Department of Science, Information Technology and Innovation

Warrego River Catchment IQQM Calibration

Upstream of Augathella GS423204A to Fords Bridge GS423001&2 (NSW)

January 2016

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Prepared by

Queensland Hydrology
Science Delivery Division
Department of Science, Information Technology and Innovation
PO Box 5078
Brisbane QLD 4001

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Executive Summary

A daily flow model of the Warrego River catchment has been developed using Version 6.75.34 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 models were 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 Warrego River catchment. The catchment was divided into reaches, based on the location of major gauging stations. The reach numbers are not sequential as the availability of data resulted in the amalgamation or removal of reaches modelled previously. The reaches for this version of modelling are:

- Reach 1 – Upstream Of Augathella
- Reach 2 – Augathella to Charleville
- Reach 3 – Upstream of Ward River at Binnowee
- Reach 4 – Charleville to Wyandra
- Reach 5 – Wyandra to Wallen
- Reach 6 – Wallen to Cunnamulla
- Reach 9 – Cunnamulla to Barringun
- Reach 11 – Barringun to Fords Bridge (NSW)
- Reach 12 – Cuttaburra Channel to Turra (NSW).

This report contains the details for the whole of catchment model. 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 *Water Resource (Warrego, Paroo, Bulloo and Nebine Catchments) Plan 2003*.

Version 6.75.34 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 models. 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.

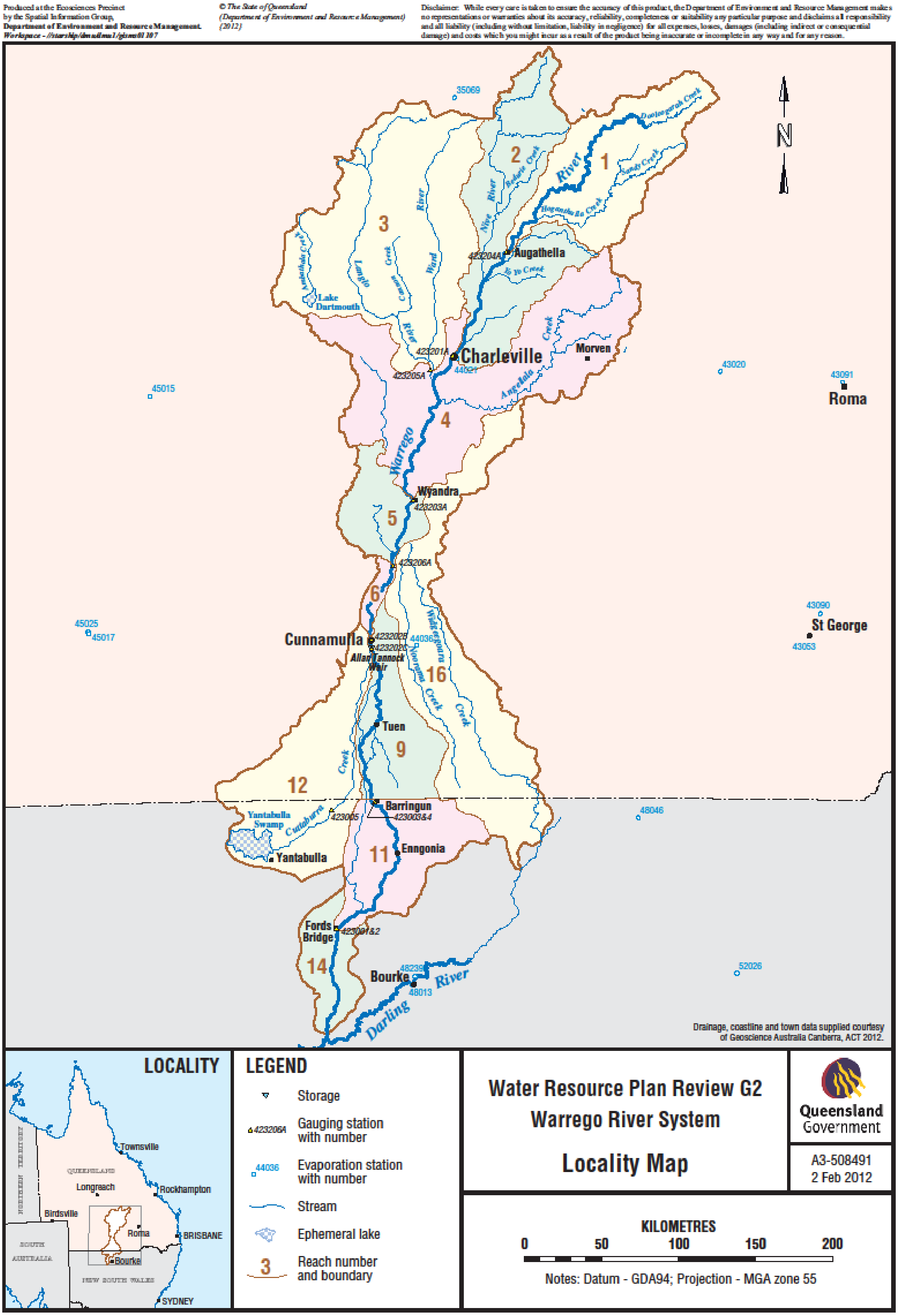


Figure 1.1: Warrego Catchment Map

2 Previous Hydrology

The Warrego 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, *Warrego River System Hydrology Volume 1-Calibration of Daily Flow Simulation Model from upstream of Augathella (QLD. AMTD 447.4 km) to Darling River (NSW AMTD 0.0 km)* (Qld DNRM, 2003). In this report the earlier study and the IQQM model developed in it will be referred to as the 2003 study or 2003 IQQM model.

3 Warrego Basin Description

3.1 Plan Area

The Warrego 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 whole Warrego River Basin to the Darling River (NSW). The plan and basin area is 78,830 square kilometres. The location is shown in Figure 1.1.

The IQQM model covers the contributing area which is 65,313 square kilometres. This includes the Cuttaburra catchment which provides water for irrigation. Cuttaburra Creek doesn't run to the Warrego but it does feed Yantabulla Swamp. It excludes the Widgeegoara and Noorama catchments (Reach 16 on Figure 1.1). That reach is represented as a diversion from the Warrego but does not feed the main river, does not pass water out of the local catchment, and is not irrigated from. Hence there is no need for a local inflow in the model. It also excludes the Fords Bridge to the Darling River Reach (Reach 14 on Figure 1.1).

3.2 Basin Description

The Warrego River headwaters are situated in Carnarvon Range, part of the Great Dividing Range in Queensland and flows into the Darling River, New South Wales, downstream of the town of Bourke. Flows in the basin are ephemeral, with long periods of no flow. Average annual rainfall varies from 316 mm/a below the Queensland–New South Wales border up to approximately 588 mm/a in the headwaters of the basin.

This report covers modelling of streamflow for the majority of the Warrego River system. Due to data restrictions, the final reach of the Warrego River from Fords Bridge to the confluence with Darling River was not modelled. Limitations also restricted the modelling of the Noorama and Widgeegoara Creeks to a breakout from the Warrego River, rather than a full scale reach model. A new gauge on Ward River at Binnowee, however, has facilitated modelling of the north-western headwaters of the Warrego catchment area. Cuttaburra Creek at Turra and Warrego River at Wallen are also new additions to this review. Major distributaries/tributaries of the Warrego River which contribute inflow include:

- Little Warrego River
- Curline Ck
- Tuen and Little Tuen Cks
- Irrara Ck
- Moon Ck
- Dooloogarah Ck
- Hoganthulla
- Gerah Crk
- Blackfellow's Ck
- Woggonorra Ck
- Gum Ck
- Thurulgoona Ck
- Eunama Watercourse
- Sandy Ck

- Yo Yo Ck
- Nive River
- Bedurie Ck
- Ward River
- Cannon Ck
- Angellala Ck
- Langlo River
- Cuttaburra Ck
- Widgeegoara Ck
- Noorama Crk
- Owen Gowen Ck
- Channin Ck.

These rivers and creeks comprise tributary inflow or loss nodes in the Warrego System River model.

4 Model Development Methodology

This section describes the development methodology for the Warrego 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.

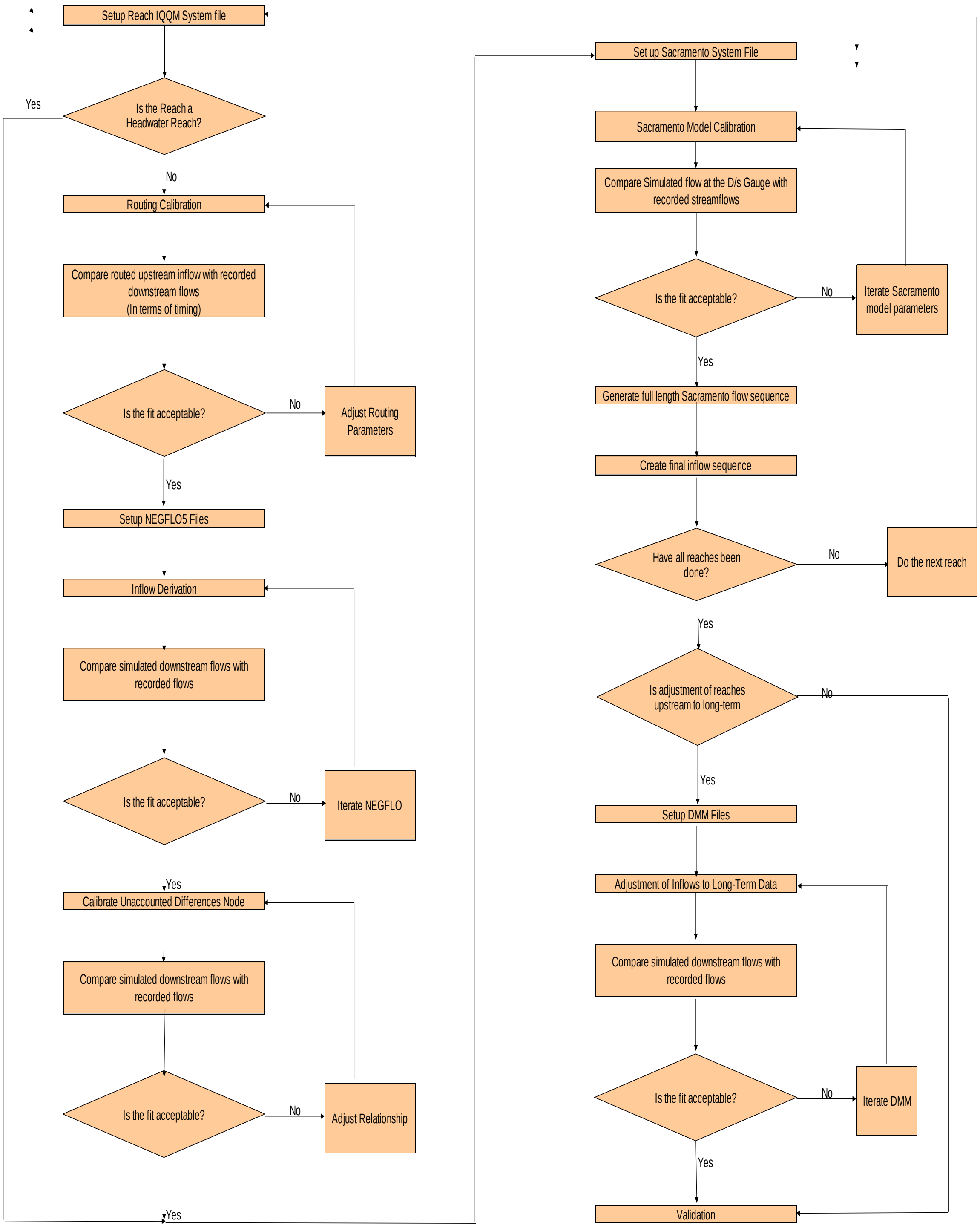


Figure 4.1: Model Development Flow Chart

4.1 Summary of the Model Calibration Process

The catchment model for the Warrego 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 included 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 a 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 iterations inflows give the best result.

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 Bulloo 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 Warrego Basin is 78,830 km^2 to the confluence with Darling River. For modelling purposes, the Warrego River system was split into reaches based on the location of major stream gauging sites. The locations and contributing catchment areas of the reaches are identified in Table 5.1 and illustrated on Figure 1.1. This report will use the name of the station only to refer to the gauge being discussed.

The IQQM model accounts for a contributing area of 65,313 square kilometres. This excludes local inflow contributions from the Widgeegoara and Noorama catchments (Reach 16 on Figure 1.1) and the Fords Bridge to the Darling River reach (Reach 14 on Figure 1.1).

Table 5.1: Warrego Basin Division

Reach	Upstream Gauge	Downstream Gauge	Catchment Area (km^2)
1		Augathella 423204a	8,070
2	Augathella 423204a	Charleville 423201a	8,229
3		Binnowee 423205a	14,671
4	Charleville 423201a	Wyandra 423203a	11,895
5	Wyandra 423203a	Wallen 423206a	4,022
6	Wallen 423206a	Cunnamulla 423202c	537
9	Cunnamulla 423202c	Barringun 423004	4,681
11	Barringun 423004	Fords Bridge 423001&2	5,123
12	Cunnamulla 423202c	Turra 423005	8,085
Total			65,313

5.2 Stream flow

Stream flow records from nine mainstream gauges along the Warrego River and one each on Ward River and Cuttaburra Creek were used. Six of the nine gauging sites are located in Queensland (Qld), with the remaining three sites being located in New South Wales (NSW).

There are three new gauging stations in this version of the model:

- Ward River at Binnowee
- Warrego River at Wallen
- Cuttaburra Creek at Turra.

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 the Qld gauges.

For Qld gauge sites, the data required for IQQM modelling 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.

The gauges used were chosen because of the reliability and quality of records. Other stream gauging stations in the area exist, but either the quality or duration of their records was considered to be inadequate for the purposes of modelling. Table 5.3 indicates the missing record periods for each gauge and

Table 5.4 shows the water balance prepared using the recorded stream flow data.

Table 5.2: Warrego River Queensland Stream Flow Gauges – Summary

Station		Period of Record		AMTD	C.A	Control	Highest Gauged Flow[1]			Highest Recorded Flow[2]		
Number	Name	Start	End	(km)	(km^2)		Date	Height (m)	Flow (m^3/s)	Date	Height (m)	Flow (m^3/s)
423001	Warrego River at Fords Bridge	03/01/1972	Current		57,228							
423002	Warrego River at Fords Bywash											
423003	Warrego River at Barringun	01/01/1967	31/12/1981		52,105							
423004	Warrego River at Barringun #2	31/05/1993	Current									
423005	Cuttaburra Creek at Turra	01/06/1993	Current		8,085							
423201A	Warrego River at Charleville	13/09/1926	31/01/1978	383	16,299	Sand	20/02/1973	5.5	494.694	03/04/1956	6.97	1,270.787

[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)

Station		Period of Record		AMTD	C.A	Control	Highest Gauged Flow[1]			Highest Recorded Flow[2]		
Number	Name	Start	End	(km)	(km^2)		Date	Height (m)	Flow (m^3/s)	Date	Height (m)	Flow (m^3/s)
423202B	Warrego River at Cunnamulla	02/01/1961	28/02/1977	131.2	47,424	N/A	25/04/1990	10.12	1125	01/01/1972	10.21	Missing 151
423202C	Warrego River at Cunnamulla Weir	16/01/1992	Current	124.5	47,424	Sheet Pylon Weir	06/02/1997	8.42	1,210.141	08/03/2010	8.729	1,591.342
423203A	Warrego River at Wyandra	27/02/1967	Current	238.2	42,865	Sand Bar	22/02/1973	8.79	2,393.931	23/04/1990	10.243	3,975.481
423204A	Warrego River at Augathella	01/10/1967	Current	447.4	8,070	Sand	12/04/1990	6.17	371.08	30/12/2010	6.463	753.714
423205A	Ward River at Binnowee	02/12/1999	Current	7.1	14,671	Gravel	20/01/2008	8.453	2,373.018	21/01/2008	8.484	2,387.362
423206A	Warrego River at Wallen	21/02/2006	Current	188.8	46,887	Sand and Gravel	04/12/2007	8.17	767.235	07/03/2010	10.283	2,936.847

Table 5.3: Warrego River Stream Flow Gauges – Missing Data Periods

Station Number	Name	Missing Period
423204A	Warrego River at Augathella	07/11/1988–26/10/1991
423205A	Ward River at Binnowee	No Missing Records
423203A	Warrego River at Wyandra	No Missing Records
423206A	Warrego River at Wallen	No Missing Records
423202C	Warrego River at Cunnamulla Weir	No Missing Records
423003	Warrego River at Barringun	No Missing Record
423004	Warrego River at Barringun #2	25/04/1997–27/04/1997
423005	Cuttaburra Creek at Turra	No Missing Records
423201A	Warrego River at Charleville	02/12/1972–31/01/1973 02/02/1973–15/02/1973 24/02/1973–01/05/1973 03/05/1973–27/11/1973 30/11/1973–04/01/1974 06/01/1974–09/01/1974 12/01/1974–14/01/1974 23/01/1974–29/01/1974 01/02/1974–19/11/1975 03/12/1975–04/12/1975 20/12/1975–15/04/1976 10/05/1976–25/05/1976 01/10/1976–01/01/1977 01/02/1977–01/01/1978 20/01/1978–31/01/1978
423001	Warrego River at Fords Bridge	17/08/1973–05/10/1973 03/02/1974–21/03/1974 09/07/1974–02/08/1974 09/02/1975–27/03/1975 18/02/1976–06/05/1976 17/03/1977–05/05/1977 26/03/1982–14/05/1982 18/03/1993–18/06/1993
423002	Warrego River at Fords Bywash	20/03/1973–17/05/1973 08/08/1975–30/10/1975 12/08/1983–03/11/1983 29/11/1983–11/12/1983 10/03/1988–14/04/1988

Table 5.4: Warrego River Recorded Data Water Balance

Station #	Station Name	Contributing Catchment Area (km2)	Period of Record	July to June			
				Mean Annual Flow (ML/a)	Mean Annual Flow (mm/a)	MARF (mm/a)	% RO Coef f
GS423204A	Warrego River at Augathella	8,070	03/10/1967 - 30/06/2011	42,330	5.25	592.51	0.01
GS423201A	Warrego River at Charleville	16,299	15/09/1926 - 31/01/1978	152,352	9.35	500.42	0.02
GS423205A	Ward River at Binnowee	14,671	11/01/2002 - 30/06/2011	451,981	30.81	557.00	0.06
GS423203A	Warrego River at Wyandra	42,865	01/03/1967 - 30/06/2011	631,059	14.72	467.55	0.03
GS423206A	Warrego River at Wallen	46,887	04/11/2005 - 30/06/2011	1,121,000	23.91	534.80	0.04
GS423202C	Warrego River at Cunnamulla	47,424	18/01/1992 - 30/06/2011	516,485	10.89	414.37	0.03
GS423004	Warrego River at Barringun	52,105	31/05/1993 - 21/11/2011	116,683	2.24	368.06	0.01
GS423001& 2	Warrego River at Fords Bridge	57,228	19/12/1972 - 30/06/2011	93,788	1.64	380.18	0.00
GS423005	Cuttaburra Creek at Turra	8,085	01/06/1993 - 21/11/2011	184,594	22.83	331.78	0.07

5.3 Rainfall

For modeling purposes, daily rainfall data for the period 01/01/1889–30/06/2011 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. The station locations can be seen on Figure 5.1. Table 5.5 shows the data for rainfall stations used in this study. These stations were tested to identify any trending and were found to have no significant trends.

Table 5.6 shows the model rainfall data used for the Sacramento models. For the Sacramento models, point data from multiple stations was used. 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. The weights are based on the catchment areas they were assumed to represent.

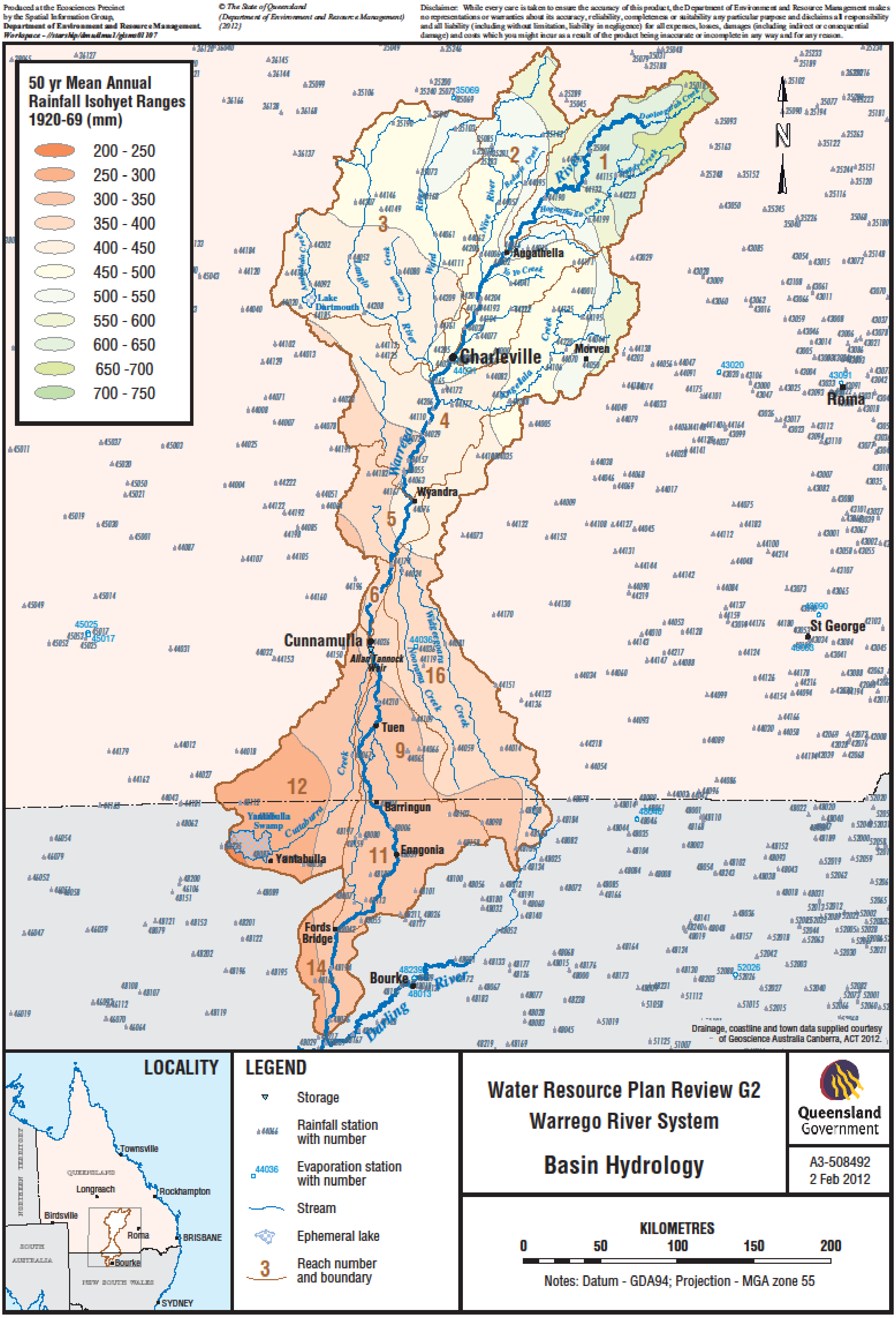


Figure 5.1: Warrego River System Basin Hydrology

Table 5.5: Warrego Rainfall Table

Station Number	Rainfall Station	Lat.	Long.	Period of Record	Mean SILO Rainfall July to June 1889-2011(mm/a)
35004	Babbiloora Station	-25.1933	147.1347	1923–current	589
35013	Bogantungan Post Office	-23.6481	147.29	1886–02/02/2004	695
35031	Glentana	-24.6017	147.5728	1911–current	610
35069	Tambo Post Office	-24.8819	146.2564	1877–current	535
35073	Toliness Station	-25.3167	146.0194	1913–current	517
35078	West Quarter	-25.2	146.3833	1912–31/12/1984	516
35190	Minnie Downs	-25.0311	145.8664	1888–current	511
44001	Angellala downs Homestead	-26.0178	147.03	1911–current	528
44002	Augathella Post Office	-25.7956	146.5858	1889–current	537
44021	Charleville Aero	-26.4139	146.2558	1942–current	494
44026	Cunnamulla Post Office	-28.0706	145.6808	1879–current	373
44050	Morven Post Office	-26.4156	147.1131	1886–current	544
44052	Mount Morris	-25.8128	145.5731	1886–current	471
44057	Nive Downs	-25.4992	146.5442	1882–current	523
44059	Noorama	-28.7008	146.2336	1883–01/02/2009	394
44062	Perola Park	-25.7067	146.3222	1916–current	515
44063	Quilberry Station	-27.0869	145.9214	1893–current	385
44064	Spring Creek	-27.2694	145.3803	1927–current	371
44065	Thurugoona	-28.7106	145.9233	1888–current	346
44067	Tinnenburra	-28.7306	145.5517	1907–current	328
44072	Werrina	-26.8842	145.8992	1908–current	416
44076	Wyandra Railway St	-27.2464	145.9808	1897–01/06/1998	407
44104	Woolabra	-26.1411	146.395	1951–current	465
44111	Wansey Downs	-25.8517	146.1894	1967–current	515
44150	Kahmoo	-28.0967	145.5075	1885–current	349
44168	Bayrick	-25.4636	146.0272	1904–current	509
44174	Wallen	-27.62	145.8281	1974–current	383
44181	Hungerford	-28.9972	144.4094	1884–current	297
48004	Barringun	-29.0155	145.7171	1881–current	349
48006	Enngonia (Belalie)	-29.1581	145.8068	1885–current	339
48039	Enngonia (Shearer Street)	-29.3174	145.8466	1889–current	361
48042	Fords Bridge	-29.7534	145.4269	1896–current	330
48087	Yantabulla Station	-29.3423	145.0032	1892–current	295

Table 5.6: Warrego Model Rainfall

Reach	Rainfall Station	Mean Annual Rainfall July to June (mm/a)	Sacramento Proportion	Mean Catchment rainfall July to June (mm/a)	Sacramento Catchment Rainfall Weighting Sum
1	35004	589	0.721	587.94	1
	35031	610	0.186		
	44002	537	0.093		
2	35069	535	0.069	522.28	1
	35078	516	0.138		
	35004	589	0.103		
	44057	523	0.172		
	44062	515	0.035		
	44002	537	0.173		
	44001	528	0.086		
	44104	465	0.129		
	44021	494	0.086		
	44111	515	0.009		
3	44111	515	0.142	505.45	1
	44062	515	0.046		
	35078	516	0.034		
	35073	517	0.082		
	44052	471	0.358		
	44021	494	0.083		
	35190	511	0.096		
	44168	509	0.110		
	35013	695	0.049		
4	44052	471	0.042	481.42	1
	44050	544	0.305		
	44104	465	0.042		
	44021	494	0.374		
	44063	385	0.237		
5	44072	416	0.061	390.47	1
	44063	385	0.177		
	44064	371	0.207		
	44076	407	0.317		
	44174	383	0.238		

Reach	Rainfall Station	Mean Annual Rainfall July to June (mm/a)	Sacramento Proportion	Mean Catchment rainfall July to June (mm/a)	Sacramento Catchment Rainfall Weighting Sum
6	44026	373	0.063	413.75	1.082
	44174	383	1.019		
9	44026	373	0.0368	251.59	0.708
	44067	328	0.321		
	44065	346	0.000284		
	44059	394	0.227		
	48004	349	0.123		
11	48004	349	0.000000365	326.84	0.954
	48006	339	0.0595		
	48039	361	0.366		
	48042	330	0.528		
12	44026	373	0.402	378.92	1.116
	44150	349	0.105		
	44067	328	0.385		
	48004	349	0.0206		
	48087	295	0.132		
	44181	297	0.072		

5.4 Evaporation

For modeling 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: Warrego 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 Warrego 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 Water Infrastructure

There is no water infrastructure of note in the catchment.

5.7 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 Augathella

6.2.1 Description

The location of Reach 1 can be seen on Figure 1.1.

This headwater reach ends at Augathella (AMTD 447.4 km) and is located in the northern part of the Warrego River System. The reach has a total area of 8,070 square kilometres. The catchment starts at the headwater of the Warrego River, which is fed by the Channin and Dooloogarah Creeks. It extends mainly east of the Warrego River, and is bound by the Great Dividing Range in the north and the Chesterton range in the east. Most of the catchment is situated in the Great Dividing Range with elevations ranging from 350 m at Augathella in the south to 807 m at Mt King in the north-east. The land is semiarid and predominantly utilised for grazing sheep and cattle with insignificant development. Carnavon Gorge National Park is a feature of this headwater reach.

Tributaries of the Warrego River within this reach include: Lousia, Hoganthulla, Sandy, Faraday, Cumalong and Christmas Creeks, all of which flow in a south-westerly direction from the Great Dividing Ranges to join the Warrego River. The average annual station rainfall varies between 537 and 609 mm/a and the catchment's annual runoff is quite small when compared to the amount of rainfall that it receives annually. This is due, in part, to it being a recharge area for the Great Artesian Basin. It is thought that the waterholes along the Warrego River in this location are permanent, but that the surrounding shallow lakes on either floodplain are seasonal. The 50 year mean annual rainfall isohyets for Reach 1 are shown on Figure 6.1.

6.2.2 Data

6.2.2.1 Flow Data

Gauge data from Augathella 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	423204a	03/10/1967–30/06/2011 (missing data 06/11/1988–25/10/1991)

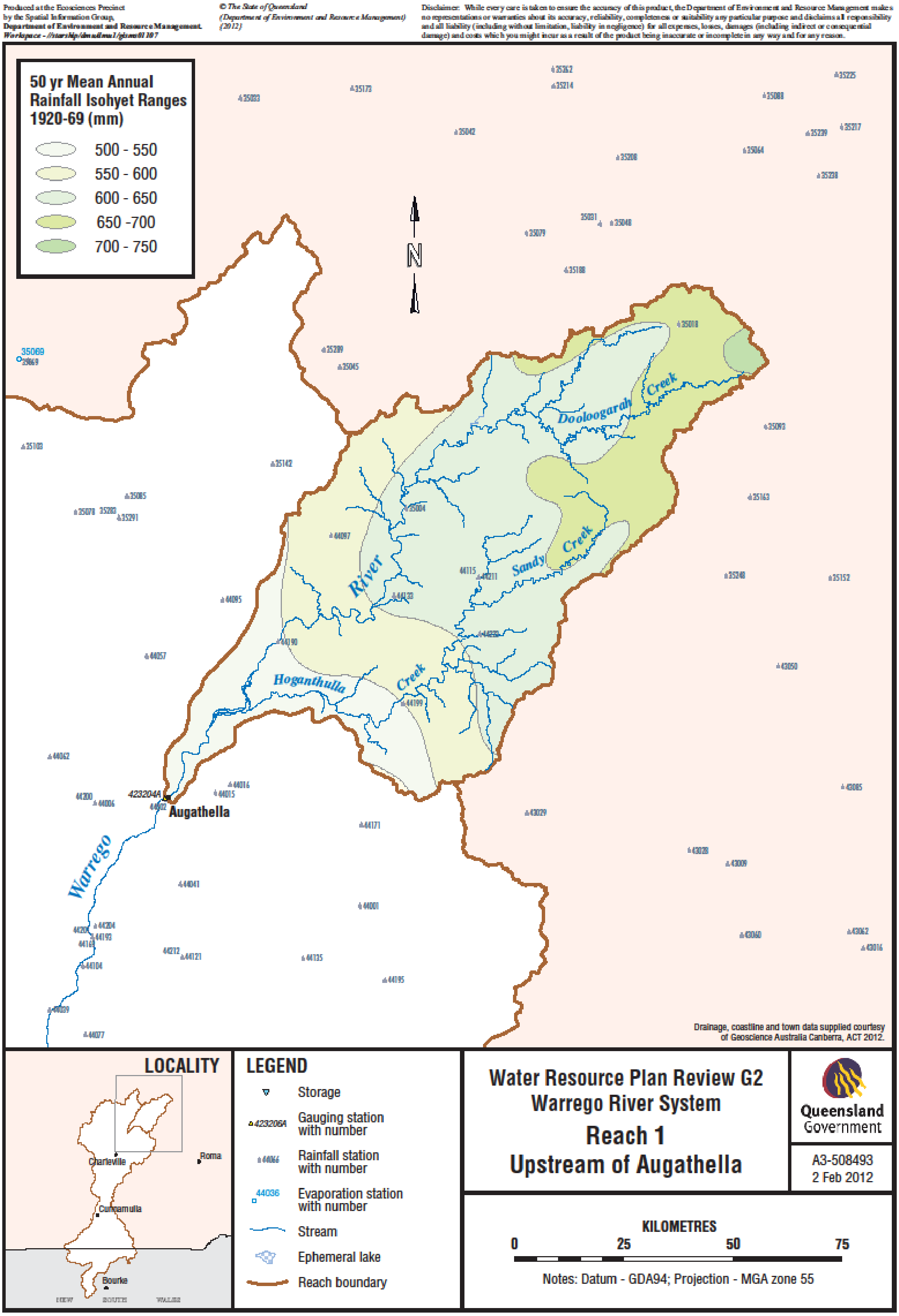


Figure 6.1: Reach 1 – Mean Annual Rainfall Isohyets Data

6.2.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 1. The weightings of each rainfall station are also summarised in Table 6.2.

6.2.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 1.

6.2.2.4 Reach Calibration and Record Based Inflow Sequence

Measured flows at Augathella for the period of record 01/01/1968 to 30/06/2011 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.

6.2.3 Sacramento Model Calibration

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

6.2.3.1 Time Period

The calibration period for the reach Sacramento was 01/01/1968 to 31/12/1987, consisting of the record prior to the period of missing data commencing in 1988. The gauge is noted as having records from 1967 however the recorded flow is zero until 1968. The period spanning 01/01/1992 to 31/12/2004 was used for the purpose of validation.

6.2.3.2 Unit Hydrograph

Table 6.2 shows the unit hydrograph adopted for calibration. During the calibration process, the unit hydrograph was adjusted by trial and error in order to improve the timing and nature of flow events. Ultimately, the original values used in the 2003 IQQM model were accepted as providing the best representation at the Augathella gauge.

6.2.3.3 Catchment Area

The total catchment area of Reach 1 is 8,070 square kilometres. All of the catchment is assumed to contribute to runoff (100%).

6.2.3.4 Sacramento Model Parameters

Table 6.2 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.

6.2.3.5 Sacramento Model Calibration Results

Table 6.3 shows the flow statistics for the recorded and calculated data for the calibration period; the statistics for the validation period are shown in Table 6.4. A report card of the Sacramento calibration is shown in Figure 6.2. There is also a report card for the Sacramento validation period in Figure 6.3 and one for the whole period in Figure 6.4. 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 6.2: Reach 1 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

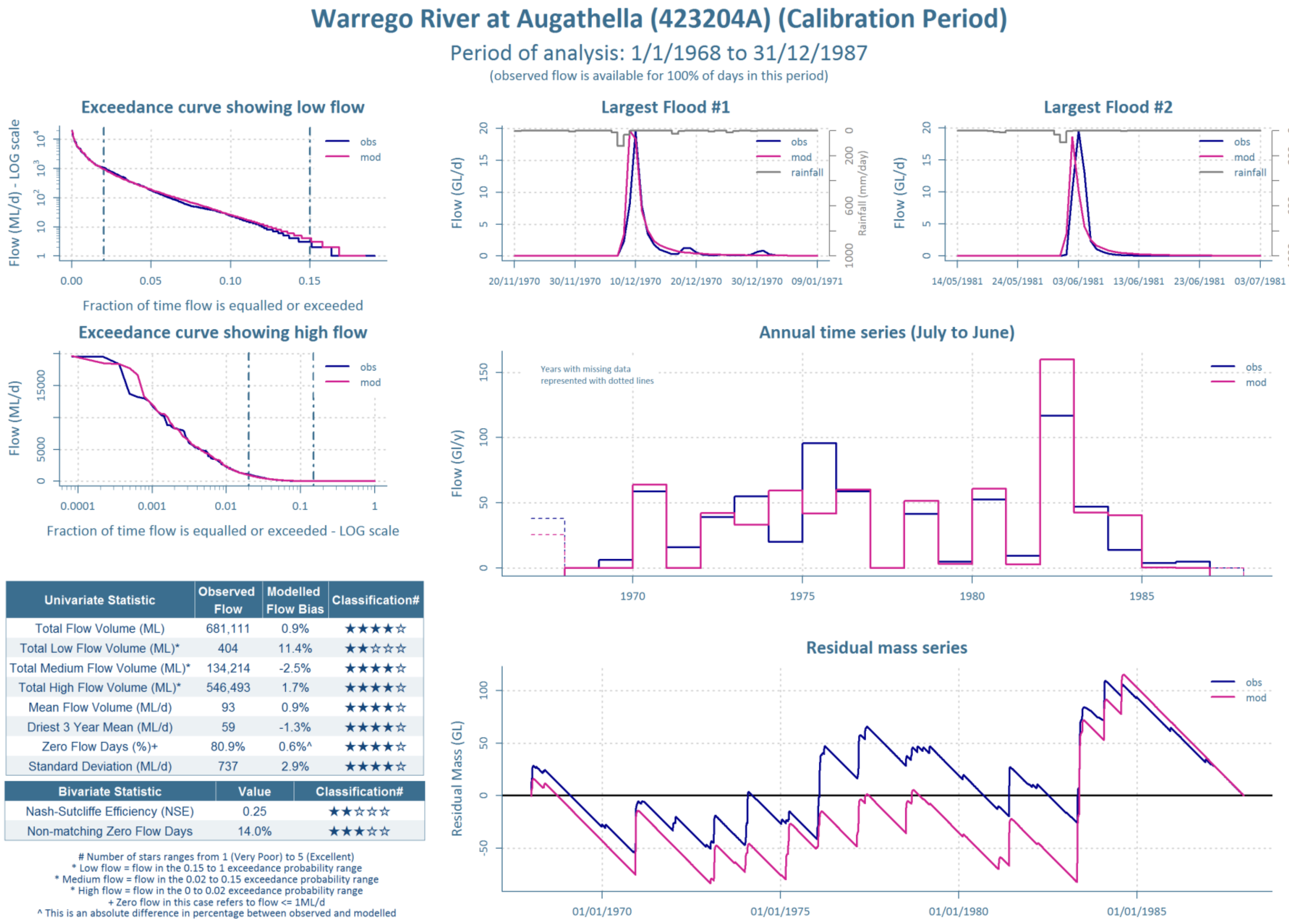
Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	1	-
Rf1 (35004)	0.721	-
Rf2 (35031)	0.186	-
Rf3 (44002)	0.093	-
adimp	0	-
lzfpm	58	0
lzfsm	134.5	0
lzpk	0.105	-
lzsk	0.34	-
lztwm	230	0
pctim	0	-
pfree	0.044	-
rexp	1	-
sarva	0	-
side	0	-
ssout	0.0001	-
uzfwm	49	0
uzk	0.1	-
uztwm	78	0
zperc	1	-
uh0	0.1	-
uh1	0.75	-
uh2	0.1	-
uh3	0.05	-

Table 6.3: Reach 1 – Sacramento Calibration Statistics

Location	Statistic	Daily	
		Recorded	Simulated
Augathella G.S.423204a 01/01/1968–31/12/1987 Calibration	Mean (ML)	93.24	94.08
	Standard Deviation (ML)	737.34	759.05
	Skew	15.05	15.37
	Maximum Flow (ML)	19,623 10/12/1970	19,651 09/12/1970
	Volume Change (%)		100.9
	Coefficient of Determination		0.405
	Coefficient of Efficiency		0.251

Table 6.4: Reach 1 – Sacramento Calibration Statistics - Validation

Location	Statistic	Daily	
		Recorded	Simulated
Augathella G.S.423204a 01/01/1992–30/06/2011 Validation	Mean (ML)	143	98
	Standard Deviation (ML)	1,441	853
	Skew	19.12	17.24
	Maximum Flow (ML)	48,738 05/02/1997	26,716 02/02/1997
	Volume Change (%)		68.26
	Coefficient of Determination		0.484
	Coefficient of Efficiency		0.696



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	681,111	0.9%	★★★★☆
Total Low Flow Volume (ML)*	404	11.4%	★★☆☆☆
Total Medium Flow Volume (ML)*	134,214	-2.5%	★★★★☆
Total High Flow Volume (ML)*	546,493	1.7%	★★★★☆
Mean Flow Volume (ML/d)	93	0.9%	★★★★☆
Driest 3 Year Mean (ML/d)	59	-1.3%	★★★★☆
Zero Flow Days (%)+	80.9%	0.6%^	★★★★☆
Standard Deviation (ML/d)	737	2.9%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.25	★★☆☆☆
Non-matching Zero Flow Days	14.0%	★★★☆☆

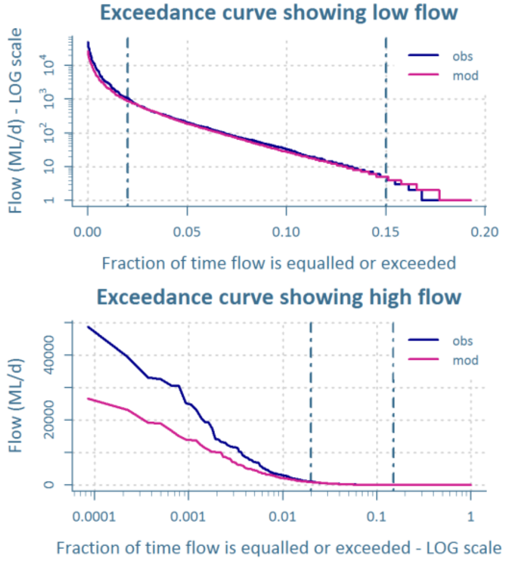
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.15 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.15 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
+ Zero flow in this case refers to flow <=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

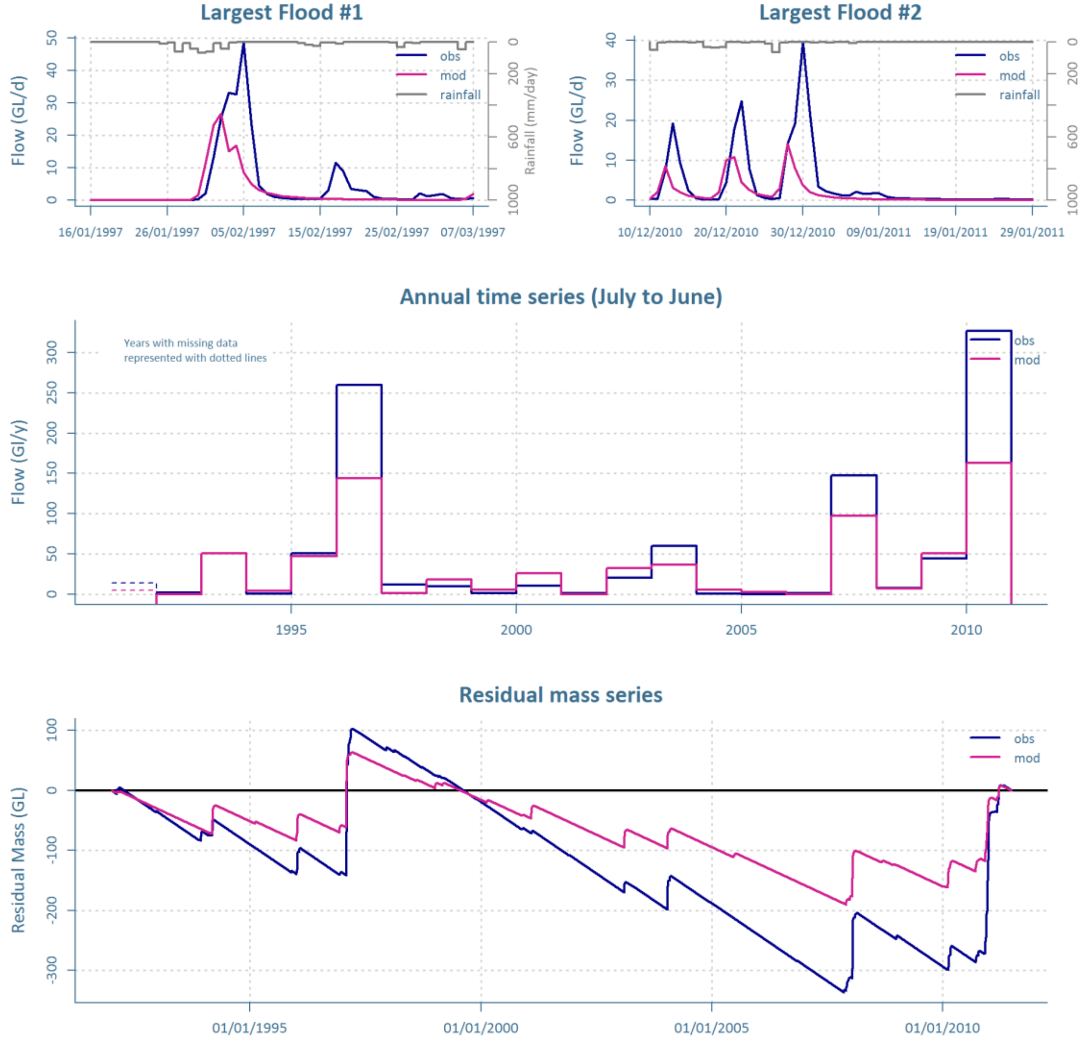
Figure 6.2: Reach 1 – Sacramento Calibration Report Card (Calibration Period)

Warrego River at Augathella (423204A) (Validation Period)

Period of analysis: 1/1/1992 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)	1,021,635	-31.7%	★☆☆☆☆
Total Low Flow Volume (ML)*	474	41.8%	★☆☆☆☆
Total Medium Flow Volume (ML)*	135,747	-6.0%	★★★☆☆
Total High Flow Volume (ML)*	885,414	-35.7%	★☆☆☆☆
Mean Flow Volume (ML/d)	143	-31.7%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	2	305.9%	★☆☆☆☆
Zero Flow Days (%)+	81.8%	1.1%^	★★★☆☆
Standard Deviation (ML/d)	1,441	-40.8%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.47	★★☆☆☆
Non-matching Zero Flow Days	15.0%	★★★☆☆

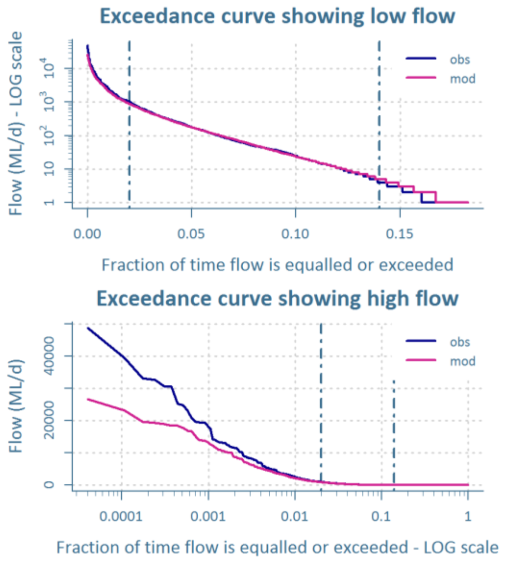
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.15 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.15 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
\+ Zero flow in this case refers to flow <=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

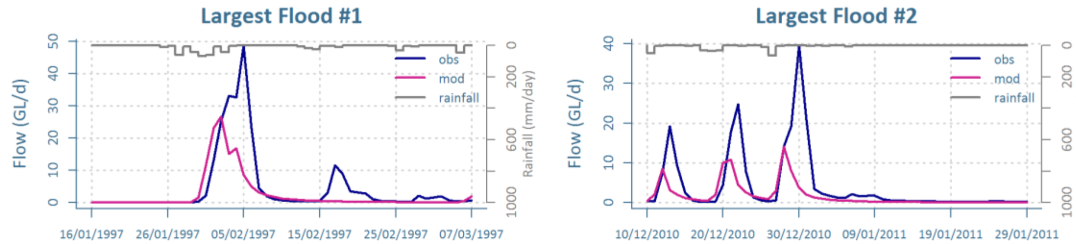
Figure 6.3: Reach 1 – Sacramento Calibration Report Card (Validation Period)

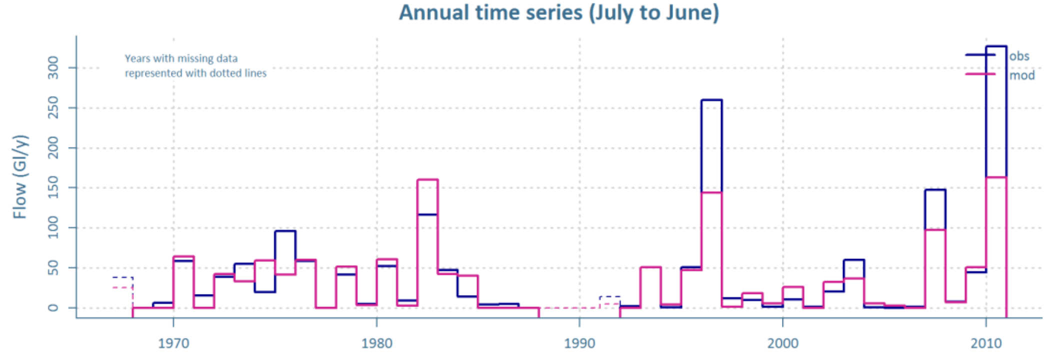
Warrego River at Augathella (423204A)

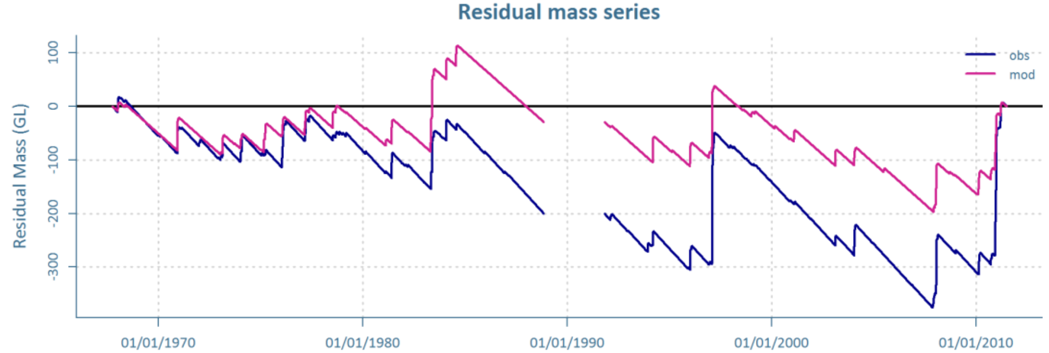
Period of analysis: 3/10/1967 to 30/6/2011

(observed flow is available for 93.2% of days in this period)









Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,702,746	-18.7%	★☆☆☆☆
Total Low Flow Volume (ML)*	1,136	30.1%	★☆☆☆☆
Total Medium Flow Volume (ML)*	259,208	-4.0%	★★★★☆
Total High Flow Volume (ML)*	1,442,402	-21.4%	★★☆☆☆
Mean Flow Volume (ML/d)	114	-18.7%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	2	305.9%	★☆☆☆☆
Zero Flow Days (%)+	81.9%	0.2%^	★★★★☆
Standard Deviation (ML/d)	1,122	-29.2%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.43	★★☆☆☆
Non-matching Zero Flow Days	14.0%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.14 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.14 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 6.4: Reach 1 – Sacramento Calibration Report Card (Whole Period)

6.2.3.6 Discussion

The Sacramento calibration aimed at reproducing the full range of flows. Over the full period of calibration, this was achieved, although some events were not reproduced, and in some cases, the simulated events occurred a few days earlier than the observed events.

The rainfall stations that were adopted for calibration were chosen on the basis of their location and length of record, and are the best combination of available data. Three stations were selected, representing rainfall in the headwaters, center and tailwaters of the reach. Despite best efforts to achieve an even distribution of rainfall stations across the catchment, there is always the risk of local events not being recorded at a rainfall station.

From Table 6.4 it can be seen that there is an under-estimation of flows in the validation period. On average, the daily recorded flows are higher in the validation period, which the model cannot replicate consistently. The daily residual mass curves show a good reproduction of flood events.

6.2.4 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.

6.2.5 Final Inflow Sequence

For this reach the full length inflow sequence was adjusted using DMM for the missing period of record. Adjustments to the Reach 1 and 2 flows were made to align the model flows to the flow record at GS423201a Warrego River at Charleville. Table 6.5 shows the adjustments performed to the Charleville gauge.

Table 6.5: Reach 1 – Flow Adjustment Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–14/09/1926	Sacramento		
15/09/1926–02/10/1967	Sacramento adjusted	423201a	Both Reach 1 and Reach 2 adjusted to 423201a using a factor of 0.5.
03/10/1967–06/11/1988	Gauge	423204a	
07/11/1988–26/10/1991	Sacramento		Missing data at 423204a
27/10/1991–30/06/2011	Gauge	423204a	

Following the calibration of Reaches 2, 3 and 4, the flow sequences from the above DMM adjustment to Charleville were then adjusted to Wyandra. The latest structure of the IQQM model separates the Ward River catchment area (now Reach 3) from the Warrego River catchment area between Charleville and Wyandra (now Reach 4). Further adjustment was required to take into account the introduction of the Reach 3 inflow from Ward River into the Warrego River below the Charleville gauge. This second adjustment accounts for the period of missing data 07/11/1988–

26/10/1991 and allows for a better correlation of the upstream flow characteristics to the gauged record at Wyandra, which is continuous from 1967. Table 6.6 and Figure 6.5 show the composition of the final inflow sequence for Reach 1.

Table 6.6: Reach 1 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–14/09/1926	Sacramento		
15/09/1926–02/10/1967	Sacramento adjusted	423201a	Reach 1 and Reach 2 adjusted to 423201a. Factor 0.5
03/10/1967–06/11/1988	Gauge	423204a	
07/11/1988–26/10/1991	Sacramento adjusted	423203a	Missing data at 423204a adjusted to 423203a. Factor proportional to catchment area contribution. Reach 1 = 0.19 Reach 2 = 0.19 Reach 3 = 0.34 Reach 4 = 0.28
27/10/1991–30/06/2011	Gauge	423204a	

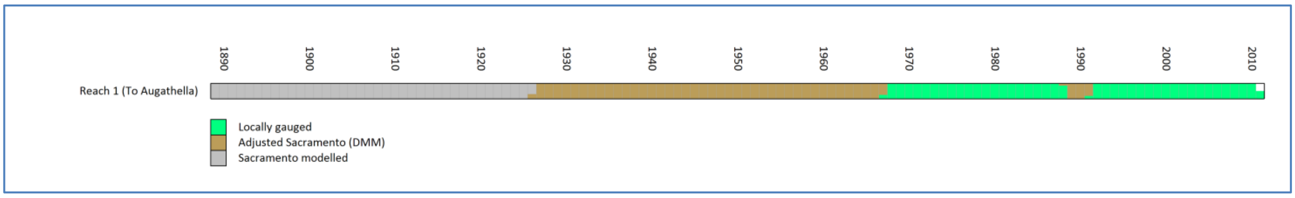


Figure 6.5: Reach 1 – Composition of Final Inflow Sequence

6.3 Reach 2 – Augathella to Charleville

6.3.1 Description

The location of Reach 2 can be seen on Figure 1.1.

Reach 2 is located in the northern part of the Warrego catchment, incorporating the area of the Warrego River between Augathella (AMTD 447.4 km) and Charleville (AMTD 383 km). The reach lies downstream of Augathella and has a catchment area of 8,229 square kilometres. Tributaries of the Warrego River within this reach include Myall, Kennedy, Borah, and Burenda Creeks from the eastern side and Blacks, Winters Creeks and the Nive River from the northern side of the catchment.

The catchment is reasonably flat with elevations ranging from around 280 metres above sea level at Charleville station, to around 400 metres above sea level in the Nive River headwaters. The average annual rainfall varies from about 460 mm/a on the floodplain in the south to a maximum of 588 mm/a in the north of the catchment. The 50 year mean annual rainfall isohyets for Reach 2 are shown on Figure 6.6.

6.3.2 Data

6.3.2.1 Flow Data

The stream flow data used for calibration can be viewed in Table 6.7.

Table 6.7: Reach 2 – Flow Data

Location	Station	Period
Upstream	423204a	01/10/1967–30/06/2011 (missing data 06/11/1988–25/10/1991)
Downstream	423201a	13/09/1926–31/01/1978 (multiple periods of missing data-see Table 5.3

6.3.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 2. The weightings of each rainfall station are also summarised in Table 6.10.

6.3.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 2.

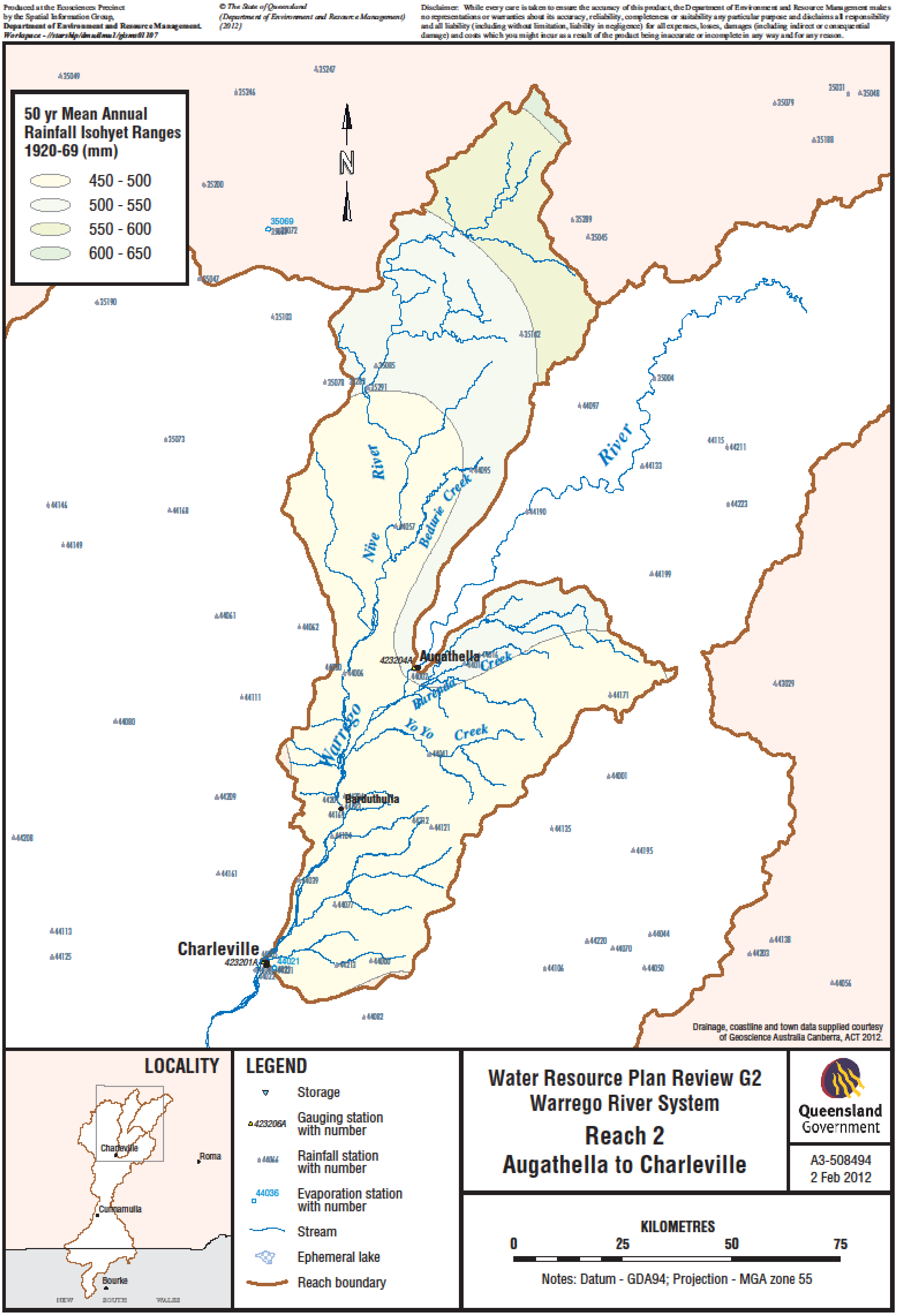


Figure 6.6: Reach 2 – Mean Annual Rainfall Isohyets Data

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. Missing periods of data at the gauges were removed from the derived residual.

6.3.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations 03/10/1967–19/01/1978. During this time, there are multiple periods of missing data at the Charleville gauge.

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.

The non-linear lag and route procedure was used for the routing that was applied at the links between nodes. The calibrated lag and routing parameters used for the reach are listed in Table 6.8.

Table 6.8: Reach 2 – Lag and Routing Parameters

Reach Length (km)	Lag Time (days)	k	m
84.3	2	0.2	0.85

6.3.3.4 Unaccounted Difference

A derived unaccounted difference relationship was added at the end of the reach. It is shown in Table 6.9. The unaccounted difference was estimated by comparing the flow duration curves of the modelled and measured flow at the downstream gauge. Most of the difference was during the low flow and probably results from the transmission losses between the gauges.

Table 6.9: Reach 2 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
70	70
130	70
1e9	70

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 03/10/1967 to 19/01/1978, the period of the derived residual. Any missing gauged data was excluded from the calibration.

6.3.4.2 Unit Hydrograph

Table 6.10 shows the unit hydrograph adopted for calibration.

6.3.4.3 Catchment Area

The total catchment area of Reach 2 is 8,229 square kilometres.

6.3.4.4 Sacramento Model Parameters

Table 6.10 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 6.10: Reach 2 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	1	-
Rf1 (35004)	0.103	-
Rf2 (35069)	0.069	-
Rf3 (35078)	0.138	-
Rf4 (44001)	0.086	-
Rf5 (44002)	0.173	-
Rf6 (44021)	0.086	-
Rf7 (44057)	0.172	-
Rf8 (44062)	0.035	-
Rf9 (44104)	0.129	-
Rf10 (44111)	0.009	-
adimp	0	-
lzfpm	24	0
lzfsm	31	0
lzpk	0.13	-
lzsk	0.4	-
lztwm	142	0
pctim	0	-
pfree	0.17	-
rexp	1	-
sarva	0.0012	-
side	0	-
ssout	0.001	-
uzfwm	10	0
uzk	0.9	-
uztwm	50	0
zperc	6	-
uh0	0.1	-
uh1	0.75	-
uh2	0.1	-
uh3	0.05	-

6.3.4.5 Sacramento Model Calibration Results

Table 6.11 shows the flow statistics for the recorded and calculated data for the calibration period. A report card of the Sacramento calibration is shown in Figure 6.7. 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 recorded flow sequence.

Table 6.11: Reach 2 – Sacramento Calibration Statistics

Location	Statistic	Daily	
		Recorded	Simulated
Augathella to Charleville 03/10/1967–19/01/1978 Calibration	Mean (ML)	293.51	293.39
	Standard Deviation (ML)	2,828	3,114
	Skew	18.33	18.53
	Maximum Flow (ML)	83,186 28/12/1971	82,172 28/12/1971
	Volume Change (%)	99.96	
	Coefficient of Determination	0.620	
	Coefficient of Efficiency	0.521	

6.3.4.6 Discussion

Reach 2 is a residual catchment, so 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.

There are multiple periods of missing data spanning 1972 to 1978. Removing these sections from the residual calibration would have reduced the period of common data between the upstream and downstream gauges to only five years (03/10/1967–01/12/1972). As a result, the derived residual has periods of no flow that are more likely to be caused by problems at the gauges than being actual periods of no flow. It is recommended that the missing gauge record from December 1972 be excluded from the next calibration model, as the only benefit to the flow sequence is to falsely extend the calibration period.

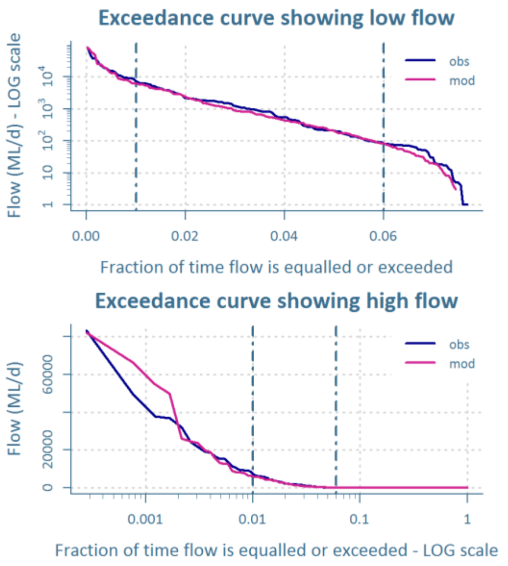
The rainfall stations selected for this reach calibration were well distributed across the catchment. However this does not guarantee that all rainfall events will be captured, which in turn affects the ability of the model to replicate gauged flow events. Future modelling may benefit from an alternative rainfall station combination.

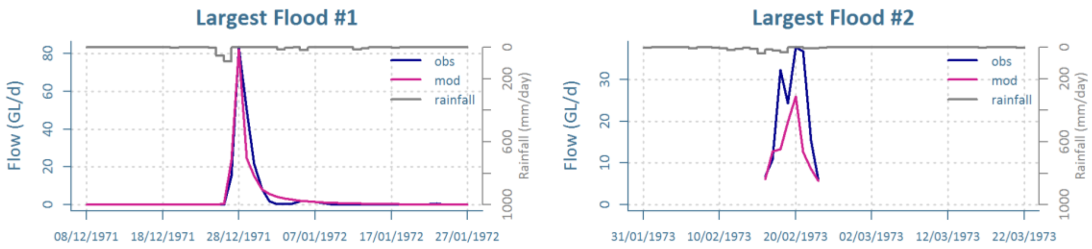
Due to the short calibration period, there was not enough data available to further assess the ability of the model parameters to convert rainfall into stream flow for this catchment. The resulting calibration was the best compromise that could be made between maintaining the magnitude of flow events and balancing low flow events. The calibration results all indicate that most flow events are being reproduced well. This provides confidence in the ability of the model to produce a suitable representation of the downstream gauged flows.

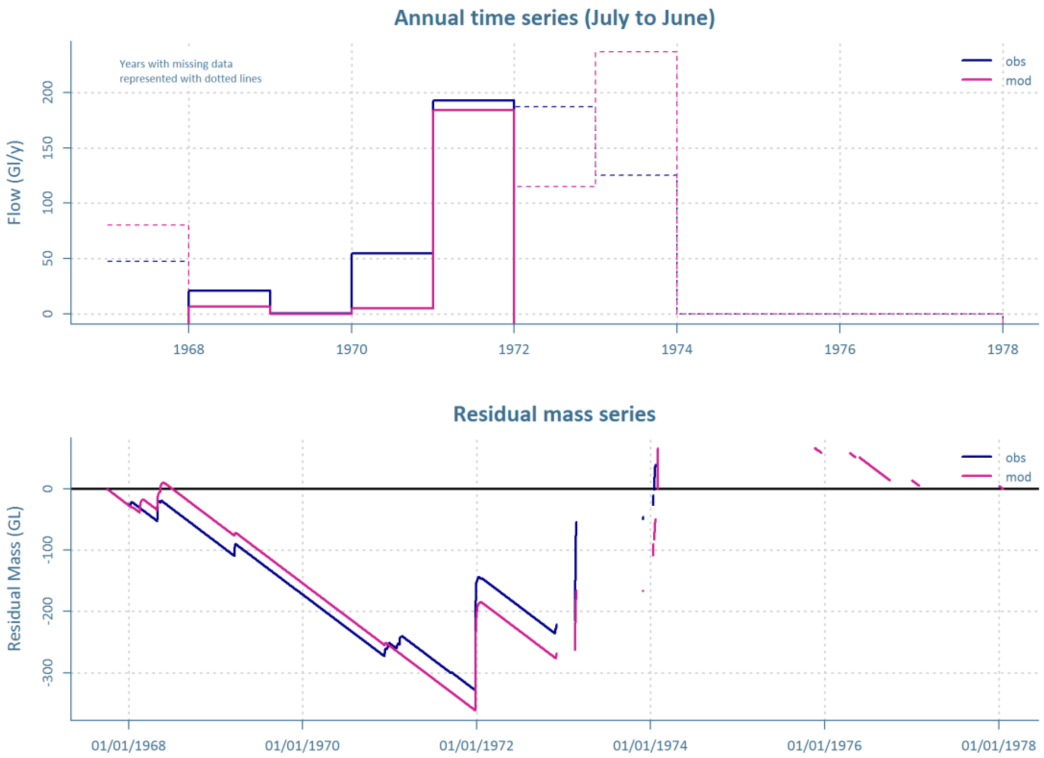
Warrego River between Auguthella (423204A) and Charleville (423201A)

Period of analysis: 3/10/1967 to 19/1/1978

(observed flow is available for 56.9% of days in this period)







Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	628,409	0.0%	★★★★★
Total Low Flow Volume (ML)*	1,561	-28.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	164,644	-11.8%	★★☆☆☆
Total High Flow Volume (ML)*	462,204	4.2%	★★★★☆
Mean Flow Volume (ML/d)	294	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	69	-84.6%	★☆☆☆☆
Zero Flow Days (%)+	92.3%	0.2%^	★★★★☆
Standard Deviation (ML/d)	2,827	10.1%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.52	★★★☆☆
Non-matching Zero Flow Days	7.0%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.06 to 1 exceedance probability range
* Medium flow = flow in the 0.01 to 0.06 exceedance probability range
* High flow = flow in the 0 to 0.01 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

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. This data was used to infill and extend the record based 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 missing period of record. Adjustments to the Reach1 and 2 flows were made to align the model flows to the flow record at GS423201a Warrego River at Charleville. Table 6.12 shows the adjustments performed to upstream inflows to match the Charleville gauge.

Following the calibration of Reaches 2, 3 and 4, the flow sequences from the above DMM adjustment to Charleville were then adjusted to Wyandra. The latest structure of the IQQM model separates the Ward River catchment area (now Reach 3) from the Warrego River catchment area between Charleville and Wyandra (now Reach 4). Further adjustment was required to take into account the introduction of the Reach 3 inflow from Ward River into the Warrego River below the Charleville gauge. This second adjustment accounts for any issues arising from periods of missing data and allows for a better correlation of the upstream flow characteristics to the gauged record at Wyandra, which is continuous from 1967. Table 6.13 and Figure 6.8 show the composition of the final residual inflow sequence for Reach 2.

Table 6.12: Reach 2 – DMM adjustment to Charleville

Period	Data Description	Downstream Gauge	Notes
01/01/1889–14/09/1926	Sacramento		
15/09/1926–02/10/1967	Sacramento adjusted	423201a	Reach 1 and Reach 2 adjusted to 423201a. Factor 0.5
03/10/1967–01/12/1972	Derived residual	423201a	
02/12/1972–31/01/1973	Sacramento		
01/02/1973–01/02/1973	Derived residual	423201a	
02/02/1973–15/02/1973	Sacramento		
16/02/1973–23/02/1973	Derived residual	423201a	
24/02/1973–01/05/1973	Sacramento		
02/05/1973–02/05/1973	Derived residual	423201a	
03/05/1973–27/11/1973	Sacramento		
28/11/1973–29/11/1973	Derived residual	423201a	
30/11/1973–04/01/1974	Sacramento		
05/01/1974–05/01/1974	Derived residual	423201a	
06/01/1974–09/01/1974	Sacramento		
10/01/1974–11/01/1974	Derived residual	423201a	
12/01/1974–14/01/1974	Sacramento		
15/01/1974–22/01/1974	Derived residual	423201a	
23/01/1974–29/01/1974	Sacramento		
30/01/1974–31/01/1974	Derived residual	423201a	
01/02/1974–19/11/1975	Sacramento		
20/11/1975–02/12/1975	Derived residual	423201a	
03/12/1975–04/12/1975	Sacramento		
05/12/1975–19/12/1975	Derived residual	423201a	
20/12/1975–15/04/1976	Sacramento		
16/04/1976–09/05/1976	Derived residual	423201a	
10/05/1976–25/05/1976	Sacramento		
26/05/1976–30/09/1976	Derived residual	423201a	
01/10/1976–01/01/1977	Sacramento		
02/01/1977–31/01/1977	Derived residual	423201a	
01/02/1977–01/01/1978	Sacramento		
02/01/1978–19/01/1978	Derived residual	423201a	
20/01/1978–30/06/2011	Sacramento		

Table 6.13: Reach 2 – DMM adjustment to Wyandra

Period	Data Description	Downstream Gauge	Notes
01/01/1889–28/02/1967	Sacramento		
01/03/1967–02/10/1967	Sacramento adjusted	423203a	Factor proportional to catchment area contribution. Reach 1 = 0.19 Reach 2 = 0.19 Reach 3 = 0.34 Reach 4 = 0.28
03/10/1967–01/12/1972	Derived residual	423201a	
02/12/1972–31/01/1973	Sacramento adjusted	423203a	
01/02/1973–01/02/1973	Derived residual	423201a	
02/02/1973–15/02/1973	Sacramento adjusted	423203a	
16/02/1973–23/02/1973	Derived residual	423201a	
24/02/1973–01/05/1973	Sacramento adjusted	423203a	
02/05/1973–02/05/1973	Derived residual	423201a	
03/05/1973–27/11/1973	Sacramento adjusted	423203a	
28/11/1973–29/11/1973	Derived residual	423201a	
30/11/1973–04/01/1974	Sacramento adjusted	423203a	
05/01/1974–05/01/1974	Derived residual	423201a	
06/01/1974–09/01/1974	Sacramento adjusted	423203a	
10/01/1974–11/01/1974	Derived residual	423201a	
12/01/1974–14/01/1974	Sacramento adjusted	423203a	
15/01/1974–22/01/1974	Derived residual	423201a	
23/01/1974–29/01/1974	Sacramento adjusted	423203a	
30/01/1974–31/01/1974	Derived residual	423201a	
01/02/1974–19/11/1975	Sacramento adjusted	423203a	
20/11/1975–02/12/1975	Derived residual	423201a	
03/12/1975–04/12/1975	Sacramento adjusted	423203a	
05/12/1975–19/12/1975	Derived residual	423201a	
20/12/1975–15/04/1976	Sacramento adjusted	423203a	
16/04/1976–09/05/1976	Derived residual	423201a	
10/05/1976–25/05/1976	Sacramento adjusted	423203a	
26/05/1976–30/09/1976	Derived residual	423201a	
01/10/1976–01/01/1977	Sacramento adjusted	423203a	
02/01/1977–31/01/1977	Derived residual	423201a	
01/02/1977–01/01/1978	Sacramento adjusted	423203a	
02/01/1978–19/01/1978	Derived residual	423201a	
20/01/1978–17/05/1999	Sacramento adjusted	423203a	

Period	Data Description	Downstream Gauge	Notes
18/05/1999–21/11/2001	Sacramento		
22/11/2001–30/06/2011	Sacramento adjusted	423203a	

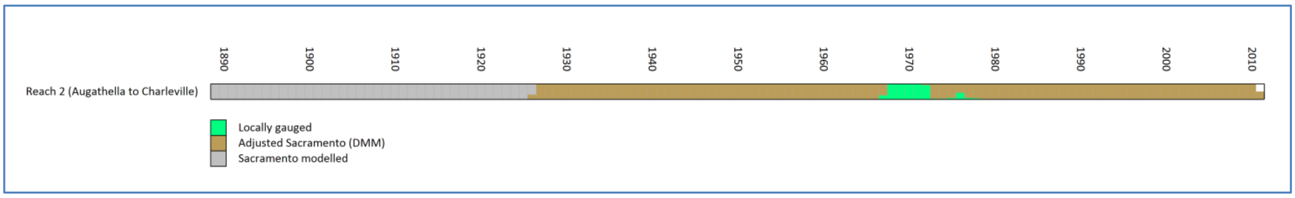


Figure 6.8: Reach 2 – Composition of Final Inflow Sequence

6.4 Reach 3 - Upstream of Ward River at Binnowee

6.4.1 Description

This headwater reach ends at Binnowee (AMTD 7.1 km) and is located in the north-western part of the Warrego River System. The location of Reach 3 can be seen on Figure 1.1.

The reach has a total area of 14,671 square kilometres. The catchment starts at the headwater of the Ward River. It extends mainly east of the Warrego River, and is bound by the Great Dividing Range in the north and Reach 2 in the east.

Tributaries within this reach include Langlo River and Cannon Creek, both of which flow in a south-easterly direction to join Ward River. The average annual station rainfall varies between 470 and 700 mm/a, however, the catchment's annual runoff trends towards the lower end of this range at approximately 505 mm/a. The 50 year mean annual rainfall isohyets for Reach 3 are shown on Figure 6.9.

6.4.2 Data

6.4.2.1 Flow Data

Gauge data from Binnowee was used for Reach 3. This is the first time that the period of flow record has been sufficient enough to utilise in the Warrego model. The stream flow data used for calibration can be found in Table 6.14.

Table 6.14: Reach 3 – Flow Data

Location	Station	Period
Downstream	423205a	02/12/1999–30/06/2011

6.4.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 3. The weightings of each rainfall station are also summarised in Table 6.15.

6.4.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 3.

6.4.3 Reach Calibration and Record Based Inflow Sequence

Measured flow records at Binnowee for the period 11/01/2002 to 30/06/2011 were used as the recorded Reach 3 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.

6.4.4 Sacramento Model Calibration

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

6.4.4.1 Time Period

The calibration period for the reach Sacramento was 1/02/2002 to 30/06/2011. The gauge is noted as having records from 1999 however the flow is recorded as zero until 11/01/2002. The start of February was used as the start of the calibration period.

6.4.4.2 Unit Hydrograph

Table 6.15 shows the unit hydrograph adopted for calibration. During the calibration process, the unit hydrograph was adjusted by trial and error in order to improve the timing and nature of flow events.

6.4.4.3 Catchment Area

The total catchment area of Reach 3 is 14,671 square kilometre. All of the catchment is assumed to contribute to runoff (100%).

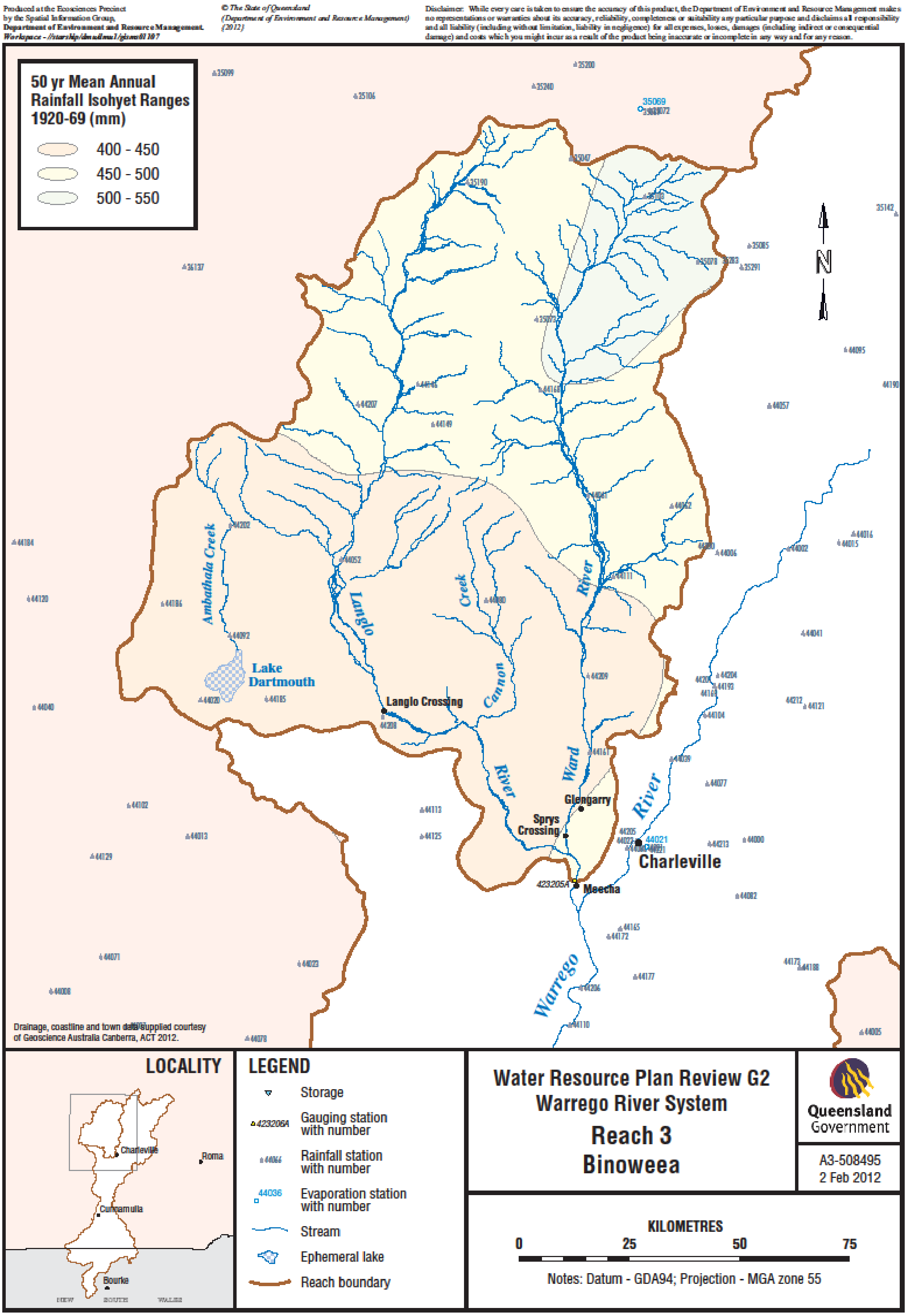


Figure 6.9: Reach 3 – Mean Annual Rainfall Isohyets Data

6.4.4.4 Sacramento Model Parameters

Table 6.15 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 6.15: Reach 3 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	1	-
Rf1 (35013)	0.049	-
Rf2 (35073)	0.082	-
Rf3 (35078)	0.034	-
Rf4 (35190)	0.096	-
Rf5 (44021)	0.083	-
Rf6 (44052)	0.358	-
Rf7 (44062)	0.046	-
Rf8 (44111)	0.142	-
Rf9 (44168)	0.11	-
adimp	0.0002	-
lzfpm	8	0
lzfsm	36.5	0
lzpk	0.08	-
lzsk	0.26	-
lztwm	182	0
pctim	0	-
pfree	0.1	-
rexp	1	-
sarva	0	-
side	0.0001	-
ssout	0.0001	-
uzfwm	24	0
uzk	0.47	-
uztwm	34.5	0
zperc	8.2	-
uh0	0.03	-
uh1	0.19	-
uh2	0.31	-
uh3	0.25	-
uh4	0.09	-
uh5	0.06	-
uh6	0.05	-

6.4.4.5 Sacramento Model Calibration Results

Table 6.16 shows the flow statistics for the recorded and calculated data for the calibration period. A report card is shown in Figure 6.10. In order to check the validity of the calibration parameters, flow statistics were assessed over two parts of the calibration period: 01/02/2002 to 01/12/2006 and 01/01/2007 to 30/06/2011. Table 6.17 and Table 6.18 show the statistics for the validation periods, and Figure 6.11 and Figure 6.12 the report cards. Appendix C3 includes daily plots of the data.

Table 6.16: Reach 3 – Sacramento Calibration Statistics

Location	Statistic	Daily	
		Recorded	Simulated
Binnowee G.S.423205a 01/02/2002–30/06/2011 Calibration	Mean (ML)	1,191	1,195
	Standard Deviation (ML)	8,223	7,978
	Skew	14.54	15.16
	Maximum Flow (ML)	201,183 21/01/2008	205,140 20/01/2008
	Volume Change (%)	100.33	
	Coefficient of Determination	0.752	
	Coefficient of Efficiency	0.742	

Table 6.17: Reach 3 – Sacramento Calibration Statistics – Validation Period 1

Location	Statistic	Daily	
		Recorded	Simulated
Binnowee G.S.423205a 01/02/2002-31/12/2006 Validation	Mean (ML)	349.58	414.05
	Standard Deviation (ML)	3,280	2,742
	Skew	20.85	11.92
	Maximum Flow (ML)	84,227 13/02/2003	51,562 11/02/2003
	Volume Change (%)		118.44
	Coefficient of Determination		0.468
	Coefficient of Efficiency		0.445

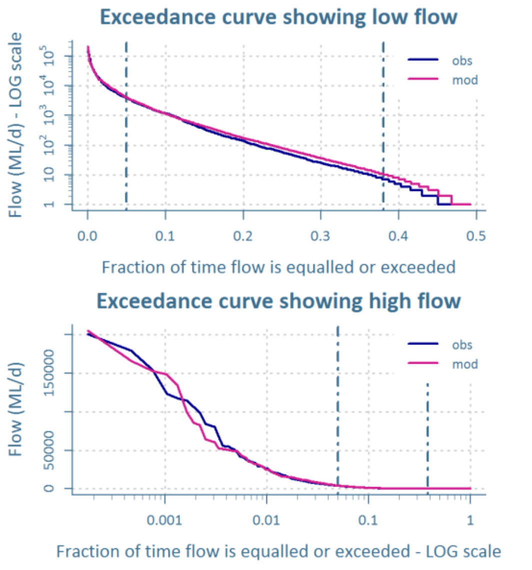
Table 6.18: Reach 3 – Sacramento Calibration Statistics – Validation Period 2

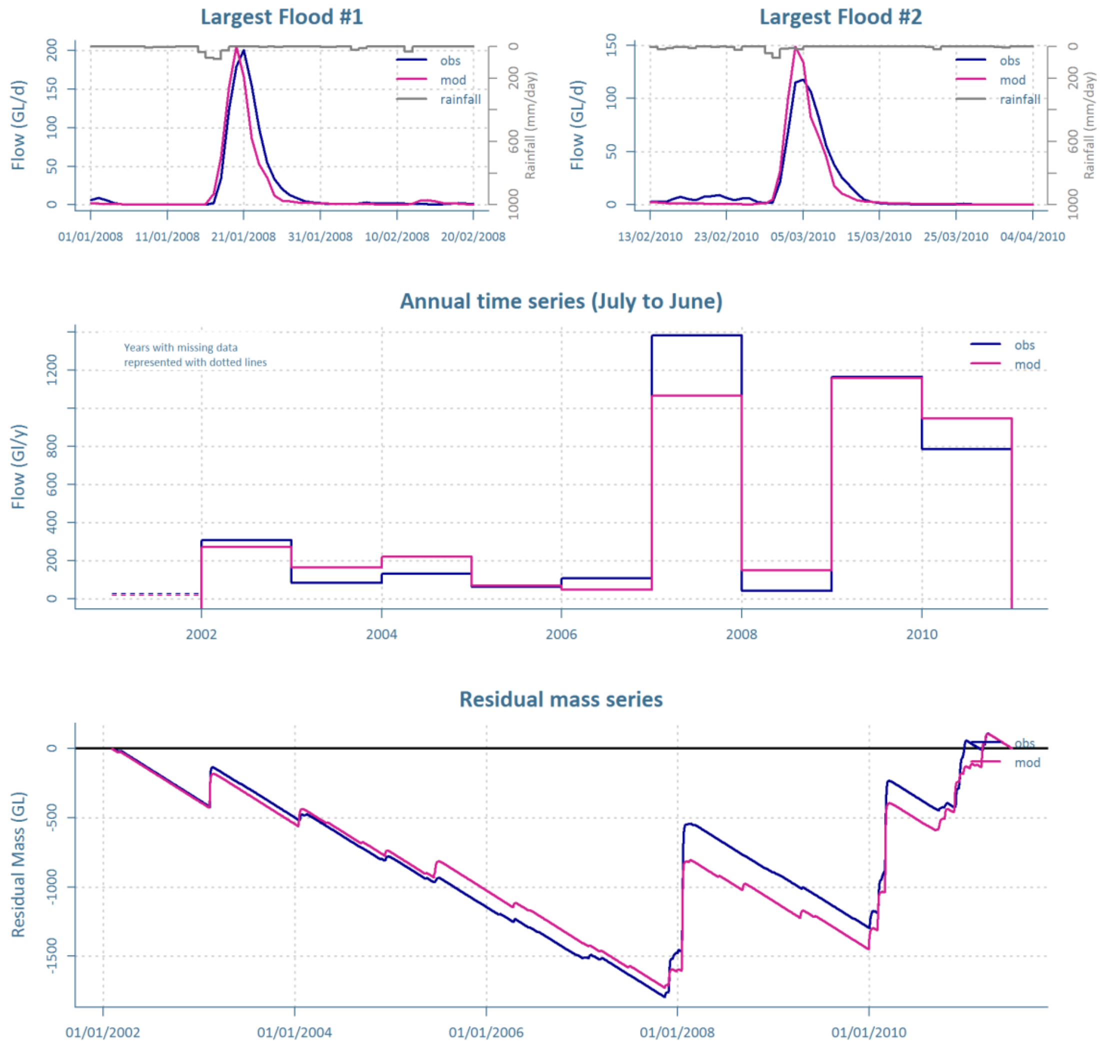
Location	Statistic	Daily	
		Recorded	Simulated
Binnowee G.S.423205a 01/01/2007-30/06/2011 Validation	Mean (ML)	2,111	2,049
	Standard Deviation (ML)	11,322	11,120
	Skew	10.89	11.32
	Maximum Flow (ML)	201,183 21/01/2008	205,140 20/01/2008
	Volume Change (%)		97.05
	Coefficient of Determination		0.776
	Coefficient of Efficiency		0.766

Ward River at Binnowee (423205A) (Calibration Period)

Period of analysis: 1/2/2002 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)	4,094,064	0.3%	★★★★☆
Total Low Flow Volume (ML)*	1,018	60.8%	★☆☆☆☆
Total Medium Flow Volume (ML)*	542,281	7.5%	★★★☆☆
Total High Flow Volume (ML)*	3,550,765	-0.8%	★★★★★
Mean Flow Volume (ML/d)	1,191	0.3%	★★★★☆
Driest 3 Year Mean (ML/d)	477	25.5%	★☆☆☆☆
Zero Flow Days (%)+	52.3%	1.5%^	★★★☆☆
Standard Deviation (ML/d)	8,221	-3.0%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.74	★★★☆☆
Non-matching Zero Flow Days	24.5%	★★★☆☆

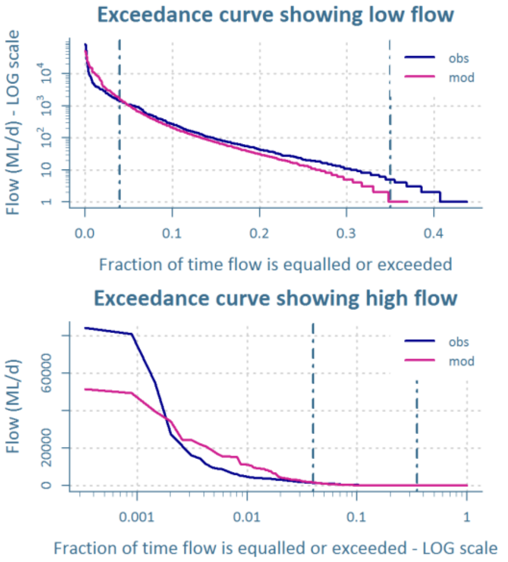
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.38 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.38 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

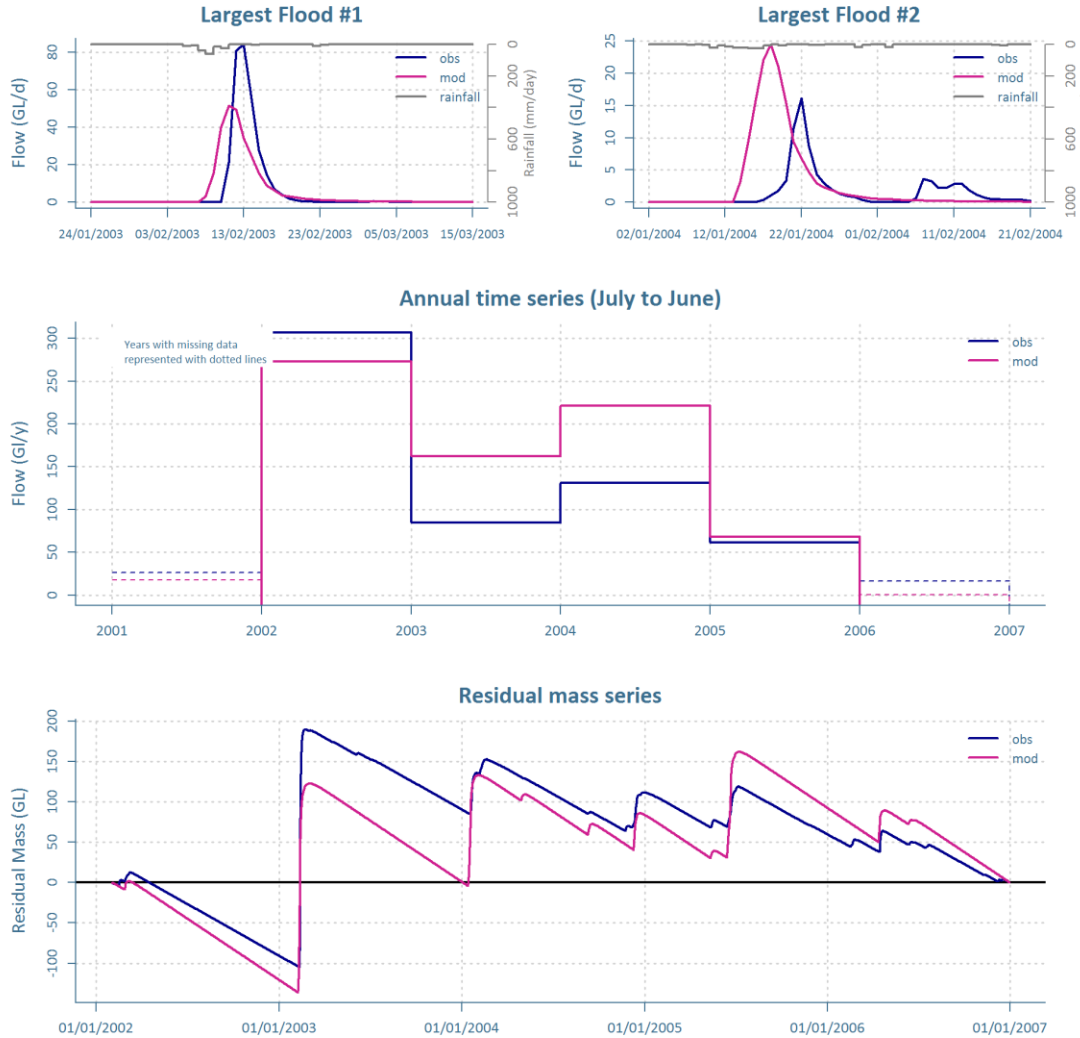
Figure 6.10: Reach 3 – Sacramento Calibration Report Card (Calibration Period)

Ward River at Binnowee (423205A) (Validation Period 1)

Period of analysis: 1/2/2002 to 31/12/2006

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





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	627,496	18.4%	★☆☆☆☆
Total Low Flow Volume (ML)*	366	-90.2%	★☆☆☆☆
Total Medium Flow Volume (ML)*	101,381	-16.0%	★★☆☆☆
Total High Flow Volume (ML)*	525,749	25.2%	★☆☆☆☆
Mean Flow Volume (ML/d)	350	18.4%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	477	25.5%	★☆☆☆☆
Zero Flow Days (%)+	56.2%	6.8%^	★★☆☆☆
Standard Deviation (ML/d)	3,279	-16.4%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.44	★★☆☆☆
Non-matching Zero Flow Days	23.6%	★★★☆☆

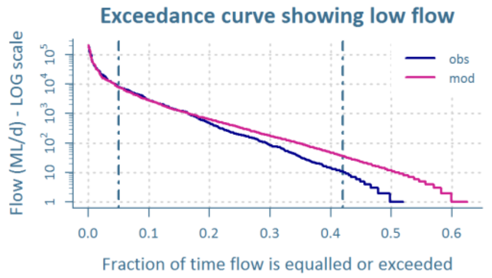
\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.35 to 1 exceedance probability range
* Medium flow = flow in the 0.04 to 0.35 exceedance probability range
* High flow = flow in the 0 to 0.04 exceedance probability range
\+ Zero flow in this case refers to flow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

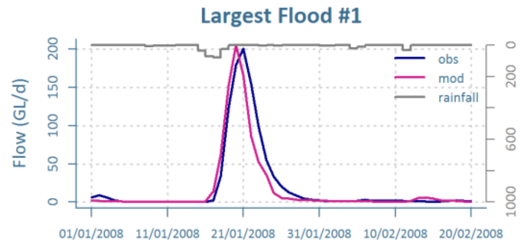
Figure 6.11: Reach 3 – Sacramento Calibration Report Card (Validation Period 1)

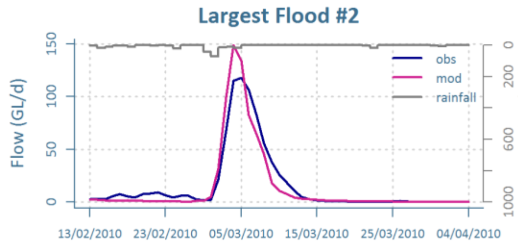
Ward River at Binnowee (423205A) (Validation Period 2)

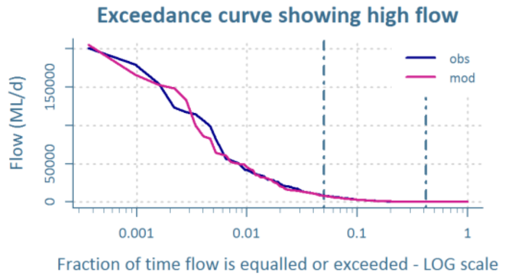
Period of analysis: 1/1/2007 to 30/6/2011

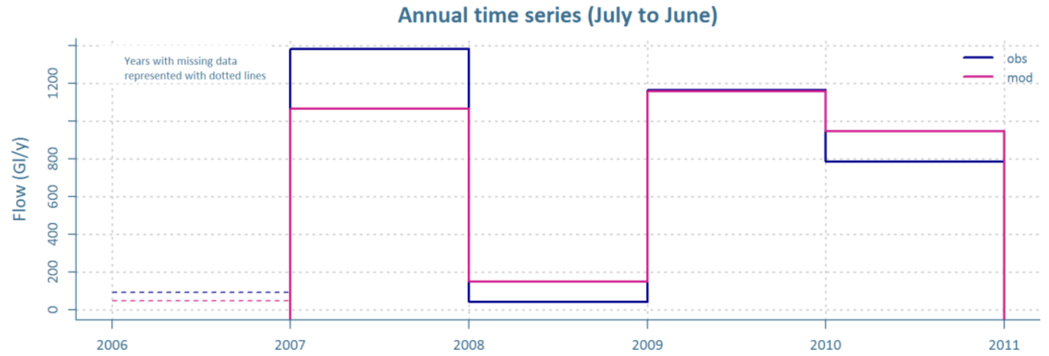
(observed flow is available for 100% of days in this period)











Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	3,466,568	-3.0%	★★★☆☆
Total Low Flow Volume (ML)*	648	479.9%	★☆☆☆☆
Total Medium Flow Volume (ML)*	695,749	0.3%	★★★★★
Total High Flow Volume (ML)*	2,770,171	-3.9%	★★★★☆
Mean Flow Volume (ML/d)	2,111	-3.0%	★★★☆☆
Driest 3 Year Mean (ML/d)	2,363	-8.4%	★★★☆☆
Zero Flow Days (%)+	48.0%	10.5%^	★☆☆☆☆
Standard Deviation (ML/d)	11,318	-1.8%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.77	★★★★☆
Non-matching Zero Flow Days	25.4%	★★☆☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.42 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.42 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

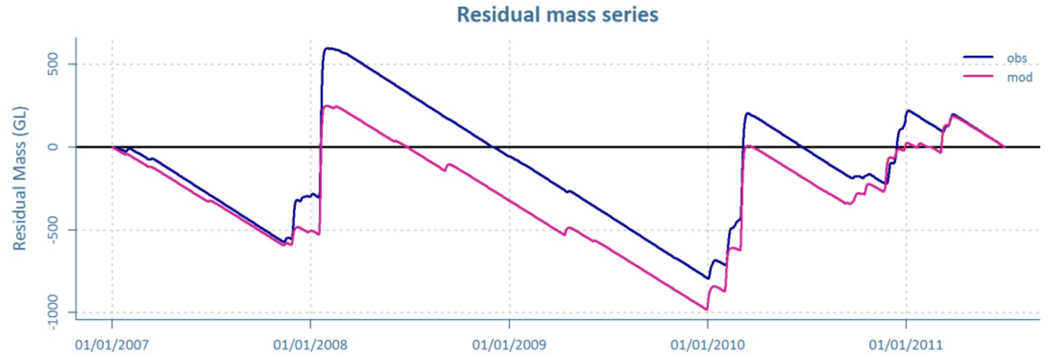


Figure 6.12: Reach 3 – Sacramento Calibration Report Card (Validation Period 2)

6.4.4.6 Discussion

The Sacramento calibration aimed at reproducing the full range of flows, as reflected in the daily flow duration curves shown on the report cards (Figure 6.10, Figure 6.11 and Figure 6.12). Over the full period of calibration, this was achieved, although some events were not reproduced, and in some cases, the simulated events are not synchronous with the observed events.

This is a very large catchment of almost 15,000 km^2 and the rainfall stations that were adopted for calibration provide the best combination of available data. However their spatial distribution is sporadic, reducing in numbers towards the southWwest of the catchment. These characteristics increase the risk of local events not being recorded at a rainfall station, thus influencing the ability of the model to replicate gauged flow events.

Efforts to improve the timing and duration of flow events via adjustments to the unit hydrograph had varied success. From Table 6.17 and Table 6.18 it can be seen that there is an over-estimation of flows in the first validation period and an under-estimation of flows in the second validation period. On average, the daily recorded flows are lower in the first validation period, which the model cannot replicate consistently. The daily residual mass curves show a good reproduction of flood events.

6.4.5 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.

6.4.6 Final Inflow Sequence

For this reach the full length inflow sequence was adjusted using DMM for the missing period of record. Table 6.19 and Figure 6.13 show the composition of the final inflow sequence for Reach 3.

The flow sequences for Reaches 1 and 2, (previously adjusted to Charleville), together with the calibrated flow sequences for Reaches 3 and 4 were adjusted to align the model flows to the flow record at GS423203a Warrego River at Wyandra. This adjustment also accounts for any issues arising from periods of missing data and allows for a better correlation of the upstream flow characteristics to the gauged record at Wyandra, which is continuous from 1967.

Some flow characteristics showed irregularities which reflect the fact that the quality codes for the flow data during this period are dissimilar to those at other gauging station records in the system. For this reason, the DMM does not adjust any reach inflows to Wyandra from 18/05/1999–21/11/2001.

Table 6.19: Reach 3 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–28/02/1967	Sacramento		
01/03/1967–17/05/1999	Sacramento adjusted	423203a	Factor proportional to catchment area contribution. Reach 1 = 0.19 Reach 2 = 0.19 Reach 3 = 0.34 Reach 4 = 0.28
18/05/1999–21/11/2001	Sacramento		Gauged data is estimated and doesn't reflect records.
22/11/2001–10/01/2002	Sacramento adjusted	423203a	See note above.
11/01/2002–30/06/2011	Gauge	423205a	

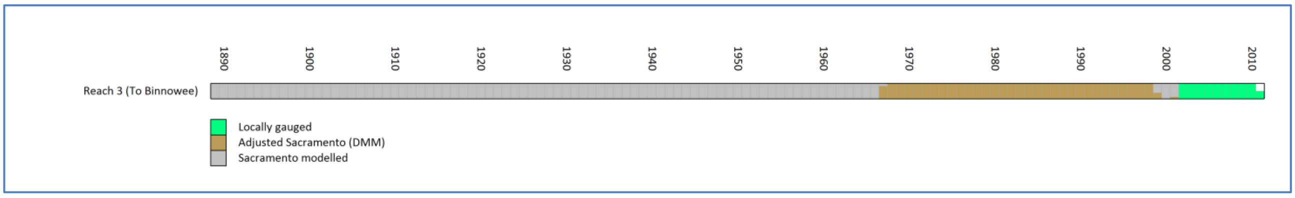


Figure 6.13: Reach 3 – Composition of Final Inflow Sequence

6.5 Reach 4 – Charleville to Wyandra

6.5.1 Description

Reach 4 is located in the central part of the Warrego catchment, incorporating the area of the Warrego River between Charleville (AMTD 383 km) and Wyandra (AMTD 238.2 km). The reach lies downstream of Augathella and has a catchment area of 11,895 square kilometres. In the 2003 study, this reach incorporated the Ward River catchment area, which is now modelled separately as Reach 3. For this reason, and the fact that there is no common period of gauged flow record between Ward River at Binnowee and the gauge at either Charleville or Wyandra, the calibrated flow for Reach 3 is used during the calibration of the residual flow for Reach 4.

The catchment is relatively steep along its north east boundary, with elevations up to 800 m in the headwaters of Angellala Creek, falling to about 280 m at the Warrego River near Charleville. The reach extends both northeast and northwest of Charleville, and is bound to the west by the Warrego Range and the Chesterton Range to the east. There are three main tributaries that join the Warrego River between Charleville and Wyandra: Ward and Langlo Rivers from the west and Angellala Creek from the east. The location of Reach 4 can be seen on can be seen on Figure 1.1.

Rainfall gauges within Reach 4 have records of average annual rainfall that range from 385 to 545 mm/a. The average catchment rainfall of Reach 4 is 481 mm/a, which is consistent with the trend for rainfall averages to decrease towards the southern reaches of the Warrego catchment. The 50 year mean annual rainfall isohyets for Reach 4 are shown on Figure 6.14.

6.5.2 Data

6.5.2.1 Flow Data

The stream flow data used for calibration can be viewed in Table 6.20.

Table 6.20: Reach 4 – Flow Data

Location	Station	Period
Upstream	423201a	13/09/1926–31/01/1978 (multiple periods of missing data-see Table 5.3)
Downstream	423203a	27/02/1967–30/06/2011

The multiple periods of missing data at the upstream gauge reduce the amount of data available in the common period of record, leading to issues during the residual calibration.

6.5.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 4. The weightings of each rainfall station are also summarised in Table 6.23.

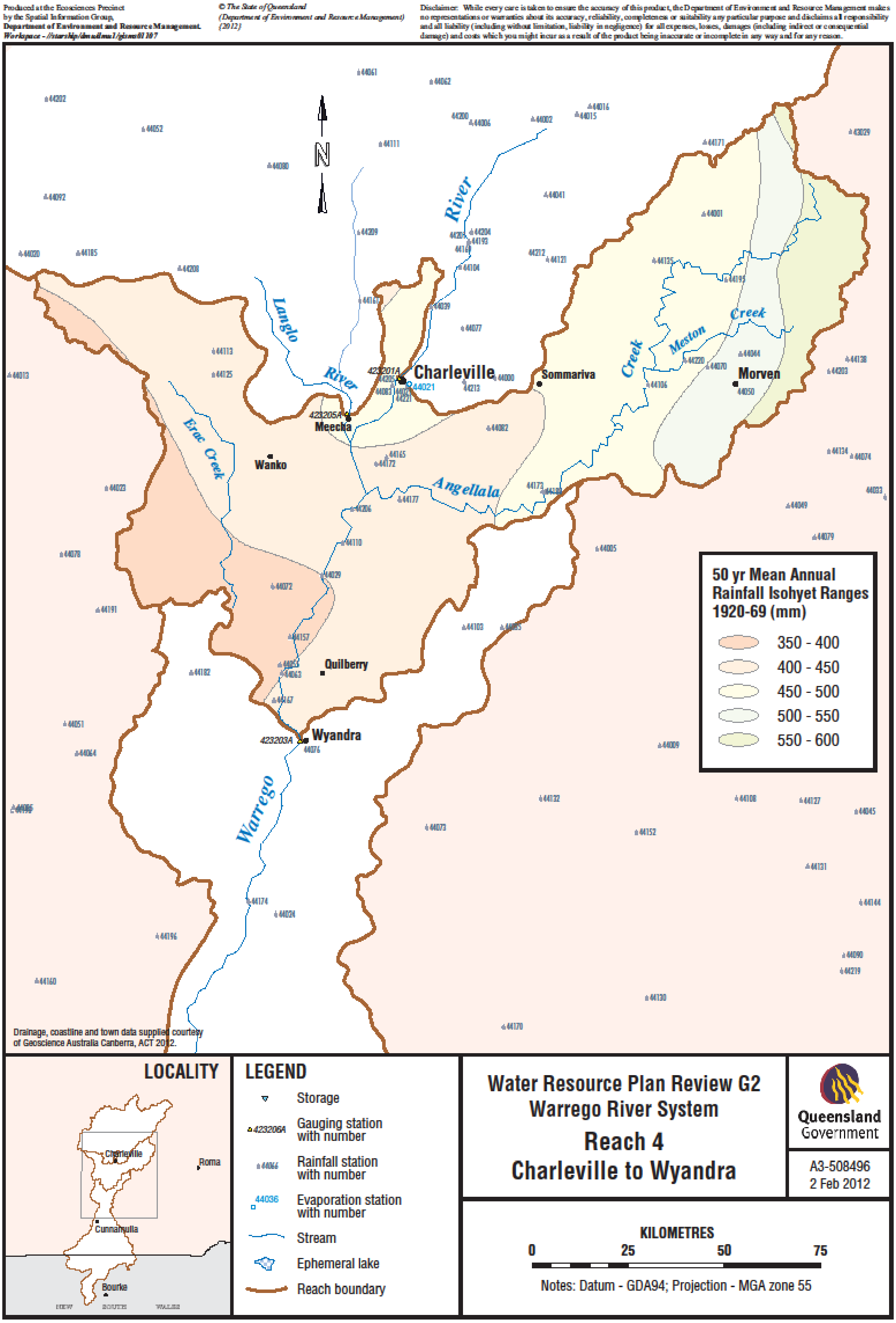


Figure 6.14: Reach 4 – Mean Annual Rainfall Isohyets Data

6.5.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 4.

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 4 was completed according to the methods outlined in Section 4.1. Only one model was required to calculate the residual inflow for Reach 4 due to there being no change in the infrastructure layout of the catchment. Missing periods of data at the gauges were removed from the derived residual.

As mentioned previously, during the 2003 study this reach incorporated the Ward River catchment area, which is now modelled separately as Reach 3. The calibrated flow, rather than the recorded gauge record at Binnowee, is used to represent the contribution of Ward River during the calibration of the residual flow for Reach 4.

6.5.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations 01/03/1967–19/01/1978. During this time, there are multiple periods of missing data at the Charleville gauge. The lack of continuous common record reduced the quality of the resulting flow calibration for Reach 4.

6.5.3.3 Routing Parameters

The routing parameters were determined using trial and error. The non-linear lag and route procedure was used for the routing that was applied at the links between nodes. Recorded flows from the upstream gauge were routed and compared with suitable recorded events at the downstream gauge. The calibrated lag and routing parameters used for the reach are listed in Table 6.21.

Table 6.21: Reach 4 – Lag and Routing Parameters

Reach	Reach Length (km)	Lag Time (days)	k	m
U/S of Ward River Junction	17.0	1.0	0.01	0.85
D/S of Ward River Junction	107.9	2.0	0.01	0.85

6.5.3.4 Unaccounted Difference

A derived unaccounted difference relationship was added at the end of the reach. It is shown in Table 6.22. The unaccounted differences were determined by a comparison of the modelled and measured flow duration curves at the downstream gauge. These differences are consist of losses between the gauges as well as modelling artefacts caused by the differences between the routing in the model and the actual system as well as uncertainties in the rating curves of the gauges. The large differences at high flows are probably caused by breakouts onto the floodplain at high flows.

Table 6.22: Reach 4 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
3	3
100	10
15,000	1,500
100,000	2,000
260,000	60,000
1e6	60,000

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 01/03/1967 to 19/01/1978, the period of the derived residual. The missing flow record at Charleville was excluded from the calibration.

6.5.4.2 Unit Hydrograph

Table 6.23 shows the unit hydrograph adopted for calibration. During calibration it was observed that adjustments to the hydrograph had limited effect on the flow characteristics. Therefore, this basic unit hydrograph has been utilised.

6.5.4.3 Catchment Area

The catchment area of Reach 4 is 11,895 square kilometres.

6.5.4.4 Sacramento Model Parameters

Table 6.23 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 6.23: Reach 4 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	1	-
Rf1 (44021)	0.374	-
Rf2 (44050)	0.305	-
Rf3 (44052)	0.042	-
Rf4 (44063)	0.237	-
Rf5 (44104)	0.042	-
adimp	0	-
lzfpm	13	0
lzfsm	65	0
lzpk	0.085	-
lzsk	0.55	-
lztwm	127	0
pctim	0	-
pfree	0.045	-
rexp	1	-
sarva	0.0002	-
side	0	-
ssout	0	-
uzfwm	15	0
uzk	0.3	-
uztwm	20	0
zperc	100	-
uh0	0.99	-
uh1	0.01	-

6.5.4.5 Sacramento Model Calibration Results

Table 6.24 shows the flow statistics for the recorded and calculated data for the calibration period. A report card of the Sacramento calibration is shown in Figure 6.15. 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.

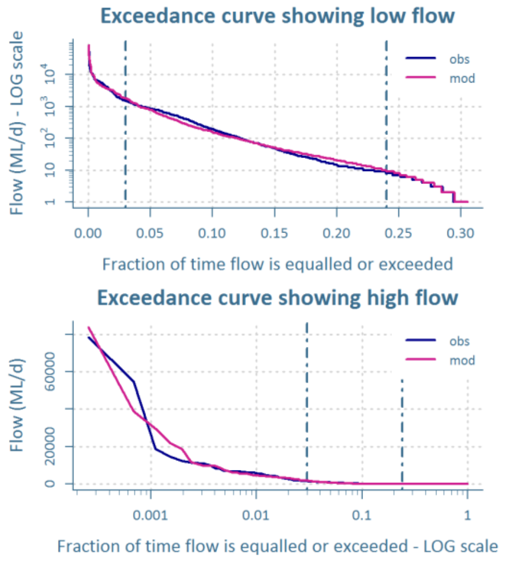
Table 6.24: Reach 4 – Sacramento Calibration Statistics

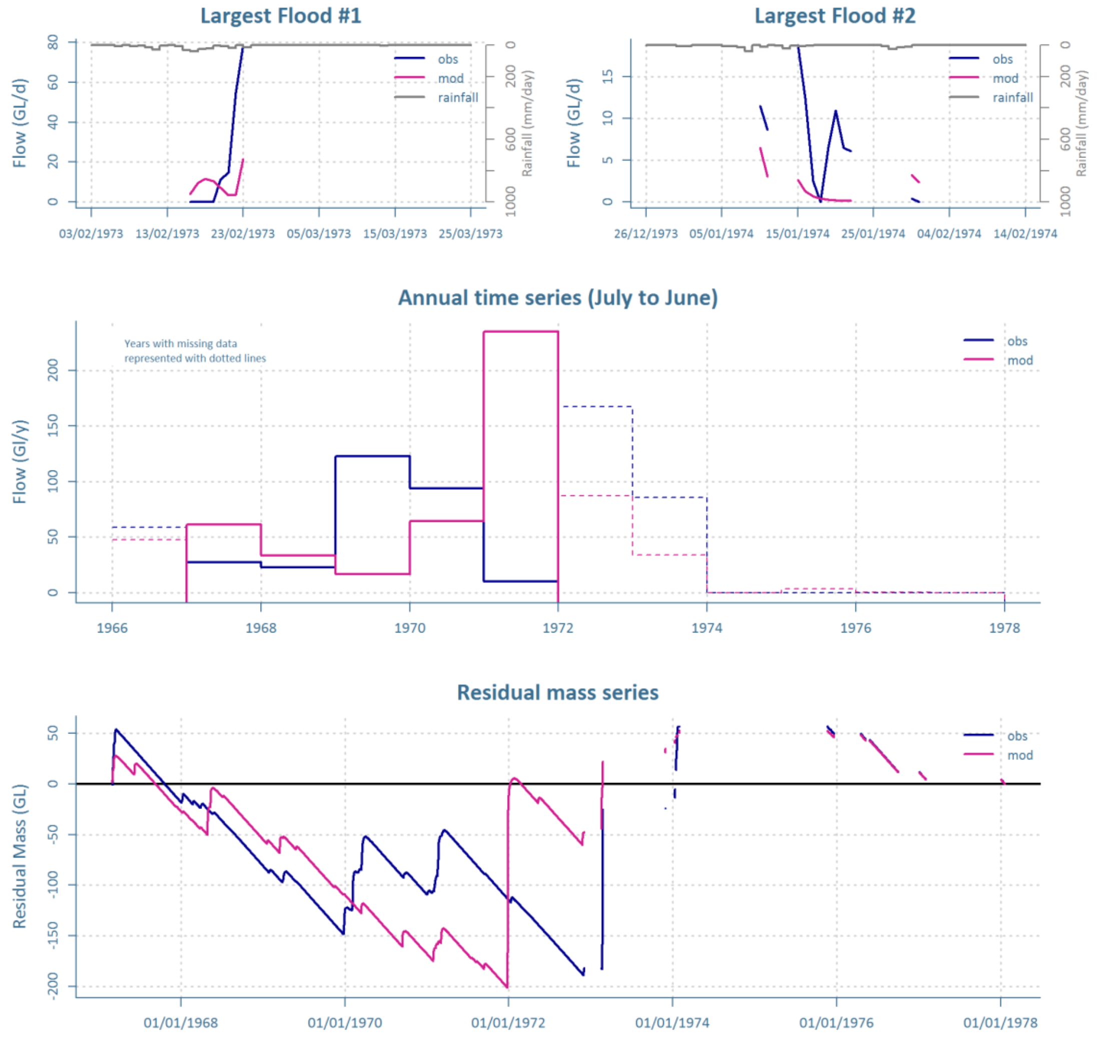
Location	Statistic	Daily	
		Recorded	Simulated
Charleville to Wyandra 01/03/1967–19/01/1978 Calibration	Mean (ML)	249.60	247.47
	Standard Deviation (ML)	2,207	2,227
	Skew	26.18	26.58
	Maximum Flow (ML)	78,487 23/02/1973	83,715 28/12/1971
	Volume Change (%)	99.15	
	Coefficient of Determination	0.040	
	Coefficient of Efficiency	-0.1998	

Warrego River between Charleville (423201A) and Wyandra (423203A)

Period of analysis: 1/3/1967 to 19/1/1978

(observed flow is available for 59.3% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	588,317	-0.9%	★★★★☆
Total Low Flow Volume (ML)*	621	9.2%	★★★☆☆
Total Medium Flow Volume (ML)*	124,169	-8.7%	★★★☆☆
Total High Flow Volume (ML)*	463,527	1.2%	★★★★☆
Mean Flow Volume (ML/d)	250	-0.9%	★★★★☆
Driest 3 Year Mean (ML/d)	158	-35.4%	★☆☆☆☆
Zero Flow Days (%)+	69.5%	0.0%^	★★★★★
Standard Deviation (ML/d)	2,207	0.9%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	-0.61	★☆☆☆☆
Non-matching Zero Flow Days	30.3%	★★☆☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.24 to 1 exceedance probability range
* Medium flow = flow in the 0.03 to 0.24 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 6.15: Reach 4 – Sacramento Calibration Report Card

6.5.4.6 Discussion

The Sacramento calibration aimed at reproducing the full range of flows, as reflected in the daily flow duration curve. Over the full period of calibration, this was achieved, although some events were not reproduced, and in some cases, the simulated events occurred earlier than the observed events.

Reach 4 is a residual catchment, and so 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.

Reach 4 demonstrates these difficulties in calibration. The upstream gauge at Charleville closed in 1978, while the downstream gauge at Wyandra commenced records in 1967. This presents a limited window of opportunity to calibrate the residual flow. Additionally there are multiple periods of missing data at the Charleville gauge, further reducing the congruence of the gauged data. The resulting calibration was therefore the best compromise that could be made to maintain the timing and magnitude of flow events.

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 the full length inflow sequence was adjusted using DMM for the missing period of record. Table 6.25 and Figure 6.16 show the composition of the final residual inflow sequence for Reach 4.

The flow sequences for Reaches 1 and 2, (previously adjusted to Charleville), together with the calibrated flow sequences for Reaches 3 and 4 were adjusted to align the model flows to the flow record at GS423203a Warrego River at Wyandra. This adjustment also accounts for any issues arising from periods of missing data and allows for a better correlation of the upstream flow characteristics to the gauged record at Wyandra, which is continuous from 1967.

During calibration it was observed that some flow characteristics showed irregularities with events from local catchments. Further scrutiny of the gauged record for Wyandra revealed that the quality codes of the flow data for these events are dissimilar to those at other gauging station records in the system. For these reasons, the DMM does not adjust any reach inflows to Wyandra from 18/05/1999–21/11/2001. This period was also excluded from the flow adjustment of Reaches 5 and 6.

Table 6.25: Reach 4 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–28/02/1967	Sacramento		
01/03/1967–02/10/1967	Sacramento adjusted	423203a	Factor proportional to catchment area contribution. Reach 1 = 0.19 Reach 2 = 0.19 Reach 3 = 0.34 Reach 4 = 0.28
03/10/1967–01/12/1972	Derived residual	423203a	
02/12/1972–31/01/1973	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
01/02/1973–01/02/1973	Derived residual	423203a	
02/02/1973–15/02/1973	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
16/02/1973–23/02/1973	Derived residual	423203a	
24/02/1973–01/05/1973	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
02/05/1973–02/05/1973	Derived residual	423203a	
03/05/1973–27/11/1973	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
28/11/1973–29/11/1973	Derived residual	423203a	
30/11/1973–04/01/1974	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
05/01/1974–05/01/1974	Derived residual	423203a	
06/01/1974–09/01/1974	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
10/01/1974–11/01/1974	Derived residual	423203a	
12/01/1974–14/01/1974	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
15/01/1974–22/01/1974	Derived residual	423203a	
23/01/1974–29/01/1974	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
30/01/1974–31/01/1974	Derived residual	423203a	

Period	Data Description	Downstream Gauge	Notes
01/02/1974–19/11/1975	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
20/11/1975–02/12/1975	Derived residual	423203a	
03/12/1975–04/12/1975	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
05/12/1975–19/12/1975	Derived residual	423203a	
20/12/1975–15/04/1976	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
16/04/1976–09/05/1976	Derived residual	423203a	
10/05/1976–25/05/1976	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
26/05/1976–30/09/1976	Derived residual	423203a	
01/10/1976–01/01/1977	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
02/01/1977–31/01/1977	Derived residual	423203a	
01/02/1977–01/01/1978	Sacramento adjusted	423203a	Missing data periods from 423201a adjusted to 423203a.
02/01/1978–19/01/1978	Derived residual	423203a	
20/01/1978–17/05/1999	Sacramento adjusted	423203a	Gauge records at 423201a end 31/01/1978.
18/05/1999–21/11/2001	Sacramento		Gauged data is estimated and doesn’t reflect records.
22/11/2001–30/06/2011	Sacramento adjusted	423203a	Gauge records at 423201a end 31/01/1978.

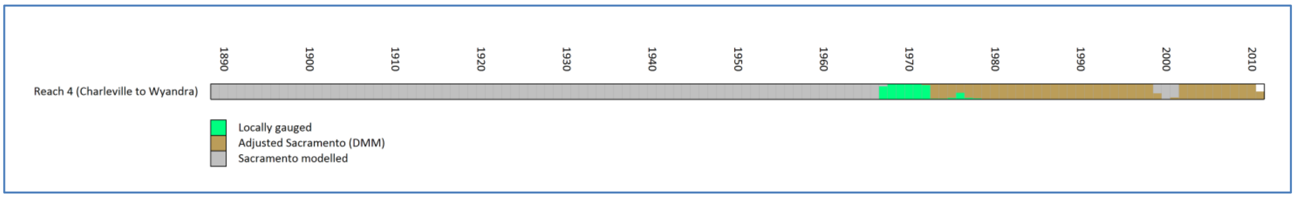


Figure 6.16: Reach 4 – Composition of Final Inflow Sequence

6.6 Reach 5 – Wyandra to Wallen

6.6.1 Description

Reach 5 is situated in the central part of the Warrego catchment, incorporating the area of the Warrego River between Wyandra (AMTD 238.2 km) and Wallen (188.8 km). The location of Reach 5 can be seen on Figure 1.1. The reach lies upstream of the Noorama and Widgeegoara Channel breakouts and has a catchment area of 4,022 square kilometres. Prior to the availability of data at the Wallen streamflow gauge, previous models extended this catchment area south along the Warrego River to Cunnamulla.

Rainfall gauges within Reach 5 have records of average annual rainfall that range from 370 to 416 millimetres per annum. The average catchment rainfall of Reach 5 is 390 mm/a, which equates to a reduction of 90 mm/a from the upstream catchment. This reduction demonstrates the southerly trend of decreasing rainfall averages in the Warrego catchment. The 50 year mean annual rainfall isohyets for Reach 5 are shown on Figure 6.17.

6.6.2 Data

6.6.2.1 Flow Data

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

Table 6.26: Reach 5 – Flow Data

Location	Station	Period
Upstream	423203a	27/02/1967–30/06/2011
Downstream	423206a	04/11/2005–30/06/2011

6.6.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 5. The weightings of each rainfall station are also summarised in Table 6.29.

6.6.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 5.

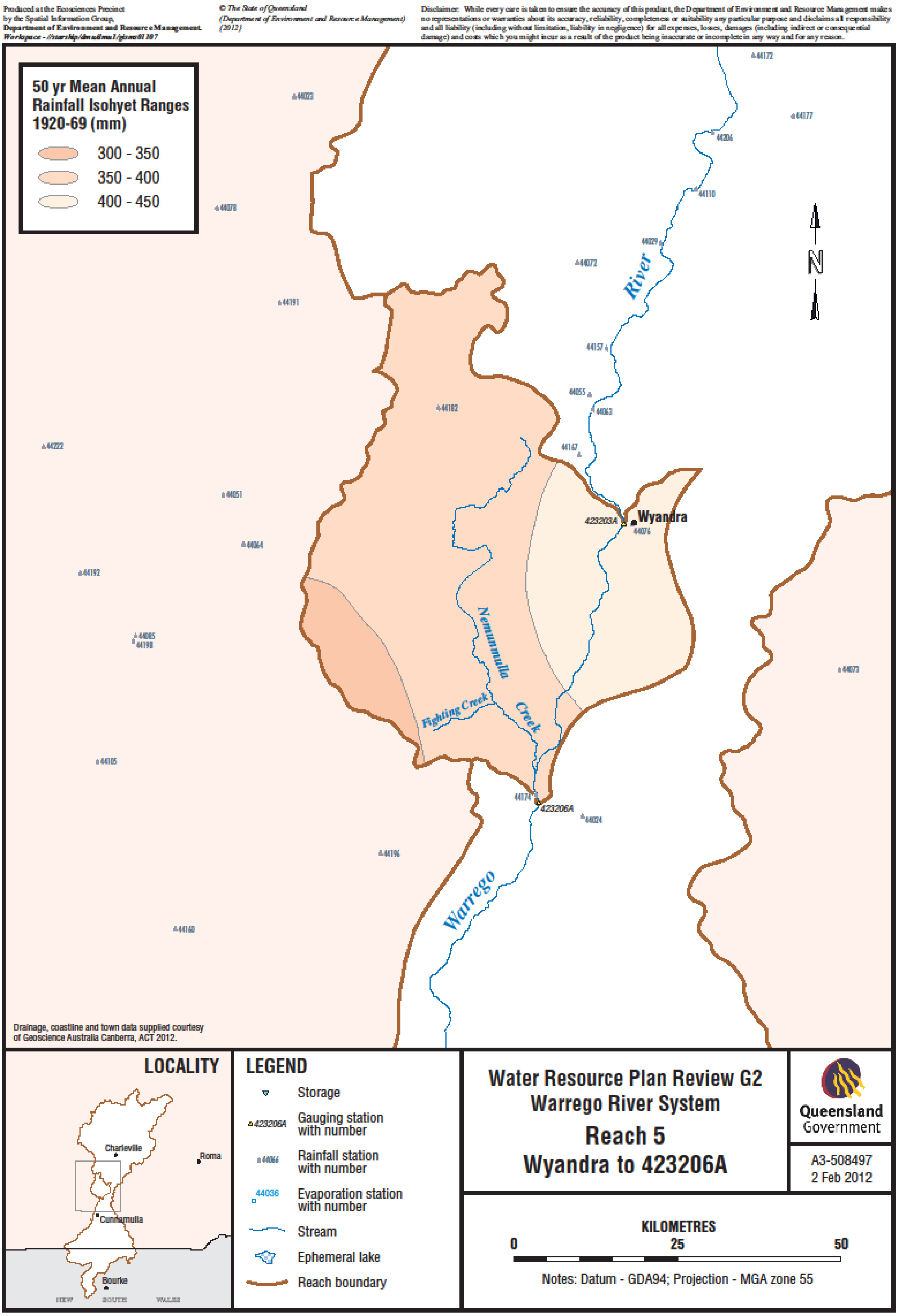


Figure 6.17: Reach 5 – Mean Annual Rainfall Isohyets Data

6.6.3 Reach Calibration and Record Based Inflow Sequence

6.6.3.1 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.

The flow records are complete at both the upstream and downstream gauge sites. The data at Wallen shows numerous sections where the HYDSTRA code indicates that the flow was estimated. The short period of common data between the upstream and downstream gauge sites was a limitation in calibrating a representative flow sequence for Reach 5.

6.6.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations 04/11/2005–30/06/2011. During this time, there are no periods of missing data at the streamflow gauges.

6.6.3.3 Routing Parameters

The routing parameters were determined using trial and error. The non-linear lag and route procedure was used for the routing that was applied at the links between nodes. Recorded flows from the upstream gauge were routed and compared with suitable recorded events at the downstream gauge. The calibrated lag and routing parameters used for the reach are listed in Table 6.27.

Table 6.27: Reach 5 – Lag and Routing Parameters

Reach	Reach Length (km)	Lag Time (days)	k	m
Warrego River at Wallen	49.4	1.0	0.01	0.85

6.6.3.4 Unaccounted Difference

A derived unaccounted difference relationship was added at the end of the reach. It is shown in Table 6.28. The unaccounted differences were determined by a comparison of the modelled and measured flow duration curves at the downstream gauge. These differences are consist of losses between the gauges as well as modelling artefacts caused by the differences between the routing in the model and the actual system as well as uncertainties in the rating curves of the gauges. The large difference at high flows are probably caused by breakouts onto the floodplain at high flows

Table 6.28: Reach 5 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
20	0
150	20
32,000	20
48,000	10,000
185,000	25,000
1e10	25,000

6.6.4 Sacramento Model Calibration

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

6.6.4.1 Time Period

The calibration period for the reach Sacramento was 04/11/2005 to 30/06/2011, the period of the derived residual.

6.6.4.2 Unit Hydrograph

Table 6.29 shows the unit hydrograph adopted for calibration.

6.6.4.3 Catchment Area

The total catchment area of Reach 5 is 4,022 square kilometres.

6.6.4.4 Sacramento Model Parameters

Table 6.29 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 6.29: Reach 5 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	1	-
Rf1 (44063)	0.177	-
Rf2 (44064)	0.207	-
Rf3 (44072)	0.061	-
Rf4 (44076)	0.317	-
Rf5 (44174)	0.238	-
adimp	0	-
lzfpm	20	0
lzfsm	90	0
lzpk	0.017	-
lzsk	0.4	-
lztwm	205	0
pctim	0	-
pfree	0.075	-
rexp	1	-
sarva	0.0008	-
side	0	-
ssout	0.0006	-
uzfwm	30	0
uzk	0.4	-
uztwm	27	0
zperc	40	-
uh0	0.99	-
uh1	0.01	-

6.6.4.5 Sacramento Model Calibration Results

Table 6.30 shows the flow statistics for the recorded and calculated data for the calibration period. A report card of the Sacramento calibration is shown in Figure 6.18. Appendix C5 includes daily plots of the data.

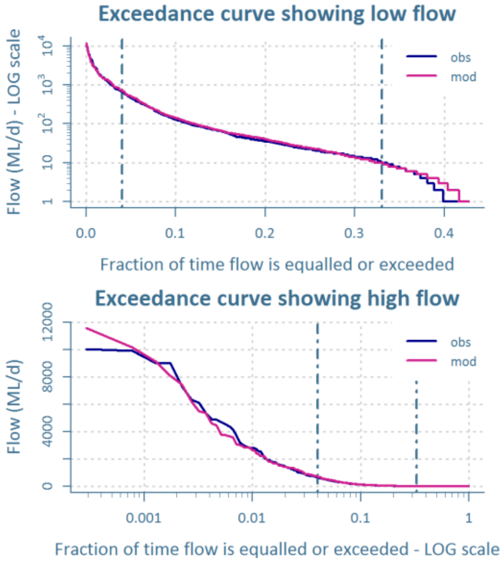
Table 6.30: Reach 5 – Sacramento Calibration Statistics

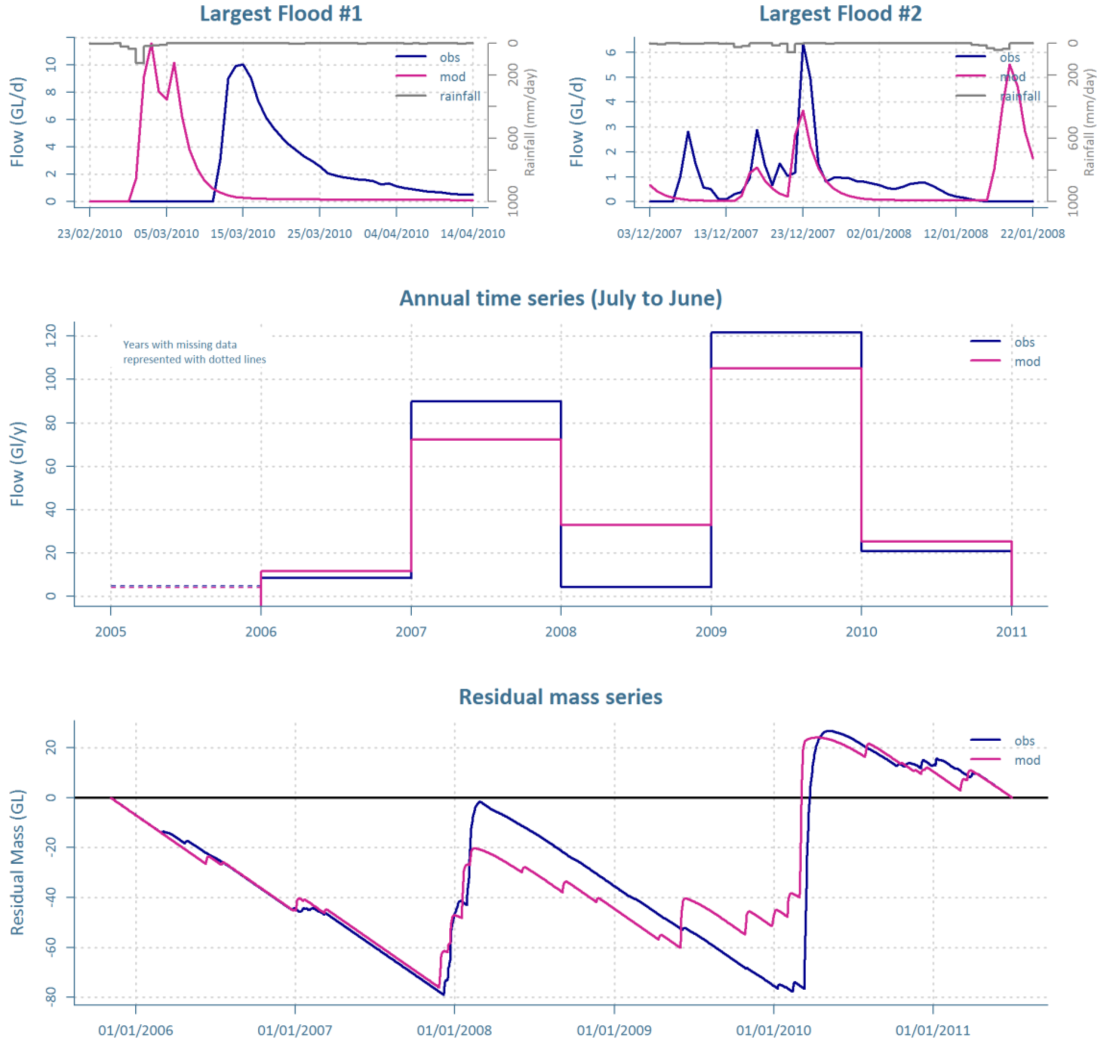
Location	Statistic	Daily	
		Recorded	Simulated
Wyandra to Wallen 04/11/2005–30/06/2011 Calibration	Mean (ML)	120.99	121.45
	Standard Deviation (ML)	631.23	624.20
	Skew	10.02	10.70
	Maximum Flow (ML)	10,021 15/03/10	11,574 03/03/10
	Volume Change (%)		100.38
	Coefficient of Determination		0.0097
	Coefficient of Efficiency		-0.783

Warrego River between Wyandra (423203A) and Wallen (423206A)

Period of analysis: 4/11/2005 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)	249,850	0.4%	★★★★☆
Total Low Flow Volume (ML)*	846	13.9%	★★☆☆☆
Total Medium Flow Volume (ML)*	56,930	6.7%	★★★☆☆
Total High Flow Volume (ML)*	192,074	-1.6%	★★★★☆
Mean Flow Volume (ML/d)	121	0.4%	★★★★☆
Driest 3 Year Mean (ML/d)	94	13.8%	★★☆☆☆
Zero Flow Days (%)+	58.6%	1.4%^	★★★☆☆
Standard Deviation (ML/d)	631	-1.1%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	-0.78	★☆☆☆☆
Non-matching Zero Flow Days	31.5%	★★☆☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.33 to 1 exceedance probability range
* Medium flow = flow in the 0.04 to 0.33 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 6.18: Reach 5 – Sacramento Calibration Report Card

6.6.4.6 Discussion

The Sacramento calibration aimed at reproducing the full range of flows, as reflected in the daily flow duration curve. The resulting calibration was the best compromise that could be made to maintain the timing, duration and magnitude of flow events.

Reach 5 is a residual catchment, and so the quality of the Sacramento calibration can be affected by the quality of the derived residual. The derived residual is dependent on a number of factors, one of which is the availability and quality of the gauged flow data.

The duration of the flow records at Wallen restricted the common period between the upstream and downstream gauges, confining the calibration period to just over five years. Consequently, there was limited opportunity to assess the performance of the calibration parameters to accurately reproduce the catchment’s characteristic streamflow sequences. It is anticipated that future calibrations will be improved by a longer duration of flow record.

6.6.5 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.

6.6.6 Final Inflow Sequence

For this reach the full length inflow sequence was adjusted using DMM for the missing period of record. Table 6.31 and Figure 6.19 show the composition of the final residual inflow sequence for Reach 5.

The flow sequences for Reaches 5 and 6 were adjusted to align the model flows to the flow record at GS423202c Warrego River at Cunnamulla. As mentioned previously, during the adjustment of the upstream flows to Wyandra a section of the gauged flow record was identified and excluded from the flow adjustment sequence. This exclusion period was carried through to the flow adjustment of Reaches 5 and 6. This allows the gauged flow events from Wyandra to be seen at Cunnamulla, facilitating continuity of the upstream flow characteristics to the downstream gauged record.

Table 6.31: Reach 5 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–17/01/1992	Sacramento		
18/01/1992–17/05/1999	Sacramento adjusted	423202c	Adjusted to 423202c. Reach 5 = 0.88 Reach 6 = 0.12
18/05/1999–21/11/2001	Sacramento	423206a	Identified period – not adjusted.
22/11/2001–03/11/2005	Sacramento adjusted	423202c	Adjusted to 423202c. Reach 5 = 0.88 Reach 6 = 0.12
04/11/2005–30/06/2011	Derived residual	423206a	

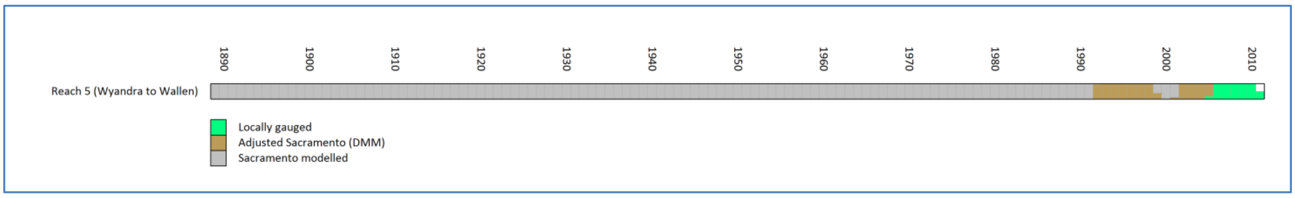


Figure 6.19: Reach 5 – Composition of Final Inflow Sequence

6.7 Reach 6 – Wallen to Cunnamulla

6.7.1 Description

Reach 6 is a narrow catchment, incorporating the area of the Warrego River between Wallen (188.8 km) and Cunnamulla Weir (124.5 km). The streamflow characteristics of Reach 6 are influenced by their adjacent proximity to the Noorama and Widgeegoara Channel breakouts. Previously, this reach was modelled as part of a larger catchment area which extended north to Wyandra along the Warrego River. The location of Reach 6 can be seen on Figure 1.1.

The average catchment rainfall of Reach 6 is 379 mm/a is consistent with the southerly trend of decreasing rainfall averages in the Warrego catchment. The 50 year mean annual rainfall isohyets for Reach 6 are shown on Figure 6.20. The catchment area is 537 square kilometres.

6.7.2 Data

6.7.2.1 Flow Data

The stream flow data used for calibration can be viewed in Table 6.32.

Table 6.32: Reach 6 – Flow Data

Location	Station	Period
Upstream	423206a	04/11/2005–30/06/2011
Downstream	423202c	16/01/1992–30/06/2011

6.7.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 6. The weightings of each rainfall station are also summarised in Table 6.36.

6.7.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 6.

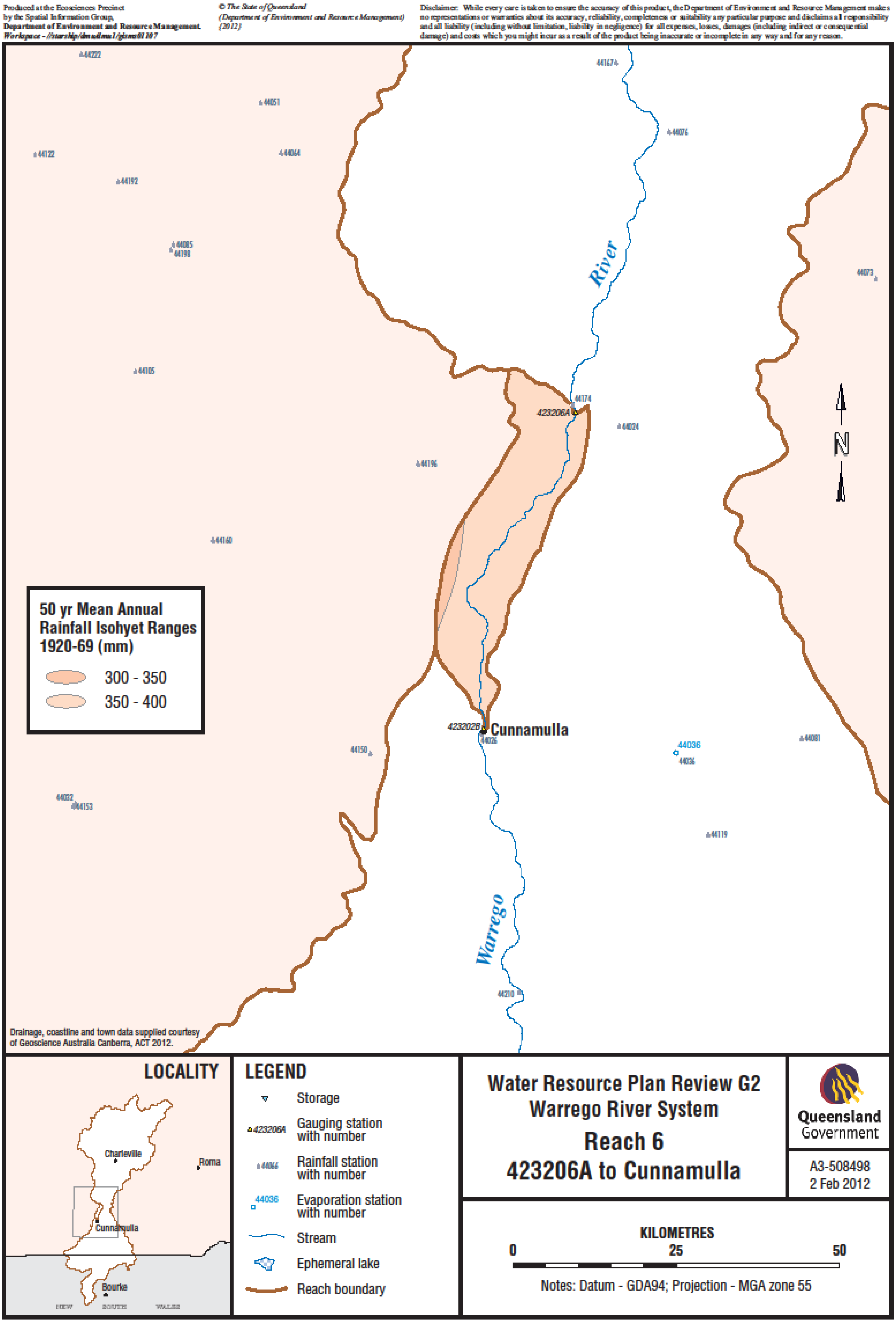


Figure 6.20: Reach 6 – Mean Annual Rainfall Isohyets Data

6.7.3 Reach Calibration and Record Based Inflow Sequence

6.7.3.1 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.

6.7.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations. During this time, there are no periods of missing data at the streamflow gauges. As Wallen is a relatively new gauge, the common period of record between the upstream and downstream gauges is restricted to 04/11/2005–30/06/2011. This limitation is reflected in the quality of the resulting calibration.

6.7.3.3 Routing Parameters

The routing parameters were determined using trial and error. The non-linear lag and route procedure was used for the routing that was applied at the links between nodes. Recorded flows from the upstream gauge were routed and compared with suitable recorded events at the downstream gauge. The calibrated lag and routing parameters used for the reach are listed in Table 6.33.

Table 6.33: Reach 6 – Lag and Routing Parameters

Reach	Reach Length (km)	Lag Time (days)	k	m
Warrego River at Cunnamulla Weir	57.6	1.0	0.01	0.85

6.7.3.4 Unaccounted Differences and Breakouts

The unaccounted differences in this reach were estimated by the comparing simulated flows with recorded flows at Cunnamulla. This involved comparing the flow duration curves for the simulated and recorded flows, and estimating losses based on observable differences in the two curves. Using a trial and error process, losses were applied, until an acceptable calibration was found.

Once calculated, the difference was split into two parts. Flows above 3000 ML/d were estimated to equate to the occurrence of a breakout representative of the Noorama Creek and Widgeegoara Creek breakout flows. A Sacramento model for the Noorama and Widgeegoara catchment was not performed due to the lack of any recorded data for the catchment.

The derived unaccounted difference and the breakout relationships were added at the end of the reach. The relationships are shown in Table 6.34 and Table 6.35.

Table 6.34: Reach 6 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
10	10
200	10
400	40
3,000	200
1e9	200

Table 6.35: Reach 6 – Breakout Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
3,000	200
80,000	1,500
120,000	5,000
140,000	20,000
240,000	106,000
1e9	106,000

6.7.4 Sacramento Model Calibration

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

6.7.4.1 Time Period

The calibration period for the reach Sacramento was 04/11/2005 to 30/06/2011, the period of the derived residual.

6.7.4.2 Unit Hydrograph

Table 6.36 shows the unit hydrograph adopted for calibration.

6.7.4.3 Catchment Area

The total catchment area of Reach 6 is 537 kilometres.

6.7.4.4 Sacramento Model Parameters

Table 6.36 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 6.36: Reach 6 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	1.082	-
Rf1 (44026)	0.0631	-
Rf2 (44174)	1.019	-
adimp	0.0115	-
lzfpm	47.55	0
lzfsm	1.09	0
lzpk	0.00000414	-
lzsk	0.00406	-
lztwm	67.91	0
pctim	0.00559	-
pfree	0.0156	-
rexp	2.27	-
sarva	0.00053	-
side	0.0000188	-
ssout	0.00553	-
uzfwm	76.31	0
uzk	0.161	-
uztwm	117.22	0
zperc	7.01	-
uh0	0	-
uh1	0.404	-
uh2	0.596	-

6.7.4.5 Sacramento Model Calibration Results

Table 6.37 shows the flow statistics for the recorded and calculated data for the calibration period. A report card of the Sacramento calibration is shown in Figure 6.21. Appendix C6 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.

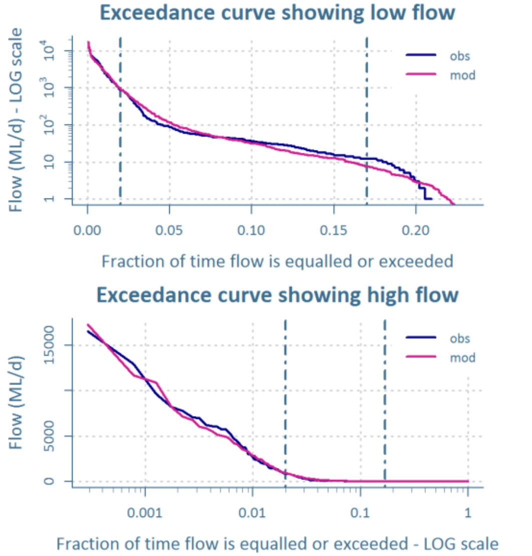
Table 6.37: Reach 6 – Sacramento Calibration Statistics

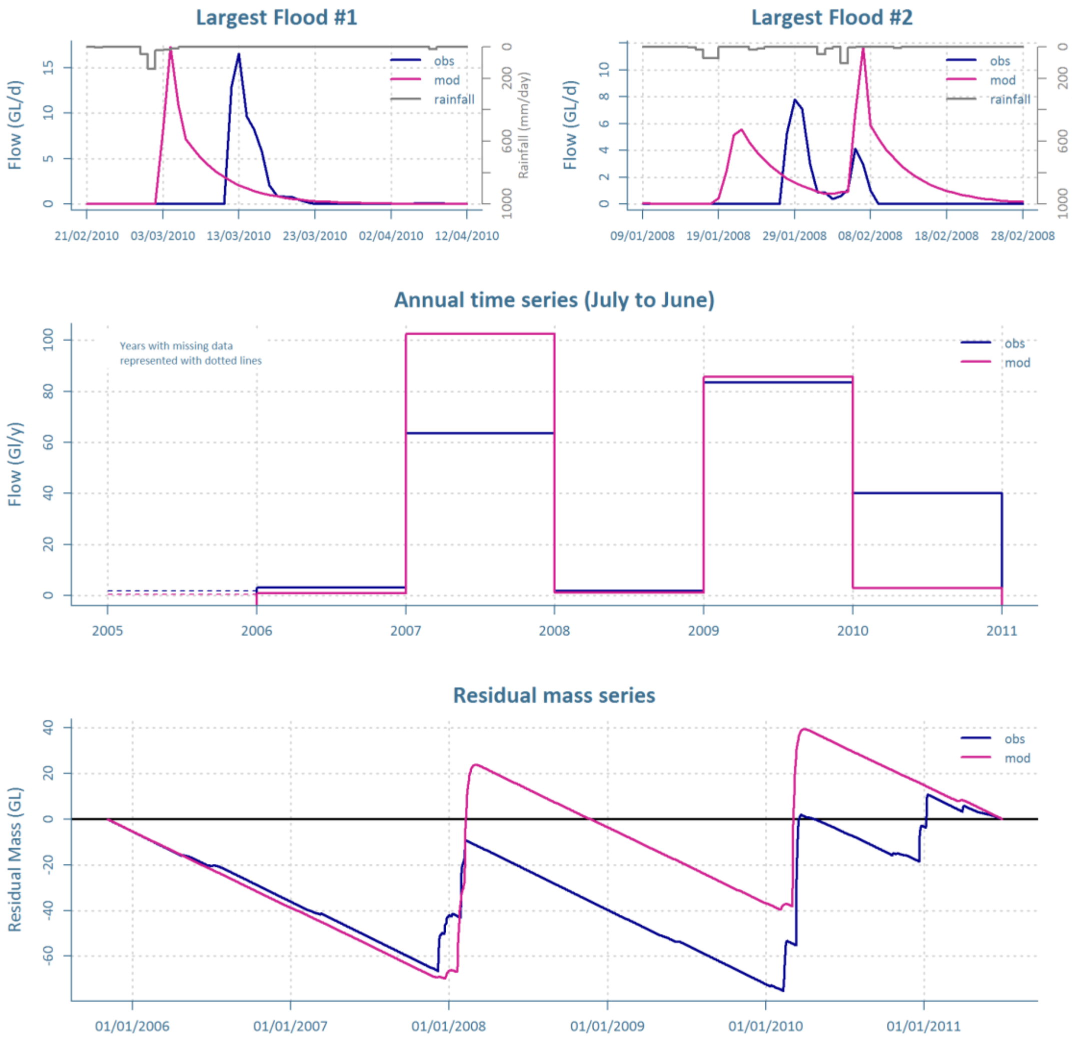
Location	Statistic	Daily	
		Recorded	Simulated
Wallen to Cunnamulla 04/11/2005–30/06/2011 Calibration	Mean (ML)	93.75	93.75
	Standard Deviation (ML)	738.21	722.81
	Skew	12.93	13.55
	Maximum Flow (ML)	16,500 13/03/10	17,262 04/03/10
	Volume Change (%)		99.93
	Coefficient of Determination		0.035
	Coefficient of Efficiency		-0.595

Warrego River between Wallen (423206A) and Cunnamulla (423202C)

Period of analysis: 4/11/2005 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)	193,584	0.0%	★★★★★
Total Low Flow Volume (ML)*	550	-24.3%	★★☆☆☆
Total Medium Flow Volume (ML)*	27,615	13.3%	★★☆☆☆
Total High Flow Volume (ML)*	165,419	-2.1%	★★★★☆
Mean Flow Volume (ML/d)	94	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	62	53.3%	★☆☆☆☆
Zero Flow Days (%)+	79.0%	1.0%^	★★★★☆
Standard Deviation (ML/d)	738	-2.1%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	-0.59	★☆☆☆☆
Non-matching Zero Flow Days	31.8%	★★☆☆☆

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 6.21: Reach 6 – Sacramento Calibration Report Card

6.7.4.6 Discussion

The Sacramento calibration aimed at reproducing the full range of flows, as reflected in the daily flow duration curve. Over the full period of calibration, this was achieved, although some events were not reproduced, and in some cases, the simulated events overestimated the recorded events.

Reach 6 is a residual catchment, and so 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 catchment is influenced by the breakouts to the Widgeegoara and Noorama Creeks. As there are no gauged records for this characteristic of the Warrego River, the breakout relationship was derived as per the unaccountable differences relationship. Adjustments during calibration are based on local knowledge and the observed relationships of events at the upstream and downstream gauge locations.

The calibration period is restricted by the period of recorded data at the upstream gauge. The resulting calibration was the best compromise that could be made to maintain the timing, duration and magnitude of flow events. It is anticipated that future calibrations will be improved by a longer duration of flow records.

6.7.5 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.

6.7.6 Final Inflow Sequence

For this reach the full length inflow sequence was adjusted using DMM for the missing period of record.

Table 6.38 and Figure 6.22 show the composition of the final residual inflow sequence for Reach 6.

The inflow sequences for Reaches 5 and 6 were adjusted to align modelled flows to the record at GS423202c Warrego River at Cunnamulla. Sacramento inflows in Reaches 1 to 4 were not adjusted to Cunnamulla.

As mentioned earlier in Section 6.5.6 the DMM to Wyandra did not adjust any upstream reach inflows from 18/05/1999–21/11/2001 due to issues with the Wyandra recorded flow data.

This exclusion period was also applied in the DMM process when the Reach 5 and 6 inflows were adjusted to Cunnamulla. This was because the Reach 5 and 6 Sacramento inflows would have been inappropriately adjusted to extremely high flows to accommodate the large difference in the modelled and recorded flows at Cunnamulla. The large difference was due to the low flows that arrive at Wyandra that were generated by Sacramento inflows in the upstream reaches. The exclusion of this period facilitated continuity of the upstream flow characteristics downstream.

Table 6.38: Reach 6 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–17/01/1992	Sacramento		
18/01/1992–17/05/1999	Sacramento adjusted	423202c	Adjusted to 423202c. Reach 5 = 0.88 Reach 6 = 0.12
18/05/1999–21/11/2001	Sacramento	423202c	Identified period – not adjusted.
22/11/2001–03/11/2005	Sacramento adjusted	423202c	Adjusted to 423202c. Reach 5 = 0.88 Reach 6 = 0.12
04/11/2005–30/06/2011	Derived residual	423202c	

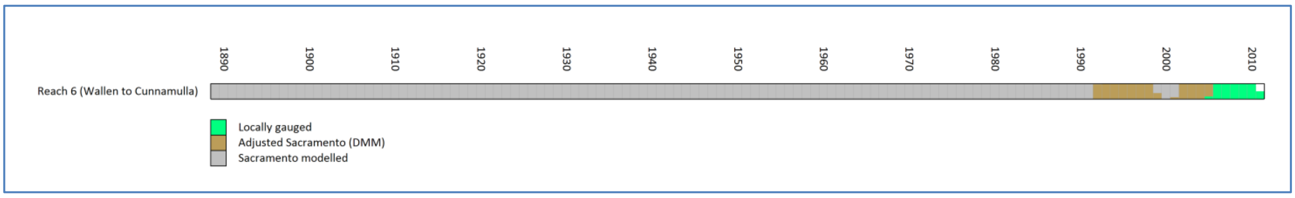


Figure 6.22: Reach 6 – Composition of Final Inflow Sequence

6.8 Reach 9 – Cunnamulla to Barringun

6.8.1 Description

Reach 9 is located in the lower part of the Warrego catchment, incorporating the area of the Warrego River between Cunnamulla (AMTD 124.5 km) and Barringun (AMTD 0.0 km). The location of Reach 9 can be seen on Figure 1.1.

With a catchment area of 4,681 km^2, this is the last mainstream reach in the Warrego catchment that lies above the Queensland-New South Wales border. The reach incorporates the diversions from Warrego River to the Cuttaburra Creek Channel (also referred to as Cuttaburra Creek) and the breakout from Warrego River to Irrara Creek.

Cuttaburra Creek is a permanent tributary breakout from the Warrego River between Cunnamulla and Barringun. The diversion point from the Warrego River is situated near Cunnamulla (AMTD 124.5 km). There is no gauge to determine Warrego River's contribution to the tributary; however a stream flow gauge is located on the Cuttaburra Creek Channel at Turra. This record was used to calibrate a relationship representing the diversion from Warrego River (Reach 9) to the Cuttaburra Creek Channel. Represented as a single node in the Reach 9 model, the flow from the diversion relationship is incorporated in the Reach 12 model as the upstream flow record.

Irrara Creek is a unique tributary of the Warrego River. Irrara Creek breaks out downstream of Cuttaburra Creek, just north of the border, before re-joining the Warrego River just north of Fords Bridge. As there is no gauge site available, flow relationships representing this tributary rely heavily on local knowledge and observations. Consequently, a portion of the unaccounted difference calibrated for Reach 9 is used to represent the inflow to Irrara Creek in Reach 11.

Rainfall gauges within Reach 9 have records of average annual rainfall that range from 328 to 394 millimetres per annum. The average catchment rainfall is 349 mm/a, which is the lowest Queensland average of the Warrego reaches. The 50 year mean annual rainfall isohyets for Reach 9 are shown on Figure 6.23.

6.8.2 Data

6.8.2.1 Flow Data

The stream flow data used for calibration can be viewed in **Error! Reference source not found.**.

Table 6.39: Reach 9 – Flow Data

Location	Station	Period
Upstream	423202c	16/01/1992–30/06/2011
Diversion channel	423005	01/06/1993–30/06/2011
Downstream	423004	31/05/1993–30/06/2011 (missing data 25/04/1997–27/04/1997)

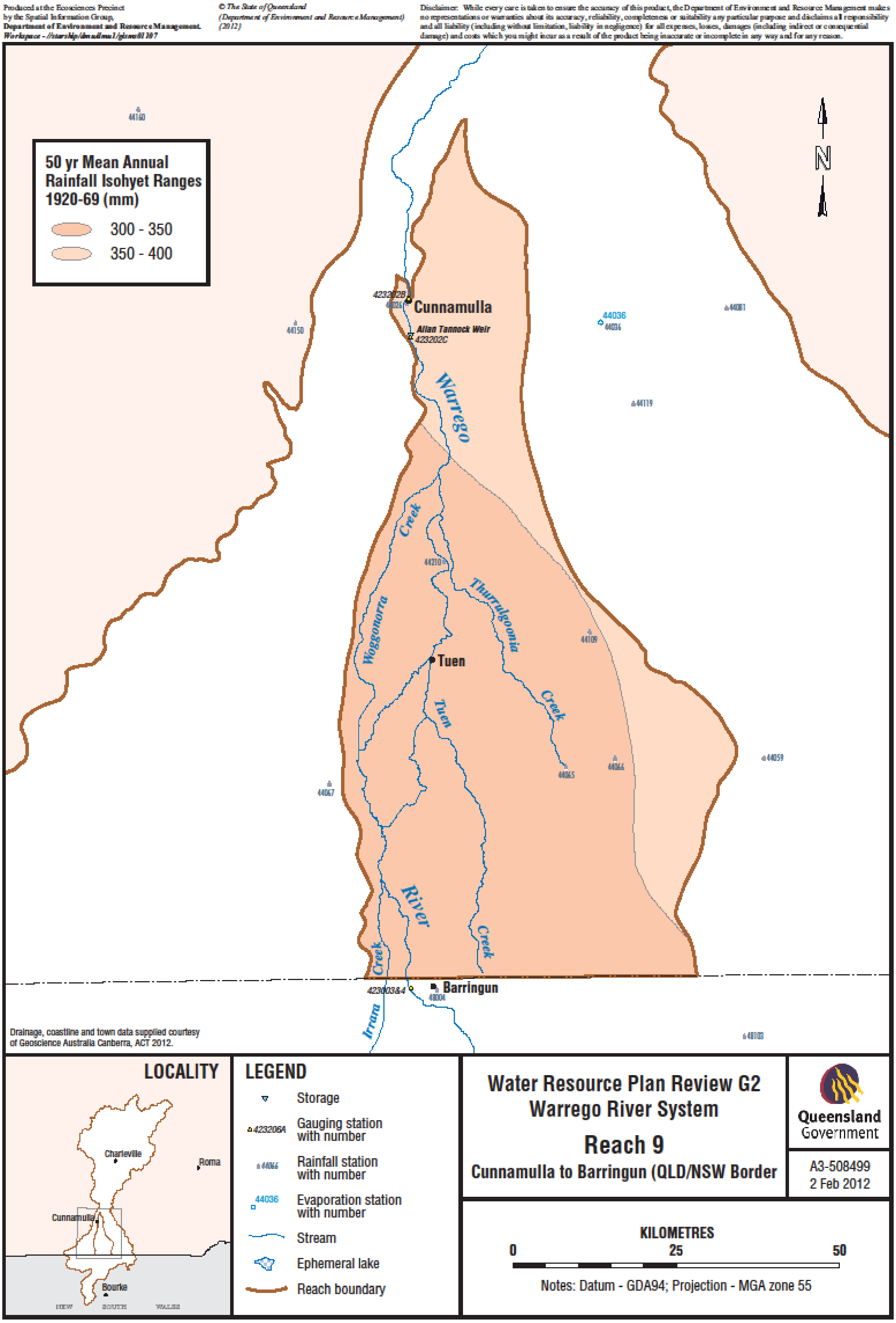


Figure 6.23: Reach 9 – Mean Annual Rainfall Isohyets Data

6.8.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 9. The weightings of each rainfall station are also summarised in Table 6.43.

6.8.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 9.

6.8.3 Reach Calibration and Record Based Inflow Sequence

6.8.3.1 Record Based Inflow Sequence

The residual inflow for Reach 9 was calculated following the derivation of the flow diversion from the Warrego River to the Cuttaburra Creek Channel.

In order to obtain a representative flow sequence for the diversion, a simple model was developed, independent of the Reach 9 calibration model. Using the gauged flow record from the Warrego River at Cunnamulla as the upstream inflow, the flow-diversion relationship (located directly below the inflow node) was adjusted until the effluent flow matched the gauged flow record for Cuttaburra Creek at Turra.

The calibrated diversion relationship was then included in the Reach 9 model, directly upstream of the unaccounted difference node. The effluent flow from the diversion relationship was also extracted and incorporated in the Reach 12 model as the upstream flow record.

The reach calibration and derivation of the record based inflow sequence for Reach 9 was then completed according to the methods outlined in Section 4.1. Only one model was required to calculate the residual inflow for Reach 9 due to there being no change in the infrastructure layout of the catchment. The period of missing data at the downstream gauge was removed from the derived residual.

6.8.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations 31/05/1993–30/06/2011. There is one period of missing data (25/04/1997–27/04/1997) at the Barringun gauge.

6.8.3.3 Routing Parameters

The routing parameters were determined using trial and error. The non-linear lag and route procedure was used for the routing that was applied at the links between nodes. Recorded flows from the upstream gauge were routed and compared with suitable recorded events at the downstream gauge.

The calibrated lag and routing parameters used for the reach are listed in Table 6.40.

Table 6.40: Reach 9 – Lag and Routing Parameters

Reach	Reach Length (km)	Lag Time (days)	k	m
Warrego River at Barringun	131.2	4.0	0.01	0.85

6.8.3.4 Cuttaburra Creek Channel Diversion Relationship

A relationship representing the flow diversion from Warrego River to the Cuttaburra Creek channel was derived and added at the end of the reach.

The Cuttaburra Creek diversion relationship was calibrated using a separate model. The flow passing the diversion point was adjusted until the simulated and recorded flows observed at the Turra gauge on the Cuttaburra Creek Channel were in agreement. This relationship was then transferred to the Reach 9 flow calibration model. The flow diverted to the Cuttaburra Creek Channel was used as an inflow to the Reach 12 flow calibration model.

The derived diversion relationship, as shown in Table 6.41 was added at the end of the reach.

Table 6.41: Reach 9 – Cuttaburra Creek Channel Diversion

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
100	2
192	10
650	150
6,000	2,307
60,000	21,346
136,138	62,415
1e8	62,415

6.8.3.5 Unaccounted Difference

A relationship representing the unaccounted difference relationship for Reach 9 was derived and added at the end of the reach. The relationship is shown in Table 6.42.

The unaccounted differences in Reach 9 were estimated by comparing the simulated flow sequence that remained (following the derivation of the diversion to the Cuttaburra Creek Channel) with recorded flows at Barringun. This involved comparing the flow duration curves for the simulated and recorded flows, and estimating losses based on observable differences in the two curves. Using a trial and error process, losses were applied, until an acceptable calibration was found. Unaccounted differences are derived so the occurrence of negative estimates of reach inflows can be reduced.

Thirty per cent of the effluent flow from the unaccounted difference node was used to represent the Irrara Creek inflow in the Reach 11 flow calibration model. The percentage of flow is based upon local knowledge and observations, which was gathered during the development of the 2003 model. There have been no changes within the catchment to warrant alterations to these relationships.

Table 6.42: Reach 9 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
1	0
12	10
46	43
74	70
132	127
193	187
301	294
589	581
1,550	1,541
7,950	7,940
73,717	73,707
1e8	73,707

6.8.4 Sacramento Model Calibration

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

6.8.4.1 Time Period

The calibration period for the reach Sacramento was 31/05/1993 to 30/06/2011, the period of the derived residual. The missing data period (25/04/1997–27/04/1997) at Barringun was excluded from the calibration.

6.8.4.2 Unit Hydrograph

Table 6.43 shows the unit hydrograph adopted for calibration.

6.8.4.3 Catchment Area

The total catchment area of Reach 9 is 4,681 square kilometres.

6.8.4.4 Sacramento Model Parameters

Table 6.43 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 6.43: Reach 9 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	0.708	-
Rf1 (44026)	0.0368	-
Rf2 (44059)	0.227	-
Rf3 (44065)	0.000284	-
Rf4 (44067)	0.321	-
Rf5 (48004)	0.123	-
adimp	0.00161	-
lzfpm	12.252	0
lzfsm	30.648	0
lzpk	0.0702	-
lzsk	0.329	-
lztwm	54.84	0
pctim	0.000243	-
pfree	0.0498	-
rexp	2.192	-
sarva	2.03E-05	-
side	0.00113	-
ssout	0.000922	-
uzfwm	47.406	0
uzk	0.315	-
uztwm	57.848	0
zperc	28.358	-
uh0	0.339	-
uh1	0.661	-

6.8.4.5 Sacramento Model Calibration Results

Table 6.44 shows the flow statistics for the recorded and calculated data for the calibration period. A report card of the Sacramento calibration is shown in Figure 6.24. Appendix C7 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.

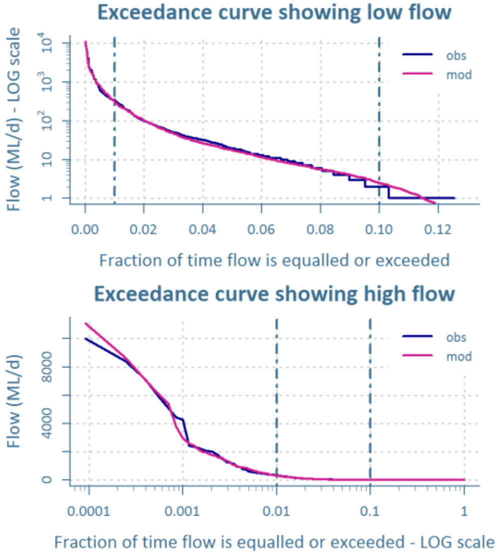
Table 6.44: Reach 9 – Sacramento Calibration Statistics

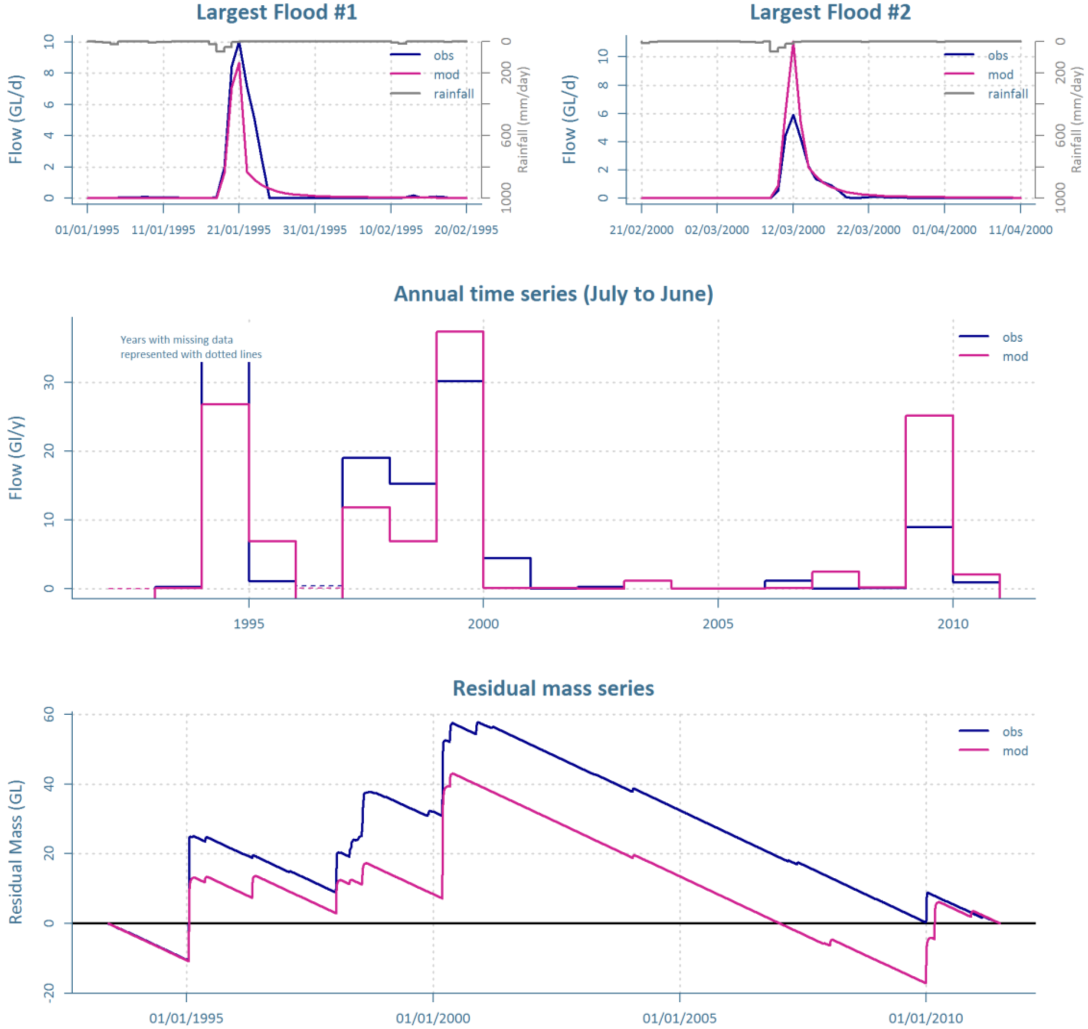
Location	Statistic	Daily	
		Recorded	Simulated
Cunnamulla to Barringun 31/05/1993–30/06/2011 Calibration	Mean (ML)	18.32	18.32
	Standard Deviation (ML)	242.97	247.93
	Skew	27.15	29.07
	Maximum Flow (ML)	10,023 21/01/1995	11,082 12/03/2000
	Volume Change (%)		99.93
	Coefficient of Determination		0.693
	Coefficient of Efficiency		0.646

Warrego River between Cunnamulla (423202C) and Barringun (423004)

Period of analysis: 31/5/1993 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)	120,942	0.0%	★★★★★
Total Low Flow Volume (ML)*	189	13.8%	★★☆☆☆
Total Medium Flow Volume (ML)*	24,061	-5.9%	★★★☆☆
Total High Flow Volume (ML)*	96,692	1.4%	★★★★☆
Mean Flow Volume (ML/d)	18	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	1	-88.6%	★☆☆☆☆
Zero Flow Days (%)+	87.5%	1.1%^	★★★☆☆
Standard Deviation (ML/d)	243	2.1%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.65	★★★☆☆
Non-matching Zero Flow Days	15.7%	★★★☆☆

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.1 to 1 exceedance probability range
* Medium flow = flow in the 0.01 to 0.1 exceedance probability range
* High flow = flow in the 0 to 0.01 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 6.24: Reach 9 – Sacramento Calibration Report Card

6.8.4.6 Discussion

The Sacramento calibration aimed at reproducing the full range of flows, as reflected in the daily flow duration curve. Over the full period of calibration, this was achieved, although some events were not reproduced, and in some cases, the simulated events occurred earlier than the observed events.

Reach 9 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, flow data, and consistency of the ratings at the flow measurement sites.

For Qld gauge sites, the data required for IQQM modeling was readily accessible from HYDSTRA. Barringun is located on the border of Qld and NSW, but is classified as a NSW gauge site. Therefore, it was necessary to obtain Barringun's flow 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. Due to the limited information available for this reach, the calibration relied heavily on flow interactions and characteristics determined from the 2003 study models.

Reach 9 is an important reach, as it also contributes flows to Reach 11 and Reach 12. The diversion of water from Reach 9 influences the timing, duration and magnitude of flow events, which affects the calibration of flow sequences in all associated reaches. The resulting calibration was the best compromise that could be made to maintain the flow characteristics of Reach 9 while providing the appropriate flow sequences for Reach 11 and Reach 12.

6.8.5 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.

6.8.6 Final Inflow Sequence

Table 6.45 and Figure 6.25 show the composition of the final residual inflow sequence for Reach 9.

Table 6.45: Reach 9 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–30/05/1993	Sacramento		
31/05/1993–24/04/1997	Derived residual	423203a	
25/04/1997–27/04/1997	Sacramento		Missing data period at Barringun.
28/04/1997–30/06/2011	Derived residual	423203a	

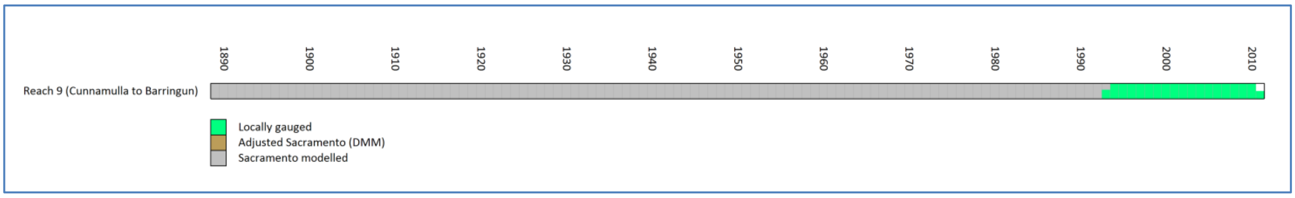


Figure 6.25: Reach 9 – Composition of Final Inflow Sequence

6.9 Reach 11 – Barringun to Fords Bridge

6.9.1 Description

The location of Reach 11 can be seen on Figure 1.1.

Reach 11 is located in the southern part of the Warrego catchment, incorporating the area of the Warrego River between Barringun (QLD AMTD 0.0 km, NSW AMTD 177.9 km) and Fords Bridge (AMTD 63.7 km). The reach lies downstream of the New South Wales border and has a catchment area of 5,123 square kilometres.

The reach extends east and west of the Warrego River, and is bound by the Noorama and Widgeegoara Creeks System to the east and the Cuttaburra Creek catchment to the west.

Tributaries of the Warrego River within this reach include Muttagoona Creek, and Toombah Creek, all of which flow in a south-easterly direction to join the Warrego River. Irrara Creek also rejoins the river, and Keribee Creek causes a permanent breakout to Lake Denman, which lies to the west of the Warrego River.

Rainfall gauges within Reach 11 have records of average annual rainfall that range from 330 to 360 mm/a. The average catchment rainfall of Reach 11 is 348 millimetres per annum. The 50 year mean annual rainfall isohyets for Reach 11 are shown on Figure 6.26.

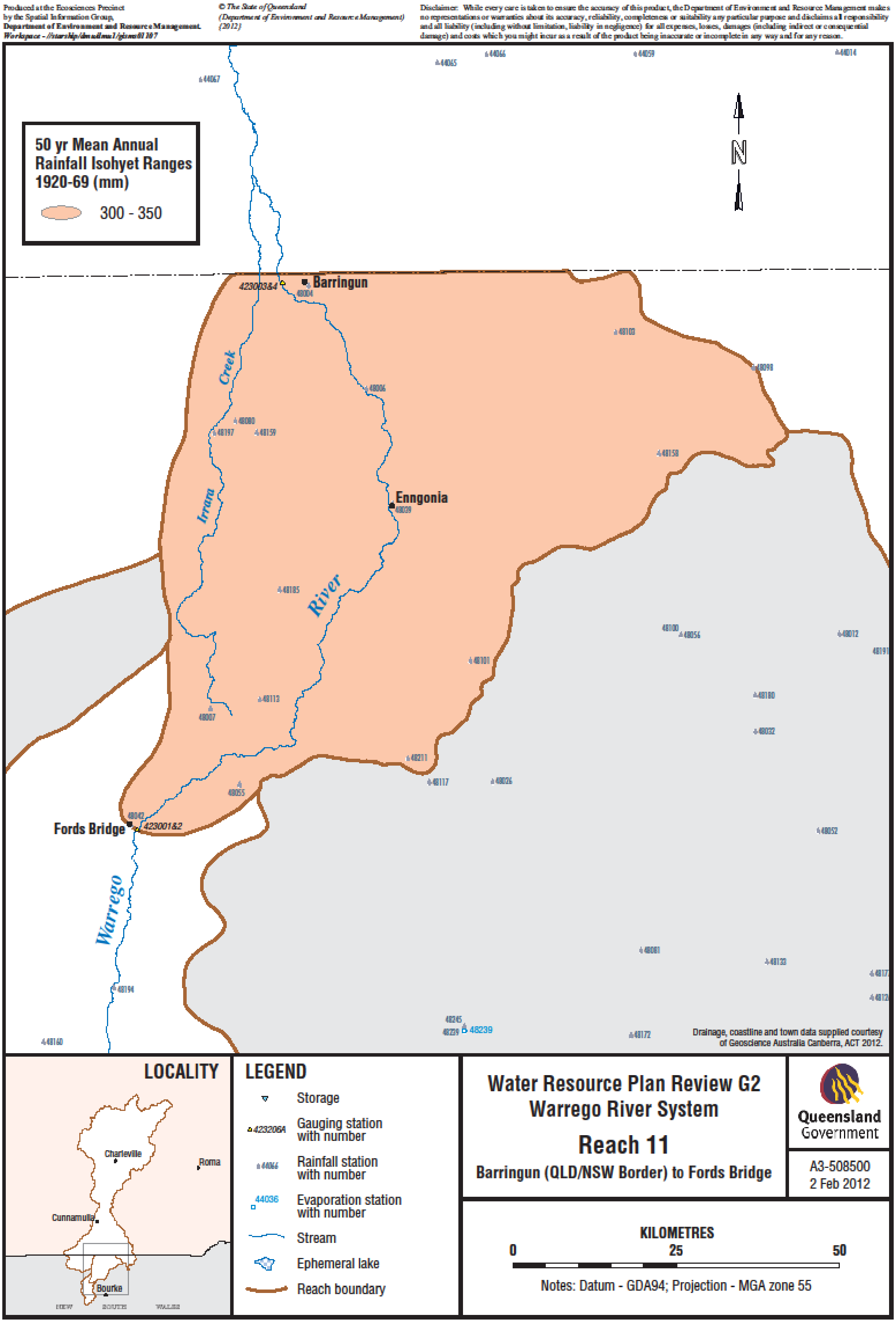


Figure 6.26: Reach 11 – Mean Annual Rainfall Isohyets Data

6.9.2 Data

6.9.2.1 Flow Data

The stream flow data used for calibration can be viewed in Table 6.46. Due to the multiple periods of missing data in the downstream flow records, the gauged flow data at this site was combined for the purpose of reach calibration. The inflow to Irrara Creek was derived during the calibration of Reach 9. Note that only 30 per cent of this flow enters Irrara Creek. Of that flow, 50 per cent is lost to the environment before the remainder returns to the Warrego River. Details of this relationship can be found in Section 6.9.3.4.

Table 6.46: Reach 11 – Flow Data

Location	Station	Period
Upstream	423004	31/05/1993–30/06/2011 (missing data 25/04/1997–27/04/1997)
Irrara Creek Inflow	n/a	31/05/1993–30/06/2011 (Effluent flow from Reach 9)
Downstream	423001	03/01/1972–30/06/2011 (multiple periods of missing data – See Table 5.3)
Downstream	423002	19/12/1972–30/06/2011 (multiple periods of missing data – See Table 5.3)

The Fords Bridge gauges each capture a portion of the floodplain and channel flow but not the total Warrego flow passing Fords Bridge. To obtain a data sequence which did capture it all the recorded data for 423001 and 423002 was combined by adding both files together to create a single flow sequence, referred to as 4230012. This combined record was then used to represent the flow sequence at the downstream gauge.

6.9.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 11. The weightings of each rainfall station are also summarised in Table 6.50.

6.9.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 11.

6.9.3 Reach Calibration and Record Based Inflow Sequence

6.9.3.1 Record Based Inflow Sequence

The reach calibration and derivation of the record based inflow sequence for Reach 11 was completed according to the methods outlined in Section 4.1. Only one model was required to calculate the residual inflow for Reach 11 due to there being no change in the infrastructure layout of the catchment. Missing periods of data at the gauges were removed from the derived residual.

6.9.3.2 Time Period

The residual inflows were derived for the period 19/06/1993 to 30/06/2011. This is shorter than the period of common record between the upstream and downstream gauging stations, due to the decision not the use the period of missing data at the start of 423004. During the calibration period, there are three days of missing data at the upstream gauge (25/04/1997–27/04/1997).

6.9.3.3 Routing Parameters

The non-linear lag and route procedure was used for the routing that was applied at the links between nodes. 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.

As no gauging station data exists for Irrara Creek, the routing parameters from the 2003 model of this reach were used. To maintain consistency within the model structure, the dual level routing was also applied for Barringun to Fords Bridge. The only alteration adopted was the reduction in lag time. The calibrated lag and routing parameters used for the reach are listed in Table 6.47.

Table 6.47: Reach 11 – Lag and Routing Parameters

Reach	Reach Length (km)	Lag Time (days)	Flow Range (ML/day)	k	m
Barringun to Fords Bridge	114.2	8 days	<200 >200	0.01 2.5	0.85 0.85
Irrara Creek	109.4	9 days	<200 >200	0.01 2.5	0.85 0.85

6.9.3.4 Irrara Creek Breakout-Return

In terms of breakout and unaccounted difference relationships, Reach 11 is the most complex model of the Warrego catchment. Unlike the Cuttaburra Creek Channel or Noorama and Widgeegoara, a portion of the diverted flow is returned to the Warrego River.

The inflow to Irrara Creek was modelled as a breakout from the Warrego River. The flow was derived in Reach 9, and is comprised of 30 per cent of the unaccounted difference effluent of that reach. It is estimated that 50 per cent of the Irrara Creek flow disperses to the environment, and the remainder returns to the Warrego River upstream of Fords Bridge. A network of relationships was used to model these breakout-return characteristics.

Firstly, a streamflow loss relationship was set up on the Warrego River below the Irrara Creek inflow to divert 50 per cent of the flow. A second relationship was then employed to remove the remaining flow from the system, simulating the loss to the environment. The relationships used to represent these characteristics are shown in

Table 6.48.

Table 6.48: Reach 11 – Irrara Creek Breakout Relationships

Flow Rate (ML/day)	Irrara Creek Transmission Losses	Non-return Flows Loss
	Loss (ML/day)	
0	0	0
500	1	
1,000	500	
1e6	5e5	
1e9		1e9

6.9.3.5 Irrara Creek Unaccounted Difference

Following the return of the effluent flow from the Irrara Creek breakout, a relationship was derived to account for the differences observed at Fords Bridge. This involved comparing the flow duration curves for the simulated and recorded flows, and estimating losses based on observable differences in the two curves. Using a trial and error process, losses were applied until an acceptable calibration was found. The unaccounted difference relationship applied in Reach 11 is shown in Table 6.49. These unaccounted differences are thought to be caused by breakouts onto the floodplain.

Table 6.49: Reach 11 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
10	6
89	48
590	200
2,000	700
4,000	1,750
8,000	4,500
16,000	10,000
18,000	11,750
1e9	11,750

6.9.4 Sacramento Model Calibration

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

6.9.4.1 Time Period

The calibration period for the reach Sacramento was 19/06/1993 to 30/06/2011, the period a residual could be derived for. Data that was missing at either gauge was excluded from the calibration.

6.9.4.2 Unit Hydrograph

Table 6.50 shows the unit hydrograph adopted for calibration.

6.9.4.3 Catchment Area

The total catchment area of Reach 11 is 5,123 square kilometres.

6.9.4.4 Sacramento Model Parameters

Table 6.50 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 6.50: Reach 11 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	0.954	-
Rf1 (48004)	3.65E-07	-
Rf2 (48006)	0.0595	-
Rf3 (48039)	0.366	-
Rf4 (48042)	0.528	-
adimp	0.000115	-
lzfpm	1.269	0
lzfsm	74.193	0
lzpk	0.00093	-
lzsk	0.106	-
lztwm	362.129	0
pctim	0.000177	-
pfree	0.101	-
rexp	2.309	-
sarva	8.25E-06	-
side	0.0208	-
ssout	0.000773	-
uzfwm	11.737	0
uzk	0.462	-
uztwm	98.665	0
zperc	187.106	-
uh0	0.424	-
uh1	0.576	-

6.9.4.5 Sacramento Model Calibration Results

Table 6.51 shows the flow statistics for the recorded and calculated data for the calibration period. A report card of the Sacramento calibration is shown in Figure 6.27. Appendix C8 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 6.51: Reach 11 – Sacramento Calibration Statistics

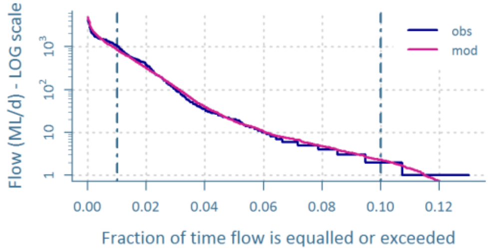
Location	Statistic	Daily	
		Recorded	Simulated
Barringun to Fords Bridge 19/06/1993–30/06/2011 Calibration	Mean (ML)	26.27	26.27
	Standard Deviation (ML)	191.02	203.28
	Skew	10.77	12.44
	Maximum Flow (ML)	4,217 23/03/2000	4,890 13/03/2000
	Volume Change (%)	99.98	
	Coefficient of Determination	0.554	
	Coefficient of Efficiency	0.452	

Warrego River between Barringun (423004) and Fords Bridge (4230012)

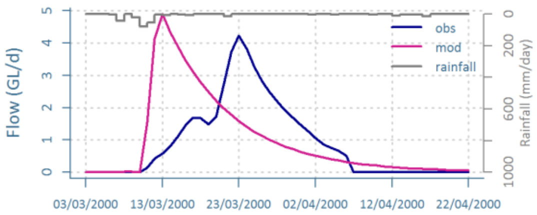
Period of analysis: 19/6/1993 to 30/6/2011

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

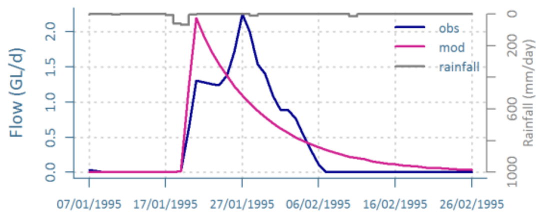
Exceedance curve showing low flow



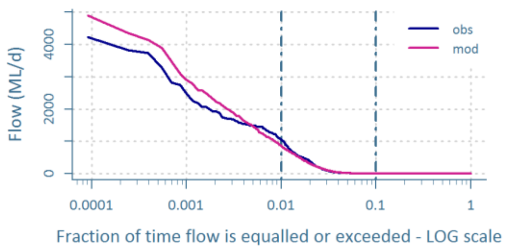
Largest Flood #1



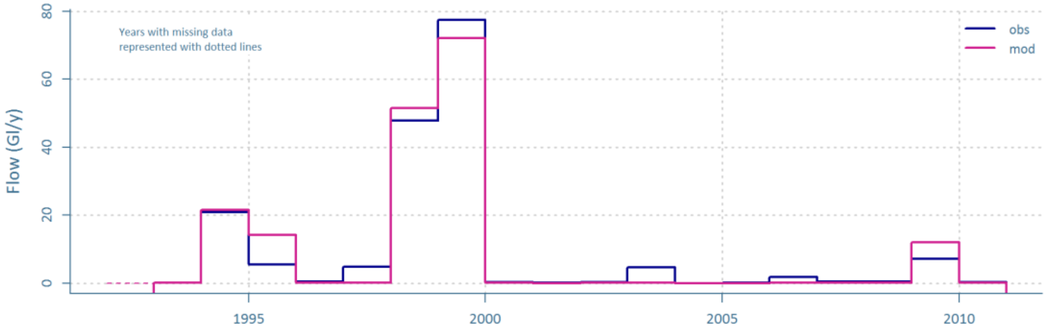
Largest Flood #2



Exceedance curve showing high flow



Annual time series (July to June)



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	173,032	0.0%	★★★★★
Total Low Flow Volume (ML)*	244	-10.7%	★★☆☆☆
Total Medium Flow Volume (ML)*	61,926	-6.7%	★★★☆☆
Total High Flow Volume (ML)*	110,862	3.8%	★★★★☆
Mean Flow Volume (ML/d)	26	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	2	-90.3%	★☆☆☆☆
Zero Flow Days (%)+	87.0%	1.5%^	★★★☆☆
Standard Deviation (ML/d)	191	6.4%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.45	★★☆☆☆
Non-matching Zero Flow Days	17.0%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.1 to 1 exceedance probability range
* Medium flow = flow in the 0.01 to 0.1 exceedance probability range
* High flow = flow in the 0 to 0.01 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Residual mass series

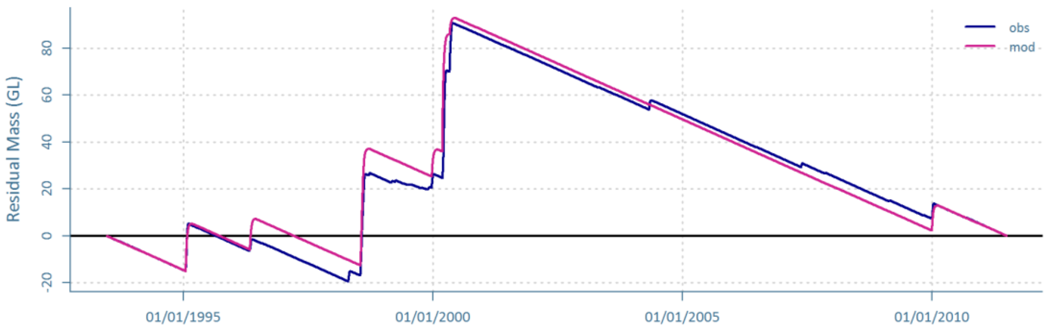


Figure 6.27: Reach 11 – Sacramento Calibration Report Card

6.9.4.6 Discussion

The Sacramento calibration aimed at reproducing the full range of flows over the full period of calibration. Some events were not reproduced, and in some cases, the simulated events overestimated the recorded events.

Reach 11 is a residual catchment, and so 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. For Qld gauge sites, the data required for IQQM modeling was readily accessible from HYDSTRA. Barringun is located on the border of Qld and NSW, and Fords Bridge is located in NSW. Therefore, it was necessary to obtain data for both gauging sites 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. Due to the limited information available for this reach, the calibration relied heavily on flow interactions and characteristics determined from previous models.

The maintenance of the dual layer routing is one such example. During the residual derivation, it was decided that the routing parameters from the 2003 IQQM model were still acceptable in this round of modelling. For consistency, future calibrations should amend the routing parameters to a single layer.

Another example of this reliance was the Irrara Creek breakout and return. The Irrara Creek inflow (derived during the Reach 9 calibration) was updated, but the mechanisms applied in the model, including the 30 per cent inflow, 50 per cent loss and the effluent loss-return relationships were all based on the 2003 study and 2003 IQQM model. The updated flow sequences necessitated the recalibration of the unaccountable difference relationships upstream of Fords Bridge. Future investigations should be conducted to confirm the characteristics of this catchment, such that the mechanisms applied in the model remain valid.

The resulting calibration was the best compromise that could be made to maintain the timing, duration and magnitude of flow events. It is anticipated that future calibrations will be improved with increased information in regards to the breakout characteristics and longer and more consistent flow records.

6.9.5 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.

6.9.6 Final Inflow Sequence

Table 6.52 and Figure 6.28 show the composition of the final residual inflow sequence for Reach 11.

Table 6.52: Reach 11 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–18/06/1993	Sacramento		
19/06/1993–24/04/1997	Derived residual	4230012	
25/04/1997–27/04/1997	Sacramento		Missing data period.
28/04/1997–30/06/2011	Derived residual	4230012	

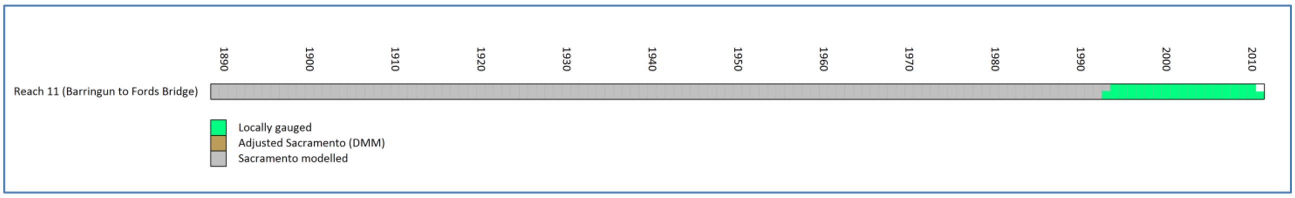


Figure 6.28: Reach 11 – Composition of Final Inflow Sequence

6.10 Reach 12 – Cuttaburra Creek Channel at Turra

6.10.1 Description

This residual reach encompasses the Cuttaburra Creek Channel catchment from the Warrego River diversion point near Cunnamulla (AMTD 124.5 km) to Turra. Cuttaburra Creek is a permanent tributary breakout from the Warrego River between Cunnamulla and Barringun. Catchment runoff feeds Cuttaburra Creek, which flows into the Yantabulla Swamp. This swamp, which has an estimated storage capacity of 300,000 ML, is estimated to overflow once every five to seven years. Every 15 years (on average) conditions facilitate the flow to reach the Paroo River System, south of Wanaaring. The location of Reach 12 can be seen on Figure 1.1.

Situated in New South Wales, the gauging station on Cuttaburra Creek at Turra is estimated to be approximately 20 km south of the Queensland–New South Wales border. The AMTD of the gauge site is not clear. The adopted stream length is 150 km, and the catchment area of Reach 12 is 8,085 square kilometres illustrates the catchment's unique position, traversing the Queensland-New South Wales border in the south-west of the Warrego River system.

Rainfall gauges within Reach 12 have records of average annual rainfall that range from 294 to 372 millimetres per annum. The average catchment rainfall of Reach 12 is 317 mm/a, which is the lowest average rainfall in the Warrego catchment. The 50 year mean annual rainfall isohyets for Reach 12 are shown on Figure 6.29.

6.10.2 Data

6.10.2.1 Flow Data

The stream flow data used for calibration can be viewed in Table 6.53. The upstream inflow was generated by listing the effluent flow from the Cuttaburra Channel diversion node in Reach 9, as mentioned in Section 6.8.3.4.

Table 6.53: Reach 12 – Flow Data

Location	Station	Period
Reach 9 diversion node	D/S 423202c	31/05/1993–30/06/2011
Downstream	423005	01/06/1993–30/06/2011

6.10.2.2 Rainfall Data

Section 5.3 describes the rainfall data used for Reach 12. The weightings of each rainfall station are also summarised in Table 6.56.

6.10.2.3 Evaporation Data

Section 5.4 describes the evaporation data used for Reach 12.

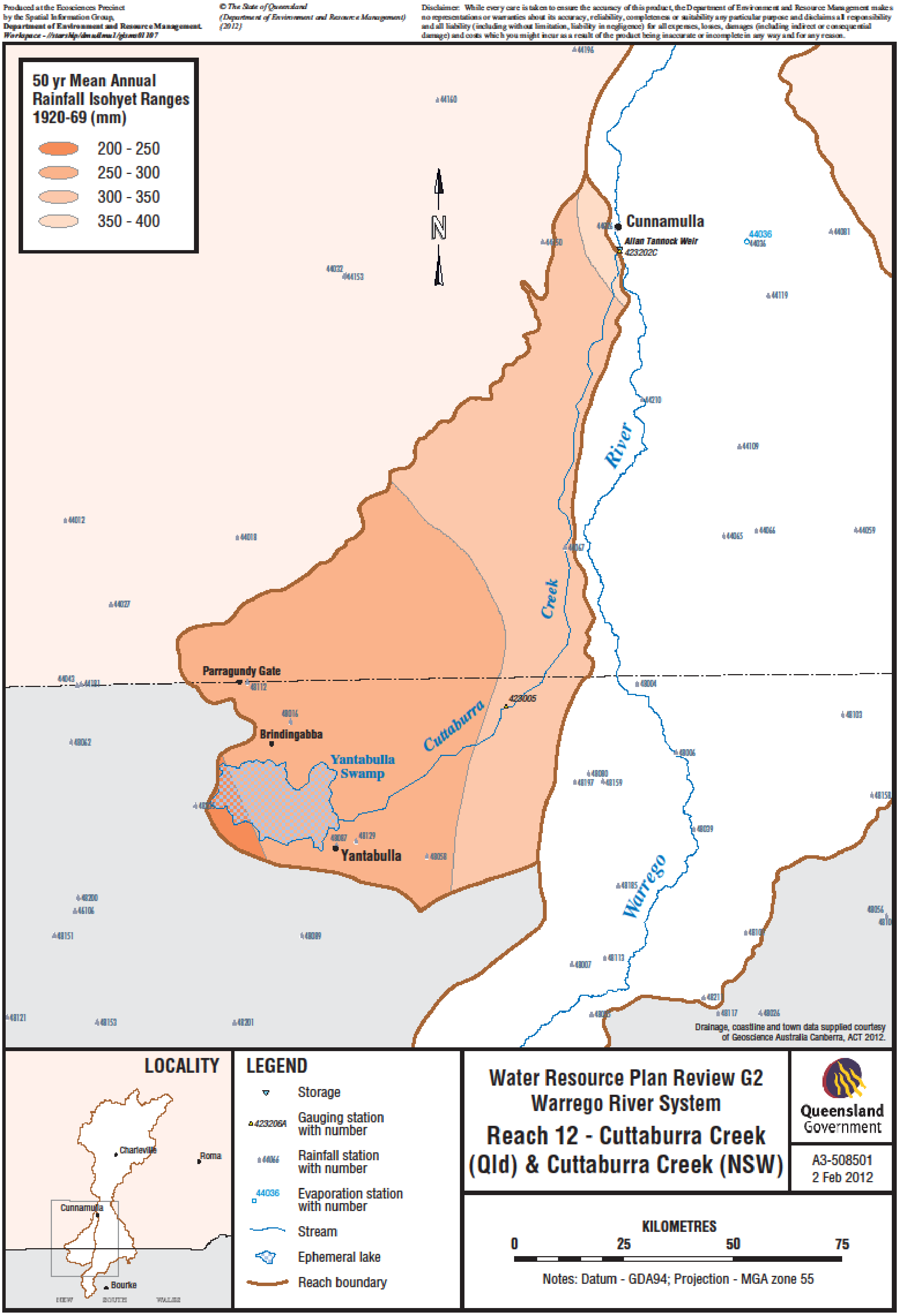


Figure 6.29: Reach 12 – Mean Annual Rainfall Isohyets Data

6.10.3 Reach Calibration and Record Based Inflow Sequence

6.10.3.1 Record Based Inflow Sequence

The reach calibration and derivation of the record based inflow sequence for Reach 12 was completed according to the methods outlined in Section 4.1. Only one model was required to calculate the residual inflow for Reach 12 due to there being no change in the infrastructure layout of the catchment.

6.10.3.2 Time Period

The residual inflows were derived for the period of common record between the upstream and downstream gauging stations 01/06/1993–30/06/2011. During this time, there are no periods of missing data in the flow records.

6.10.3.3 Routing Parameters

The non-linear lag and route procedure was used for the routing that was applied at the links between nodes. 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.

The calibrated lag and routing parameters used for the reach are listed in Table 6.54.

Table 6.54: Reach 12 – Lag and Routing Parameters

Reach	Reach Length (km)	Lag Time (days)	k	m
Cuttaburra Ck Channel at Turra	150	4.0	0.01	0.85

6.10.3.4 Unaccounted Difference

A derived unaccounted difference relationship was added at the end of the reach. It is shown in Table 6.55. The unaccounted differences were determined by a comparison of the modelled and measured flow duration curves at the downstream gauge. These differences are consist of losses between the gauges as well as modelling artefacts caused by the differences between the routing in the model and the actual system as well as uncertainties in the rating curves of the gauges. The large difference at high flows are probably caused by breakouts onto the floodplain at high flows

Table 6.55: Reach 12 – Unaccounted Difference Relationship

Stream flow (ML/d)	Unaccounted Difference (ML/d)
0	0
2	2
10	5
20	15
50	25
100	30
1,000	200
10,000	500
20,000	1,000
25,000	4,000
35,000	8,000
45,000	10,000
1,000,000	10,000

6.10.4 Sacramento Model Calibration

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

6.10.4.1 Time Period

The calibration period for the reach Sacramento was 01/06/1993 to 30/06/2011, the period of the derived residual.

6.10.4.2 Unit Hydrograph

Table 6.56 shows the unit hydrograph adopted for calibration.

6.10.4.3 Catchment Area

The total catchment area of Reach 12 is 8,085 square kilometres.

6.10.4.4 Sacramento Model Parameters

Table 6.56 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 6.56: Reach 12 – Sacramento Rainfall Weightings, Model Parameters and Unit Hydrograph

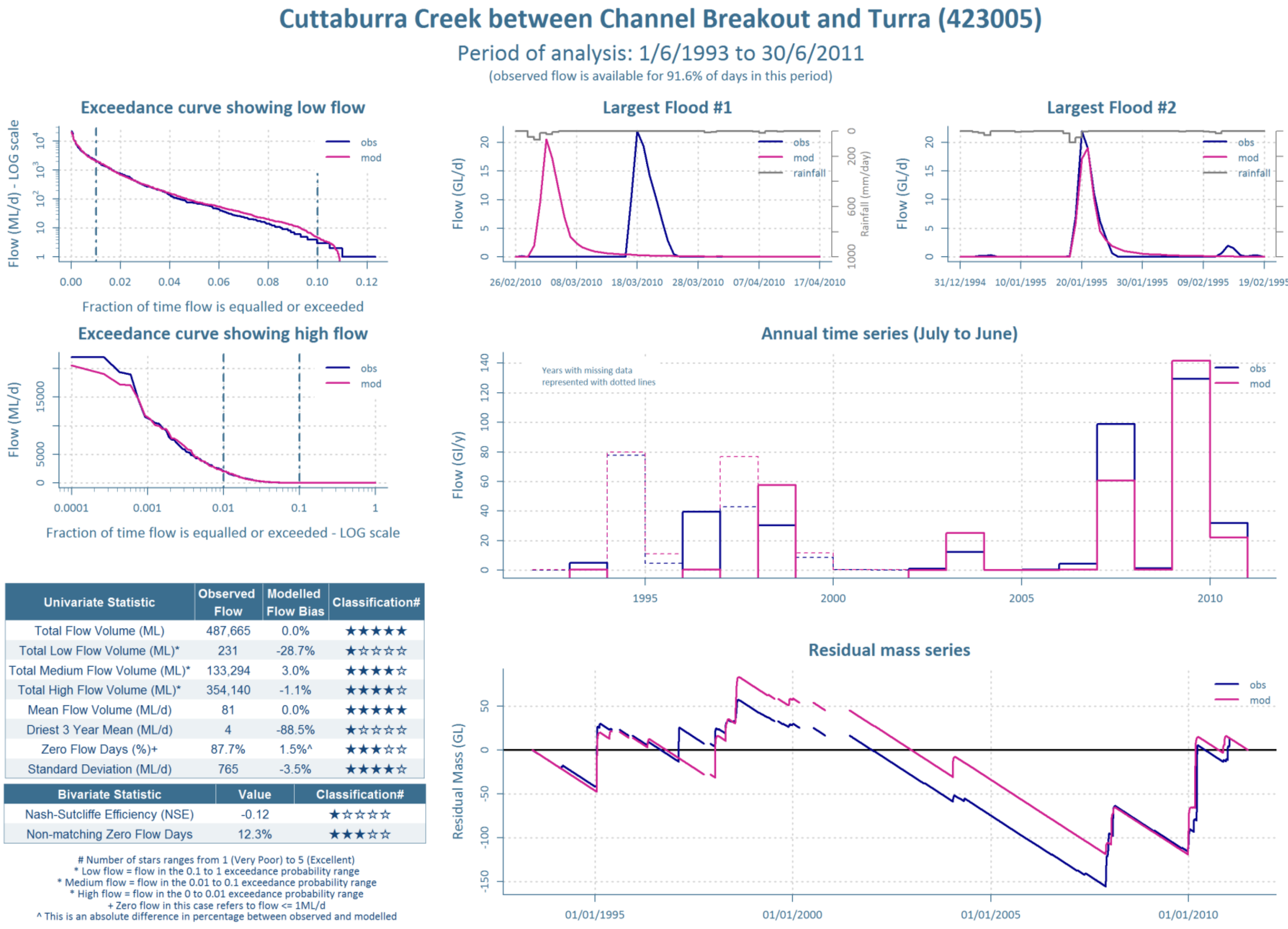
Sacramento Parameter	Adopted Value	Initial Volume
Rfsum	1.116	-
Rf1 (44026)	0.402	-
Rf2 (44150)	0.105	-
Rf3 (44067)	0.385	-
Rf4 (48004)	0.0206	-
Rf5 (48087)	0.132	-
Rf6 (44181)	0.072	-
adimp	0.00488	-
lzfpm	28.256	0
lzfsm	67.064	0
lzpk	0.114	-
lzsk	0.463	-
lztwm	211.367	0
pctim	0.00047	-
pfree	0.0733	-
rexp	1.705	-
sarva	4.76E-06	-
side	0.00217	-
ssout	0.0036	-
uzfwm	25.725	0
uzk	0.277	-
uztwm	65.416	0
zperc	6.57	-
uh0	0	-
uh1	0.593	-
uh2	0.407	-

6.10.4.5 Sacramento Model Calibration Results

Table 6.57 shows the flow statistics for the recorded and calculated data for the calibration period. A report card of the Sacramento calibration is shown in Figure 6.30. Appendix C9 includes daily plots of the data.

Table 6.57: Reach 12 – Sacramento Calibration Statistics

Location	Statistic	Daily	
		Recorded	Simulated
Cuttaburra Ck Channel to Turra 01/06/1993–30/06/2011 Calibration	Mean (ML)	80.58	80.58
	Standard Deviation (ML)	764.69	737.76
	Skew	18.12	16.62
	Maximum Flow (ML)	21,951 18/03/2010	20,519 03/03/2010
	Volume Change (%)	99.96	
	Coefficient of Determination	0.178	
	Coefficient of Efficiency	-0.117	



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	487,665	0.0%	★★★★★
Total Low Flow Volume (ML)*	231	-28.7%	★☆☆☆☆
Total Medium Flow Volume (ML)*	133,294	3.0%	★★★★☆
Total High Flow Volume (ML)*	354,140	-1.1%	★★★★☆
Mean Flow Volume (ML/d)	81	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	4	-88.5%	★☆☆☆☆
Zero Flow Days (%)+	87.7%	1.5%^	★★★☆☆
Standard Deviation (ML/d)	765	-3.5%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	-0.12	★☆☆☆☆
Non-matching Zero Flow Days	12.3%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.1 to 1 exceedance probability range
* Medium flow = flow in the 0.01 to 0.1 exceedance probability range
* High flow = flow in the 0 to 0.01 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 6.30: Reach 12 – Sacramento Calibration Report Card

6.10.4.6 Discussion

Data limitations were detrimental to the quality of the calibration for Reach 12. As Turra is located in NSW, data collection was difficult. Therefore, it was necessary to obtain Barringun's flow 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. Details such as the AMTD and catchment area were unconfirmed, and it was unclear how much area contributes to runoff. As this reach was not modeled during the 2003 study, there was no opportunity to confirm data or compare the model performance.

In addition, there was no headwater gauge at the upstream limit of the reach. To compensate for the lack of flow information, the headwater gauged flow was substituted with the derived unaccounted difference effluent determined during the calibration of Reach 9. Despite an acceptable relationship being derived, the quality of the residual proved inadequate and the resulting Sacramento calibration is very poor statistically and visually.

The resulting calibration was the best compromise that could be made to maintain the timing, duration and magnitude of flow events. It is anticipated that future calibrations will be improved by a longer duration of flow record and more substantial catchment information.

6.10.5 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.

6.10.6 Final Inflow Sequence

Table 6.58 and Figure 6.31 show the composition of the final residual inflow sequence for Reach 12.

Table 6.58: Reach 12 – Final Inflow Sequence

Period	Data Description	Downstream Gauge	Notes
01/01/1889–31/05/1993	Sacramento		
01/06/1993–08/06/1995	Derived residual	423005	
09/06/1995–15/08/1995	Sacramento		
16/08/1995–07/11/1995	Derived residual	423005	
08/11/1995–13/12/1995	Sacramento		
14/12/1995–03/10/1997	Derived residual	423005	
04/10/1997–01/12/1997	Sacramento		
02/12/1997–16/07/1999	Derived residual	423005	
17/07/1999–17/08/1999	Sacramento		
18/08/1999–29/02/2000	Derived residual	423005	
01/03/2000–06/07/2000	Sacramento		
07/07/2000–25/10/2000	Derived residual	423005	
26/10/2000–05/06/2001	Sacramento		
06/06/2001–16/01/2002	Derived residual	423005	
17/01/2002–22/01/2002	Sacramento		
23/01/2002–30/06/2011	Derived residual	423005	

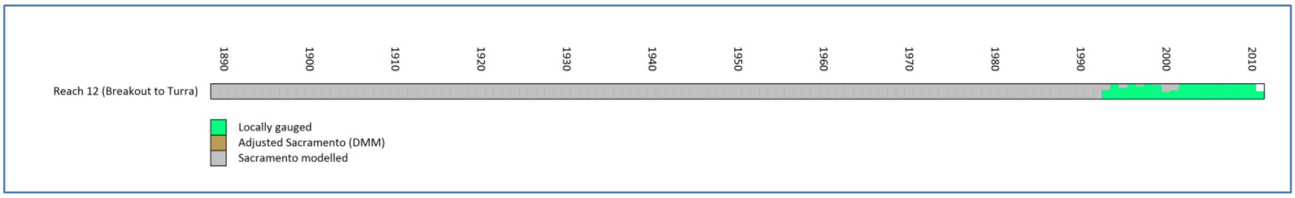


Figure 6.31: Reach 12 – Composition of Final Inflow Sequence

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 model to reproduce recorded flow behaviour in the system.

7.2 Model Structure

The model covers the Warrego River from its headwaters to Fords Bridge. 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.

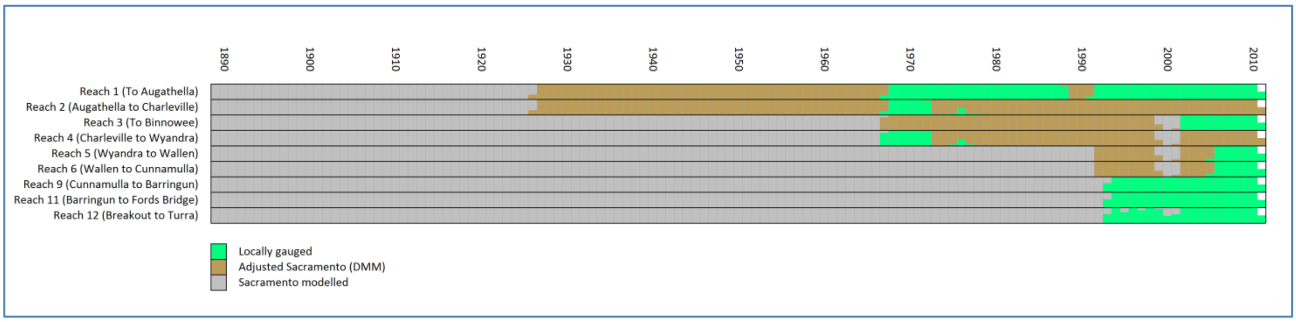


Figure 7.1: Composition of Final Inflow Sequence for all Reaches

Note that there is no reporting node for the Binnowee gauging station on Ward River. The contribution of this catchment is represented by an inflow node below Charleville, as per the Reach 4 flow sequence calibration model.

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 two validation model flows at the gauge locations for the complete simulation period from 1889 to 2011. In general the Sacramento validation model mean annual flows are around 10 per cent higher than the Final Flows validation model flows. Figure 7.3 to Figure 7.10 show the 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.

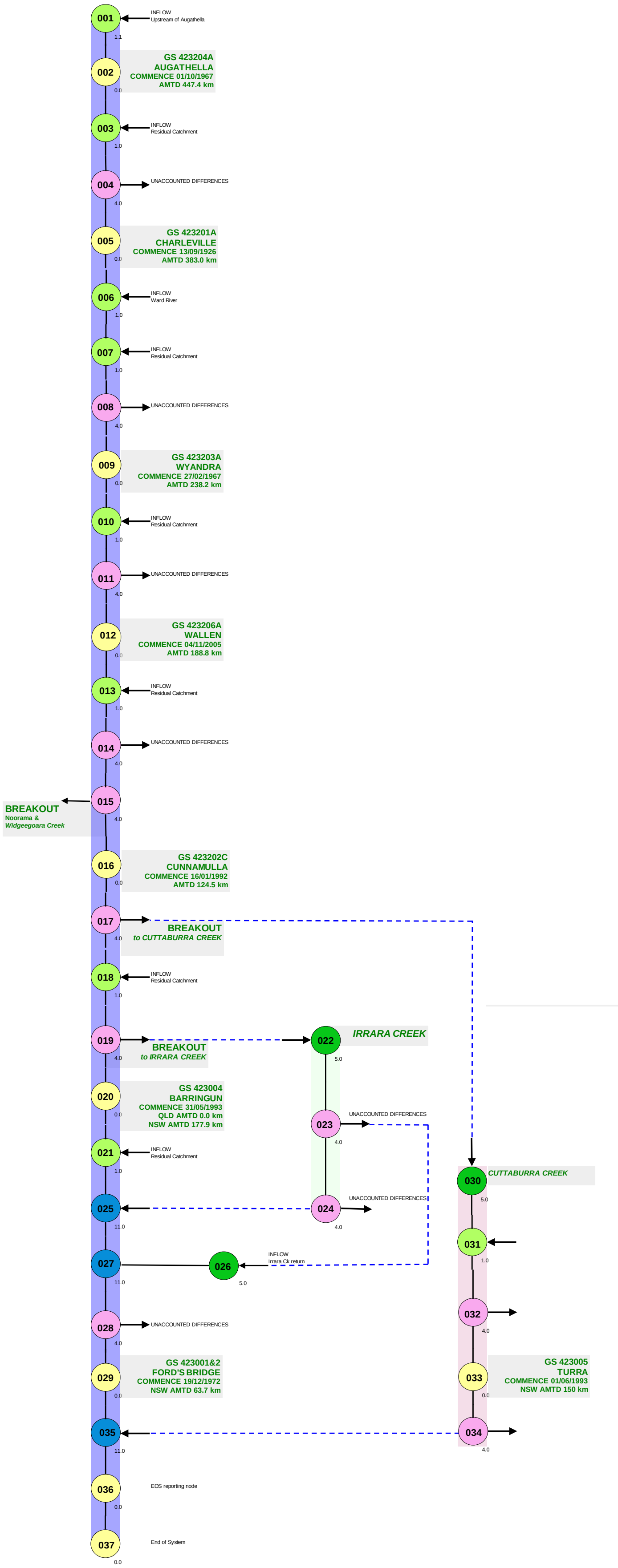


Figure 7.2: Warrego Validation Model IQQM Schematic

Table 7.1: Warrego Validation Models Daily Results

Location	Statistic	Daily		
		Recorded	Simulated – Sacramento Flows Validation	Simulated – Final Flows Validation
Augathella 423204a (03/10/1967–30/06/2011)	Mean (ML)	114.33	92.97	114.33
	Standard Deviation (ML)	1123	794.41	1123
	Skew	21.47	16.80	21.47
	Maximum Flow (ML)	48,738	26,716	48,738
	Volume Change (%)		81.32	100
	Coefficient of Determination		0.43	1.0
	Coefficient of Efficiency		0.43	1.0
Charleville 423201a (15/09/1926–19/01/1978)	Mean (ML)	425.24	647.75	424.72
	Standard Deviation (ML)	2,950	5,662	2,946
	Skew	14.19	22.44	14.22
	Maximum Flow (ML)	83,714	287,747	83,714
	Volume Change (%)		152.33	99.88
	Coefficient of Determination		0.57	1.0
	Coefficient of Efficiency		-0.79	1.0
Wyandra 423203a (01/03/1967–17/05/1999 and 22/11/2001–30/06/2011)	Mean (ML)	1,597	1,907	1,609
	Standard Deviation (ML)	11,870	15,434	11,873
	Skew	16.1	27.71	16.08
	Maximum Flow (ML)	334,602	946,173	334,602
	Volume Change (%)		119.47	100.77
	Coefficient of Determination		0.59	1
	Coefficient of Efficiency		0.3	1
Wallen 423206a (04/11/2005–30/06/2011)	Mean (ML)	2,732	2,921	2,801
	Standard Deviation (ML)	14,737	17,670	15,424
	Skew	10.92	14.03	11.21
	Maximum Flow (ML)	243,845	426,442	244,844
	Volume Change (%)		106.92	102.54
	Coefficient of Determination		0.48	0.99
	Coefficient of Efficiency		0.23	0.99
Cunnamulla	Mean (ML)	1,389	1,525	1,505
	Standard Deviation (ML)	8,298	8,906	8,446

Location	Statistic	Daily		
		Recorded	Simulated – Sacramento Flows Validation	Simulated – Final Flows Validation
423202c (18/01/1992–30/06/2011)	Skew	10.77	15.52	11.03
	Maximum Flow (ML)	136,138	329,905	150,943
	Volume Change (%)		109.77	108.35
	Coefficient of Determination		0.51	0.92
	Coefficient of Efficiency		0.38	0.92
Barringun 423004 (01/01/1967–31/12/1981 and 31/05/1993–30/06/2011)	Mean (ML)	285.19	376.1	342.5
	Standard Deviation (ML)	1,184	2,443	1,354
	Skew	9.15	56.96	9.79
	Maximum Flow (ML)	19,557	210,797	34,093
	Volume Change (%)		131.88	120.1
	Coefficient of Determination		0.13	0.54
	Coefficient of Efficiency		-2.78	0.38
Fords Bridge 423001&2 (19/12/1972–30/06/2011)	Mean (ML)	249.82	394.94	248.23
	Standard Deviation (ML)	901.37	4,581	865.16
	Skew	9.17	40.61	17.19
	Maximum Flow (ML)	19,809	245,539	34,451
	Volume Change (%)		158.09	99.37
	Coefficient of Determination		0.35	0.68
	Coefficient of Efficiency		-19.86	0.66
Turra 423005 (01/06/1993-30/06/2011)	Mean (ML)	548.95	594.76	583.79
	Standard Deviation (ML)	3,241	3,117	3,378
	Skew	11.19	10.93	11.18
	Maximum Flow (ML)	62,414	54,050	62,742
	Volume Change (%)		108.35	106.35
	Coefficient of Determination		0.50	0.91
	Coefficient of Efficiency		0.44	0.91

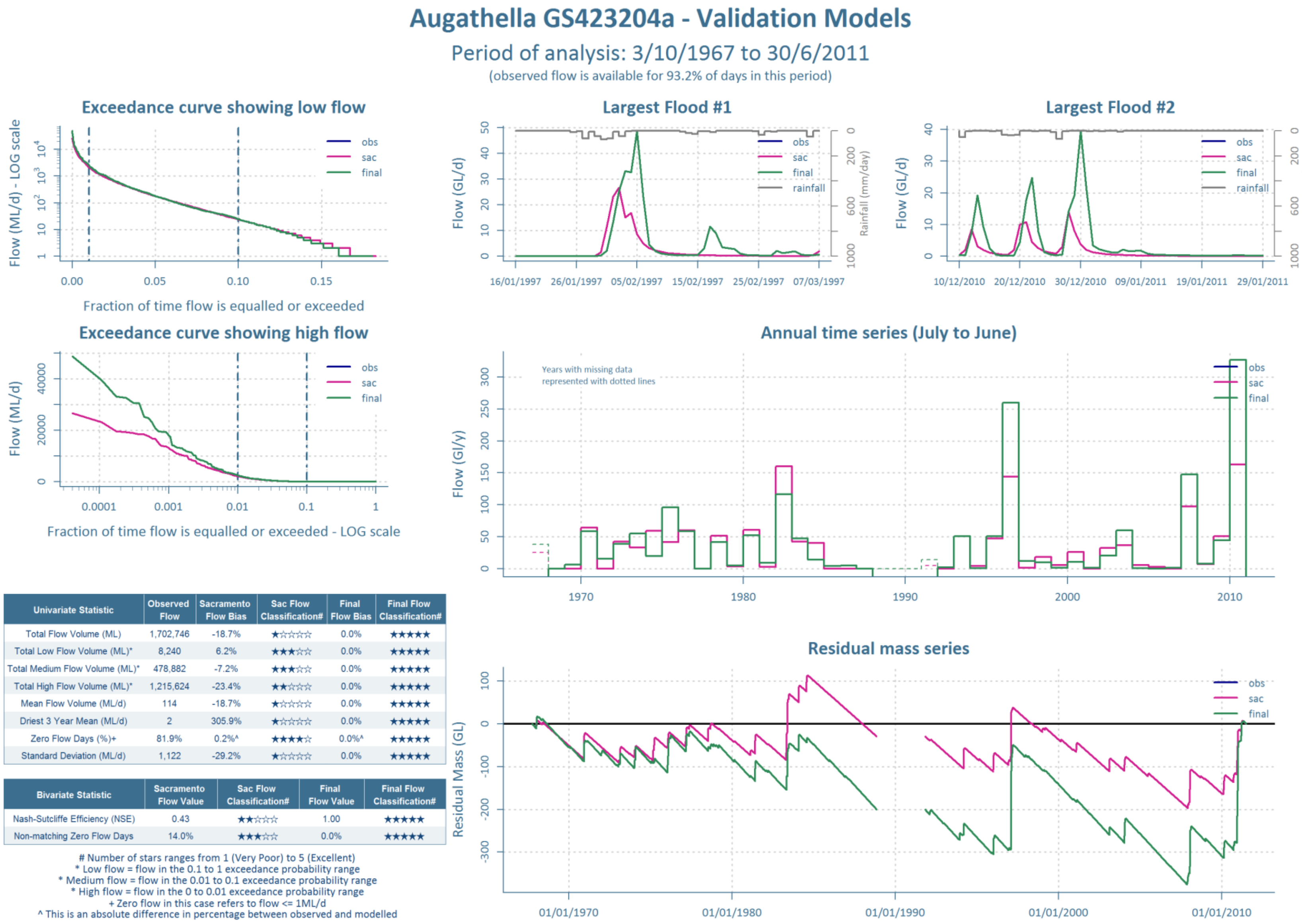
Table 7.2: Warrego Validation Models Mean Annual Flows 1889–2011

Location	Sacramento Validation July to June (ML/a)	Final Sequence Validation July to June (ML/a)	%
Augathella	77,867	66,588	86
Charleville	256,200	220,399	86
Wyandra	789,670	724,218	92
Wallen	754,562	696,655	92
Cunnamulla	696,334	641,495	92
Barringun	177,449	154,209	87
Fords Bridge	130,152	109,409	84
Turra	248,517	235,090	95

Table 7.3 shows the water balance of the validation (final flows) model. The runoff coefficients for each reach from the validation model are slightly lower than those from the recorded flow data. The size of the runoff coefficients are reasonable for the location of this catchment and the pattern of rise and fall in the coefficients as you move down the catchment is as you would expect given the rainfall differences between reaches.

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

Station		C.A	MARF	Validation Model Mean Annual Flow July to June		
Number	Name	(km2)	(mm/a)	(ML/a)	(mm/a)	% RO Coeff
423204a	Augathella	8,070	588	66,588	8.25	1.4
423201a	Charleville	16,299	522	220,399	13.52	2.6
423203a	Wyandra	42,865	481	724,218	16.90	3.5
423206a	Wallen	46,887	390	696,655	14.85	3.8
423202c	Cunnamulla	47,424	379	641,495	13.53	3.6
423004	Barringun	52,105	252	154,209	2.96	1.2
423001&2	Fords Bridge	57,228	327	109,409	1.91	0.6
423005	Turra (local inflow only)	8,085	379	30,744	3.80	1.0



Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	1,702,746	-18.7%	★☆☆☆☆	0.0%	★★★★★
Total Low Flow Volume (ML)*	8,240	6.2%	★★★☆☆	0.0%	★★★★★
Total Medium Flow Volume (ML)*	478,882	-7.2%	★★★☆☆	0.0%	★★★★★
Total High Flow Volume (ML)*	1,215,624	-23.4%	★★☆☆☆	0.0%	★★★★★
Mean Flow Volume (ML/d)	114	-18.7%	★☆☆☆☆	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	2	305.9%	★☆☆☆☆	0.0%	★★★★★
Zero Flow Days (%)+	81.9%	0.2%^	★★★★☆	0.0%^	★★★★★
Standard Deviation (ML/d)	1,122	-29.2%	★☆☆☆☆	0.0%	★★★★★

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.43	★★☆☆☆	1.00	★★★★★
Non-matching Zero Flow Days	14.0%	★★★☆☆	0.0%	★★★★★

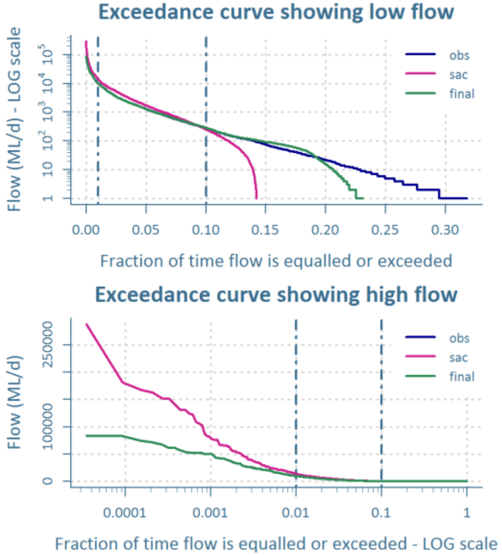
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.1 to 1 exceedance probability range
* Medium flow = flow in the 0.01 to 0.1 exceedance probability range
* High flow = flow in the 0 to 0.01 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 7.3: Validation Models Report Card – GS423204a Augathella

Charleville GS423201a - Validation Models

Period of analysis: 15/9/1926 to 19/1/1978

(observed flow is available for 91.4% 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)	7,286,042	52.3%	★☆☆☆☆	-0.1%	★★★★☆
Total Low Flow Volume (ML)*	177,790	-59.6%	★☆☆☆☆	4.3%	★★★★☆
Total Medium Flow Volume (ML)*	2,988,271	37.0%	★☆☆☆☆	-0.3%	★★★★★
Total High Flow Volume (ML)*	4,119,981	68.3%	★☆☆☆☆	-0.2%	★★★★★
Mean Flow Volume (ML/d)	425	52.3%	★☆☆☆☆	-0.1%	★★★★☆
Driest 3 Year Mean (ML/d)	129	-48.7%	★☆☆☆☆	-5.4%	★★★☆☆
Zero Flow Days (%)+	68.2%	17.6%^	★☆☆☆☆	8.7%^	★★☆☆☆
Standard Deviation (ML/d)	2,950	91.9%	★☆☆☆☆	-0.1%	★★★★★

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	-0.79	★☆☆☆☆	1.00	★★★★★
Non-matching Zero Flow Days	21.6%	★★★☆☆	10.9%	★★★☆☆

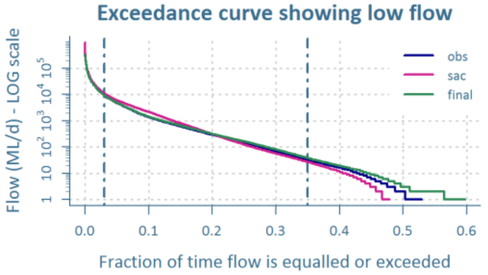
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.1 to 1 exceedance probability range
* Medium flow = flow in the 0.01 to 0.1 exceedance probability range
* High flow = flow in the 0 to 0.01 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

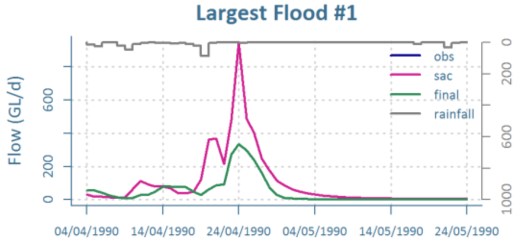
Figure 7.4: Validation Models Report Card – GS423201a Charleville

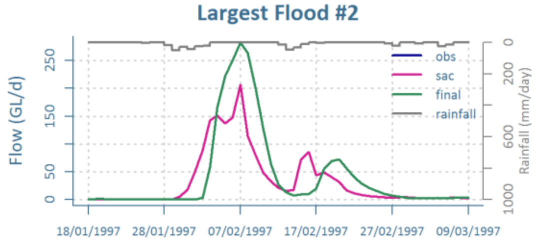
Wyandra GS423203a - Validation Models

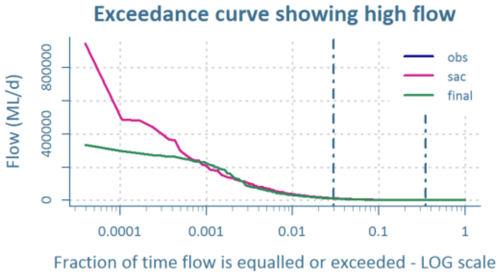
Period of analysis: 1/3/1967 to 30/6/2011

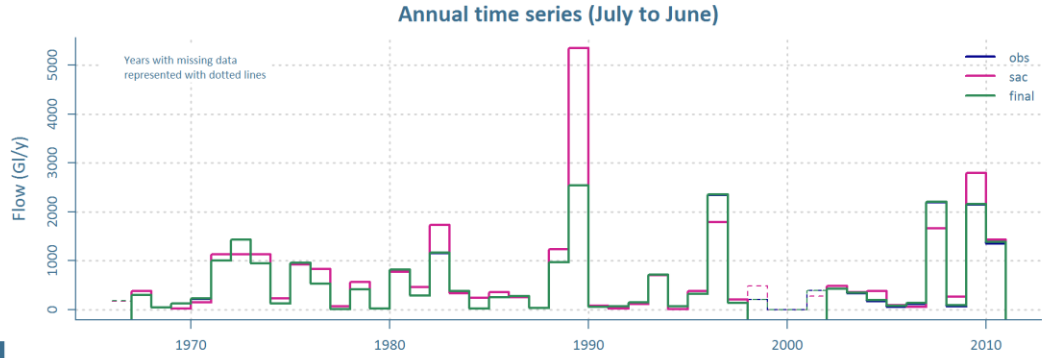
(observed flow is available for 94.3% of days in this period)











Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	24,387,496	19.5%	★☆☆☆☆	0.8%	★★★★☆
Total Low Flow Volume (ML)*	29,518	-31.6%	★☆☆☆☆	30.8%	★☆☆☆☆
Total Medium Flow Volume (ML)*	5,331,908	30.8%	★☆☆☆☆	2.8%	★★★★☆
Total High Flow Volume (ML)*	19,026,070	16.4%	★★☆☆☆	0.2%	★★★★★
Mean Flow Volume (ML/d)	1,597	19.5%	★☆☆☆☆	0.8%	★★★★☆
Driest 3 Year Mean (ML/d)	249	-22.9%	★★☆☆☆	0.2%	★★★★★
Zero Flow Days (%)+	47.1%	5.0%^	★★☆☆☆	6.9%^	★★☆☆☆
Standard Deviation (ML/d)	11,869	30.0%	★☆☆☆☆	0.0%	★★★★★

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.30	★★☆☆☆	1.00	★★★★★
Non-matching Zero Flow Days	20.4%	★★★☆☆	7.6%	★★★★☆

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 0.03 to 0.35 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

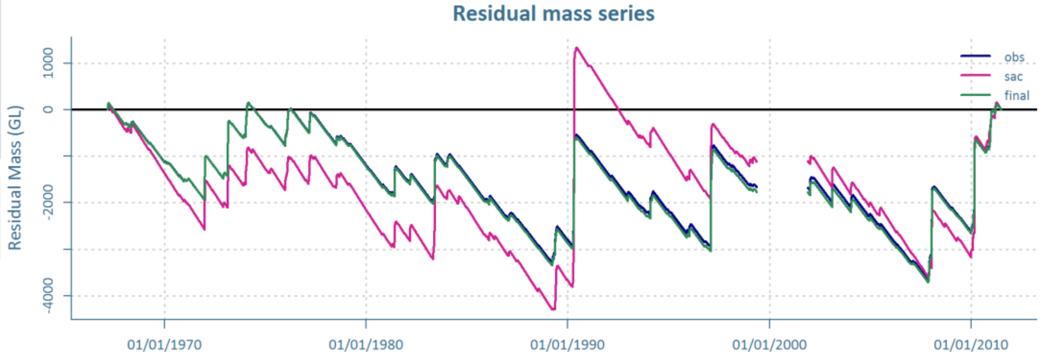
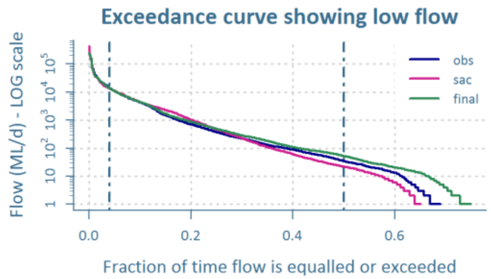


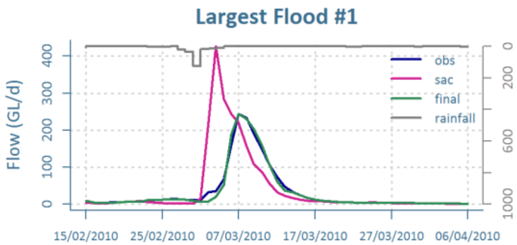
Figure 7.5: Validation Models Report Card – GS423203a Wyandra

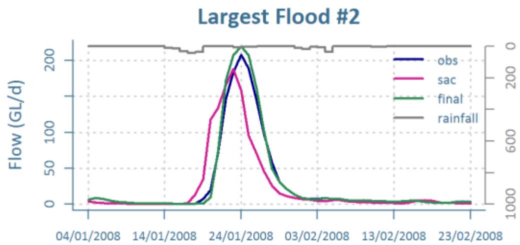
Wallen GS423206a - Validation Models

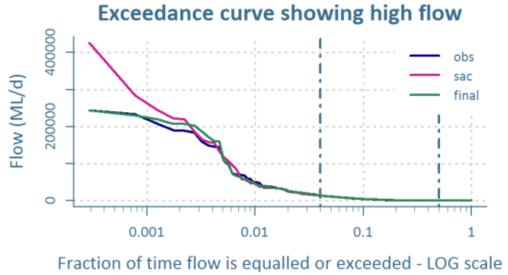
Period of analysis: 4/11/2005 to 30/6/2011

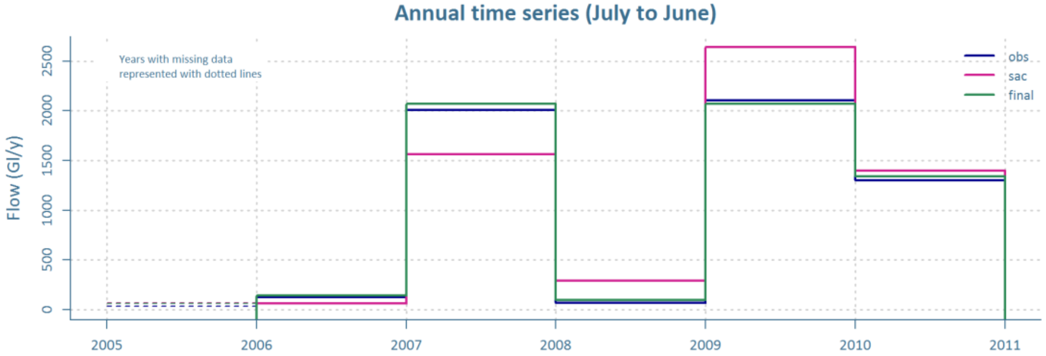
(observed flow is available for 100% of days in this period)











Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	5,641,201	6.9%	★★☆☆☆	2.5%	★★★☆☆
Total Low Flow Volume (ML)*	5,525	-44.5%	★☆☆☆☆	72.9%	★☆☆☆☆
Total Medium Flow Volume (ML)*	1,475,945	9.3%	★★★☆☆	4.9%	★★★★☆
Total High Flow Volume (ML)*	4,159,731	6.1%	★★★☆☆	1.6%	★★★★☆
Mean Flow Volume (ML/d)	2,732	6.9%	★★☆☆☆	2.5%	★★★☆☆
Driest 3 Year Mean (ML/d)	2,007	-12.7%	★★☆☆☆	4.9%	★★★★☆
Zero Flow Days (%)+	31.1%	3.9%^	★★★☆☆	6.0%^	★★☆☆☆
Standard Deviation (ML/d)	14,733	19.9%	★★☆☆☆	4.7%	★★★★☆

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.23	★☆☆☆☆	0.99	★★★★★
Non-matching Zero Flow Days	14.8%	★★★☆☆	8.3%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.5 to 1 exceedance probability range
* Medium flow = flow in the 0.04 to 0.5 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

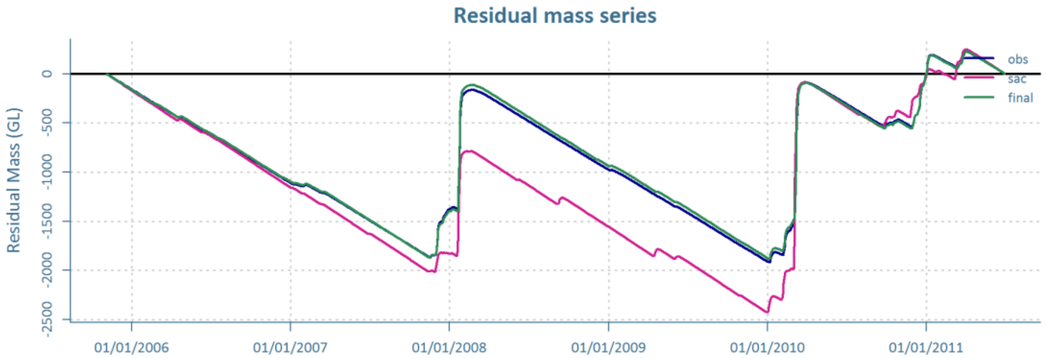
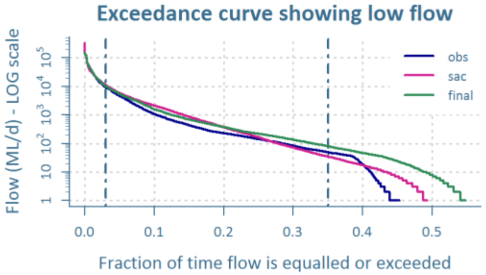


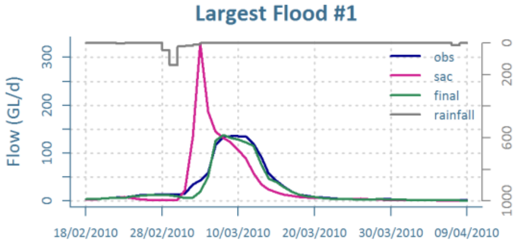
Figure 7.6: Validation Models Report Card – GS423206a Wallen

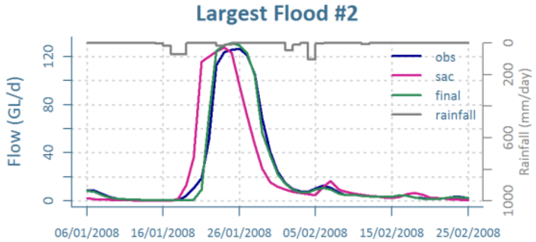
Cunnamulla GS423202C - Validation Models

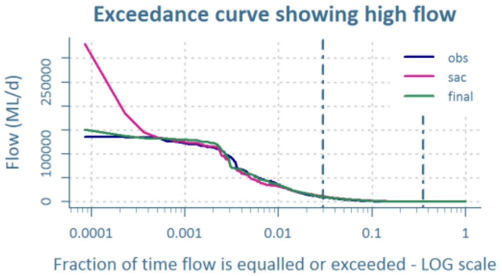
Period of analysis: 18/1/1992 to 30/6/2011

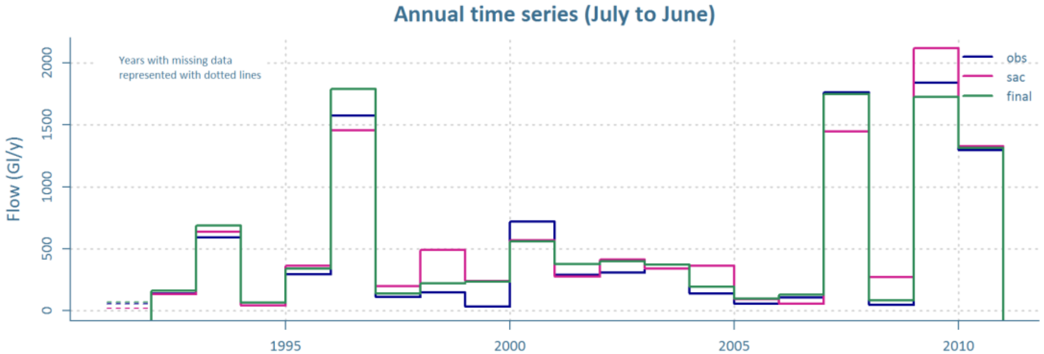
(observed flow is available for 100% of days in this period)











Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	9,866,761	9.8%	★★☆☆☆	8.3%	★★☆☆☆
Total Low Flow Volume (ML)*	15,404	-8.5%	★★★☆☆	165.1%	★☆☆☆☆
Total Medium Flow Volume (ML)*	2,277,938	42.3%	★☆☆☆☆	28.3%	★☆☆☆☆
Total High Flow Volume (ML)*	7,573,419	0.0%	★★★★★	2.0%	★★★★☆
Mean Flow Volume (ML/d)	1,389	9.8%	★★☆☆☆	8.3%	★★☆☆☆
Driest 3 Year Mean (ML/d)	714	42.4%	★☆☆☆☆	22.4%	★★☆☆☆
Zero Flow Days (%)+	54.7%	4.0%^	★★★☆☆	9.5%^	★★☆☆☆
Standard Deviation (ML/d)	8,298	7.3%	★★★☆☆	1.9%	★★★★☆

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.38	★★☆☆☆	0.92	★★★★★
Non-matching Zero Flow Days	21.1%	★★★☆☆	12.8%	★★★☆☆

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 0.03 to 0.35 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

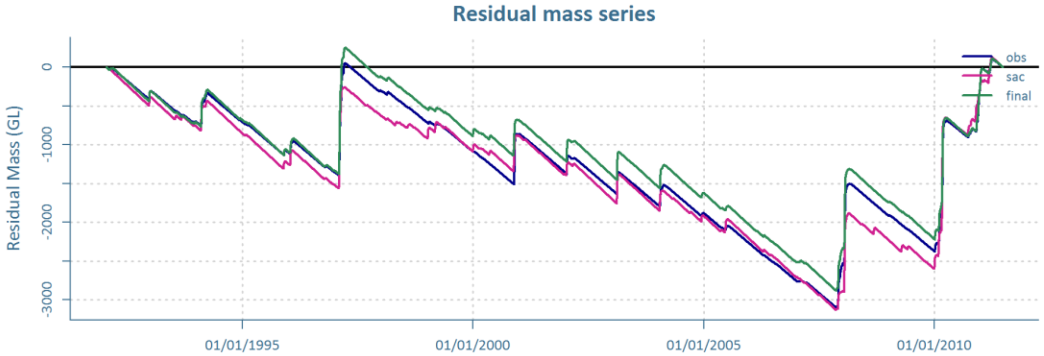
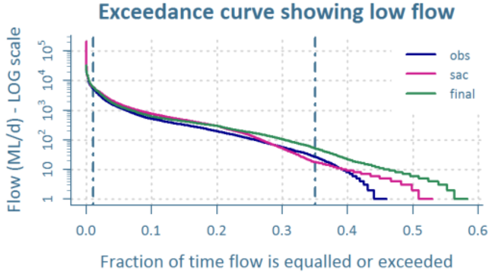


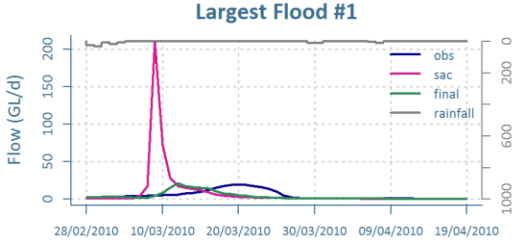
Figure 7.7: Validation Models Report Card – GS423202c Cunnamulla

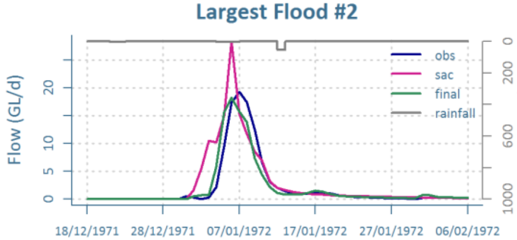
Barringun GS423004 - Validation Models

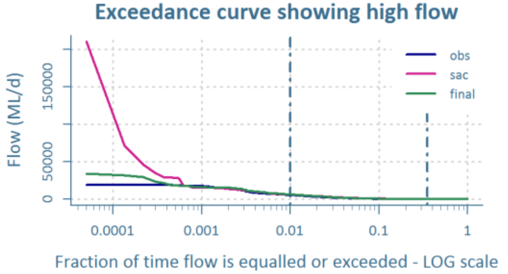
Period of analysis: 1/1/1967 to 30/6/2011

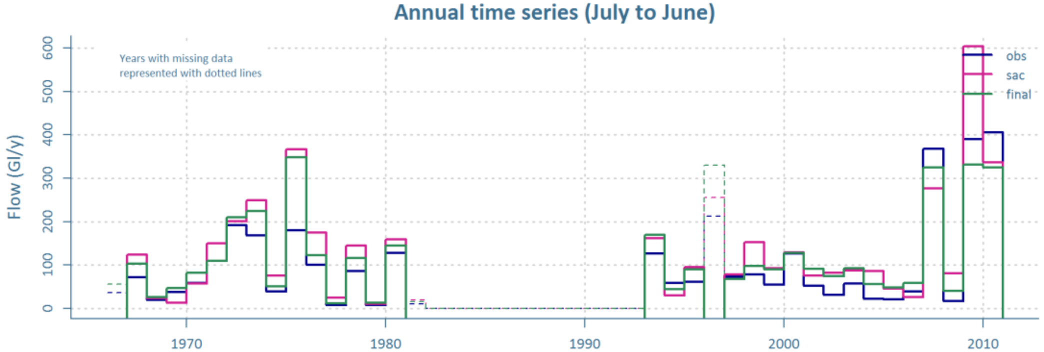
(observed flow is available for 74.3% of days in this period)











Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	3,445,409	31.9%	★☆☆☆☆	20.1%	★☆☆☆☆
Total Low Flow Volume (ML)*	12,158	25.4%	★☆☆☆☆	223.8%	★☆☆☆☆
Total Medium Flow Volume (ML)*	2,257,003	32.6%	★☆☆☆☆	23.0%	★★☆☆☆
Total High Flow Volume (ML)*	1,176,248	30.5%	★☆☆☆☆	12.5%	★★☆☆☆
Mean Flow Volume (ML/d)	285	31.9%	★☆☆☆☆	20.1%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	76	91.0%	★☆☆☆☆	96.4%	★☆☆☆☆
Zero Flow Days (%)+	54.0%	7.0%^	★★☆☆☆	12.4%^	★☆☆☆☆
Standard Deviation (ML/d)	1,184	106.4%	★☆☆☆☆	14.4%	★★☆☆☆

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	-2.78	★☆☆☆☆	0.38	★★☆☆☆
Non-matching Zero Flow Days	22.0%	★★★☆☆	16.1%	★★★☆☆

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 0.01 to 0.35 exceedance probability range
* High flow = flow in the 0 to 0.01 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

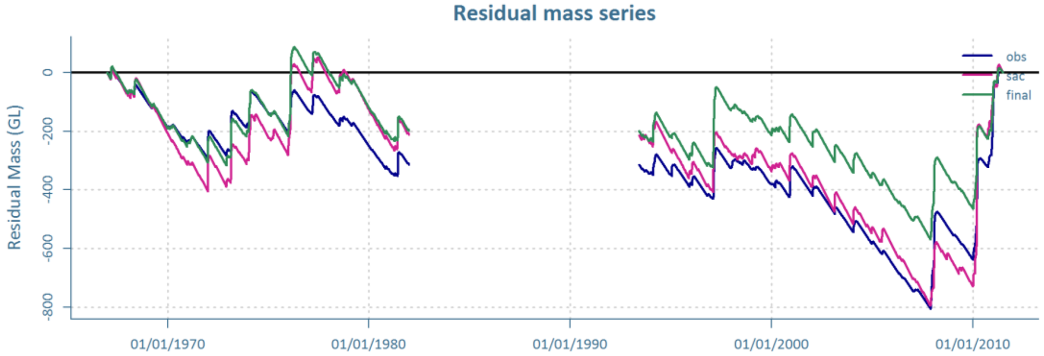
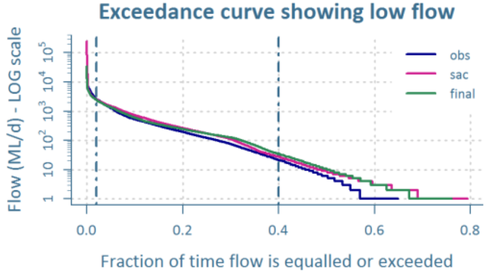


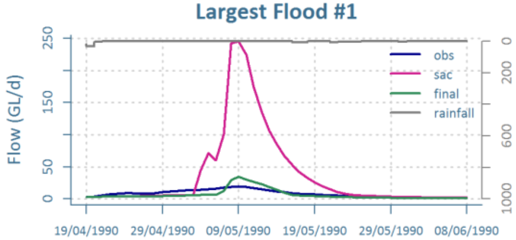
Figure 7.8: Validation Models Report Card – GS423004 Barringun

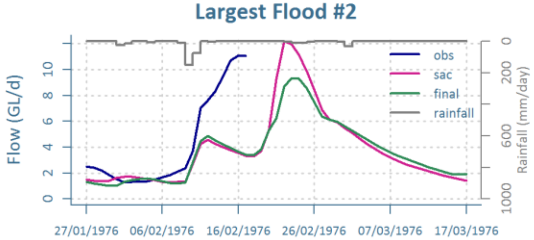
Fords Bridge GS423001&2 - Validation Models

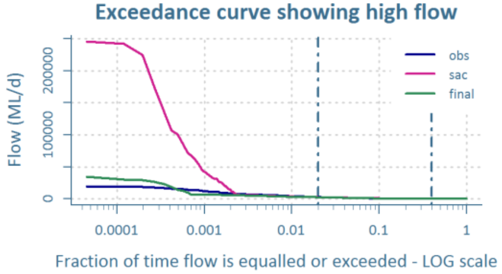
Period of analysis: 19/12/1972 to 30/6/2011

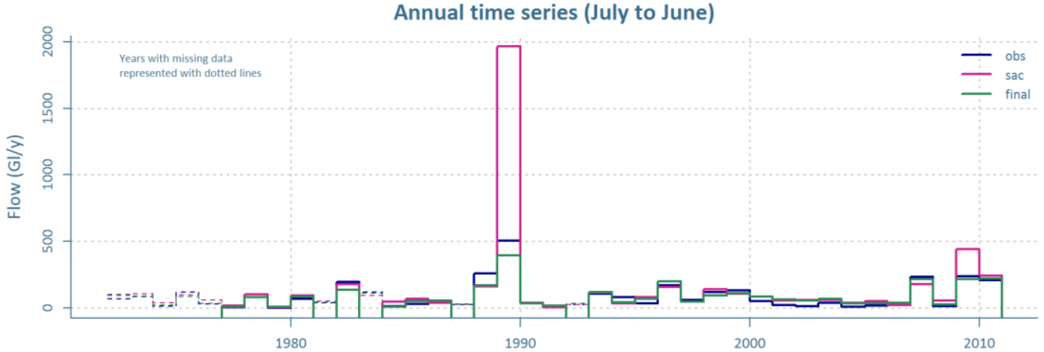
(observed flow is available for 94.9% of days in this period)











Univariate Statistic	Observed Flow	Sacramento Flow Bias	Sac Flow Classification#	Final Flow Bias	Final Flow Classification#
Total Flow Volume (ML)	3,337,090	58.1%	★☆☆☆☆	-0.6%	★★★★☆
Total Low Flow Volume (ML)*	20,328	61.9%	★☆☆☆☆	88.5%	★☆☆☆☆
Total Medium Flow Volume (ML)*	1,945,659	22.0%	★★☆☆☆	10.3%	★★☆☆☆
Total High Flow Volume (ML)*	1,371,103	109.3%	★☆☆☆☆	-17.5%	★★☆☆☆
Mean Flow Volume (ML/d)	250	58.1%	★☆☆☆☆	-0.6%	★★★★☆
Driest 3 Year Mean (ML/d)	50	98.0%	★☆☆☆☆	96.6%	★☆☆☆☆
Zero Flow Days (%)+	35.1%	14.4%^	★☆☆☆☆	11.2%^	★☆☆☆☆
Standard Deviation (ML/d)	901	408.3%	★☆☆☆☆	-4.0%	★★★★☆

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	-19.86	★☆☆☆☆	0.66	★★★☆☆
Non-matching Zero Flow Days	22.7%	★★★☆☆	20.8%	★★★☆☆

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 0.02 to 0.4 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

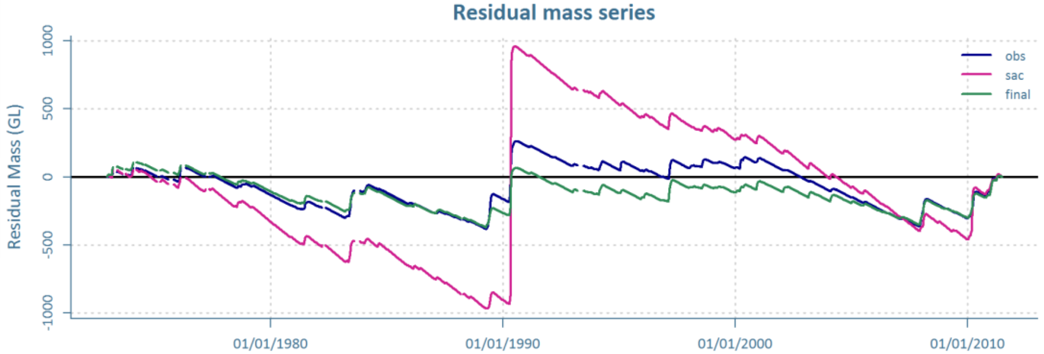
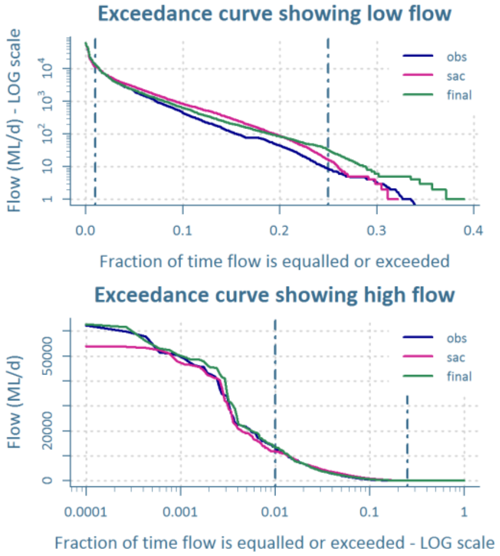


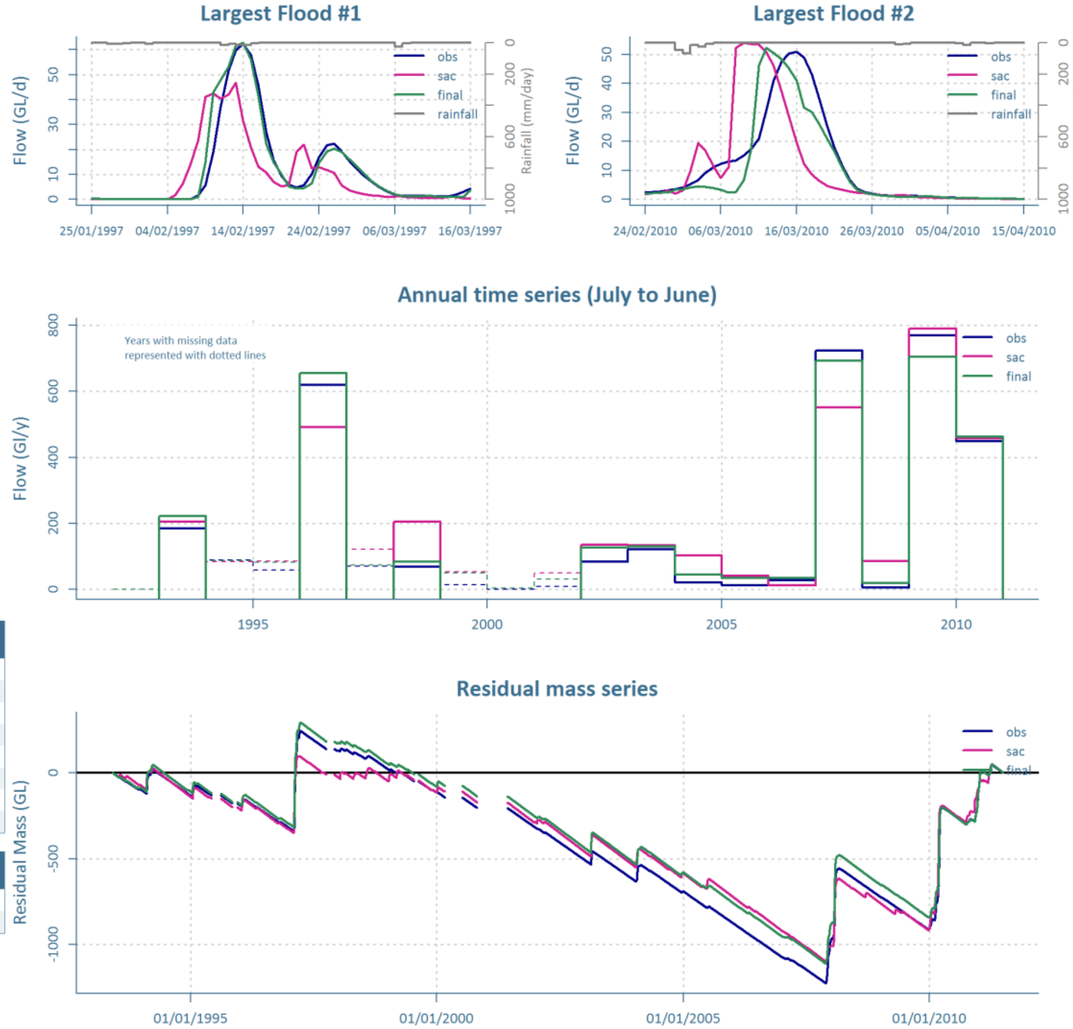
Figure 7.9: Validation Models Report Card – GS423001&2 Fords Bridge

Turra GS423005- Validation Models

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

(observed flow is available for 91.6% 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)	3,322,238	8.3%	★★☆☆☆	6.3%	★★☆☆☆
Total Low Flow Volume (ML)*	2,073	11.8%	★★☆☆☆	220.2%	★☆☆☆☆
Total Medium Flow Volume (ML)*	1,684,193	22.6%	★★☆☆☆	7.6%	★★★☆☆
Total High Flow Volume (ML)*	1,635,973	-6.3%	★★★☆☆	4.7%	★★★★☆
Mean Flow Volume (ML/d)	549	8.3%	★★☆☆☆	6.3%	★★☆☆☆
Driest 3 Year Mean (ML/d)	54	157.4%	★☆☆☆☆	91.8%	★☆☆☆☆
Zero Flow Days (%)+	66.5%	1.3%^	★★★☆☆	5.5%^	★★☆☆☆
Standard Deviation (ML/d)	3,240	-3.8%	★★★★☆	4.2%	★★★★☆

Bivariate Statistic	Sacramento Flow Value	Sac Flow Classification#	Final Flow Value	Final Flow Classification#
Nash-Sutcliffe Efficiency (NSE)	0.44	★★☆☆☆	0.91	★★★★★
Non-matching Zero Flow Days	20.8%	★★★☆☆	14.4%	★★★☆☆

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 0.01 to 0.25 exceedance probability range
* High flow = flow in the 0 to 0.01 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 7.10: Validation Models Report Card – GS423005 Turra

7.4 Discussion

7.4.1 Augathella

In the Sacramento validation the timing of major events is good but the magnitude is often underestimated. This is particularly true of events after the break in flow record where the flow sequence is characterised by peaks followed by periods of low or no flow. There is a tendency for the simulated events to occur earlier than the recorded, especially when the peak is underestimated. In general, high flow events are reproduced with low flows not well represented. Despite rainfall events occurring at the time of streamflow events it is not always of the correct magnitude, mid to small flows are not always reproduced, e.g. the January 1972 event is not represented at all in the Sacramento model flows.

The April 1989 to July 1989 Sacramento event cannot be assessed due to missing flow record. There is also no record for the March 1990 to June 1990 event. This Sacramento event is carried downstream in the inflow sequence in both validation models. The Wyandra record also showed a large event in 1990 so it could be expected that it would also have been large at Augathella.

7.4.2 Charleville

During the period 03/10/1967–19/01/1978 (the Charleville Sacramento calibration period), the timing of the Sacramento generated flows is good, however there is some underestimation of event magnitude. Outside this period overestimation of events is observed.

The Sacramento validation model volume is 152 per cent of the recorded volume. Most of this occurs in large events. This mismatch is caused by large upstream Sacramento inflows. This may be a result of issues with the rainfall representation. It may also be related to the Sacramento response in Reaches 1 and 2 being too large but the Sacramento model calibrations in both these reaches appear reasonable. Without a more recent record for Charleville, and as there is no data as far back in time anywhere else in the catchment as at Charleville, it cannot be confirmed if there is an issue or what the issue may be.

The model has been tied into the available data at Charleville by DMM adjustment and this is the best that can be done with the data available.

7.4.3 Wyandra

The timing of some flow events at Wyandra are a little early, otherwise the validation model presents a good representation of the gauged flow. This is achieved despite the unfavourable influences of the upstream gauging station at Charleville.

The 1990 event in the Sacramento validation is very large but it has been aligned to the recorded data at Wyandra with DMM so the final flows validation model matches well.

Future studies could review in more detail the recorded data between 1999–2001 (coded as estimated or poor) which was not used in this study. Other records across the catchment might be able to help to identify if some of the high flows could be aligned at Wyandra using DMM. This would in turn improve the models representation of Fords Bridge.

7.4.4 Wallen

At Wallen, the maximum flow event in the Sacramento validation is overestimated and the timing is early by approximately three days. Most events are observed to be occurring earlier rather than later, with low flow events generally overestimated and some spurious events being generated.

Where there is overestimation in the final flows validation the overestimation is a result of overestimated local inflows or additional flow being carried through from upstream. All of the gauged flow record has been used, much of which is coded as fair to poor.

This gauge is relatively new, and it is hoped the quality of the rating will improve with age and correspondingly the ability to bed down flow characteristics in this part of the river.

7.4.5 Cunnamulla

In the Sacramento validation model the timing of simulated events tends to occur earlier than in the recorded flow sequence. Also in the Sacramento validation additional events sometimes appear which are due to inaccurate rainfall representation producing inaccurate Sacramento inflows. March 2010 is such an event. It was not carried through to the final flows validation model as the final upstream inflows were tied to recorded flows in multiple upstream reaches. Similar events which are inaccurate in the Sacramento validation occur in June, September and December 2008.

The 1997 event is overestimated at Cunnamulla. This is associated with the size of the recorded flows at Wyandra for this event which the model was tied to not being able to be attenuated correctly using the reach structure in the model.

7.4.6 Barringun

At Barringun there are some timing issues for both validation runs with events occurring early. There is also variability in the magnitude of events.

The overall volume balance is reasonable (a bit high at 120 per cent) for the final flows validation. Some of the variation is attributable to a single relationship being used to represent the Cuttaburra Creek breakout whereas in reality it is variable. It should be noted that the earlier Barringun gauge was not used in the model calibration and if the volume change is considered in the period of records available at the more recent station (31/05/1993 to 30/06/2011) it is 112 per cent.

Also, although the volume difference for the Sacramento model validation is high (132 per cent) if flows below 50,000 ML/day are considered which included everything except the top of the 1990 and 2010 events then the Sacramento comparison is 124 per cent.

In the Sacramento validation additional events appear or others are missing where inaccurate rainfall representation has produced inaccurate Sacramento inflows. Some of these events also appear or are missing in the final flows validation model when the final inflows have no or few ties to recorded data.

The February 1976 event is partially the result of Sacramento inflows. The model is tied in to Wyandra recorded data but there is a large reach inflow in the Reach 9 Sacramento inflows which leads to the event being overestimated at Barringun as the model is not tied into flow data from the earlier Barringun station.

The large event in April and May 1990 is caused by Sacramento inflows. In the final inflows these were adjusted to the recorded data at Wyandra so the event is reduced in size in the final flows validation model. Below Wyandra there was no recorded and so Sacramento inflows remained. There are no recorded flows at Cunnamulla or Barringun for this period to check the accuracy.

The overestimated event in March 2010 is another example. The Sacramento data produced an extreme event but this was not carried through to the final flows validation as upstream inflows were tied to recorded flows in multiple upstream reaches.

In some events additional flow accumulates at Barringun. This appears to result from the effect of average lag, routing and unaccounted differenced and also the simplified channel breakout relationships. The effects of these in reality vary across flow ranges and in time and when the simplifications are applied to the Cunnamulla model flows the result is overestimation of some events at Barringun. February 1997 is an example. For this event the final validation model matches at Wyandra and there is little inflows below that point but the attenuation produced in the model is not able to bring about the reduction in flow required for the recorded and modelled Barringun flows to match. Hence these events are overestimated at Barringun.

7.4.7 Fords Bridge

The flow sequence at Fords Bridge is a product of the amalgamation of the available gauged records. The validation appears reasonable. The timing of events is more aligned than at the upstream gauge. Where timing issues are observed, the tendency is for events to occur earlier than records indicate. Simulated flow events are generally responsive to the events recorded in the reach rainfall data.

The February 1976 event is mostly missing at Fords Bridge; however, the losses between Barringun and Ford's Bridge appear to have brought the event more into line with what would have been expected at Ford's Bridge.

As at Barringun the May 1990 event is very large in the Sacramento model validation. In the final flows validation model it fitted well at Wyandra and below that there was no record to compare it against. The flow by the time it reaches Fords Bridge shows an overestimation of the peak which is due mainly to the Sacramento inflows from upstream and probably also attenuation, unaccounted differences and breakouts that are not quite correct. The shape of the event is a result of the methodology applied. The volume of the modelled event, however, is only 80 per cent of the recorded event so it was decided a one off adjustments to improve the peak was not appropriate. The extreme difference in the Sacramento validation model indicates that the rainfall estimated for this event was just not correct, probably across the whole Warrego basin.

Similarly the March 2010 event shows the same patterns as at Barringun. In the Sacramento validation there is an overestimation; however, in the final flows validation model the flows have been aligned by adjustments made to upstream inflows. Again it is likely that there were problems with the 2010 rainfall representation in the model.

Although the volume difference for the Sacramento model validation is high (158 per cent) if flows below 130,00 ML/day are considered which included everything except the top of the May 1990 and March 2010 events then the Sacramento comparison is 108 per cent.

7.4.8 Turra

The Turra validation model results are good.

7.4.9 Summary

The Warrego River IQQM is a simple model with no infrastructure. Most of the final flow sequences were in good agreement with the recorded flow sequences. The degree of representation decreased towards the end of the system, as inconsistencies observed at upstream locations filtered down through the catchment. Large differences are discussed in the previous sections.

Throughout the model results, the Sacramento flows validation model results especially, there are examples of events were the rainfall distribution across the catchment has not been well captured. This is especially true of very large events. This is a problem which is caused by the sparseness of the rainfall recording network and its lack of ability to capture the spatial and temporal variability of rainfall correctly. It is not something that is likely to ever improve.

There are also other problems which influence the models ability to reproduce recorded flows. These include the assumptions of constant lag and routing and unaccounted differences, and the representation of channels flowing in and out of the main river in large events. In this flat country these parameters can all in reality change from event to event. It is therefore very hard to obtain accuracy in the very high flows and especially so the further down the catchment you move as you move into true channel country.

8 Quality Assurance

Quality assurance procedures were followed out for this calibration and are reported on in the QA report. 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 models 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, mid and high flow ranges are defined by the flexion points on the daily flow duration curves.

The performance of the Sacramento model calibrations varies as shown in the report cards. 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 Warrego River System, from the headwaters upstream of Augathella to Fords Bridge.

Nine individual IQQM models of river reaches between stream gauging stations in the Warrego River System were set up. All reaches were calibrated using downstream gauging station data.

For each reach the following occurred. 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 and waterhole parameters. 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. Some further adjustments were made to Sacramento data in catchments where the downstream gauge records were longer than the calculated record based residual inflow. The final adjustments produced the final reach inflow sequence used for the validation model and for use in future simulations.

This information was used to develop a validation IQQM model of the Warrego River System which was checked for quality of calibration over different periods for each reach. The quality of the data 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, more sophisticated model structure, and additional information on regional groundwater levels.

The models developed constitute a whole river system IQQM and are considered adequate for use in Water Resource Planning studies and other water resource investigations.

10 Recommendations

The gauges throughout the system should be maintained and kept for assessment purposes. The influence of natural breakouts, losses and returns in the system is significant, however, successful modelling of these relationships is limited by a lack of data. Additional information regarding these characteristics would improve future models. Of most interest are the Widgeegoara and Noorama Creek diversions and the Irrara Creek diversion, loss and return.

It would also be beneficial to hydrological investigations that the recorded data be streamlined for catchments that span multiple states. This would allow for all the appropriate comparisons and validations to be made.

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) *Warrego River System Hydrology – Calibration of Daily Flow Simulation Model from upstream of Augathella (Qld AMTD 447.4km) to Darling River (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.

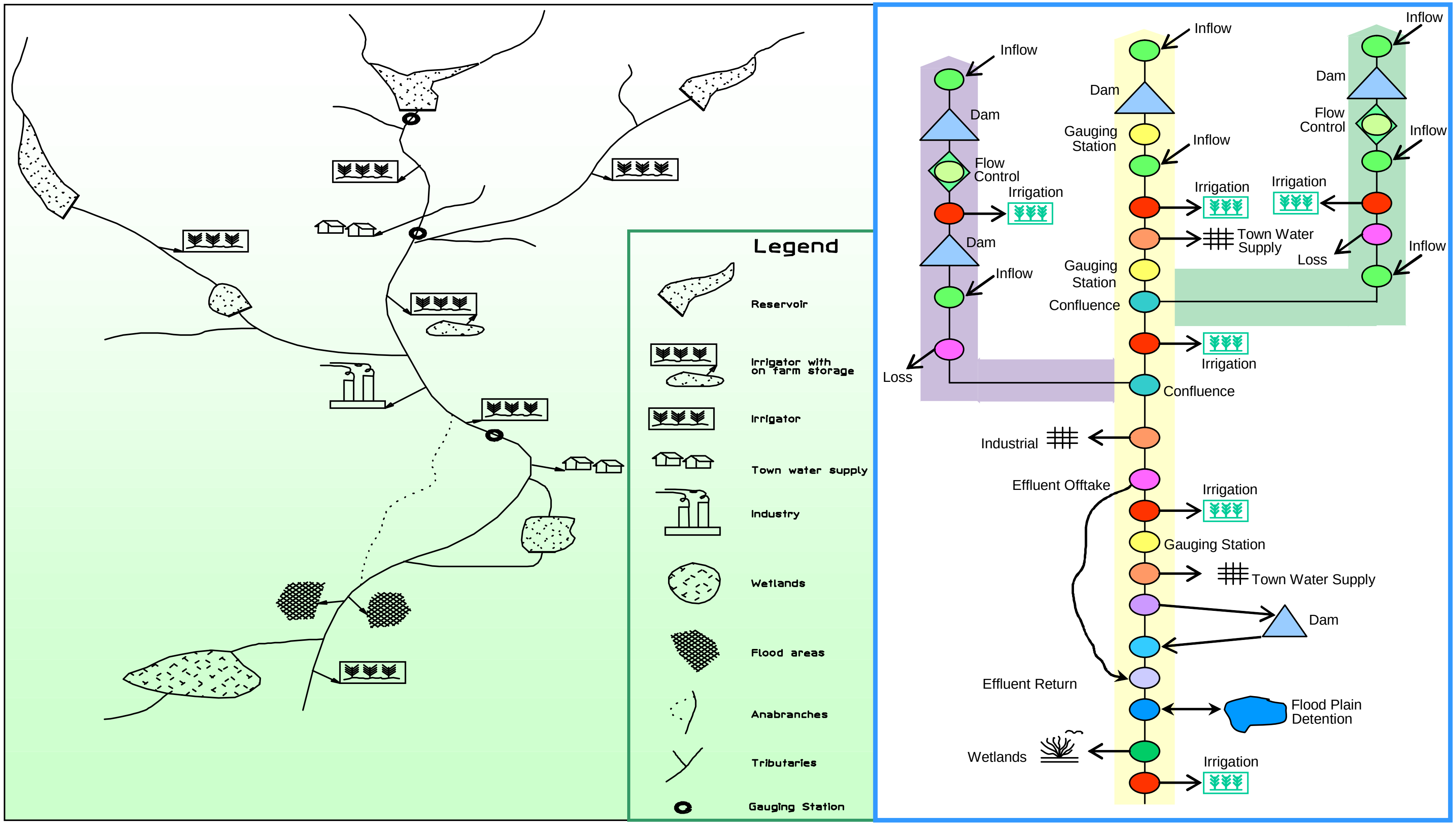


Figure A1 – IQQM Node Diagram Representation

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.

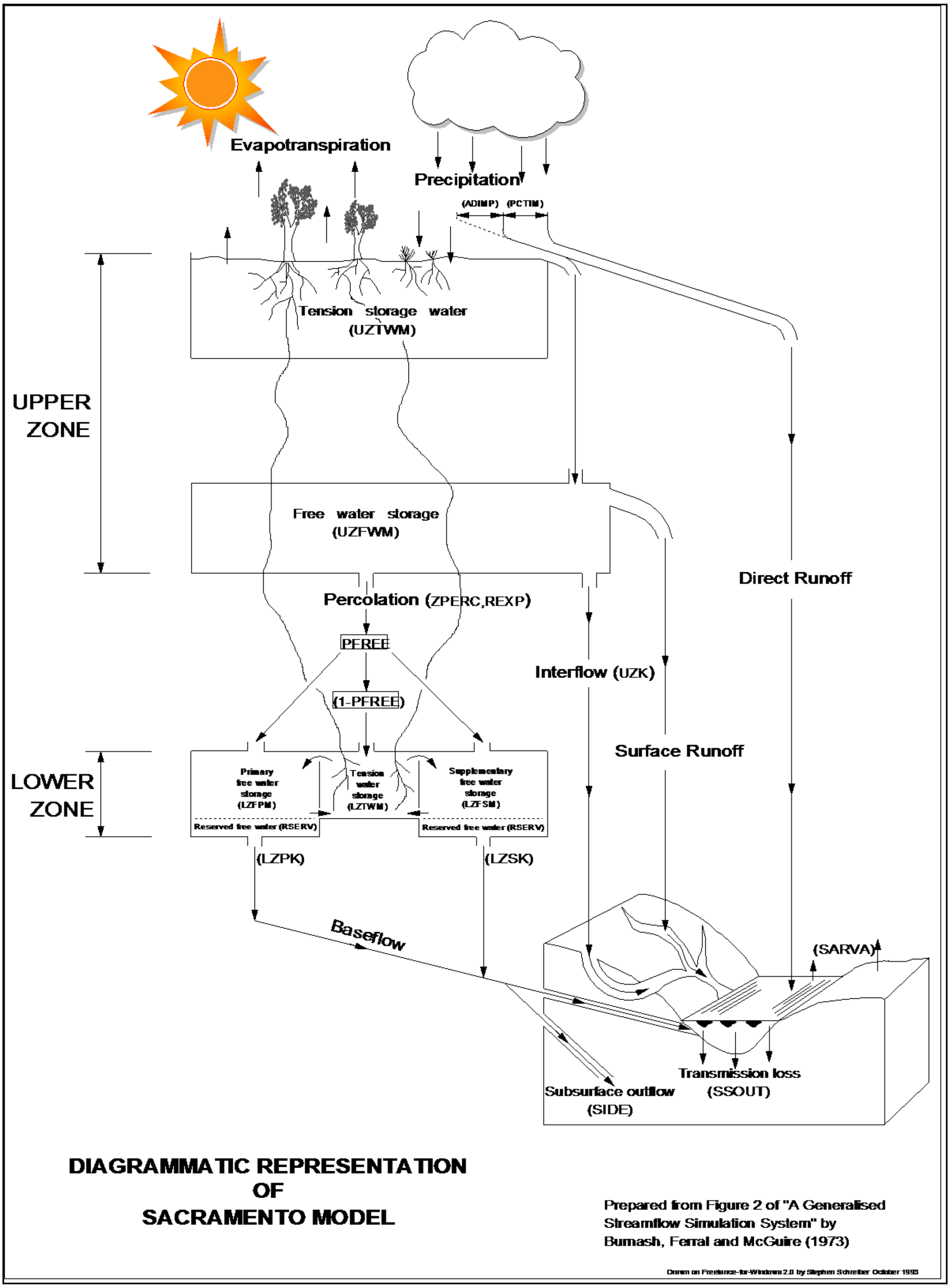


Figure A2 – Sacramento Model Schematic

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 that 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.

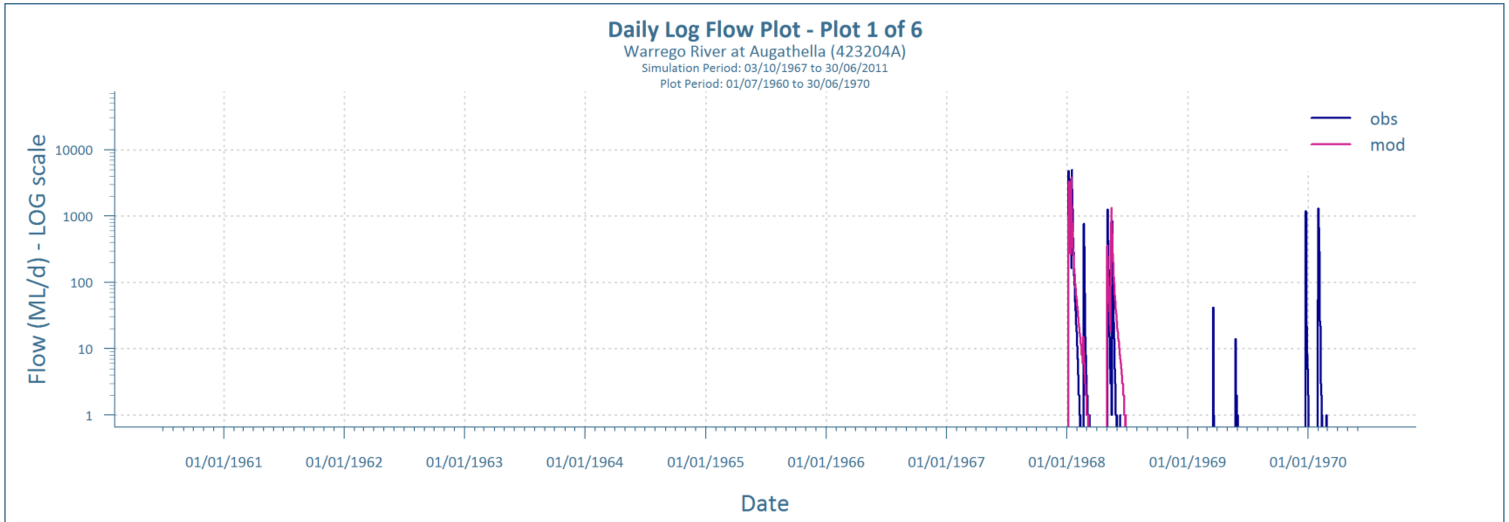
IQQM has difficulty accurately predicting effect of routing for all flood events, especially the change in routing for large events compared with small events. The routing parameters used in the IQQM are usually a compromise that gives the best agreement for most flood events. In some flood events, the 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.

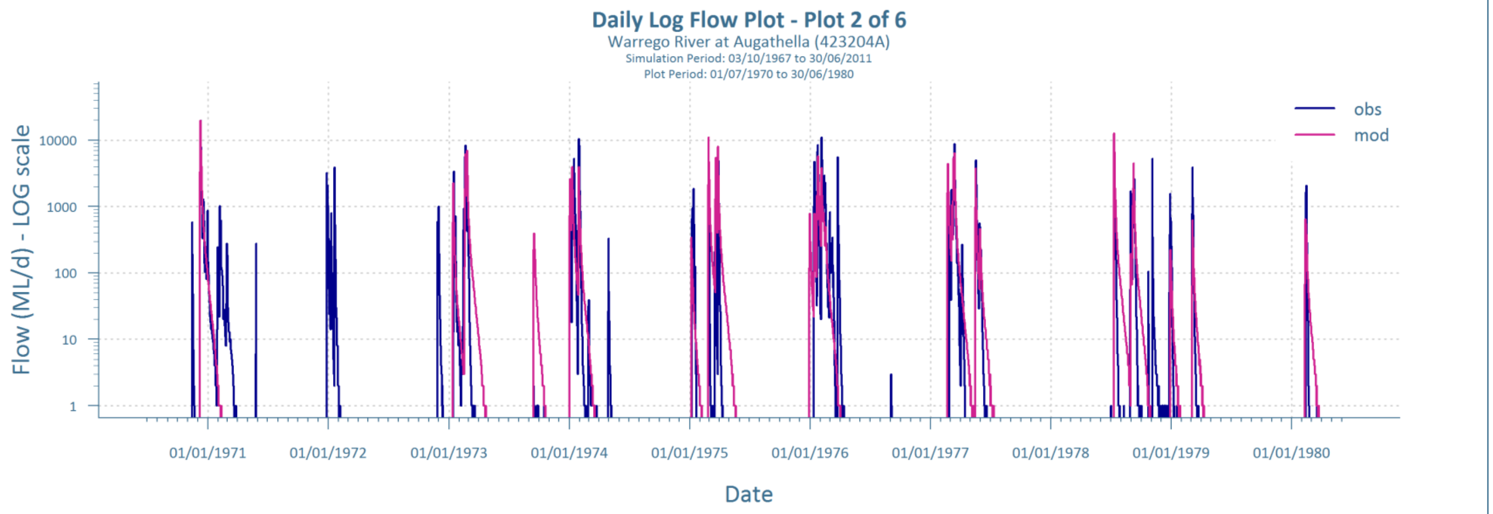
Multiple Reaches

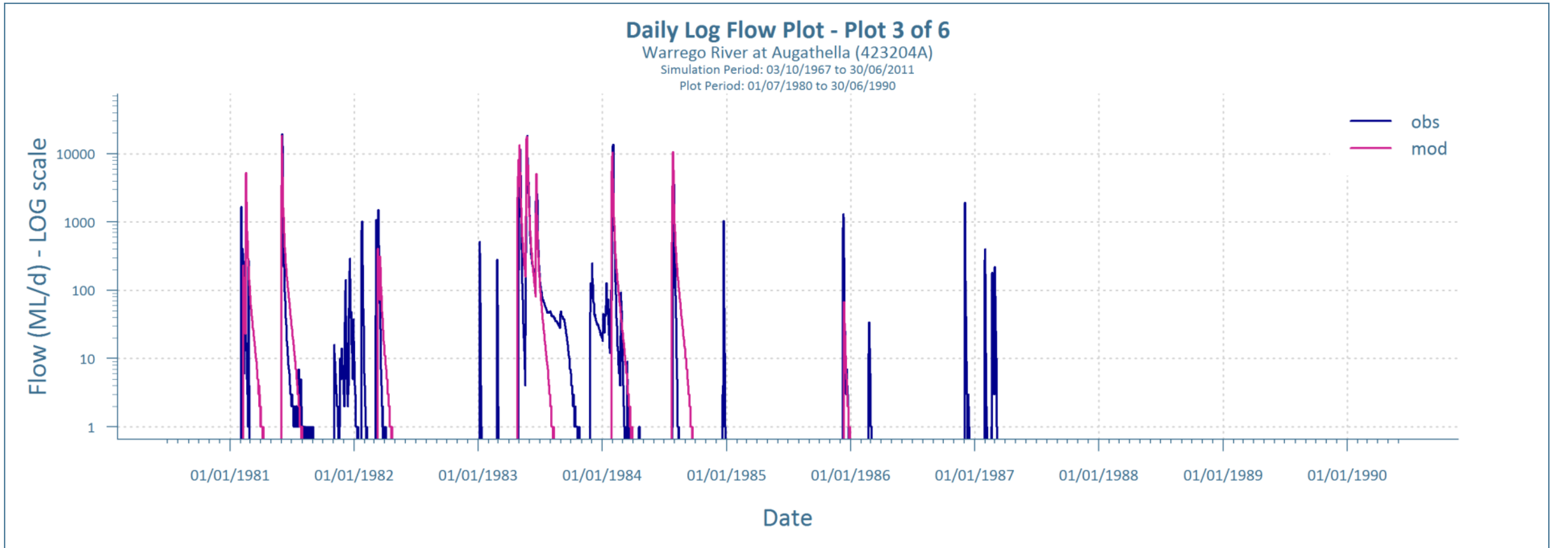
The DMM process is carried out in each reach upstream of a gauge. When this process has been completed for each reach, a daily inflow sequence is created for each subarea upstream of the stream gauge consisting of flows originally estimated using the Sacramento model. In some periods, the flow has been 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.

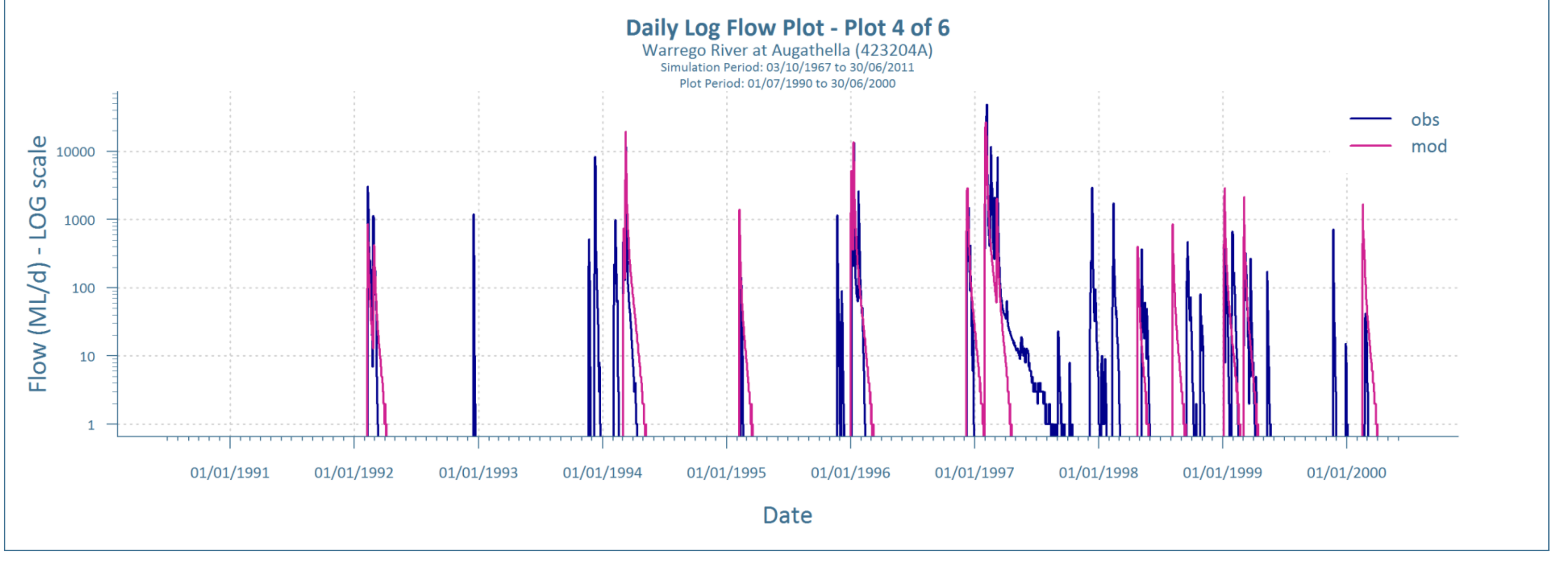
In the final IQQM model, the flow at a downstream gauge is an accumulation of all the subarea inflows from all the reaches upstream. Sometimes there is a long-term gauge at the end of system and a comparison between the predicted flow and the recorded flow shows considerable differences in the period 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.

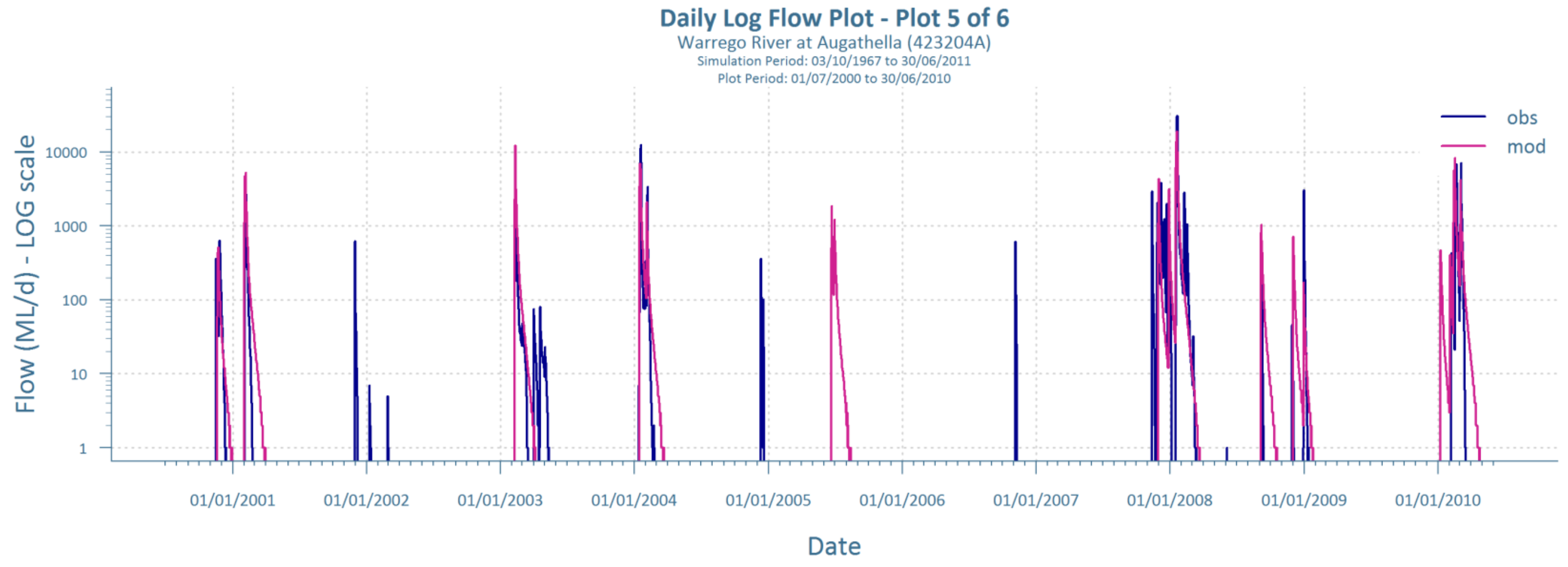
Appendix C1 – Reach 1 Recorded and Sacramento Daily Flows

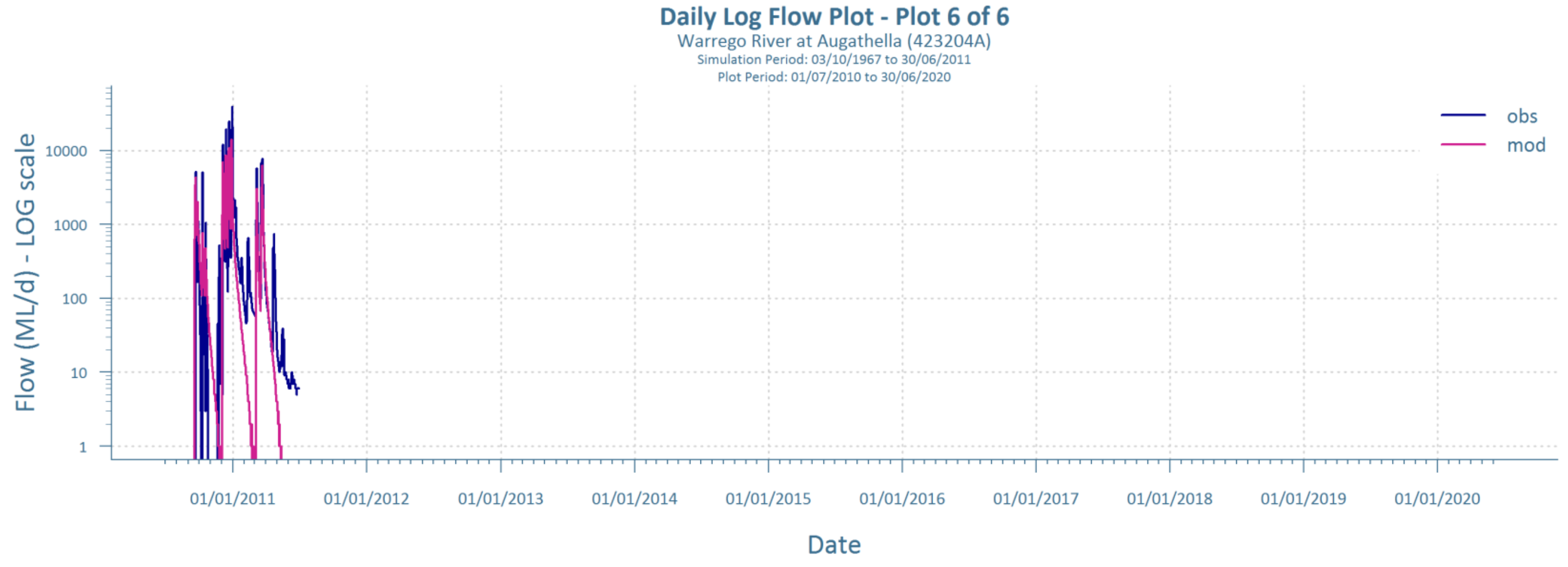




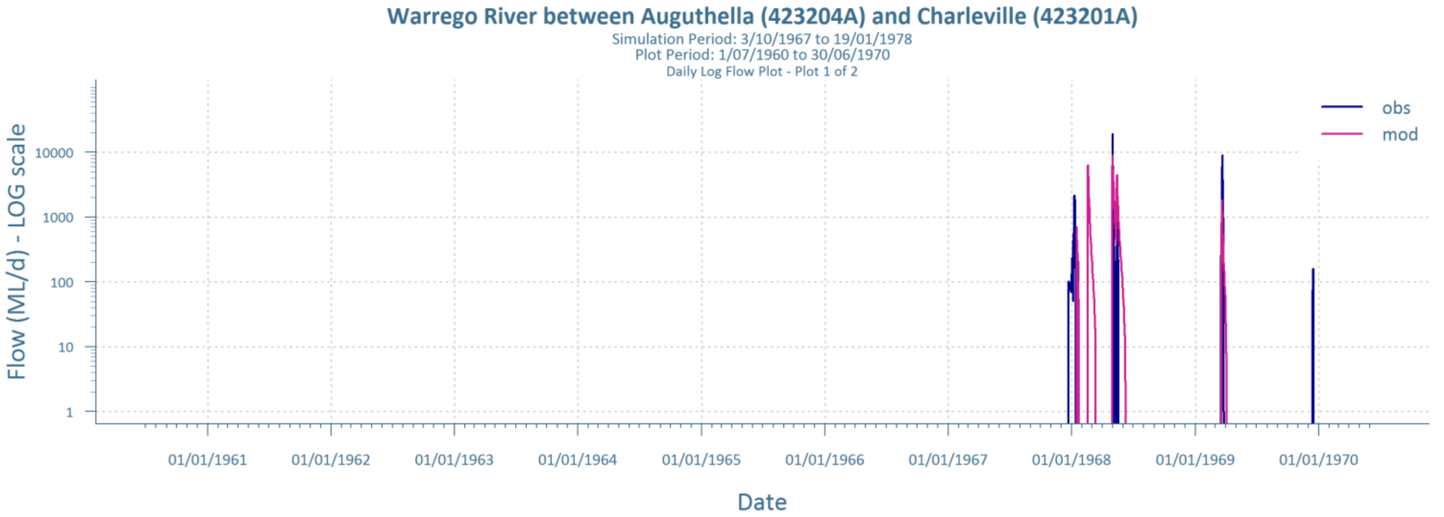

Daily Log Flow Plot - Plot 3 of 6
Warrego River at Augathella (423204A)
Simulation Period: 03/10/1967 to 30/06/2011
Plot Period: 01/07/1980 to 30/06/1990
obs
mod
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/1981
01/01/1982
01/01/1983
01/01/1984
01/01/1985
01/01/1986
01/01/1987
01/01/1988
01/01/1989
01/01/1990
Date

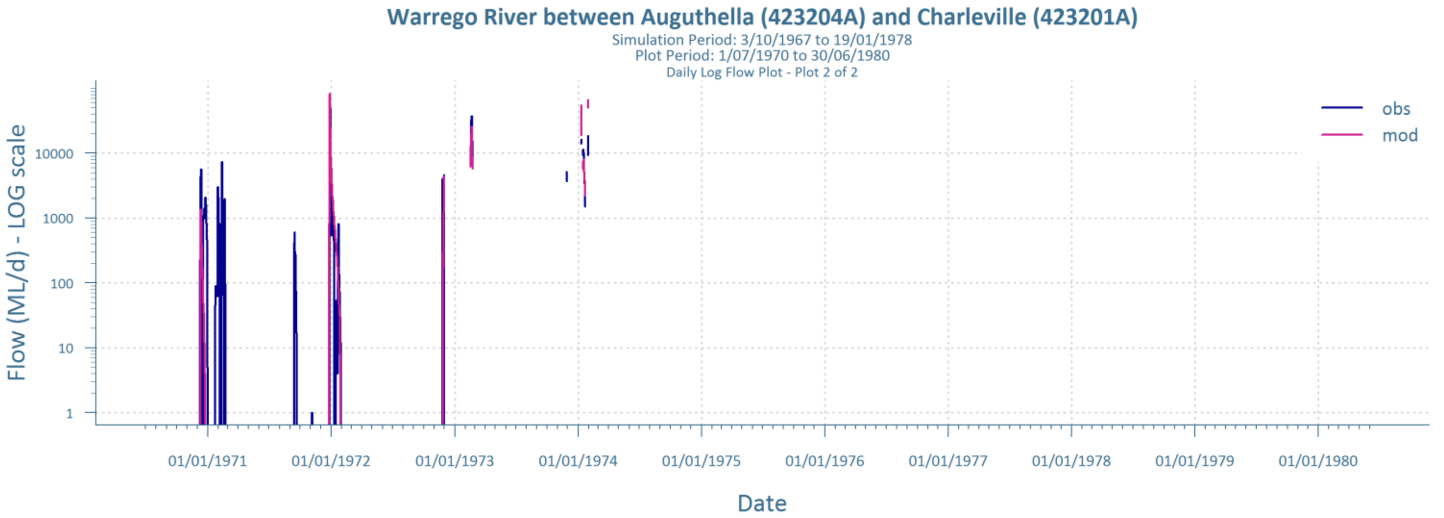

Daily Log Flow Plot - Plot 4 of 6
Warrego River at Augathella (423204A)
Simulation Period: 03/10/1967 to 30/06/2011
Plot Period: 01/07/1990 to 30/06/2000
obs
mod
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/1991
01/01/1992
01/01/1993
01/01/1994
01/01/1995
01/01/1996
01/01/1997
01/01/1998
01/01/1999
01/01/2000
Date


Daily Log Flow Plot - Plot 5 of 6
Warrego River at Augathella (423204A)
Simulation Period: 03/10/1967 to 30/06/2011
Plot Period: 01/07/2000 to 30/06/2010
Flow (ML/d) - LOG scale
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

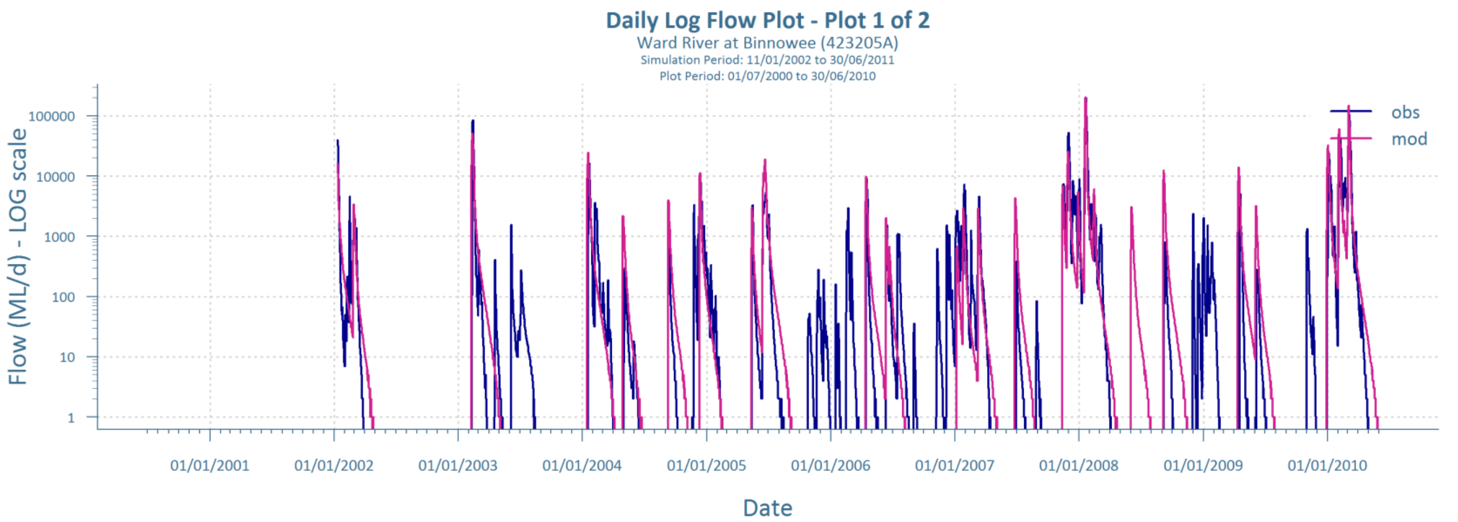

Daily Log Flow Plot - Plot 6 of 6
Warrego River at Augathella (423204A)
Simulation Period: 03/10/1967 to 30/06/2011
Plot Period: 01/07/2010 to 30/06/2020
Flow (ML/d) - LOG scale
10000
1000
100
10
1
obs
mod
01/01/2011
01/01/2012
01/01/2013
01/01/2014
01/01/2015
01/01/2016
01/01/2017
01/01/2018
01/01/2019
01/01/2020
Date

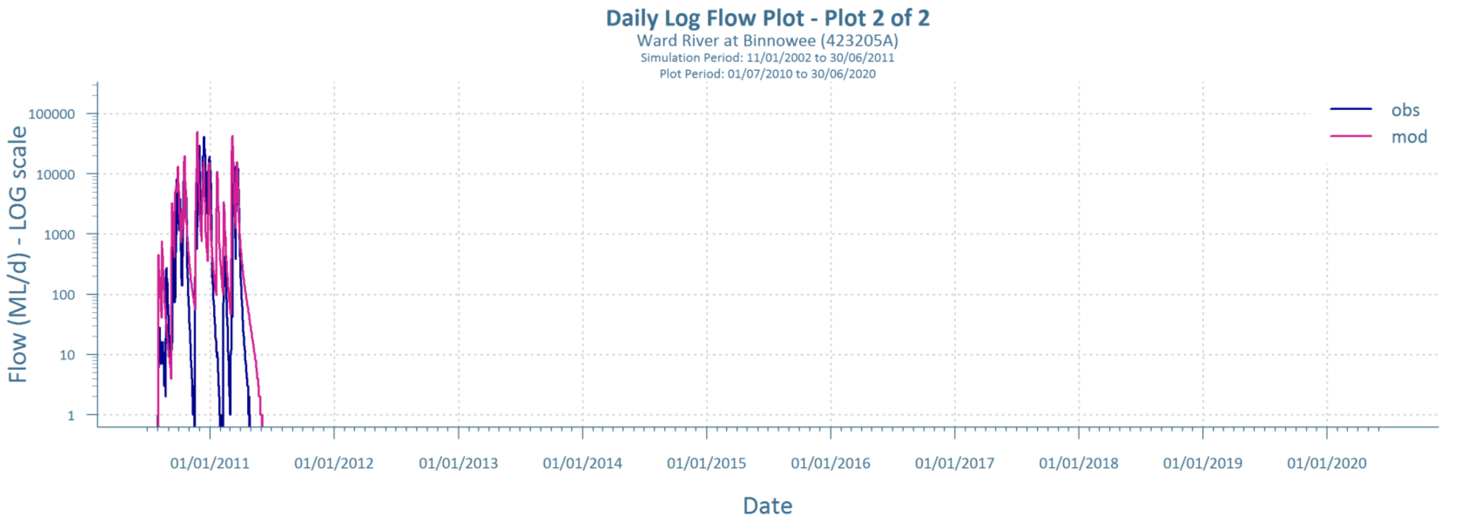
Appendix C2 – Reach 2 Recorded and Sacramento Daily Flows



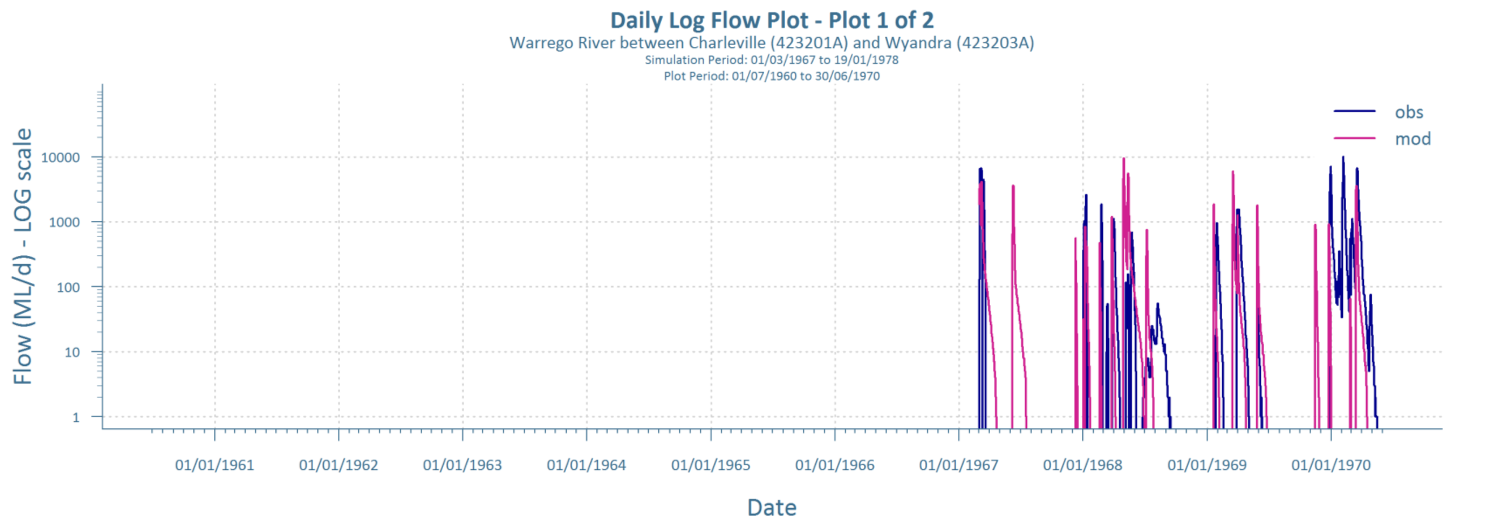


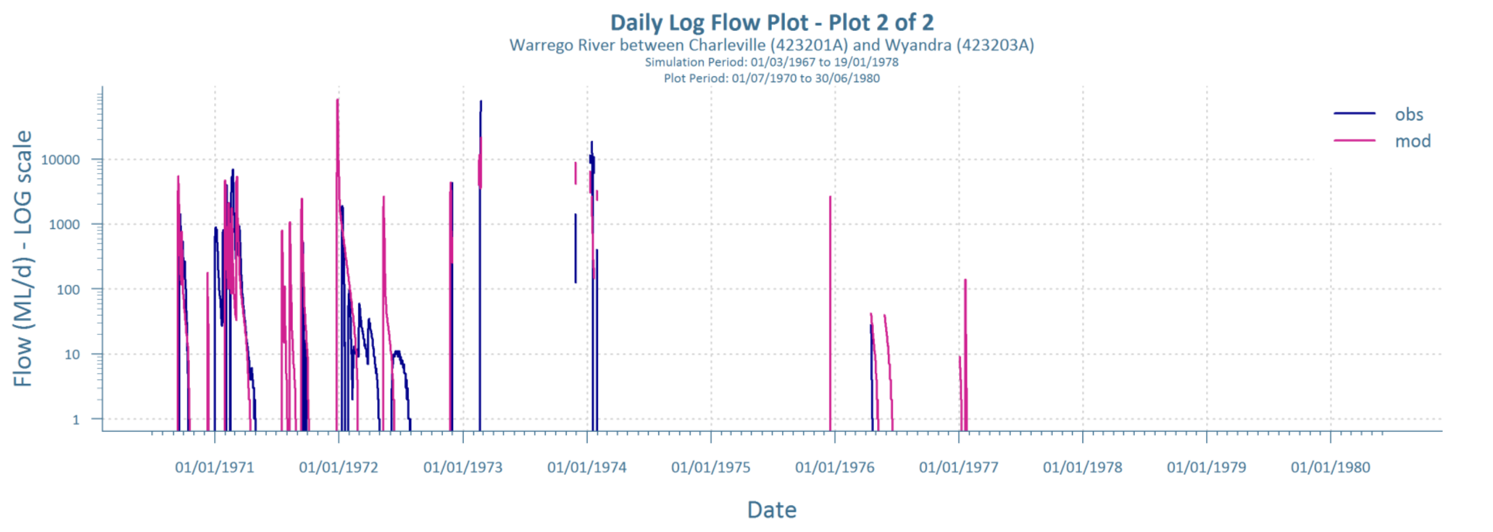
Appendix C3 – Reach 3 Recorded and Sacramento Daily Flows



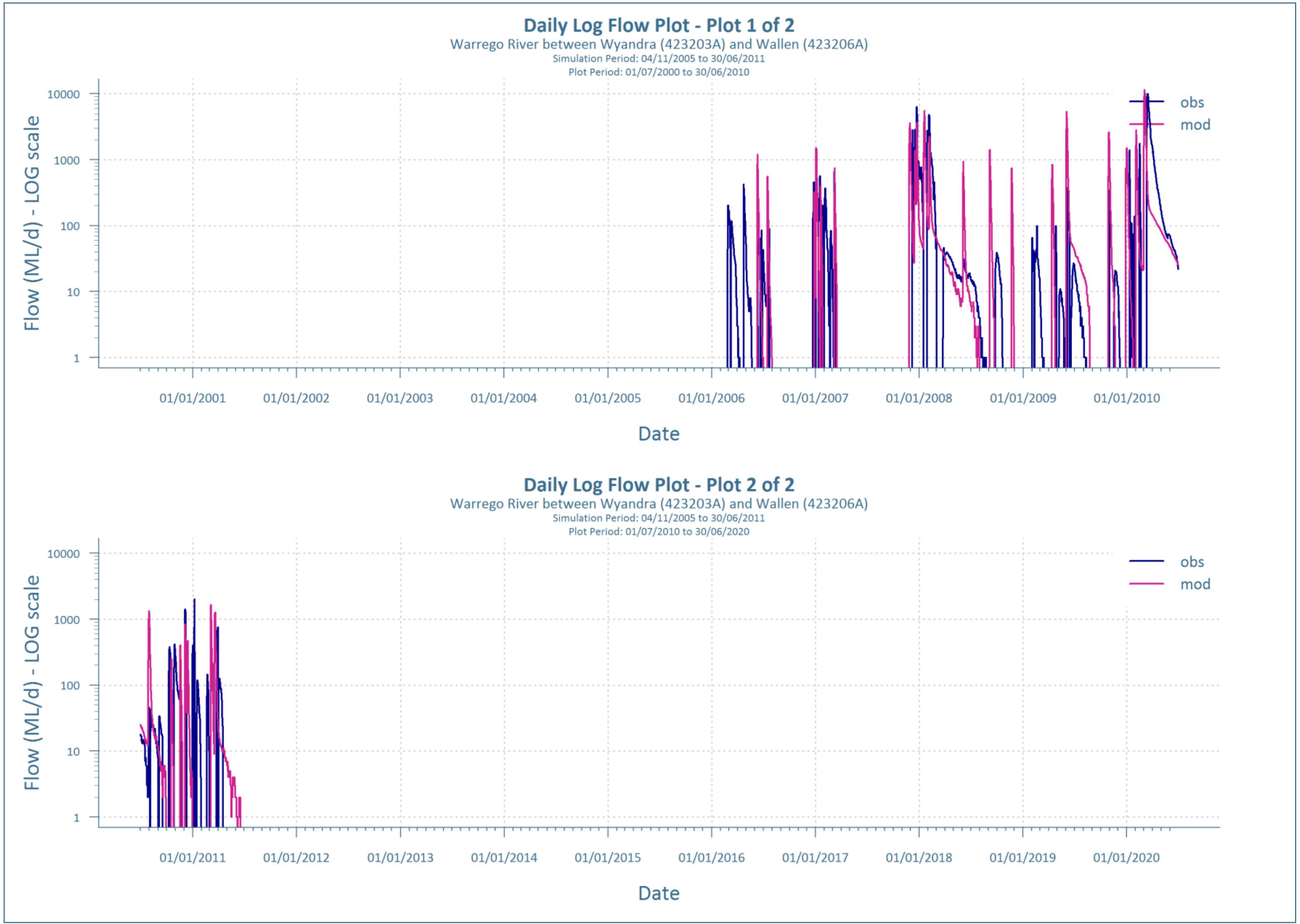


Appendix C4 – Reach 4 Recorded and Sacramento Daily Flows

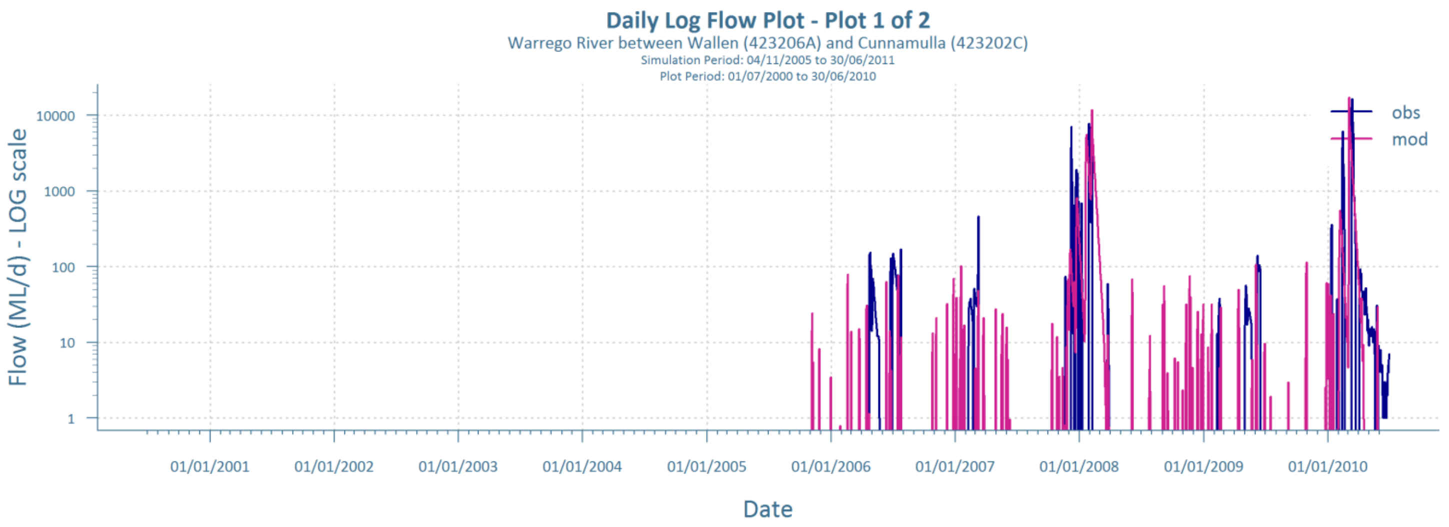


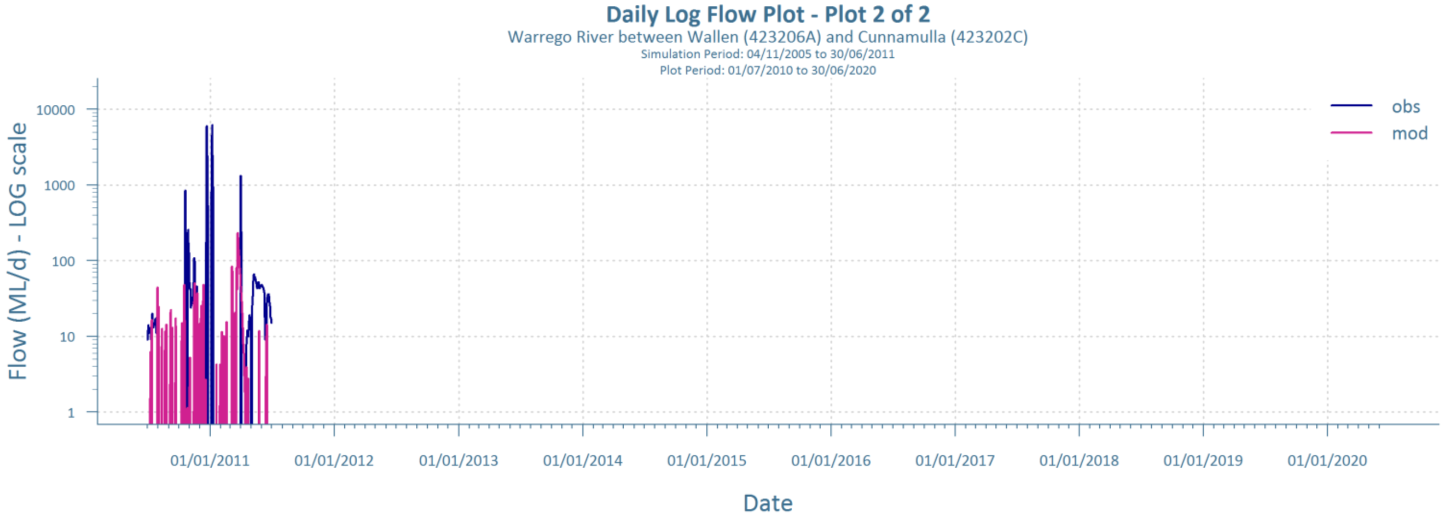


Appendix C5 – Reach 5 Recorded and Sacramento Daily Flows

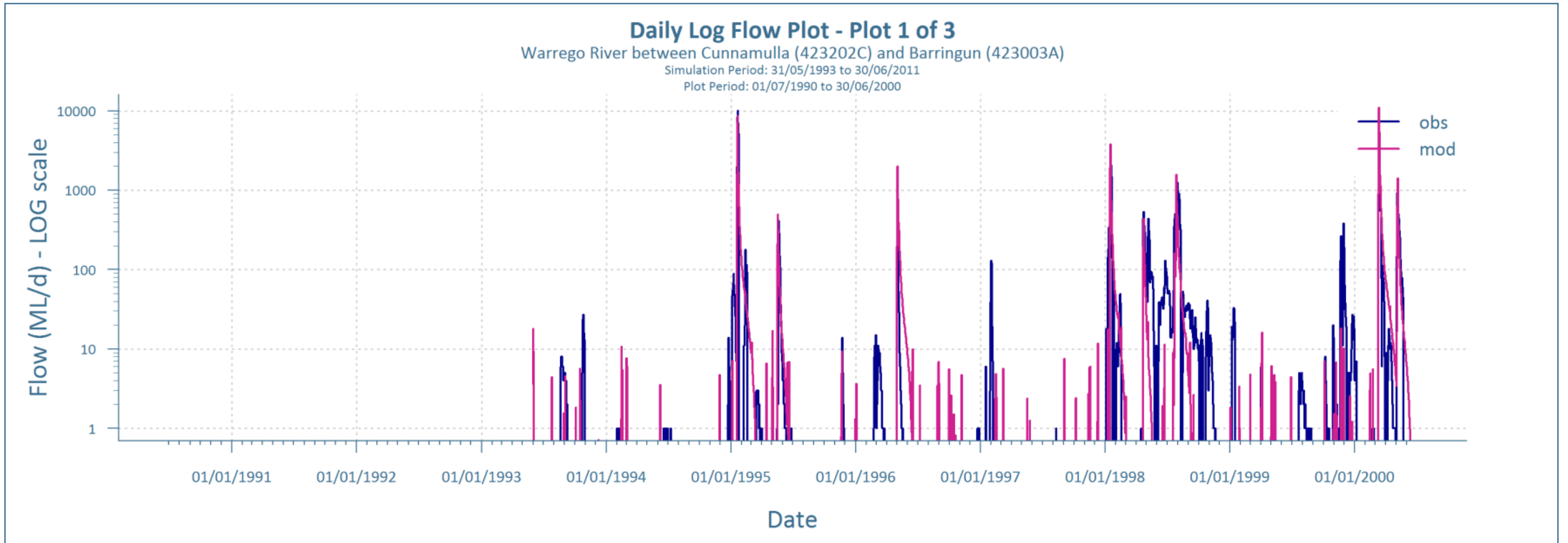


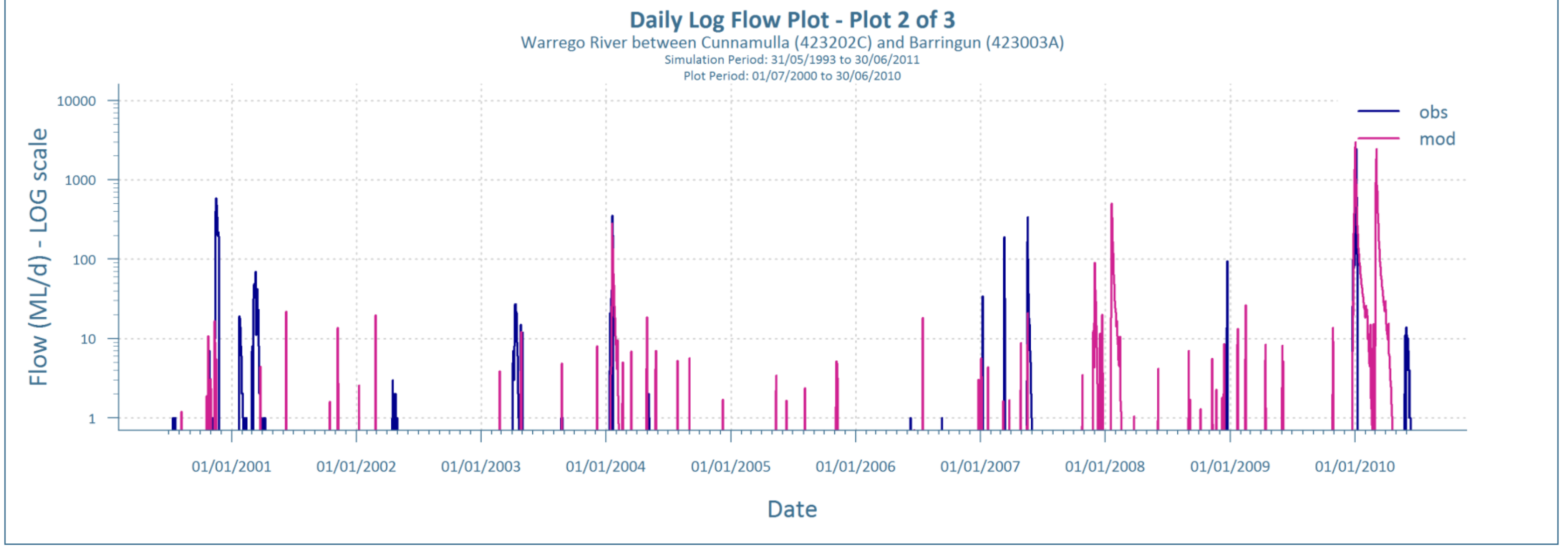
Appendix C6 – Reach 6 Recorded and Sacramento Daily Flows

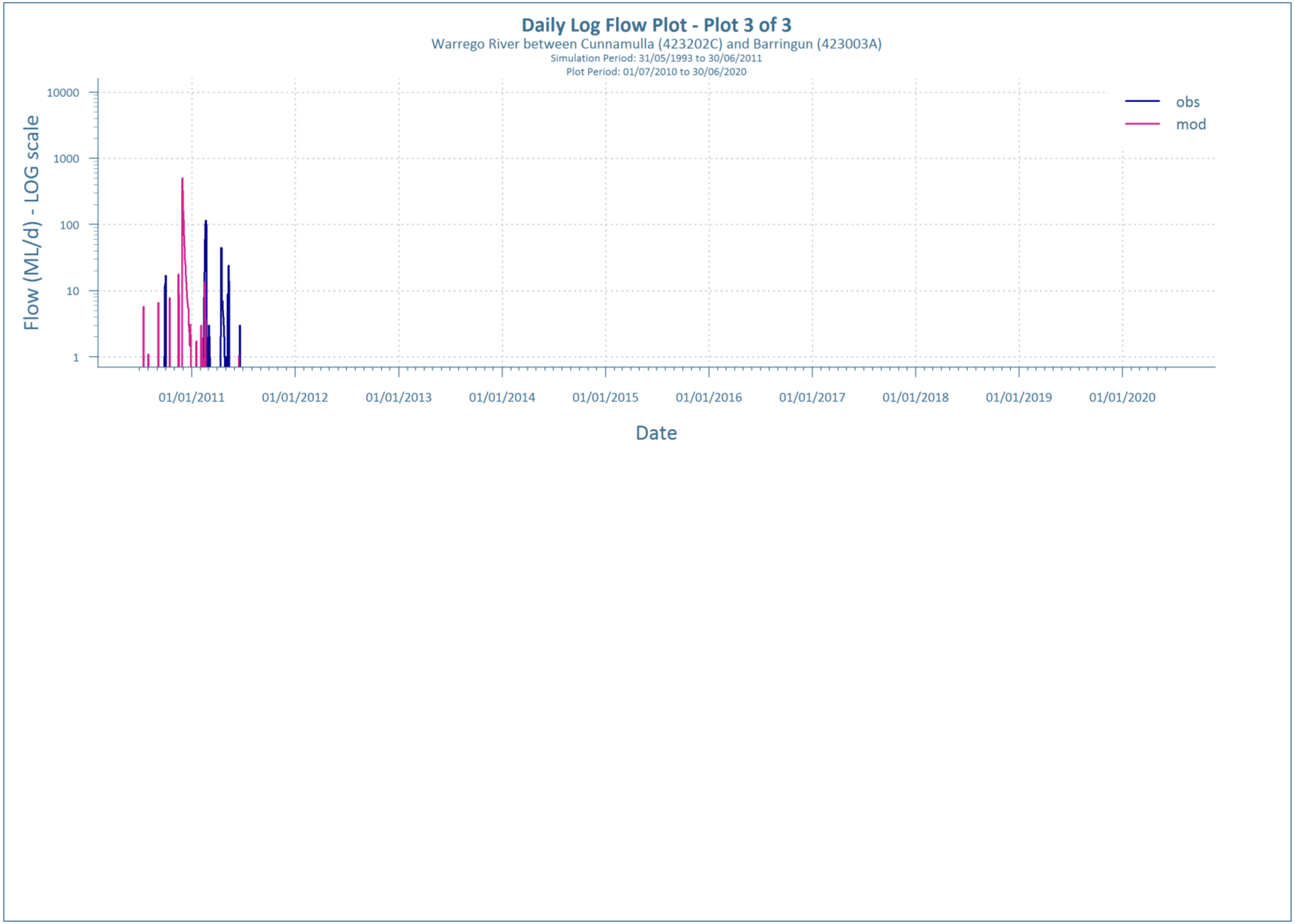




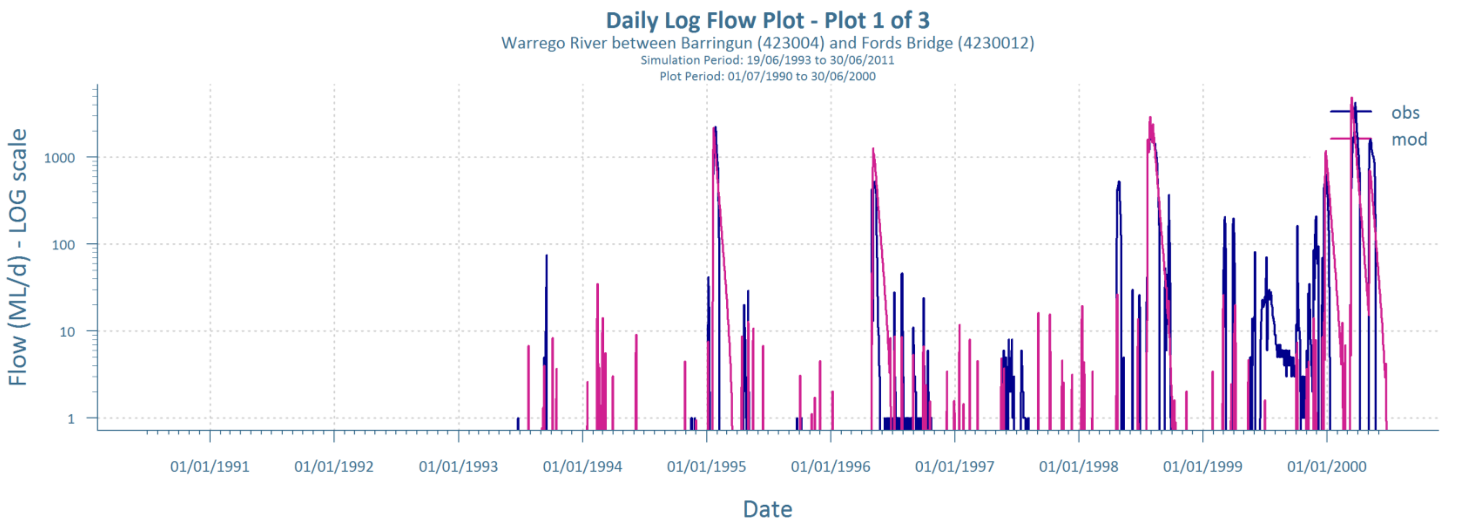
Appendix C7 – Reach 9 Recorded and Sacramento Daily Flows

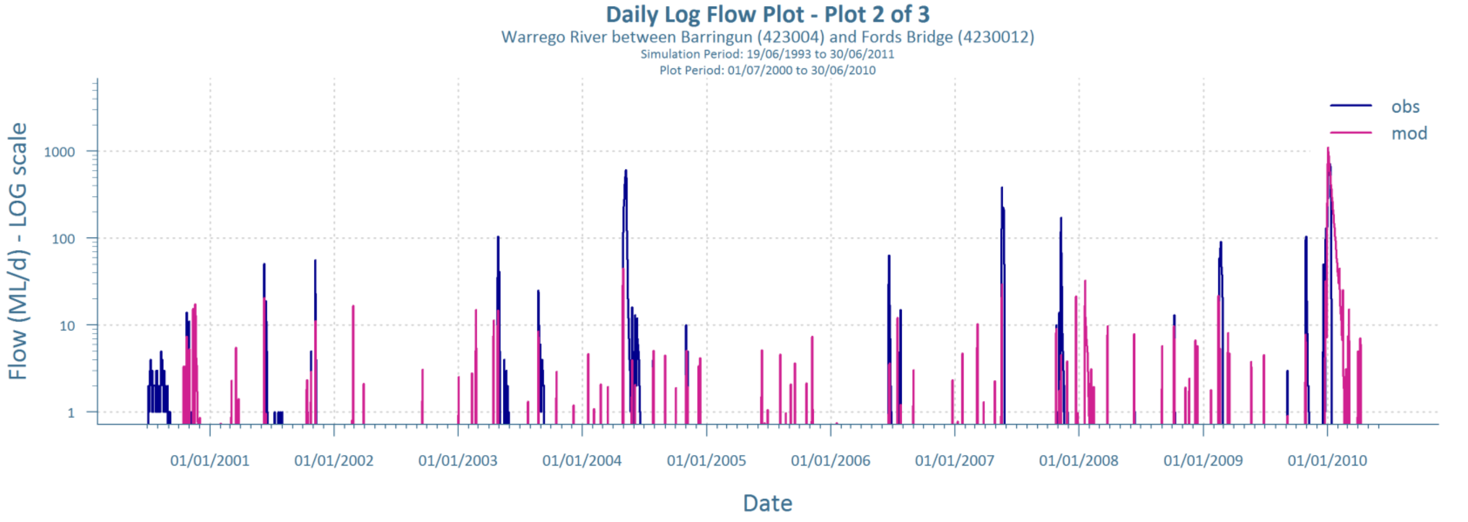


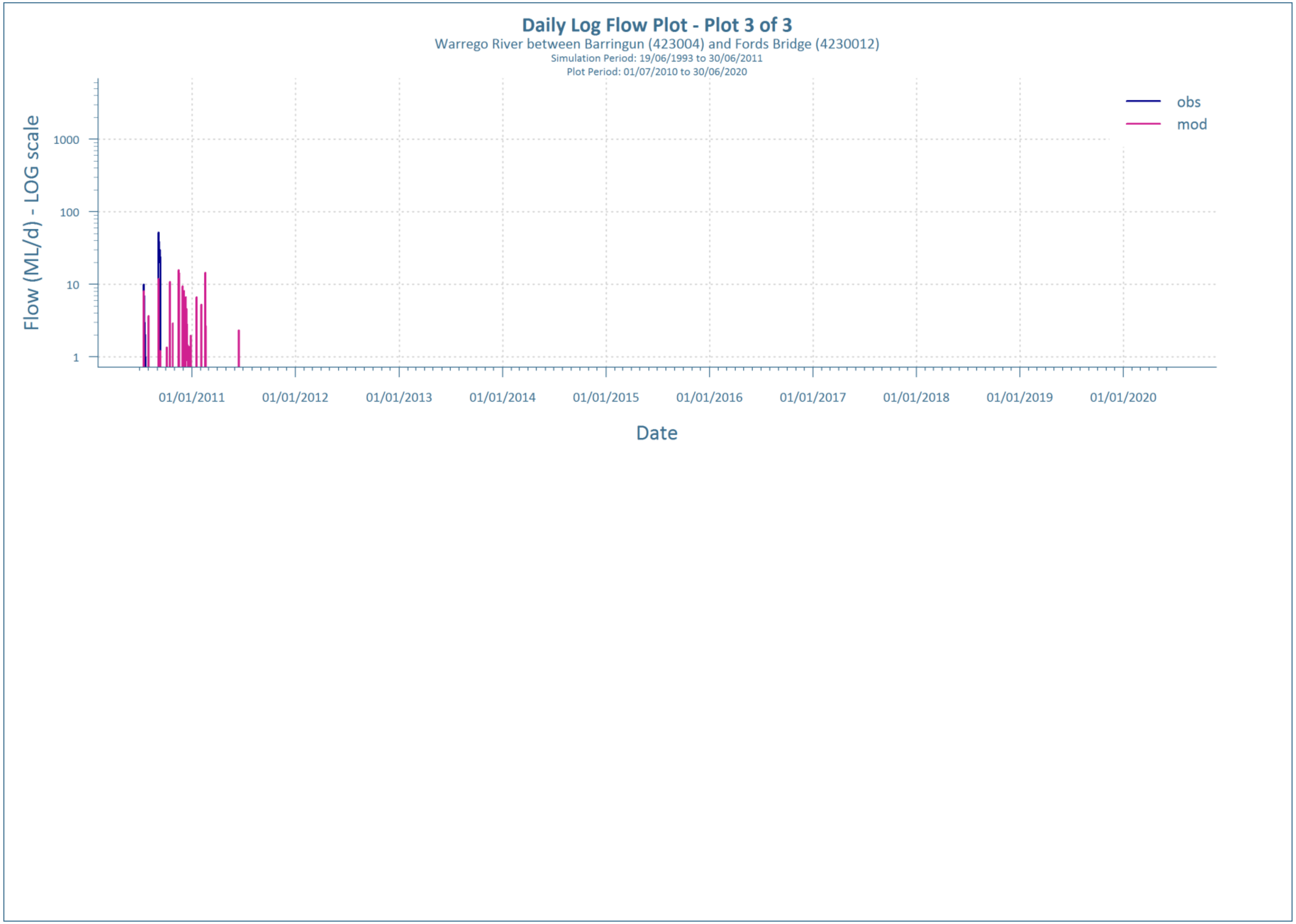



Daily Log Flow Plot - Plot 3 of 3
Warrego River between Cunnamulla (423202C) and Barringun (423003A)
Simulation Period: 31/05/1993 to 30/06/2011
Plot Period: 01/07/2010 to 30/06/2020
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/2011
01/01/2012
01/01/2013
01/01/2014
01/01/2015
01/01/2016
01/01/2017
01/01/2018
01/01/2019
01/01/2020
Date
obs
mod

Appendix C8 – Reach 11 Recorded and Sacramento Daily Flows

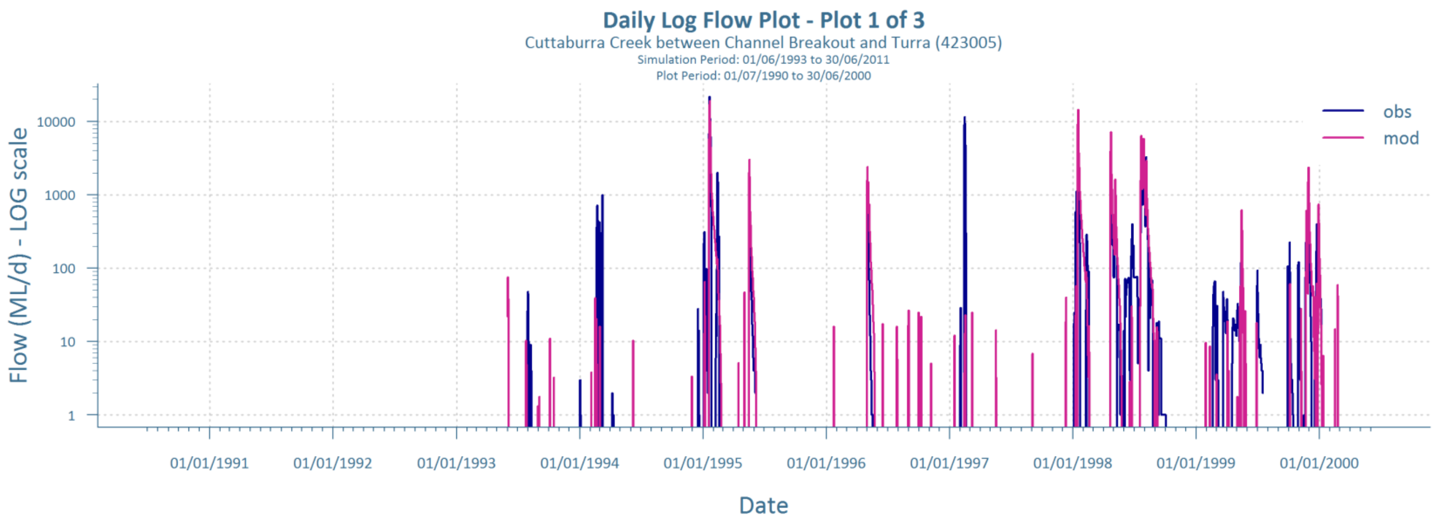


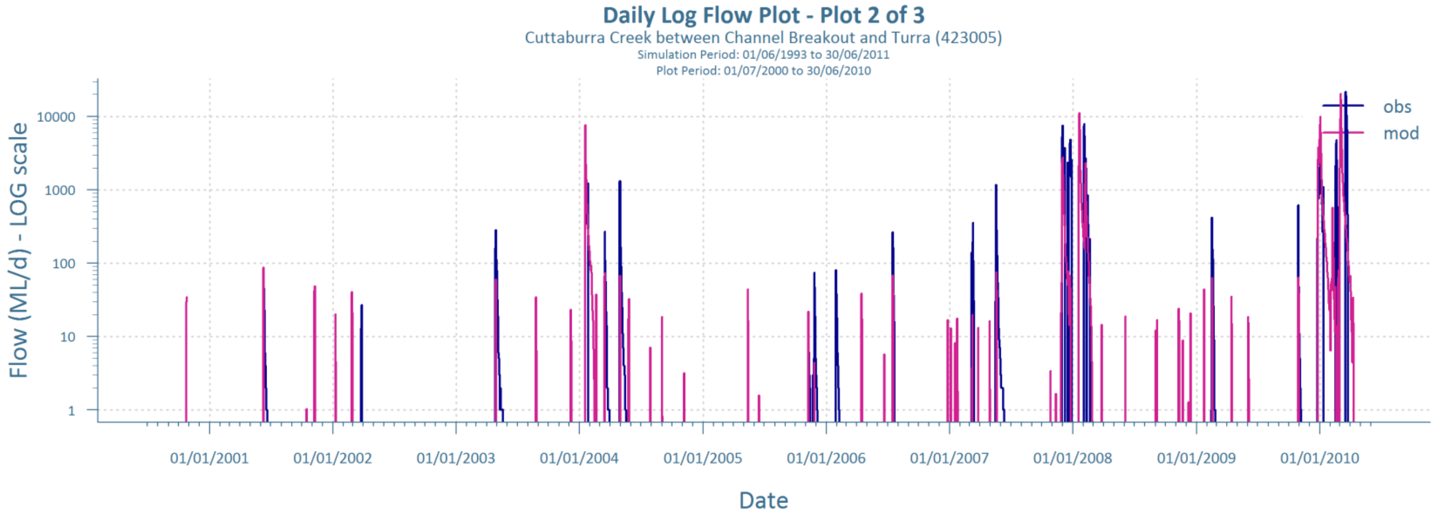


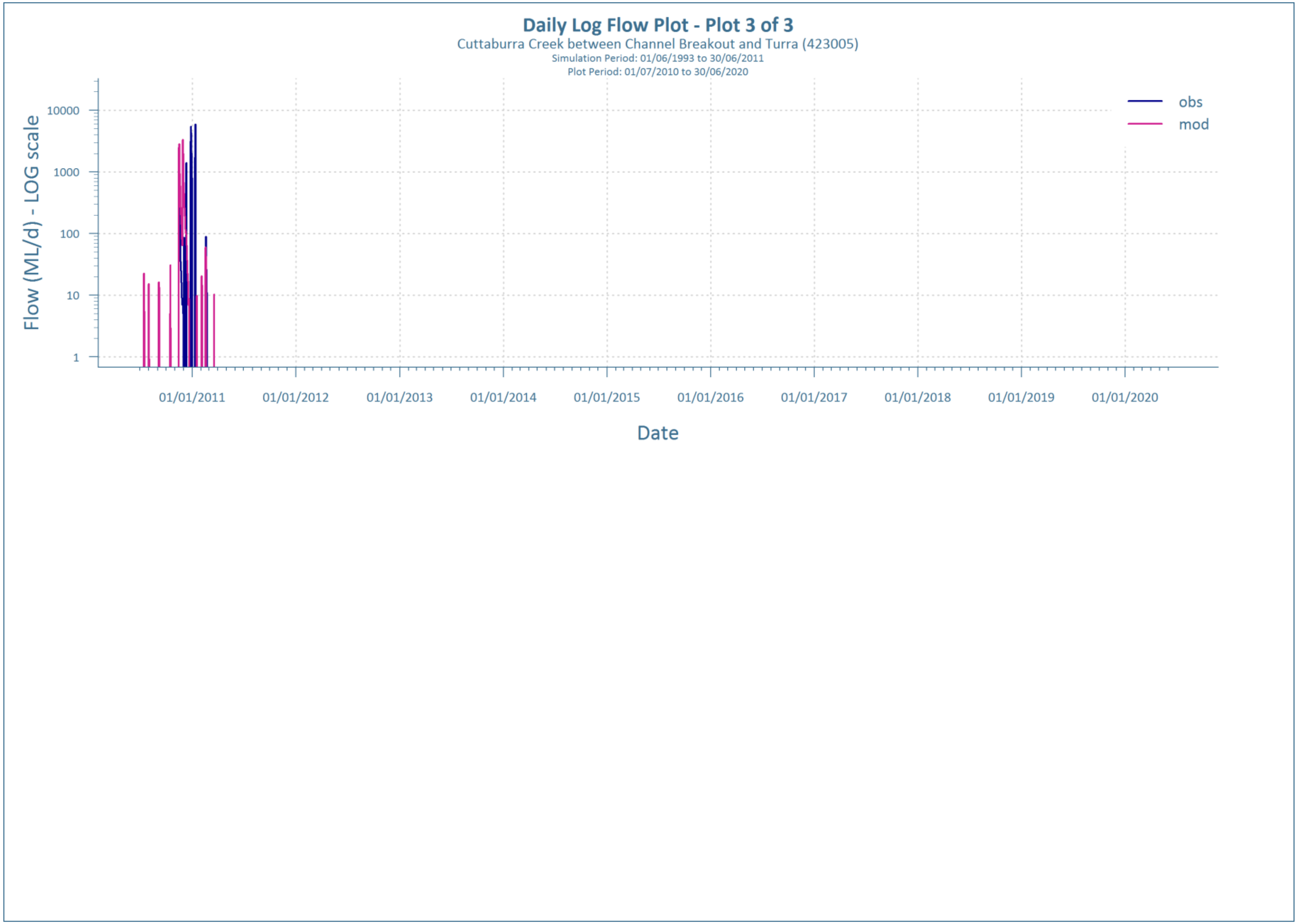


Daily Log Flow Plot - Plot 3 of 3
Warrego River between Barringun (423004) and Fords Bridge (4230012)
Simulation Period: 19/06/1993 to 30/06/2011
Plot Period: 01/07/2010 to 30/06/2020
Flow (ML/d) - LOG scale
1000
100
10
1
obs
mod
01/01/2011
01/01/2012
01/01/2013
01/01/2014
01/01/2015
01/01/2016
01/01/2017
01/01/2018
01/01/2019
01/01/2020
Date

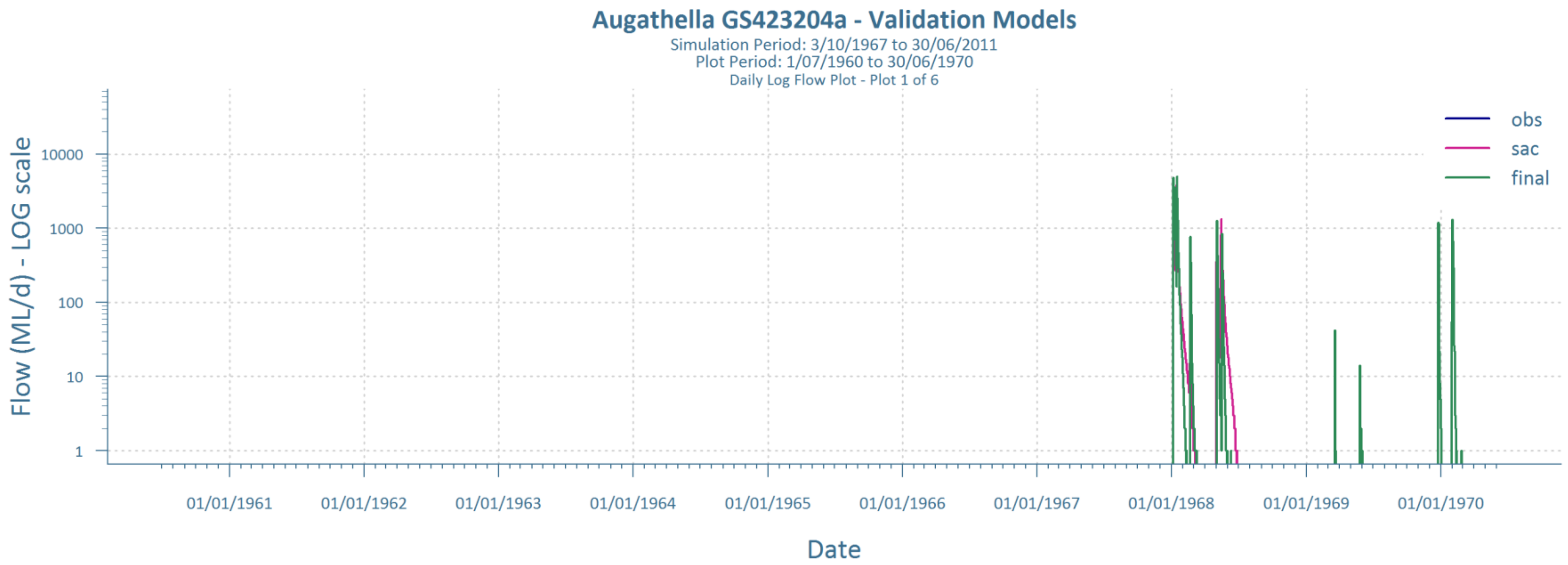
Appendix C9 – Reach 12 Recorded and Sacramento Daily Flows

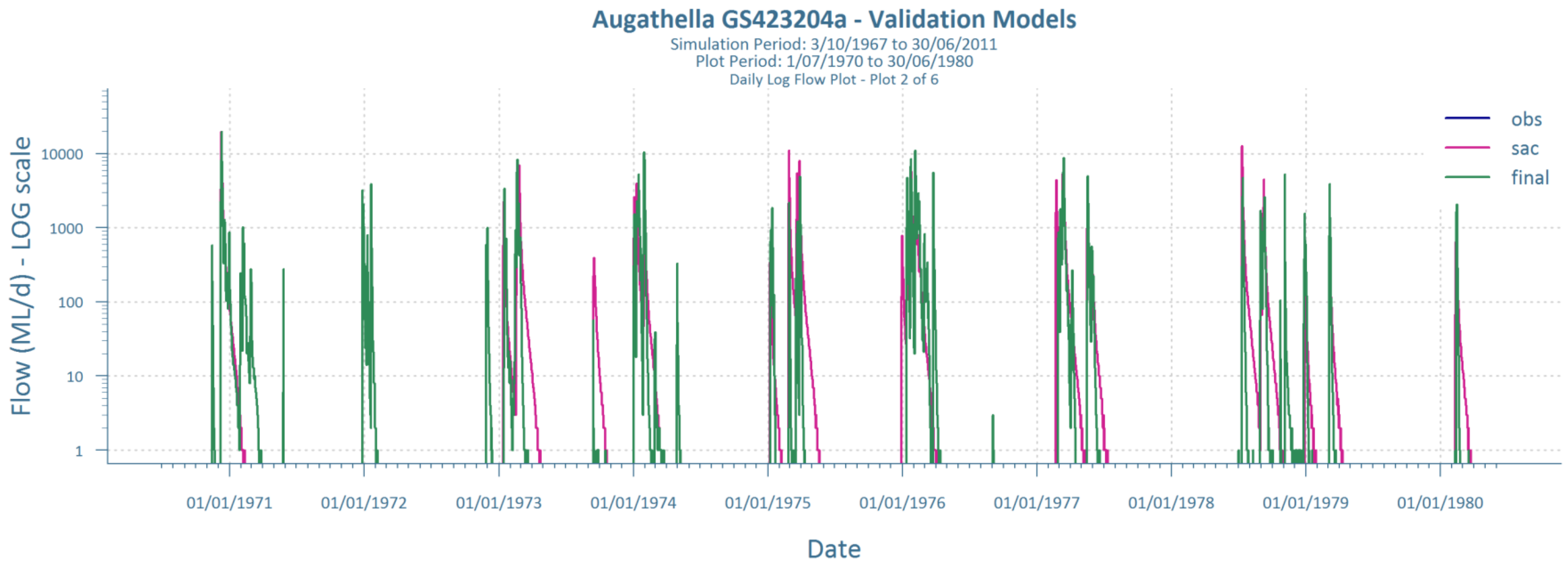


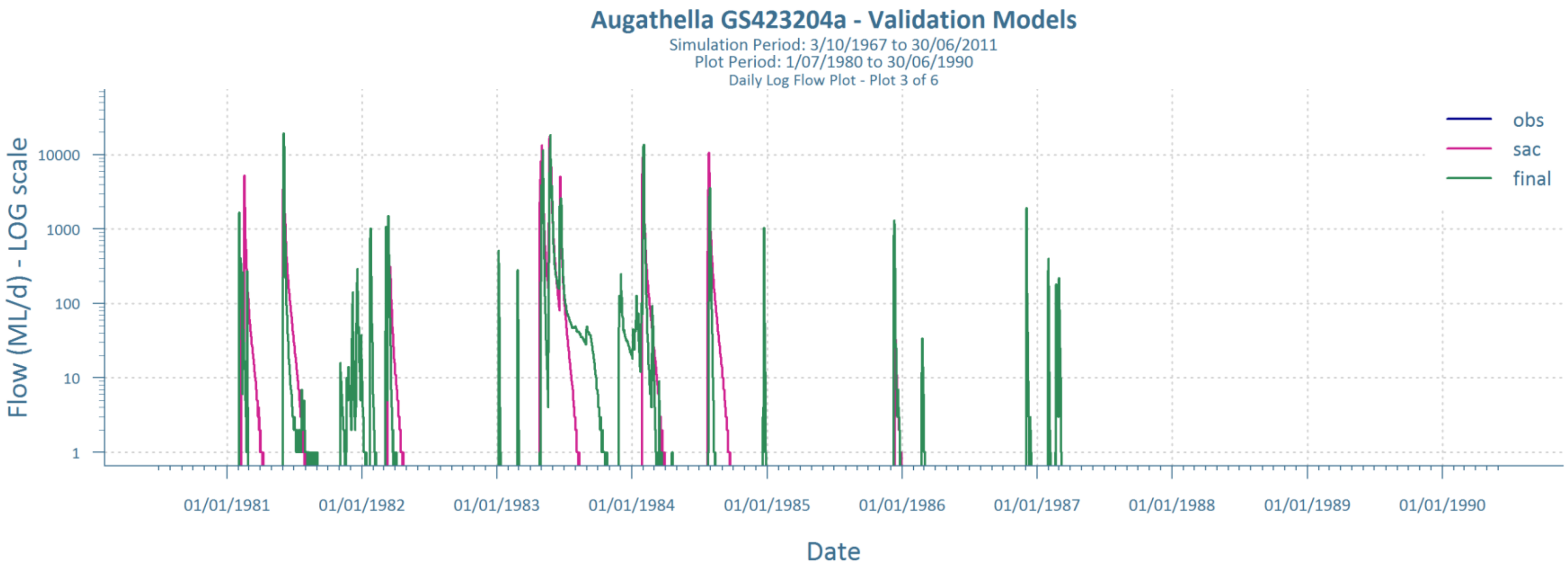


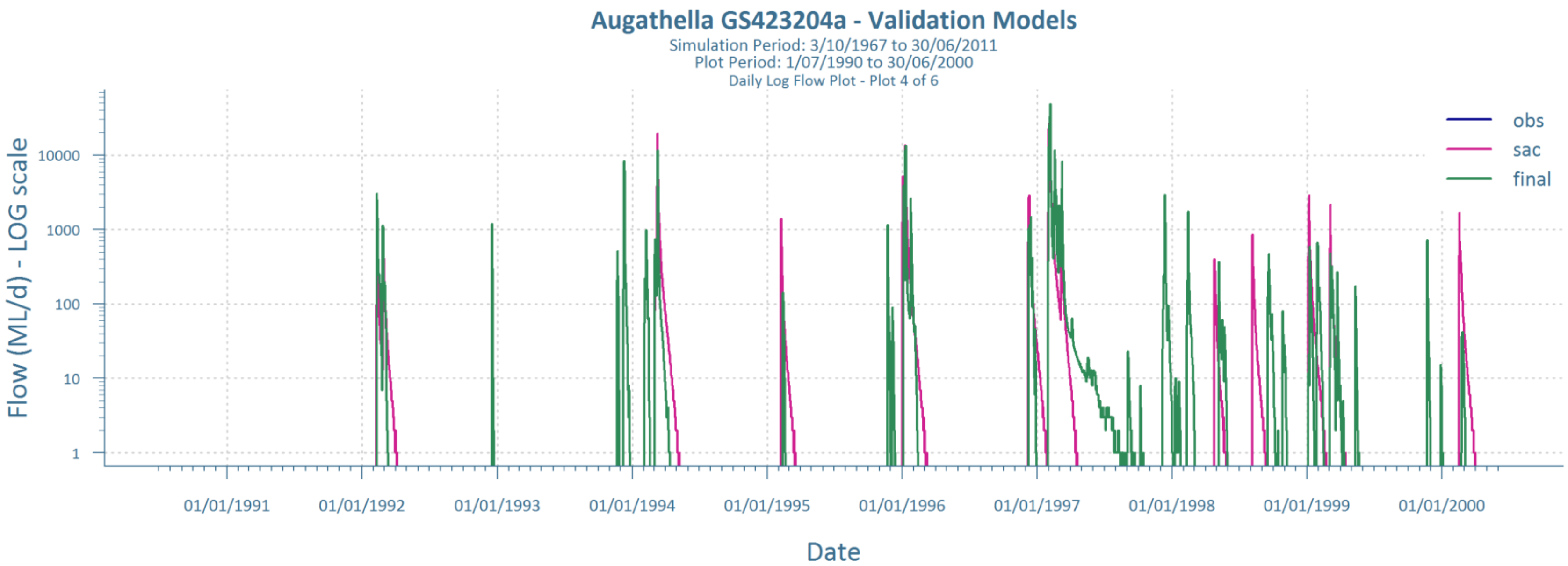

Daily Log Flow Plot - Plot 3 of 3
Cuttaburra Creek between Channel Breakout and Turra (423005)
Simulation Period: 01/06/1993 to 30/06/2011
Plot Period: 01/07/2010 to 30/06/2020
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/2011
01/01/2012
01/01/2013
01/01/2014
01/01/2015
01/01/2016
01/01/2017
01/01/2018
01/01/2019
01/01/2020
Date
obs
mod

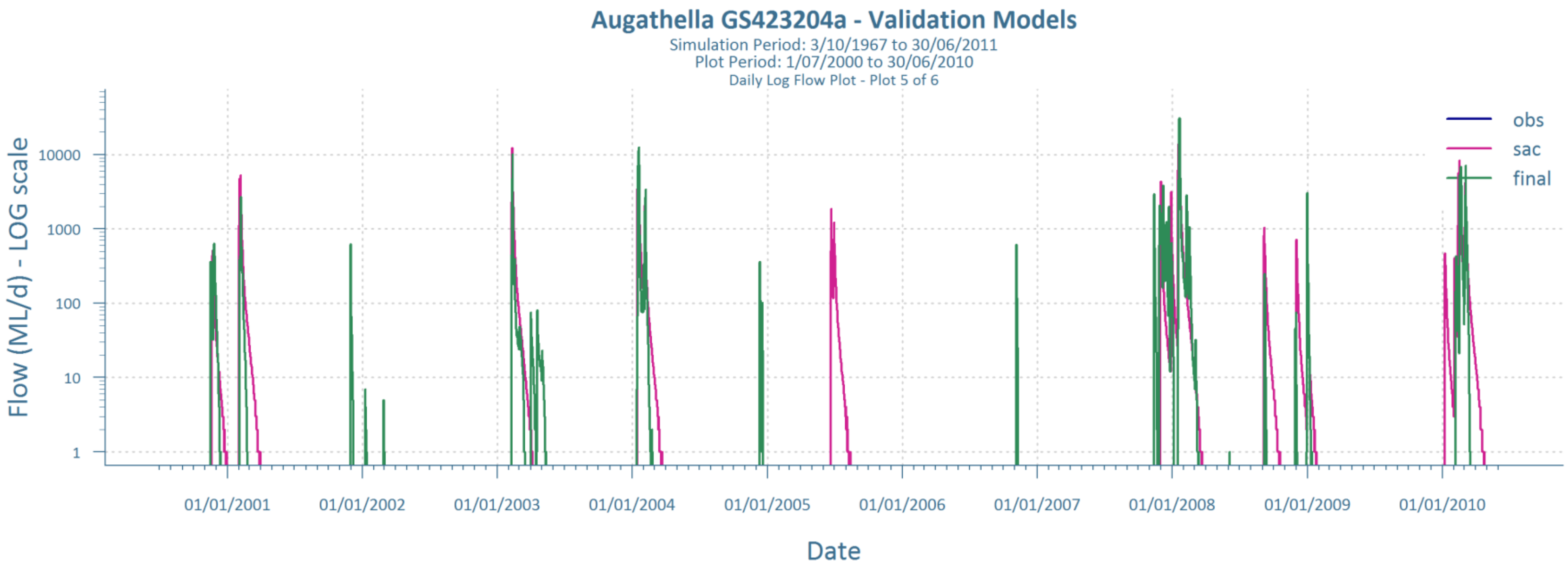
Appendix D – Validation Model Daily Flows

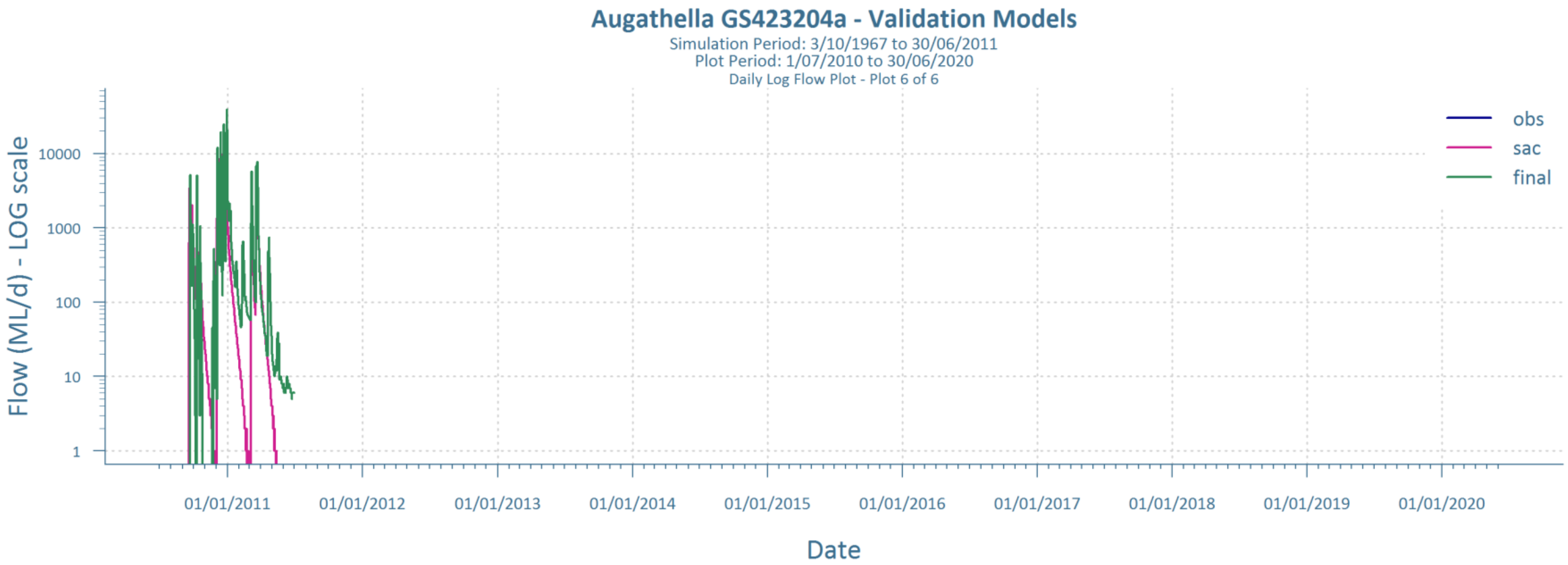

Augathella GS423204a - Validation Models
Simulation Period: 3/10/1967 to 30/06/2011
Plot Period: 1/07/1960 to 30/06/1970
Daily Log Flow Plot - Plot 1 of 6
Flow (ML/d) - LOG scale
10000
1000
100
10
1
obs
sac
final
01/01/1961
01/01/1962
01/01/1963
01/01/1964
01/01/1965
01/01/1966
01/01/1967
01/01/1968
01/01/1969
01/01/1970
Date

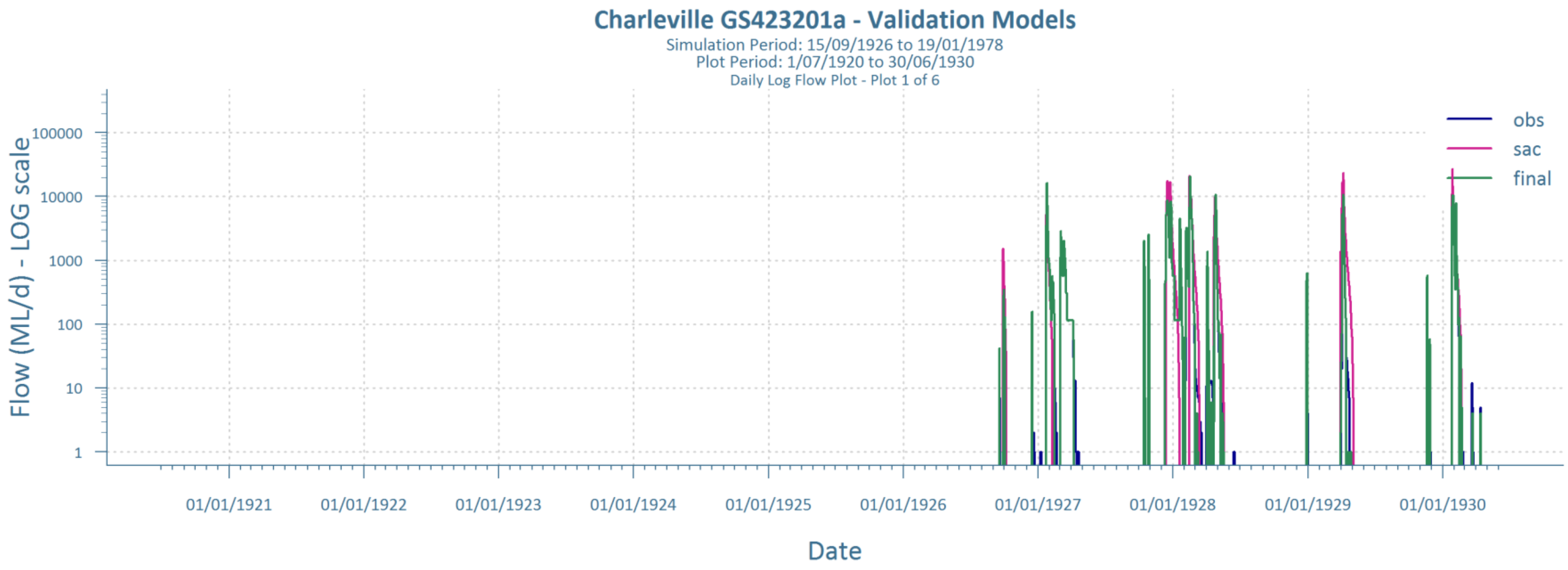

Augathella GS423204a - Validation Models
Simulation Period: 3/10/1967 to 30/06/2011
Plot Period: 1/07/1970 to 30/06/1980
Daily Log Flow Plot - Plot 2 of 6
Flow (ML/d) - LOG scale
10000
1000
100
10
1
obs
sac
final
01/01/1971
01/01/1972
01/01/1973
01/01/1974
01/01/1975
01/01/1976
01/01/1977
01/01/1978
01/01/1979
01/01/1980
Date

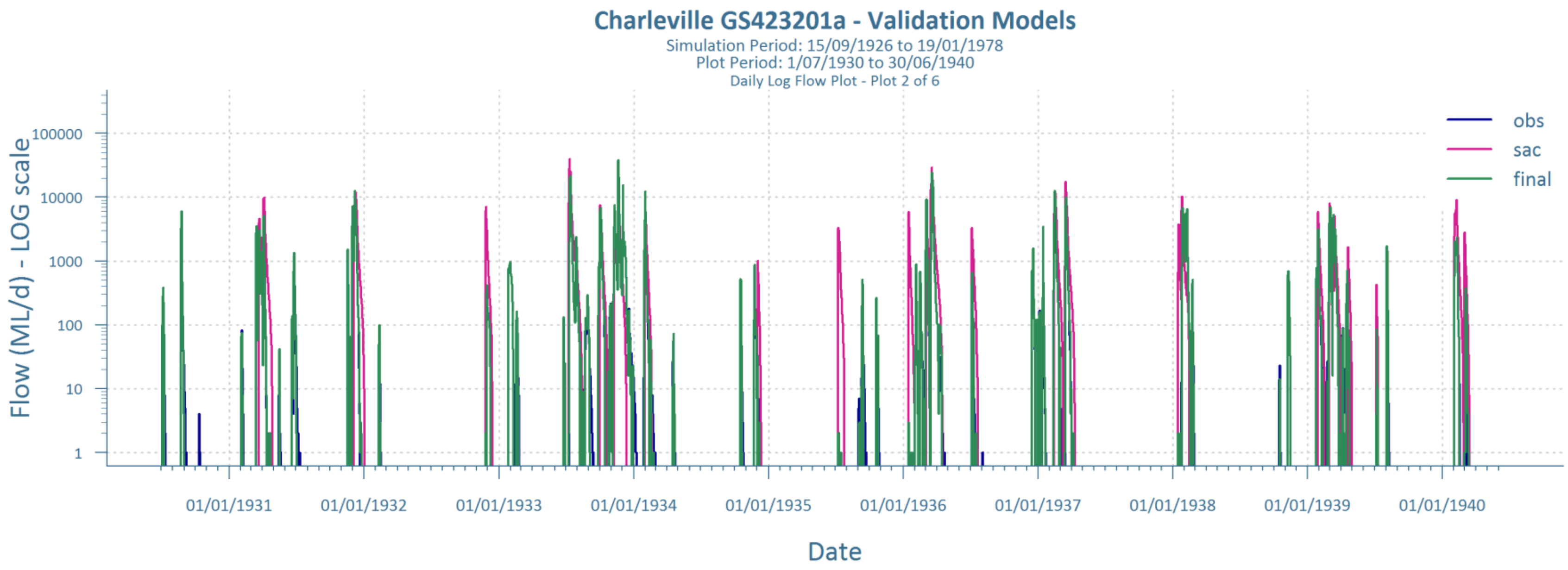

Augathella GS423204a - Validation Models
Simulation Period: 3/10/1967 to 30/06/2011
Plot Period: 1/07/1980 to 30/06/1990
Daily Log Flow Plot - Plot 3 of 6
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/1981
01/01/1982
01/01/1983
01/01/1984
01/01/1985
01/01/1986
01/01/1987
01/01/1988
01/01/1989
01/01/1990
Date
obs
sac
final

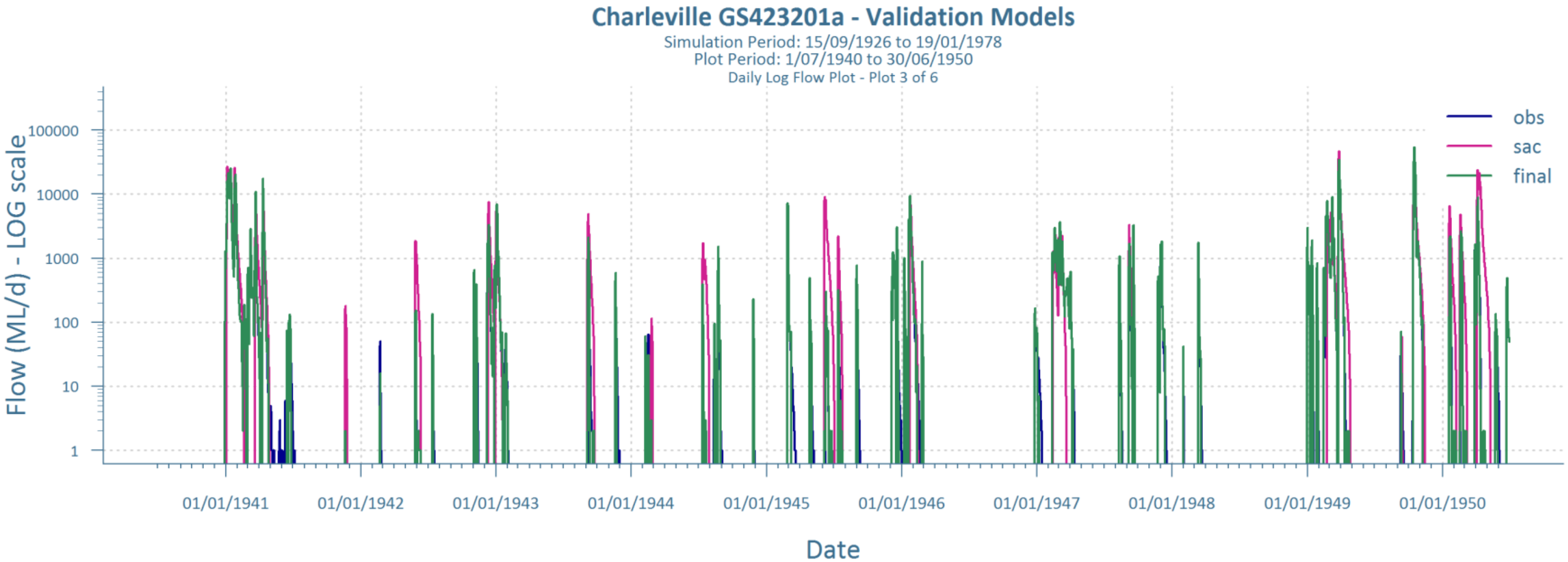

Augathella GS423204a - Validation Models
Simulation Period: 3/10/1967 to 30/06/2011
Plot Period: 1/07/1990 to 30/06/2000
Daily Log Flow Plot - Plot 4 of 6
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/1991
01/01/1992
01/01/1993
01/01/1994
01/01/1995
01/01/1996
01/01/1997
01/01/1998
01/01/1999
01/01/2000
Date
obs
sac
final

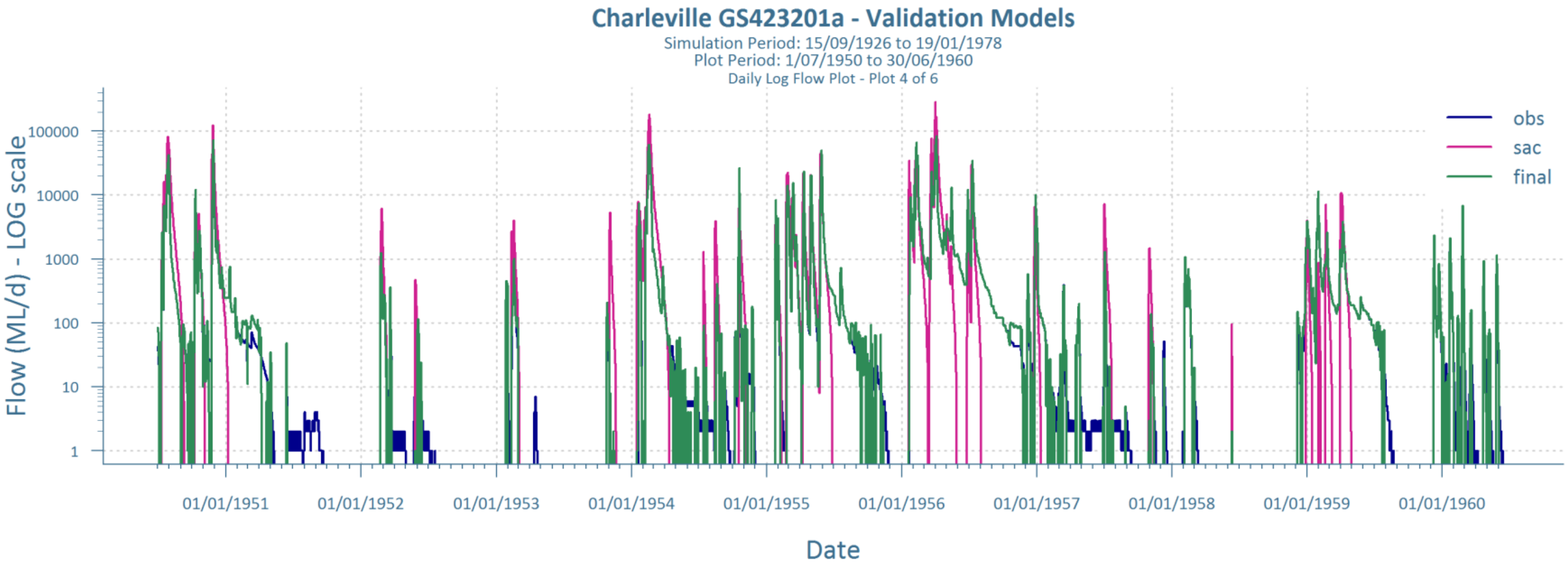

Augathella GS423204a - Validation Models
Simulation Period: 3/10/1967 to 30/06/2011
Plot Period: 1/07/2000 to 30/06/2010
Daily Log Flow Plot - Plot 5 of 6
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
01/01/2006
01/01/2007
01/01/2008
01/01/2009
01/01/2010
Date
obs
sac
final

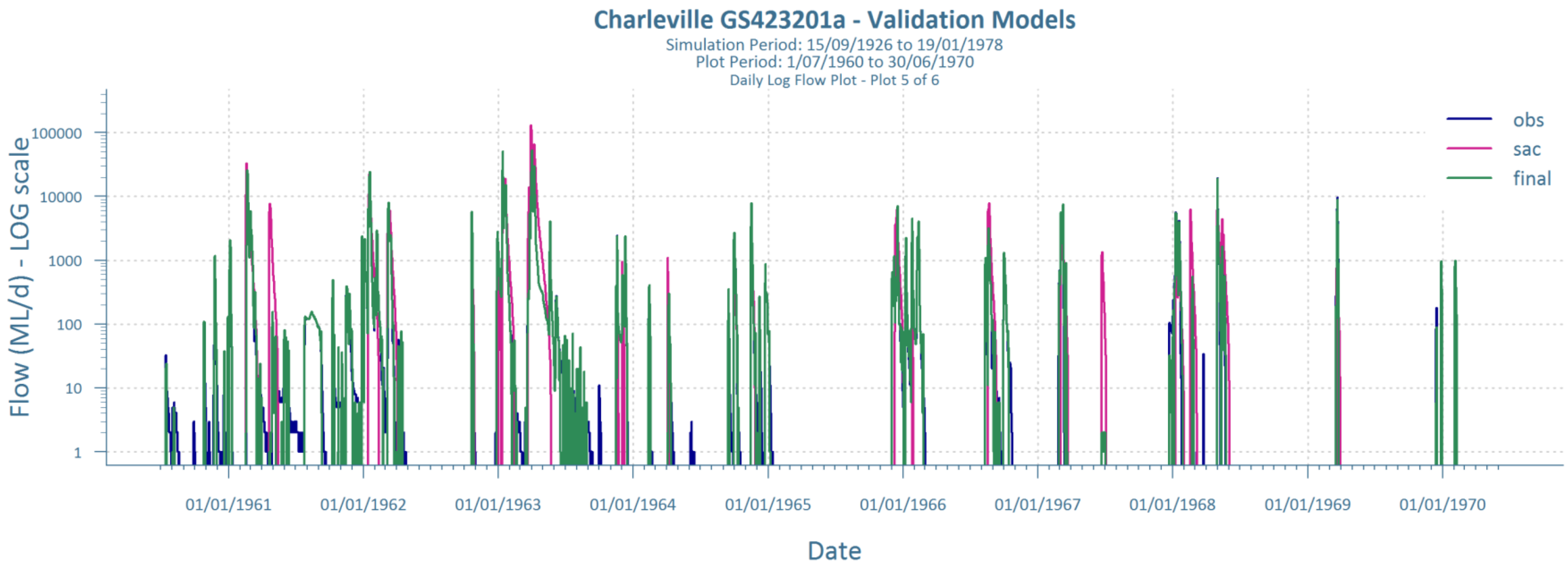

Augathella GS423204a - Validation Models
Simulation Period: 3/10/1967 to 30/06/2011
Plot Period: 1/07/2010 to 30/06/2020
Daily Log Flow Plot - Plot 6 of 6
Flow (ML/d) - LOG scale
10000
1000
100
10
1
01/01/2011
01/01/2012
01/01/2013
01/01/2014
01/01/2015
01/01/2016
01/01/2017
01/01/2018
01/01/2019
01/01/2020
Date
obs
sac
final

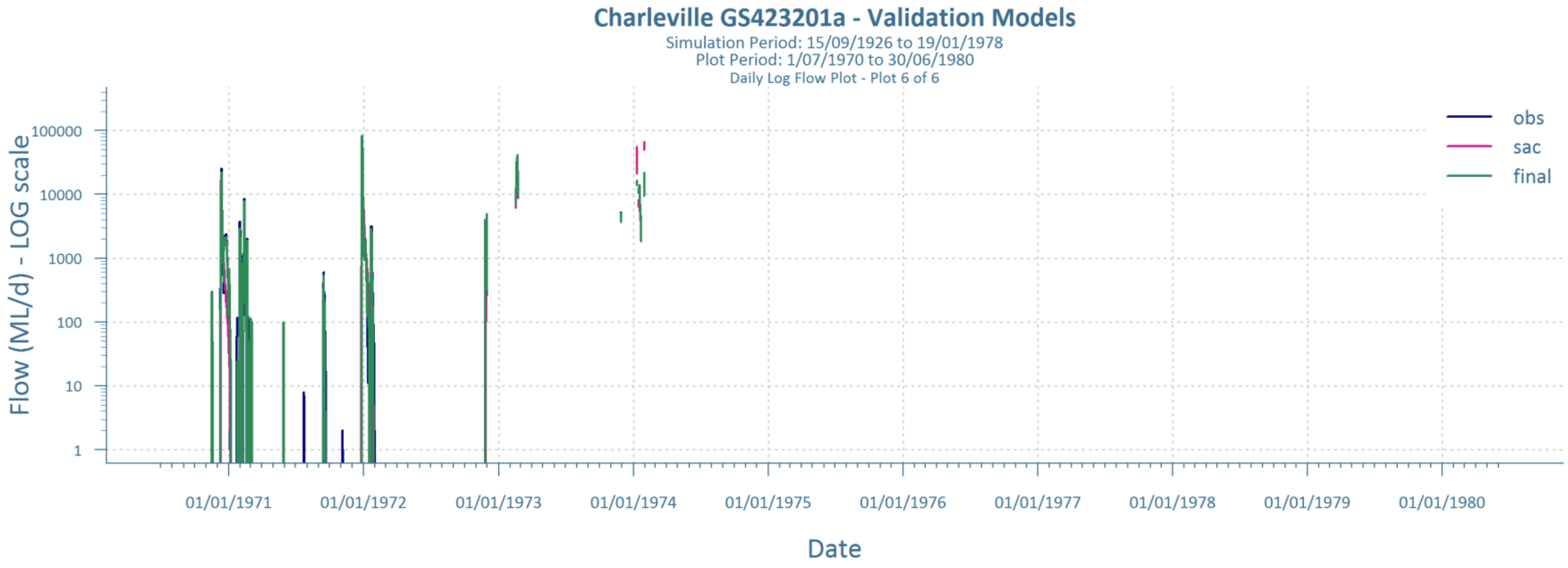

Charleville GS423201a - Validation Models
Simulation Period: 15/09/1926 to 19/01/1978
Plot Period: 1/07/1920 to 30/06/1930
Daily Log Flow Plot - Plot 1 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/1921
01/01/1922
01/01/1923
01/01/1924
01/01/1925
01/01/1926
01/01/1927
01/01/1928
01/01/1929
01/01/1930
Date
obs
sac
final

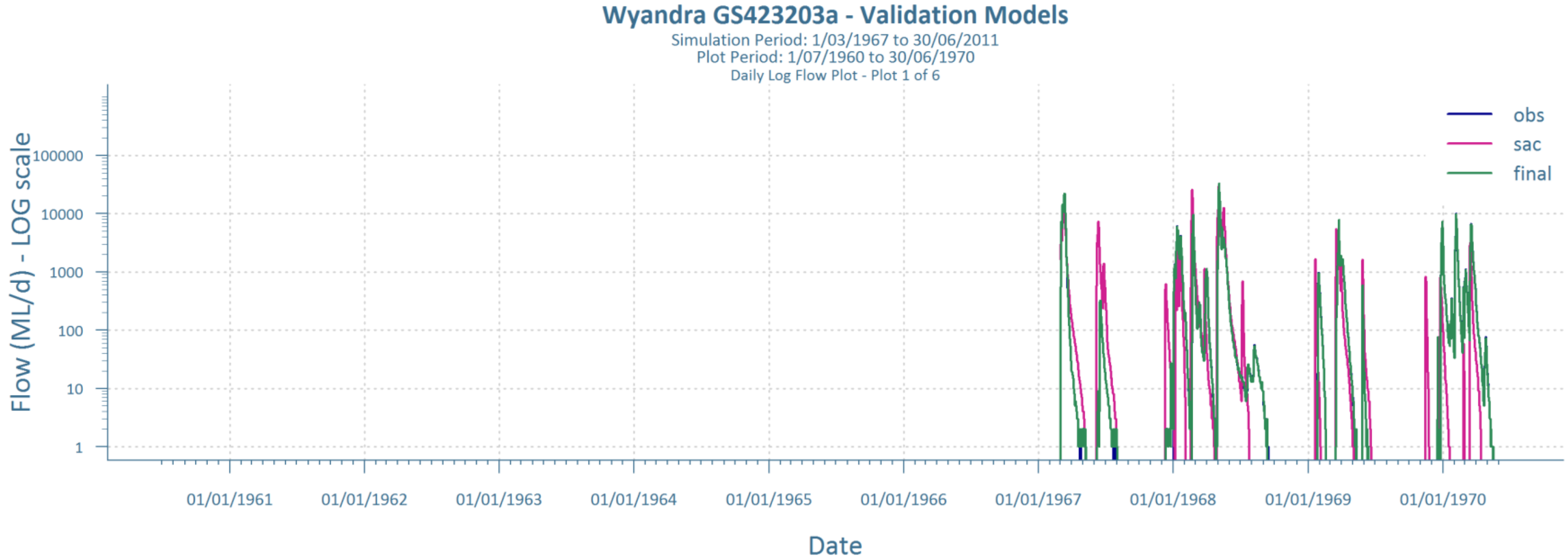

Charleville GS423201a - Validation Models
Simulation Period: 15/09/1926 to 19/01/1978
Plot Period: 1/07/1930 to 30/06/1940
Daily Log Flow Plot - Plot 2 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
01/01/1931
01/01/1932
01/01/1933
01/01/1934
01/01/1935
01/01/1936
01/01/1937
01/01/1938
01/01/1939
01/01/1940
Date
obs
sac
final

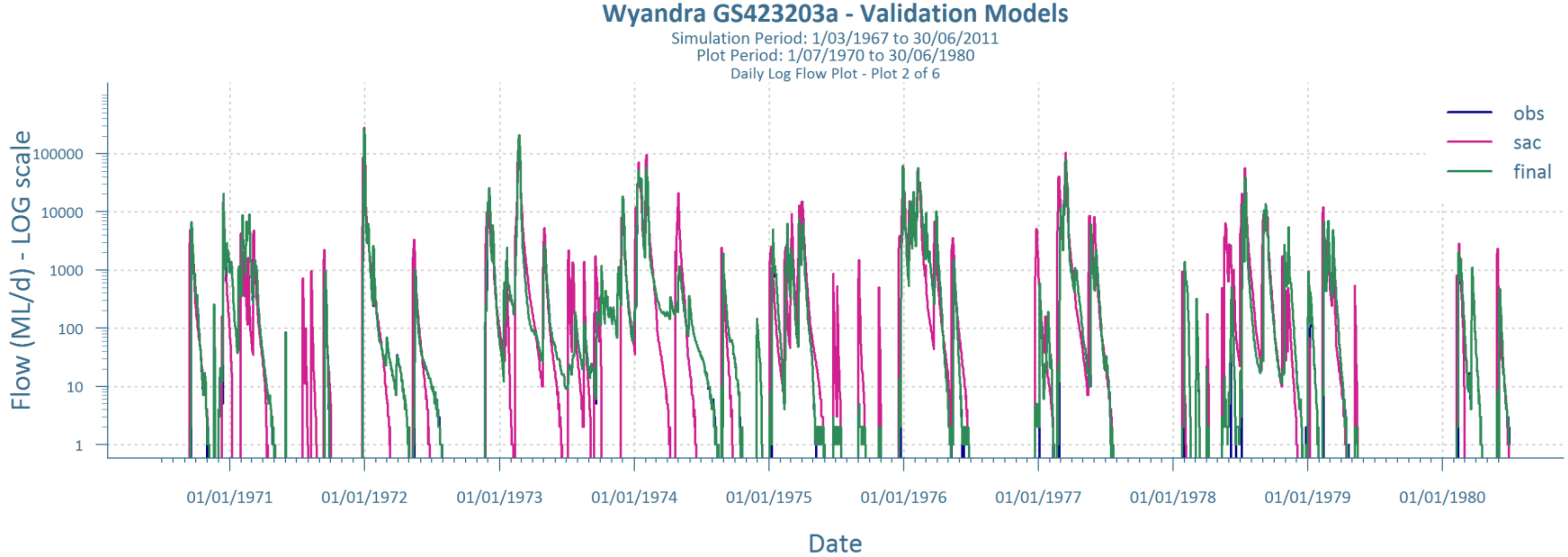

Charleville GS423201a - Validation Models
Simulation Period: 15/09/1926 to 19/01/1978
Plot Period: 1/07/1940 to 30/06/1950
Daily Log Flow Plot - Plot 3 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
sac
final
01/01/1941
01/01/1942
01/01/1943
01/01/1944
01/01/1945
01/01/1946
01/01/1947
01/01/1948
01/01/1949
01/01/1950
Date

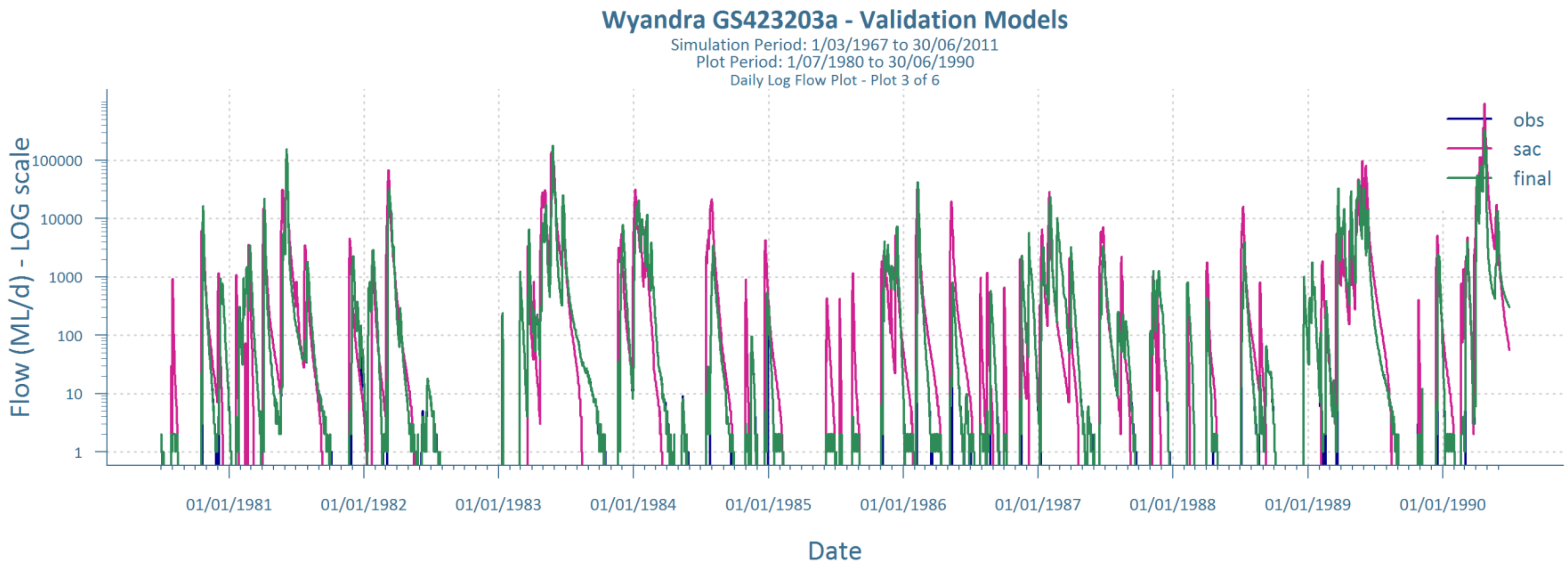

Charleville GS423201a - Validation Models
Simulation Period: 15/09/1926 to 19/01/1978
Plot Period: 1/07/1950 to 30/06/1960
Daily Log Flow Plot - Plot 4 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
sac
final
01/01/1951
01/01/1952
01/01/1953
01/01/1954
01/01/1955
01/01/1956
01/01/1957
01/01/1958
01/01/1959
01/01/1960
Date

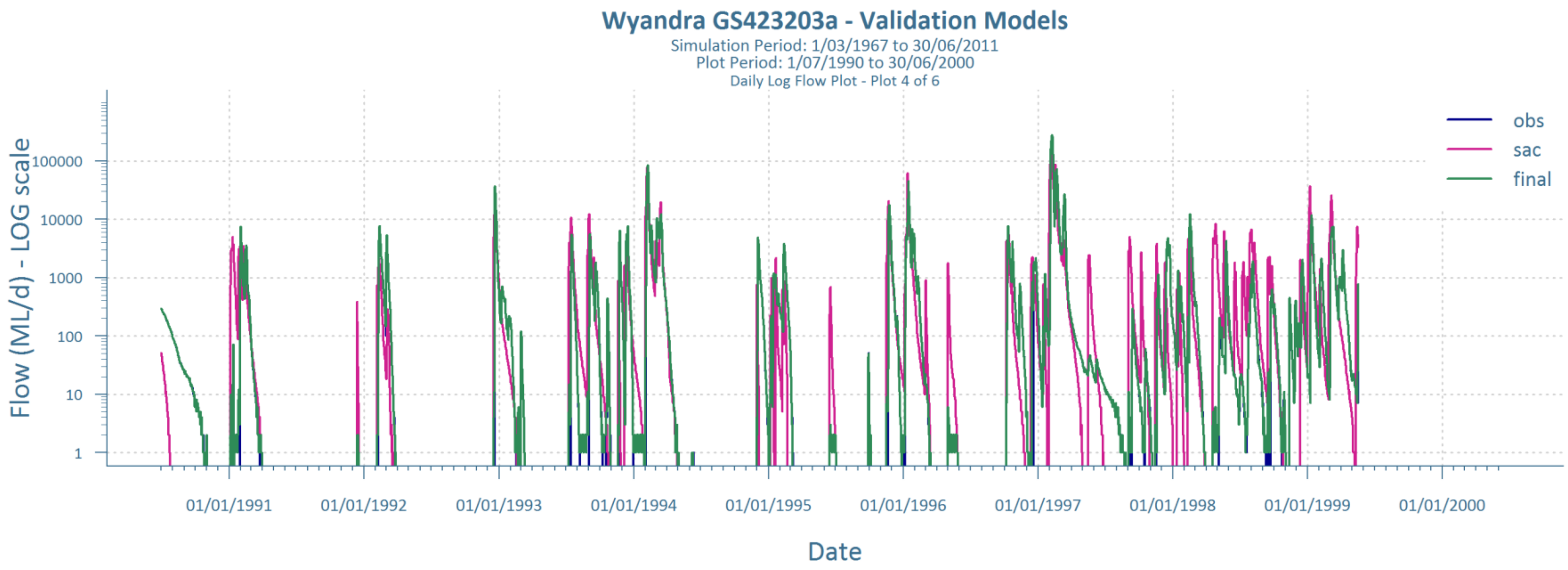

Charleville GS423201a - Validation Models
Simulation Period: 15/09/1926 to 19/01/1978
Plot Period: 1/07/1960 to 30/06/1970
Daily Log Flow Plot - Plot 5 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
sac
final
01/01/1961
01/01/1962
01/01/1963
01/01/1964
01/01/1965
01/01/1966
01/01/1967
01/01/1968
01/01/1969
01/01/1970
Date


Charleville GS423201a - Validation Models
Simulation Period: 15/09/1926 to 19/01/1978
Plot Period: 1/07/1970 to 30/06/1980
Daily Log Flow Plot - Plot 6 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
sac
final
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


Wyandra GS423203a - Validation Models
Simulation Period: 1/03/1967 to 30/06/2011
Plot Period: 1/07/1960 to 30/06/1970
Daily Log Flow Plot - Plot 1 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
sac
final
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


Wyandra GS423203a - Validation Models
Simulation Period: 1/03/1967 to 30/06/2011
Plot Period: 1/07/1970 to 30/06/1980
Daily Log Flow Plot - Plot 2 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
100
10
1
obs
sac
final
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


Wyandra GS423203a - Validation Models
Simulation Period: 1/03/1967 to 30/06/2011
Plot Period: 1/07/1980 to 30/06/1990
Daily Log Flow Plot - Plot 3 of 6
Flow (ML/d) - LOG scale
100000
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


Wyandra GS423203a - Validation Models
Simulation Period: 1/03/1967 to 30/06/2011
Plot Period: 1/07/1990 to 30/06/2000
Daily Log Flow Plot - Plot 4 of 6
Flow (ML/d) - LOG scale
100000
10000
1000
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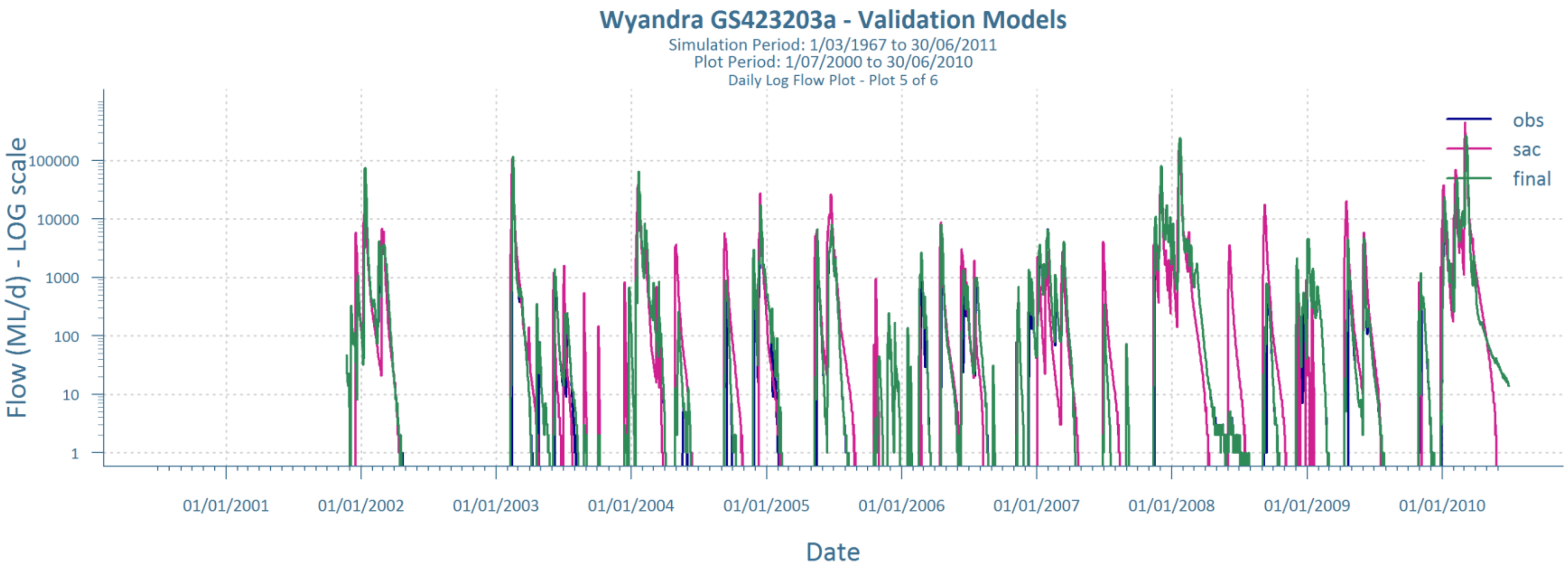
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Flow (ML/d) - LOG scale
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01/01/2010
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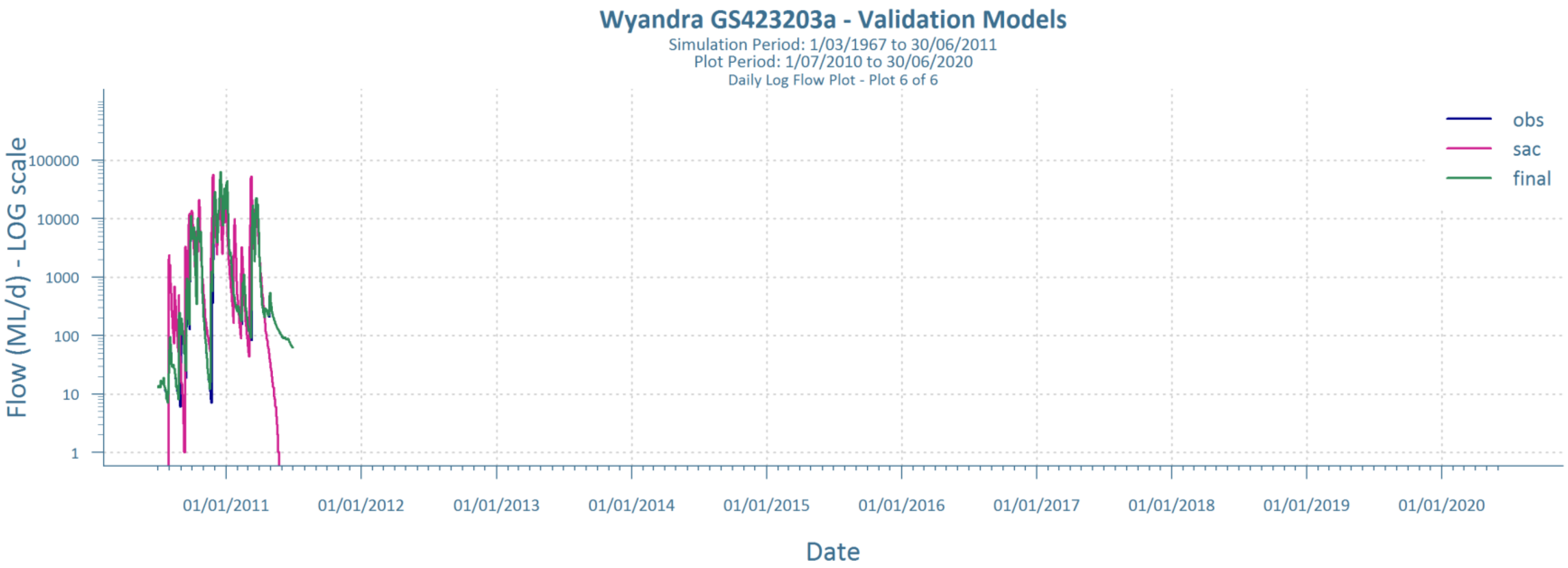
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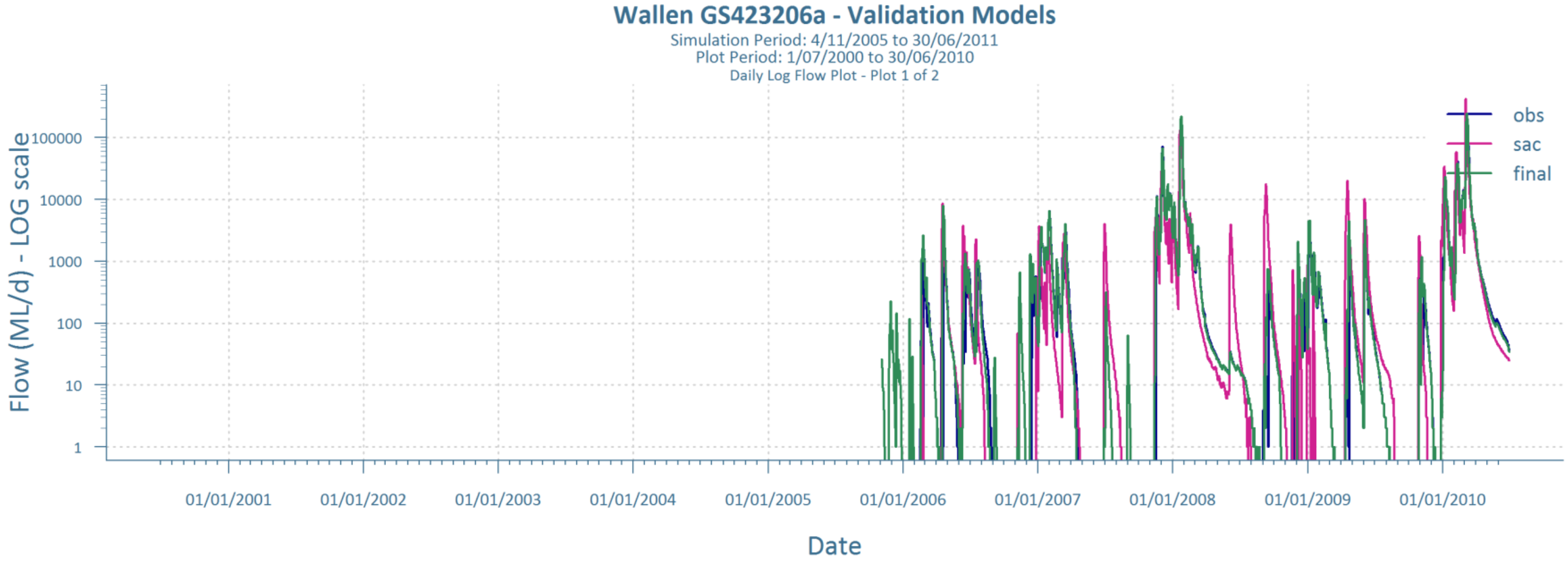
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Flow (ML/d) - LOG scale
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01/01/2010
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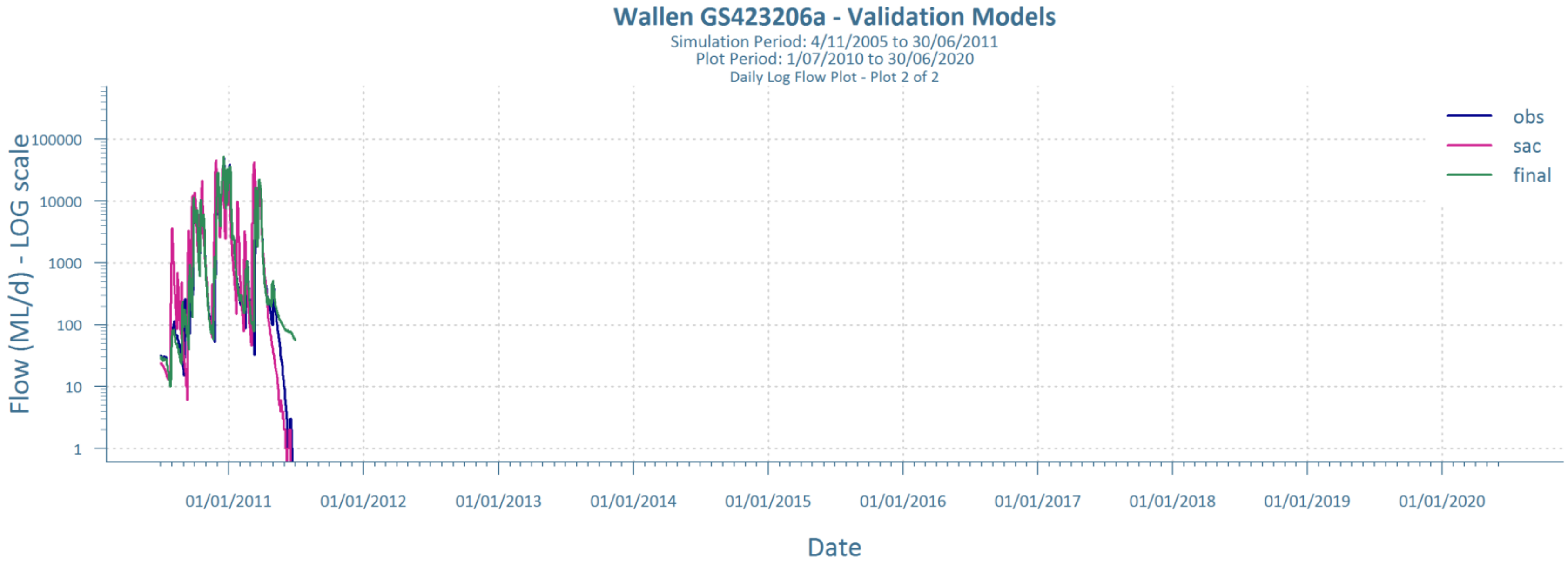
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Flow (ML/d) - LOG scale
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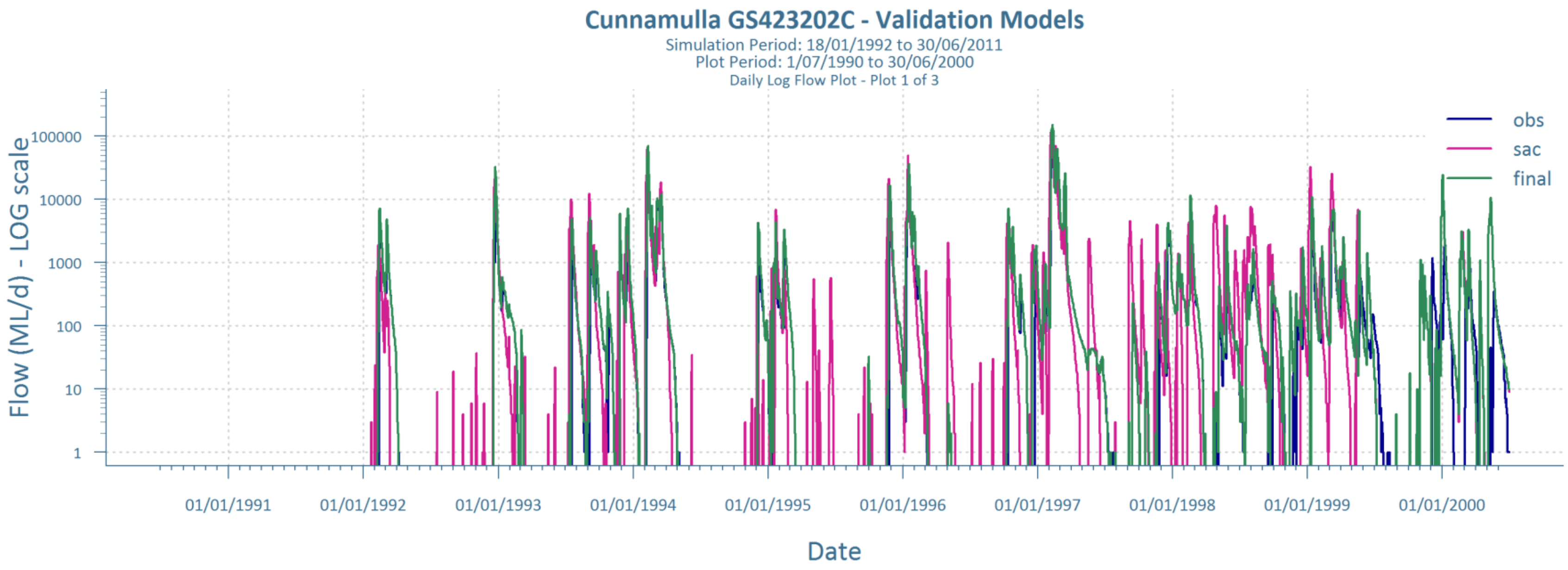
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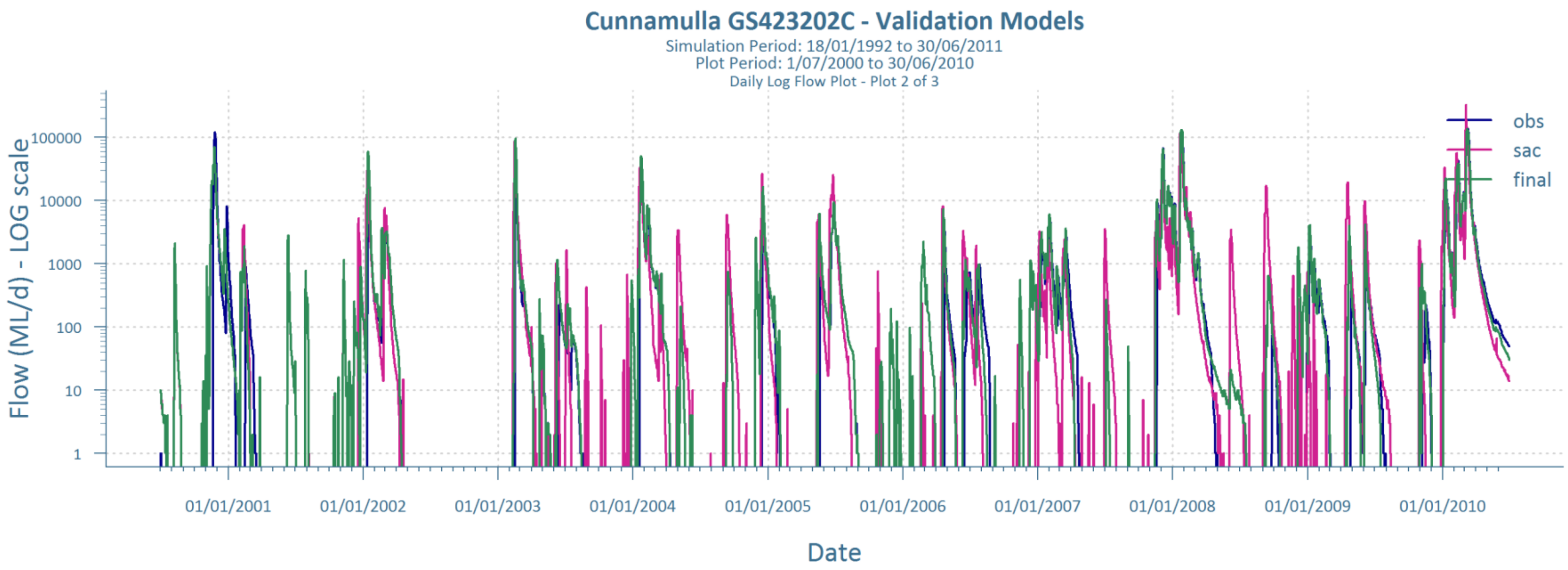
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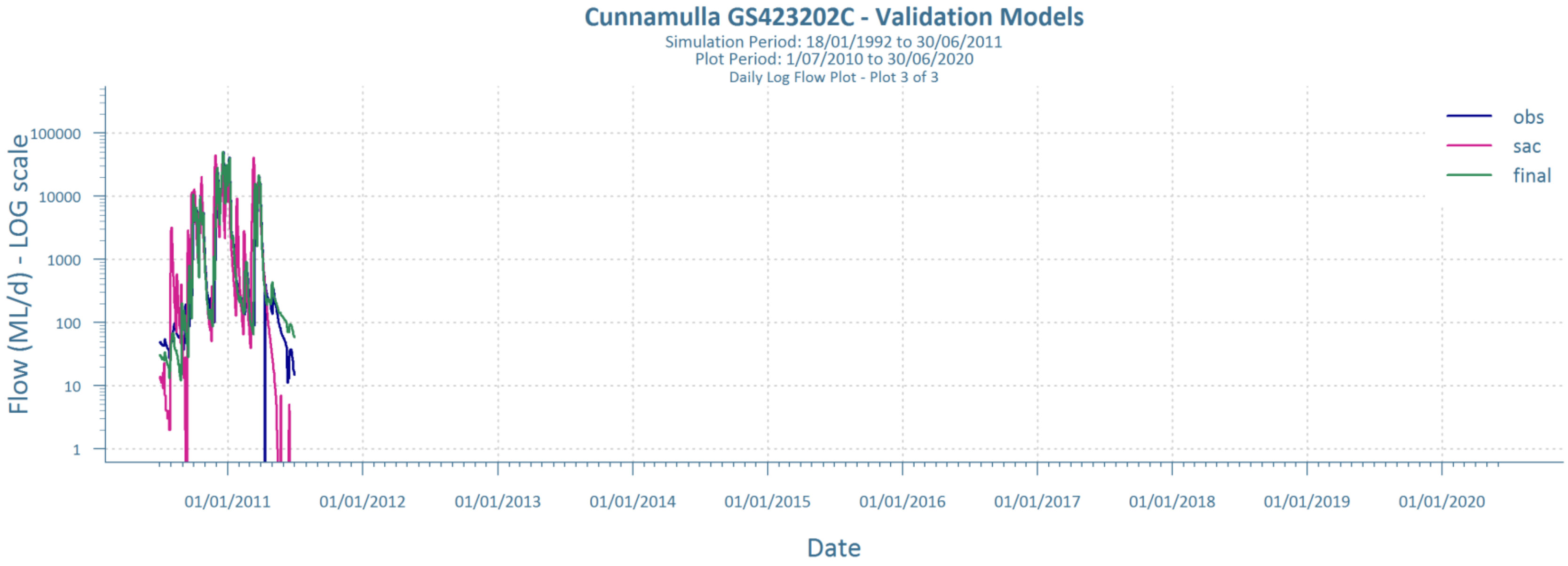
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Flow (ML/d) - LOG scale
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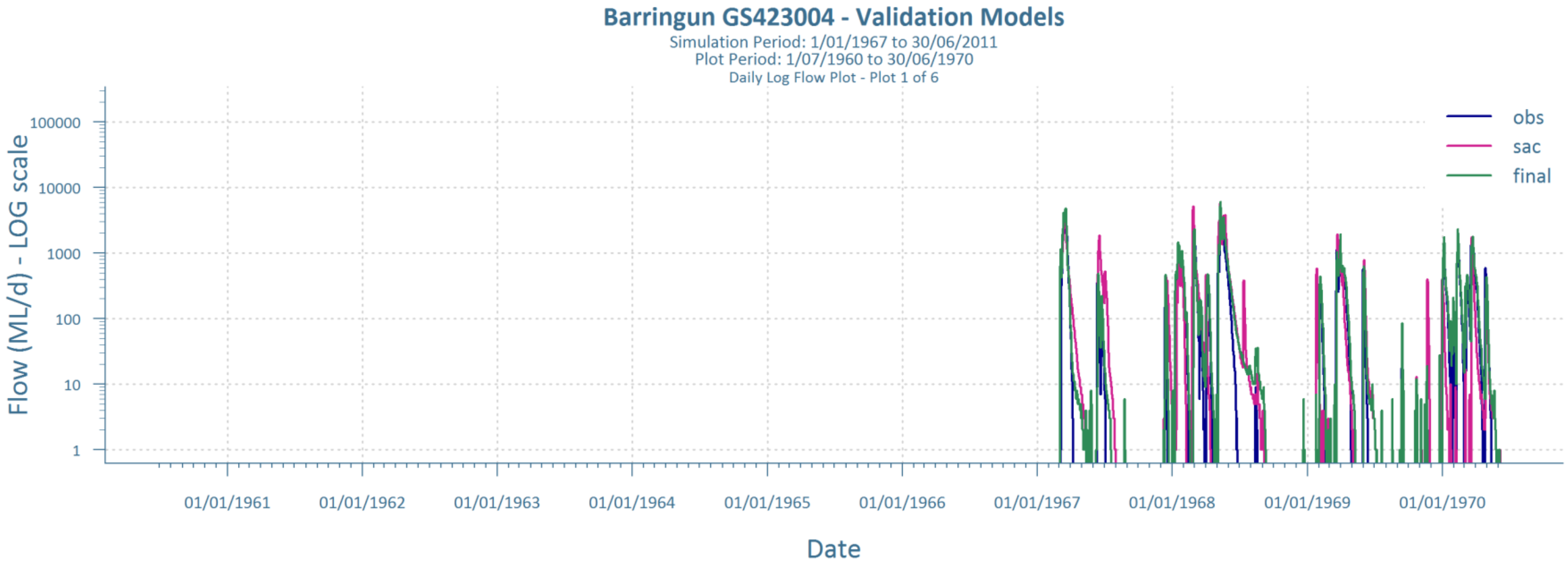
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Simulation Period: 1/01/1967 to 30/06/2011
Plot Period: 1/07/1960 to 30/06/1970
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Flow (ML/d) - LOG scale
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01/01/1963
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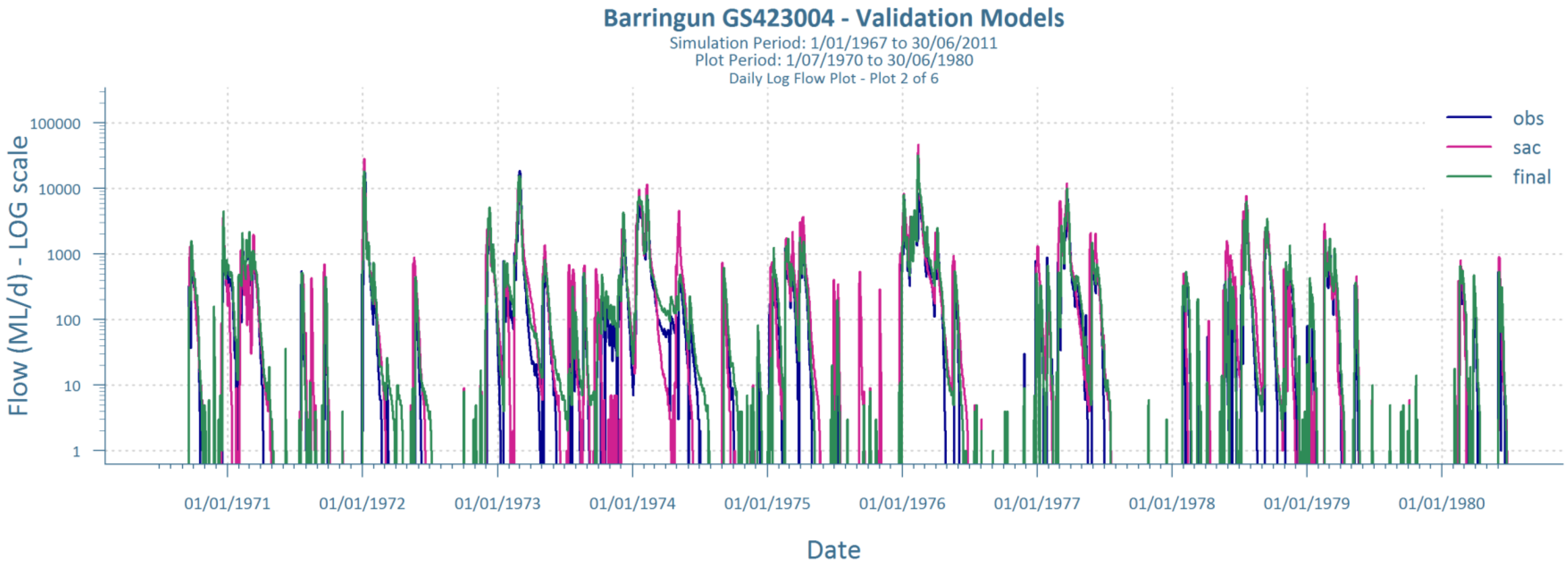
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Simulation Period: 1/01/1967 to 30/06/2011
Plot Period: 1/07/1970 to 30/06/1980
Daily Log Flow Plot - Plot 2 of 6
Flow (ML/d) - LOG scale
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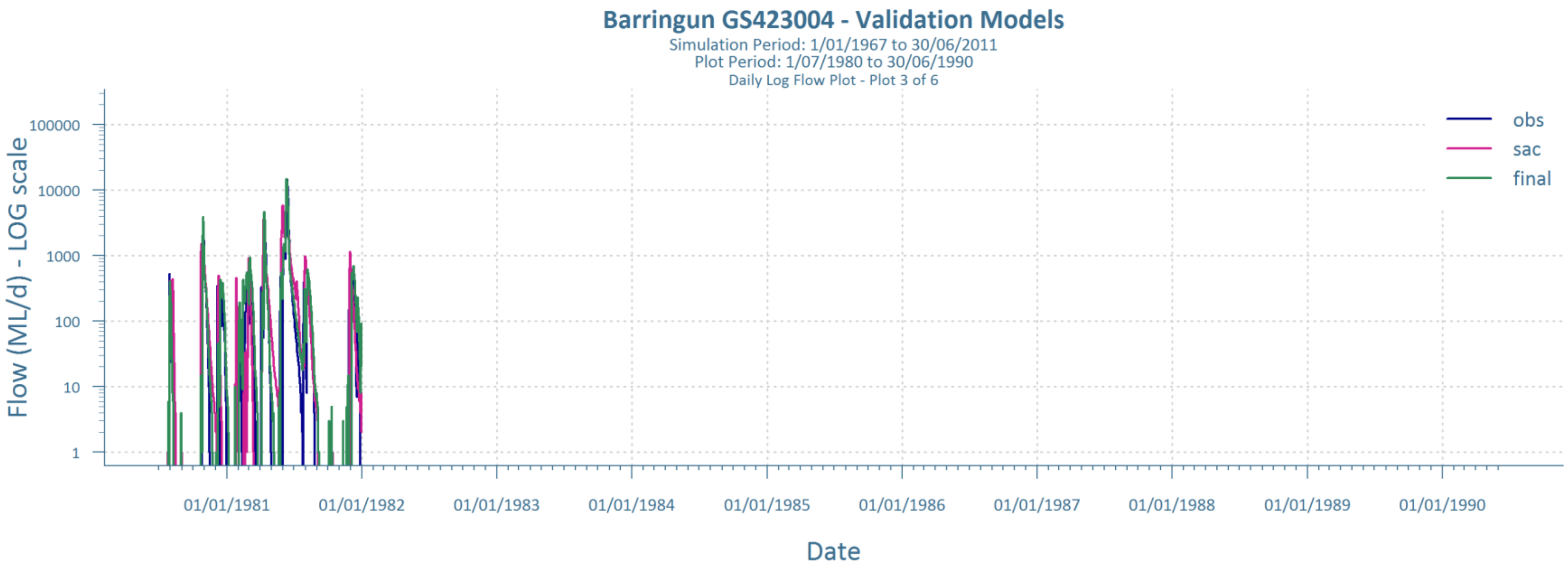

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Plot Period: 1/07/1980 to 30/06/1990
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Flow (ML/d) - LOG scale
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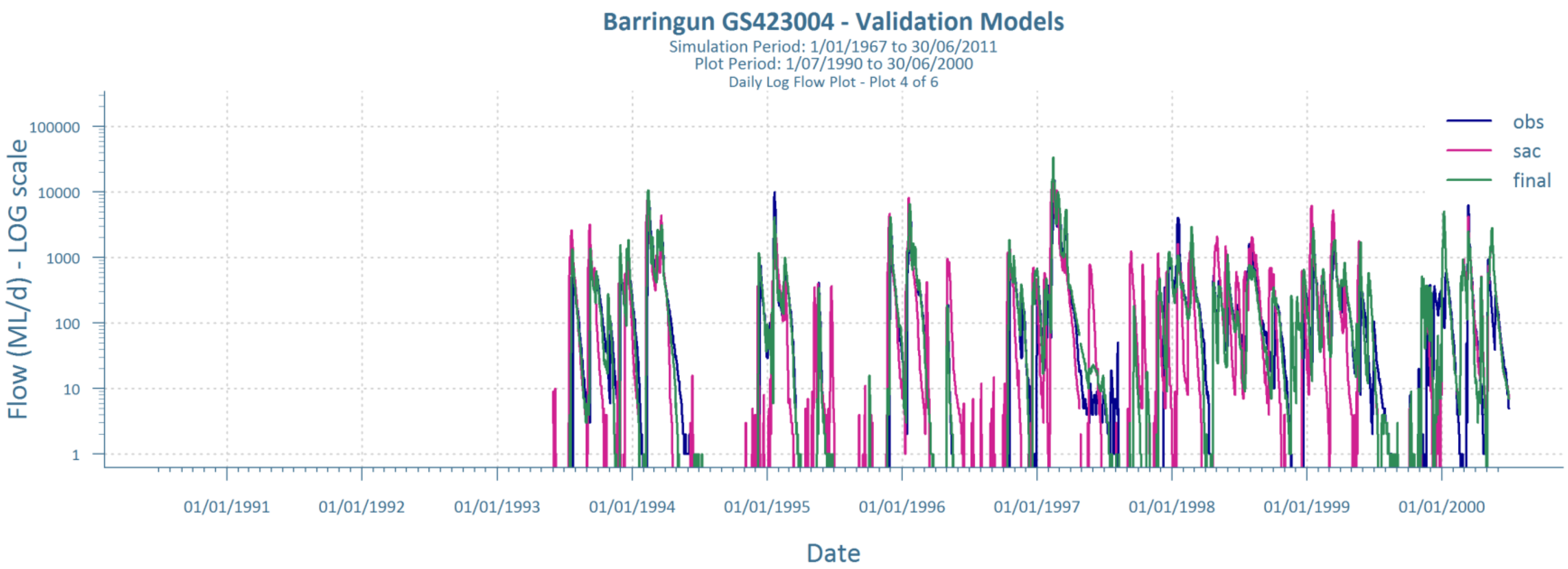

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Plot Period: 1/07/1990 to 30/06/2000
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Flow (ML/d) - LOG scale
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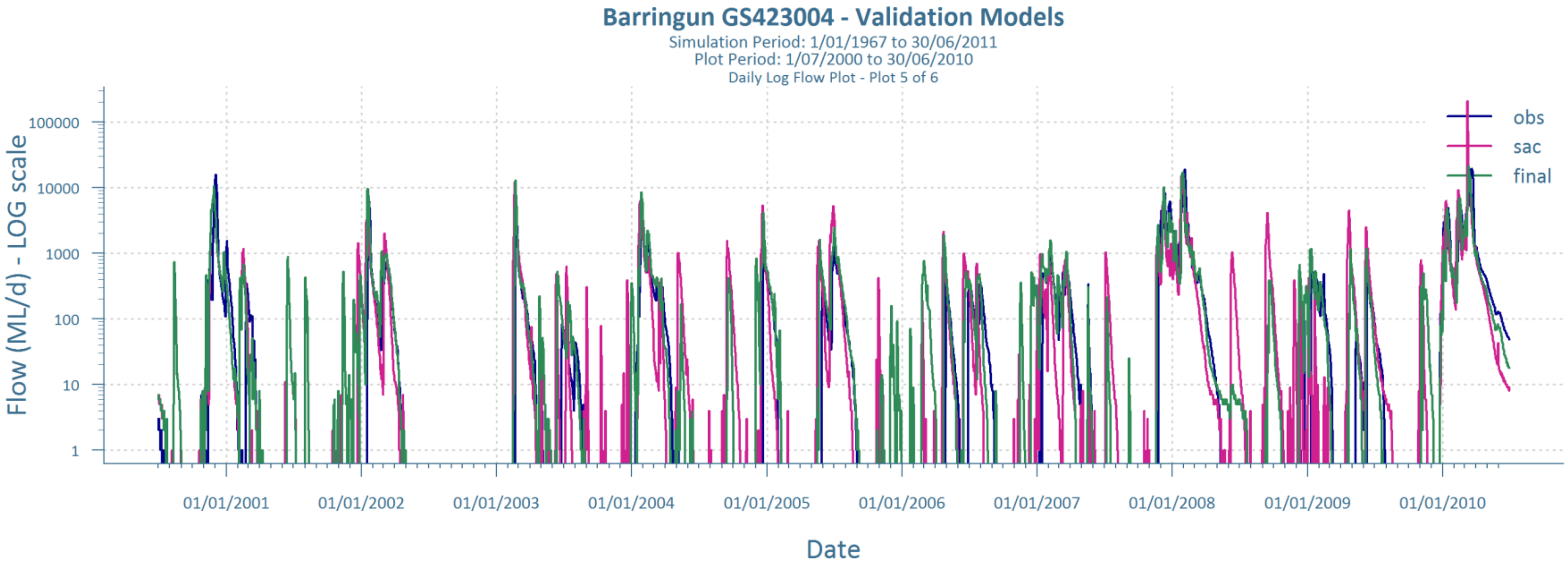
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Flow (ML/d) - LOG scale
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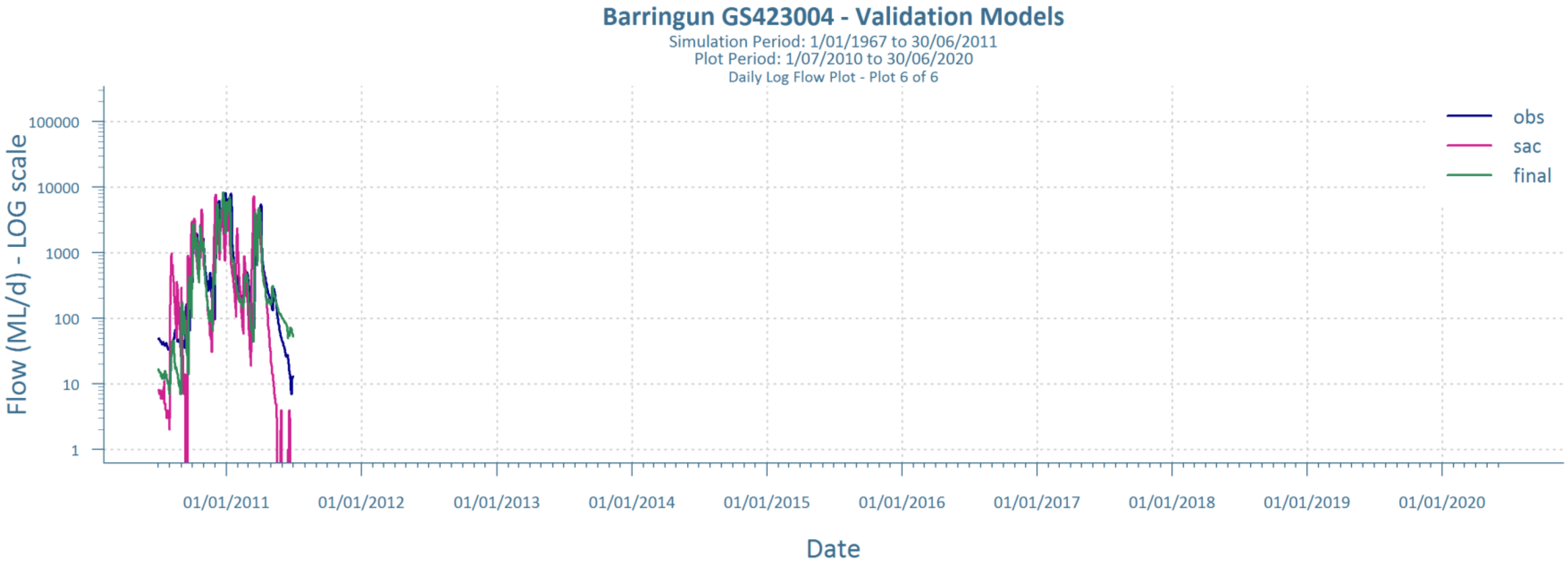
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Plot Period: 1/07/2010 to 30/06/2020
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Flow (ML/d) - LOG scale
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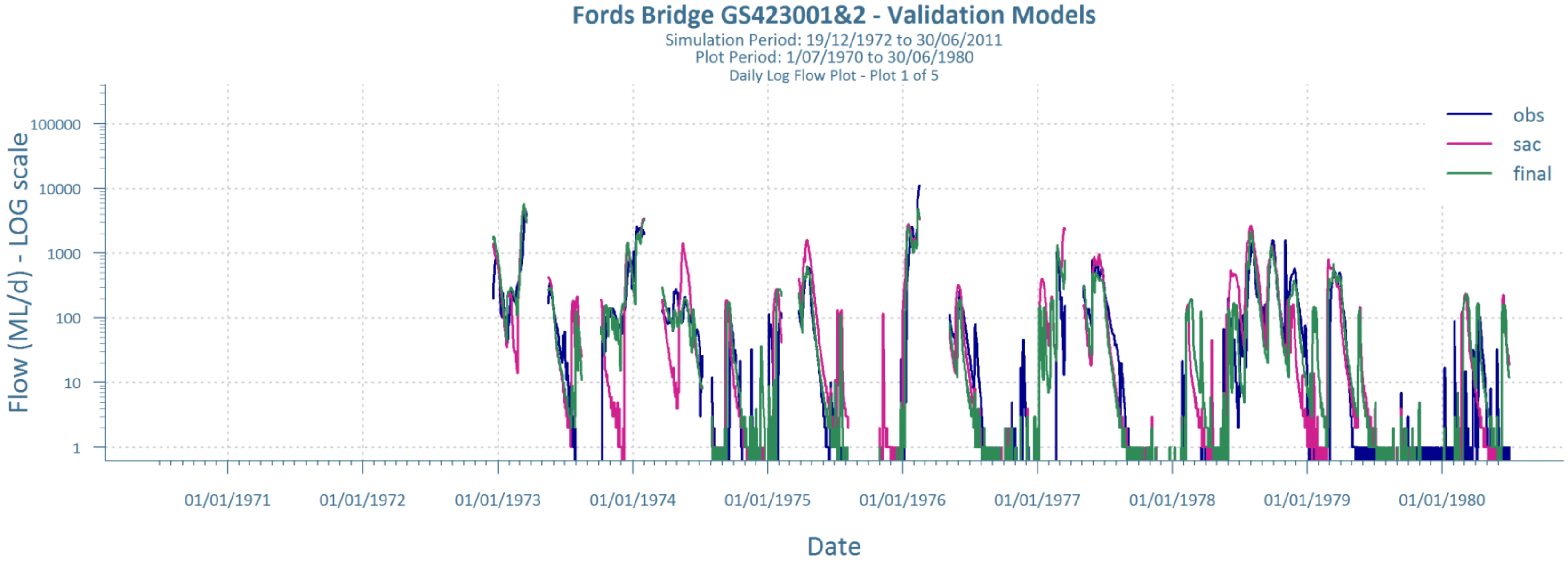
Fords Bridge GS423001&2 - Validation Models
Simulation Period: 19/12/1972 to 30/06/2011
Plot Period: 1/07/1970 to 30/06/1980
Daily Log Flow Plot - Plot 1 of 5
Flow (ML/d) - LOG scale
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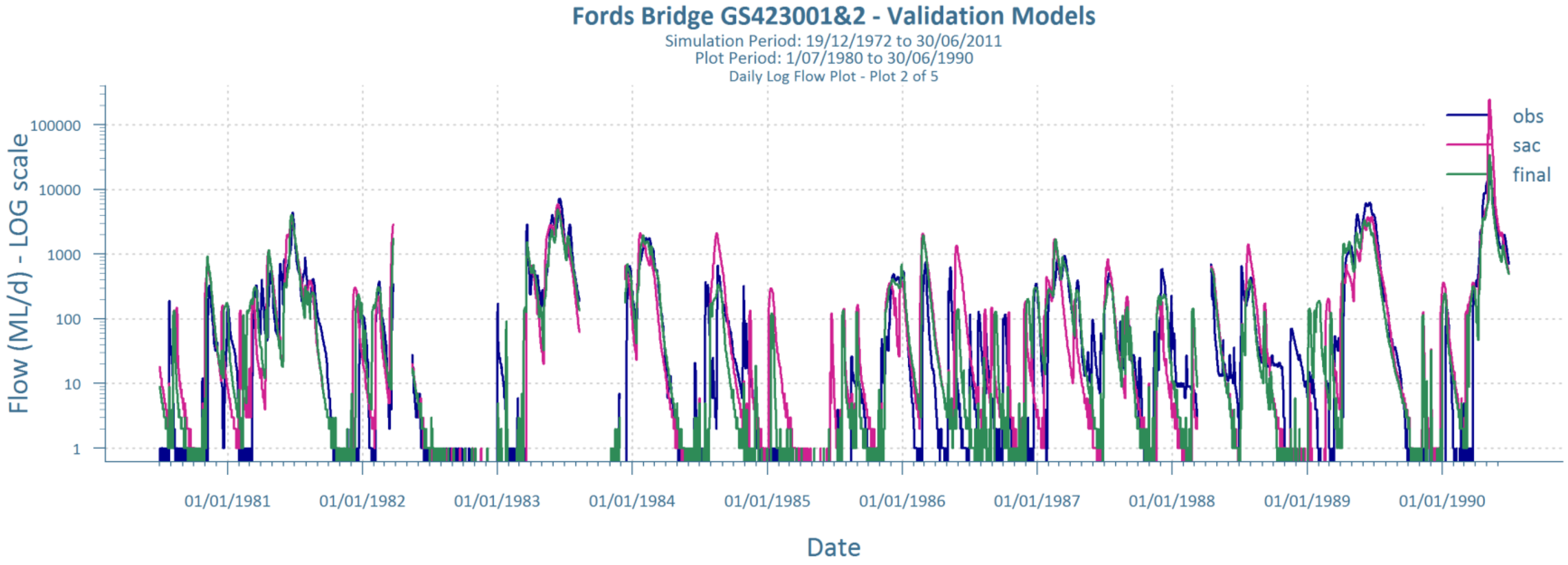
Fords Bridge GS423001&2 - Validation Models
Simulation Period: 19/12/1972 to 30/06/2011
Plot Period: 1/07/1980 to 30/06/1990
Daily Log Flow Plot - Plot 2 of 5
Flow (ML/d) - LOG scale
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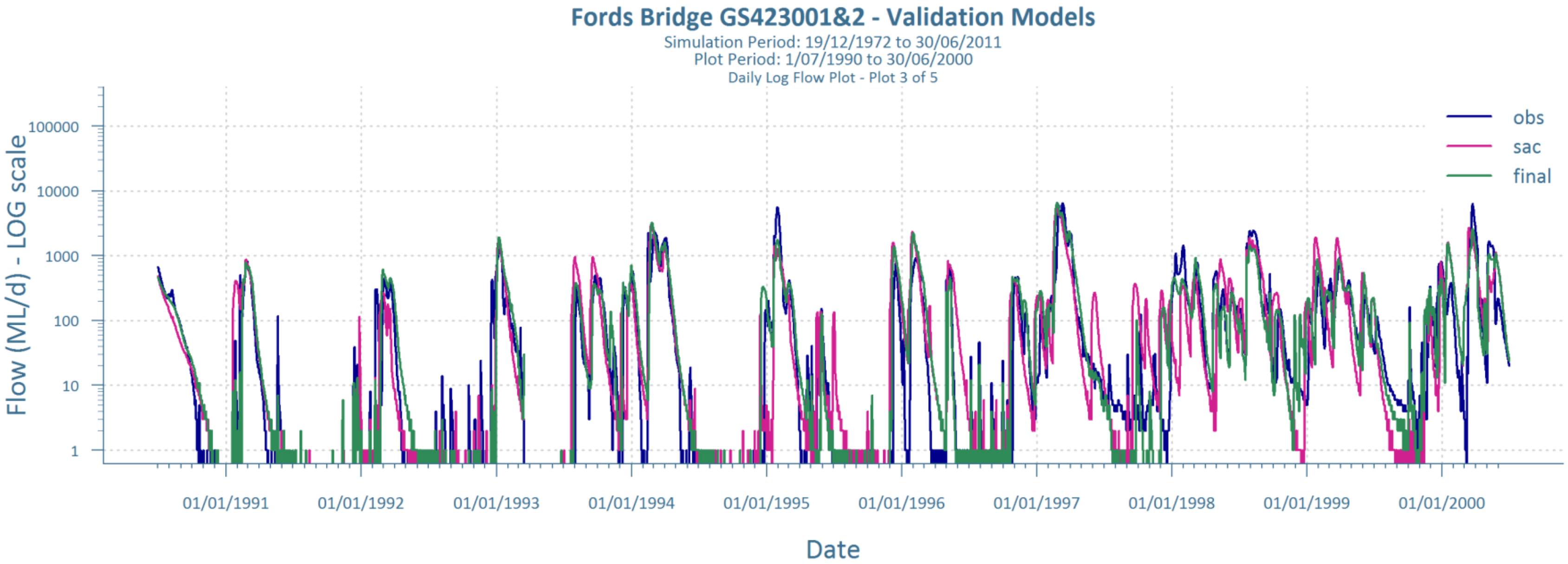

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Plot Period: 1/07/1990 to 30/06/2000
Daily Log Flow Plot - Plot 3 of 5
Flow (ML/d) - LOG scale
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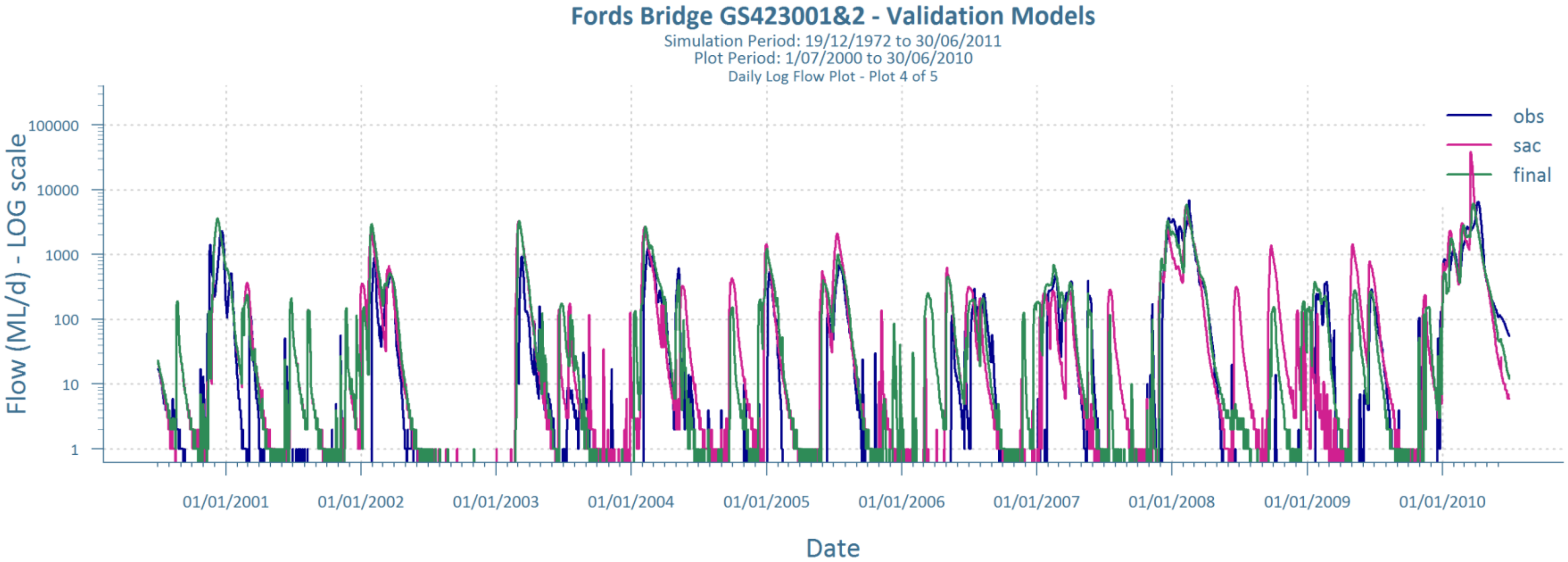

Fords Bridge GS423001&2 - Validation Models
Simulation Period: 19/12/1972 to 30/06/2011
Plot Period: 1/07/2000 to 30/06/2010
Daily Log Flow Plot - Plot 4 of 5
Flow (ML/d) - LOG scale
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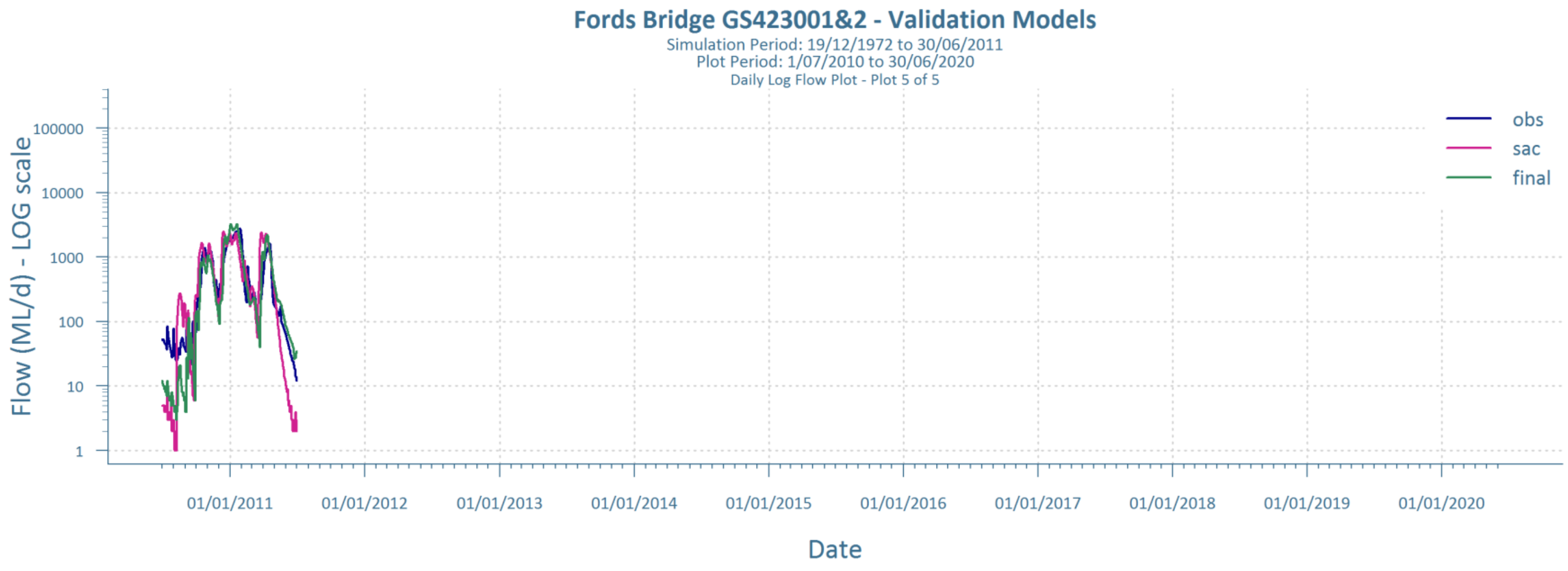
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Plot Period: 1/07/2010 to 30/06/2020
Daily Log Flow Plot - Plot 5 of 5
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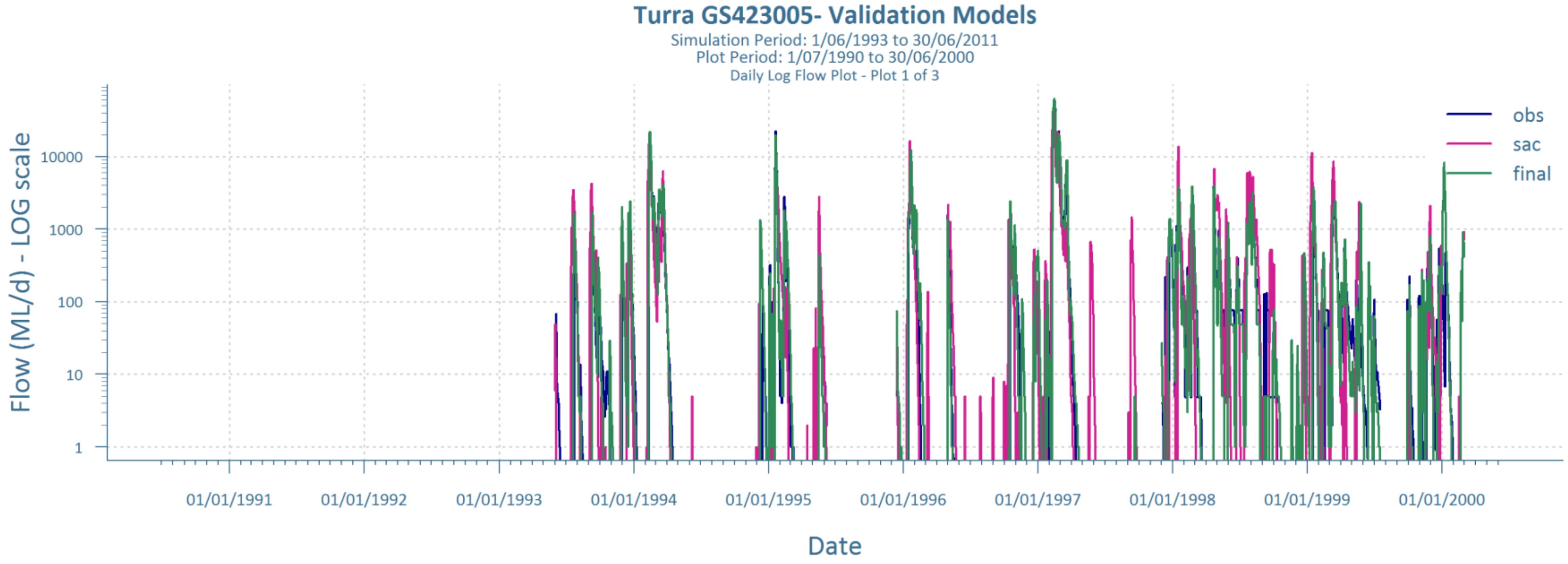
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Daily Log Flow Plot - Plot 1 of 3
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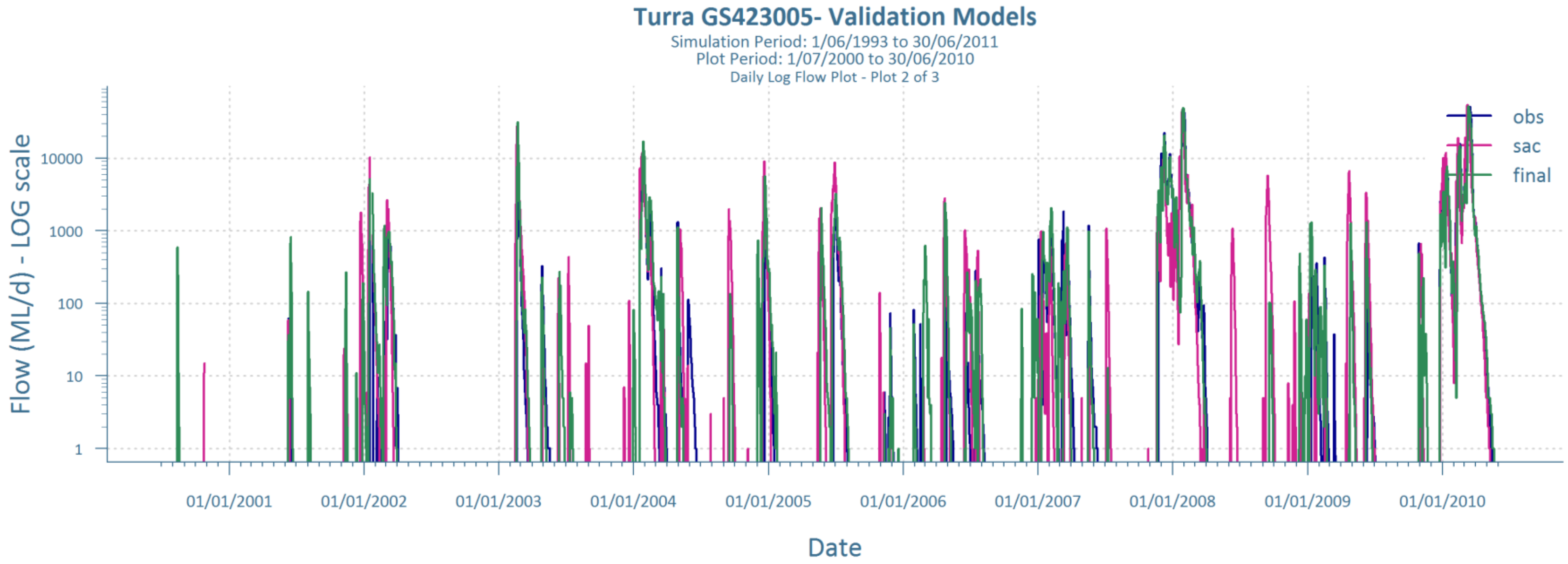
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10000
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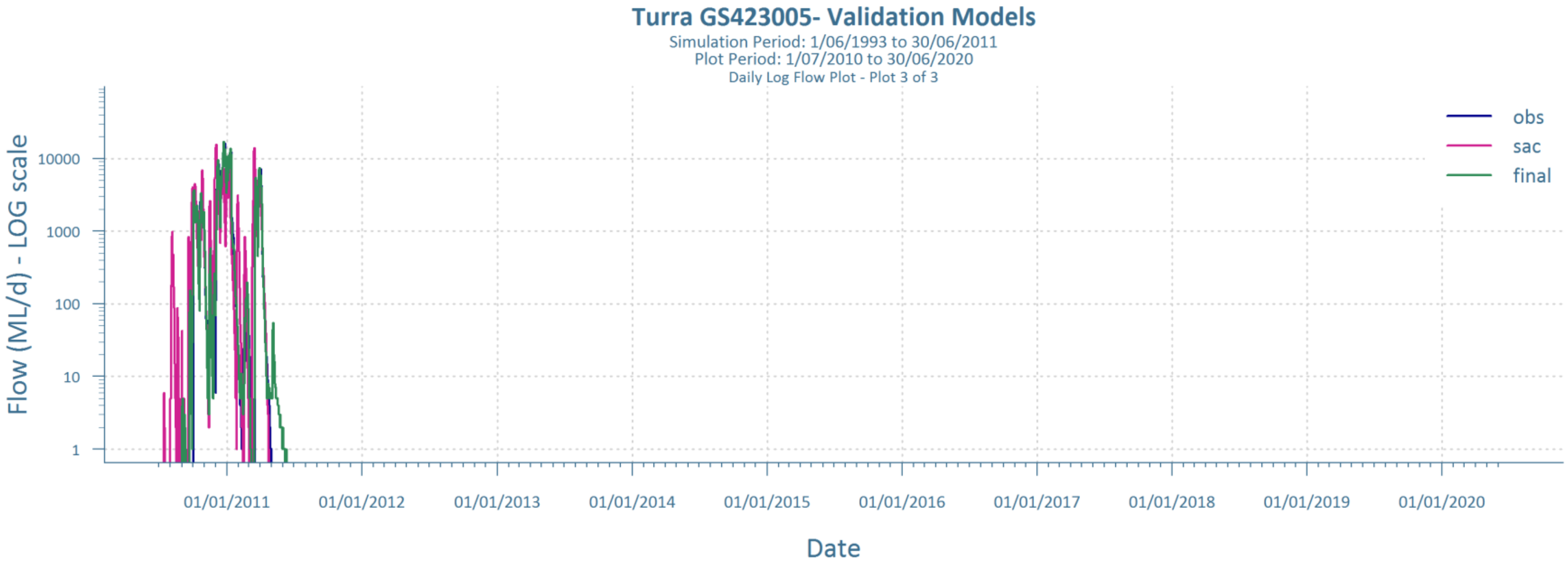
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01/01/2019
01/01/2020
Date
obs
sac
final

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 2000*, 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, instream 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* 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.