Waratah River Yield Analysis

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Executive summary

Waratah River is the single source of water supply to the township of Waratah. During the recent portfolio risk assessment of TasWater's Dam Assets, conducted by Entura in 2013, Waratah Dam was determined to be at High Risk of dam failure. TasWater are considering the option of decommissioning the Waratah Dam. The results from this study will serve as guide to inform TasWater of the long-term water availability in the Waratah River, should the Dam be decommissioned.

There are no at-site streamflow records available, therefore a regionalization method was used to estimate the long term flow in the catchment. To this end, daily rainfall-runoff models were setup in Hellyer and Que River catchments with an implicit assumption that these catchments were hydrologically similar to Waratah River catchment. The model performance in Que and Hellyer Rivers was investigated, and the calibrated parameters from Hellyer catchment, deemed to be marginally better than Que, were transposed to Waratah River catchment to derive a 55 year long sequence of simulated flows.

From the modelling results it was found that, at least 0.02 m^3/s of flow would be available in Waratah River in the dry season and maximum of 6.13 m^3/s would be available in wet season.

A thorough evaluation of the model performance was conducted using linearly scaled flows derived from two catchments. The fact that the Waratah rainfall runoff model was driven by a pluviograh record (independent of SILO rainfall record used for model calibration) and that the model was tested on two separate catchments does reduce the possibility of the model skill being artificially inflated. However, because there was no at-site gauge (to further confirm the model performance in Waratah) this cannot be guaranteed. Noting that Hellyer Catchment is approximately 10 times larger than Waratah, there is a possibility that zero flow events in Waratah might not be picked up by modelling using the transposed parameters from Hellyer. A streamflow gauging station, if established within the catchment, could further substantiate these findings and is therefore recommended.

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1. Introduction

Waratah River is the single source of water supply to the township of Waratah. During the recent portfolio risk assessment of TasWater's Dam Assets, conducted by Entura in 2013, Waratah Dam was determined to be at High Risk of dam failure. TasWater are considering the option of decommissioning the Waratah Dam. The results from this study will serve as a guide to inform TasWater of the long-term water availability in the Waratah River, should the Dam be decommissioned.

1.1 Scope

The scope of this study covers:

- Development of rainfall-runoff models on three catchments; Waratah Dam catchment, Hellyer River catchment and the Que River catchment.
- Calibration of the rainfall–runoff models on Hellyer River and Que River using the data from Hellyer River gauging station at Guildford Junction, Que River at Murchison Highway.
- Additionally, model outputs and calibrated parameters from Idaho Creek model developed for a previous study will also be studied for its suitability for transposition to Waratah Dam catchment.
- Estimation of the Flow duration curves of the daily flow for each month from the simulated inflow record at Waratah Dam catchment.

2. Catchments and Data

Waratah Dam catchment is located in the Northwest of Tasmania. The catchment is approximately 10 km^2 in size. A meteorological station exists near the Dam, however there are no streamflow gauging stations within the catchment.

Two gauging stations (Figure 2.1) are located in Hellyer River (at Guilford Junction) and Que River (at Murchison Highway) at distances of roughly 12 km and 18.5 km respectively from the Dam. The catchments covered by these gauges potentially share the similar hydrologic and climatic characteristics with the Waratah Dam catchment. The Waratah and the neighbouring gauged catchments are shown in Figure 2.1. Additionally a third streamflow station, Idaho Creek, is located more than 67 km south of Waratah Reservoir but was considered the least favourable option for parameter transposition among the three. Details of the data available at the catchments are given in Table 2.1.

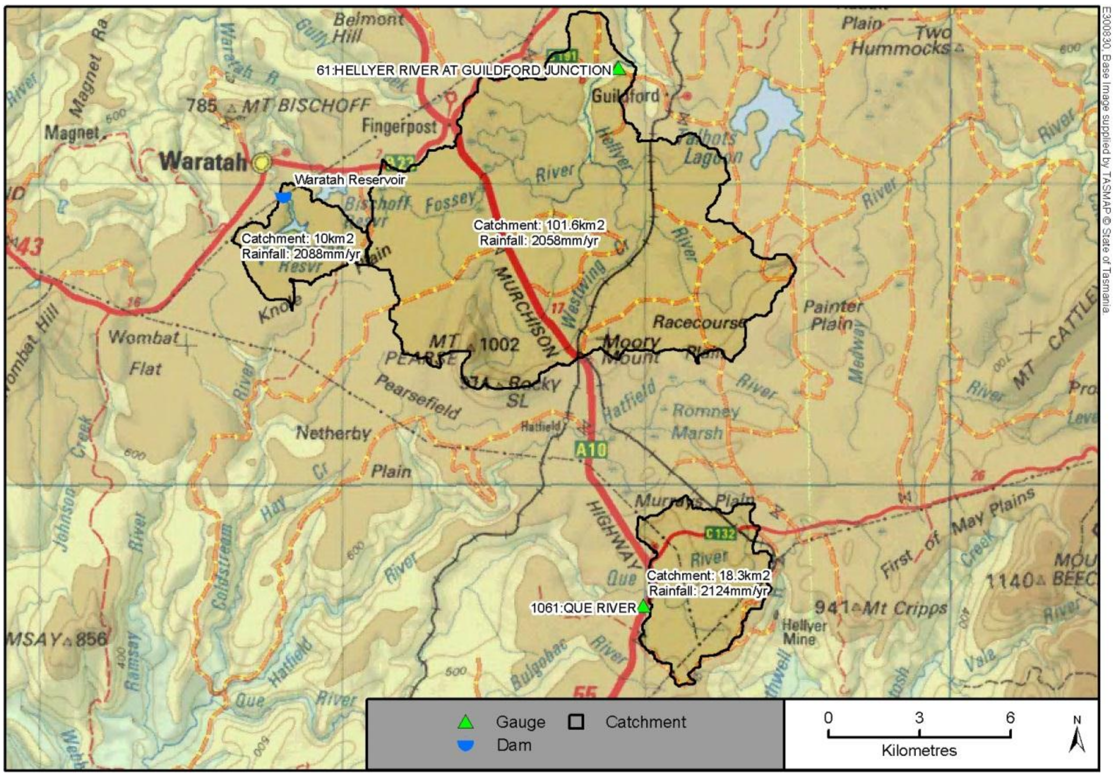

Figure 2.1: Location of the Waratah Dam and neighbouring gauged catchments

Table 2.1: Catchment details and data used for the analysis

Name	**Station ID**	**Source**	**Station Type**	**Catchment Area (Km^2)**	**Elevation (m)**	**Annual Rainfall (m)**	**Data Period**
Hellyer River at Guildford Junction	61	HT	Flow	101.6	564	2058	01/01/1925 to 01/01/2015
Que River at Murchinson Highway	1061	HT	Flow	18.3		2124	01/04/1987 to 28/10/2010
Waratah Meteorological Station	1459	HT	Rainfall	10	620	2088	09/12/1994 to 08/01/2015
SILO Precipitation	[1]	Qld government	Various	-	-	-	1889 to current
Idaho Creek above Linda Creek	775	HT	Flow	2.8	272	3097	27/05/1987 to 15/02/1996

[1] Available in a regular 0.05° x 0.05° grid, which is approximately 5 km x 5 km

In addition, the SILO database (Queensland Government, Natural Resources and Mines 1996) provides climate data for individual stations (so-called patched point data) as well as interpolated values (so-called data drill data) for each climate element between observation stations from 1889 onwards. 15 different climate variables are available in the SILO database, including, but not limited to, rainfall and various types of evaporation and evapotranspiration. Continuous, daily time step records have been constructed from ground-based observational data and using spatial interpolation algorithms to estimate missing data (Jeffry et al. 2001). Two criteria make using SILO data drill data for this project particularly attractive, namely the long record length and the availability of a continuous, gap-free record.

The SILO precipitation and the potential evapotranspiration data were downloaded for Hellyer River catchment (~41 27'S 145 39'E), Que River catchment (~41 36'S 145 42'E) and Waratah Dam catchment (~41 27'S 145 33'E). The downloaded SILO precipitation data at the Waratah was found to compare reasonably well (Figure A.1, Figure A.2 in Appendix A) with the precipitation data available at the Waratah Meteorological station.

Synthetic SILO precipitation and potential evapotranspiration data (calculated using the FAO Penman-Monteith formula) were used as input to the hydrologic models established in Hellyer and Que catchments. The at-site precipitation data in Waratah was augmented to create a long series of 'gap-free' precipitation in Waratah Dam catchment. The augmented precipitation data and the SILO potential evapotranspiration data were used to drive the Waratah rainfall-runoff model.

3. Methodology

The following steps were implemented to derive long term simulated yield in Waratah River.

1) Hydrologic models (rainfall runoff models) were setup in each individual catchment. The hydrologic model used in this study is the GR4J model. GR4J is a four-parameter rainfall-runoff model that runs on a daily time-step. The model showed a good performance in comparative studies (e.g., Perrin et al., 2001) and has been extensively tested in France, the US and Australia.

2) The GR4J models established for Hellyer River and Que River were calibrated against the streamflow data available in each catchment. The models were calibrated with an automated optimization algorithm, the Generalized Reduced Gradient (GRG) nonlinear algorithm provided with the MS EXCEL solver. The objective function used for the calibration was the Nash-Sutcliffe efficiency (NSE, equation 1). To reduce errors due to improper initialization of model states, a warm-up period of 1 year was allowed prior to the calibration period.

$$\boldsymbol{NSE} = \mathbf{1} - \frac{\sum(\boldsymbol{Q_{obs}} - \boldsymbol{Q_{sim}})^2}{\sum(\boldsymbol{Q_{obs}} - \overline{\boldsymbol{Q_{obs}}})^2} \qquad (1)$$

Where, $\boldsymbol{Q_{obs}}$ is the observed flow, $\boldsymbol{Q_{sim}}$ is the simulated flow and $\overline{\boldsymbol{Q_{obs}}}$ is the mean of the observed flow.

NSE can range from $-\infty$ to 1. NSE of 1 corresponds to a perfect match of modelled discharge to the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas NSE less than zero occur when the observed mean is a better predictor than the model. In general, the NSE values greater than 0.6 are considered to be an 'acceptable' representation of the observed data.

3) The calibrated Hellyer and Que River models were validated (Table 4.2) over an independent period of data (not used for calibration). The model performance over the calibration and the independent period (hereafter called validation period) were compared using NSE, NSEL and percentage bias. The NSEL is equivalent to the NSE of the log flows and emphasises the model to data fit around the region of low flows. The NSEL value varies $-\infty$ to 1, with best model performance being 1. Percentage bias denotes volume bias over the entire period, with positive value denoting the underestimation of flow by the model.

4) A GR4J model, established for Waratah Dam catchment, was run using the pluvio record from Waratah Meteorological Station. The parameters from the calibrated Que River model and Hellyer River model were transposed to Waratah and two sequences of modelled flow were generated. The two sequences of the flow generated using the transposed parameters are hereafter called SimW-H (simulated flow sequence generated using transposed parameters from Hellyer model) and SimW-Q (simulated flow sequence generated using the transposed parameters from the Que model).

5) These sequences were then compared against the area scaled flow derived from Que and Hellyer River catchments. To derive the area scaled flow linear scaling factor, taken as the ratio of the ungauged catchment (Waratah) to the parent catchment (either Que or Hellyer), was multiplied to the flow at each catchment. The area scaled flows derived for Hellyer and Que are hereafter called Scaled-H and Scaled-Q respectively.

6) Finally, the best performing model (either SimW-H or SimW-Q) was used to generate a long term flow in Waratah River catchment. The model is driven by augmented precipitation input that combines precipitation values from the pluvio and the SILO.

4. Results

4.1 Calibration results

The values of the parameters calibrated for Que and Hellyer catchments are shown in Table 4.1. Also shown are the values of the parameters for the previously calibrated model (Entura 2012) for Idaho Creek. The values of the parameters show a large degree of scatter. In particular, the Idaho Creek parameters show a large degree of variation from the parameter sets calibrated for Que and Hellyer River catchments. Idaho Creek catchment was not considered for further analysis, due fact that it is located quite far from Waratah catchment and was considered to be unrepresentative of the Waratah Dam catchment.

The calibration and the validation statistics for the model calibrated for Hellyer (hereafter called Cal-Hellyer) and Que River (hereafter called Cal-Que) are shown in Table 4.2, Figure 4.1, Figure 4.2 and Figure 4.3. In general the calibration and validation statistics, the hydrographs and the scatter plots point to very good model performances in both the catchments.

Table 4.1: Value of the parameters calibrated for the Hellyer, Que and Idaho Creek catchments

Model parameters	**Calibrated Parameter Values**		
	Hellyer	**Que**	**Idaho Creek**
x1: Capacity of production store (mm)	44.3	12.2	1.0
x2: Water exchange coefficient (mm)	-1.5	-1.5	-4.7
x3: Capacity of routing store (mm)	317.0	95.7	59.7
x4: UH time base (days)	2.1	1.5	1.0

Table 4.2: Calibration and Validation statistics

Catchment	**Period**		**NSE**	**NSEL**	**Bias (%)**
Hellyer	Calibration	02/01/1971 - 31/12/1984	0.88	0.94	0.14
	Validation	10/12/1995 - 31/12/2014	0.91	0.9	-10
Que	Calibration	01/04/1988 - 31/03/2002	0.8	0.82	3.34
	Validation	10/12/1995 - 28/10/2010	0.84	0.86	-8.34

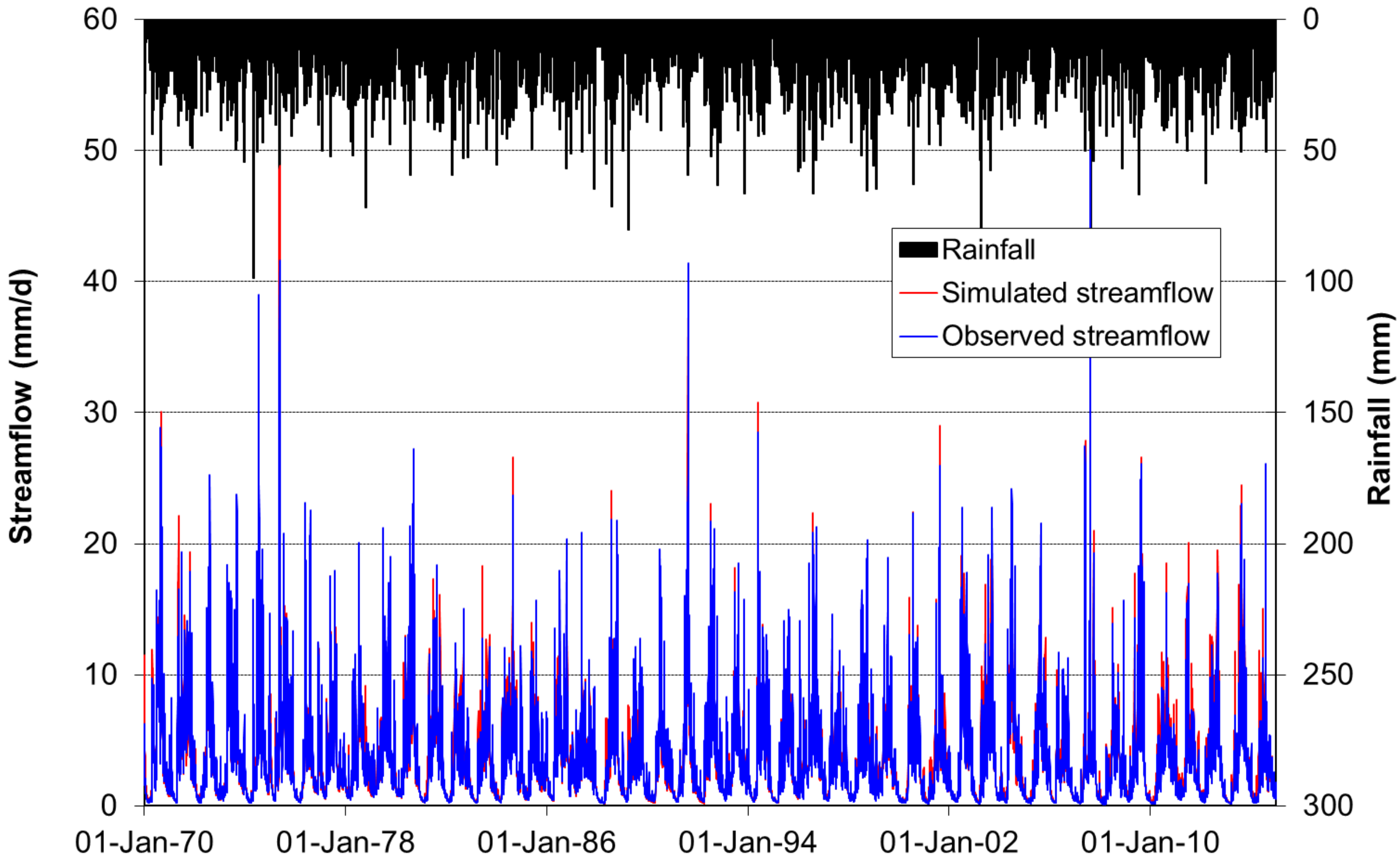

Figure 4.1: Model calibration result – Simulated vs. Observed streamflow in Hellyer

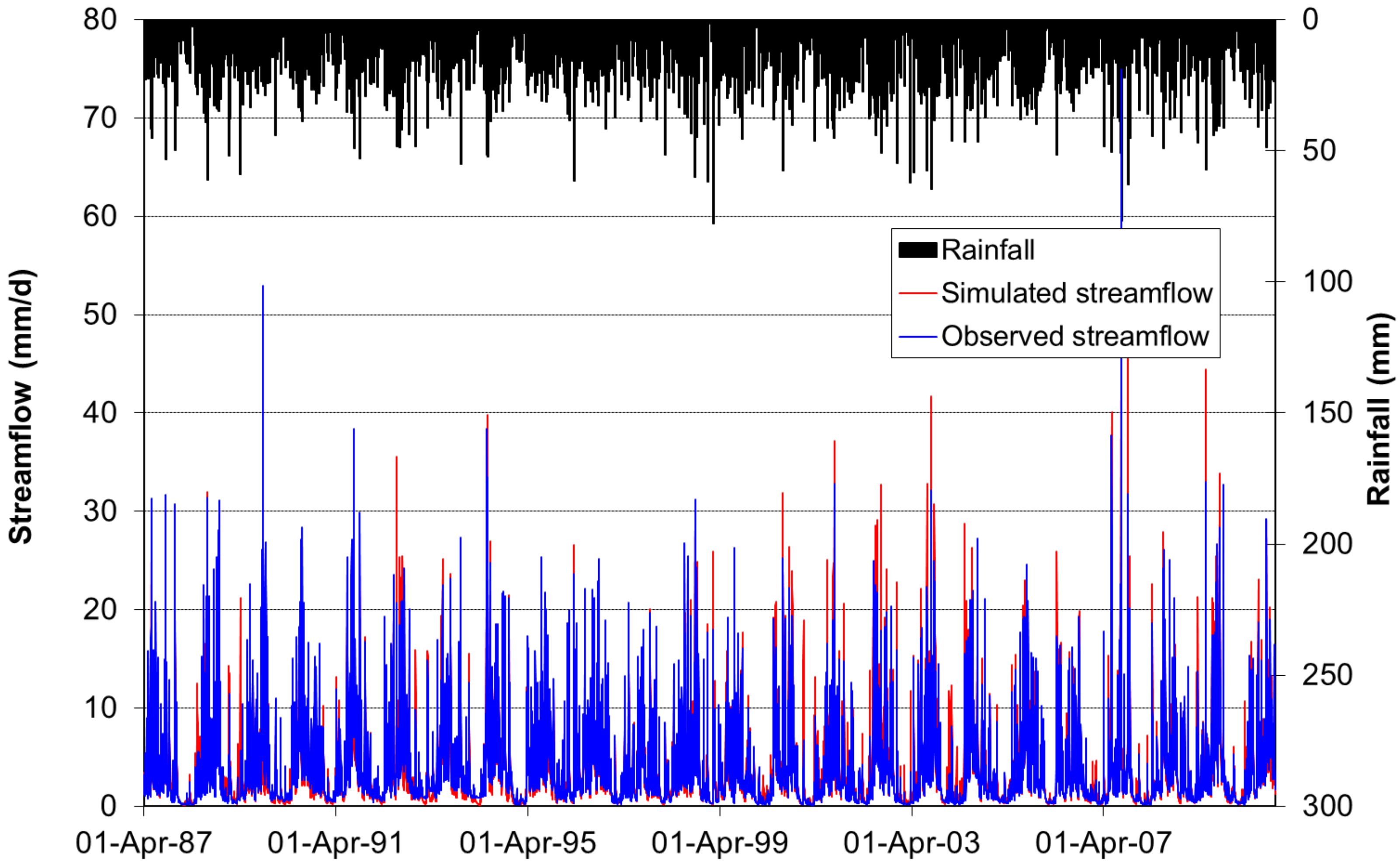

Figure 4.2: Model calibration result – Simulated vs. Observed streamflow in Que River

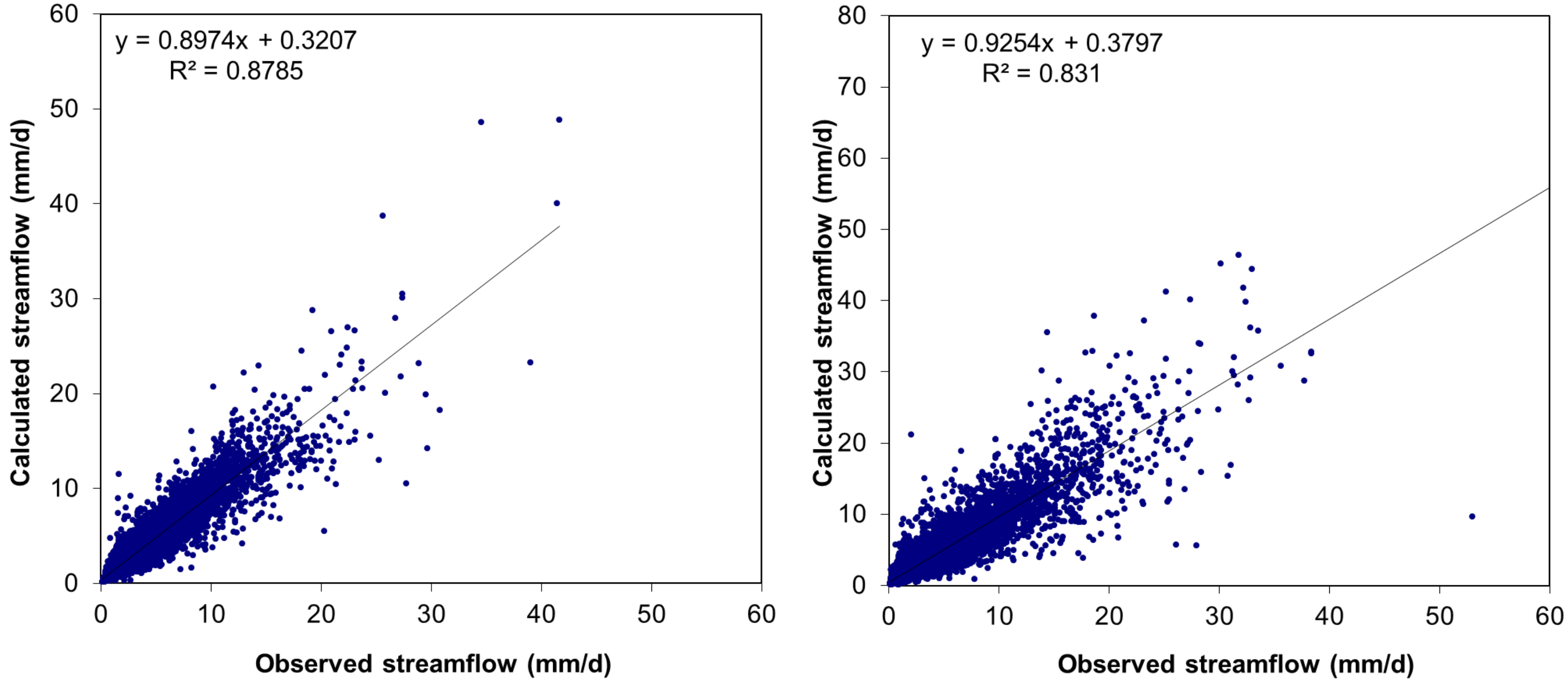

Figure 4.3: Simulated vs. the observed flow in Hellyer catchment (left plot) and Que River catchment (Right plot)

4.2 Long-term flow simulation in Waratah

4.2.1 Waratah Simulation model validation

The validation of SimW-H and SimW-Q against Scaled-Q and Scaled-H are given in Table 4.3 and in Figure 4.4 - Figure 4.7 and Figure B.1 - Figure B.4 (in the appendix). In general, the simulated flows at Waratah provide an exceptionally good match to the scaled flow derived from their parent catchment (ie. SimW-H against Scaled-H and SimW-Q against Scaled-Q), and reasonably good match in the other case (ie. SimW-H against Scaled-Q and SimW-Q against Scaled-Q).

Among the two, SimW-H provides a marginally better performance over the two validation datasets and is therefore used to derive a long sequence of modelled flows in Waratah. In addition, Hellyer catchment is located adjacent to Waratah, and could potentially share more similar catchment and climatic characteristics compared to Que.

Table 4.3: Validation of the model established for Waratah catchment against the area scaled flows from Hellyer and Que River

	Validation data	**Model**	
		SimW-H	SimW-Q
NSE	Scaled-Q	0.66	0.81
Bias (%)	Scaled-Q	7.08	8.63
NSEL	Scaled-Q	0.74	0.79
NSE	Scaled-H	0.90	0.67
Bias (%)	Scaled-H	-5.36	-3.60
NSEL	Scaled-H	0.89	0.71

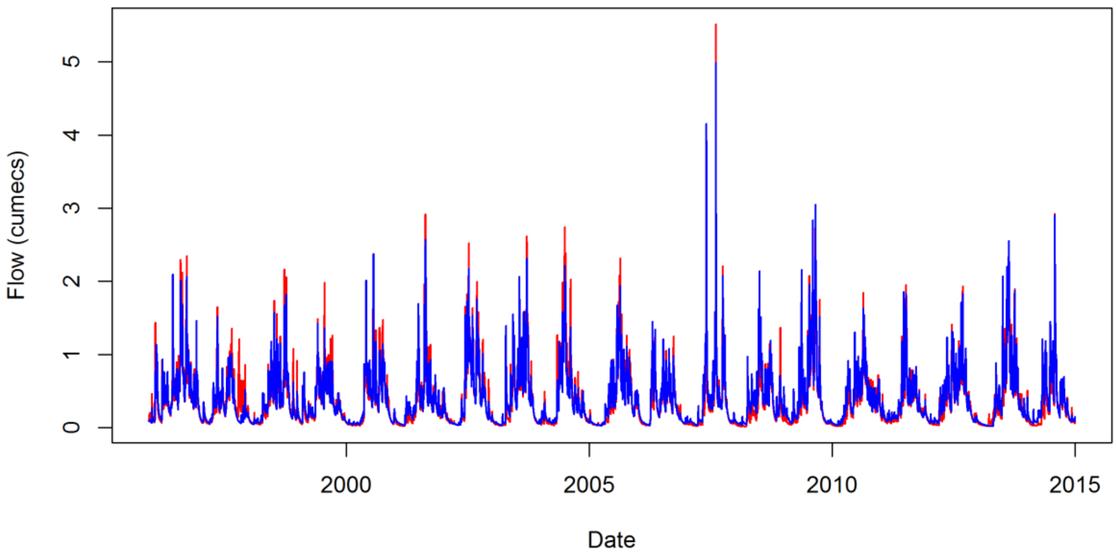

Figure 4.4: Comparison between SimW-H (blue line) and the Scaled – H (red line).

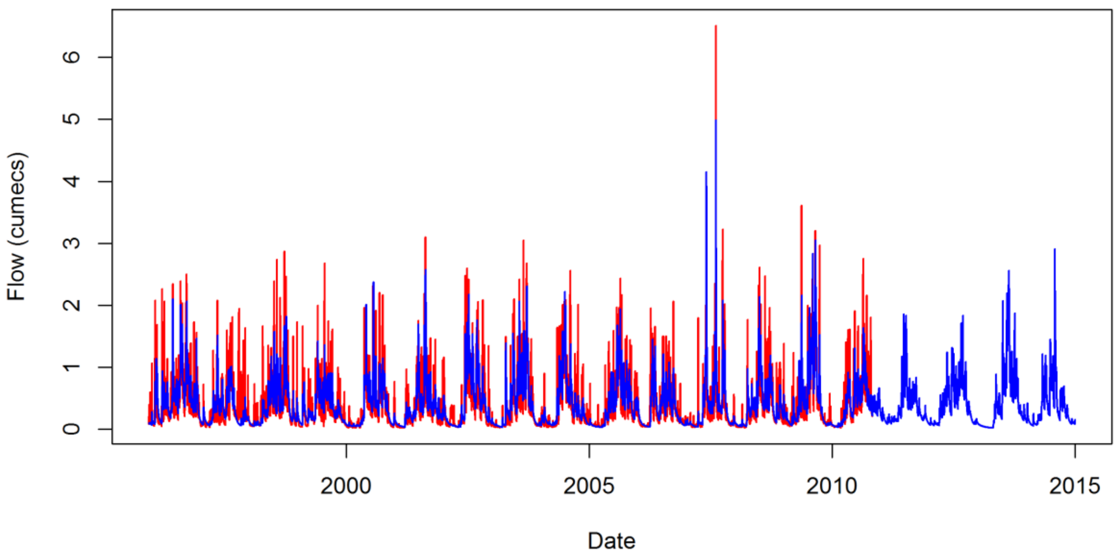

Figure 4.5: Comparison between SimW-H (blue line) and the Scaled–Q (red line)

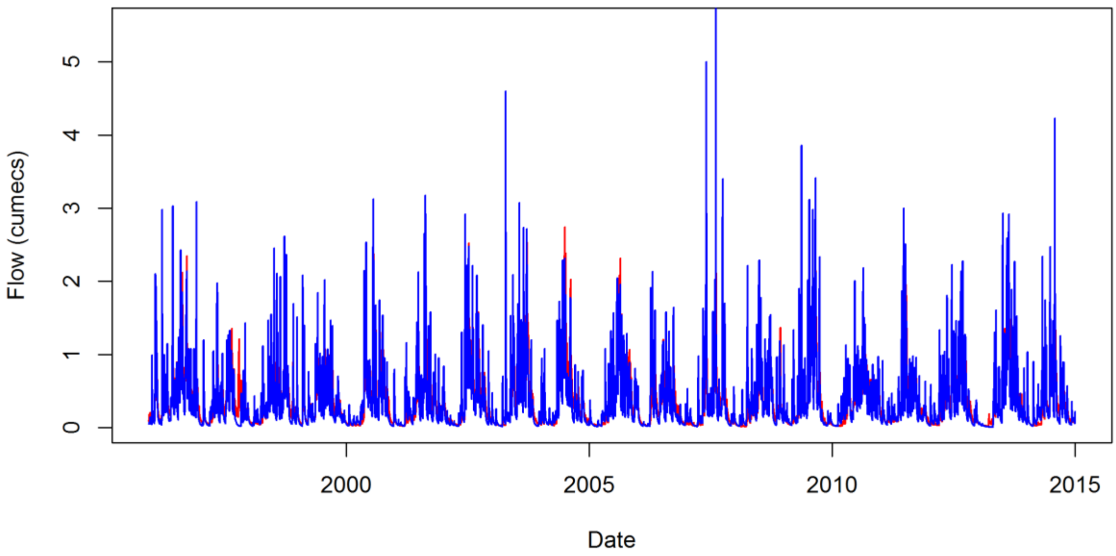

Figure 4.6: Comparison between SimW-Q (blue line) and the Scaled – H (red line).

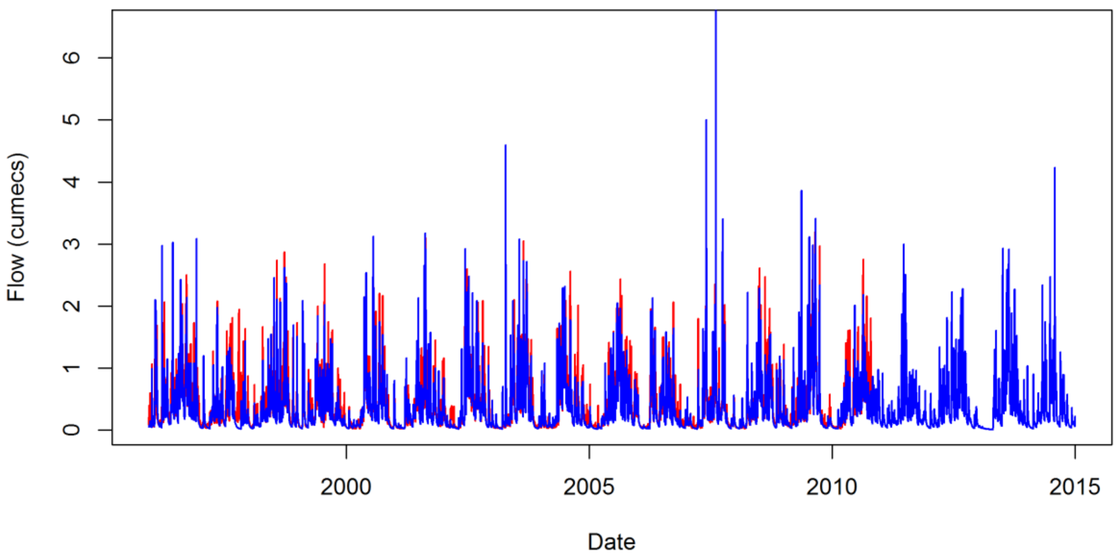

Figure 4.7: Comparison between SimW-Q (blue line) and the Scaled – Q (red line).

4.2.2 Estimation of river yield in Waratah

The SILO data was compared with the at-site pluviograph data at Waratah and was found to be representative of the at-site data (Figure A.1 and Figure A.2). Therefore a rainfall series starting from 01/01/1960 to 31/12/2014 was derived at Waratah by augmenting the pluviograph data with the SILO rainfall data. The augmented rainfall series was then used to drive the GR4J hydrologic model established for Waratah Dam catchment using the calibrated parameters from Hellyer catchment.

The resulting flow duration curve and the corresponding values are shown in Figure 4.9, Table 4.4 and Table 4.5.

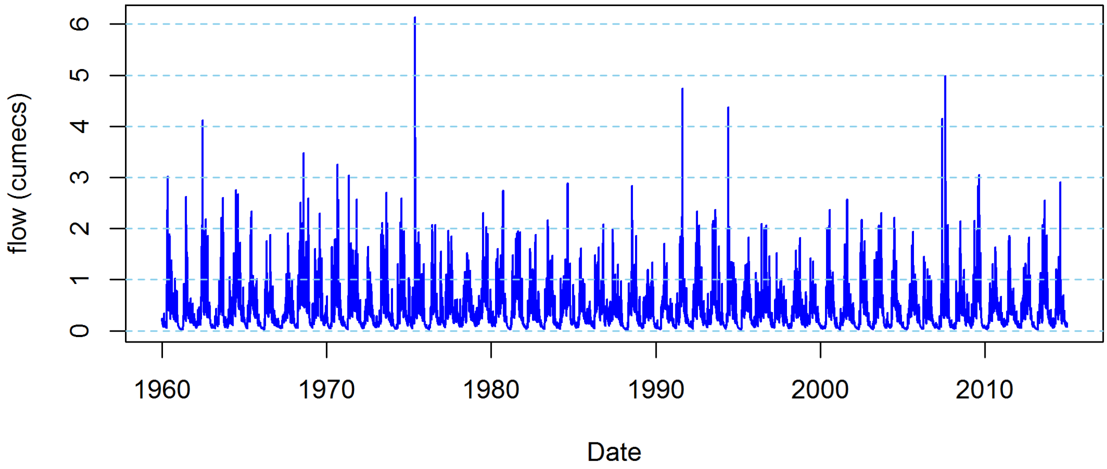

Figure 4.8: Simulated flow in Waratah Dam catchment

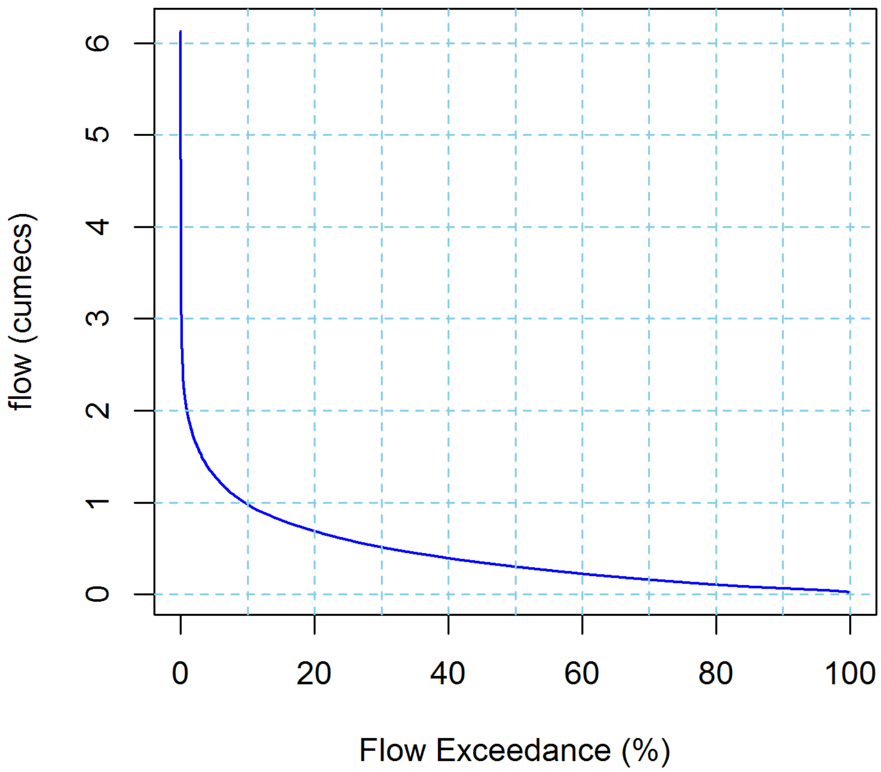

Figure 4.9: Simulated flow duration at Waratah Dam catchment

Table 4.4: Simulated flow duration values in Waratah Dam catchment

Non Exceedance (%)	Flow (m^3/s)
100	0.02
80	0.11
60	0.22
50	0.30
40	0.39
20	0.69
0	6.13

Table 4.5: Monthly breakdown of the flow duration values in Waratah Dam catchment (flows are in m^3/s)

Non Exceedance (%)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
100	0.04	0.03	0.02	0.02	0.04	0.11	0.16	0.20	0.14	0.07	0.06	0.05
80	0.07	0.05	0.04	0.08	0.24	0.32	0.43	0.43	0.34	0.23	0.15	0.09
60	0.09	0.07	0.06	0.18	0.37	0.45	0.59	0.60	0.48	0.31	0.20	0.13
50	**0.11**	**0.08**	**0.07**	**0.22**	**0.45**	**0.53**	**0.69**	**0.71**	**0.56**	**0.36**	**0.23**	**0.16**
40	0.13	0.09	0.09	0.28	0.53	0.64	0.79	0.83	0.66	0.43	0.26	0.19
20	0.21	0.13	0.16	0.45	0.81	0.94	1.07	1.20	0.91	0.68	0.38	0.30
0	1.01	1.14	1.02	2.37	6.13	4.12	2.83	4.99	2.74	2.57	2.59	1.55

5. Conclusion

This study investigated the long term water availability in Waratah River. There are no at-site streamflow records available, therefore a regionalization method was used to estimate the long term flow in the catchment. To this end, daily rainfall-runoff models were setup in Hellyer and Que River catchments with an implicit assumption that these catchments were hydrologically similar to Waratah River catchment. The model performance in Que and Hellyer River was investigated, and the calibrated parameters from Hellyer catchment, deemed to be marginally better than Que, were transposed to Waratah River catchment to derive a 55 year long sequence of simulated flows.

From the modelling results it seems that, at least 0.02 m^3/s of flow would be available in Waratah River in the dry season and maximum of 6.13 m^3/s would be available in wet season. The monthly minimum, maximum and median of the simulated daily discharge in Waratah River is given in Table 5.1.

Table 5.1: Water availability in Waratah River

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Maximum (m^3/s)	1.01	1.14	1.02	2.37	6.13	4.12	2.83	4.99	2.74	2.57	2.59	1.55
Median (m^3/s)	0.11	0.08	0.07	0.22	0.45	0.53	0.69	0.71	0.56	0.36	0.23	0.16
Minimum flow (m3/s)	0.04	0.03	0.02	0.02	0.04	0.11	0.16	0.20	0.14	0.07	0.06	0.05

A thorough evaluation of the model performance was conducted using linearly scaled flows derived from two catchments, in a strategy functionally similar to ‘proxy basin’ validation (Klemeš, 1986).

The fact that the Waratah rainfall runoff model was driven by a pluviograph record (independent of SILO rainfall record used for model calibration) and that the model was tested on two separate catchments does reduce the possibility of the model skill being artificially inflated. However, because there was no at-site gauge (to further confirm the model performance in Waratah) this cannot be guaranteed. A streamflow gauging station if established within the catchment could further substantiate these finding and is, therefore, recommended if more certainty is required

6. References

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Appendices

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A Comparison between the Silo data and Pluviograph data at Waratah

A.1 Rainfall scatter plots

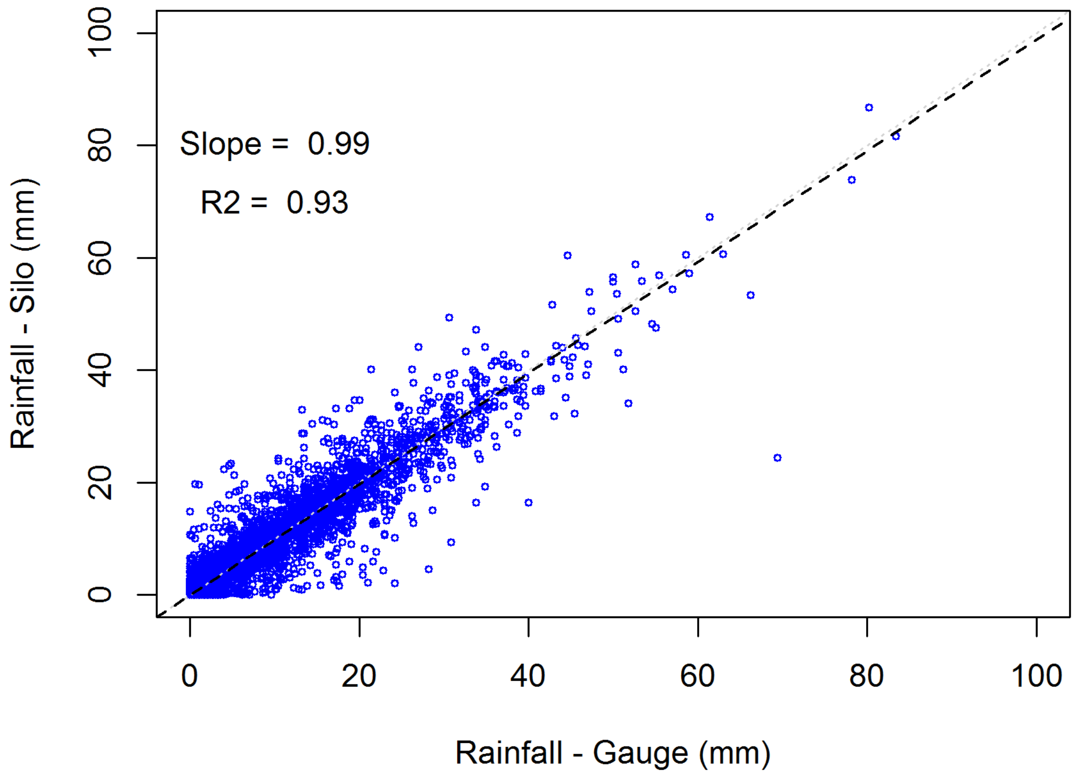

Figure A.1: Comparison between the SILO and the at-site pluviograph record at Waratah.

A.2 Rainfall duration curves

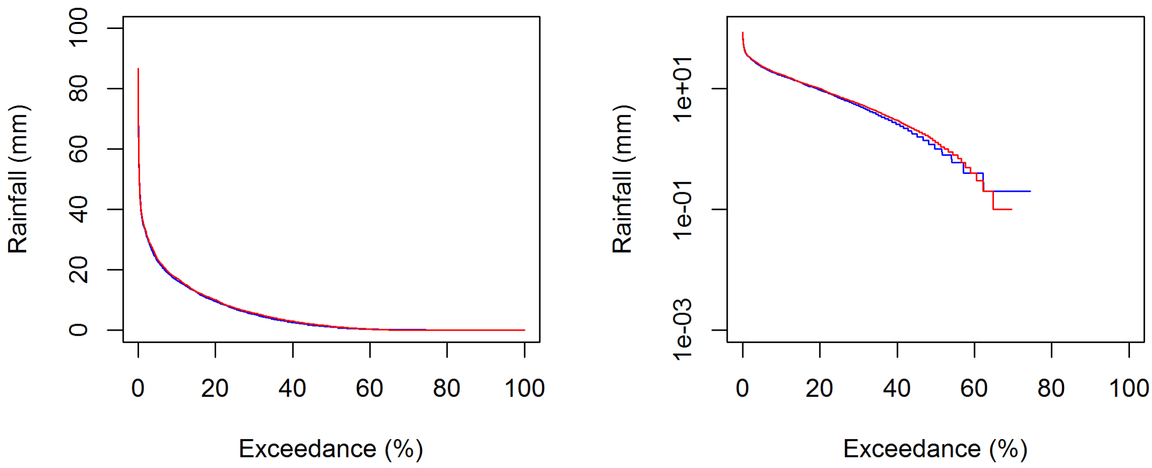

Figure A.2: Rainfall exceedance curves (red lines – pluviograph, blue lines SILO data)

B Comparison of simulated flows in Waratah with the area scaled flows

B.1 Scatter plots

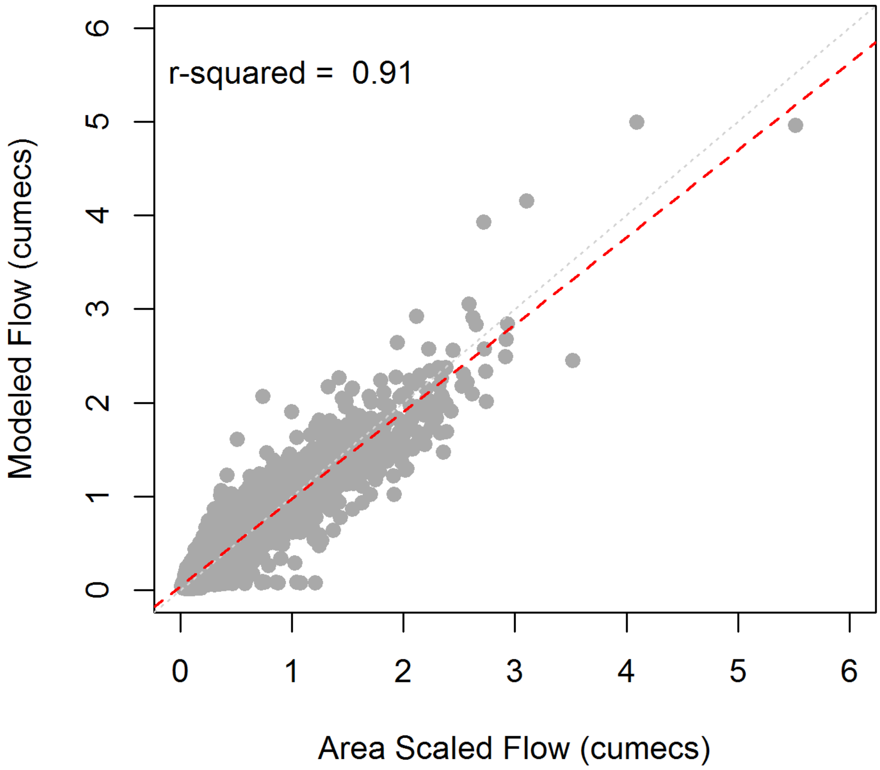

Figure B.1: Scatterplot : SimW-H vs. Scaled-H

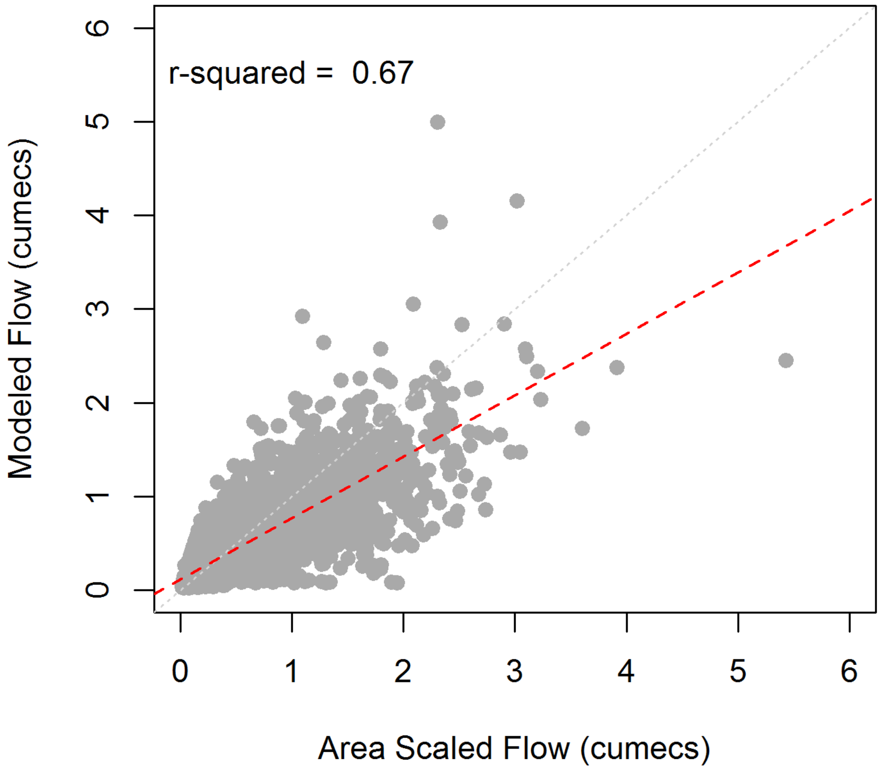

Figure B.2: Scatterplot : SimW-H vs. Scaled-Q

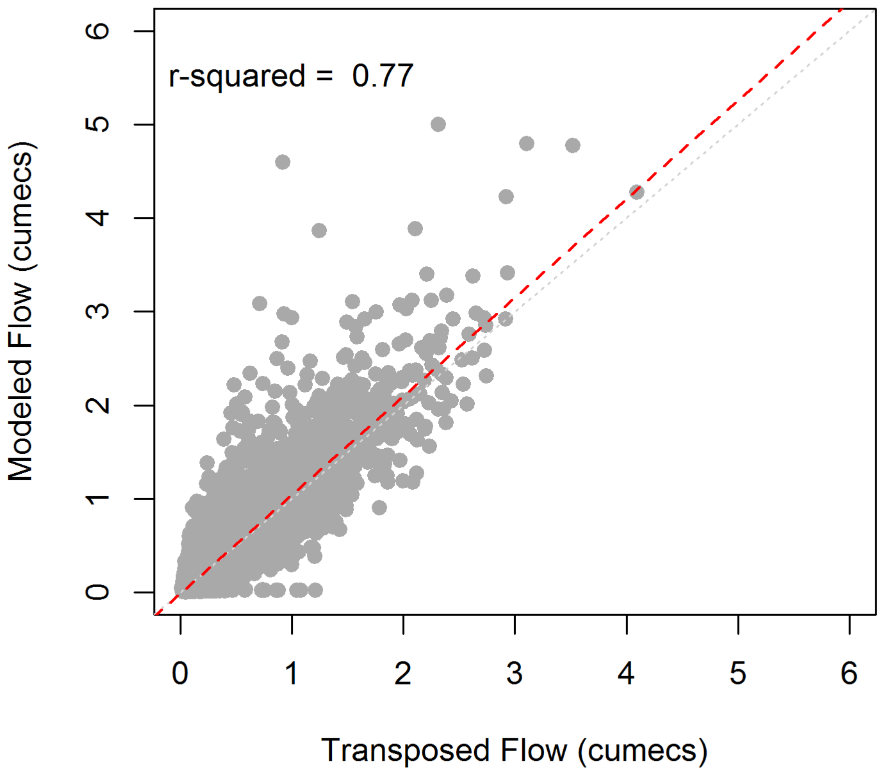

Figure B.3: Scatterplot : SimW-Q vs. Scaled-H

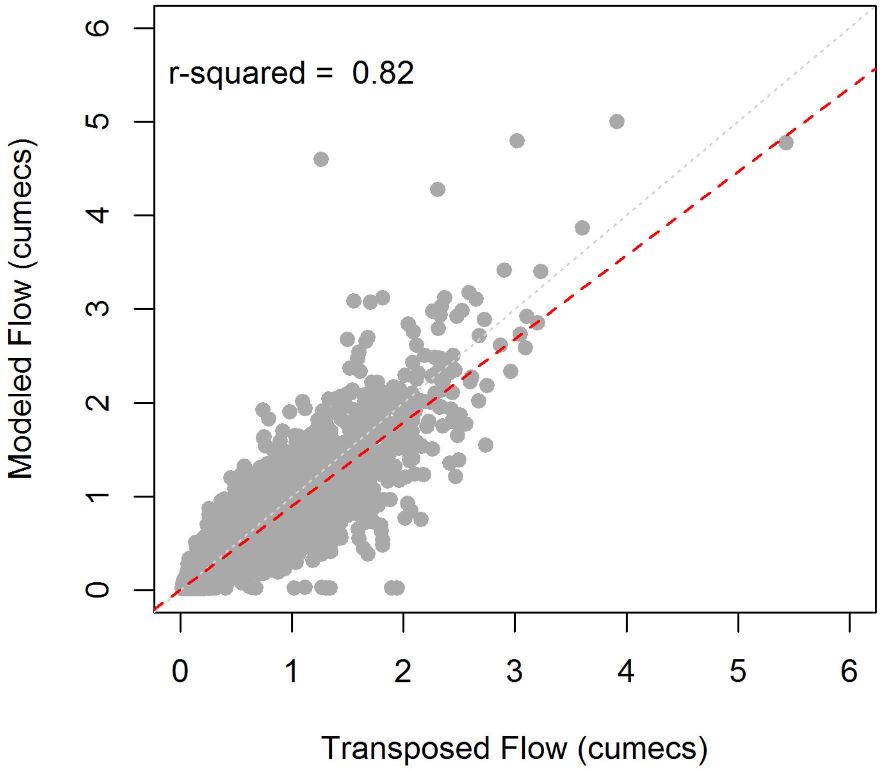

Figure B.4: Scatterplot : SimW-Q vs. Scaled-Q