Department of Science, Information Technology and Innovation

Warrego River

Warrego River Model Results to Support Basin Plan Requirements

Water Planning and Coastal Sciences

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1 Introduction

The Warrego Model was developed by using IQQM Model as a platform. A detailed background to the data used, methodology, calibration and validation of the model development is documented in *Warrego River Catchment IQQM Calibration – Upstream of Augathella GS423204A to Fords Bridge GS 423001&2 (NSW) (DSITI, 2016).*

1.1 Current model

In preparing a water resource plan (WRP) and a resource operations plan (ROP) under the *Water Act 2000* (Qld), Queensland develops a hydrologic model to test management scenarios. The current plans, viz. the Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 (current WRP) and the Warrego, Paroo, Bulloo and Nebine resource operations plan January 2006 (current ROP), use the Integrated Quantity Quality Model (IQQM) for the catchment models.

The current ROP model for the Warrego River also forms the basis for the audited Cap model which supports Cap Reporting requirements under the Murray–Darling Basin Agreement and in the transition to the Basin Plan Section 71 reporting. Note that the current ROP and Cap models use different simulation periods but are otherwise the same.

1.2 Proposed Model

Queensland has developed a new model for the Warrego River as part of the review of the current WRP and ROP and for the Water Resource Plan package being developed to comply with Basin Plan requirements. This new ROP model differs from the current model on the following points:

- Updated Methodology – Queensland has updated the model methodology based on the learnings from previous model builds to improve the robustness of the model. This update has come from model application, internal and external audits and developments external to technology. This is addressed in Appendix A. A key driver for this update was so that the model could be used to determine the sustainable diversion limit (SDL) and the baseline diversion limit (BDL) consistent with the Basin Plan requirements i.e. Chapter 10 and Position Statement 3 C Method for Determining Take.
- Better Data – With every review more data becomes available. This is particularly significant in the case of the Warrego where new streamflow gauges at Wallen, Turra and Barringun have provided the capacity to better understand and simulate the flows in the stream. This is addressed in Appendix A.
- Overland Flow has been removed from the model as the information supporting this was poor. When reliable information becomes available as Overland Certification occurs in the catchment, it will be reflected in the model.

It needs to be noted that there have been no changes to water allocations between the current and new ROP models in either the flow management or threshold of access conditions.

1.3 Basin Plan Requirements

The Basin Plan prescribes requirements that Queensland needs to address to meet accreditation.

The key requirements that need to be addressed by the model are:

1. BDL — Baseline diversion limit of a SDL resource unit. The Baseline diversion limits are determined based on development conditions as specified in Schedule 3 of the Basin Plan. In general, the BDL is a sum of:
   - take from water courses
   - take from regulated river
   - take by floodplain harvesting
   - take by commercial plantation
   - take from basic rights.

   The model provides a component of the take identified in Schedule 3 is the long-term annual average limit on the quantity of water that can be taken from the watercourse and from regulated rivers. The other forms of take are considered in the Water Accounting Methods Report (NRM, 2016).

2. SDL — Sustainable diversion limit of the Water Resource Plan area. The SDL is the long-term average sustainable diversion limit from a SDL resource unit as defined in Schedule 2 and 4 of the Basin Plan. Clause 10.10 of the Basin Plan specifies that the Water Resource Plan must set out the method for determining the maximum quantity of water that the plan permits to be taken for consumptive use during a water accounting period. This method may include modelling. For the Warrego SDL resource unit, Queensland prepared the IQQM Model to meet this requirement. As there are no SDL adjustment measures proposed for the Warrego, the difference between BDL and SDL is achieved by Commonwealth water recovery. To simulate SDL in the model, the Commonwealth's water entitlements are treated as inactive (i.e. not used for consumptive take).

3. Annual Actual Take — Determination of annual actual take must be specified. As per clause 10.15 of the Basin Plan, the determination of the quantity of water, actually or estimated, taken for the consumptive use by each form of take from each SDL resource unit will be determined after the end of a water accounting period. The method used to estimate the quantities should be same as used to determine BDL and SDL.

4. Environmental Water — Determination of the environmental water requirements of environmental assets and ecosystem functions. Clause 8.51, sub-section (1) and (2) of the Basin Plan list a number of measures to determine the environmental water requirements of an environmental asset and states that a method to estimate them may include a conceptual model. The Warrego River has a relatively intact flow regime with only minor impacts. Existing environmental water recovered as part of the Water for the Future program will assist in further protecting the existing flow regime.

5. SDL Adjustment Proposals — Models are an important tool for evaluating the SDL adjustment proposals. Chapter 7 of the Basin Plan states that the Authority can propose adjustments to the surface water SDLs if certain additional changes in infrastructure are proposed through the implementation of 'supply measures' and 'efficiency measures'. Currently there are no SDL Adjustment Proposals in the Warrego. There may be a redistribution of the Northern Basin shared reduction under Chapter 7 of the Basin Plan, which could change the SDLs for each resource unit. However, this would be achieved by Commonwealth water recovery, which is reflected in the model.

Sections 10.22, 10.49 and 10.50 of the Basin Plan specify requirements that the WRP package should meet:

a) Section 10.22 states that a water resource plan must describe what was done to comply with the requirements mentioned in Part 4, Chapter 10 of the Basin Plan.

b) Section 10.49 states that:

- A water resource plan must be based on the best available information
- The water resource plan must identify and describe the significant sources of information on which the water resource plan is based.

c) Section 10.50 states that:
"A water resource plan must identify any significant method, model or tool that has been used to develop the water resource plan".

This report covers the requirements outlined above.

2 Warrego IQQM Model

The Warrego River model was developed by using the IQQM Model as a platform. A detailed background to the data used, methodology, calibration and validation of the model development is documented in *Warrego River Catchment IQQM Calibration – Upstream of Augathella GS423204A to Fords Bridge GS 423001&2 (NSW) (DSITI, 2016).*

3 Model Scenarios

In this section, the model scenarios are described. The details of the model scenarios are described in Table 1.

Table 1 Detail of the Model Scenarios

Case Number	Model Name	Description	Simulation Period
200A	Pre-development	A scenario with infrastructure and extractions for consumptive use removed from the model to simulate the predevelopment flows.	1889–2011
0902A	Current ROP	This model was developed to underpin the first generation Water Resource Plan and was later extended to cover the Basin Plan Period. The model corresponds to the Resource Operation Plan (2006).	1889–2009
1601A	New ROP	This model was developed to underpin the second generation Water Resource Plan representing all of the Water Allocations and licences in the basin. The model corresponds to the Resource Operation Plan (2016).	1889–2011
1601B	SDL	This model was developed at the request of the Murray Darling Basin Authority. Queensland does not utilise this model for available water calculations.	1889–2011

All of the model scenarios cover a period greater than the Basin Plan (1895 - 2009) so they are able to fulfil the Plan's requirements. All results in this report are provided for the Basin Plan period.

These scenarios were used to simulate the extractions (BDL) under the Resource Operation Plan for the Warrego River System.

The model simulated the:

- Water Allocations (including those held by the Commonwealth Environmental Water Holder (CEWH))
- Unallocated Water
- Water Licences

3.1 Reference Case (Case 200A)

A Pre-development case (case 200A) was simulated to describe the flow regime without any instream extraction across the river basin. The flows identified in this case were used as the baseline for evaluating how the various development scenarios affected streamflow.

3.2 New Resource Operation Plan (Scenario 1601A)

Details of the Resource Operation Plan IQQM are presented below.

3.2.1 Storage Details and Assumptions

No significant water infrastructure of note in the catchment.

3.2.2 Management System

The Cunnamulla Water Supply Scheme is supplied by Alan Tannock Weir. The weir has a capacity of 4,770 ML with a Dead Storage level of 500 ML and is represented by node 283 in the model. The water sharing rules are represented in the resource assessment in the IQQM.

3.2.3 High Priority Demand

There is no high priority demand supplied by the Warrego River System.

3.2.4 Medium Priority Demand

The demand from the weir is 2,612 ML/a (total entitlement available under the Warrego, Paroo, Bulloo and Nebine ROP).

3.2.5 Unsupplemented Licensed Data

This section presents the information used to model various types of water use within the Basin.

A few licences have not been converted to allocations, and are still in the ROP model. These licences are described in Table 2. The crop model was not utilised in the new model as the water availability and individual water allocation/licence conditions control access.

Table 2 Resource Operation Plan Case 1601A – Licence Representation

Sub-Catchment	Licence Number	Pump Capacity (ML/day)	Nominal Volume	Start Threshold
Augathella to Charleville	32791E	5	100	0
Charleville to Wyandra	12421E	Gravity diversion channel	-	0
	41589E	2.2	7.5	0
Wallen to Cunnamulla	29573E	1	35.8	0
	43950E	2.2	22.5	0
	43890E	1	24.1	0

The water allocations in the model are presented in Table 3. The water allocations were represented with no infrastructure limit and an annual volumetric limit.

Table 3 Unsupplemented Water Allocations in the Warrego Catchment

Water Allocation Number	Nominal Volume (ML)	Volumetric Limits (ML/year)	Max Rate for Taking Water (ML/day)	Flow Conditions	Special Conditions
	Warrego Zone G				
01	80	160	2.2	Nil	Nil
02	120	240	2.2	Nil	Nil
86	4000	6,050	86.4	86.4 ML/day passing Charleville	Nil
03	20	40	2.2	Nil	Nil
04	20	40	3.9	Nil	Nil
	Warrego Zone E				
06	10	20	0.43	Nil	Nil
07	40	80	7.3	Nil	Nil
08	50	50	7.3	Nil	Nil
09	30	60	7.3	Nil	Nil
10	10	20	5.6	Nil	Nil
11	200	400	1.9	Nil	Nil
76	80	160	39	Nil	Nil
12	100	100	15.6	Nil	Nil
32	600	1,100	15	1,100 ML/day passing Wyandra	The flow reference point for an announced period is Wyandra gauging station.

				Gauging Station	The flow volume for an announced period is 13,400 ML/day at Wyandra gauging station
13	250	500	5.6	Nil	Nil
14	200	400	15.6	Nil	Nil
15	100	200	7.3	Nil	Nil
16	40	80	0.86	Nil	Nil
17	30	60	0.69	Nil	Nil
	Warrego Zone K				
22	100	200	3.2	Nil	Nil
23	60	120	0.95	Nil	Nil
24	20	40	0.26	Nil	Nil
25	80	160	0.86	Nil	Nil
	Warrego Zone D				
18	90	180	3.9	Nil	Nil
19	40	80	3.9	Nil	Nil
34	5,933	11,900	175	1,650 ML/day passing flow at Cunnamulla Weir	Reference point is Cunnamulla Weir. Volume of 10,550 ML/d at Cunnamulla Weir. Water taken under the authority of this water allocation must not be stored unless the water is being stored in the notified storage works as described under Overland Flow Works Notification Acknowledgements 184047–184050 and 184055 with Works Reference 17762,17765,17767,17770 & 17784
35	10,700	24600	300	1,100 ML/day passing flow at Cunnamulla Weir	Reference point is Cunnamulla Weir. Volume of 10,000 ML/d at Cunnamulla Weir. Water taken under the authority of this water allocation must not be stored unless the water is being stored in the notified storage works as described under Overland Flow Works Notification

					Acknowledgements 184047–184050 and 184055 with Works Reference 17762,17765,17767,17770 & 17784
	Warrego Zone A				
20	80	160	5.6	Nil	Nil
37	2,700	6,200	87	1,000 ML/day passing flow at Cunnamulla Weir	Nil
38	800	3,000	87	6,000 ML/day passing flow at Cunnamulla Weir	Nil
39	1,960	4,400	87	1,475 ML/day passing flow at Cunnamulla Weir	The flow reference point for an announced period is Cunnamulla Weir. The flow volume for an announced period is 10,375 ML/d at Cunnamulla Weir
40	4,300	9,700	175	1,365 ML/day passing flow at Cunnamulla Weir	The flow reference point for an announced period is Cunnamulla Weir. The flow volume for an announced period is 10,265 ML/d at Cunnamulla Weir
41	2,475	5,700	120	1,890 ML/day passing flow at Cunnamulla Weir	The flow reference point for an announced period is Cunnamulla Weir. The flow volume for an announced period is 10,790 ML/d at Cunnamulla Weir
84	4,000	10,000	350	2,125 ML/day passing flow at Cunnamulla Weir	Nil
	Warrego Zone B				
26	20	40	0.17	Nil	Nil
27	20	40	12.1	Nil	Nil
42	1,170	3,100	87	1,190 ML/day	The flow reference point

				passing flow at Cunnamulla Weir	for an announced period is Cunnamulla Weir. The flow volume for an announced period is 10,090 ML/d at Cunnamulla Weir
43	1,325	3,800	120	1,770 ML/day passing flow at Cunnamulla Weir	The flow reference point for an announced period is Cunnamulla Weir. The flow volume for an announced period is 10,670 ML/d at Cunnamulla Weir
44	220	500	12.1	432 ML/day passing flow at point of take	Nil
	Warrego Zone C				
33	2,100	4,500	86.4	1,036 ML/day passing flow at Cunnamulla Weir	Nil
21	200	400	5.6	5.6 ML/day passing flow at Cunnamulla Weir	Nil
36	630	1,350	21.6	1,036 ML/day passing flow at Cunnamulla Weir	Nil
	Warrego Zone I				
45	3,000	7,000	87	10 ML/day passing flow at point of take	Nil

4 Reconciliation with Murray–Darling Basin Plan Schedule 3

The Basin Plan places limits on water extractions within the SDL resource units. The model 1601A is proposed to estimate the available water, specifically the take from watercourses for water allocations and licences. This will support the Water Accounting Methods proposed in the Water Accounting Methods Report (NRM, 2016) for the other forms of take and classes of water access right. For the details on these proposed methods, see the report cited above.

The following section provides the comparison and a breakdown of the long term diversions between the model scenarios 0902A and 1601A, using the Basin Plan simulation period 1895–2009. Table 4 provides a comparison between the long term diversion of the water allocations in the model scenarios while Table 5 and Table 6 present the Baseline Diversion Limits for the current Resource Operation Plan (2006) and the new Resource Operation Plan (2016) model scenarios. The difference between the results of the two models is due to improvements in the model and data used, as discussed in Appendix A.

Table 4 Long Term Diversions for the two respective Water Resource Plans (1895–2009)

Water Allocation Group	Water Allocation	Nominal Volume (ML)	Mean Annual Diversion (ML/yr) WRP (2006) 0902A	Mean Annual Diversion (ML/yr) WRP (2016) 1601A
WAG – A				
	20	80	160	160
	37	2,700	2,100	2,970
	38	800	807	1,139
	39	1,960	1,265	2,033
	40	4,300	2,778	4,424
	41	2,475	1,820	2,730
WAG – B				
	26	20	15	19
	27	20	38	40
	42	1,170	1,627	1,996
	43	1,325	2,082	2,214
	44	220	200	336
WAG – C				
	33	2,100	2,184	2,934
	21	200	400	386
	36	630	484	797
WAG – D				
	18	90	178	180
	19	40	80	80
	34	5,933	3,641	5,359
	35	10,700	7,384	10,917
WAG – E				
	6	10	20	20
	7	40	80	80
	8	50	50	50
	9	30	60	60
	10	10	20	20
	11	200	282	322
	12	100	100	100
	13	250	465	478
	14	200	398	400
	15	100	199	199

Water Allocation Group	Water Allocation	Nominal Volume (ML)	Mean Annual Diversion (ML/yr) WRP (2006) 0902A	Mean Annual Diversion (ML/yr) WRP (2016) 1601A
	32	600	484	608
	76	80	160	160
	16	40	77	75
	17	30	58	56
WAG – G				
	1	80	147	143
	2	120	191	190
	3	20	40	38
	4	20	40	39
WAG – I				
	45	3,000	3,370	4,361
WAG – K				
	22	100	194	192
	23	60	102	103
	24	20	31	32
	25	80	108	114
WAG – Extra				
	84	4,000	3,777	4,011
	84	4,000	3,654	5,510
	Supplemented	2,612	2,530	2,465
	Unallocated town water supply	200	322	98

Table 5 Long Term Diversions from the Resource Operation Plan 2006 (1895–2009)

Water Product	Mean Annual Diversions (ML/yr)
Take from watercourse – Supplemented Water Allocations	2,530
Take from watercourse – Unsupplemented Water Allocations	33,919
Take from watercourse – Stock Licences	89
Take from watercourse – Unallocated Water	7,753
Take from watercourse – Overland Flow	431
TOTAL	**44,722**

The Commonwealth held water was accounted for in the unallocated water at the time of the plan development. It was later gifted to the Commonwealth.

Table 6 Long Term Diversions from the Resource Operation Plan 2016 (1895–2009)

Water Product	Mean Annual Diversions (ML/yr)
Take from watercourse – Supplemented Water Allocations	2,465
Take from watercourse – Unsupplemented Water Allocations – without flow conditions	3,736
Take from watercourse – Unsupplemented Water Allocations – with flow conditions (Includes Commonwealth entitlements)	52,356
Take from watercourse – Unallocated Water	98
Take from watercourse – Water License volume limited	90
Take from watercourse – Water License non-volume limited	258
TOTAL	**59,003**

5 Conclusion

The new model for the Warrego River has benefited from additional information that has become available to update the legislative models that support the Queensland Water Resource Planning process and Murray-Darling Basin Plan requirements. The models have benefited from:

- New climatic and streamflow data
- Updated methodology
- Longer simulation period and better representation of climatic variability

The Basin Plan has a simulation period from 1895 to 2009 which differs from both the current Resource Operation Plan (2006) and the new Resource Operation Plan (2016), causing some of the variation in the diversion figures between Basin Plan and State Plan. When a consistent period is applied, it is possible to compare take from watercourses by allocations and licences for the two plans, as shown in Table 7. CEWH entitlements are identified separately to assist with demonstrating how the SDL will be achieved through Commonwealth water recovery in the Warrego SDL resource unit. For estimates of the BDL and SDL, please refer to the Water Accounting Methods Report (NRM, 2016), as these estimates are comprehensive and include forms of take and classes of water access right not considered in the IQQM models. Appendix B presents the modelled water balance for the Scenario ROP 2016 (1601A).

Table 7 Long term mean annual diversions from watercourses under water allocations and licences: comparison of model 0902A and 1601A

Mean annual diversions (1895-2009)	ROP 2006 (0902A)	ROP 2016 (1601A)
Total	44.7 GL	59.0 GL
CEWH entitlements only	7.4 GL	9.5 GL
Total less CEWH entitlements	37.3 GL	49.5 GL

As can be seen in Table 7, the ROP 2016 (1601A) estimates of mean annual diversions are higher than the estimates provided by the ROP 2006 (0902A) model. The main difference between the two models as discussed in Appendix A has occurred downstream of Cunnamulla Weir where new gauge information from the Warrego River at Barringun and Cuttaburra Creek at Turra streamflow stations has been used to better model the complex breakouts downstream of Cunnamulla. The modelled diversion of all entitlements in this section of the catchment is 13 GL higher in the ROP 2016 model than the ROP 2006 model. This accounts for all but 1 GL of the difference between the two models.

The new model demonstrates Queensland's commitment to improve on the previous model's robustness and defensibility. All future models will build on the new model and use the latest information, methodologies and technology available at the time when the next new model is developed.

6 References

Department of Natural Resources and Mines (2016), *Water Accounting Methods Paper for Warrego-Paroo-Nebine Water Resource Plan, State of Queensland, February 2016.*

Department of Science, Information Technology and Innovation (2016), Warrego River Catchment IQQM Calibration – *Upstream of Augathella GS 423204A to Fords Bridge GS 423001&2 (NSW)*

Appendix A – Methodology and Data Differences

Methodology and Data Differences 2003 to 2015

Variations in inflows and the model's physical components, such as loss and natural breakout representations, result from differences in the data and methodology used. The 2015 methods are different to those used in 2003. As a result it is extremely difficult to say exactly what causes variations between the models over short and long time periods.

Given the variations in methods it is more appropriate to work through the methodology used in the 2015 model. If the methodology is acceptable and has been applied correctly then the resultant model should be acceptable.

It should be noted that while in-bank flows are reasonably well defined, out of bank and high flow is not. This is due to the fact that on the flat landscape in extreme events water is likely to change its flow path. While this has been built into the model, it is likely that the behaviour in extreme events will differ to that in the model. This is true of both the 2003 and 2015 models.

Key variations between the 2003 and 2015 data and methods are outlined below. The following models are referred to:

- 2003 model – Basin plan model (This model was used to inform the development of the Murray Darling Basin Plan).
- 2012 model – New WRP model (Initial model supplied to the MDBA to meet Basin Plan requirements of accreditation).
- 2015 model – Updated WRP model with changes made following the MDBA review. Only the Warrego was changed as a result of the review so for the Paroo and Nebine the 2012 and 2015 models are the same and are referred to here as the 2015 model.

Rainfall and Evaporation

Different rainfall and evaporation data were used. Since the 2003 models were calibrated, a number of issues have been identified with using grid data, especially for catchments where there is sub-optimum spatial and temporal station coverage, as is the case in these western rivers.

SILO patched point data, which is recorded station rainfall infilled with SILO data drill (grid) data at that location, was used in 2015 instead of mean reach rainfalls derived from the SILO data drill (grid) data. This change in climatic data has produced better response to flow events but the spatial and temporal patterns differ across the catchment between the two models.

In 2015, rainfall stations were chosen to give good spatial and temporal coverage in the reach. Various combinations of stations were considered during the Sacramento calibrations. Generally the 2015 reach mean rainfalls were higher.

In 2015, evaporation data were taken from the Warwick site, which is outside the catchment. The grid data in these catchments are extrapolated out from the Warwick station and very few others and it was felt it was better to use something that was based to some extent on real data. The evaporation at Warwick would be fairly similar to evaporation in these catchments and any errors are unlikely to have a large effect on the model.

Flow Data

Recorded flow data used to develop the 2003 and 2015 models has varied in a number of ways.

- Different and additional gauges used.
- Longer records with flows associated with more extreme weather conditions.
- Rating changes. This will change earlier flow records if the rating curves change.
- Data may have been extracted differently. Variations include use of different time offsets and different conversion calculations used to generate flow data from levels.

In the Nebine, in the 2003 model no flow data was available for model calibration. In the 2015 model data from two new gauges Wallam Ck. @ Cardiff and Nebine Ck. @ Roseleigh Crossing was used. This allowed the derivation and distribution of inflows and losses within the catchment to be significantly improved as in the 2003 study many assumptions on the catchment responses were based on the models developed for the surrounding catchments.

In the Paroo the main difference was just the extension of records with time.

In the Warrego, there were two key differences. Firstly, the Barringun flow data used in model calibration. There are records from two gauges at Barringun which do not overlap. The 2003 study used only 423003 (1968–81). In 2015, the earlier record could not be used to calculate the residual, as the return flow from Irrara Creek based on recorded data could only be generated from 1993. This was because this was the start of the recorded data used for the upstream reach model. This reach model was used to estimate the breakout flows. The full data set from the two gauges was used to review the accuracy of the 2015 validation model.

Secondly, data from three additional gauges, Cuttaburra Ck @ Turra, Ward River @ Binowee and Warrego River @ Wallen were used in the calibration. This allowed the inflow distribution within the catchment to be modelled better. The Turra station was especially useful as it allowed a much improved representation of what was occurring in the Cuttaburra system. Previously the lack of a gauge meant a lot of guess work occurred.

Use of all flow data where stations were still operational allowed for additional catchment responses to be captured in calibration using the longer data sets.

Residual Calculation Periods

The period's residuals were calculated differently. In the 2015 model, it was decided to derive residuals using only recorded data at both the upstream and downstream gauges. Conversely, in 2003, residuals were calculated for the full length of the downstream gauge by using flow data from the upstream gauge from the full model to that upstream gauge. The 2003 full model used inflows (in all upstream reaches) that included residuals based on a combination of real and Sacramento data coming from upstream catchments and Sacramento data from the reach Sacramento models calibrated to these residuals.

The aim of working with recorded data only this time was to develop a cleaner model where the development of downstream residual inflows was not based on Sacramento data upstream, only recorded data.

Sacramento Calibrations

The 2015 Sacramento models are different to the 2003 ones. They use different catchment areas, rainfall, evaporation and flow data (residuals were developed on numerous different modelling assumptions and for different time periods and, in some cases, flow data were extracted differently).

In the Nebine in 2003 there was not enough flow data to calibrate an in-catchment Sacramento model whereas the 2015 model is based on an in catchment Sacramento calibration.

In the Warrego, Sacramento models were calibrated to residuals developed on numerous different modelling assumptions. This led to different time periods being used to the 2003 model, as shown in following figure. Different hydrological regimes were captured. Some calibrations were based on short periods of data but it was decided it was better to base the calibrations on recorded data rather than residuals derived using combinations of recorded and Sacramento data. In Sacramento calibrations, particular attention was made to ensure recessions were reproduced. Looking at the 2003 calibrations, this may not have been as much of a focus.

In the reaches above Wallen, the Sacramento calibrations were done manually in 2012 as reported in the 2012 report. Sacramento models in the Warrego reaches below Wallen were revisited after the initial MDBA review. A more recently developed and improved methodology was applied. This included using an assessment of trend in rainfall stations and flow/rainfall correlations to choose rainfall stations, and optimisation to derive the Sacramento parameter sets and rainfall station weightings.

Use of Historical Diversions in Residual Calculations

There are very few actual diversions and only recent departmental records of these. Trying to define and spread actual extractions in time and then add them back into the model for calibration would be very difficult and likely to cause errors in the low flows. In reality, there is little use of existing entitlements and limited meter records, so it was considered better to not include them.

Effect of not including Non-Licensable Storages and Waterholes

Large waterholes occur naturally throughout the Western River System. In 2003, an attempt was made to quantify them using satellite imagery and local knowledge (primarily local knowledge) as stakeholders requested that they be represented in the model.

When the 2003 basic data were reviewed, it was decided the volume estimates were not reliable and waterholes would not be included in the model unless it could be seen in downstream flow comparisons for a reach that there was a real need for waterholes to improve the modelling of antecedent conditions or attenuation. If this occurred, they would be included in the model calibration where they were required, rather than as an addition after the calibration process.

Non-licensable storages include excavated tanks and gully dams that are used for stock watering, but are not required to have a licence and small waterholes along the waterways.

The total estimated volume of these was small. As indicated in the 2003 reports, ‘These were assumed to have minimal effect on calibration results due to their size and date of construction relative to the calibration period. Thus, they were included in the model after calibration of the reach was completed.’

The storages were put on tributary branches and the additional inflows derived were to compensate for the inflow upstream of the storage that the storages captured. This basically produced a mass balance of what flowed downstream before the storage was added. The full utilisation of existing licences scenario only included extraction nodes below the additional inflow estimates so overall there was no impact on use estimates caused by adding them.

As with larger waterholes, the data on these storages obtained from regional staff within DNR&M and local knowledge was limited. For the 2015 models, it was decided they were more likely to reduce the accuracy of the low flow calibration than to add any value, so they were not included in the estimation of inflows.

Inflow Adjustment (using DMM)

In the Warrego, inflow adjustment (using the DMM program) was applied differently in the 2015 models to the 2003 models. In the 2015 models, Sacramento flows were not adjusted to flows at Barringun or Ford's Bridge using DMM, while in the 2003 model they were adjusted. This is a major difference in methodology. Not adjusting inflows means the contribution of the Sacramento inflows to the lower reaches is more apparent.

For the 1976 event in the 2003 study, the residual inflows upstream were tied to the recorded data at the Barringun gauge. In the 2015 model, upstream inflows below Wyandra were all Sacramento inflows, with no adjustments to the recorded data at Barringun. This led to an overestimation of the event at Barringun.

Similarly the 1990 event at Ford’s Bridge is overestimated due to Sacramento inflows in the lower reaches not being adjusted to the Ford’s Bridge flows.

It was decided that the model comparisons to recorded flows at both Barringun and Ford’s Bridge were acceptably accurate so adjusting the inflows to these gauges was not undertaken. This was also partially because adjusting the inflows up through the complicated breakouts in the lower reaches could have introduced errors into the model.

Flow Adjustment Explained

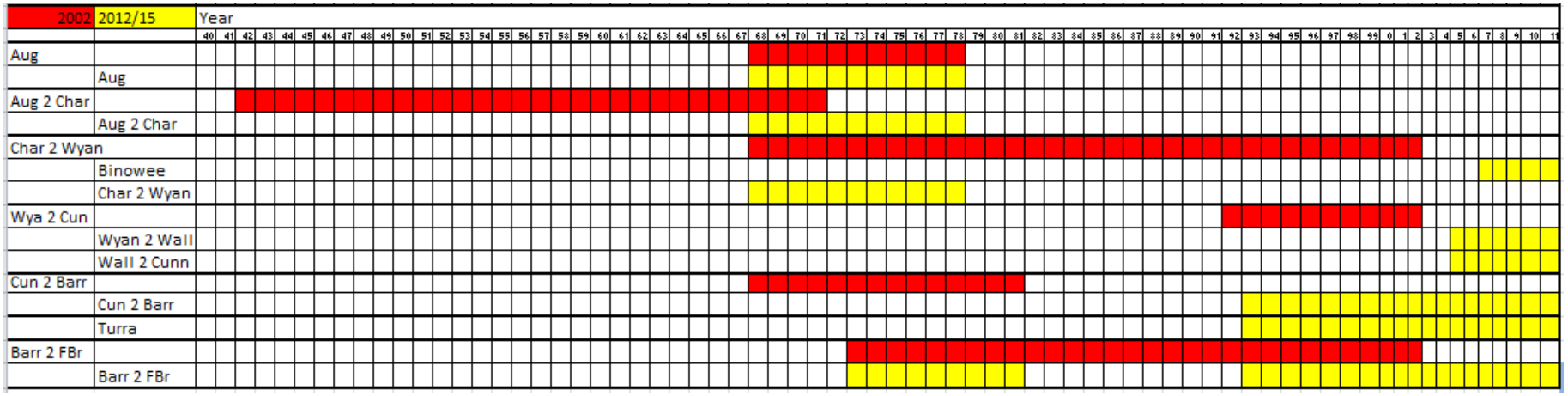
Once the full length inflow sequences for the whole model were included, further adjustments were made to the Sacramento parts of them to obtain a better match between the model and the long term recorded flow data in the catchment. The program DMM was used to make the adjustments.

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 which, when put with the calibrated model’s assumptions, will result in better alignment of the modelled and gauge flows at the long term gauge. It does multiple iterations to converge towards a best set of adjusted inflows and then the user decides which iteration’s inflows give the best result overall. A range of different methods are available to distribute the calculated difference upstream.

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 used in the model validation and model simulation runs.



Warrego Calculated Residual and Sacramento Model Calibration Period

Appendix B – Warrego River Water Balance – Scenario ROP 2016 (1601A)

	System Inflows ML				System Losses ML					Extractions ML			Storage ML		Error
Year	Tributary	Pumped	Effluent	Link	End sys	Effluent	Wetland	Link	Storage	Fixed Demands	HS Demands	GS Demands	Reservoir	Link	ML
1889	470,566	38,152	167,388	0	60751	474069	0	0	1,779	38,630	0	100,637	548	-786	-0.016
1890	10,629,924	68,217	4,964,283	0	1,373,294	14,102,473	0	0	1,413	68,490	0	118,062	581	726	-0.022
1891	5,514,745	61,001	2,576,011	0	440,753	7,566,409	0	0	1,440	61,204	0	82,791	1,061	-222	-0.014
1892	437,933	27,288	153,488	0	51,937	461,615	0	0	1,940	27,677	0	73,961	-1,365	-215	-0.018
1893	337,354	18,558	134,077	0	45,105	371,369	0	0	1,780	18,786	0	54,508	1,078	481	-0.017
1894	3,147,483	55,027	1,444,891	0	286,961	4,173,489	0	0	1,869	55,275	0	120,322	-1,835	-7,651	-0.021
1895	246127	28,439	841,47	0	34,457	241,645	0	0	2,168	28,772	0	51,062	103	-718	0.004
1896	1,199,607	21,093	521,228	0	122,083	1,542,194	0	0	1,761	21,266	0	65,503	2,505	8,383	-0.052
1897	112,637	13,792	21,963	0	10,155	75,065	0	0	1,670	14,146	0	21,787	-2,568	-23,017	-0.001
1898	645,997	22,858	285,905	0	91,107	780,224	0	0	1,572	23,179	0	84,929	3,261	23,008	-0.009
1899	32,234	4,965	8,053	0	4,111	26,517	0	0	1,418	5,089	0	8,410	281	10	-0.001
1900	59,292	9,359	15,043	0	7,558	47,997	0	0	1,351	9,638	0	15,682	-1,461	-8	-0.004
1901	369,910	23,831	141,026	0	50,968	396,506	0	0	1,612	24,127	0	61,578	24	0	-0.025
1902	192,665	8,672	76,939	0	2,463	190,376	0	0	977	8,967	0	30,043	-2,213	-43,307	0.002
1903	439,932	29,071	177,664	0	82,851	517,804	0	0	1,992	29,380	0	52,714	25	38,070	-0.018
1904	531,166	39,440	198,003	0	69,846	548,771	0	0	2,056	39,703	0	82,156	-25	-26,061	0.007
1905	316,445	22,245	112,003	0	60,314	337,645	0	0	1,947	22,412	0	60,953	1,372	31,254	-0.016
1906	3,838,316	51,518	1,742,437	0	277,751	5085,935	0	0	1,740	51,952	0	172,686	-1,372	-40,899	-0.136
1907	188,114	21,877	57,911	0	34,954	188,952	0	0	2,036	22,123	0	37,992	0	18,165	0.002
1908	257,072	28,731	94,334	0	46,943	277,069	0	0	1,977	28,961	0	47,829	450	22,253	-0.014
1909	276,995	27,607	101,065	0	41,035	297,713	0	0	1,920	27,888	0	35,563	543	-2,104	-0.019
1910	2,457,941	45,120	1,074,705	0	326,275	3,097,345	0	0	2,168	45,515	0	103,839	-838	-1,777	0.019
1911	1,221,796	22,290	541,918	0	119,316	1,582,935	0	0	1,467	22,456	0	66,719	2,534	4,361	0.018
1912	935,108	19,463	417,930	0	100,185	1,166,948	0	0	1,515	19,760	0	83,662	-474	41	-0.046
1913	891,373	45,112	357,387	0	115,009	1,032,123	0	0	1,872	45,426	0	76,576	-2,215	-20,746	-0.047

1914	296,873	29,180	113,697	0	47,089	328,151	0	0	2,190	29,454	0	48,694	37	15,871	-0.013
1915	16,880	2,990	1,124	0	3,612	7,910	0	0	1,994	3,150	0	4,878	9	547	0.001
1916	778,981	40,088	286,032	0	79,943	814,747	0	0	1,604	40,505	0	118,163	-46	-49,998	0
1917	3,446,074	51,592	1,627,527	0	383,201	4695,833	0	0	1,959	51,880	0	43,735	197	51,132	0.062
1918	910,044	29,862	406,617	0	122,265	1125,486	0	0	1,912	29,964	0	71,992	1,896	3,197	-0.009
1919	70,129	10,871	19,640	0	9,388	60,895	0	0	2,083	11,123	0	14,722	-1,786	-649	-0.002
1920	2,034,400	56,864	853,446	0	206,155	2,535,593	0	0	1,859	57,274	0	142,118	-55	-1,653	-0.111
1921	1,922,172	52,888	777,189	0	199,071	2,276,725	0	0	1,673	53,177	0	98,878	-252	-122,555	-0.026
1922	167,600	12,152	104,135	0	25,945	286,861	0	0	1,883	12,417	0	34,137	0	77,365	-0.004
1923	255,292	17,072	65,243	0	39,171	195,974	0	0	2,237	17,301	0	28,867	0	-54,060	0
1924	1694,803	54,538	786,543	0	209,894	2,206,033	0	0	2,161	54,910	0	161,959	344	98,808	-0.085
1925	406,152	30,026	129,167	0	54,145	428,082	0	0	1,908	30,314	0	49,670	-270	-978	-0.016
1926	219,157	14,772	28,865	0	42,059	181,118	0	0	1,888	15,060	0	22,863	96	95	0.002
1927	367,679	20,154	123,967	0	18,983	301,259	0	0	2,128	20,442	0	50,697	-170	-118,153	-0.001
1928	319,203	29,916	126,701	0	75,883	428,106	0	0	1,946	30,112	0	58,630	154	118756	-0.015
1929	203,735	11,400	85,425	0	30,656	233,328	0	0	2,077	11,687	0	28,517	2,682	3,026	-0.012
1930	525,203	23,670	188,921	0	66,498	582,198	0	0	1,743	23,992	0	61,812	-1,519	-33	-0.019
1931	802,092	32,807	300,048	0	69,451	891,009	0	0	1,596	33,154	0	99,988	-1,318	-38,428	-0.015
1932	70,980	16,568	17,713	0	34,088	75,301	0	0	2,100	16,832	0	17,058	1,723	38,399	-0.002
1933	863,975	42,205	347,654	0	110,528	980,408	0	0	1,933	42,517	0	107,664	-1,501	-9,269	-0.027
1934	193,322	20,117	68,981	0	33,922	208,827	0	0	2,004	20,405	0	26,837	363	9,193	-0.007
1935	99,900	14,618	28,908	0	12,853	88,963	0	0	1,959	14,906	0	26,016	1,156	120	-0.002
1936	693,363	33,995	245,793	0	99,902	733,456	0	0	1,862	34,254	0	90,178	-1,741	-11,785	-0.005
1937	404,237	21,456	163,592	0	61,114	470,658	0	0	1,956	21,599	0	48,803	3,061	11,811	-0.011
1938	284,031	17,142	90,491	0	34,915	288,251	0	0	2,049	17,535	0	47,358	-1,526	-31	-0.011
1939	402,676	37,046	139,263	0	53,399	405,366	0	0	1,881	37,303	0	81,531	477	19	-0.014
1940	270,398	15,419	110,495	0	37,886	302,619	0	0	1,882	15,656	0	33,921	1,210	-5,563	-0.003
1941	2,005,902	40,923	893,768	0	184,286	2,612,319	0	0	1,933	41,212	0	105,600	-807	5,569	-0.104
1942	459,665	23,501	138,191	0	34,740	468,667	0	0	1,636	23,939	0	52,154	-2,416	-37,804	0.008
1943	159,986	19,414	54,814	0	40,650	174,747	0	0	2,211	19,702	0	35,257	697	37,656	-0.004
1944	98,305	16,322	25,792	0	13,800	86,129	0	0	2,135	16,531	0	21,706	-127	10	-0.004

1945	241,428	26,712	81,289	0	34,120	242,491	0	0	2,060	27,078	0	42,034	-449	-1,211	-0.004
1946	189,194	10,158	77,637	0	28,293	214,138	0	0	1,816	10,305	0	27,054	3,500	1,127	-0.004
1947	404,123	40,218	124,113	0	49,816	387,030	0	0	1,703	40,648	0	79,521	-3,500	-6,242	-0.009
1948	97,875	11,823	14,769	0	13,354	77,178	0	0	1,724	11,956	0	17,403	2,340	-5,203	0
1949	2,386,922	49,735	1,024675	0	195,701	3,091357	0	0	1,767	50,179	0	132,017	-1,562	11,271	-0.064
1950	4264,740	92,786	1,812,124	0	419,566	5,464,745	0	0	981	93,074	0	176,129	-862	-14,292	-0.009
1951	70,840	15,549	18,587	0	19,694	79,904	0	0	1,993	15,762	0	4,665	2,361	14,680	0
1952	171,271	27,655	44,373	0	22,814	151,565	0	0	1,621	27,911	0	38,265	-1,086	-38	0.001
1953	176,870	21,802	55,504	0	24,892	168,135	0	0	1,942	22,106	0	36,886	-216	4	-0.001
1954	1,535,741	48,130	665,509	0	161,522	1,920,189	0	0	1,727	48,511	0	116,959	-215	-257	-0.06
1955	1,848,971	54,484	824,686	0	229,400	2,361,987	0	0	1,700	54,765	0	80,702	162	250	0.006
1956	5,497,673	73,533	2,529,192	0	498,217	7,343,622	0	0	1,225	73,829	0	152,962	454	-30,998	0.043
1957	154,547	24,123	54,915	0	25,084	177,793	0	0	2,417	24,408	0	32,090	-1,103	29,313	-0.006
1958	89,360	16,084	17,968	0	12,255	67,985	0	0	1,967	16,373	0	15,478	1,562	-10,917	-0.003
1959	437,248	48,106	148,164	0	57,163	437,965	0	0	1,817	48,390	0	87,623	-1,937	1,362	-0.015
1960	99,869	16,484	24,545	0	19,800	94,351	0	0	2,075	16,737	0	20,236	1,220	11,091	-0.001
1961	598,068	32,049	197,972	0	81,295	632,265	0	0	2,126	32,378	0	72,038	-1,100	-6,912	-0.004
1962	591,128	27,064	220,985	0	69,874	620,562	0	0	1,651	27,323	0	64,701	-139	-54,957	-0.017
1963	1,626,879	50,188	749,649	0	180,501	2,145,388	0	0	1,948	50,506	0	109,065	284	60,457	-0.083
1964	290,561	24,813	75,972	0	38,317	286,646	0	0	2,036	25,102	0	38,976	149	-416	-0.01
1965	80,724	9,797	22,538	0	3,155	64,436	0	0	1,569	10,086	0	23,879	-391	-9,542	0
1966	394,080	26,165	152,052	0	59,305	426444	0	0	2,095	26,453	0	70,928	1,388	11,543	-0.012
1967	271,299	13,573	100,244	0	40,164	294,386	0	0	1,931	13,776	0	34,674	-138	-40	-0.008
1968	477,930	31,808	159,651	0	64,471	494,960	0	0	1,688	32,064	0	77,443	1,166	66	-0.015
1969	132,042	15,776	24,584	0	12,136	98,585	0	0	1,734	16,024	0	21,439	-2,458	-20,091	-0.002
1970	254,163	34,045	88,354	0	32,088	255,179	0	0	2,095	34,340	0	50,683	0	-2,157	-0.011
1971	1,316,967	26,968	69,738	0	37,751	382,963	0	0	1,763	27,208	0	49,528	0	-914,501	-0.007
1972	349,204	22,399	694,895	0	85,825	1,819,953	0	0	1,857	22,743	0	61,762	171	925,544	0.031
1973	1,735,731	49,893	797,727	0	127,936	2,331,554	0	0	1,857	50,181	0	77,502	62	5,628	-0.01
1974	1,086,432	40,551	437,239	0	144,532	1,316,185	0	0	1,729	40,839	0	68,079	1,570	5,574	-0.046
1975	417,218	24,492	61,858	0	23,196	209,093	0	0	1,422	24,679	0	45,707	-1,803	-197,775	-0.005

1976	1,854,823	37,027	628,953	0	239,010	2,337,299	0	0	1,285	37,289	0	103,242	933	196,495	0.005
1977	634,688	31,459	248,300	0	91,388	728,934	0	0	1,843	31,692	0	63,401	1,524	1,290	-0.027
1978	420,397	33,784	154,181	0	56,557	448,797	0	0	1,774	34,255	0	61,653	-1,728	-3,598	-0.006
1979	97,591	16,405	30,269	0	14,595	94,547	0	0	2,013	16,530	0	22,409	2,230	3,599	-0.001
1980	103,060	18,667	28,039	0	15,997	91,887	0	0	2,246	19,119	0	16,851	-2685	-983	0.001
1981	922,654	36,213	393,072	0	89,265	1,166,284	0	0	2,035	36,501	0	57,976	148	-16	-0.058
1982	287,340	16,476	120,642	0	41,130	330,430	0	0	1,945	16,586	0	38,122	2,750	999	-0.002
1983	1,620,858	44,122	668,494	0	165,549	2,003,455	0	0	1,419	44,588	0	112,370	-2,889	-3,204	-0.021
1984	471,219	29,313	160,467	0	59,022	495,591	0	0	1,907	29,554	0	78,693	1,783	1,977	-0.011
1985	114,248	19,506	29,381	0	12,066	94,611	0	0	1,126	19,795	0	28,166	-1,904	-5,439	-0.003
1986	223,314	17,787	89,165	0	34,627	257,705	0	0	2,111	18,075	0	21,624	85	3,760	0.003
1987	335,064	44,781	110,308	0	53,194	336,432	0	0	1,986	45,069	0	56,254	269	2,527	-0.007
1988	157,433	15,813	18,696	0	20,918	131,687	0	0	1,766	16,101	0	20,995	945	-1,435	-0.005
1989	1,291,227	44,481	553,242	0	160,724	1,576,182	0	0	1,792	44,707	0	101,576	-1,402	-2,547	0.009
1990	3,820,219	49,562	1,823,582	0	371,583	5,176,382	0	0	1,921	49,912	0	100,180	2,255	4,353	0.039
1991	160,457	9,613	34,239	0	12,468	152,539	0	0	1,518	9,734	0	29,349	1,296	3	-0.004
1992	299,906	15,300	100,996	0	11,575	296,657	0	0	1,548	15,721	0	39,397	-3,610	-47,759	0.004
1993	185,609	36,007	52,616	0	48,451	189,803	0	0	2,112	36,329	0	36,470	104	38,881	-0.006
1994	721,458	24,642	306539	0	85,718	880,151	0	0	2,126	24,928	0	66,827	221	6,883	-0.026
1995	317,365	20,021	69,930	0	50,998	298,491	0	0	1,452	20,311	0	34,995	81	-1,149	-0.005
1996	390,313	28,860	140,279	0	52,437	405,251	0	0	1,938	29,148	0	65,745	-407	-4,517	-0.037
1997	2,984,187	37,770	1,473,529	0	177,915	4,185,129	0	0	2,051	38,058	0	91,041	13	-1,308	0.082
1998	332,722	44,814	50,169	0	81,513	274,523	0	0	1,762	45,102	0	29,982	127	5,055	0
1999	376,715	39,479	86,297	0	48,177	273,715	0	0	1,794	39,692	0	46,491	-140	-92,548	-0.012
2000	1,023,094	42,237	388,126	0	153,226	1,236,447	0	0	1,701	42,601	0	102,665	17	83,215	-0.051
2001	46,704	13,974	7,809	0	14,625	37,947	0	0	2,217	14,258	0	10,316	65	10,825	0.001
2002	460,025	21,061	190,791	0	54,614	556,956	0	0	2,069	21,166	0	42,853	3,365	2,426	-0.036
2003	520,797	18,200	229,494	0	51,017	668,280	0	0	1,819	18,584	0	26,064	-1,297	-1,449	-0.038
2004	588,053	32,394	227,434	0	62,562	652,302	0	0	1,997	32,773	0	74,899	-2,150	-21,206	-0.011
2005	166,564	26,486	51,439	0	36,592	159,421	0	0	2,094	26,674	0	44,528	2,206	22,642	-0.003
2006	108,297	28,117	24,801	0	17,433	89,797	0	0	2,076	28,489	0	18,059	-2,147	-3,219	-0.003

2007	944,970	36,361	355,086	0	69,902	1,034,188	0	0	1,684	36,664	0	108,959	-59	-84,986	-0.093
2008	2,073,056	34,473	1,025,478	0	154,105	2,976,163	0	0	1,763	34,762	0	42,884	284	76,407	0.001
2009	104,597	24,605	24,163	0	19,051	97,911	0	0	1,892	24,893	0	21,159	828	10,720	-0.002
2010	4,035,535	70,606	1,769,574	0	257,975	4,980,493	0	0	1,246	70,894	0	198,489	-1,112	-365,536	0.129
Average	**906,502**	**30,180**	**384,695**	**0**	**99,002**	**1,128,897**	**0**	**0**	**1,835**	**30,464**	**0**	**61,175**	**428**	**-1,011**	**-1.419**