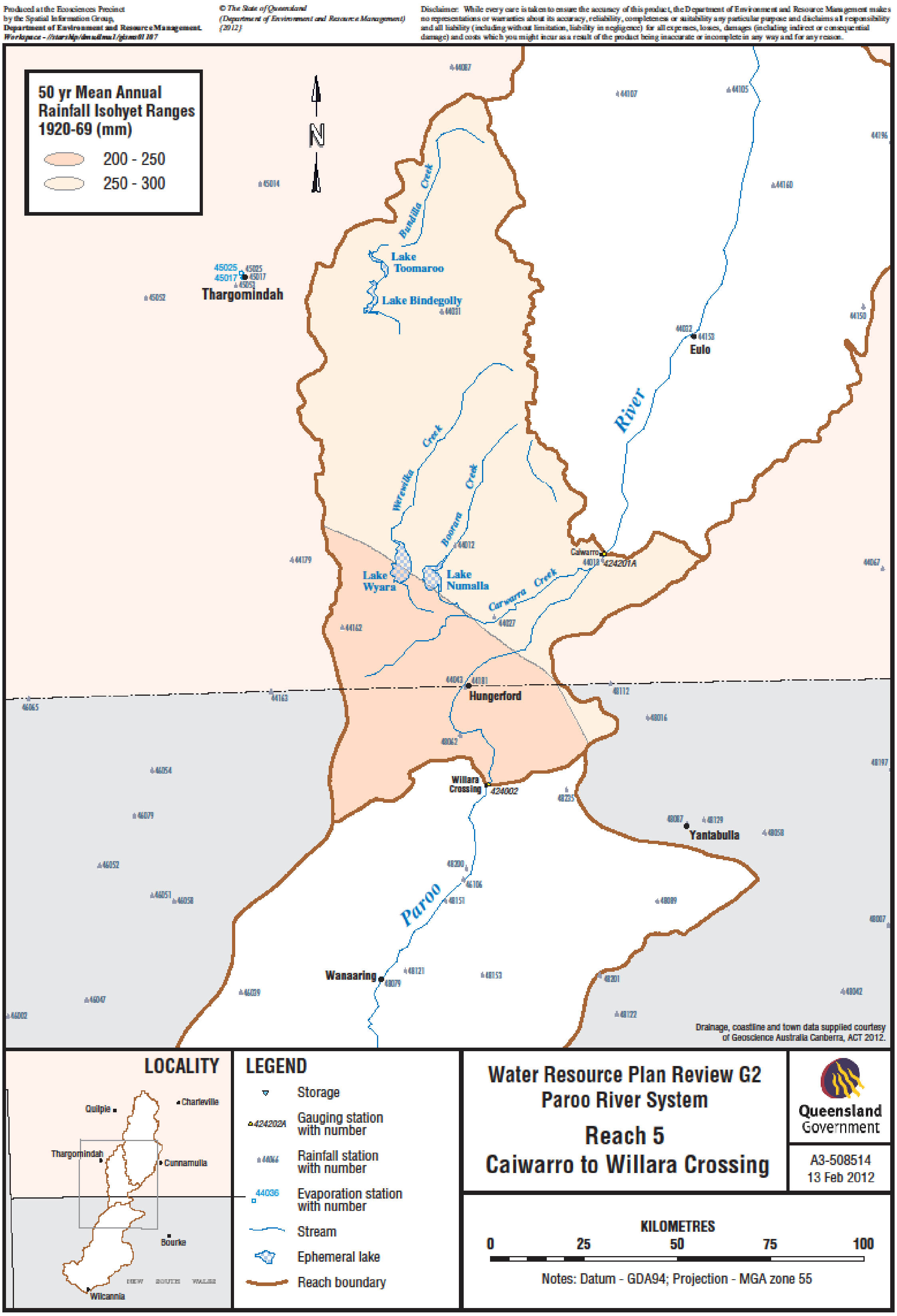


Figure 6.11: Map of Reach 5 – Caiwarro to Willara Crossing

6.4.2 Data

6.4.2.1 Flow Data

The stream flow data used for calibration can be viewed in Table 6.17.

Table 6.17: Reach 5 – Flow Data

Location	Station	Period
Upstream	424201a	19/04/1967–date
Downstream	424002	25/11/1975–date

6.4.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 5.

6.4.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 5.

6.4.3 Reach Calibration and record Based Inflow Sequence

6.4.3.1 Record Based Inflow Sequence

The reach calibration and derivation of the record based inflow sequence for Reach 5 was completed according to the methods outlined in Section 4.1. Only one model was required to calculate the residual inflow for Reach 5 due to there being no change in the infrastructure layout of the catchment.

Missing periods at either gauge were removed from the derived residual.

6.4.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations, 25/11/1975 to 30/06/2011.

6.4.3.3 Routing Parameters

The routing parameters were determined using trial and error. Recorded flows from the upstream gauge were routed and compared with suitable recorded events at the downstream gauge. Events were chosen which had negligible runoff. This was achieved by selecting events from upstream which showed up as smaller events at the Willara Crossing gauge during periods of low or no rainfall. There were a few events which fit these criteria.

The non-linear lag and route procedure was used for the routing that was applied at the most upstream model link. The calibrated lag and routing parameters used for the reach are listed in Figure 6.18

Table 6.18: Reach 5 – Lag and Routing Parameters

Reach Length (km)	Lag Time (days)	k	m
94.8	4	0.4	0.95

6.4.3.4 Unaccounted Difference

A derived unaccounted difference relationship was added at the end of the reach. It is shown in Table 6.19.

For the unaccounted difference node, the mean annual river flow during the period of calibration was 520,906 ML/a, with a mean annual unaccounted difference of 157,160 megalitres per annum. The unaccounted difference was 30 per cent and was most likely caused by losses or breakouts onto the floodplain.

Table 6.19: Reach 5 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
1	1
3	2
5	3
10	6
50	27
100	49
500	165
1,000	251
5,000	1,351
10,000	2,960
20,000	7,400
50,000	16,496
100,000	16,500
1,000,000	16,500

6.4.4 Sacramento Model Calibration

The Sacramento model was calibrated to the record based inflow sequence. Residual flow during periods of missing data was estimated using the Sacramento model.. Note that missing days at the Caiwarro Gauge (424201A) were added back into the residual four days late to account for lag.

6.4.4.1 Time Period

The calibration period for the reach Sacramento was 25/11/1975 to 30/06/2011, the period a residual could be derived for. Data that was missing at either gauge was excluded from the calibration. The validation periods were defined by dividing the recorded flow data in half.

6.4.4.2 Unit Hydrograph

Table 6.20 shows the unit hydrograph adopted for calibration. The unit hydrograph was adjusted during the calibration process in order to improve the timing and width of flow events.

Table 6.20: Reach 5 – Unit Hydrograph

1	2	3	4	5
0.05	0.2	0.4	0.3	0.05

6.4.4.3 Catchment Area

The contributing catchment area of Reach 5 is 2,792 square kilometres. The total area (including the non-contributing areas) is 10,749 kilometres.

6.4.4.4 Sacramento Model Parameters

Table 6.21 shows the Sacramento Model parameters for the reach. These are the parameters that provided the best statistical and visual match of the flow characteristics of the reach.

Table 6.21: Reach 5 – Sacramento Model Parameters

Parameter	Adopted Value	Initial Volume
LZTWM	150	0
UZFWM	50	0
UZK	0.05	
REXP	2	
UZTWM	54	0
PFREE	0.1	
ZPERC	3	
LZFPM	20	0
SIDE	1.00E-04	
LZSK	0.05	
PCTIM	1.00E-02	
LZFSM	8	0
SARVA	5.00E-03	
LZPK	0.2	
ADIMP	5.00E-02	
SSOUT	3.00E-03	
RSERV	0.3	
RFADJ	1	

6.4.4.5 Sacramento Model Calibration Results

Table 6.22, Table 6.23 and Table 6.24 show the flow statistics for the recorded and calculated data for the calibration period and the two validation periods. Figure 6.12, Figure 6.13 and Figure 6.14 present the Report Cards. Appendix C3 includes daily plots of the data. The statistics and figures have been compiled by excluding data for the periods where there is missing data in the recorded flow sequence.

Table 6.22: Reach 5 – Sacramento Calibration Statistics

Location		Daily Recorded	Daily Simulated
Caiwarro to Willara Crossing 25/11/1975 to 30/06/2011 Calibration	Mean (ML)	117	117
	Standard Deviation (ML)	2,379	1,992
	Skew	45	57
	Maximum Flow (ML)	139,336	150,165
	Volume Change (%)		100
	Coefficient of Determination		0.0748
	Coefficient of Efficiency		-0.2431

Table 6.23: Reach 5 – Sacramento Validation 1 Statistics

Location		Daily Recorded	Daily Simulated
Caiwarro to Willara Crossing 25/11/1975 to 30/06/1993 Validation 1	Mean (ML)	198	152
	Standard Deviation (ML)	3,402	2,739
	Skew	31.74	44.15
	Maximum Flow (ML)	139,336	150,165
	Volume Change (%)		77
	Coefficient of Determination		0.0714
	Coefficient of Efficiency		-0.2180

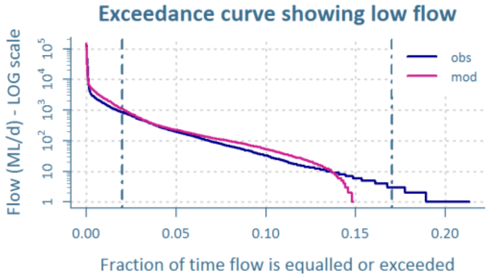
Table 6.24: Reach 5 – Sacramento Validation 2 Statistics

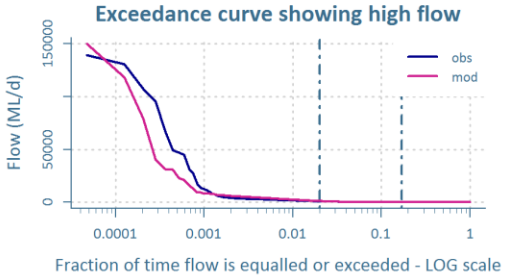
Location		Daily Recorded	Daily Simulated
Caiwarro to Willara Crossing 01/07/1993 to 30/06/2011 Validation 2	Mean (ML)	42	86
	Standard Deviation (ML)	328	811
	Skew	18.43	31.54
	Maximum Flow (ML)	12,630	40,084
	Volume Change (%)		206
	Coefficient of Determination		0.4248
	Coefficient of Efficiency		-2.9085

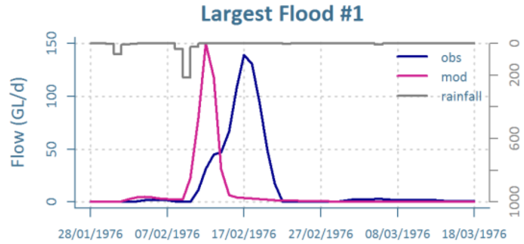
Reach 5-Caiwarro to Willara Crossing Sacramento Calibration

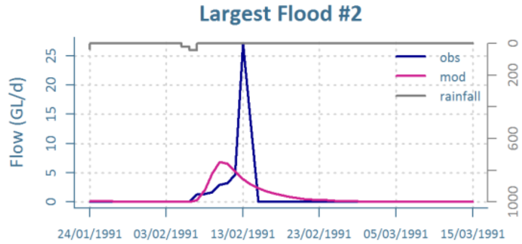
Period of analysis: 25/11/1975 to 30/6/2011

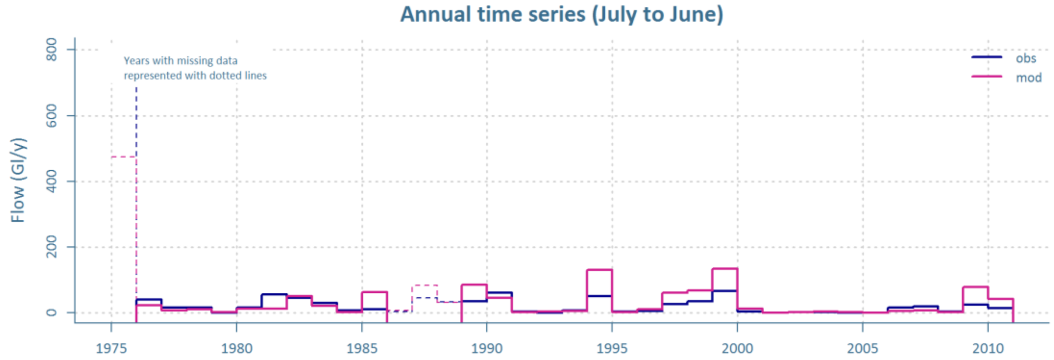
(observed flow is available for 97.9% of days in this period)











Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,491,115	0.5%	★★★★☆
Total Low Flow Volume (ML)*	889	-100.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	232,961	17.2%	★★☆☆☆
Total High Flow Volume (ML)*	1,257,265	-2.5%	★★★★☆
Mean Flow Volume (ML/d)	117	0.5%	★★★★☆
Driest 3 Year Mean (ML/d)	4	155.4%	★☆☆☆☆
Zero Flow Days (%)+	78.7%	6.4%^	★★☆☆☆
Standard Deviation (ML/d)	2,379	-16.3%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	-0.24	★☆☆☆☆
Non-matching Zero Flow Days	21.8%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.17 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.17 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
\+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

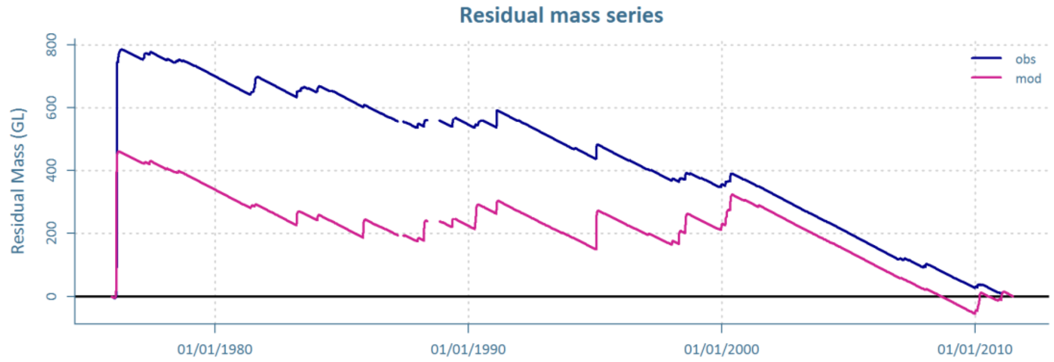
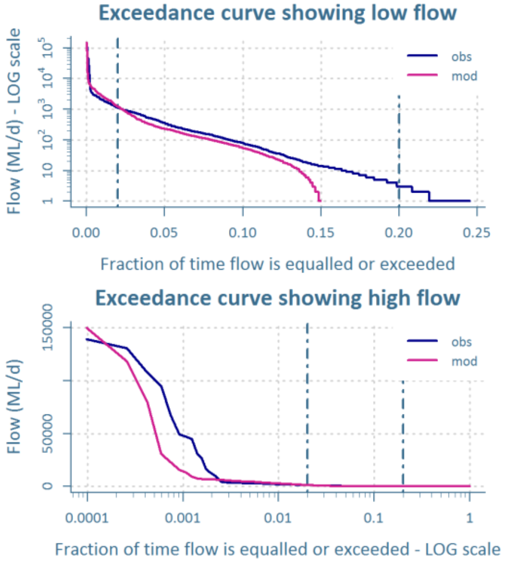


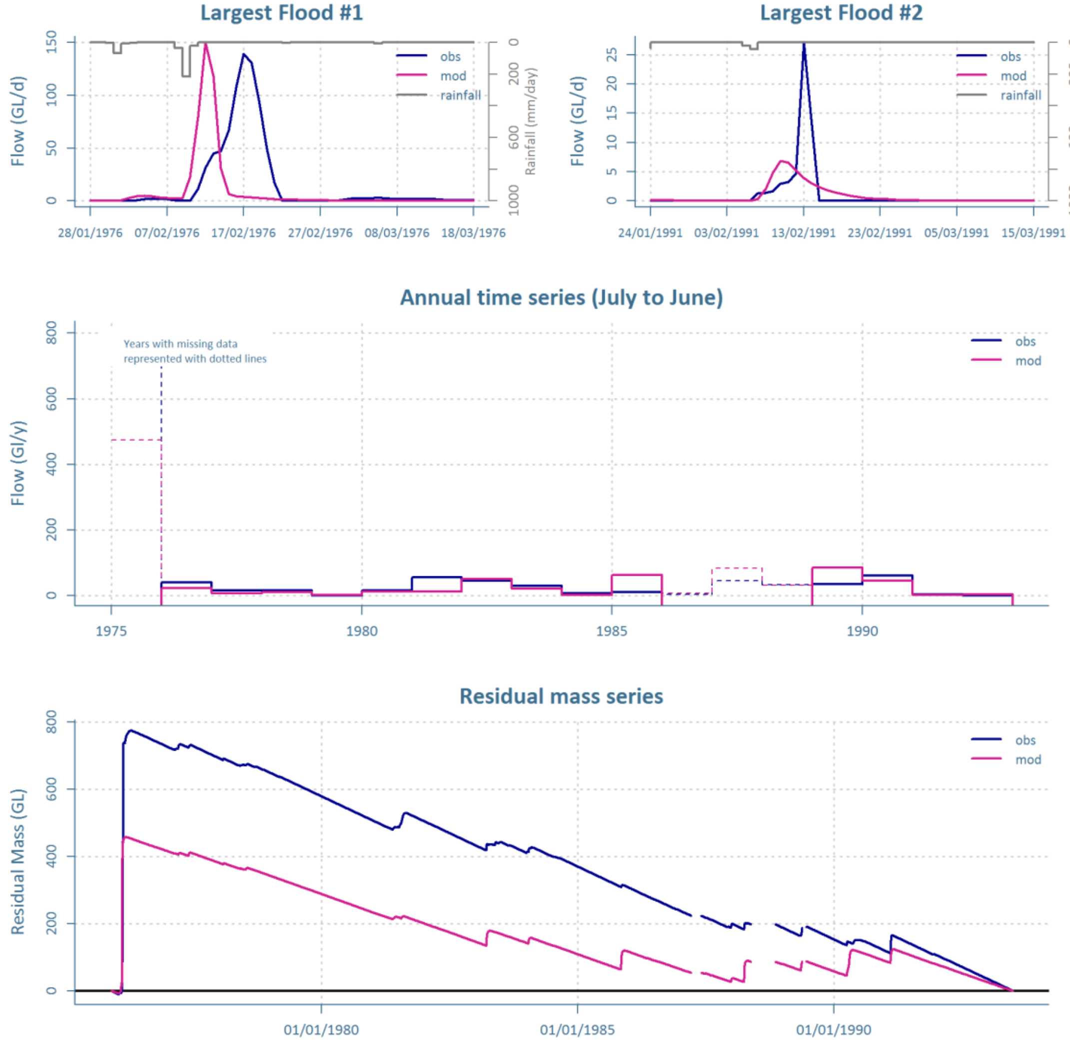
Figure 6.12: Reach 5 – Sacramento Calibration Report Card

Reach 5-Caiwarro to Willara Crossing Sacramento Validation 1

Period of analysis: 25/11/1975 to 30/6/1993

(observed flow is available for 95.8% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,216,971	-23.3%	★☆☆☆☆
Total Low Flow Volume (ML)*	445	-100.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	191,910	-26.0%	★☆☆☆☆
Total High Flow Volume (ML)*	1,024,616	-22.7%	★★☆☆☆
Mean Flow Volume (ML/d)	198	-23.3%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	29	-40.8%	★☆☆☆☆
Zero Flow Days (%)+	75.5%	9.5%^	★★☆☆☆
Standard Deviation (ML/d)	3,402	-19.5%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	-0.22	★☆☆☆☆
Non-matching Zero Flow Days	22.9%	★★★☆☆

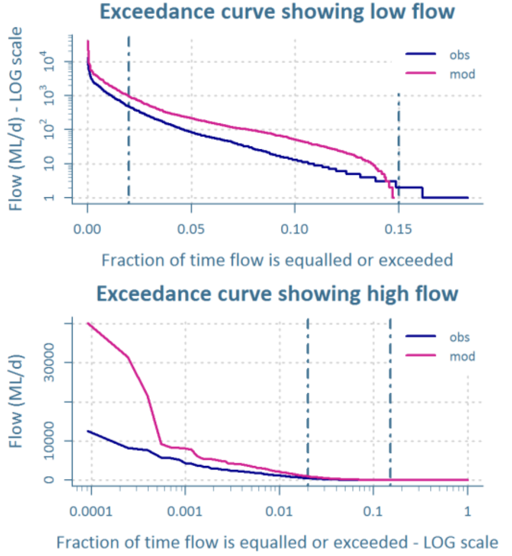
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.2 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.2 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

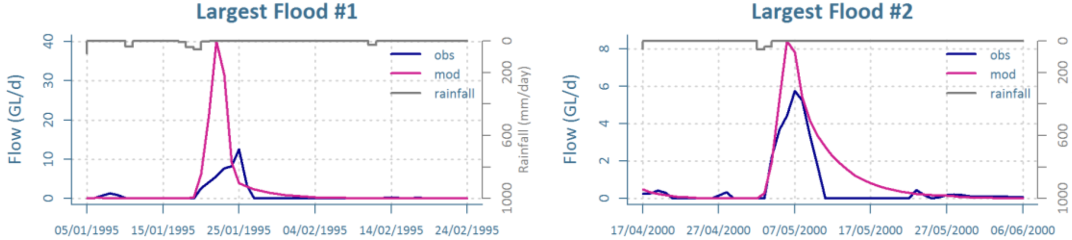
Figure 6.13: Reach 5 – Sacramento Validation 1 Report Card

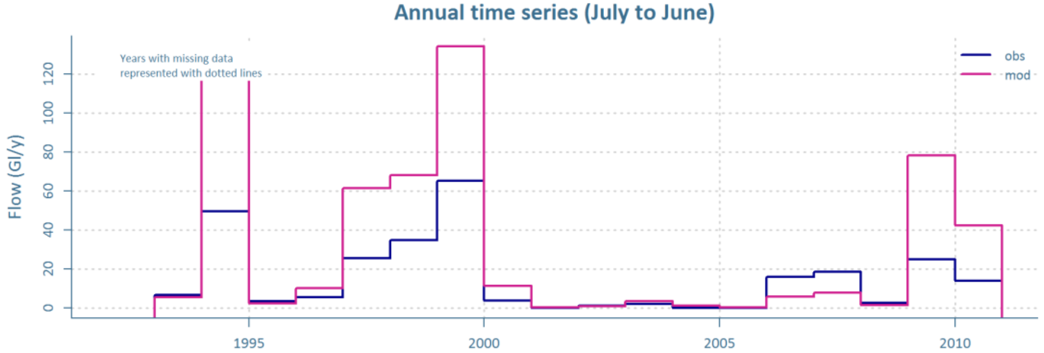
Reach 5-Caiwarro to Willara Crossing Sacramento Validation 2

Period of analysis: 1/7/1993 to 30/6/2011

(observed flow is available for 100% of days in this period)







Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	274,144	105.9%	★☆☆☆☆
Total Low Flow Volume (ML)*	294	-100.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	57,028	133.9%	★☆☆☆☆
Total High Flow Volume (ML)*	216,822	98.8%	★☆☆☆☆
Mean Flow Volume (ML/d)	42	105.9%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	4	155.4%	★☆☆☆☆
Zero Flow Days (%)+	81.7%	3.6%^	★★★☆☆
Standard Deviation (ML/d)	328	147.3%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	-2.91	★☆☆☆☆
Non-matching Zero Flow Days	20.7%	★★★☆☆

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.15 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.15 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
\+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

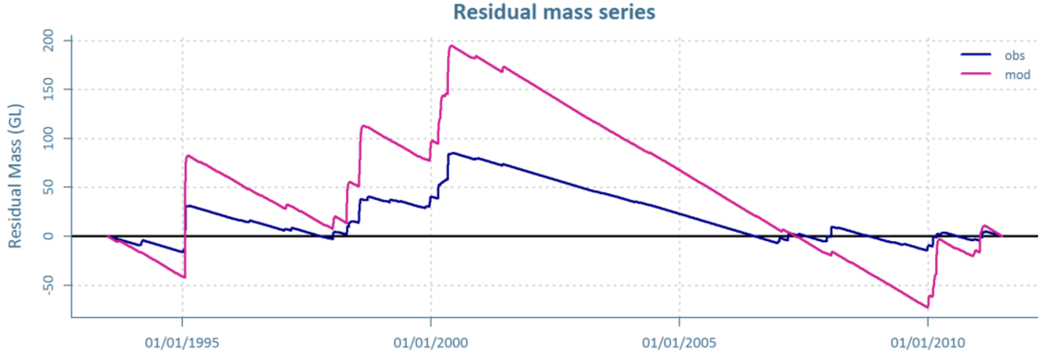


Figure 6.14: Reach 5 – Sacramento Validation 2 Report Card

6.4.4.6 Discussion

Reach 5 is a residual catchment, and the quality of the Sacramento calibration can be affected by the quality of the derived residual. The derived residual is dependent on the accuracy of the lag and routing parameters, the flow data, and the consistency of the ratings at the flow measurement sites. Inaccuracies in the modelled flows due to input data errors and assumptions are easier to see where the residual catchment is small and the residual flow is small compared to the inflow from upstream.

This reach has a small residual inflow compared to the upstream inflow and the quality of the residual is only average. As indicated above, the averaging effects of model parameterisation and data errors mean that upstream and downstream flows can misalign so that when the upstream flow is subtracted from the downstream flow negative inflows can occur. The smoothing process used to improve the residual deals with maintaining the correct residual inflow volume over time but the residual can still show problems. Following the smoothing process, the Reach 5 residual was still very spiky with drop outs in some events. These characteristics would not be real and proved hard to calibrate to.

Over the full period of calibration a volume balance was achieved. In the validation periods there are volume mismatches. The underestimation in the earlier period is mainly due to the under estimation of the volume of the early 1976 event (likely due to an underestimation of rainfall), and the over estimation in the latter period which is caused by the overestimation of medium sized events. The daily residual mass curves show these mismatches. The residual mass curve for the 2nd validation period also shows that the model had trouble reproducing the flow patterns in 2007 and 2008.

The Sacramento calibration aimed at reproducing the full range of flows and did reasonably well over the full period of calibration, as shown in Figure 6.12. However, as with the statistics, the daily flow duration curves show that a biased match is obtained over the two validation periods (Figure 6.13 and Figure 6.14).

It could be argued that the 1976 event should have been removed from the calibration. However, it was not removed as it was the only large event in the calibration period.

The resulting calibration is the best compromise that could be made between maintaining the magnitude of flow events, balancing low flow events and maintaining an overall volume match.

The resulting model is acceptable for converting rainfall into stream flow for this catchment.

6.4.5 Full Length Inflow Sequence

The calibrated Sacramento model was used to generate inflows for the full IQQM model period 01/01/1889230/06/2011. This data was used to infill and extend the record based pre-development inflows to produce the full length residual reach inflow sequence.

6.4.6 Final Inflow Sequence

For this reach, no further adjustments were applied to the full length inflow sequence. Table 6.25 and Figure 6.15 show the composition of the final residual inflow sequence for Reach 5. The mean daily inflow is 85 ML/day and the mean annual inflow is 31,411 megalitres per annum.

Table 6.25: Reach 5 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–24/11/1975	Sacramento		
25/11/1975–21/03/1987	Calculated residual	424002	
22/03/1987–01/06/1987	Sacramento		
02/06/1987–20/05/1988	Calculated residual	424002	
21/05/1988–09/11/1988	Sacramento		
10/11/1988–20/05/1989	Calculated residual	424002	
21/05/1989–16/6/1989	Sacramento		
17/06/1989–30/06/2011	Calculated residual	424002	

Figure 6.15: Reach 5 – Composition of Final Inflow Sequence

6.5 Reach 6 – Willara Crossing to Wanaaring

6.5.1 Description

The location of Reach 6 can be seen on Figure 1.1 and is shown in more detail on Figure 6.16.

The Paroo River reach between Willara Crossing and Wanaaring is very flat with its highest point being less than 200 m above sea level. There are no distinct tributaries. In times of extreme low flow the Paroo will pond and form ephemeral lakes. These lakes along with the numerous waterholes hold a lot of the water contained in this catchment.

The average annual rainfall from the two stations used in this study are 275 and 298 millimetres per annum.

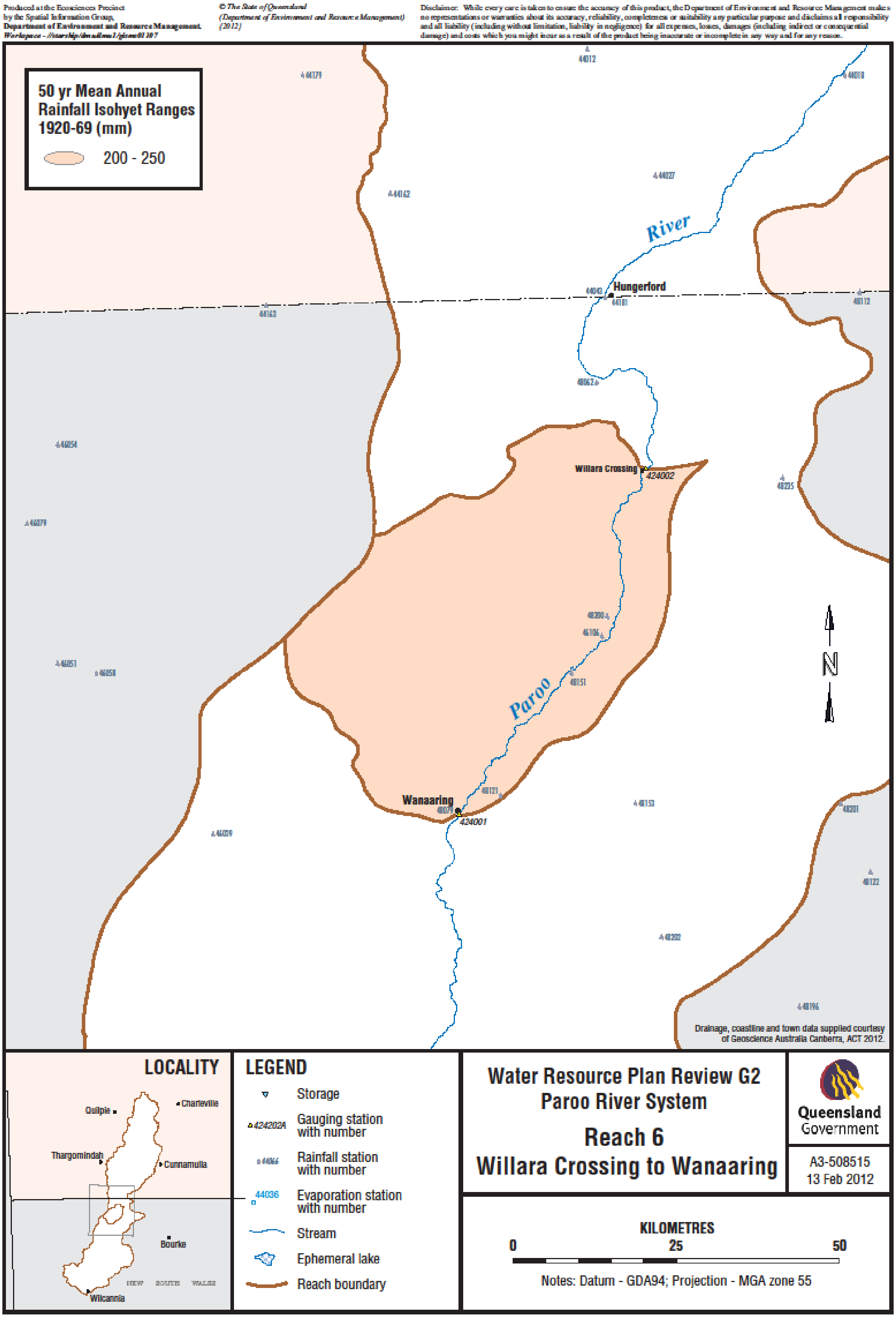


Figure 6.16: Map of Reach 6 – Willara Crossing to Wanaaring

6.5.2 Data

6.5.2.1 Flow Data

The stream flow data used for calibration can be viewed in Table 6.26.

Table 6.26: Reach 6 – Flow Data

Location	Station	Period
Upstream	424002	25/11/1975–date
Downstream	424001	02/01/1968–31/12/1983

6.5.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 6.

6.5.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 6.

6.5.3 Reach Calibration and Record Based Inflow Sequence

6.5.3.1 Record Based Inflow Sequence

The reach calibration and derivation of the record based inflow sequence for Reach 6 was completed according to the methods outlined in Section 4.1. Only one model was required to calculate the residual inflow for Reach 6 due to there being no change in the infrastructure layout of the catchment.

Missing periods at either gauge were removed from the derived residual.

6.5.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations, 25/11/1975 to 31/12/1983.

6.5.3.3 Routing Parameters

The routing parameters were determined using trial and error. Recorded flows from the upstream gauge were routed and compared with suitable recorded events at the downstream gauge. Events were chosen which had negligible runoff.

The non-linear lag and route procedure was used for the routing that was applied at the most upstream link in the reach. The calibrated lag and routing parameters used for the reach are listed in

Table 6.27.

Table 6.27: Reach 6 – Lag and Routing Parameters

Reach Length (km)	Lag Time (days)	k	m
62.4	3	0.1	0.8

6.5.3.4 Unaccounted Difference

A derived unaccounted difference relationship was added at the end of the reach. It is shown in Table 6.28.

For the unaccounted difference node, the mean annual river flow during the period of calibration was 265,423 ML/a, with a mean annual unaccounted difference of 50,624 megalitres per annum. The unaccounted difference ratio was 19.07 per cent and was most likely caused by losses or breakouts onto the floodplain.

Table 6.28: Reach 6 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
1	1
3	2
7	3
12	4
30	12
50	22
100	37
200	90
500	186
1,000	392
2,000	795
3,000	797
4,700	800
5,500	805
8,100	810
14,500	815
17,200	1,431
36,400	1,705
66,900	11,910
100,000	38,619
220,000	145,173
1,000,000	150,000

6.5.4 Sacramento Model Calibration

The Sacramento model was calibrated to the record based inflow sequence.

6.5.4.1 Time Period

The calibration period for the reach Sacramento was 25/11/1975 to 31/12/1983, the period a residual could be derived for. Data that was missing at either gauge was excluded from the calibration. The validation periods were defined by dividing the recorded flow data in half.

6.5.4.2 Unit Hydrograph

Table 6.29 shows the unit hydrograph adopted for calibration. The unit hydrograph was adjusted during the calibration process in order to improve the timing and width of flow events.

Table 6.29: Reach 6 – Unit Hydrograph

1	2	3	4
0.05	0.15	0.45	0.35

6.5.4.3 Catchment Area

The total and contributing catchment area of Reach 6 is 2,292 square kilometres.

6.5.4.4 Sacramento Model Parameters

Table 6.30 shows the Sacramento Model parameters for the reach. These are the parameters that provided the best statistical and visual match of the flow characteristics of the reach.

Table 6.30: Reach 6 – Sacramento Model Parameters

Parameter	Adopted Value	Initial Volume
LZTWM	561	0
UZFWM	31.4498	0
UZK	0.7952	
REXP	1.1	
UZTWM	9.5	0
PFREE	0.0719	
ZPERC	28.0	
LZFPM	19.9775	0
SIDE	0.0100	
LZSK	0.5650	
PCTIM	0.0038	
LZFSM	5.6000	0
SARVA	0	
LZPK	0.535	
ADIMP	7.7572e-4	
SSOUT	0	
RSERV	0.3	
RFADJ	1	

6.5.4.5 Sacramento Model Calibration Results

Table 6.31, Table 6.32 and Table 6.33 show the flow statistics for the recorded and calculated data for the calibration period and the two validation periods. Figure 6.17, Figure 6.18 and Figure 6.19 present Report Cards. Appendix C4 includes daily plots of the data. The statistics and figures have been compiled by excluding data for the periods where there is missing data in the recorded flow sequence.

Table 6.31: Reach 6 – Sacramento Calibration Statistics

Location		Daily Recorded	Daily Simulated
Willara Crossing to Wanaaring 25/11/1975 to 31/12/1983 Calibration	Mean (ML)	127	128
	Standard Deviation (ML)	1,397	1,502
	Skew	18.49	25.83
	Maximum Flow (ML)	37,792	52,968
	Volume Change (%)		100.494
	Coefficient of Determination		0.4784
	Coefficient of Efficiency		0.3317

Table 6.32: Reach 6 – Sacramento Validation 1 Statistics

Location		Daily Recorded	Daily Simulated
Willara Crossing to Wanaaring 25/11/1975 to 30/06/1979 Validation 1	Mean (ML)	168	220
	Standard Deviation (ML)	1,665	2,219
	Skew	17.2401	17.8784
	Maximum Flow (ML)	37,792	52,968
	Volume Change (%)		130.9333
	Coefficient of Determination		0.7693
	Coefficient of Efficiency		0.5603

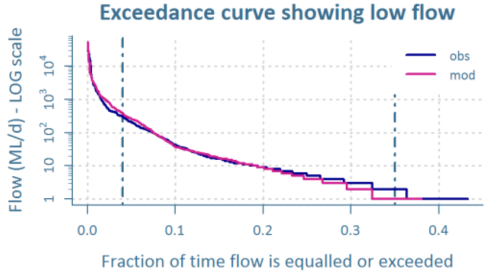
Table 6.33: Reach 6 – Sacramento Validation 2 Statistics

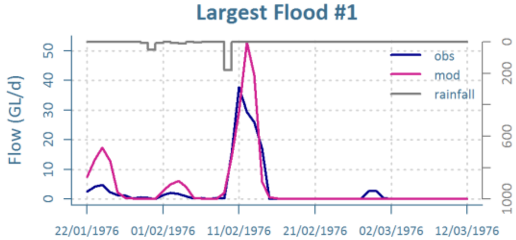
Location		Daily Recorded	Daily Simulated
Willara Crossing to Wanaaring 01/07/1979 to 31/12/1983 Validation 2	Mean (ML)	94.8	54.4
	Standard Deviation (ML)	1,139	333
	Skew	18.3916	9.8982
	Maximum Flow (ML)	26,374	5,333
	Volume Change (%)		57.3516
	Coefficient of Determination		0.002195
	Coefficient of Efficiency		-0.0595

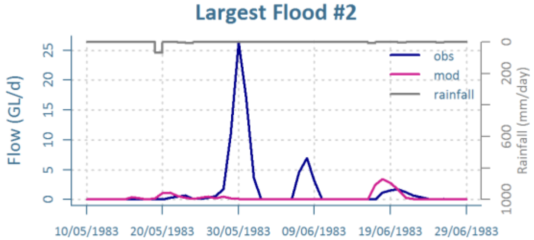
Reach 6-Willara Crossing to Wanarring Sacramento Calibration

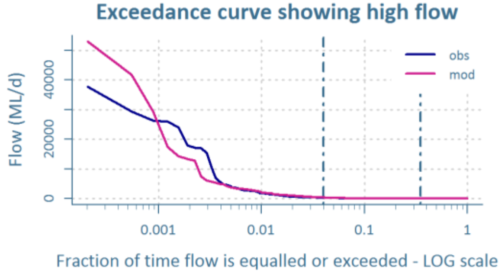
Period of analysis: 25/11/1975 to 31/12/1983

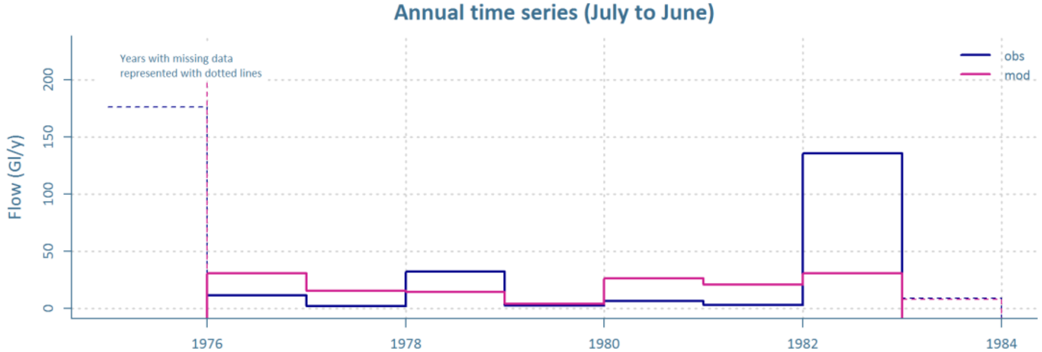
(observed flow is available for 100% of days in this period)











Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	377,106	0.5%	★★★★☆
Total Low Flow Volume (ML)*	284	-68.7%	★☆☆☆☆
Total Medium Flow Volume (ML)*	30,235	13.3%	★★☆☆☆
Total High Flow Volume (ML)*	346,587	-0.6%	★★★★★
Mean Flow Volume (ML/d)	127	0.5%	★★★★☆
Driest 3 Year Mean (ML/d)	33	-7.2%	★★★☆☆
Zero Flow Days (%)+	56.7%	5.3%^	★★☆☆☆
Standard Deviation (ML/d)	1,397	7.5%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.33	★★☆☆☆
Non-matching Zero Flow Days	45.4%	★★☆☆☆

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.35 to 1 exceedance probability range
* Medium flow = flow in the 0.04 to 0.35 exceedance probability range
* High flow = flow in the 0 to 0.04 exceedance probability range
\+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

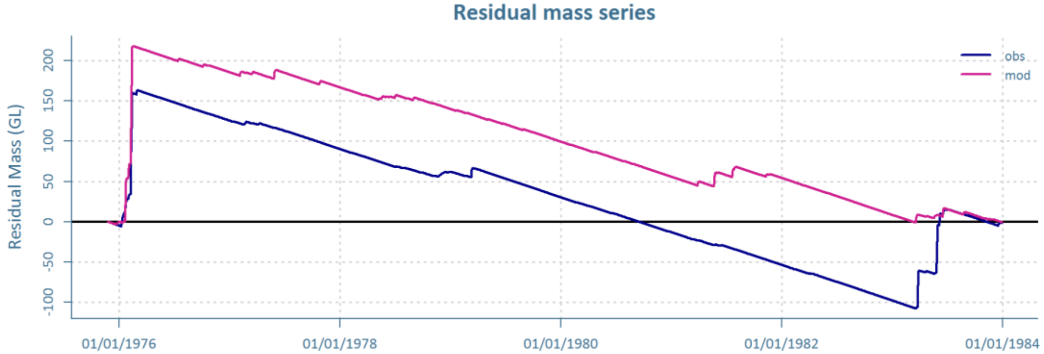
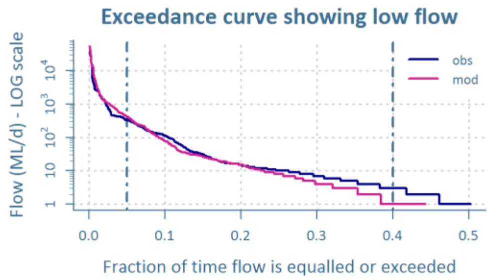


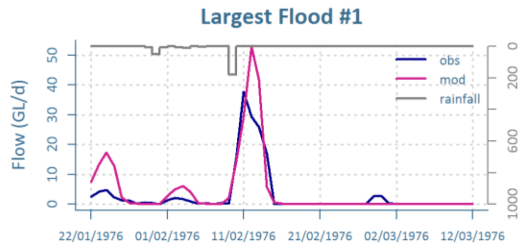
Figure 6.17: Reach 6 – Sacramento Calibration Report Card

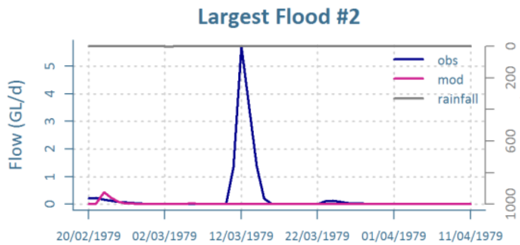
Reach 6-Willara Crossing to Wanarring Sacramento Validation 1

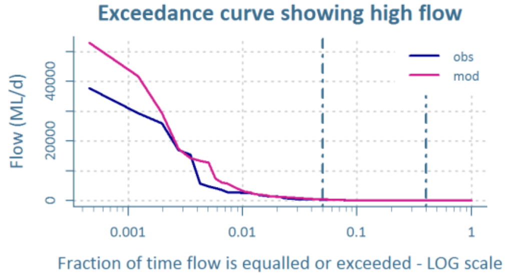
Period of analysis: 25/11/1975 to 30/6/1979

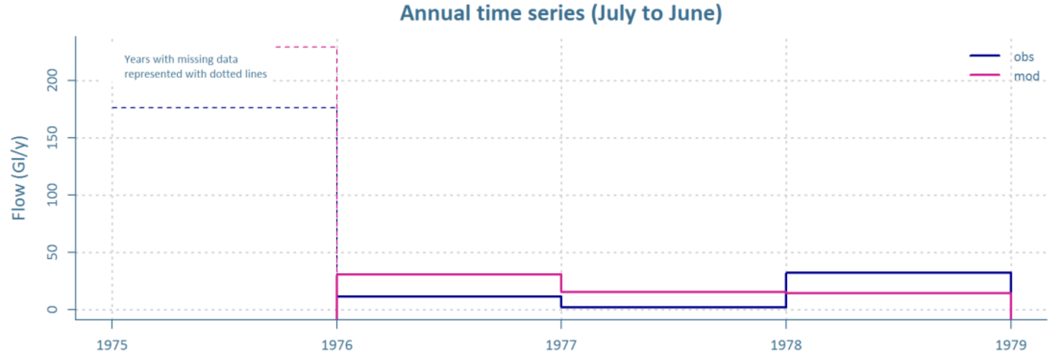
(observed flow is available for 100% of days in this period)











Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	221,105	30.9%	★☆☆☆☆
Total Low Flow Volume (ML)*	235	-76.2%	★☆☆☆☆
Total Medium Flow Volume (ML)*	19,802	-6.2%	★★★☆☆
Total High Flow Volume (ML)*	201,068	34.7%	★☆☆☆☆
Mean Flow Volume (ML/d)	168	30.9%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	41	34.2%	★☆☆☆☆
Zero Flow Days (%)+	49.7%	5.9%^	★★☆☆☆
Standard Deviation (ML/d)	1,664	33.3%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.56	★★★☆☆
Non-matching Zero Flow Days	47.5%	★★☆☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.4 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.4 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

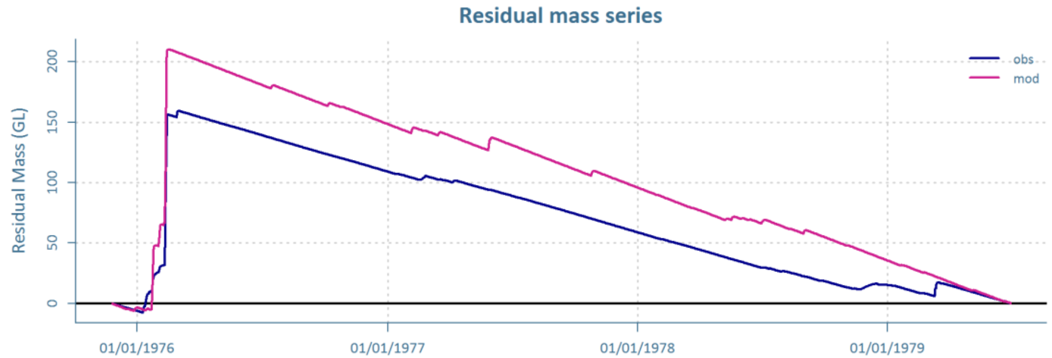
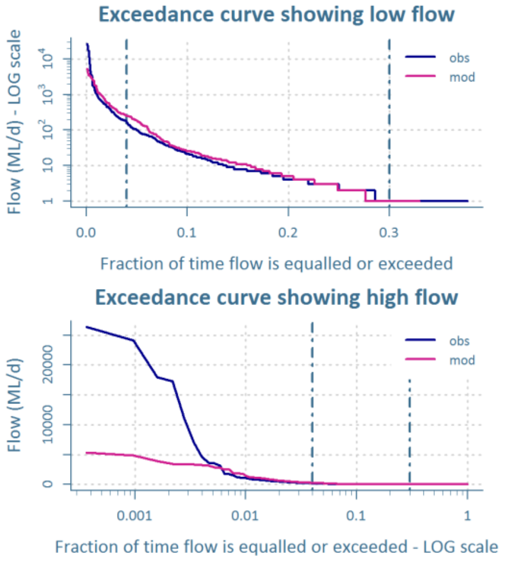


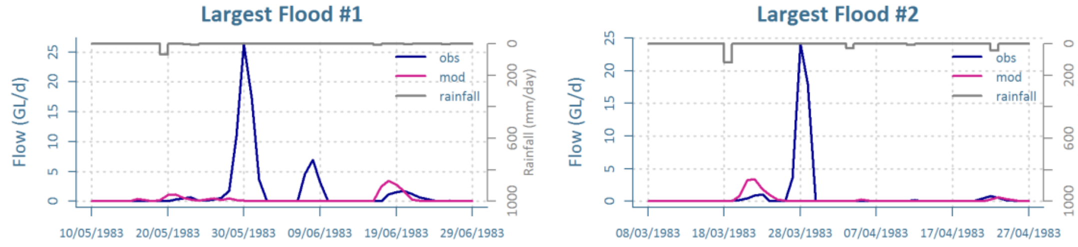
Figure 6.18: Reach 6 – Sacramento Validation 1 Daily Report Card

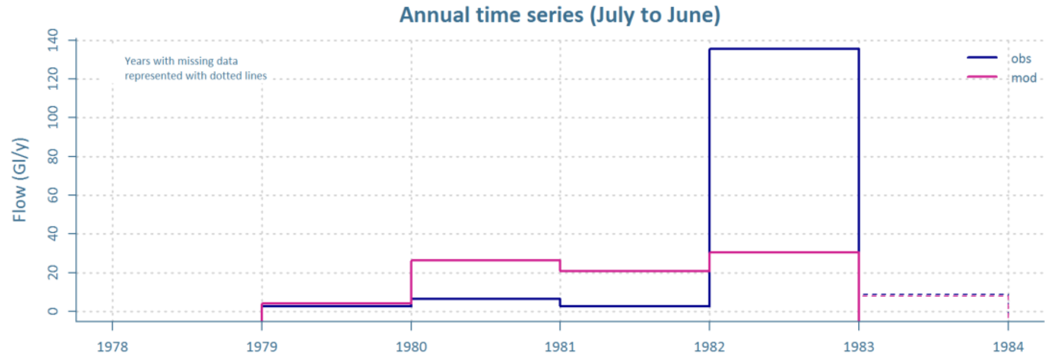
Reach 6-Willara Crossing to Wanarring Sacramento Validation 2

Period of analysis: 1/7/1979 to 31/12/1983

(observed flow is available for 100% of days in this period)







Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	156,001	-42.6%	★☆☆☆☆
Total Low Flow Volume (ML)*	128	-60.9%	★☆☆☆☆
Total Medium Flow Volume (ML)*	8,050	47.3%	★☆☆☆☆
Total High Flow Volume (ML)*	147,823	-47.5%	★☆☆☆☆
Mean Flow Volume (ML/d)	95	-42.6%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	11	344.0%	★☆☆☆☆
Zero Flow Days (%)+	62.2%	4.7%^	★★★☆☆
Standard Deviation (ML/d)	1,139	-70.7%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	-0.06	★☆☆☆☆
Non-matching Zero Flow Days	43.6%	★★☆☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.3 to 1 exceedance probability range
* Medium flow = flow in the 0.04 to 0.3 exceedance probability range
* High flow = flow in the 0 to 0.04 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

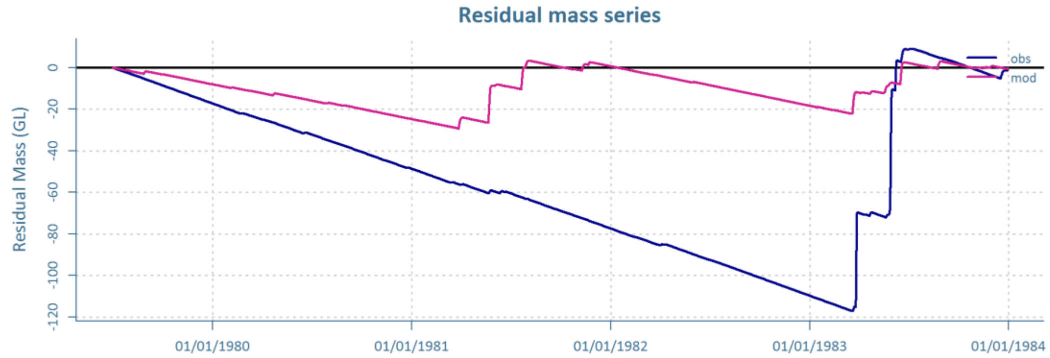


Figure 6.19: Reach 6 – Sacramento Validation 2 Report Card

6.5.4.6 Discussion

Reach 6 is a residual catchment, and the quality of the Sacramento calibration can be affected by the quality of the derived residual. The derived residual is dependent on the accuracy of the lag and routing parameters, the flow data, and the consistency of the ratings at the flow measurement sites. Inaccuracies in the modelled flows due to input data errors and assumptions are easier to see where the residual catchment is small and the residual flow is small compared to the inflow from upstream.

As with Reach 5, this reach illustrates these problems. The residual derived was very spiky and there were drop outs in some events which would have been highly unlikely to be real. Over the full period of calibration however a volume balance was achieved.

The Sacramento calibration aimed at reproducing the full range of flows and did reasonably well over the calibration and validation periods. However the residual mass curves indicate that the model overestimated in early 1976 and was unable to reproduce the 1983 event. This is likely caused by the spatial and temporal inaccuracies in the point rainfall data used. The resulting calibration is the best compromise that could be made between maintaining the magnitude of flow events, balancing low flow events and maintaining an overall volume match. The resulting model is acceptable for converting rainfall into stream flow for this catchment.

6.5.5 Full Length Inflow Sequence

The calibrated Sacramento model was used to generate inflows for the full IQQM model period 01/01/1889–30/06/2011. This data was used to infill and extend the record based pre-development inflows to produce the full length residual reach inflow sequence.

6.5.6 Final Inflow Sequence

For this reach no further adjustments were applied to the full length inflow sequence. Table 6.34 and Figure 6.20 show the composition of the final residual inflow sequence for Reach 6. The mean daily inflow is 73.85 ML/day and the mean annual inflow is 26,923 megalitres per annum.

Table 6.34: Reach 6 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–24/11/1975	Sacramento		
25/11/1975–31/12/1983	Calculated residual	424001	
01/01/1984–30/06/2011	Sacramento		

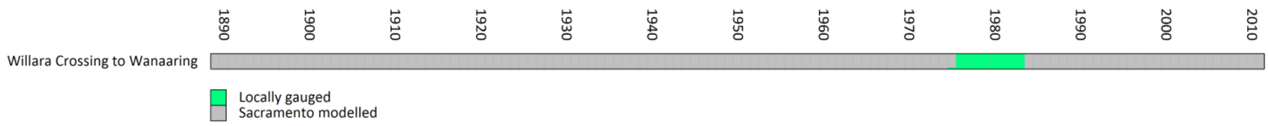


Figure 6.20: Reach 6 – Composition of Final Inflow Sequence

7. Model Validation

7.1 Introduction

Once the reach calibrations and the final inflow sequences had been completed, the reaches were combined into one model to validate the ability of the complete model to reproduce recorded flow behaviour in the system.

7.2 Model Structure

The model covers the Paroo River from its headwaters to the Wanaaring gauge. Figure 1.1 shows the catchment and Figure 7.2 shows the IQQM node diagram for the complete system. As there is no modelled infrastructure for the complete period the validation run was undertaken using one model (no infrastructure) and one period of simulation, 1/1/1889 to 30/06/2011.

The validation model was run with two sets of inflow sequences: all Sacramento model inflows and the final flow sequences. The composition of the final inflow sequences is summarised in Figure 7.1

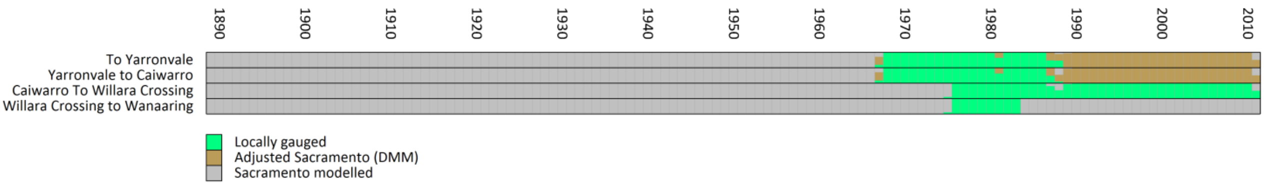


Figure 7.1: Composition of Final Inflow Sequence for all Reaches

7.3 Results

Table 7.1 shows how well the model performs against recorded data on a daily basis and Table 7.2 presents a comparison of the validation model flows at the gauge locations for the complete simulation period 1889–2011. Figure 7.3 to Figure 7.6 show Report Cards. Appendix D shows the daily flows at each gauge for the validation model run. It can be seen that the simulated flows show good agreement with recorded data.

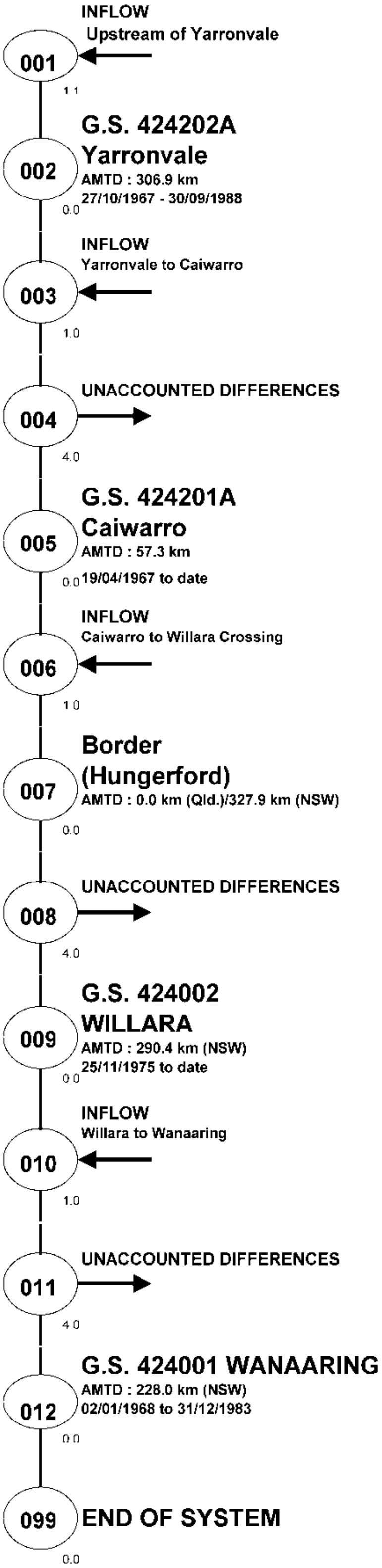


Figure 7.2: Paroo Validation Model IQQM Schematic

Table 7.1: Paroo Validation Models Daily Results

Location	Statistic	Daily		
		Recorded	Simulated – Sacramento Flow Validation	Simulated – Final Flow Validation
Yarronvale (27/10/1967–29/09/1988)	Mean (ML/day)	165	165	165
	Standard Deviation (ML/day)	1,446	1,368	1,446
	Skew	27.56	26.62	27.56
	Maximum Flow (ML/day)	76,281	65,097	76,281
	Volume Change (%)		100	100
	Coefficient of Determination		0.7331	1.00
	Coefficient of Efficiency		0.7251	1.00
Caiwarro (19/04/1967–30/06/2011)	Mean (ML/day)	1,521	1,528	1,523
	Standard Deviation (ML/day)	7,453	8,224	7,451
	Skew	8.54	10.37	8.54
	Maximum Flow (ML/day)	149,463	204,866	149,463
	Volume Change (%)		100	100
	Coefficient of Determination		0.6388	0.9998
	Coefficient of Efficiency		0.5463	0.9998
Willara Crossing (25/11/1975–30/06/2011)	Mean (ML/day)	1,126	1,184	1,135
	Standard Deviation (ML/day)	6,129	6,175	5,995
	Skew	17.16	12.06	15.36
	Maximum Flow (ML/day)	226,021	176,806	209,479
	Volume Change (%)		105	101
	Coefficient of Determination		0.5591	0.9678
	Coefficient of Efficiency		0.4915	0.9678
Wanaaring (02/01/1968–31/12/1983)	Mean (ML/day)	1,160	1,102	1,125
	Standard Deviation (ML/day)	5,528	5,169	5,281
	Skew	7.83	7.70	7.53
	Maximum Flow (ML/day)	74,784	69,662	73,625
	Volume Change (%)		95	97
	Coefficient of Determination		0.7227	0.8370
	Coefficient of Efficiency		0.7153	0.8354

Table 7.2: Paroo Validation Models Mean Annual Flows 1889–2011

Location	Sacramento Validation July to June (ML/a)	Final Sequence Validation July to June (ML/a)	%
Yarronvale	51,386	54,197	105.5
Caiwarro	517,858	517,135	99.9
Willara Crossing	383,853	382,425	99.6
Wanaaring	340,310	340,041	99.9

Table 7.3 shows the water balance of the validation (final flows) model. The runoff coefficients for each reach from the validation model are very similar to those from the recorded flow. This gives confidence in the model.

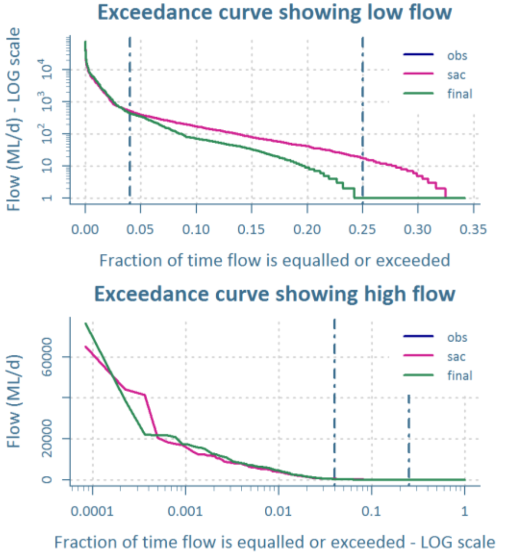
Table 7.3: Paroo Final Flows Validation Model Water Balance 1889–2011

Location	Catchment Area km^2	MARF July 1889 to June 2011 mm/a	Validation Model Mean Annual Flow July to June		
			ML/a	mm/a	% RO Coeff
Yarronvale	1,819	390	54,197	29.79	8
Caiwarro	21,446	367	517,135	24.11	7
Willara Crossing	24,238	359	382,425	15.78	4
Wanaaring	26,530	352	340,041	12.82	4

Yarronvale GS424202a - Validation Models

Period of analysis: 27/10/1967 to 29/9/1988

(observed flow is available for 93.9% of days in this period)



Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	1,182,004	0.0%	★★★★★	0.0%	★★★★★
Total Low Flow Volume (ML)*	661	586.7%	★☆☆☆☆	0.0%	★★★★★
Total Medium Flow Volume (ML)*	115,850	75.5%	★☆☆☆☆	0.0%	★★★★★
Total High Flow Volume (ML)*	1,065,493	-8.5%	★★★☆☆	0.0%	★★★★★
Mean Flow Volume (ML/d)	165	0.0%	★★★★★	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	105	-37.5%	★☆☆☆☆	0.0%	★★★★★
Zero Flow Days (%)+	65.8%	0.7%^	★★★★☆	0.0%^	★★★★★
Standard Deviation (ML/d)	1,446	-5.4%	★★★☆☆	0.0%	★★★★★

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.73	★★★☆☆	1.00	★★★★★
Non-matching Zero Flow Days	30.7%	★★☆☆☆	0.0%	★★★★★

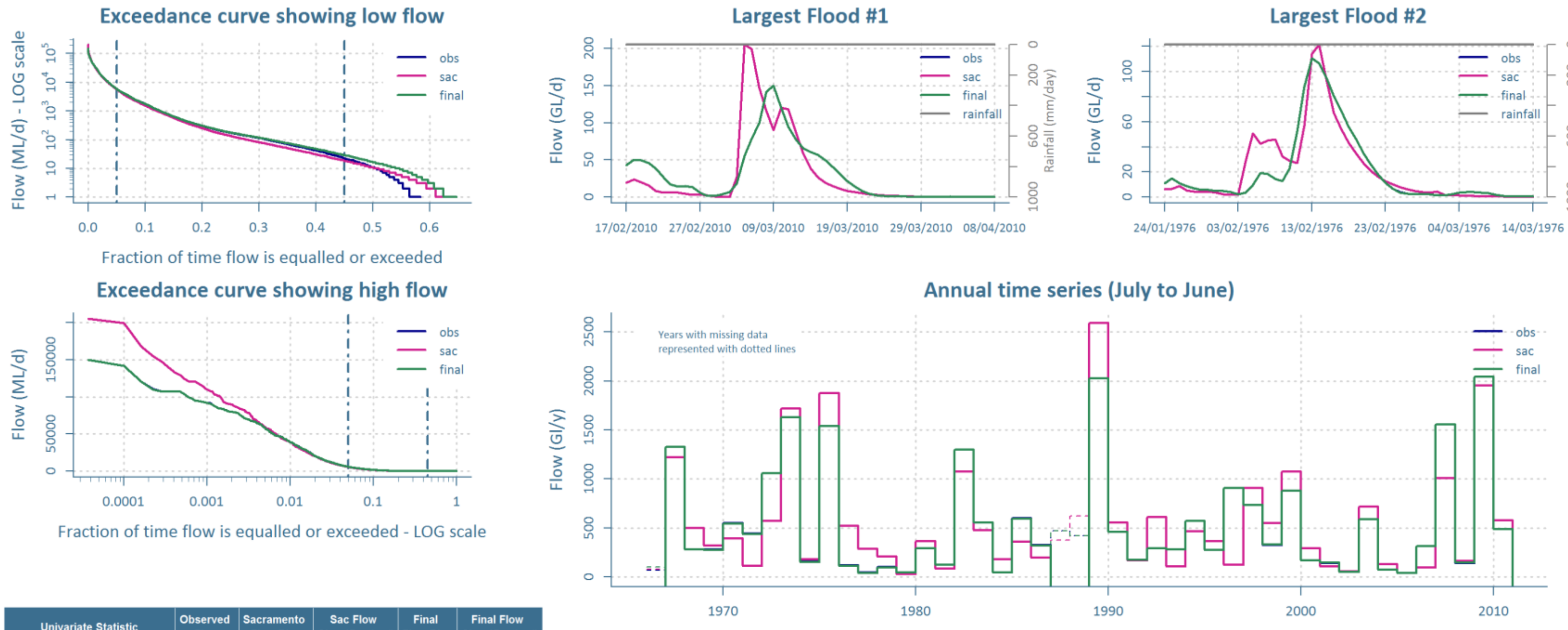
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.25 to 1 exceedance probability range
* Medium flow = flow in the 0.04 to 0.25 exceedance probability range
* High flow = flow in the 0 to 0.04 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 7.3: Validation Model Report Card – GS424202a Yarronvale

Caiwarro GS424201a - Validation Models

Period of analysis: 19/4/1967 to 30/6/2011

(observed flow is available for 98.8% of days in this period)



Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	24,246,683	0.5%	★★★★☆	0.2%	★★★★☆
Total Low Flow Volume (ML)*	18,837	12.5%	★★☆☆☆	78.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	4,222,743	-10.8%	★★☆☆☆	0.6%	★★★★★
Total High Flow Volume (ML)*	20,005,103	2.9%	★★★★☆	0.0%	★★★★★
Mean Flow Volume (ML/d)	1,521	0.5%	★★★★☆	0.2%	★★★★☆
Driest 3 Year Mean (ML/d)	1,718	7.9%	★★★☆☆	-0.1%	★★★★★
Zero Flow Days (%)+	41.6%	4.5%^	★★★☆☆	6.3%^	★★☆☆☆
Standard Deviation (ML/d)	7,453	10.3%	★★☆☆☆	0.0%	★★★★★

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.55	★★★☆☆	1.00	★★★★★
Non-matching Zero Flow Days	29.2%	★★☆☆☆	11.4%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.45 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.45 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

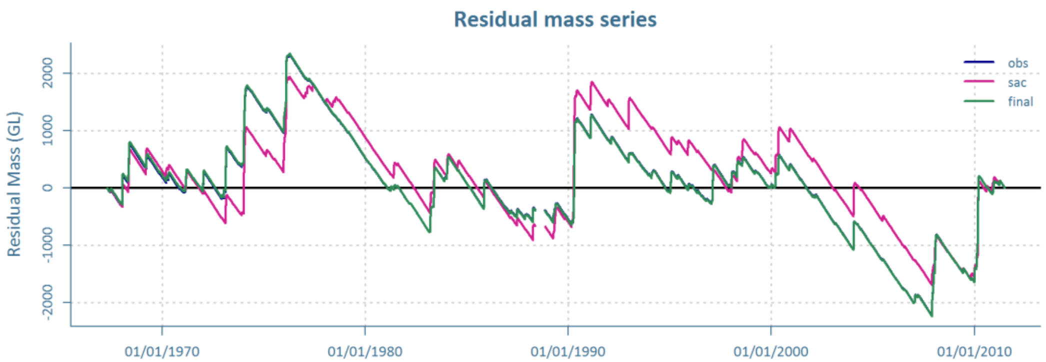
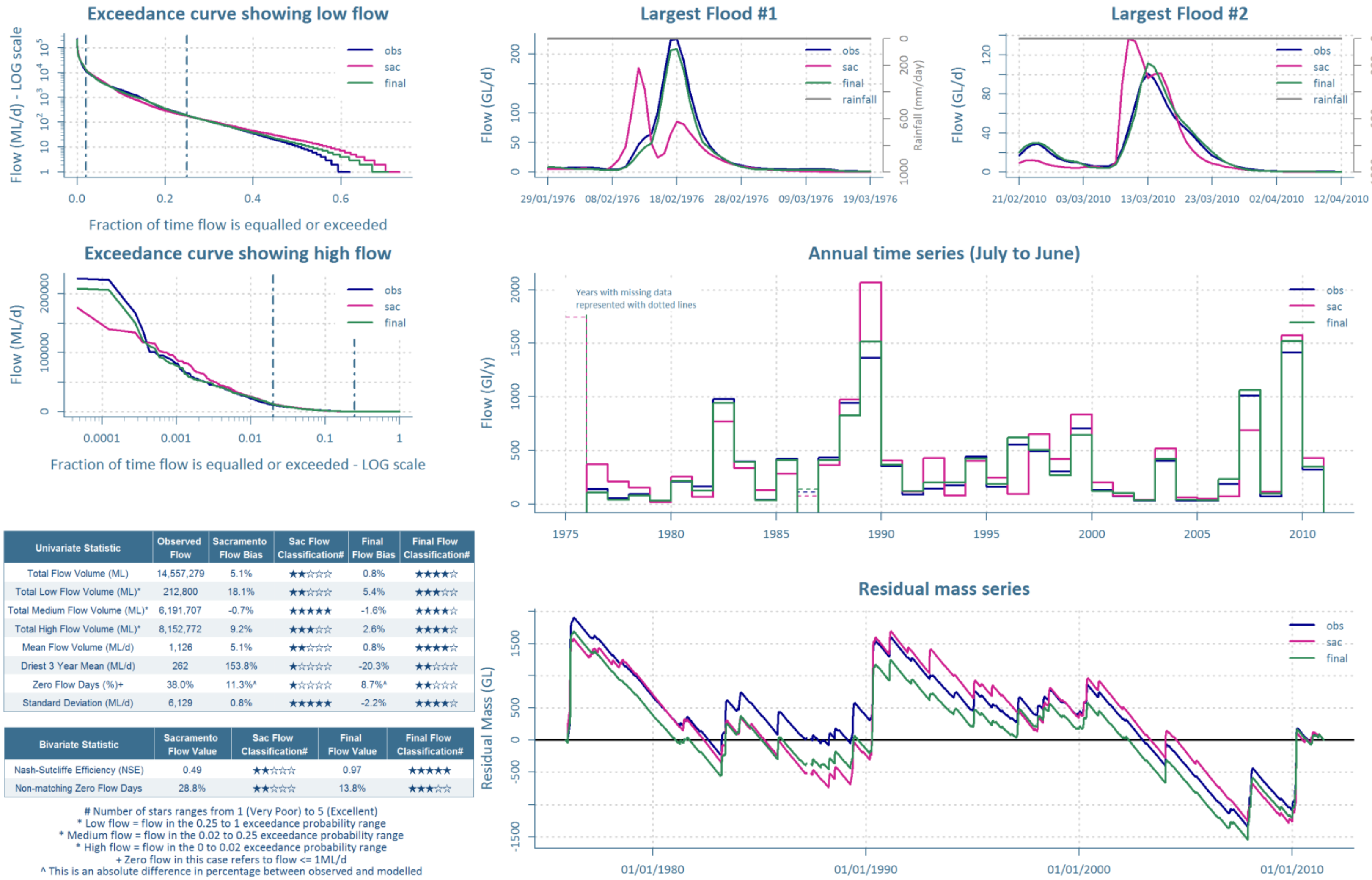


Figure 7.4: Validation Model Report Card – GS424201a Caiwarro

Willara Crossing GS424002 - Validation Models

Period of analysis: 25/11/1975 to 30/6/2011

(observed flow is available for 99.4% of days in this period)



Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	14,557,279	5.1%	★★☆☆☆	0.8%	★★★★☆
Total Low Flow Volume (ML)*	212,800	18.1%	★★☆☆☆	5.4%	★★★☆☆
Total Medium Flow Volume (ML)*	6,191,707	-0.7%	★★★★★	-1.6%	★★★★☆
Total High Flow Volume (ML)*	8,152,772	9.2%	★★★☆☆	2.6%	★★★★☆
Mean Flow Volume (ML/d)	1,126	5.1%	★★☆☆☆	0.8%	★★★★☆
Driest 3 Year Mean (ML/d)	262	153.8%	★☆☆☆☆	-20.3%	★★☆☆☆
Zero Flow Days (%)+	38.0%	11.3%^	★☆☆☆☆	8.7%^	★★☆☆☆
Standard Deviation (ML/d)	6,129	0.8%	★★★★★	-2.2%	★★★★☆

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.49	★★☆☆☆	0.97	★★★★★
Non-matching Zero Flow Days	28.8%	★★☆☆☆	13.8%	★★★☆☆

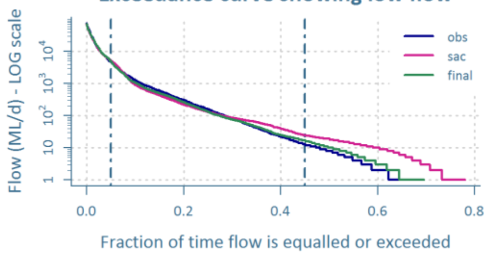
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.25 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.25 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

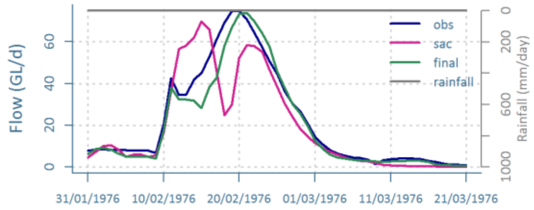
Figure 7.5: Validation Model Report Card – GS424002 Willara Crossing

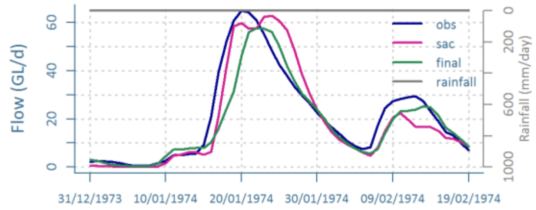
Wanaaring GS424001 - Validation Models

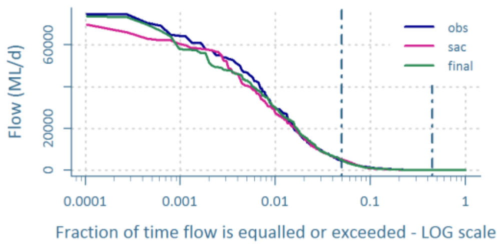
Period of analysis: 2/1/1968 to 31/12/1983

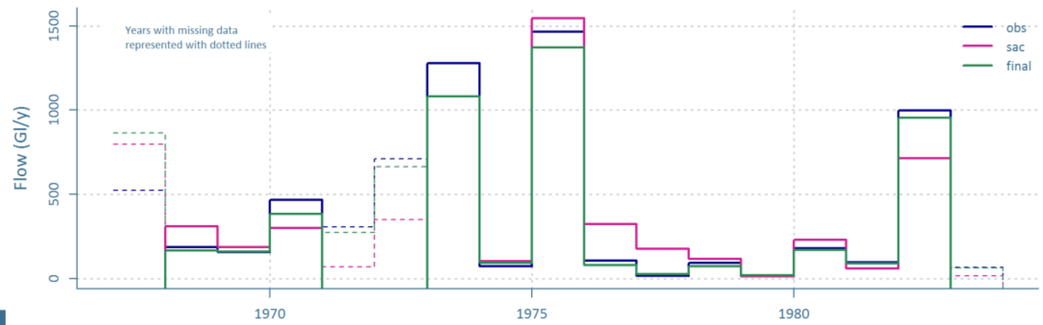
(observed flow is available for 99.5% of days in this period)











Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	6,741,709	-5.0%	★★☆☆☆	-3.0%	★★★☆☆
Total Low Flow Volume (ML)*	6,277	195.6%	★☆☆☆☆	35.3%	★☆☆☆☆
Total Medium Flow Volume (ML)*	1,224,663	-7.4%	★★★☆☆	-9.8%	★★★☆☆
Total High Flow Volume (ML)*	5,510,769	-4.7%	★★★★☆	-1.5%	★★★★☆
Mean Flow Volume (ML/d)	1,160	-5.0%	★★☆☆☆	-3.0%	★★★☆☆
Driest 3 Year Mean (ML/d)	739	-1.6%	★★★★☆	-12.0%	★★☆☆☆
Zero Flow Days (%)+	31.2%	9.2%^	★★☆☆☆	0.7%^	★★★★☆
Standard Deviation (ML/d)	5,528	-6.5%	★★★☆☆	-4.5%	★★★★☆

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.72	★★★☆☆	0.84	★★★★☆
Non-matching Zero Flow Days	32.9%	★★☆☆☆	22.3%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.45 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.45 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
\+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

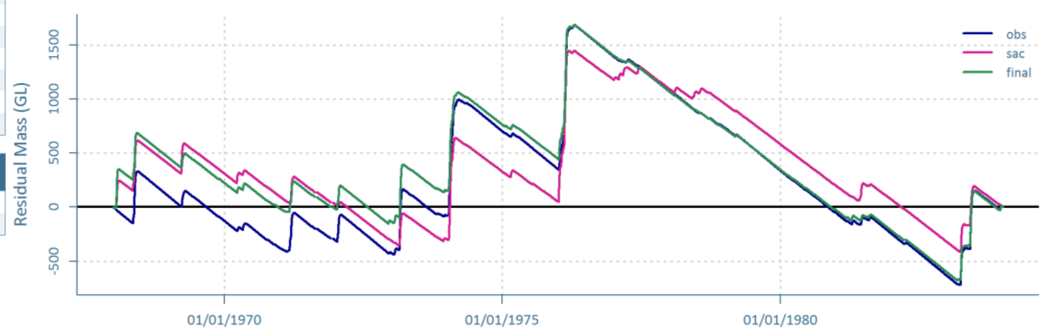


Figure 7.6: Validation Model Report Card – GS424001 Wanaaring

7.4 Discussion

The Paroo River IQQM is a simple model with no infrastructure. For the Final Flow Validation model, in periods where inflows could be calculated from recorded flow data, the modelled flows at the key gauges generally show good reproduction of the recorded flows. In periods where inflows include Sacramento data there are some anomalies.

The residual mass curves at Willara Crossing shows an underestimation of the 1975 event. This is due to the high unaccounted differences at high flows that are introduced by the average unaccounted differences relationship developed for the reach. In reality the unaccounted difference would have been expected to be low in 1975 due to the 1974 flood event producing extremely wet antecedent conditions. Consideration should be given to incorporating a floodplain loss function that reflects antecedent conditions in future upgrades of the model.

The 1968 divergences in the Wanaaring residual mass curves are due to an event from upstream passing down the model which corresponded to a period of zero flow at the Wanaaring gauge. It was recorded at Yarronvale and Caiwarro so it is likely that it did occur; hence, the Wanaaring record is questionable. As that period of the Wanaaring record was not used in deriving the residual for Reach 6, it will not have influenced the development of the Paroo model.

The other divergence at Wanaaring (which actually realigns the curves) occurs in the 1974 event and can be explained by the Sacramento inflows in Reaches 5 and 6 being overestimated. This is not unexpected as the event was extreme and the rainfall network may not have captured the event well.

The comparisons for the Sacramento Validation Model show that there is some accumulation of error at Wanaaring but it is not extreme. Generally there is a good match, indicating that it is appropriate to use the Sacramento model data to infill missing inflows.

The Validation run results give confidence that the model provides an accurate representation of the catchment.

8. Quality Assurance

Quality assurance procedures were followed. This was divided into five sections:

- Model Setup – this ensures that procedures are in place to document decisions made regarding the set-up of the model. This also includes the planning stage of the model work.
- Data Review – this includes the collation and checking of basic data (stream flow, rainfall, evaporation, etc.), to identify data gaps and data quality issues.
- IQQM Reach Model Calibration Review – this documents the calibrated reach model's ability to reproduce the recorded downstream flows.
- Rainfall Runoff Model Calibration Review – this documents the Sacramento model parameters and the performance of the Sacramento model in reproducing the recorded or residual inflows.
- IQQM Validation Model Review – this considers the whole-of-model checks that are performed on the models developed for the full system at completion of the calibration. It considers the match at the calibration gauges.

A star system (more stars are better) was used on report cards to indicate the quality of calibrations. The report cards for Sacramento calibrations and Validation model results along with their star ratings are shown in this report.

Ratings are shown for volume ratios for the whole flow range, as well as the low, mid and high flow ranges. The low, mid and high flow ranges provide an indication of how well the Reach Sacramento and the Final Sequences Validation models reproduce each range of flows. The low, medium and high flow ranges are defined by the flexion points on the daily flow duration curves.

The performance of the Sacramento model calibrations vary. Some are extremely poor while others are of a better quality. In general the mid and high flow ranges were better reproduced than the low flow ranges.

The performance of the Validation models against the full period of record at each gauge returned higher ratings for the final flows model than the Sacramento validation as is be expected due to the use of recorded data in the final flows. Once again, the mid to high flow ranges were better reproduced.

There were no significant changes recommended as a result of the internal quality assessment review.

9. Conclusions

This report describes the calibration of an Integrated Quality Quantity Model (IQQM) for the Paroo River System from the headwaters upstream of Yarronvale to the Wanaaring gauge.

IQQM reach models were set up for four reaches of the Paroo River to Wanaaring. All reaches were calibrated using recorded flow data. For each reach the following occurred to obtain inflows and model parameters for the reach:

- A reach model was set up and the flow attenuation parameters were calibrated using the available flow record. The reach model was then used to estimate reach inflows and derive unaccounted difference relationships and waterhole parameters (if needed). In the case of a headwater reach these two steps were not necessary.
- The record based inflow sequence was used to calibrate a Sacramento rainfall-runoff model, which in turn was used to extend and infill the record based inflow sequences to cover the period 1/1/1889 to 30/6/2011.
- Further adjustments were made to Sacramento data in catchments where the downstream gauge records (below the end of the reach) were longer than the calculated record based residual inflow. The final adjustments produced the final reach inflow sequences.

This information was used to develop a Validation IQQM model of the whole Paroo River to Wanaaring which was checked for quality of calibration over different periods for each reach. The quality of the system Validation Model was judged to be satisfactory although some model inadequacies with respect to response to low flow regimes occurred. This would not be able to be resolved without longer periods of flow record, better rainfall coverage and more sophisticated model structure especially in terms of modelling antecedent conditions and variable lags and unaccounted differences.

The model developed constitutes a whole river system IQQM and is considered adequate for use in Water Resource Planning and Salinity studies and other water resource investigations.

10. Recommendations

It is important that the Caiwarro and Willara Crossing flow gauges remain well maintained and rated. The Paroo is a large catchment and without them there would be great difficulty understanding what happens in the catchment. The Paroo is a system relatively unimpacted by development. If there was development at some latter time another gauge above Caiwarro would be useful to help identify flow variability within the catchment as the two gauges currently open are reasonably close together and have large catchment areas.

11. References

Burnash, R,J.C., Ferral, R.L., and McGuire, R.A. (1973) *A Generalised Streamflow Simulation System: Conceptual Modelling for Digital Computers*, Joint Federal-State River Forecast Centre, U.S. National Weather Service and California Department of Water Resources, Sacramento, California.

Jeffrey, S.J., Carter, J.O., Moodie, K.M and Beswick, A.R. (2001) *Using Spatial Interpolation to Construct a Comprehensive Archive of Australian Climate Data,* Environmental Modelling and Software, Vol 16/4, p. 309-330.

Kisters Pty. Ltd (2010) *Hydstra Version 10.*

NSW DLWC (1996) *Integrated Quantity-Quality Model (IQQM) User Manual*, Department of Land and Water Conservation, NSW.

Qld. DNRM (2003) *Paroo River System Hydrology Volume 1 - Calibration of Daily Flow Simulation Model from upstream of Yarronvale (QLD. AMTD 303.7km) to Darling River/Paroo River Confluence (NSW AMTD 0.0 km).*

Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 (Qld).

Appendix A1 – Hydrological Models: IQQM

Description of IQQM

The system was simulated using the daily Integrated Quantity-Quality Model (IQQM) developed by the Department of Land and Water Conservation in New South Wales. The model represents the system as a series of links and nodes with the links describing the routing of river flows and the nodes representing catchment processes such as the operation of a storage, demands or losses. The program is described in its manual (DLWC, 1996).

IQQM was developed as a tool for planning and evaluating water resource management policies at the river basin scale. This model can be applied to supplemented and unsupplemented streams, and is capable of addressing water quality and environmental issues, as well as water quantity issues. The model operates on a continuous basis and can be used to simulate river system behaviour for periods ranging up to hundreds of years. It is designed to operate at a daily time step but some processes can be simulated at time steps down to one hour.

IQQM Processes

The major processes that are simulated in IQQM include:

- flow routing in rivers, effluent systems and irrigation channels
- reservoir operation
- resource assessment
- irrigation
- urban water supply and other consumptive uses
- wetland and environmental flow requirements.

Types of IQQM Nodes

The model represents a river system as a sequence of nodes and links. Each node represents something along the system, for example inflows, losses, storages, irrigation, or town water supplies just to name a few. These nodes are joined by links that allow the adjustment of lag and attenuation of the flows between the nodes so that the system can be better simulated.

The main node types used by the calibration model are briefly described in Table A1.

Figure A1 shows an example of a typical river basin, and its IQQM node diagram representation.

Table A1 – Types of IQQM Nodes

Node Type	Node Name	Main Purpose of the Node
0	Gauge	Used for measuring simulated flows.
1	Inflow	Unmodelled tributaries and pumped inflows joining the main river.
2	On-river storage	On-river storage water balance and operation.
3	Fixed demand	Fixed demand node for simulating town water supplies, industrial demands and pumped extractions.
4	Effluent offtake	Diversion of flows into an effluent channel or loss.
5	Effluent return	Return of effluent flows to a river section.
6	Re-regulating off-river storage inflow	Off-river storage water balance and operation.
7	Re-regulating off-river storage release	Outlet from off-river storage.
8	Irrigation demand	Irrigation demands, diversions and on-farm storage operation for supplemented and unsupplemented irrigators.
9	Flow control	Maintains regulated flow conditions and controls off-allocation usage.
10	Wetland	Controls on- and off-river wetlands and replenishment of effluents and streams.
11	Confluence	Confluence of two river sections.
12	Flood plain detention storage	Overbank flows during large floods and their return to river as river levels recede.

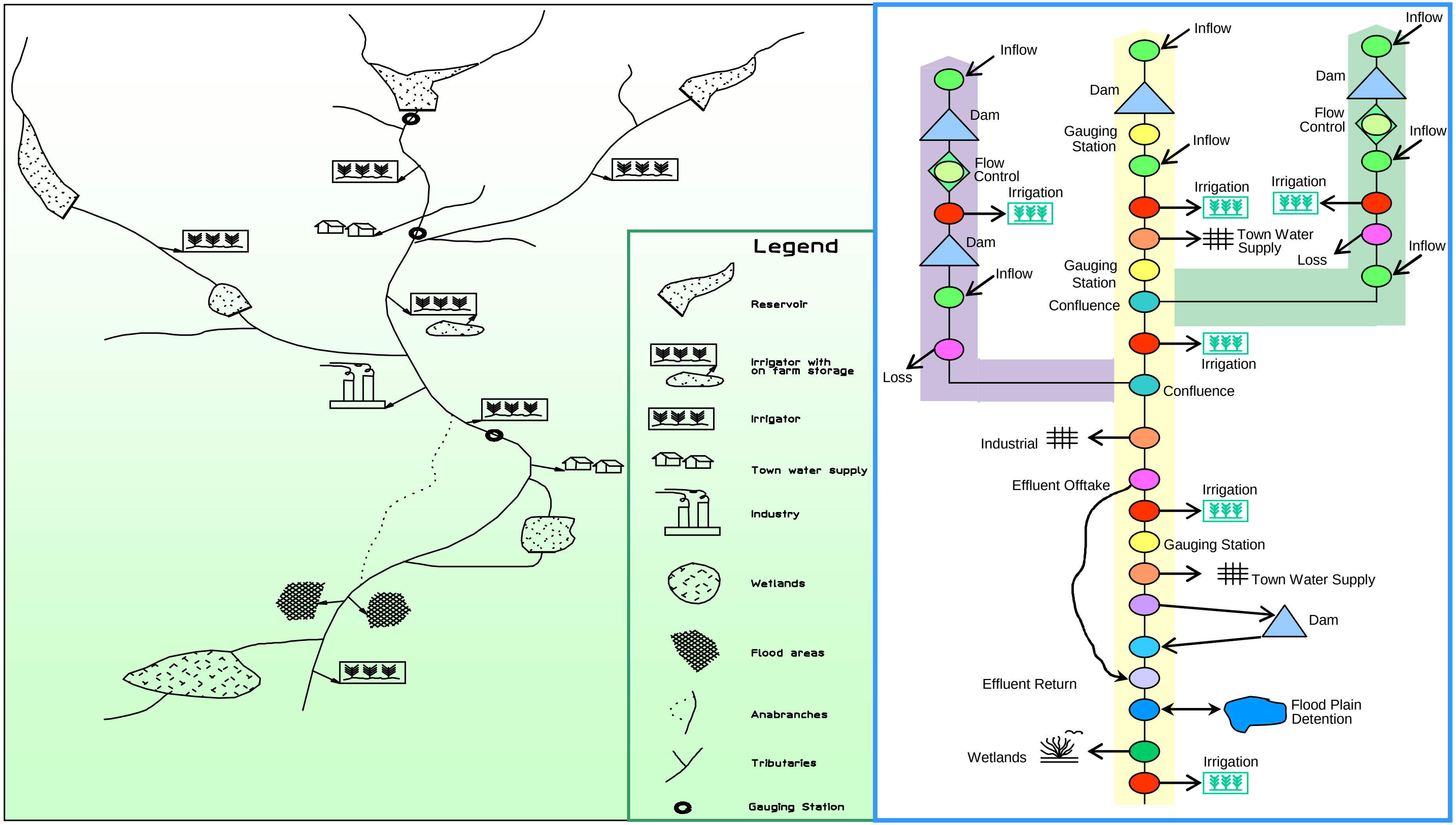


Figure A1 – IQQM Node Diagram Representation

Appendix A2 – Hydrological Models: The Sacramento Model

The Sacramento rainfall-runoff model was developed by Burnash, Ferral and McGuire (1973). It can be implemented through the computer programs WINSAC and/or IQQM. It is an explicit soil moisture accounting type model developed by the United States National Weather Service and the California Department of Water Resources, originally for flood forecasting applications.

The Sacramento model consists of a number of storages connected by catchment processes. The model components and the relationships between them are shown on Figure A2.

Rainfall on the catchment is considered as falling on one of two types of surface: permeable areas; or impervious areas that are linked to the channel system. Runoff is produced from impervious areas in any rainfall event.

The permeable area, in contrast, produces runoff only when the rainfall is sufficiently heavy. In this portion, initial soil moisture storage (the upper zone tension storage) must be filled before water is available to enter other storages. This represents the depth of precipitation required to meet interception requirements and is water bound closely to soil particles. When this tension storage is filled, water is accumulated in the upper zone free water storage, from where it is free to drain to deeper storages or to move laterally to appear in the stream channel as interflow.

The vertically draining water, or percolation, can enter one of three lower zone storages, the lower zone tension storage (the depth of water held closely by the soil particles) or one of the two lower zone free water storages, primary and supplemental (that are available for drainage as baseflow or subsurface outflow). The two free water storages fill simultaneously but drain independently at different rates to produce the variable baseflow recession.

Evaporation occurs from surface water areas at the potential rate, but in other areas, varies with both evapotranspiration demand and the volume and distribution of tension water storage.

The surface runoff and interflow are routed to the catchment outlet by a non-dimensional unit hydrograph. In catchments where significant nonlinearities may be present, such as extensive flood plains that may alter the mean travel times, a layered Muskingum routing technique, effectively introducing a number of linear storage-discharge relationships, can be used.

To implement the model in a given catchment, a set of 18 parameters must be defined. These parameters define the generalised model for a particular catchment. The parameters are usually derived for a gauged catchment by a process of calibration where the recorded stream flows are compared with calculated stream flows and the parameters are adjusted to produce the best match between the means and standard deviations of the daily stream flows, and reducing the difference in peak flow discharge.

For ungauged catchments, parameter sets from adjacent or nearby gauged catchments may be used. A parameter set may be called a regional parameter set especially if the ungauged catchment is located in the same local region where the catchment with the calibrated parameter set is located.

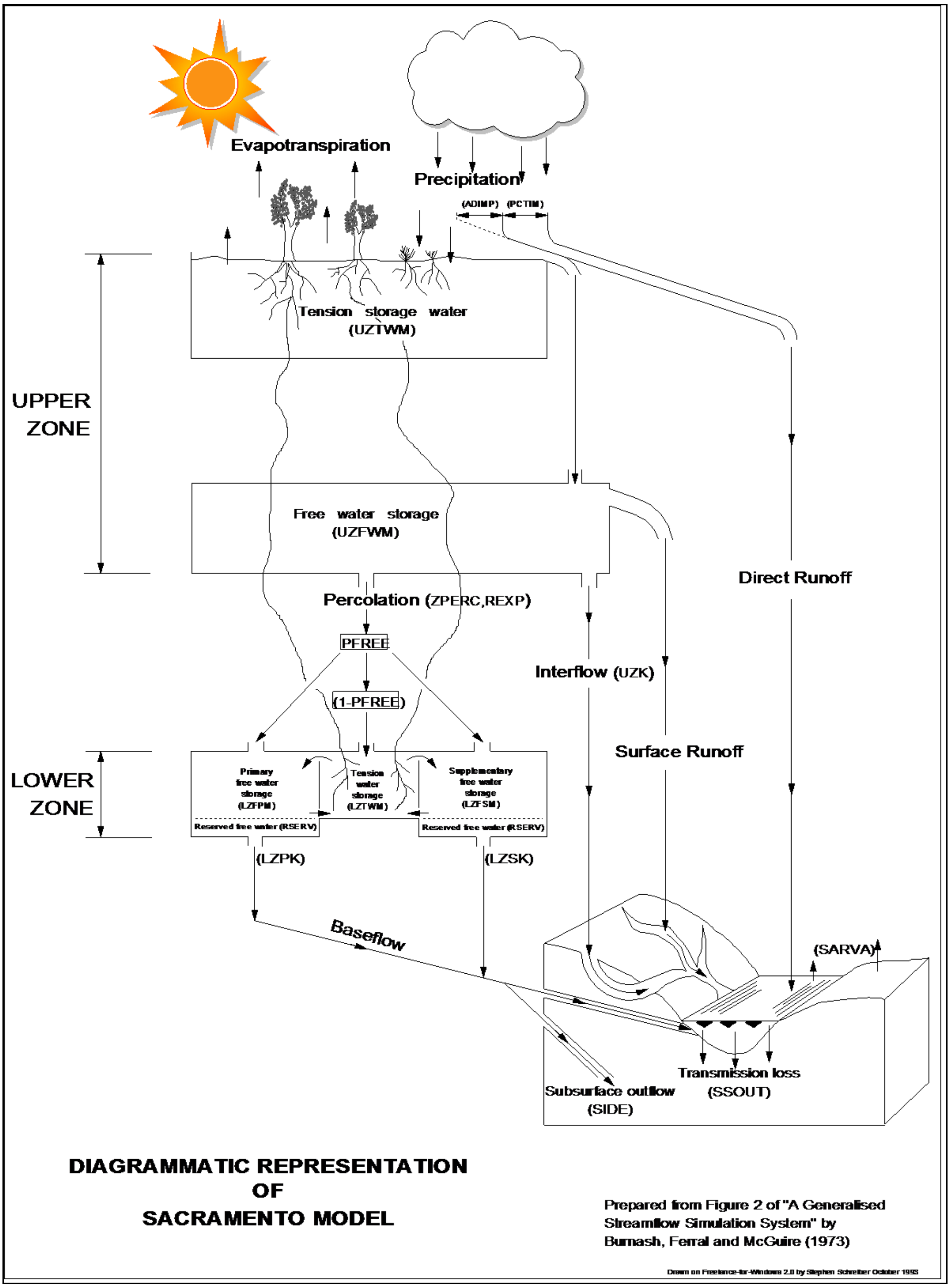


Figure A2 – Sacramento Model Schematic

Appendix B – The DMM Process

The Data Modification Module (DMM) consists of a number of programs that can be used to adjust subarea inflows on a daily basis to give good agreement between the IQQM predicted flow and the flow recorded at a stream gauge.

The inflows estimated by the calibrated Sacramento model for each subarea are used in the IQQM to simulate the flows at the stream gauge for the period of record. The DMM compares the recorded and simulated flow to determine daily factors that are used to adjust the inflow sequences.

When the modelled flow is greater than zero, the daily inflow from each subarea is multiplied by the following factor:

> *Factor = (Measured Flow + Unaccounted difference) / (Modelled Flow + Unaccounted difference)*

where the Unaccounted difference is from the IQQM model, which is specified by the user.

When there is no modelled flow, a daily flow is added to the appropriate daily flow in each inflow sequence. The amount of flow added to a particular subarea inflow is determined by the difference between the measured flow and the modelled flow scaled by a factor. The scaling factor is usually estimated by dividing the subarea area by the total catchment area upstream of the gauge.

The DMM process is undertaken in two steps. In the first step, the factors are estimated from the measured and modelled flow. In the second step, the factors are applied to the inflow sequences allowing for any lag caused by routing in the IQQM. In the second step, the user can define the periods of time that the DMM factors are to be applied.

It should be noted that the IQQM is nonlinear because of routing, impacts of weirs and losses that depend on the flow. The DMM process is essentially a linear process. Therefore in most situations it may be necessary to iterate the process a number of times. In some situations, smoothing may have to be used to smooth out oscillations in the low flows.

Residual Catchments

In adjusting the subarea inflows for residual catchments, which are catchments between two stream gauges, the process needs to take into account the flows recorded at the upstream gauge (or gauges). Because these flows have been recorded, they cannot be adjusted. All adjustments have to be carried out on the subarea inflows downstream of the upstream gauge.

The formula used to calculate the adjustment factors in this situation are as follows.

When the modelled flow is greater than the upstream flow, the daily flow from each subarea is multiplied by the following factor:

> *Factor = (Measured Flow − Upstream Flow + Unaccounted difference) / (Modelled Flow − Upstream Flow + Unaccounted difference))*

where the Unaccounted difference is the Unaccounted difference in the IQQM model specified by the user.

When the modelled flow is less than the upstream flow, a value is added to each subarea inflow as described above.

If there is routing and lag between the upstream gauge and the downstream gauge, the upstream flow sequence should be routed through the IQQM before being used in the program.

When there are inconsistencies between the rating curves of the two gauges, the DMM process will try to compensate. For example, if the rating curve of the upstream gauge underestimates the flow, then the DMM process will increase the flow in the downstream catchments to ensure that the predicted flow at the downstream gauge matches the upstream flow. A small discrepancy can be almost impossible to detect. If the rating curve of the upstream gauge overestimates the flow, the DMM process will reduce the flow in the downstream catchments. If the problem is severe, there will be no flow in the downstream catchments. This situation is easier to detect. Any suspicions about the stream gauge ratings are referred to the hydrographers.

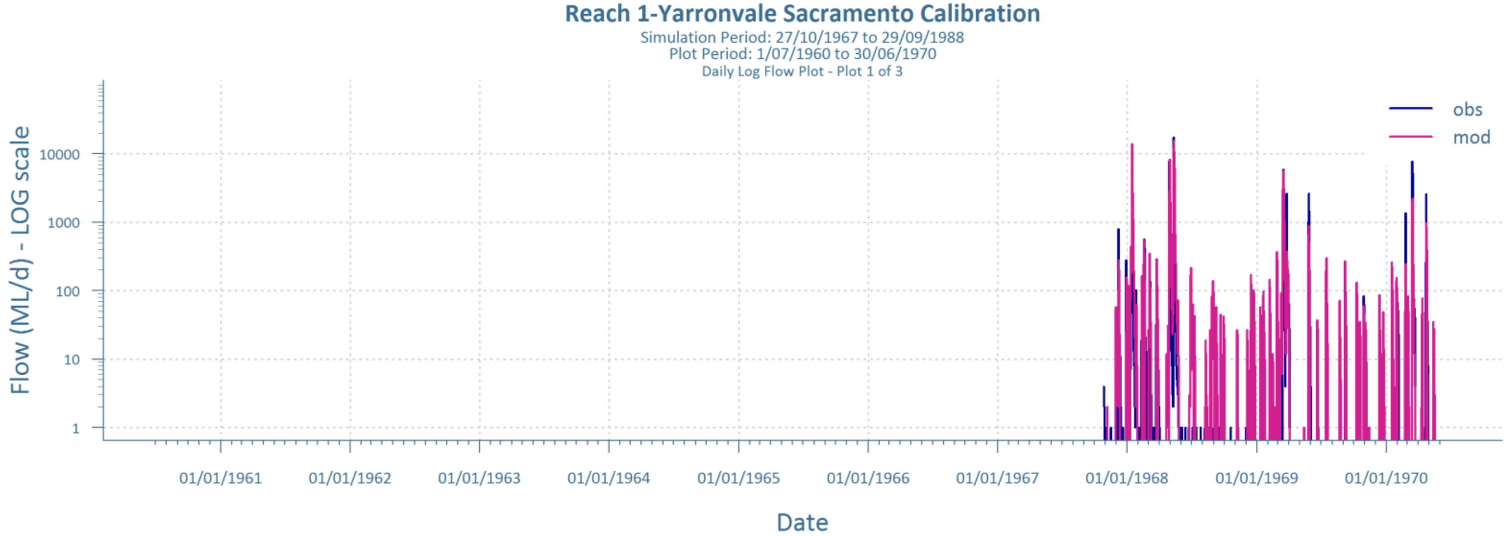
IQQM has difficulty in accurately predicting the effect of routing for all flood events, especially the change in routing for large events compared with small events. The routing parameters used in the IQQM are usually a compromise that gives the best agreement for most flood events. In some flood events, the predicted flood peak may not coincide with the measured peak in residual catchments. The DMM process will tend to increase the inflows to match the measured flow. However, it cannot change the poorly-routed flow from the upstream gauge. This usually leads to an overestimation of the flows. This can be dealt with using an overall adjustment process built into the software.

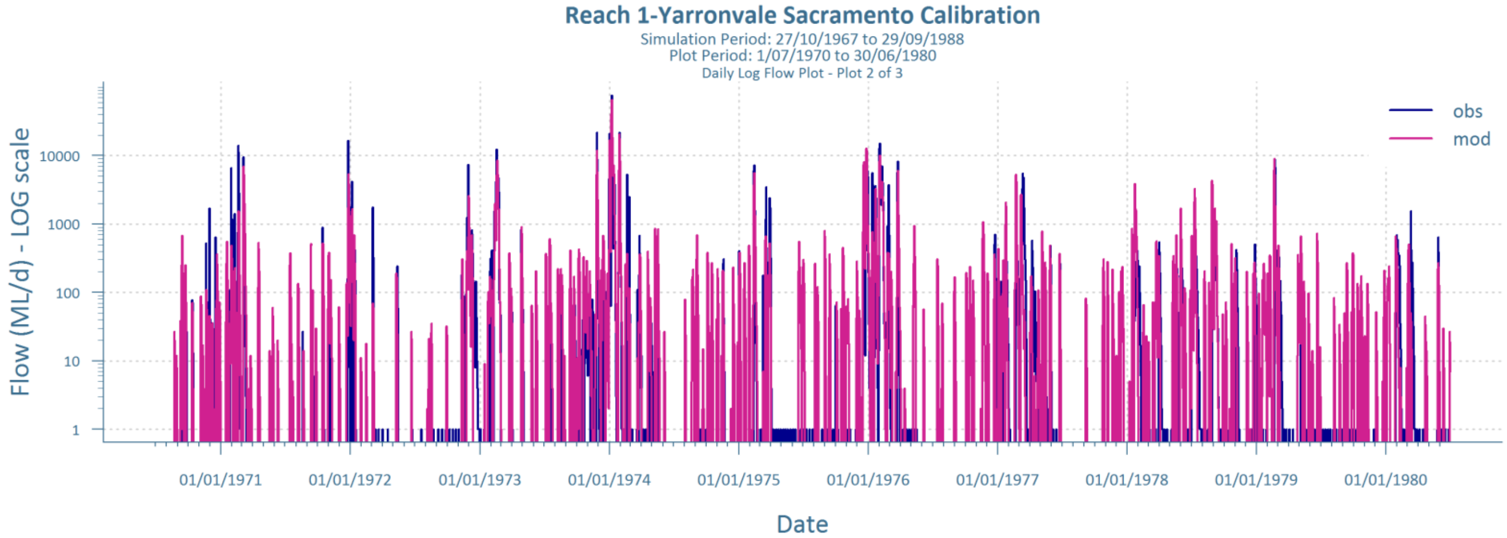
Multiple Reaches

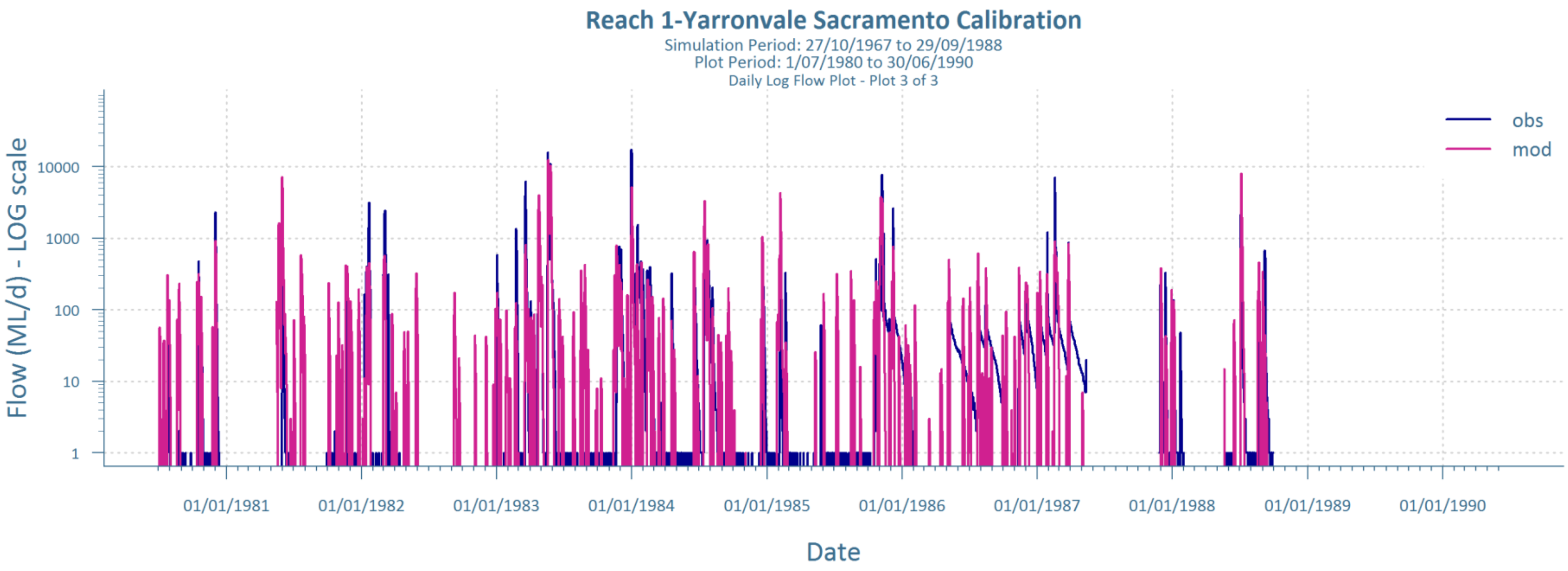
The DMM process is carried out in each reach upstream of a gauge. When this process has been completed for each reach, a daily inflow sequence is created for each subarea upstream of the stream gauge consisting of flows originally estimated using the Sacramento model. In some periods, the flow has been adjusted using the DMM process to give good agreement to the flows recorded at the downstream gauge. For the periods of time when there is no recorded data at the gauge, the flows are purely Sacramento model estimates.

In the final IQQM model, the flow at a downstream gauge is an accumulation of all the subarea inflows from all the reaches upstream. Sometimes there is a long-term gauge at the end of system and a comparison between the predicted flow and the recorded flow shows considerable differences in the period where the upstream subarea flows are based purely on the Sacramento model. In this situation, the DMM process can be applied to all the subarea inflows upstream. This is done only for the periods when there is no local stream gauge data to undertake a local DMM process.

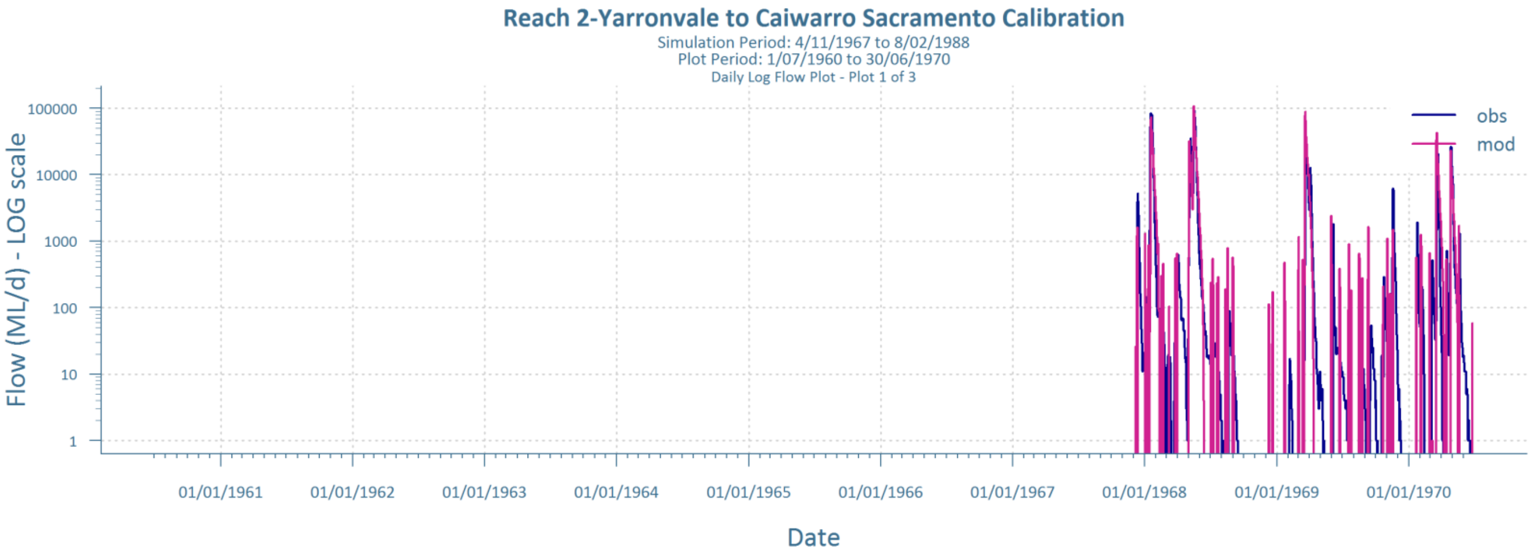
Appendix C1 - Reach 1 Recorded and Sacramento Daily Flows

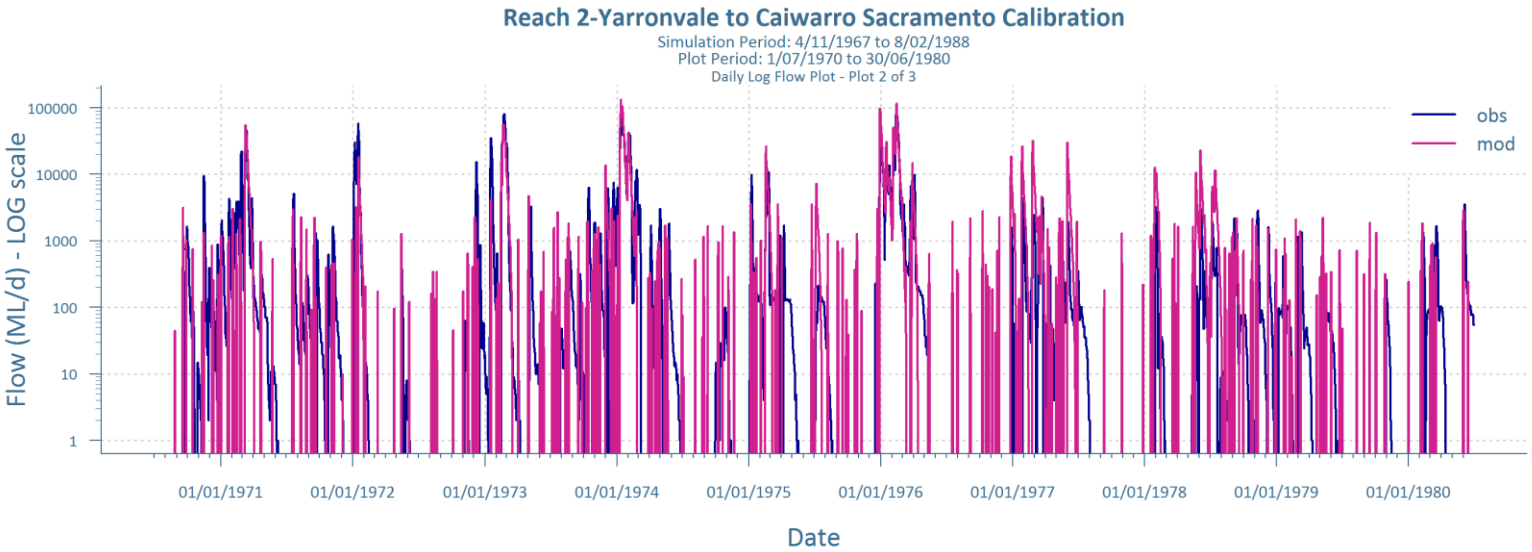


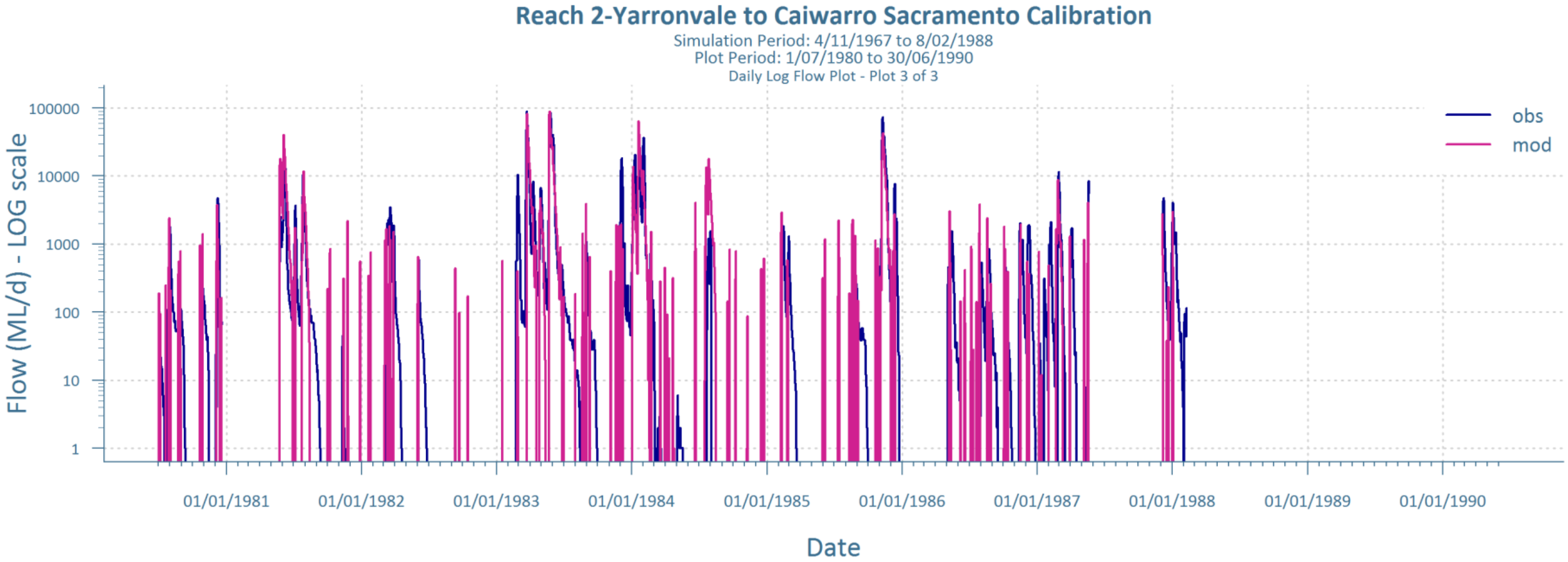



Reach 1-Yarronvale Sacramento Calibration
Simulation Period: 27/10/1967 to 29/09/1988
Plot Period: 1/07/1980 to 30/06/1990
Daily Log Flow Plot - Plot 3 of 3
Flow (ML/d) - LOG scale
10000
1000
100
10
1
obs
mod
01/01/1981
01/01/1982
01/01/1983
01/01/1984
01/01/1985
01/01/1986
01/01/1987
01/01/1988
01/01/1989
01/01/1990
Date

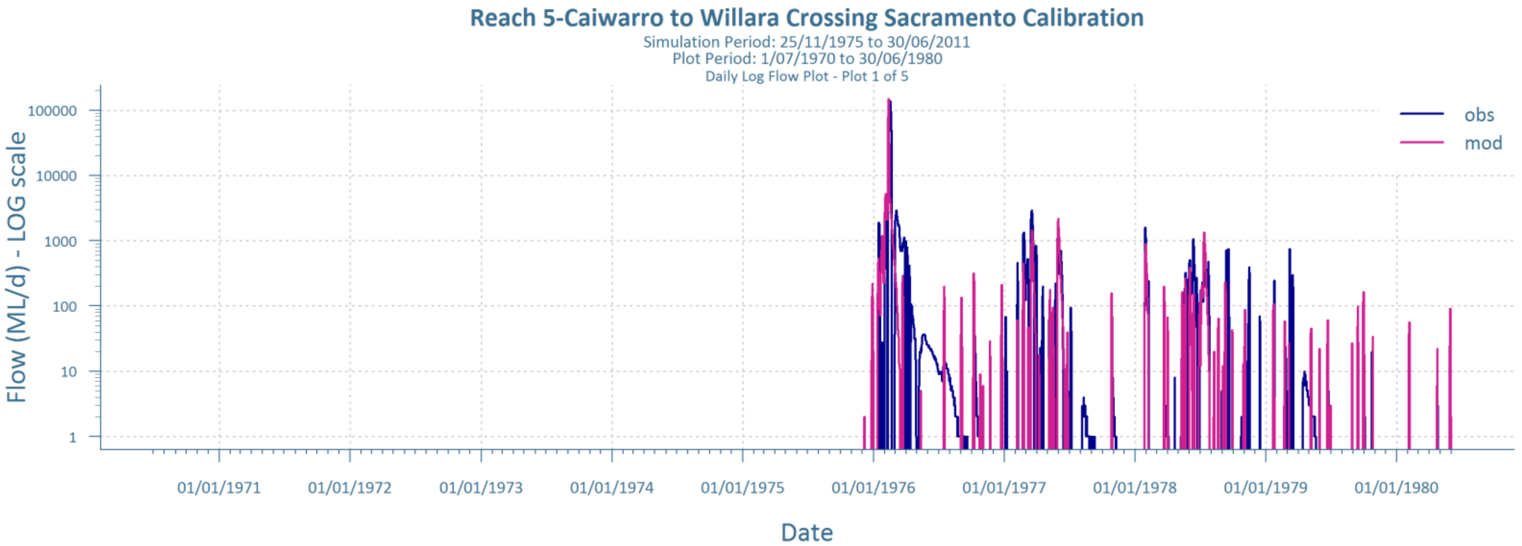
Appendix C2 - Reach 2 Recorded and Sacramento Daily Flows

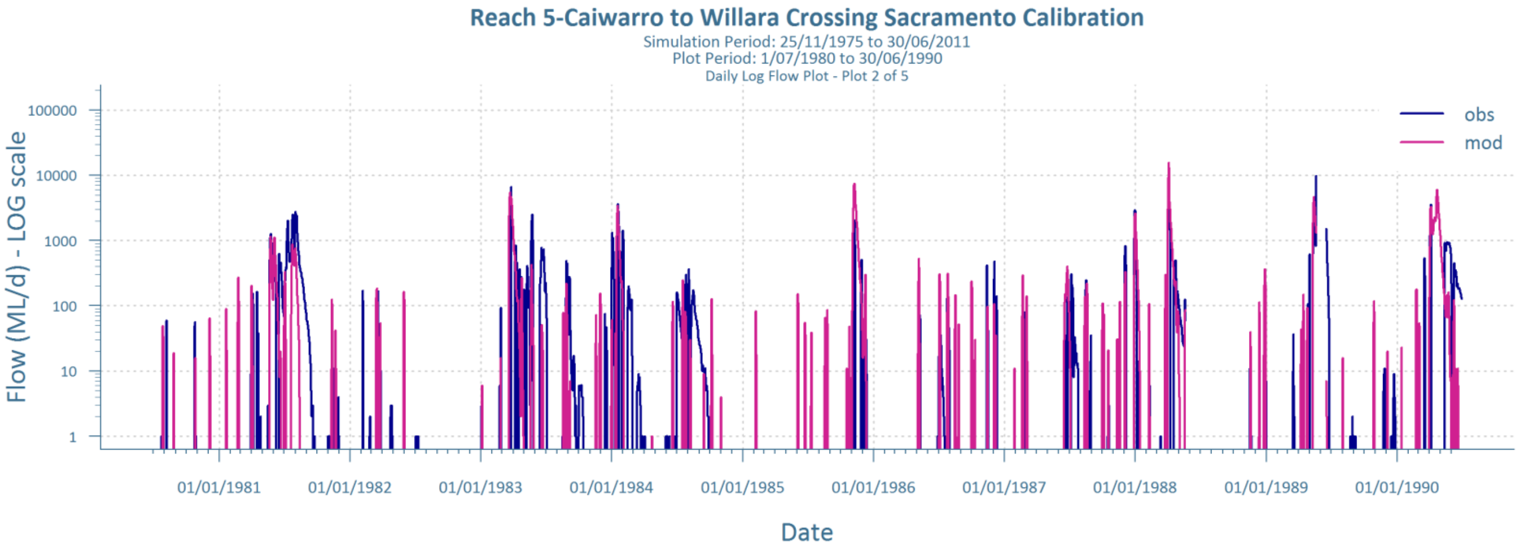


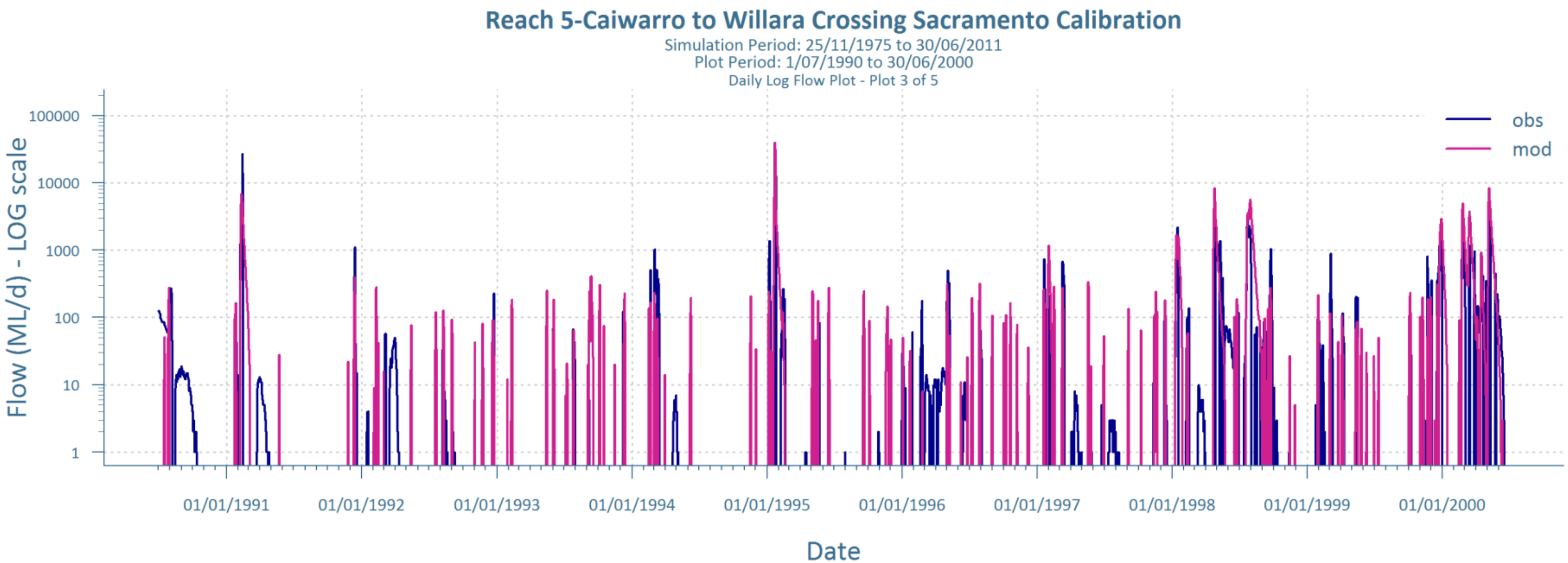



Reach 2-Yarronvale to Caiwarro Sacramento Calibration
Simulation Period: 4/11/1967 to 8/02/1988
Plot Period: 1/07/1980 to 30/06/1990
Daily Log Flow Plot - Plot 3 of 3
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
mod
01/01/1981
01/01/1982
01/01/1983
01/01/1984
01/01/1985
01/01/1986
01/01/1987
01/01/1988
01/01/1989
01/01/1990
Date

Appendix C3 – Reach 5 Recorded and Sacramento Daily Flows






Reach 5-Caiwarro to Willara Crossing Sacramento Calibration
Simulation Period: 25/11/1975 to 30/06/2011
Plot Period: 1/07/1990 to 30/06/2000
Daily Log Flow Plot - Plot 3 of 5
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
mod
01/01/1991
01/01/1992
01/01/1993
01/01/1994
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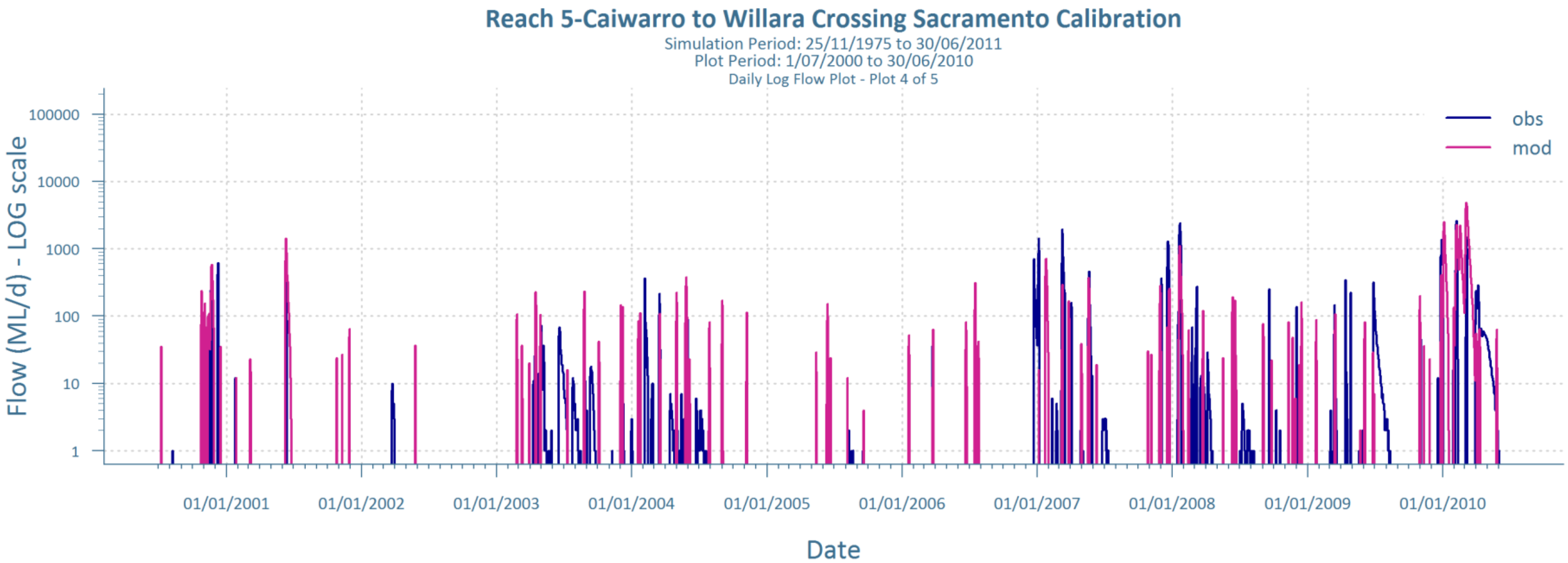
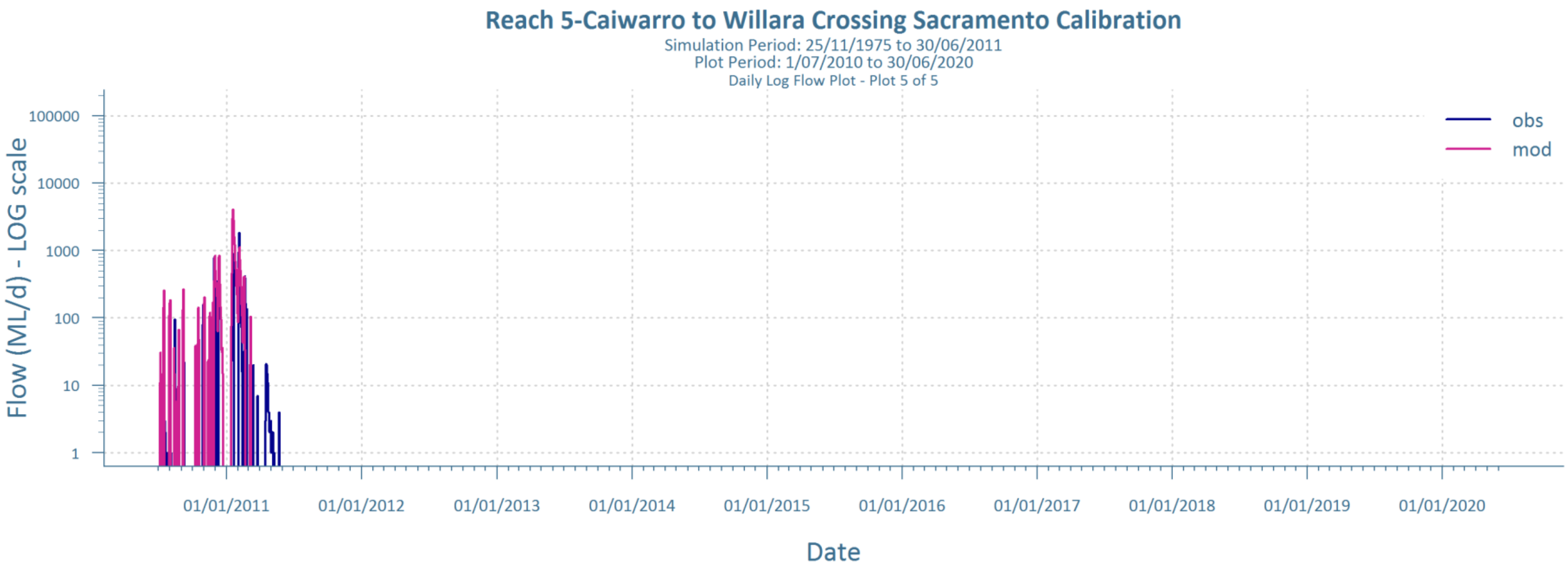
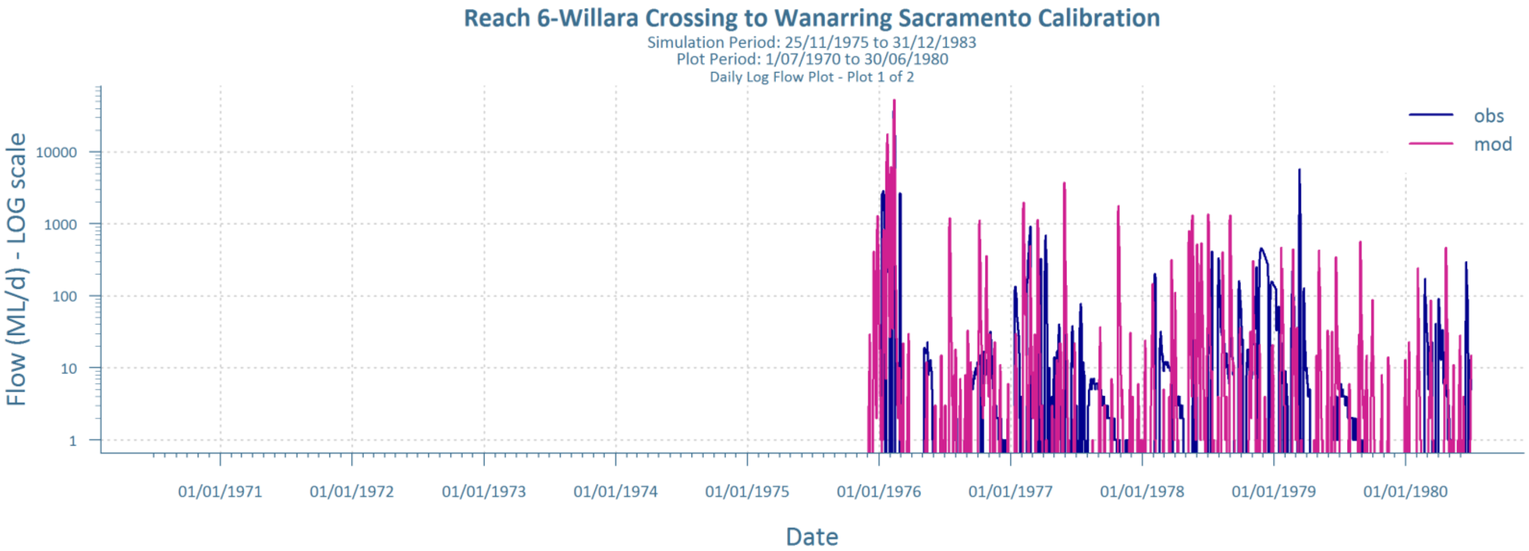
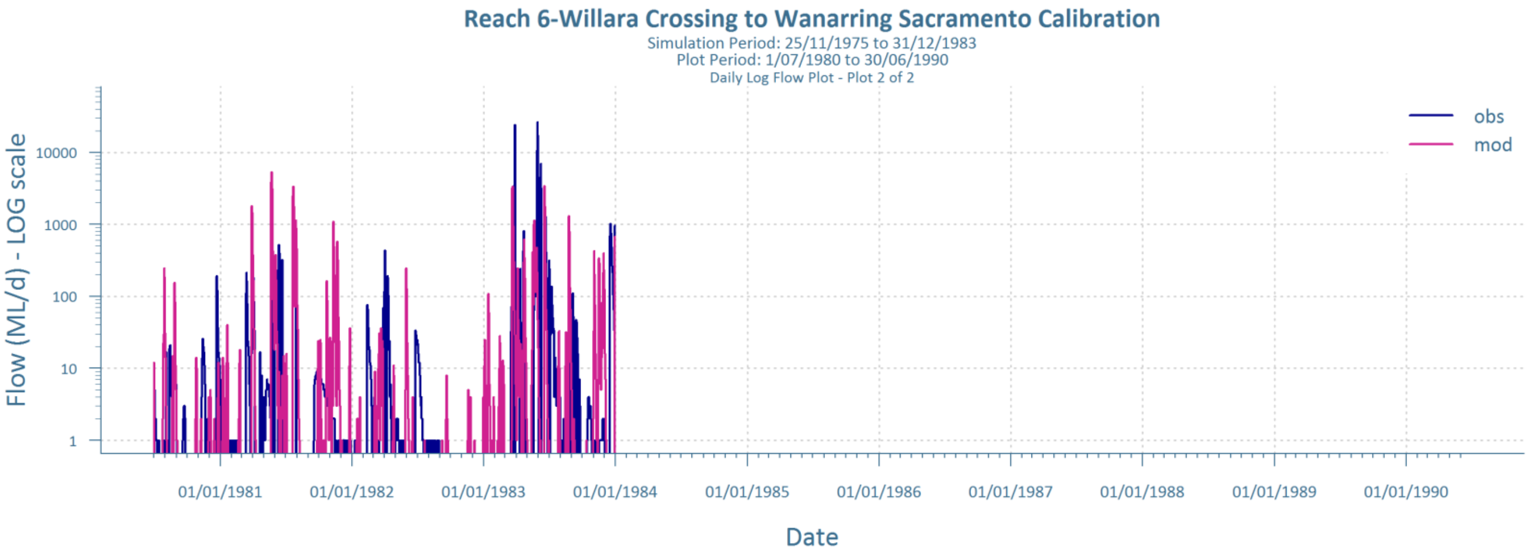
01/01/1999
01/01/2000
Date


Reach 5-Caiwarro to Willara Crossing Sacramento Calibration
Simulation Period: 25/11/1975 to 30/06/2011
Plot Period: 1/07/2000 to 30/06/2010
Daily Log Flow Plot - Plot 4 of 5
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
mod
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
01/01/2006
01/01/2007
01/01/2008
01/01/2009
01/01/2010
Date

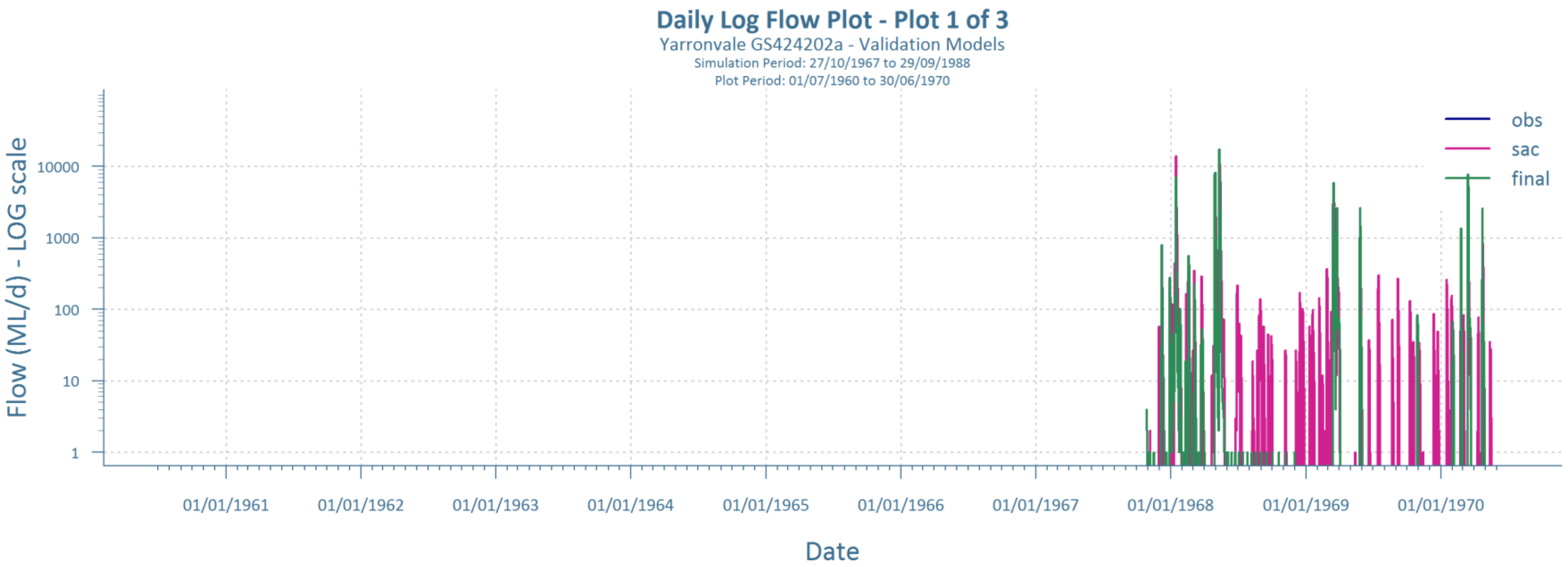

Reach 5-Caiwarro to Willara Crossing Sacramento Calibration
Simulation Period: 25/11/1975 to 30/06/2011
Plot Period: 1/07/2010 to 30/06/2020
Daily Log Flow Plot - Plot 5 of 5
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
mod
01/01/2011
01/01/2012
01/01/2013
01/01/2014
01/01/2015
01/01/2016
01/01/2017
01/01/2018
01/01/2019
01/01/2020
Date

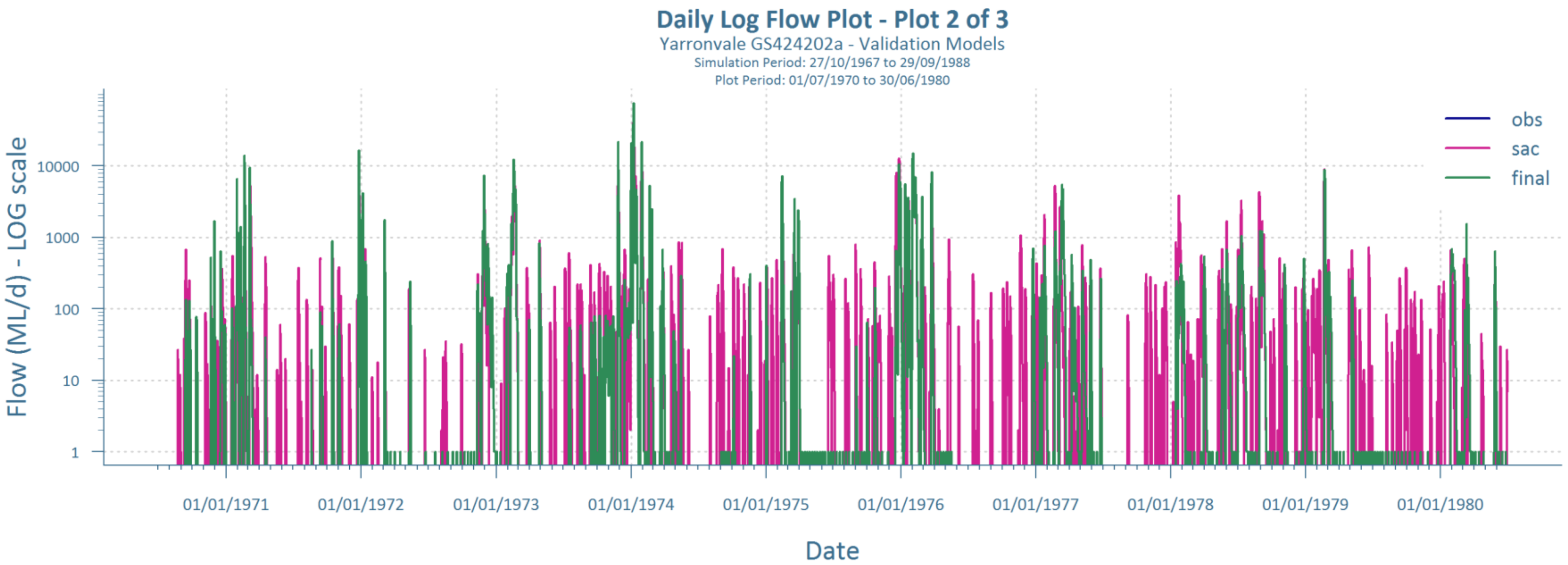
Appendix C4 – Reach 6 Recorded and Sacramento Daily Flows

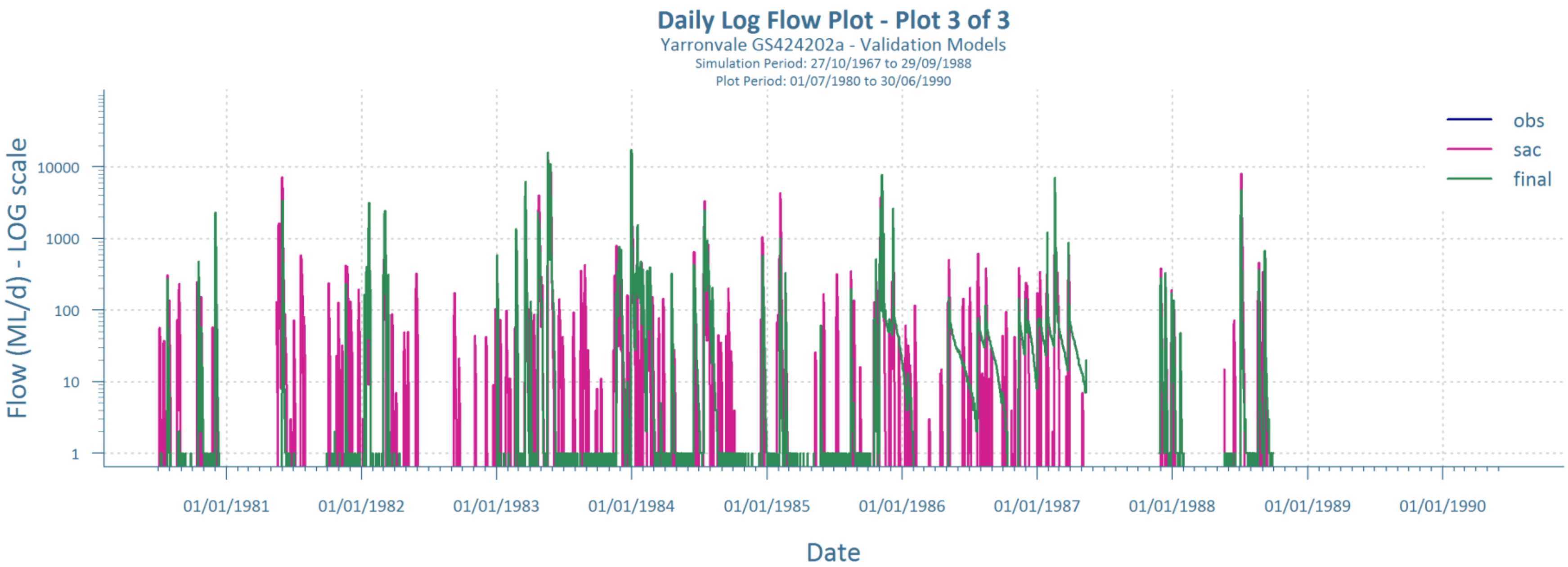




Appendix D – Validation Model Daily Flows


Daily Log Flow Plot - Plot 1 of 3
Yarronvale GS424202a - Validation Models
Simulation Period: 27/10/1967 to 29/09/1988
Plot Period: 01/07/1960 to 30/06/1970
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/1961
01/01/1962
01/01/1963
01/01/1964
01/01/1965
01/01/1966
01/01/1967
01/01/1968
01/01/1969
01/01/1970
Date
obs
sac
final


Daily Log Flow Plot - Plot 2 of 3
Yarronvale GS424202a - Validation Models
Simulation Period: 27/10/1967 to 29/09/1988
Plot Period: 01/07/1970 to 30/06/1980
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/1971
01/01/1972
01/01/1973
01/01/1974
01/01/1975
01/01/1976
01/01/1977
01/01/1978
01/01/1979
01/01/1980
Date
obs
sac
final


Daily Log Flow Plot - Plot 3 of 3
Yarronvale GS424202a - Validation Models
Simulation Period: 27/10/1967 to 29/09/1988
Plot Period: 01/07/1980 to 30/06/1990
Flow (ML/d) - LOG scale
10000
1000
100
10
1
obs
sac
final
01/01/1981
01/01/1982
01/01/1983
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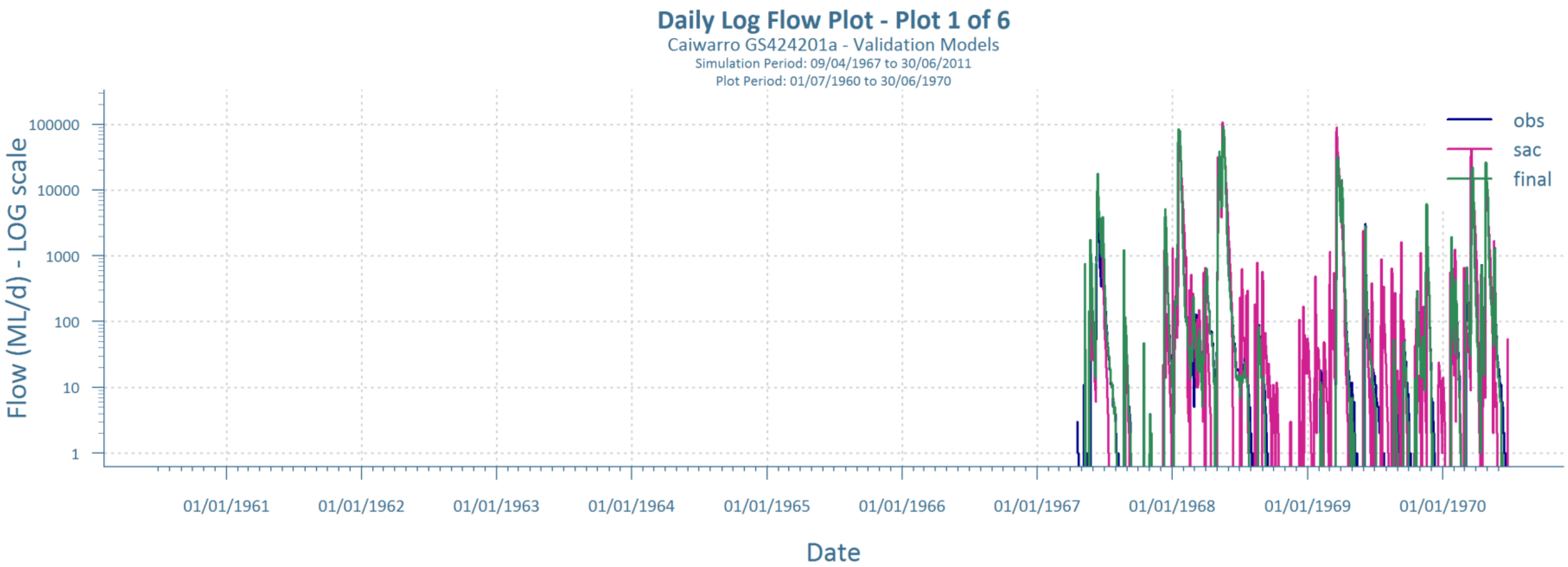
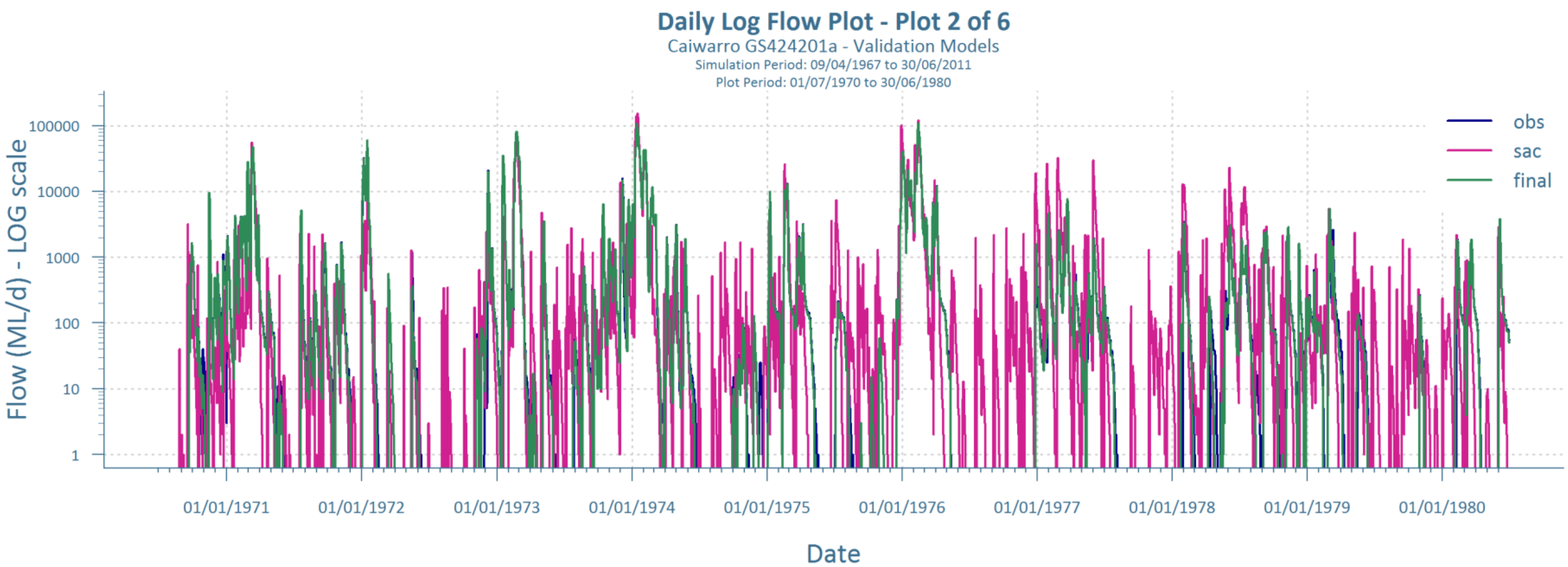
01/01/1985
01/01/1986
01/01/1987
01/01/1988
01/01/1989
01/01/1990
Date


Daily Log Flow Plot - Plot 1 of 6
Caiwarro GS424201a - Validation Models
Simulation Period: 09/04/1967 to 30/06/2011
Plot Period: 01/07/1960 to 30/06/1970
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/1961
01/01/1962
01/01/1963
01/01/1964
01/01/1965
01/01/1966
01/01/1967
01/01/1968
01/01/1969
01/01/1970
Date
obs
sac
final


Daily Log Flow Plot - Plot 2 of 6
Caiwarro GS424201a - Validation Models
Simulation Period: 09/04/1967 to 30/06/2011
Plot Period: 01/07/1970 to 30/06/1980
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
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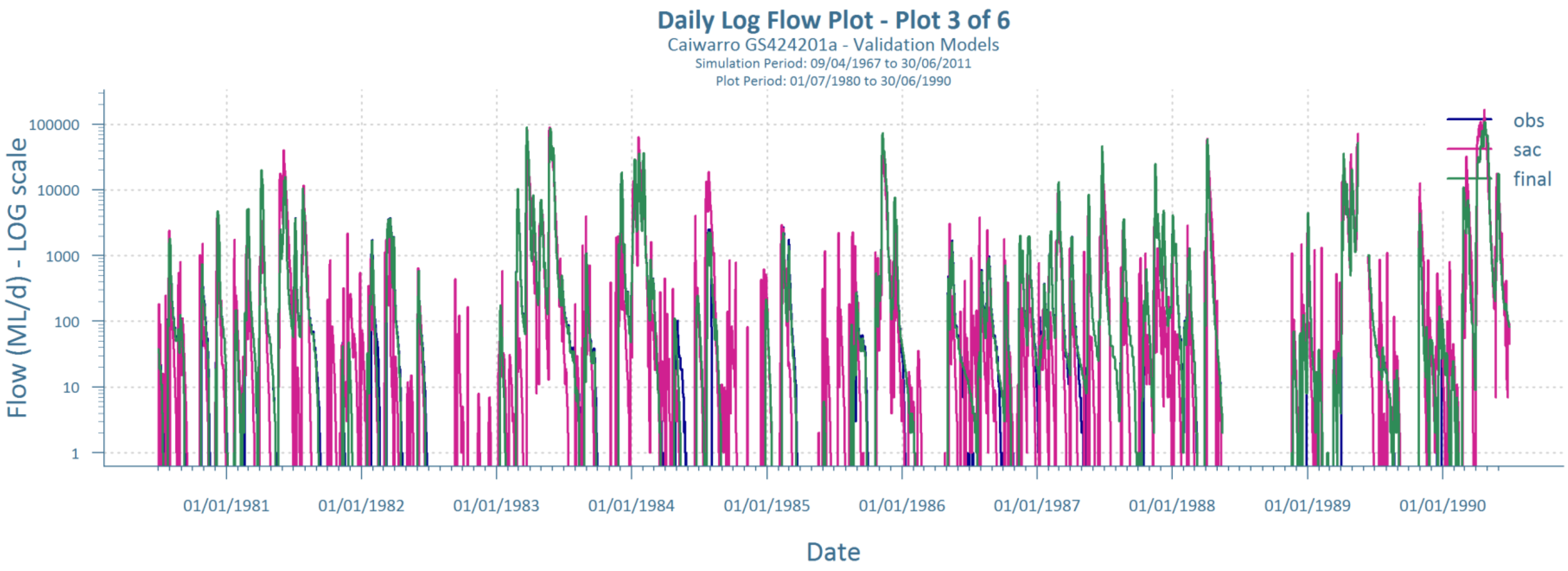
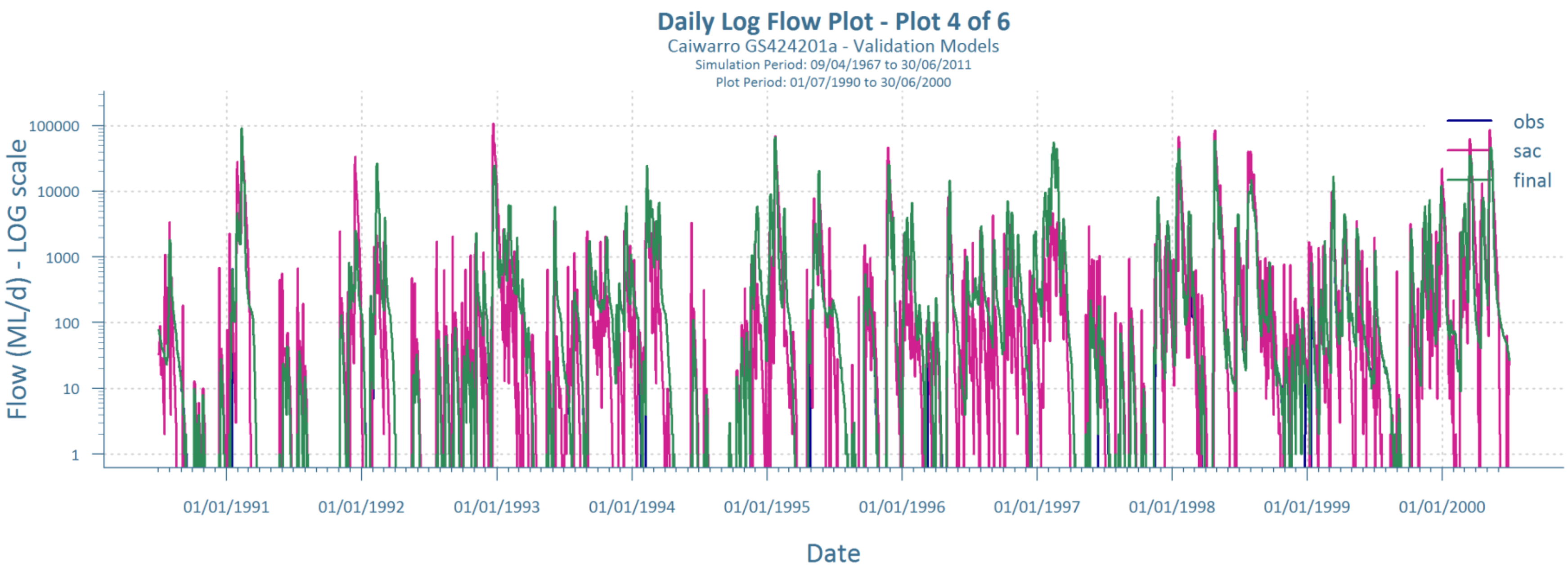
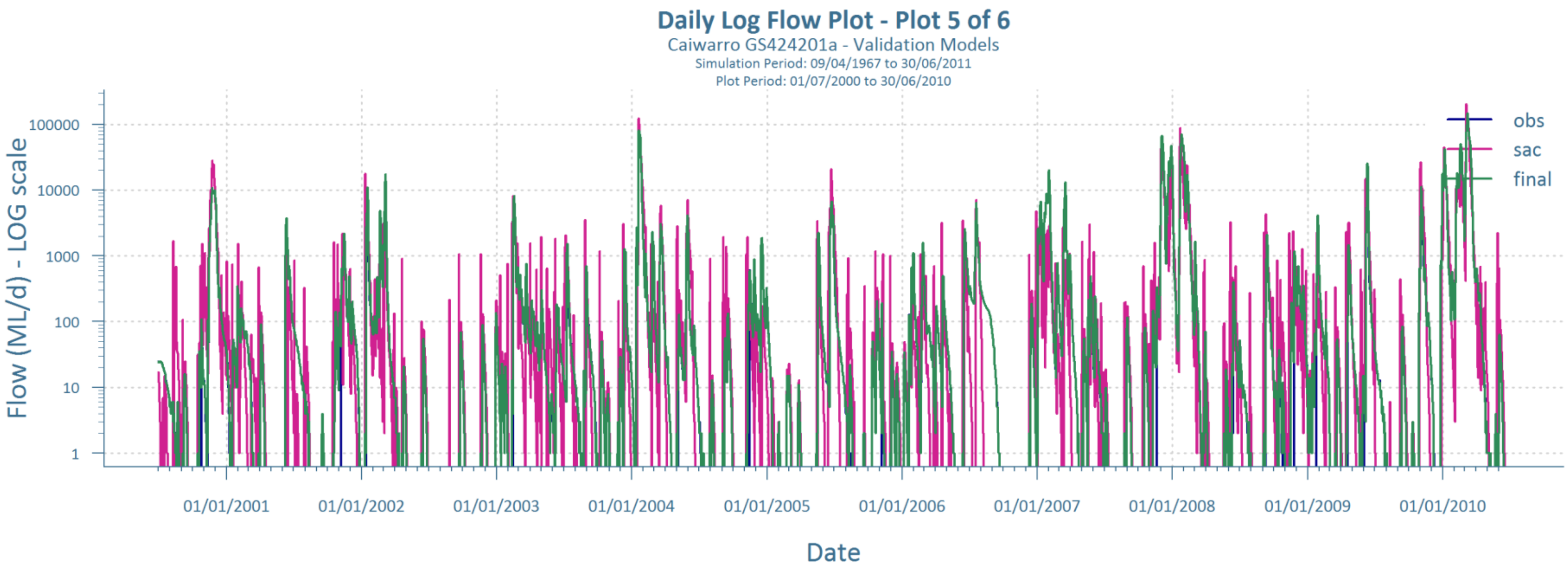
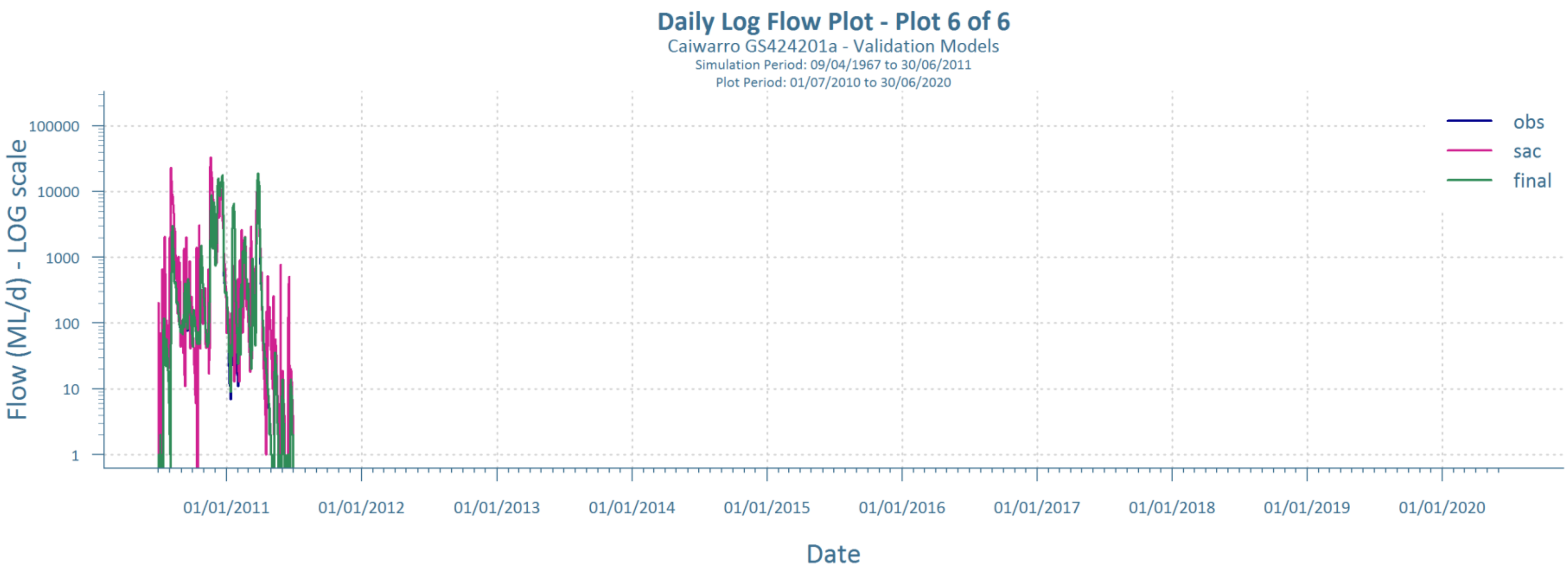
01/01/1971
01/01/1972
01/01/1973
01/01/1974
01/01/1975
01/01/1976
01/01/1977
01/01/1978
01/01/1979
01/01/1980
Date
obs
sac
final


Daily Log Flow Plot - Plot 3 of 6
Caiwarro GS424201a - Validation Models
Simulation Period: 09/04/1967 to 30/06/2011
Plot Period: 01/07/1980 to 30/06/1990
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/1981
01/01/1982
01/01/1983
01/01/1984
01/01/1985
01/01/1986
01/01/1987
01/01/1988
01/01/1989
01/01/1990
Date
obs
sac
final


Daily Log Flow Plot - Plot 4 of 6
Caiwarro GS424201a - Validation Models
Simulation Period: 09/04/1967 to 30/06/2011
Plot Period: 01/07/1990 to 30/06/2000
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/1991
01/01/1992
01/01/1993
01/01/1994
01/01/1995
01/01/1996
01/01/1997
01/01/1998
01/01/1999
01/01/2000
Date
obs
sac
final


Daily Log Flow Plot - Plot 5 of 6
Caiwarro GS424201a - Validation Models
Simulation Period: 09/04/1967 to 30/06/2011
Plot Period: 01/07/2000 to 30/06/2010
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
01/01/2006
01/01/2007
01/01/2008
01/01/2009
01/01/2010
Date
obs
sac
final


Daily Log Flow Plot - Plot 6 of 6
Caiwarro GS424201a - Validation Models
Simulation Period: 09/04/1967 to 30/06/2011
Plot Period: 01/07/2010 to 30/06/2020
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/2011
01/01/2012
01/01/2013
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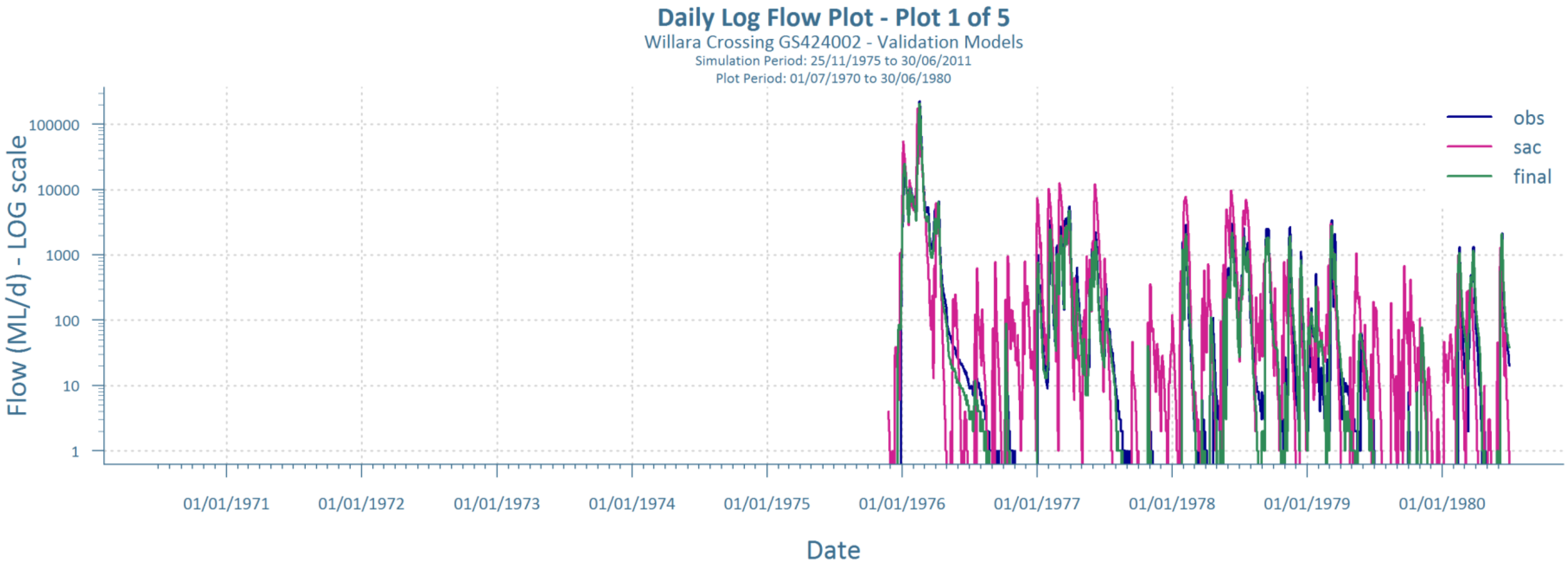
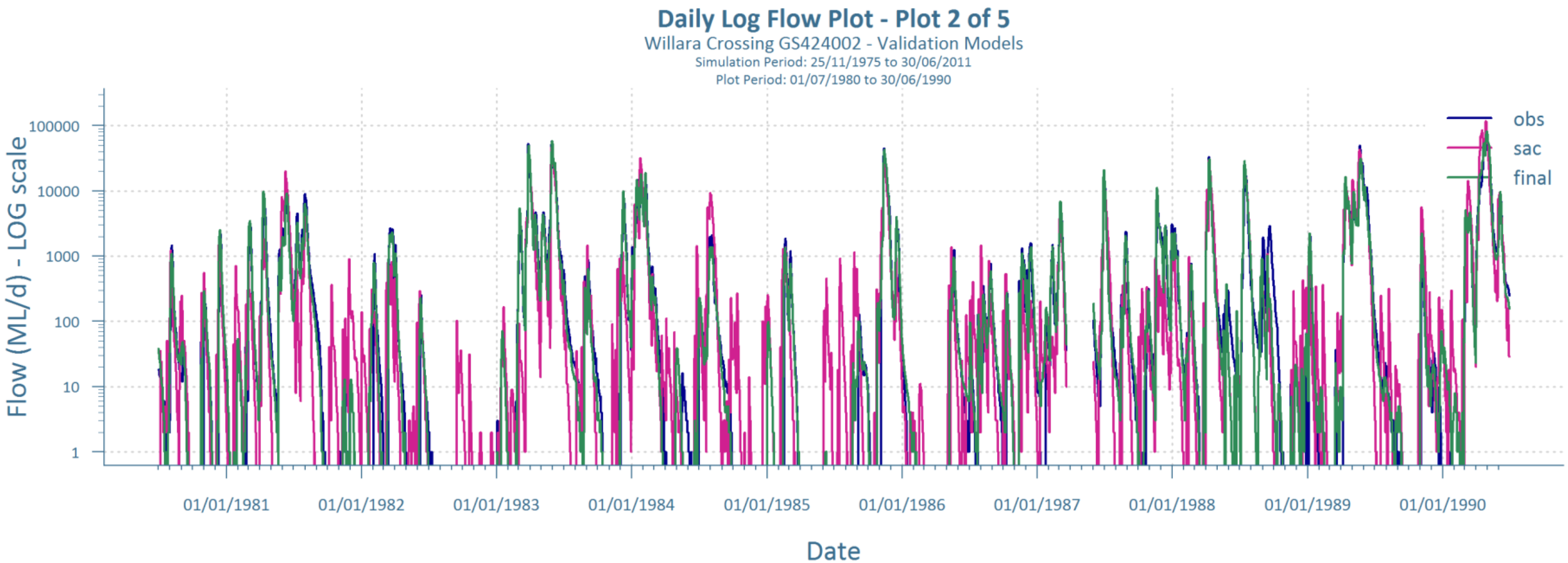
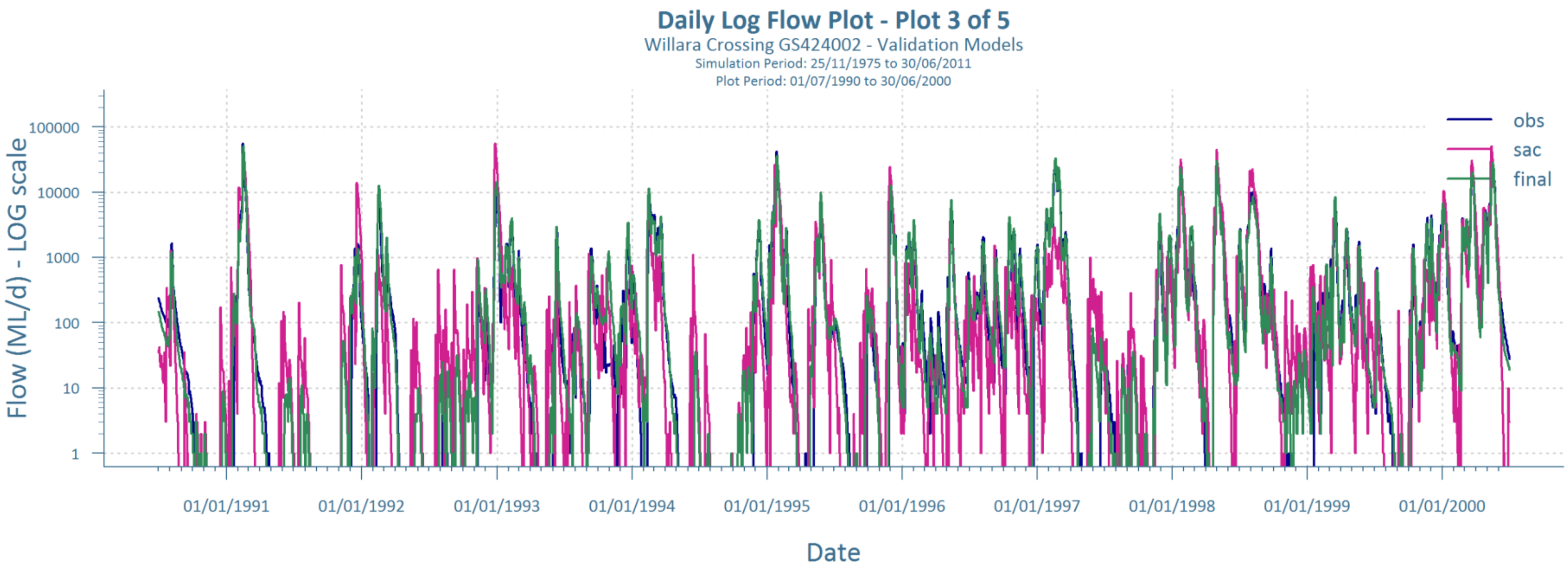
01/01/2016
01/01/2017
01/01/2018
01/01/2019
01/01/2020
Date
obs
sac
final

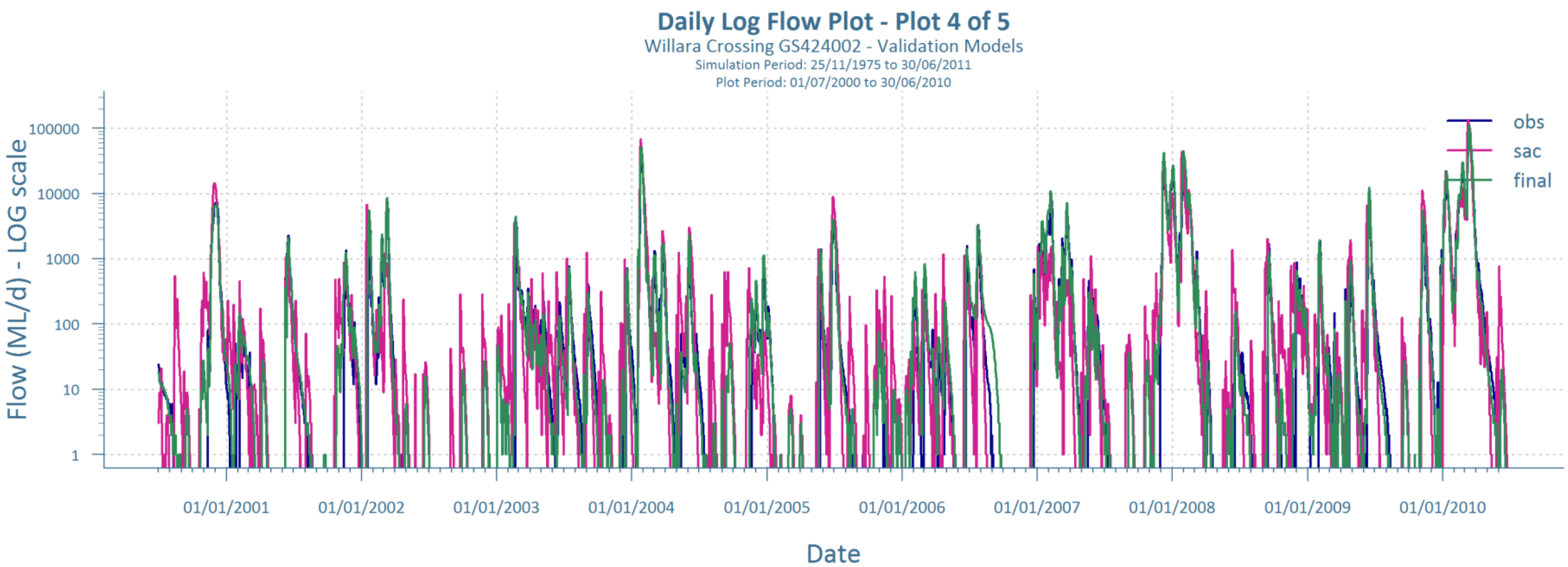


Daily Log Flow Plot - Plot 1 of 5
Willara Crossing GS424002 - Validation Models
Simulation Period: 25/11/1975 to 30/06/2011
Plot Period: 01/07/1970 to 30/06/1980
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/1971
01/01/1972
01/01/1973
01/01/1974
01/01/1975
01/01/1976
01/01/1977
01/01/1978
01/01/1979
01/01/1980
Date
obs
sac
final



Daily Log Flow Plot - Plot 2 of 5
Willara Crossing GS424002 - Validation Models
Simulation Period: 25/11/1975 to 30/06/2011
Plot Period: 01/07/1980 to 30/06/1990
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/1981
01/01/1982
01/01/1983
01/01/1984
01/01/1985
01/01/1986
01/01/1987
01/01/1988
01/01/1989
01/01/1990
Date
obs
sac
final


Daily Log Flow Plot - Plot 3 of 5
Willara Crossing GS424002 - Validation Models
Simulation Period: 25/11/1975 to 30/06/2011
Plot Period: 01/07/1990 to 30/06/2000
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/1991
01/01/1992
01/01/1993
01/01/1994
01/01/1995
01/01/1996
01/01/1997
01/01/1998
01/01/1999
01/01/2000
Date
obs
sac
final


Daily Log Flow Plot - Plot 4 of 5
Willara Crossing GS424002 - Validation Models
Simulation Period: 25/11/1975 to 30/06/2011
Plot Period: 01/07/2000 to 30/06/2010
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/2001
01/01/2002
01/01/2003
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01/01/2006
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01/01/2008
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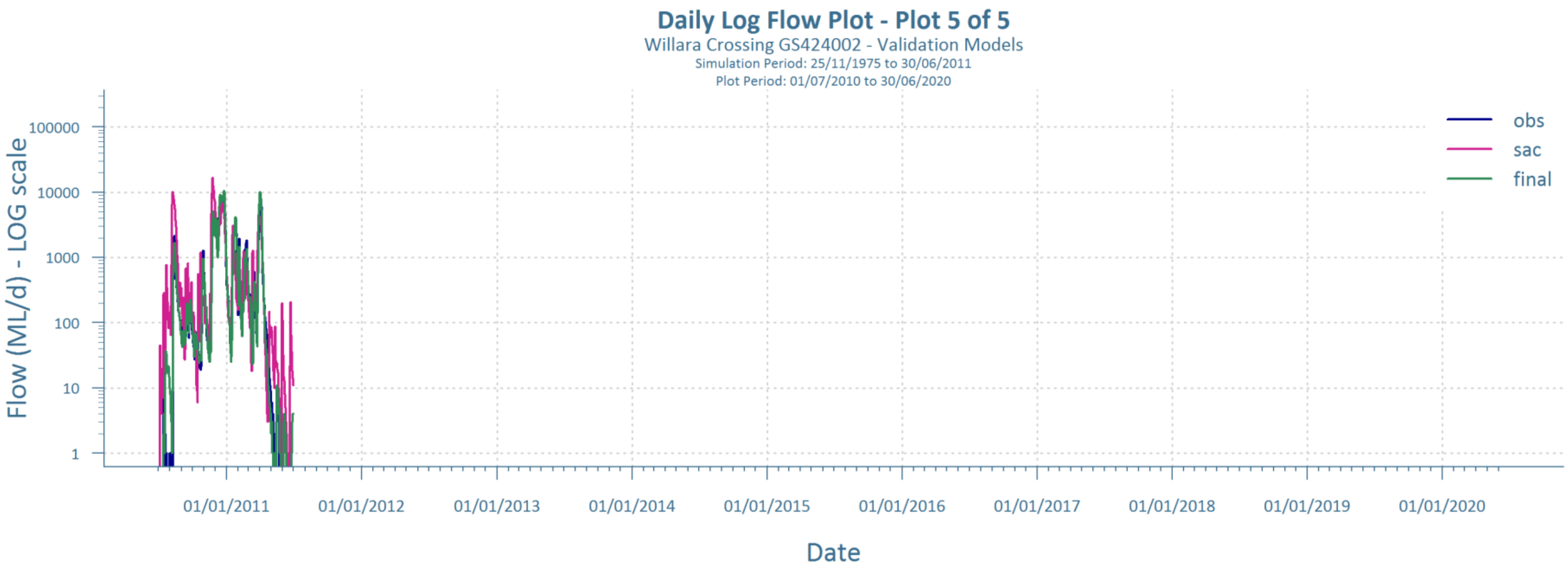
Daily Log Flow Plot - Plot 5 of 5
Willara Crossing GS424002 - Validation Models
Simulation Period: 25/11/1975 to 30/06/2011
Plot Period: 01/07/2010 to 30/06/2020
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/2011
01/01/2012
01/01/2013
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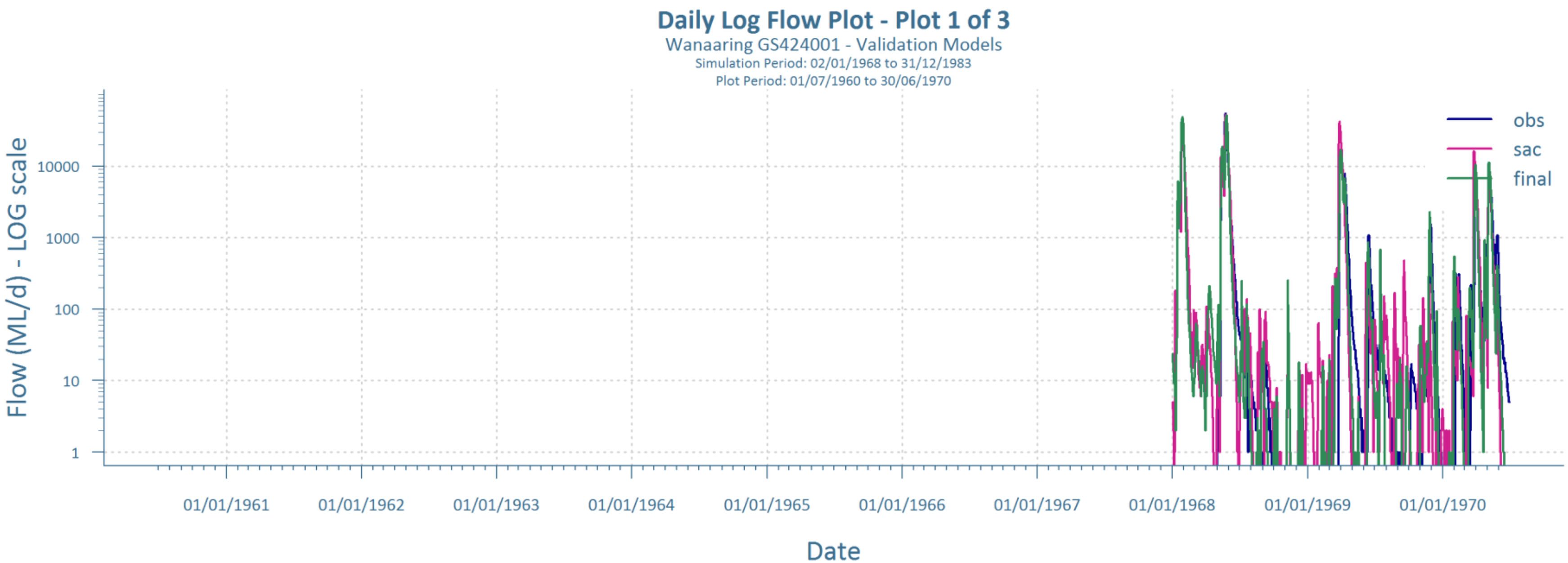
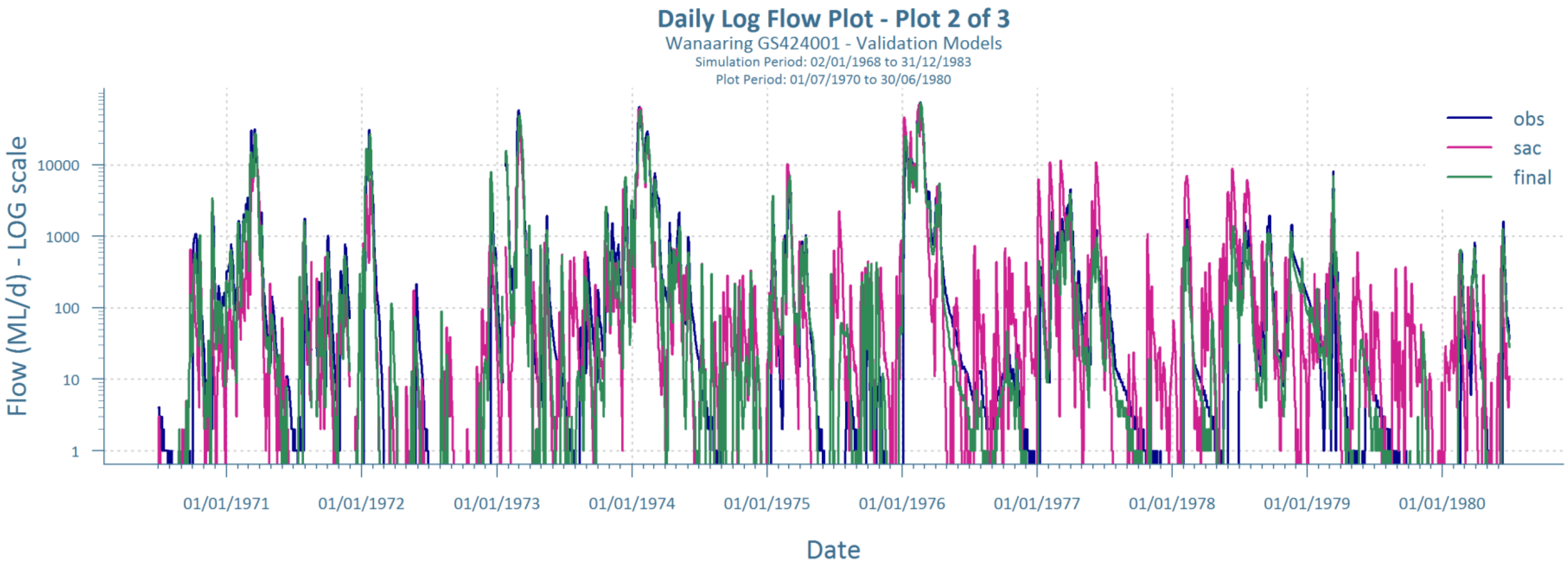
01/01/2017
01/01/2018
01/01/2019
01/01/2020
Date
obs
sac
final


Daily Log Flow Plot - Plot 1 of 3
Wanaaring GS424001 - Validation Models
Simulation Period: 02/01/1968 to 31/12/1983
Plot Period: 01/07/1960 to 30/06/1970
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/1961
01/01/1962
01/01/1963
01/01/1964
01/01/1965
01/01/1966
01/01/1967
01/01/1968
01/01/1969
01/01/1970
Date
obs
sac
final


Daily Log Flow Plot - Plot 2 of 3
Wanaaring GS424001 - Validation Models
Simulation Period: 02/01/1968 to 31/12/1983
Plot Period: 01/07/1970 to 30/06/1980
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/1971
01/01/1972
01/01/1973
01/01/1974
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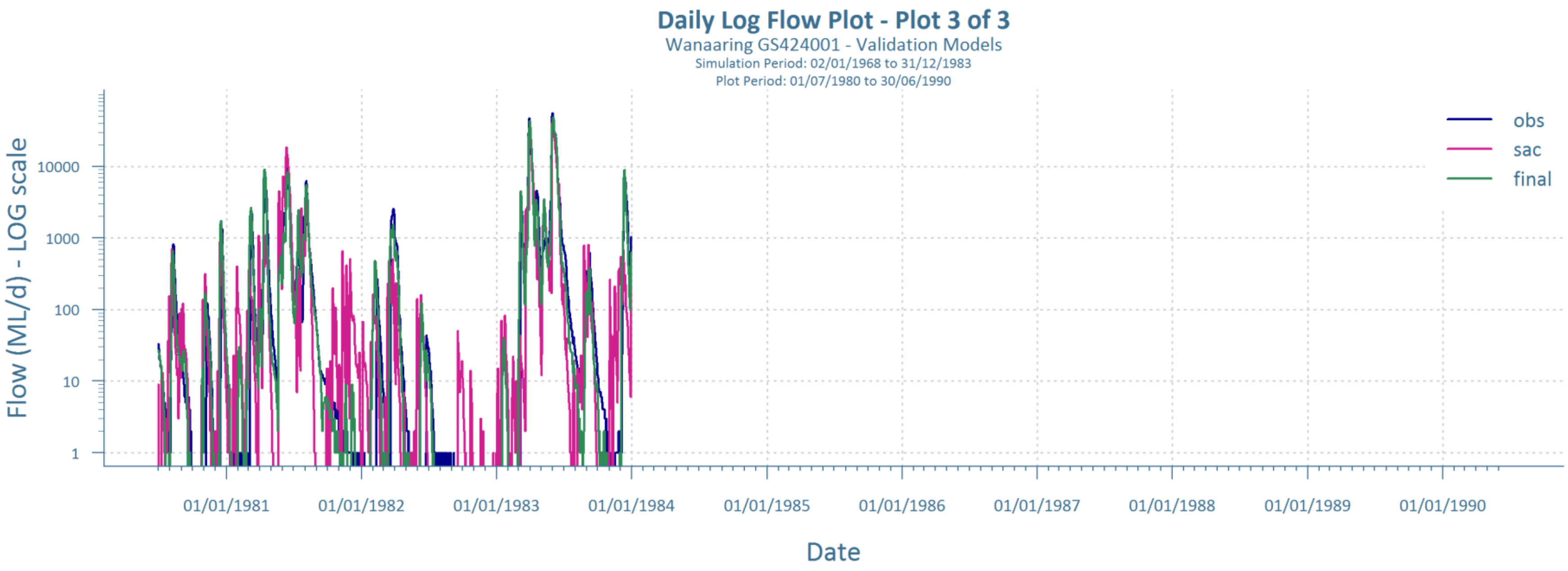
01/01/1976
01/01/1977
01/01/1978
01/01/1979
01/01/1980
Date
obs
sac
final


Daily Log Flow Plot - Plot 3 of 3
Wanaaring GS424001 - Validation Models
Simulation Period: 02/01/1968 to 31/12/1983
Plot Period: 01/07/1980 to 30/06/1990
Flow (ML/d) - LOG scale
10000
1000
100
10
1
obs
sac
final
01/01/1981
01/01/1982
01/01/1983
01/01/1984
01/01/1985
01/01/1986
01/01/1987
01/01/1988
01/01/1989
01/01/1990
Date

Abbreviations

AHD	Australian Height Datum
AMTD	Adopted Middle Thread Distance
APFD	Annual Proportional Flow Deviation
BoM	Bureau of Meteorology
CA	catchment area
CINRS	Climate Impacts and Natural Resource Systems (a group within DERM)
Ck	Creek
cumecs	cubic metres per second
DERM	Department of Environment and Resource Management (Qld)
DLWC	Department of Land and Water Conservation (NSW)
DMM	Data Modification Module
DPI	Department of Primary Industries
D/S	downstream
DS	dead storage
DVWSS	Dawson Valley Water Supply Scheme
EFO	Environmental Flow Objective
FBWSS	Fitzroy Barrage Water Supply Scheme
FSA	full supply area
FSL	full supply level
FSV	full supply volume
GL	gigalitres
GS	Gauging Station
ha	hectare
HNFY	historical no-failure yield
HW	headwater
IQQM	Integrated Quantity-Quality Model
IROL	Interim Resource Operations Licence
IRM	Integrated Resource Management

IWA	Interim Water Allocation
km	kilometres
km^2	square kilometres
Lat	latitude
LFWSS	Lower Fitzroy Water Supply Scheme
Long	longitude
m	metres
MAD	Mean Annual Diversion
MAF	Mean Annual Flow
MAR	Mean Annual Rainfall
MARO	Mean Annual Runoff
Max	maximum
Min	minimum
ML	megalitres
mm	millimetres
mth	month
m^3/s	cubic metres per second
n/a	not applicable
NMWSS	Nogoa Mackenzie Water Supply Scheme
PET	potential evapotranspiration
ROL	Resource Operations Licence
ROP	Resource Operations Plan
Qld	Queensland
SID	Storage Inflow Derivation
SILO	DSITI's Internet website that provides meteorological and agricultural data
TWS	town water supply
U/S	upstream
WASO	Water Allocation Security Objectives
WERD	Water Entitlements Registration Database
WRP	Water Resource Plan
WSI	Water Sharing Index

WSS	Water Supply Scheme

Glossary

Alluvial: Alluvial refers to deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.

Adopted Middle Thread Distance (AMTD): AMTD is the distance in kilometres, measured along the middle of a watercourse, from the mouth or junction.

Allocation: A water allocation is an authority granted under Section 121 or 122 of the *Water Act 2000* to take water.

Announced allocation: Announced allocation is a ratio (expressed as a percentage), which is announced from time to time by the Resource Operation Licence holder which sets a limit to the amount of supplemented water which a water allocation holder can divert during the water year as a proportion of the water allocation holder's nominal volume. The announced allocation may increase but cannot decrease during a water year.

Aquifer: An aquifer is a body of permeable material or rock, capable of transmitting significant amounts of water underlain by impermeable material and through which underground water flows.

Artesian (water): Artesian water is water that occurs naturally in, or is introduced artificially into, an aquifer, which if tapped by a bore, would flow naturally to the surface.

A-depletion: A-depletion is the depletion (expressed in millimetres) in soil moisture from the maximum soil moisture capacity that a crop can withstand before it requires watering to sustain it. Once the A-depletion value falls below the nominated value, the allocation holder starts placing irrigation water orders to restore the soil moisture capacity to the nominated A-depletion value.

Authorisation: An authorisation refers to a licence, permit, interim water allocation or other authority to take water given under the *Water Act* or the repealed *Water Act*, other than a permit for stock or domestic purposes.

Annual Proportional Flow Deviation (APFD): APFD refers to the statistical measure of changes to flow seasonality and volume in the simulation period.

Baseflow: Baseflow is the natural stream flow derived from underground water seepage from aquifers and/or through the lateral movement of water through soils and into the stream. At times of peak flow, baseflow represents only a small proportion of total flow, whereas in periods of drought, it may represent all of the flow.

Basin: A basin is the total area from which water drains to a river system, or a grouping of adjacent river systems. In geological terms, a basin is defined as either a broad tract of land in which the rock strata are tilted toward a common centre, or a large, bowl-shaped depression in the surface of the land or ocean floor.

Benefited/Supplemented groundwater area: A benefited/supplemented groundwater area contains aquifers that are recharged from augmented surface water supplies from water storage structures.

Bore: A bore is a hole drilled to extract, recharge or investigate groundwater resources. In the *Water Act*, it means a shaft, well, gallery, spear or excavation and any works constructed in connection with the shaft, well, gallery, spear or excavation, which taps the aquifer.

Calibration model: A calibration model involves the modelling of flows, extractions, operational rules and infrastructure that occurred historically.

Catchment: A catchment is an area, bounded by natural topographic features such as hills or mountains, from which a drainage system derives its water.

Confluence node: A confluence node is defined as a node representing the confluence of two watercourses. These watercourses may be supplemented or unsupplemented streams.

Current development: The current development case is modelling the existing entitlements within the system, to the degree to which they are presently operating. Authorisations are set to take only the water they are currently accessing, as indicated by data investigation reports and knowledge of the system operation.

Dam: A dam is works that include a barrier, whether permanent or temporary, that does, or could, or would, impound, divert or control water; and the storage area created by the works.

Discharge (water): Discharge is the rate at which a volume of water passes through a cross-section per unit of time; measured in cubic metres per second (m^3/s) or in megalitres per day (ML/d).

Distribution efficiency: Distribution efficiency is the efficiency of the system in delivering water from the dams to the users. This is determined by dividing deliveries by releases. (Note: this often excludes hydropower releases and deliveries).

Data Modification Module (DMM): DMM is a program used to adjust inflows using recorded flows downstream.

Drawdown: Drawdown is the lowering of the water table resulting from the extraction of water.

Entitlement: A water entitlement is a water allocation, interim water allocation or water licence.

Environmental flow: Environmental flow is the flow required to sustain a healthy environment. The release of water from a storage to a stream to maintain the healthy state of the stream.

Environmental Flow Objective (EFO): An EFO is a flow objective associated with a water resource plan (WRP), for the protection of the health of natural ecosystems for the achievement of ecological outcomes.

Event duration: The event duration for a flow at a point in a watercourse, means the period of time when the discharge is greater than or less than the level necessary for a particular riverine process to happen.

Full development case: The full development case is modelling the full use of existing entitlements within the system. Authorisations are set to take all the water they are allowed to, regardless of climate or other factors not specifically mentioned in the licence. Generally, the full development case represents a higher level of use than the current development case, as it can include underutilised licences and sleepers.

Headwater: A headwater reach is the source and upper reaches of a stream.

Hydrograph: A hydrograph is a graph showing the change in stream flow discharge at some location over time.

Hydrologic model: A hydrologic model is a computer program that simulates stream flows, water losses, storages, releases, in-stream infrastructure, water diversion and water management rules within a river system.

Infiltration: Infiltration is the downward entry of water into soil through the soil surface.

Interim Resource Operations Licence (IROL): An IROL is a licence granted under Section 175 of the *Water Act 2000*. An IROL authorises the holder to interfere with the flow of water to the extent necessary to operate water infrastructure to which the licence applies. IROLs may be granted in relation to existing infrastructure in an area where a resource operations plan (ROP) has not been approved or proposed infrastructure.

Interim Water Allocation: An interim water allocation is an authority under the *Water Act 2000* to take water managed under an IROL or ROL that represents a volumetric share of water and any conditions attaching to the authority.

Integrated Quantity-Quality Model (IQQM): IQQM is a computer program, with associated statistical analysis and reporting programs, which simulates daily stream flows, flow management, storages, releases, in stream infrastructure, water diversions, water demands and other hydrologic events within a modelled area.

Licence: A water licence is licence granted under chapter 2, part 6, division 2 of the *Water Act 2000* for the taking and using of water or for interfering with the flow of water. A water licence does not have a specified performance.

Licence volume: Licence volume is the nominal volume of water that may be taken under a water licence in one water year. The amount drawn may be subject to other licence conditions or allocation rules.

Link: A link in an IQQM model is a reach of river between two nodes.

Low flow regime: The low flow regime for a watercourse refers to magnitude, frequency, duration, timing and rate of change of low flow through the watercourse.

Mean Annual Diversion (MAD): The mean annual diversion is the average volume of water taken by an allocation or group of allocations in a year. It is calculated by adding the total volume of water taken over a period of years and dividing by the number of years in that period. The calculation is performed on a water year basis.

Mean Annual Flow (MAF): The mean annual flow is the average volume of water in a year that would flow past a point and is calculated by adding the total volume of flow over a period of years and dividing by the number of years in that period. The calculation is performed on a water year basis.

Node: A node in an IQQM model is used to represent a point on a river system where certain processes occur. The node type identifies the rules and parameters that are used by the model to simulate the relevant processes at a given location.

Nominal operating volume: A nominal operating volume of a storage is the level that is to be maintained during the specified period by releasing extra water (if available) from the upstream storage.

Nominal volume: A nominal volume is the volume of water, in megalitres, that represents the proportional annual volumetric share of water available to be taken by holders of water allocations in a priority group or a water allocation group.

On-Farm storage: An on-farm storage is a private storage constructed on a property to store water.

Order time: Order time is the number of days in advance that an order has to be made to ensure that the ordered water arrives on time.

Over order factor: An over order factor in an IQQM model is the factor by which water orders need to be increased to account for operational inefficiencies in a water supply scheme. This factor is additional to transmission losses in the model.

Overland flow water: Overland flow water is water, including floodwater, flowing over land, other than in a watercourse or lake after having fallen as rain, or after rising to the surface naturally from underground, or in any other way.

Pre-development case: The pre-development case is created by removing all infrastructure, diversions and operation rules from the full development case. No adjustment is made for the effect of land clearing, natural changes in river course, or climate change.

Performance indicators: Performance indicators are measures that are calculated and stated in the WRP with the purpose of assessing the effect of allocation and management decisions or proposals on water entitlements and natural ecosystems.

Plan Area: The Plan Area is the total area to be managed under the WRP.

Pseudo crop method: The pseudo crop method involves the arrangement of evaporation, crop factors and planted area in an IQQM model to ensure that the full amount of water allowed to be diverted each year is diverted if available.

Reach: A reach in an IQQM model is a series of nodes connected by links. A river reach refers to a defined stretch of river.

Recharge (of underground water/aquifer): The replenishment of underground water by the gradual downward movement of water from the soil to the water table, by actions such as rainfall, overland flow or infiltration from streams percolating through the unsaturated zone; the volume of water added to the amount of water stored in the aquifer over a particular period; by artificial means, such as direct injection.

Resource Operations Licence (ROL): A ROL is granted under Section 108 of the *Water Act 2000* and in accordance with a resource operations plan (ROP). It authorises the holder of the licence to interfere with the flow of water to the extent necessary to operate the water infrastructure to which the licence applies.

Resource Operations Plan (ROP): A ROP is used to implement a WRP in specified areas. It details the operating rules for water infrastructure and other management rules that will be applied in the day-to-day management of the flow of water in a reach or subcatchment. ROP specifies water access rules, environmental flow rules, trading rules, the conversion of licences to water allocations and monitoring requirements.

Return flow: Return flow is the water that flows out of the end of a channel system and back into a natural river system without being diverted by any user.

Riparian: Riparian refers to the area adjacent to a watercourse. Riparian access refers to an authority for an owner of land abutting a watercourse to take water for stock watering or domestic purposes.

River section: A river section in an IQQM model comprises a chain of links and nodes commencing with a headwater inflow node or a confluence node and finishing with a confluence or end-of system node.

Riverine: Riverine refers to rivers and their flood plains.

Routing: Routing occurs as water flows from one point to another in a system. Routing is the attenuation (flattening out) of the flow hydrograph as water moves down the system.

Scenario/Simulation model: A scenario/simulation model involves a fixed set of parameters for infrastructure, rules and licences. Scenario/simulation models are used to produce a representation of what may occur in the system, if the selected set of parameters were in place.

Simulation period: The simulation period is defined by the start and end dates of the model.

Sleepers: A sleeper is a licence which is current, but not in use.

Subartesian water: Subartesian water is water that occurs naturally in, or is introduced artificially into an aquifer, which, if tapped by a bore, would not flow naturally to the surface.

Subcatchment area (subarea): A subarea is a portion of a catchment within the Plan Area. A subarea may be physically defined or simply a result of breaking the catchment into smaller sections for the purposes of modelling.

Supplemented: Supplemented refers to a water supply where the natural flow is reduced or increased by a dam or some other water storage facility.

Surface water: Surface water is water that is on the earth’s surface, such as in a watercourse, spring, lake or reservoir.

Sustainable management: Sustainable management allows for the allocation and use of water for the physical, economic and social wellbeing of people within limits that can be sustained indefinitely while protecting the biological diversity and health of natural ecosystems.

Transmission losses: Transmission losses are losses from surface water (other than into defined groundwater systems) as it flows from one location in a system to another. This can include evaporation, seepage, uptake by plants and unauthorised usage.

Tributary: A tributary is a stream that joins another stream or body of water.

Tributary recession factor: The tributary recession factor in an IQQM model specifies the percentage of each tributary inflow which can be used by downstream water users as part of the supplemented water supply.

Underground water: Underground water or groundwater is water found in the cracks, voids or pore spaces or other spaces between particles of clay, silt, sand, gravel or rock within the saturated zone of a geologic formation. In the saturated zone, all cracks, voids or pore spaces are completely filled with water – not to be confused with soil water in the unsaturated zone where voids are filled with both air and water. The upper surface of the saturated zone is called the water table.

Underground water levels: The physical measurement of the distance from the natural surface or reference point to the water surface in a subartesian bore when it is in a fully recovered state. A negative value indicates that the water level is below the reference point. Underground water level measurements provide an estimate of the ‘depth to the water table’ — or upper surface to the saturated zone — where the reference point is the natural surface.

Unsupplemented: Refers to water in a watercourse that is not supplemented from storage or diversion facilities.

Water year: A water year is a continuous 12 month period starting from a specified month, used for the accounting of entitlements.

Water Allocation Security Objectives (WASO): WASOs are objectives that may be expressed as performance indicators and are stated in a WRP to ensure protection of a water entitlement to obtain water in accordance with a water allocation.

Water Supply Scheme (WSS): A WSS is a water infrastructure development designed and constructed for storage, supply and distribution of water from and to a watercourse.

Water harvesting: Water harvesting is an entitlement to take unsupplemented water from a watercourse during specified high flow events and generally involves diverting water into an on-farm storage for later use. Water harvesting is licensed.

Weir: A weir is a barrier constructed across a watercourse below the banks of the watercourse that hinders or obstructs the flow of water in the watercourse.