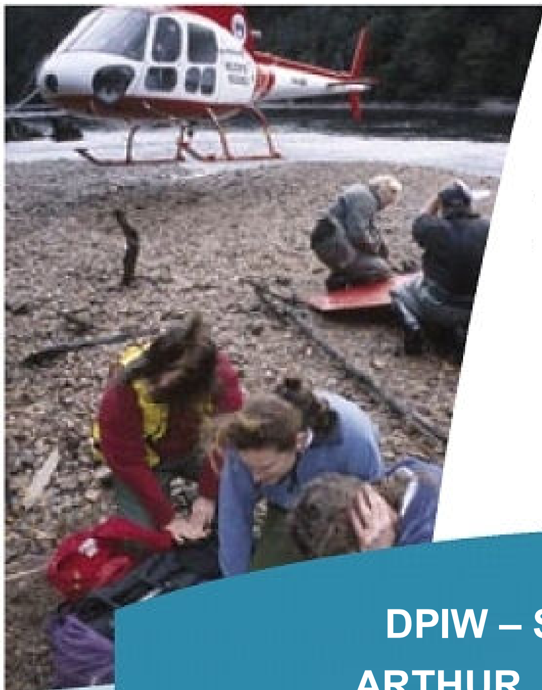

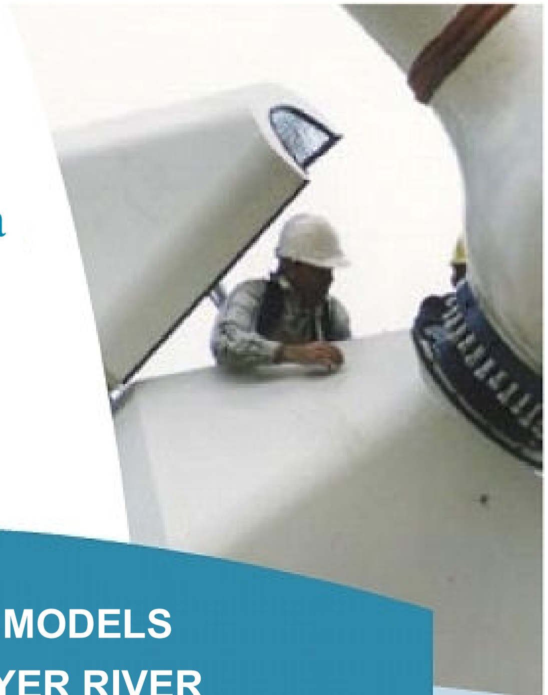

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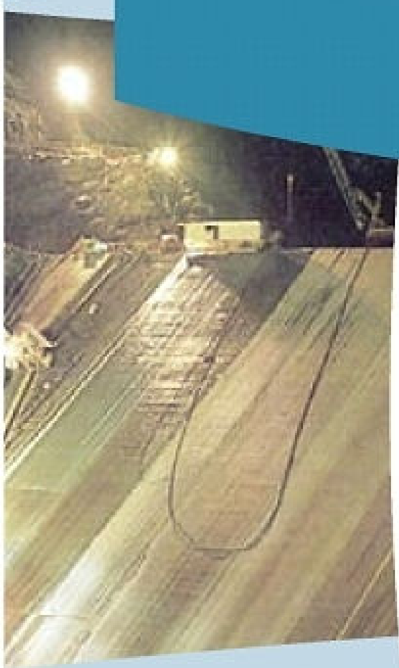
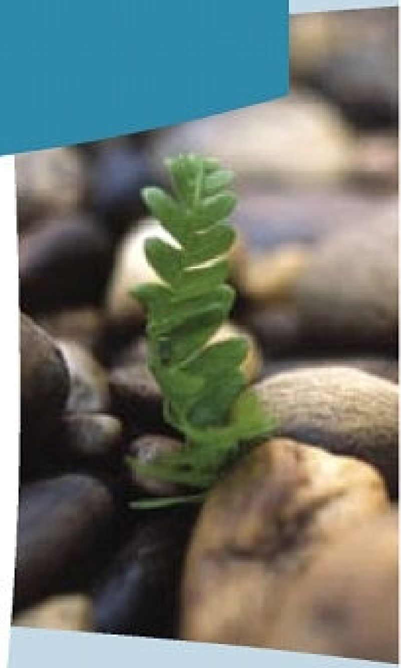
DPIW – SURFACE WATER MODELS

ARTHUR, RAPID AND HELLYER RIVER CATCHMENTS





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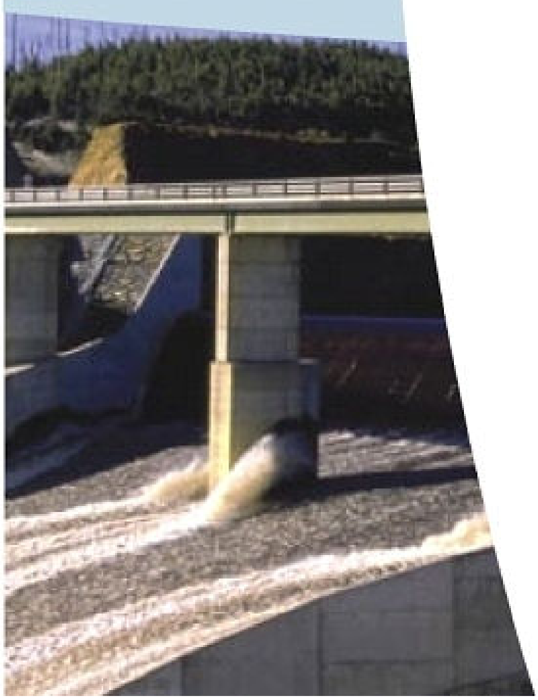

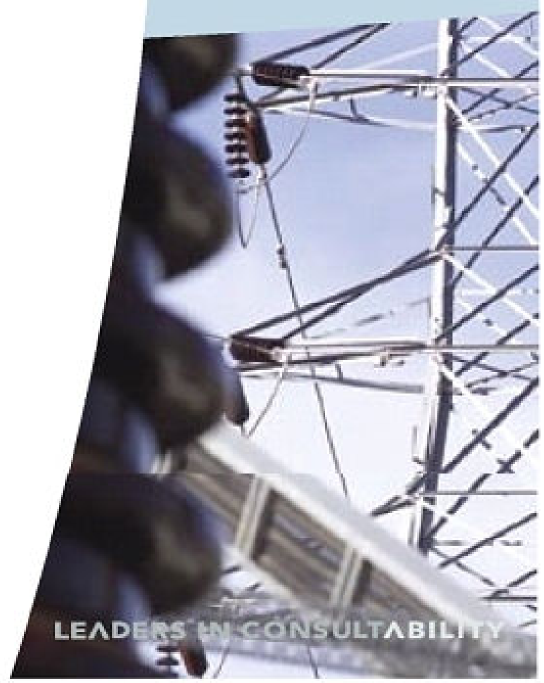

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EXECUTIVE SUMMARY

This report is part of a series of reports which present the methodologies and results from the development and calibration of surface water hydrological models for 25 catchments (Tascatch – Variation 2) under both current and natural flow conditions. This report describes the results of the hydrological model developed for the Arthur, Rapid and Hellyer River catchments.

A model was developed for the Arthur, Rapid and Hellyer River catchments that facilitates the modelling of flow data for three scenarios:

- Scenario 1 – No entitlements (Natural Flow);
- Scenario 2 – with Entitlements (with water entitlements extracted);
- Scenario 3 - Environmental Flows and Entitlements (Water entitlements extracted, however low priority entitlements are limited by an environmental flow threshold).

The results from the scenario modeling allow the calculation of indices of hydrological disturbance. These indices include:

- Index of Mean Annual Flow
- Index of Flow Duration Curve Difference
- Index of Seasonal Amplitude
- Index of Seasonal Periodicity
- Hydrological Disturbance Index

The indices were calculated using the formulas stated in the Natural Resource Management (NRM) Monitoring and Evaluation Framework developed by SKM for the Murray-Darling Basin (MDBC 08/04).

A user interface is also provided that allows the user to run the model under varying catchment demand scenarios. This allows the user to add further extractions to catchments and see what effect these additional extractions have on the available water in the catchment of concern. The interface provides sub-catchment summary of flow statistics, duration curves, hydrological indices and water entitlements data. For information on the use of the user interface refer to the *Operating Manual for the NAP Region Hydrological Models* (Hydro Tasmania 2004).

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1. INTRODUCTION

This report forms part of a larger project commissioned by the Department of Primary Industries and Water (DPIW) to provide hydrological models for 25 regional catchments (Tascatch – Variation 2).

The main objectives for the individual catchments are:

- To compile relevant data required for the development and calibration of the hydrological model (Australian Water Balance Model, AWBM) for the Arthur, Rapid and Hellyer River catchments;
- To source over 100 years of daily time-step rainfall and streamflow data for input to the hydrologic model;
- To develop and calibrate each hydrologic model, to allow running of the model under varying catchment demand scenarios;
- To develop a User Interface for running the model under these various catchment demand scenarios;
- Prepare a report summarising the methodology adopted, assumptions made, results of calibration and validation and description relating to the use of the developed hydrologic model and associated software.

2. CATCHMENT CHARACTERISTICS

The Arthur River drains a 2500 km^2 catchment in north-western Tasmania, flowing west from the mountainous centre of Tasmania into the Southern Ocean. The Rapid and Hellyer Rivers are major tributaries of the Arthur River, with catchment areas of 301 km^2 and 332 km^2, respectively. The other major tributary of the Arthur is the Frankland River (555 km^2), which flows into the Arthur near the west coast. The Arthur catchment is remote from major human settlements, and as a result has few flow gauging sites compared to other Tasmanian streams with similarly large catchments.

The headwaters of the Arthur are fed by runoff from highland plains at 1000 m ASL. Weather patterns that affect the catchment are predominantly westerly, and these act in concert with the orographic effect of the highlands to produce consistently high rainfall. Average annual rainfall totals range between 1600 – 2400 mm for the majority of the Arthur catchment, and drop to 1200 mm closer to the west coast (Figure 3-1).

The vast majority of the catchment is State Forest, and is managed for forestry. The catchment is very sparsely inhabited; the only township of notable size is Waratah, in the upper Arthur catchment. Agriculture is practiced in the western lowlands of the catchment.

The Arthur and Rapid catchments are characterised by steep topography, causing these rivers to be generally fast-flowing. The high rainfall and fast flow of the rivers gives them considerable erosive force, and this is reflected in the deep gorges that characterise parts of these rivers. These characteristics are also present for most of the length of the Hellyer River (it is famous for its gorge), however the upper catchment of the Hellyer River is characterised by flat, boggy buttongrass plains, leading to considerably different hydrological characteristics in this portion of the Hellyer River. The Frankland River catchment is generally flatter than the Arthur and Rapid catchments, and it is to be expected that it exhibits different hydrologic behaviour – this is difficult to verify, however, as no gauging station is present on the Frankland. Due to these differences in catchments, the upper Hellyer River and the Frankland River have been treated separately in the Arthur and Rapid rivers in the modelling calibration process.

The upper region of the model catchment has been modified. The 5500 ML Talbots Lagoon (SC 3_a) was constructed on the upper Wey River – a tributary of the Hellyer River – in 1960. A pipeline diverts water from Talbots lagoon into the Emu River to supply additional water to the private company North Forests Burnie. Transfers are not gauged, and there is only one operating rule for the pipeline: that flows never drop below 1 ML/day. Transfers through this pipeline had to be estimated for this model, and the method for estimating Transfers is described in Section 4.2.1. There are also two smaller storages on the Waratah River (a small tributary of the Arthur River): Waratah Reservoir and Bischoff Reservoir, which are maintained for recreational and water supply purposes, respectively, for the residents of the small nearby town of Waratah. Because these two reservoirs are small in relation to the catchment, not special measures were taken to account for them when constructing the surface water model.

There are 47 registered (current) entitlements for water extraction on the Water Information Management System (WIMS July 2007) divided between only 8 sub-catchments. The extractions in the lower sub-catchments relate to agriculture, while those concentrated on the town of Waratah in the upper Arthur catchment relate to the Waratah and Bischoff reservoirs. The largest three extraction entitlements are all for 1350 ML (i.e., a total of 4050 ML) taken from the Waratah Reservoir. As expected most of the upper sub-catchments have few or no registered WIMS entitlements as they are unpopulated and utilized largely for forestry.

The Arthur, Hellyer and Rapid catchments are referred to in this report as the Arthur catchment for brevity. For modelling purposes, the Arthur River catchment was divided into 70 subareas. The delineation of these areas and the assumed stream routing network is shown in Figure 2-1.

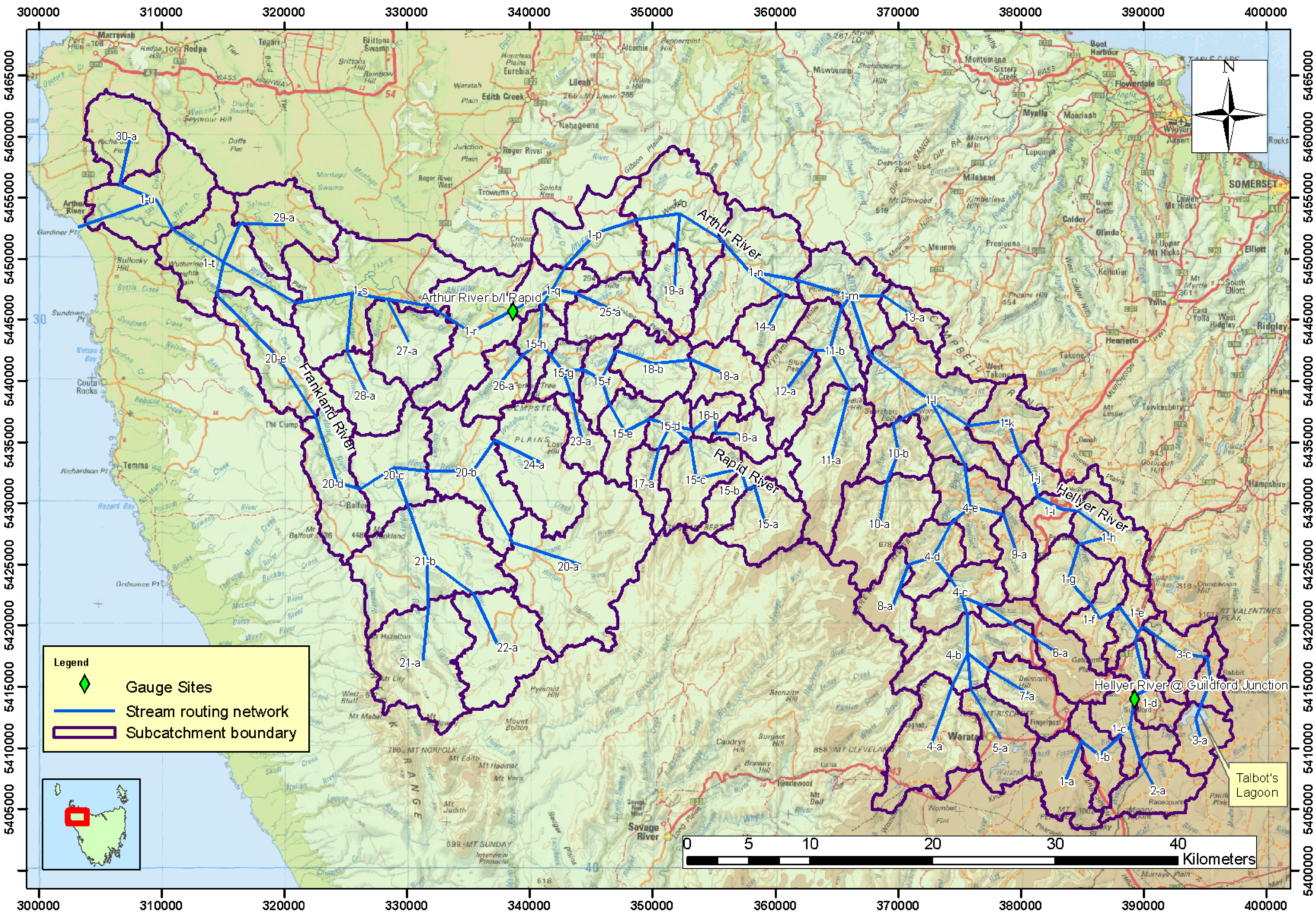

Figure 2-1 Sub-catchment boundaries

3. DATA COMPILATION

3.1 Climate data (Rainfall & Evaporation)

Daily time-step climate data was obtained from the Queensland Department of Natural Resources & Mines (QDNRM).

The Department provides time series climate drill data from 0.05° x 0.05° (about 5 km x 5 km) interpolated gridded rainfall and evaporation data based on over 6000 rainfall and evaporation stations in Australia (see www.nrm.qld.gov.au/silo) for further details of climate drill data.

3.2 Advantages of using climate DRILL data

This data has a number of benefits over other sources of rainfall data including:

- Continuous data back to 1889 (however, further back there are less input sites available and therefore quality is reduced. The makers of the data set state that gauge numbers have been somewhat static since 1957, therefore back to 1957 distribution is considered "good" but prior to 1957 site availability may need to be checked in the study area).

- Evaporation data (along with a number of other climatic variables) is also included which can be used for the AWBM model. According to the QNRM web site, all Data Drill evaporation information combines a mixture of the following data.

  1. Observed data from the Commonwealth Bureau of Meteorology (BoM).

  2. Interpolated daily climate surfaces from the on-line NR&M climate archive.

  3. Observed pre-1957 climate data from the CLIMARC project (LWRRDC QPI-43). NR&M was a major research collaborator on the CLIMARC project, and these data have been integrated into the on-line NR&M climate archive.

  4. Interpolated pre-1957 climate surfaces. This data set, derived mainly from the CLIMARC project data, is available in the on-line NR&M climate archive.

  5. Incorporation of Automatic Weather Station (AWS) data records. Typically, an AWS is placed at a user's site to provide accurate local weather measurements.

For the Arthur River catchment the evaporation data was examined and it was found that prior to 1970 the evaporation information is based on the long term daily averages of the post 1970 data. In the absence of any reliable long term site data this is considered to be the best available evaporation data set for this catchment.

3.3 Transposition of climate DRILL data to local catchment

Ten climate Data Drill sites were selected to give good coverage of the Arthur River catchment.

See the following Figure 3-1 for a map of the climate Data Drill sites and Table 3.1 for the location information.

Table 3.1 Data Drill site locations

Site	Latitude	Longitude
Arthur_01	-41:00:00	144:42:00
Arthur_02	-41:06:00	144:51:00
Arthur_03	-41:06:00	145:15:00
Arthur_04	-41:12:00	145:00:00
Arthur_05	-41:12:00	145:21:00
Arthur_06	-41:15:00	145:12:00
Arthur_07	-41:15:00	145:30:00
Arthur_08	-41:21:00	145:00:00
Arthur_09	-41:24:00	145:30:00
Arthur_10	-41:24:00	145:42:00

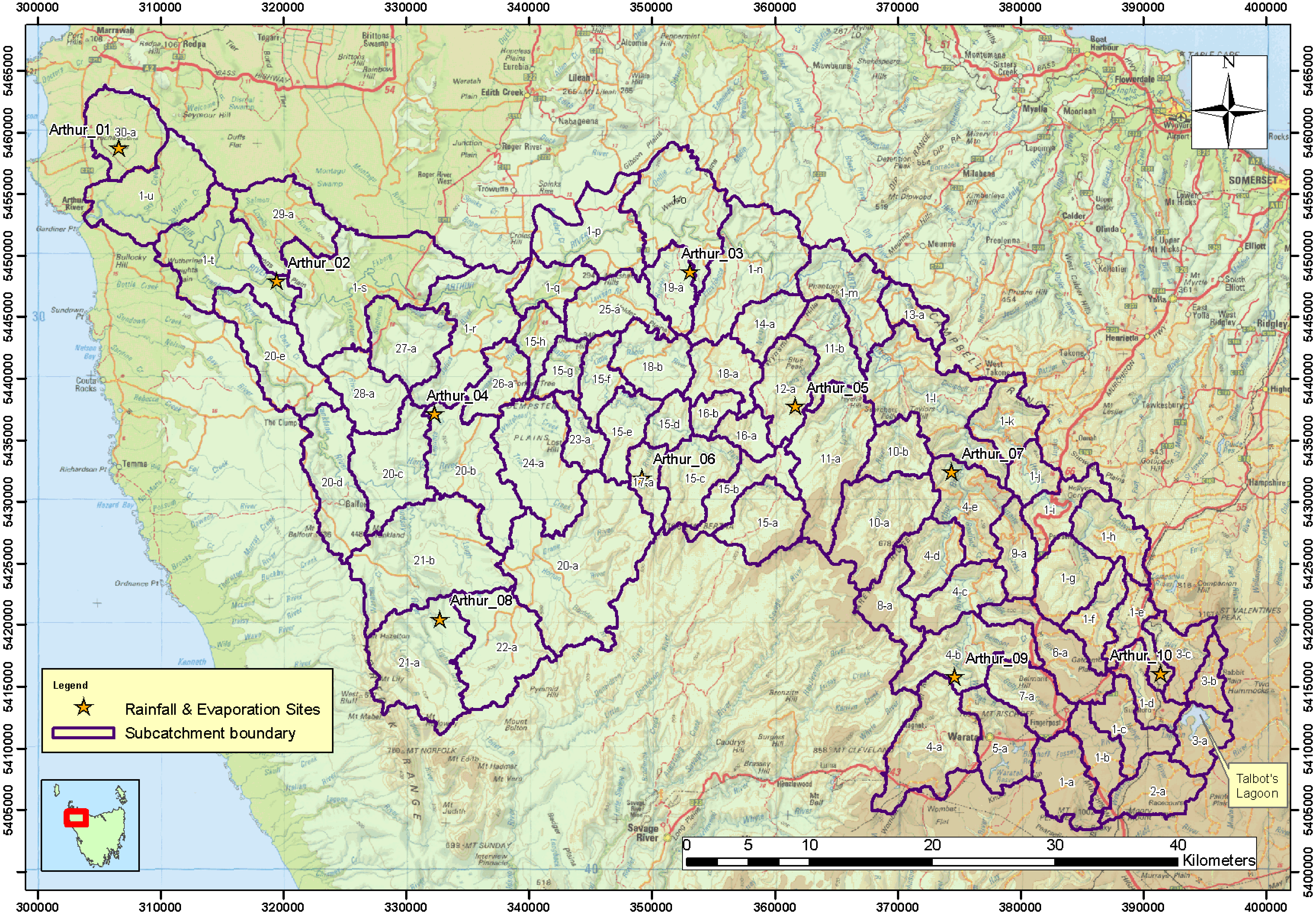

Figure 3-1 Climate Drill Site Locations

3.4 Comparison of Data Drill rainfall and site gauges

As rainfall data is a critical input to the modeling process it is important to have confidence that the Data Drill long term generated time series does in fact reflect what is being observed within the catchment. Rainfall sites in closest proximity to the Data Drill locations were sourced and compared. The visual comparison and the R^2 value indicate that there appears to be good correlation between the two, which is to be expected as the Data Drill information is derived from site data. The annual rainfall totals of selected Data Drill sites and neighbouring sites for coincident periods are plotted in Figure 3-2.

Although the Data Drill and site gauges compare well, the Arthur Catchment is remote and has few rainfall gauges within it. Accordingly, the Data Drill climate information may not accurately represent the precipitation in all subcatchments. Despite this limitation, the Data Drill rainfall and precipitation records are deemed the best available.

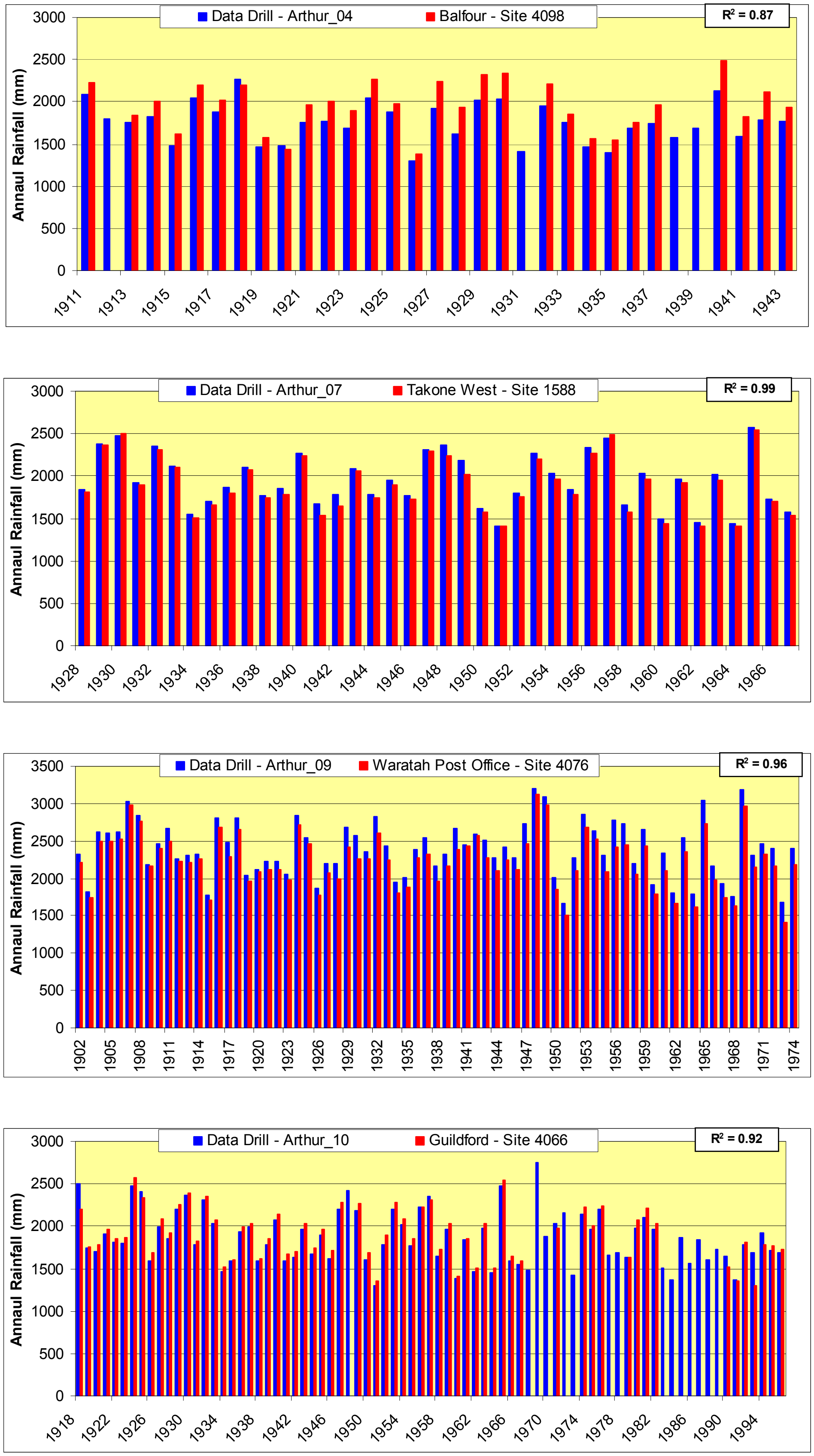

Figure 3-2 Rainfall and Data Drill comparisons

3.5 Streamflow data

There were two gauging sites in the catchment area that had sufficiently long and reliable records with which to calibrate the model (Table 3.2). Arthur River below Rapid River (site 159) gauges flow draining some 1500 km^2 of the Arthur catchment. Hellyer at Guildford Junction (site 61) gauges flows from a much smaller catchment, but the area upstream of this site is much flatter and marshier than most of the catchment, and the flow exhibits different hydrological characteristics to the lower parts of the catchment (e.g. hydrographs are generally much slower to rise than those downstream). As this was such a large catchment model, and the two calibration sites effectively represented areas with different hydrological characteristics, both sites were used to calibrate this model.

Table 3.2 Potential calibration sites

Site Name	Site No.	Subcatchment Location	Period of Record	Easting	Northing	Comments
Arthur River below Rapid River	159	SC1_q	25/05/1954 to 12/09/1996	338600	5445700	Mid-Catchment. Long, reliable record.
Hellyer River at Guildford Junction	61	SC1_c	25/01/1922 to Present	389250	5414000	One of the longest stream flow records in Tasmania. Immediately Downstream of flat, marshy plains.

Investigations of the rating histories and qualities contained on the Hydro Tasmania's archives at Arthur River below Rapid that 3 ratings cover the calibration period and the data appears to be reliable during the period of interest. The record at Hellyer at Guildford Junction is based on a concrete and rock control structure. The site was moved 80 m upstream in 1991, and five ratings cover the calibration period, however the record is considered very reliable.

3.6 Irrigation and water usage

Information on the current water entitlement allocations in the catchment was obtained from DPIW and is sourced from the Water Information Management System (WIMS July 2007). The WIMS extractions or licenses in the catchment are of a given Surety (from 1 to 8), with Surety 1-3 representing high priority extractions for modeling purposes and Surety 4-8 representing the lowest priority. The data provided by DPIW contained a number of sites which had a Surety of 0. DPIW staff advised that in these cases the Surety should be determined by the extraction "Purpose" and assigned as follows:

Table 3.3 Assumed Surety of unassigned records

Purpose	Surety
Aesthetic	6
Aquaculture	6
Commercial	6
Domestic	1
Industrial	6
Irrigation	6
Storage	6
Other	6
Power Generation	6
Recreation	6
Stock and Domestic S & D	1
Stock	1
Water Supply	1
Fire Fight	1
Dust Proof	6

In total there were 6531 ML unassigned entitlements (Surety = 0) identified for inclusion in the surface water model, all of which were assigned Surety 6.

DPIW staff also advised that the water extraction information provided should be filtered to remove the following records:

- Extractions relating to fish farms should be omitted as this water is returned to the stream. These are identified by a Purpose name called "*fish farm*" or "*Acquacult".* There were no fish farms identified in this catchment.

- The extraction data set includes a "WE_status" field where only "*current"* and "*existing"* should be used for extractions. All other records, for example deleted, deferred, transferred, suspended and proposed, should be omitted.

When modeling Scenario 3 (Environmental flows and Entitlements), water will only be available for Low Priority entitlements after environmental flow requirements have been met.

There were multiple communications with DPIW staff, on allowances for extractions not yet included in the WIMS (July 2007) water licence database. DPIW advised that the unlicensed extractions estimate should be three times the current Surety 5 direct extractions. This unlicensed estimate should be apportioned across the sub-catchments the same as the Surety 5 extractions. There were 1938 ML of direct Surety 5 extractions (current) in the WIMS database and accordingly an estimate of 5814 ML of unlicensed extractions was apportioned across the catchment. DPIW advised that these unlicensed extractions should be assigned as Surety 6 and be extracted during the months of October through to April.

In addition to the extractions detailed above, an estimate was made for small farm dam extractions currently not requiring a permit and hence not listed in the WIMS database. These extractions are referred to in this report as unlicensed (small) farm dam extractions and details of the extraction estimate are covered in Section 3.6.1.

A summary table of total entitlement volumes on a monthly basis by sub-catchment is provided below in Table 3.4 and in the Catchment User Interface. These values include the estimates of unlicensed extractions, unlicensed farm dams and WIMS database extractions. A map of the WIMS (July 2007) water allocations in the catchment is shown in Figure 3-3.

Table 3.4 Sub Catchment High and Low Priority Entitlements

Water Entitlements Summarized - Monthly Demand (ML) for each Subarea & Month

Subcatch	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
High Priority Entitlements													
SC1_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_f	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_i	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_j	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_n	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_o	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_p	11.55	10.43	11.55	11.18	14.10	13.65	14.10	14.10	13.65	11.55	11.18	11.55	149
SC1_q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_r	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_s	0.00	0.00	0.00	0.00	7.66	7.41	7.66	7.66	7.41	0.00	0.00	0.00	38
SC1_t	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_u	0.00	0.00	0.00	0.00	6.81	6.59	6.81	6.81	6.59	0.00	0.00	0.00	34
SC2_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC3_a	0.00	0.00	0.00	0.00	0.28	0.27	0.28	0.28	0.27	0.00	0.00	0.00	1
SC3_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC3_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_a	0.00	0.00	0.00	0.00	1.13	1.10	1.13	1.13	1.10	0.00	0.00	0.00	6
SC4_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

SC5_a	3.00	2.00	3.00	3.00	5.27	5.20	5.27	5.27	5.20	3.00	3.00	3.00	**46**
SC6_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC7_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC8_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC9_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC10_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC10_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC11_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC11_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC12_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC13_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC14_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_f	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC16_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC16_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC17_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC18_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC18_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC19_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC21_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC21_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC22_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC23_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC24_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC25_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC26_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC27_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC28_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC29_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC30_a	0.00	0.00	0.00	0.00	34.89	33.76	34.89	34.89	33.76	0.00	0.00	0.00	**172**
Total	**15**	**12**	**15**	**14**	**70**	**68**	**70**	**70**	**68**	**15**	**14**	**15**	**445**
Low Priority Entitlements													
SC1_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_f	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_i	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

SC1_j	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_l	19.37	17.50	19.37	18.75	6.04	5.84	6.04	6.04	5.84	22.27	21.55	19.37	**168**
SC1_m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_n	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_o	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_p	0.00	0.00	0.00	0.00	10.43	10.09	10.43	10.43	10.09	10.43	10.09	0.00	**72**
SC1_q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_r	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_s	1451	1311	1194	922	0	0	0	0	0	829	802	1051	**7,560**
SC1_t	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_u	0.00	0.00	0.00	0.00	13.48	13.04	13.48	13.48	13.04	13.48	0.00	0.00	**80**
SC2_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC3_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC3_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC3_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC5_a	579.1	523.2	564.1	542.5	555.7	537.8	555.7	555.7	536.8	560.5	542.5	560.5	**6,614**
SC6_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC7_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC8_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC9_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC10_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC10_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC11_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC11_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC12_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC13_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC14_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_f	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC16_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC16_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC17_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC18_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC18_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC19_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC21_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

SC21_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC22_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC23_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC24_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC25_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC26_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC27_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC28_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC29_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC30_a	0.00	0.00	0.00	0.00	6.52	6.31	6.52	6.52	6.31	6.52	6.31	0.00	**45**
Total	**2,050**	**1,852**	**1,777**	**1,483**	**592**	**573**	**592**	**592**	**572**	**1,442**	**1,383**	**1,631**	**14,539**
All Entitlements													
SC1_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_f	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_i	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_j	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_l	19.37	17.50	19.37	18.75	6.04	5.84	6.04	6.04	5.84	22.27	21.55	19.37	**168**
SC1_m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_n	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_o	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_p	11.55	10.43	11.55	11.18	24.53	23.74	24.53	24.53	23.74	21.98	21.27	11.55	**221**
SC1_q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_r	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_s	1451	1311	1194	921.6	7.66	7.41	7.66	7.66	7.41	829.1	802.4	1051	**7,598**
SC1_t	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC1_u	0.00	0.00	0.00	0.00	20.29	19.63	20.29	20.29	19.63	13.48	0.00	0.00	**114**
SC2_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC3_a	0.00	0.00	0.00	0.00	0.28	0.27	0.28	0.28	0.27	0.00	0.00	0.00	**1**
SC3_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC3_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_a	0.00	0.00	0.00	0.00	1.13	1.10	1.13	1.13	1.10	0.00	0.00	0.00	**6**
SC4_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC4_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC5_a	582.1	525.2	567.1	545.5	561.0	543.0	561.0	561.0	542.0	563.5	545.5	563.5	**6,660**
SC6_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC7_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC8_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC9_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC10_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC10_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC11_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC11_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC12_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC13_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

SC14_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_f	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC15_h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC16_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC16_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC17_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC18_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC18_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC19_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC20_e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC21_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC21_b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC22_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC23_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC24_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC25_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC26_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC27_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC28_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC29_a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
SC30_a	0.00	0.00	0.00	0.00	41.41	40.07	41.41	41.41	40.07	6.52	6.31	0.00	**217**
Total	**2,064**	**1,864**	**1,792**	**1,497**	**662**	**641**	**662**	**662**	**640**	**1,457**	**1,397**	**1,645**	**14,984**

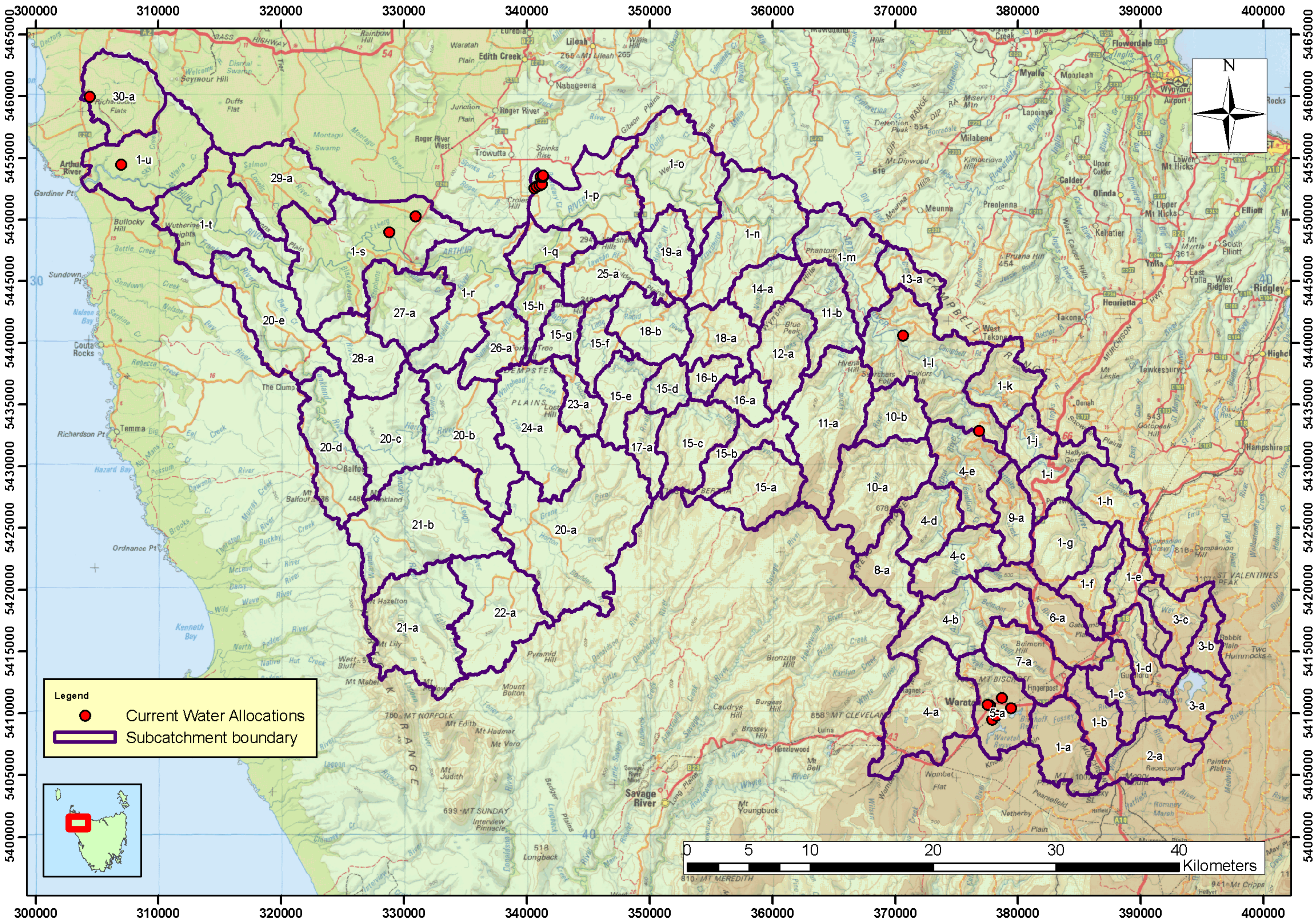

Figure 3-3 WIMS Water Allocations

3.6.1 Estimation of unlicensed (small) farm dams

Under current Tasmanian law, a dam permit is not required for a dam if it is not on a watercourse and holds less than 1ML of water storages (prior to 2000 it was 2.5 ML), and only used for stock and domestic purposes. Therefore there are no records for these storages. The storage volume attributed to unlicensed dams was estimated by analysis of aerial photographs and the methodology adopted follows:

- Aerial photographs were analysed. There was reasonable coverage of this catchment with high resolution photography. GoogleEarth and aerial photographs supplied by DPIW had the best photographs, which covered the majority of areas of interest. The dates of the GoogleEarth maps varied between 2002 and 2007, while the dates of the DPIW photos are unknown. Almost the entire area of the catchment was covered by aerial photography. Areas that were not covered by photography were confined to state forest, and managed for forestry. Unlicensed dams were concentrated in only a few subcatchments; of the 196 unlicensed dams counted, 123 were located in SC30_a. It was assumed that there were no unlicensed dams in forestry areas (i.e. all the area not covered by photographs); this assumption was verified by the lack of any dams in the large tracts of forestry areas that were visible in aerial photographs. For the remainder of the catchment, the number of dams of any size were counted for each sub-catchment from the available aerial photographs.
- It was assumed most of these dams would be legally unlicensed dams (less than 1 ML and not situated on a water course) however, it was assumed that there would be a proportion of illegal unlicensed dams up to 20ML in capacity. Some of these were visible on the aerial photographs.
- A frequency distribution of farm dam sizes presented by Neal et al (2002) for the Marne River Catchment in South Australia showed that the average dam capacity for dams less than 20 ML was 1.4 ML (Table 3.5).
- Following discussions with DPIW staff, the unlicensed dam demand was assumed to be 100%. The assumption is that all unlicensed dams will be empty at the start of May and will fill over the winter months, reaching 100% capacity by the end of September.
- Assuming this dam size distribution is similar to the distribution of the study catchment in South Australia, then the total volume of unlicensed dams can be estimated as 274.4 ML (196 * 1.4ML). The total volume of existing

permitted dams extractions in the study catchment is 6884 ML. Therefore the 274.4 ML of unlicensed dams equates to approximately 3.8% of the total dam extractions from the catchment.

There are some inherent difficulties in detecting farm dams from aerial photography by eye. Depending on the season and time of day that the aerial photograph is taken, farm dams can appear clearly or blend into the surrounding landscape. Vegetation can obscure the presence of a dam, and isolated stands of vegetation can appear as a farm dam when in fact no such dam exists. On balance, however, the number of false detections is countered by the number of missed detections and in the absence of another suitably rapid method the approach gives acceptable results.

Table 3.5 Average capacity for dams less than 20 ML by Neal et al (2002)

Size Range (ML)	Average Volume (ML)	Number of Dams	Total Volume (ML)
0 - 0.5	0.25	126	31.5
0.5 - 2	1.25	79	98.75
2 - 5	3.5	13	45.5
5 - 10	7.5	7	52.5
10 - 20	15	6	90
	27.5	231	318.25
Average Dam Volume:			**1.4 ML**

3.7 Environmental flows

One of the modeling scenarios (Scenario 3) was to account for environmental flows within the catchment. DPIW advised, that for the Arthur River catchment, they currently do not have environmental flow requirements defined. In the absence of this information it was agreed that the calibrated catchment model would be run in the Modelled – No entitlements (Natural) scenario and the environmental flow would be assumed to be:

- The 20th percentile for each sub-catchment during the winter period (01May to 31st Oct);
- The 30th percentile for each sub-catchment during the summer period (01 Nov – 30 April).

The Modelled – No entitlements (Natural) flow scenario was run from 01/01/1970 to 01/01/2007.

A summary table of the environmental flows on a monthly breakdown by sub-catchment is provided in the following table and in the Catchment User Interface.

Table 3.6 Environmental Flows

Model Sub-catch	Catch-ment Area (km^2)	Environmental Flow (ML/d) Per Month at subcatchment												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
SC1_a	**29.5**	23	14	10	32	73	116	147	153	137	87	70	40	**75**
SC1_b	**19.9**	39	23	17	51	116	191	243	247	225	142	113	65	**123**
SC1_c	**24.3**	75	49	32	96	221	381	487	488	439	277	216	129	**241**
SC1_d	**18.0**	89	56	40	117	256	438	563	556	507	321	248	152	**279**
SC1_e	**21.4**	149	87	64	201	405	673	879	876	782	488	368	247	**435**
SC1_f	**20.3**	166	96	71	225	449	744	967	971	860	540	407	273	**481**
SC1_g	**30.2**	189	108	81	258	516	855	1098	1124	981	615	464	308	**550**
SC1_h	**26.7**	207	120	90	284	570	950	1211	1250	1082	676	511	338	**608**
SC1_i	**21.7**	221	128	97	300	610	1018	1299	1352	1160	724	545	360	**651**
SC1_j	**14.3**	229	134	101	308	632	1057	1354	1415	1207	753	561	374	**677**
SC1_k	**25.0**	240	142	107	320	666	1132	1444	1523	1282	799	585	398	**720**
SC1_l	**71.4**	625	333	272	789	1789	2787	3378	3944	3124	1928	1413	909	**1774**
SC1_m	**39.5**	714	390	322	930	2086	3300	4019	4671	3736	2272	1652	1048	**2095**
SC1_n	**64.2**	747	414	338	981	2213	3490	4296	4973	3912	2410	1737	1099	**2217**
SC1_o	**57.6**	777	435	340	1011	2332	3686	4543	5236	4059	2516	1808	1141	**2323**
SC1_p	**47.8**	797	447	352	1030	2407	3853	4688	5392	4156	2567	1850	1165	**2392**
SC1_q	**21.3**	1006	569	463	1299	3237	4914	6060	6856	5117	3199	2344	1474	**3045**
SC1_r	**56.4**	1028	584	482	1338	3315	5080	6235	7053	5238	3298	2407	1522	**3132**
SC1_s	**90.7**	1077	615	529	1415	3488	5528	6668	7511	5530	3537	2556	1636	**3341**
SC1_t	**60.6**	1402	791	710	2037	4436	7725	8768	9850	7158	4695	3446	2196	**4435**
SC1_u	**53.6**	1439	806	728	2062	4475	8024	8906	10053	7284	4780	3536	2228	**4527**
SC2_a	**27.5**	20	13	9	25	59	102	130	129	116	73	56	35	**64**
SC3_a	**19.4**	14	8	6	20	39	65	82	78	70	41	29	22	**39**
SC3_b	**12.2**	22	13	10	33	63	106	134	128	113	66	47	36	**64**
SC3_c	**21.5**	37	22	16	55	106	177	225	215	190	112	78	60	**108**
SC4_a	**53.0**	51	29	24	98	183	219	273	322	256	161	114	69	**150**
SC4_b	**43.3**	148	82	69	274	527	638	797	931	736	465	333	199	**433**
SC4_c	**26.2**	198	107	92	348	690	862	1068	1252	976	619	440	266	**577**
SC4_d	**24.1**	235	123	108	404	807	1032	1264	1492	1166	737	527	317	**684**
SC4_e	**34.9**	273	142	122	443	898	1208	1475	1732	1353	853	611	366	**790**
SC5_a	**31.8**	30	16	14	53	105	130	162	188	146	92	66	40	**87**
SC6_a	**33.3**	27	15	12	41	86	128	152	177	137	82	59	36	**79**
SC7_a	**28.3**	26	14	11	44	88	115	140	164	127	78	56	34	**75**
SC8_a	**24.4**	20	11	9	31	67	92	111	128	102	62	44	28	**59**
SC9_a	**20.7**	14	8	7	18	42	73	84	98	76	45	31	21	**43**
SC10_a	**50.5**	31	18	15	33	93	168	193	215	169	102	71	46	**96**
SC10_b	**21.8**	43	25	19	44	126	235	270	300	235	143	99	64	**134**
SC11_a	**57.3**	32	21	15	39	111	193	223	243	181	112	81	52	**109**
SC11_b	**28.7**	66	44	31	79	224	392	450	497	367	226	164	108	**221**
SC12_a	**30.8**	18	12	8	23	60	105	121	133	97	61	44	29	**59**
SC13_a	**14.5**	8	5	3	8	24	47	54	57	43	26	19	12	**25**
SC14_a	**20.3**	11	7	5	11	33	64	75	79	58	34	25	17	**35**
SC15_a	**31.3**	20	12	10	30	68	110	122	143	107	67	49	30	**64**
SC15_b	**23.4**	34	21	17	52	118	190	213	249	186	115	85	53	**111**
SC15_c	**32.7**	55	32	27	81	186	302	334	392	297	181	135	83	**175**

SC15_d	**13.0**	86	51	42	123	292	474	526	615	467	282	210	131	**275**
SC15_e	**22.1**	98	59	48	143	340	544	605	707	540	327	242	151	**317**
SC15_f	**18.7**	132	81	66	188	471	774	868	999	757	454	336	211	**445**
SC15_g	**14.4**	147	89	74	211	530	866	968	1112	841	507	375	237	**496**
SC15_h	**15.5**	164	98	83	237	596	977	1087	1239	933	565	420	264	**555**
SC16_a	**12.9**	7	5	3	9	25	44	50	55	40	25	18	12	**24**
SC16_b	**10.0**	13	8	6	17	44	76	88	96	71	43	32	21	**43**
SC17_a	**15.4**	10	6	5	15	36	53	57	67	50	32	23	14	**31**
SC18_a	**25.1**	14	8	6	16	45	82	95	101	75	45	33	22	**45**
SC18_b	**29.6**	29	17	13	33	93	174	201	214	156	94	69	47	**95**
SC19_a	**21.2**	9	6	4	9	26	55	70	70	50	28	22	14	**30**
SC20_a	**107.5**	60	37	34	119	235	367	385	456	333	215	155	98	**208**
SC20_b	**54.1**	113	69	63	220	437	694	743	870	627	402	300	192	**394**
SC20_c	**44.5**	247	152	147	484	867	1473	1659	1857	1290	855	645	402	**840**
SC20_d	**44.4**	271	164	157	503	916	1544	1797	2014	1400	929	702	438	**903**
SC20_e	**48.4**	293	173	165	516	929	1628	1928	2167	1486	991	731	476	**957**
SC21_a	**63.6**	34	22	24	82	134	218	236	263	181	123	87	56	**122**
SC21_b	**85.8**	108	69	73	239	411	687	741	827	560	381	276	176	**379**
SC22_a	**52.3**	28	18	20	67	112	180	196	220	154	103	74	47	**102**
SC23_a	**15.1**	8	5	4	13	32	49	53	61	47	29	21	13	**28**
SC24_a	**54.8**	28	17	15	49	111	170	185	214	160	99	73	48	**97**
SC25_a	**32.4**	16	9	7	15	49	91	110	112	80	48	36	23	**49**
SC26_a	**21.9**	10	5	5	15	38	63	69	75	55	34	25	16	**34**
SC27_a	**37.6**	15	8	8	24	57	101	116	118	87	52	40	27	**54**
SC28_a	**30.4**	12	7	7	20	47	82	94	96	70	43	33	22	**44**
SC29_a	**41.0**	11	6	6	15	31	80	115	108	65	42	31	21	**44**
SC30_a	**35.4**	7	4	4	10	17	52	84	83	49	30	22	15	**31**

4. MODEL DEVELOPMENT

4.1 Sub-catchment delineation

Sub-catchment delineation was performed using CatchmentSIM GIS software.

CatchmentSIM is a 3D-GIS topographic parameterisation and hydrologic analysis model. The model automatically delineates watershed and sub-catchment boundaries, generalises geophysical parameters and provides in-depth analysis tools to examine and compare the hydrologic properties of sub-catchments. The model also includes a flexible result export macro language to allow users to fully couple CatchmentSIM with any hydrologic modeling package that is based on sub-catchment networks.

For the purpose of this project, CatchmentSIM was used to delineate the catchment, break it up into numerous sub-catchments, determine their areas and provide routing lengths between them.

These outputs were manually checked to ensure they accurately represented the catchment. If any minor modifications were required these were made manually to the resulting model.

For more detailed information on CatchmentSIM see the CatchmentSIM Homepage www.toolkit.net.au/catchsim/

4.2 Hydstra Model

A computer simulation model was developed using Hydstra Modelling. The sub-catchments, described in Figure 2-1, were represented by model “nodes” and connected together by “links”. A schematic of this model is displayed in Figure 4-1. The model is divided into three regions, reflecting changes in hydrologic characteristics due to differences in the topography:

1. the Frankland River;
2. the upper Hellyer River;
3. Other rivers in the Arthur catchment.

Flows in the upper Hellyer catchment (shown in orange in Figure 2-1) were modelled with model parameters derived using the Hellyer at Guildford junction calibration fit. Flows in the remainder of the Arthur catchment excepting the Frankland River (shown in purple in Figure 2-1) were modelled with model parameters derived from the Arthur River below Rapid River calibration fit. Flows in the Frankland River (shown in sky blue in Figure 2-1) were modelled with a hybrid of model parameters derived from the two calibration fits (see section 4.4).

Rainfall and evaporation are calculated for each sub-catchment using inverse-distance gauge weighting. The gauge weights were automatically calculated at the start of each model run. The weighting is computed for the centroid of the sub-catchment. A quadrant system is drawn, centred on the centroid. A weight for the closest gauge in each quadrant is computed as the inverse, squared, distance between the gauge and centroid. For each time step and each node, the gauge weights are applied to the incoming rainfall and evaporation data.

The AWBM Two Tap rainfall/runoff model (Parkyn & Wilson 1997) was used to calculate the runoff for each sub-catchment separately. This was chosen over the usual method of a single-tap AWBM model for the whole catchment as it allows better simulation of base flow recessions.

The flow is routed between each sub-catchment, through the catchment via a channel routing function.

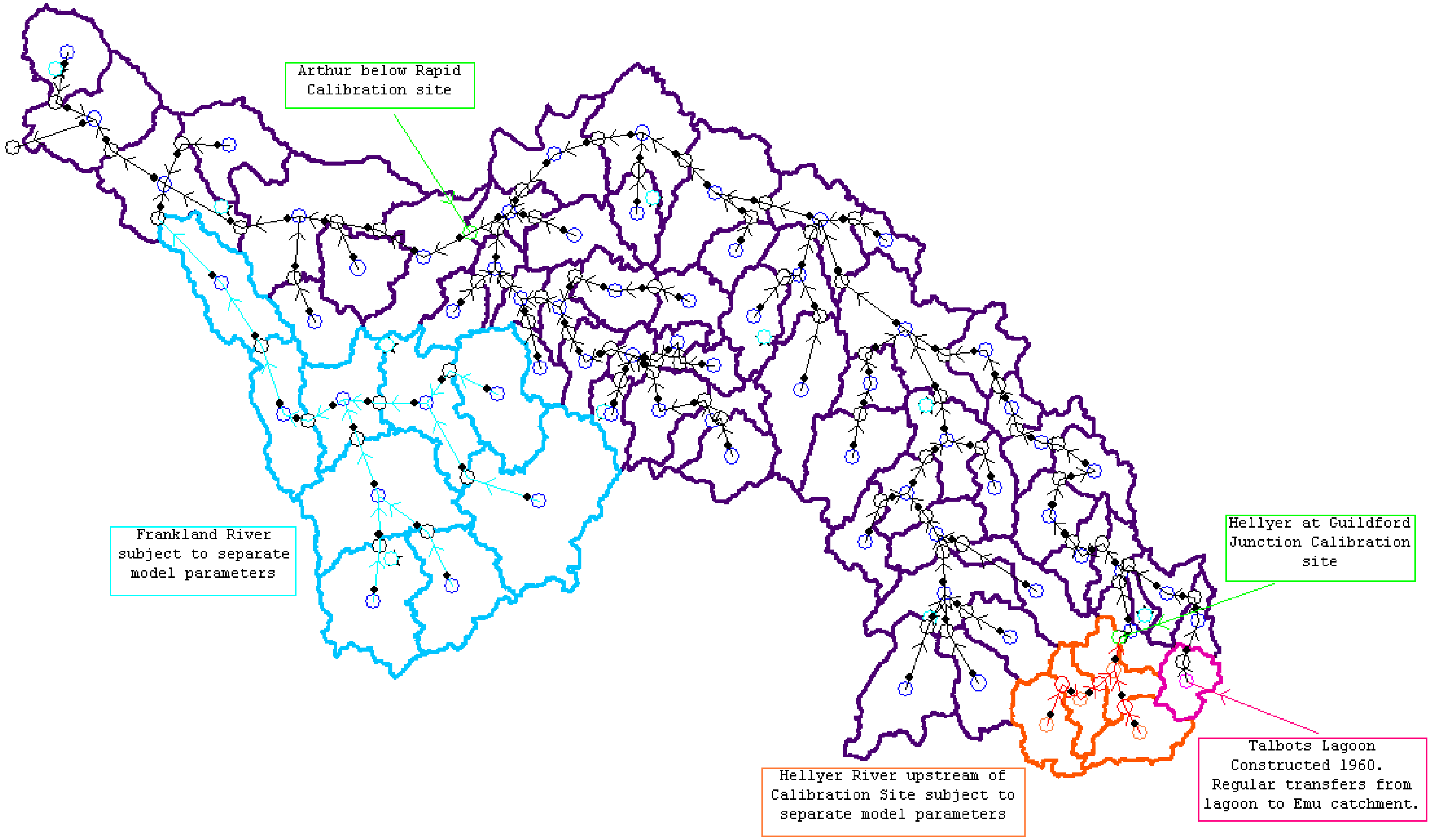

Figure 4-1 Hydstra Model Schematic

4.2.1 Talbots Lagoon

Talbots Lagoon (SC3_a) is of significant size and will impact the flow regime downstream of this storage (in addition to the transfers out of the catchment from this storage, detailed in Section 4.2.2). Accordingly Talbots Lagoon was treated specially in the Arthur surface water model. Following discussions with DPIW staff on the appropriate way to model this lake, the following model rules were adopted:

- Scenario 1, "*No Entitlements (Defines 'Natural' Flows)"* will model the catchment with no dam or lake present for all of record.
- Both the Scenario 2 "*with Entitlements (extraction not limited by Env.Flows)"* and Scenario 3, "*Environmental Flows & Entitlements ('Low Priority Ents. Limited by Env Flows')"* scenarios will model the catchment with:
    - No dam or lake present in the model prior of 1961 (when the dam was commissioned).
    - From 1961 onwards, the lake will be modelled using a basic volume balance rule assuming the following:
        - Maximum lake volume will be 5455 ML (from DPIW dams database);
        - Water entitlements falling within the Talbots Lagoon sub-catchment (SC3_a) will be extracted from the lake volume. Refer to section 3.6 regarding estimates of water extractions for the Talbots Lagoon;
        - Net inflows (inflow + pickup – interbasin transfers) in excess of the lake volume will be discharged downstream as spill;
        - If the *Environmental Flows & Entitlements* scenario is selected then a flow will be released downstream equal to the environmental flow specified in the user interface, for the Lake sub-catchment (SC3_a). However when the modelled net inflow to the lake is less than the specified environmental flow, the downstream release will be reduced to equal this. This has been done to stop excessive draw down of the lake due to environmental release in periods of low inflow.

A basic reservoir evaporation rule was also included in the model for this sub-catchment. The approximate surface area of the lake was determined from 1:25k TASMAP to be 2.742 km^2. Change in lake volume attributable to rainfall and evaporation falling on this area was determined on a daily basis utilising the Data Drill rainfall and evaporation inputs and added to the basic volume balance rule described above.

4.2.2 Inter-Basin Transfer: Talbots Lagoon

The Arthur catchment is subject to transfers to the Emu River. Water is released from Talbots Lagoon on the upper Wey River (SC3_a) and transferred by pipeline to the Emu River upstream of Companion Reservoir. Talbots Lagoon and the pipeline were completed in 1961 and are operated by North Forests Burnie, which operates Australian Paper's papermill on the Emu River. No flow records from the pipeline were identified and no operating rules govern the transfer except that the minimum flow through the pipeline is 1 ML/day. Transfers were estimated for the Emu River surface model (Trebilcock 2007) as follows:

- The maximum capacity of the pipeline was 45 ML/day between 1961 and 1987, and was increased to 65 ML/day in 1988.
- A minimum flow threshold was set for the Emu River at Companion Reservoir for summer months. This threshold was varied according to anecdotal accounts of water use by Australian Paper, as follows: 45 ML/day from 1961 to 1987, 65 ML/day from 1988 to 1998, and 30 ML/day from 1999 onwards. When the natural inflows into the Emu river upstream of Companion Reservoir together with water stored within the Emu catchment were insufficient to supply these flow thresholds, it was assumed the shortfall was provided from Talbots Lagoon.
- It was assumed that no transfers occurred from Talbots Lagoon in winter. When constructing the Emu catchment model, Trebilcock (2007) was unaware of the operating rule limiting minimum transfers to 1 ML/day.

The Emu model was used to estimate average monthly transfers from Talbots Lagoon, with the added condition that transfers could not be less than 1 ML/day. As there are three distinct periods of water use by Australian Paper in the Emu River catchment, average monthly transfers were calculated for 1961-1987, 1988-1998, and 1999 onwards. The average monthly transfers from Talbots Lagoon are given in Table 4.1. These average monthly transfers were then incorporated into the Arthur-Rapid-Hellyer surface model at sub-catchment SC3_a.

Table 4.1 Monthly Interbasin Transfers from Talbots Lagoon (ML/day)

Month	Before 1961	1961-1987	1988-1998	1999 onwards
January	No Transfer	12.6	19.9	7.2
February	No Transfer	13.2	19.0	6.8
March	No Transfer	13.3	22.5	8.2
April	No Transfer	8.7	16.5	6
May	No Transfer	1	1	1
June	No Transfer	1	1	1
July	No Transfer	1	1	1
August	No Transfer	1	1	1
September	No Transfer	1	1	1
October	No Transfer	1.1	1.2	1.1
November	No Transfer	8.7	14.6	6.7
December	No Transfer	8.6	17.7	7.9

Custom code was entered into the model to alter the outflow at sub-catchment SC3-a. The basic rules associated with this code are:

- Scenario 1, "*No Entitlements (Defines 'Natural' Flows)"* will model the catchment with no dam or transfers present for all of record.
- Both the Scenario 2 "*with Entitlements (extraction not limited by Env.Flows)"* and Scenario 3, "*Environmental Flows & Entitlements ('Low Priority Ents. Limited by Env Flows')"* scenarios will model the catchment with:
  - No dam or transfers present in the model prior to its construction completion date.
  - All years following the completion date, flows downstream of the dam will be a total of the spill, resulting after interbasin transfers have been accounted for.

4.3 AWBM Model

The AWBM Two Tap model (Parkyn & Wilson 1997) is a relatively simple water balance model with the following characteristics:

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

For these reasons parameters can more easily be transferred to ungauged catchments.

The AWBM routine used in this study is the Boughton Revised AWBM model (Boughton, 2003), which reduces the three partial areas (A1 to A3) and three surface storage capacities (Cap1 to Cap3) to relationships based on an average surface storage capacity.

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

Table 4.2 Boughton & Chiew, AWBM surface storage parameters

Partial area of S1	A_1=0.134
Partial area of S2	A_2=0.433
Partial area of S3	A_3=0.433
Capacity of S1	Cap1=(0.01*CapAve/A_1)=0.075*CapAve
Capacity of S2	Cap2=(0.33*CapAve/ A_2)=0.762*CapAve
Capacity of S3	Cap3=(0.66*CapAve/ A_3)=1.524*CapAve

To achieve a better fit of seasonal volumes, the normally constant store parameter CapAve has been made variable and assigned a seasonal profile. In order to avoid rapid changes in catchment characteristics between months, CapAves of consecutive months were smoothed. A CapAve of a given month was assumed to occur on the middle day of that month. It was assumed that daily CapAves occurring between consecutive monthly CapAves would fit to a straight line, and a CapAve for each day was calculated on this basis. The annual profile of CapAves for the catchment is shown in Figure 4-3.

The AWBM routine produces two outputs; direct run-off and base-flow. Direct run-off is produced after the content of any of the soil stores is exceeded and it is applied to the stream network directly. Base-flow is supplied unrouted directly to the stream network, at a rate proportional to the water depth in the ground water store. The ground water store is recharged from a proportion of excess rainfall from the three surface soil storages.

Whilst the AWBM methodology incorporates an account of baseflow, it is not intended that the baseflow prediction from the AWBM model be adopted as an accurate estimate of the baseflow contribution. The base flow in the AWBM routine is based on a simple model and does not specifically account for attributes that affect baseflow such as geology and inter-catchment ground water transfers. During the model calibration the baseflow infiltration and recession parameters are used to ensure a reasonable fit with the observed surface water information.

The AWBM processes are shown in the following Figure 4-2.

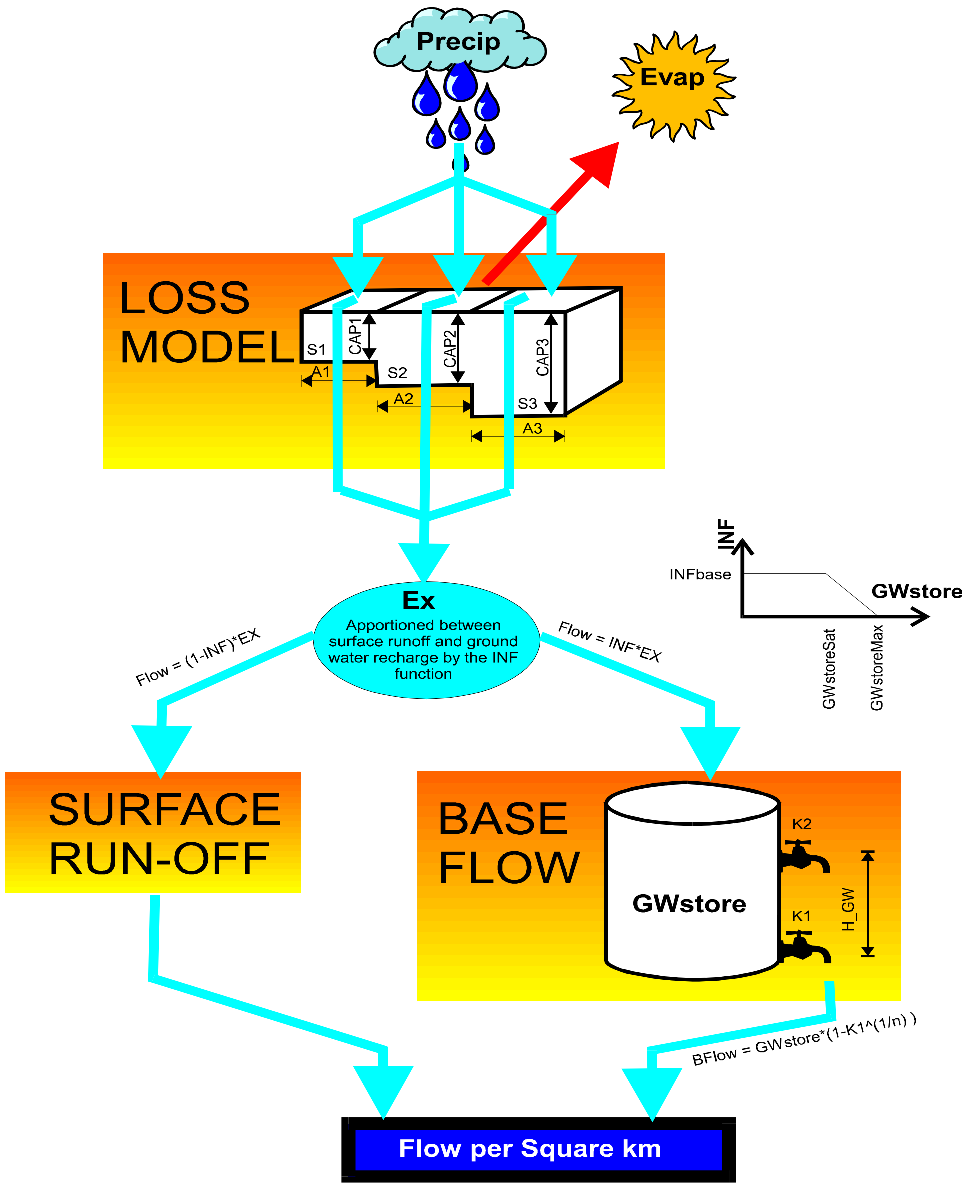

Figure 4-2 Two Tap Australian Water Balance Model schematic

4.3.1 Channel Routing

A common method employed in nonlinear routing models is a power function storage relation.

$$S \quad = K.Q^n$$

K is a dimensional empirical coefficient, the reach lag (time). In the case of Hydstra/TSM Modelling:

$$\alpha$$

and

L_i = Channel length (km)

α = Channel Lag Parameter

n = Non-linearity Parameter

Q = Outflow from Channel Reach (m^3/s)

A reach length factor may be used in the declaration of α to account for varying reach lag for individual channel reaches. eg. α.fl where fl is a length factor.

Parameters required by Hydstra/TSM Modelling and their recommended bounds are:

Table 4.3 Hydstra/TSM Modelling Parameter Bounds

α	Channel Lag Parameter	Between 0.0 and 5.0
L	Channel Length (km)	Greater than 0.0 (km)
n	Non-linearity Parameter	Between 0.0 and 1.0

As previously noted, the hydrologic properties exhibited at the Hellyer at Guildford Junction gauging site differ from those at the Arthur River below Rapid gauging site, and these are both likely to differ from the Frankland River. The upper Hellyer catchment is distinguished by flat marshy alpine plains, while the lower Hellyer and the Arthur and Rapid catchments are distinguished by their steep topography and, in parts, gorges. The Frankland River catchment sits somewhere between these extremes: it is steeper than the upper Hellyer, but not as steep as the lower Hellyer, Arthur and Rapid rivers. One of the model parameters that is affected by these catchment characteristics is the channel lag parameter, Alpha (α). The channel lag is higher in the upper Hellyer and lower in the gorges of the Arthur, Rapid and lower Hellyer rivers. The Frankland River is likely to exhibit an Alpha value typical of other Tasmanian streams (set to 3 in most other surface models), although as there is no flow record for the Frankland this is impossible to verify. Alpha was been adjusted accordingly in the calibration process.

4.4 Model Calibration

The model is divided into three regions, reflecting changes in hydrologic characteristics due to differences in the topography (see Figure 4-1):

1. the Frankland River,
2. the upper Hellyer River,
3. Other rivers in the Arthur catchment

As the regions have different hydrological characteristics, they are treated individually in the model and have differing model parameters. Flows in the upper regions of the Hellyer River catchment (shown in orange in Figure 4-1) are modelled using calibration parameters derived at the Hellyer at Guildford junction site. Most of the Arthur catchment is very steep and flows in these regions are modelled using calibration parameters derived from the Arthur below Rapid site.

There was a marked difference in the timing of hydrographs at the two gauging sites for the same flow events: despite being recorded significantly further downstream, hydrographs from the Arthur below Rapid record consistently rose *before* those recorded at Hellyer at Guildford Junction for the same event. The Hellyer catchment above the Hellyer at Guildford Junction site is distinguished from the lower Hellyer and the Arthur and Rapid catchments by being much flatter and marshier, and it was this difference in topography that was adjudged the prime reason for the differences in hydrographs. Very steep catchments generally result in reduced channel lag (water flows faster and with greater erosive force, tending to straighten out stream bends), and therefore the differences in the timing of hydrographs was attributed largely to channel routing.

Initially, calibration at both sites was attempted with Alpha = 3 (a method consistent with other DPIW surface water models). While these attempts resulted in excellent modelled monthly volumes, the time series of daily flows were consistently poor; it was not possible to get a sufficiently good calibration without adjusting for differences in channel lag. Accordingly, a higher Alpha value (5) was attributed to the upper Hellyer, while a lower Alpha value (1) was ascribed to Arthur below rapid calibration. As expected, daily flow was sensitive to changes in Alpha while monthly volumes were not.

The Frankland River catchment (shown in sky blue in Figure 4-1) is neither as flat as the upper Hellyer, nor as steep as the remainder of the Arthur catchment. As previously noted, there was no flow record available for the Frankland River. As it is in other ways more similar to the Arthur River (it is further West than the upper Hellyer, and has a much larger catchment), the Frankland was ascribed the same model parameters as the Arthur catchment, with the exception of the Alpha parameter. However, the flatter topography of the Frankland Catchment was determined through practitioner judgement to distinguish the Frankland's hydrological characteristics from the Arthur's, and accordingly an alpha value of 3.0 was applied to the Frankland.

Calibration was achieved by adjusting catchment parameters so that the modeled data best replicates the record at the site selected for calibration (for information on this site, refer to Section 3.5). The best fit of parameters was achieved by comparing the monthly, seasonal and annual volumes over the entire calibration period, using regression statistics and using practitioner judgment when observing daily and monthly time series comparisons. It should be noted that during the calibration process matching of average long term monthly volumes (flows) was given the highest priority and matching of peak flood events and daily flows was given lower priority. Further discussion of the model calibration fit is given in 4.4.2.

The calibration process can best be understood as attempting to match the modeled calibration flow (MCF) to the observed flow record. The MCF can be described as:

MCF = MNEM - (WE x TPRF)

Where:
MCF = Modelled Calibration Flow
MNEM = Modelled - No Entitlements (Modified). *
WE = Water Entitlements
TPRF = Time Period Reduction Factor

*** Refer to Glossary for additional explanation of these terms**

In the Arthur River catchment, data from the period 11/09/1976 to 01/09/1996 was selected at Arthur River below Rapid (site 159) for calibration, as this was the most recent 20-year period available. More recent flows were available for Hellyer River at Guildford Junction (site 61), and thus data from the period 11/09/1987 to 11/09/2007 was chosen for calibration.

Water entitlements were included in the calibration model and adjusted to the time period of calibration by applying a Time Period Reduction Factor (TPRF). The TPRF was calculated by a method developed in the Tasmanian State of the Environment report

(1996). This states that water demand has increased by an average of 6% annually over the last 4 decades. However, following discussions with DPIW the TPRF was capped at 50% of the current extractions if the mid year of the calibration period was earlier than 1995. In the Arthur River catchment, data from the period 11/09/1976 to 01/09/1996 was selected for calibration and accordingly a TPRF of 50% was applied to all extractions as the mid year of the calibration period was deemed to be 1986 which is prior to the 50% capped date of 1995. In the case of the Arthur River the water entitlement extractions at the calibration site are insignificant in relation to the observed flow (approx 0.4%), and accordingly the model calibration would be unchanged regardless of the TPRF applied. There are no extractions upstream of the Hellyer at Guildford Junction gauging site, and therefore it was unnecessary to account for any reduction in water extractions.

The model was calibrated to the observed flow as stated in the formula MCF = MNEM - (WE x TPRF). Other options of calibration were considered, including adding the water entitlements to the observed flow. However, the chosen method is considered to be the better option as it preserves the observed flow and unknown quantities are not added to the observed record. The chosen method also preserves the low flow end of the calibration, as it does not assume that all water entitlements can be met at any time.

In the absence of information on daily patterns of extraction, the model assumes that water entitlements are extracted at a constant daily flow for each month. For each daily time step of the model if water entitlements cannot be met, the modeled outflows are restricted to a minimum value of zero and the remaining water required to meet the entitlement is lost. Therefore the MCF takes account of very low flow periods where the water entitlements demand cannot be met by the flow in the catchment.

Table 4.6 shows the monthly water entitlements (demand) used in the model calibration upstream of the calibration site.

The adopted calibrated model parameters are shown in Table 4.4 and Table 4.5. These calibration parameters are adopted for all three scenarios in the user interface. Although it is acknowledged that some catchment characteristics such as land use and vegetation will have changed over time, it is assumed that the rainfall run-off response defined by these calibration parameters has not changed significantly over time and therefore it is appropriate to apply these parameters to all three scenarios.

As detailed in Section 4.3 to achieve a better fit of seasonal volumes, the normally constant store parameter CapAve has been made variable and assigned a seasonal profile. The annual profile of CapAve for the catchment is shown in the following table and graph.

Table 4.4 Adopted Calibration Parameters for Hellyer River above Hellyer gauging site

PARAMETER	VALUE	PARAMETER	VALUE
INFBase_H	0.85	CapAve_H Jan	27
K1_H	0.975	CapAve_H Feb	37
K2_H	0.96	CapAve_H Mar	25
GWstoreSat_H	100	CapAve_H Apr	36
GWstoreMax_H	140	CapAve_H May	54
H_GW_H	35	CapAve_H Jun	60
EvapScaleF_H	1	CapAve_H July	58
Alpha_H	5	CapAve_H Aug	54
N	0.8	CapAve_H Sept	45
		CapAve_H Oct	33
		CapAve_H Nov	15
		CapAve_H Dec	8

Table 4.5 Adopted Calibration Parameters Arthur River, Rapid River, Frankland River, and Hellyer River below Hellyer gauging site

PARAMETER	VALUE	PARAMETER	VALUE
INFBase	0.6	CapAve Jan	19
K1	0.975	CapAve Feb	24
K2	0.96	CapAve Mar	18
GWstoreSat	80	CapAve Apr	30
GWstoreMax	120	CapAve May	48
H_GW	35	CapAve Jun	61
EvapScaleF	1	CapAve July	67
Alpha	1	CapAve Aug	66
Alpha_F	3	CapAve Sept	59
N	0.8	CapAve Oct	41
		CapAve Nov	20
		CapAve Dec	9

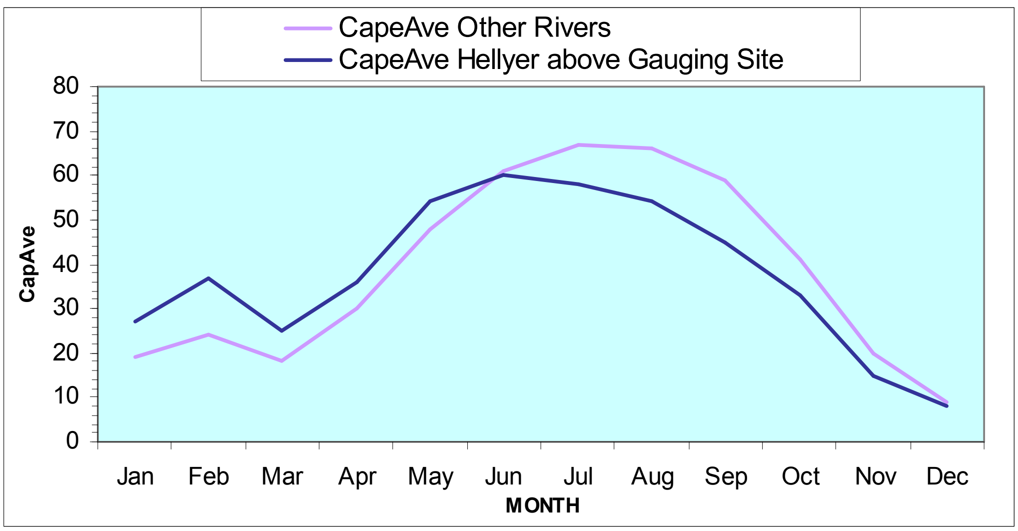

Figure 4-3 Monthly Variation of CapAve Parameter

Results of the calibration are shown in the plots and tables that follow in this section. In all comparisons the "Modelled Calibration Flow" (refer to previous description) has been compared against the observed flow at the calibration locations.

Daily time series plots of three discrete calendar years for the upper Hellyer River (Figure 4-4 to Figure 4-6) and for the Arthur River (Figure 4-7 to Figure 4-9) have been displayed for the two calibration locations, showing a range of relatively low to high inflow years and a range of calibration fits. The general fit for each annual plot is described in the caption text. This indication is a visual judgement of the relative model performance for that given year compared to the entire observed record. There is also a goodness of fit statistic (R^2) shown on each plot to assist in the judgement of the model performance.

The catchment average precipitation as input to the model is also displayed to provide a representation of the relative size of precipitation events through the year. Note that the precipitation trace is plotted on an offset, secondary scale (mm per day).

The monthly time series, over the whole period of observed record, are plotted in Figure 4-10 and Figure 4-11 and overall show a good comparison between Modelled Calibration Flow and observed totals at the calibration locations.

The monthly, seasonal and annual volume balances for the whole period of calibration record are presented in

Figure 4-12, Figure 4-13 and Table 4.6. The demand values shown represent the adopted total water entitlements upstream of the calibration location, which in this case are small and accordingly have been multiplied by 20 for plotting purposes. The demand has been included to provide a general indication of the relative amount of water being extracted from the river.

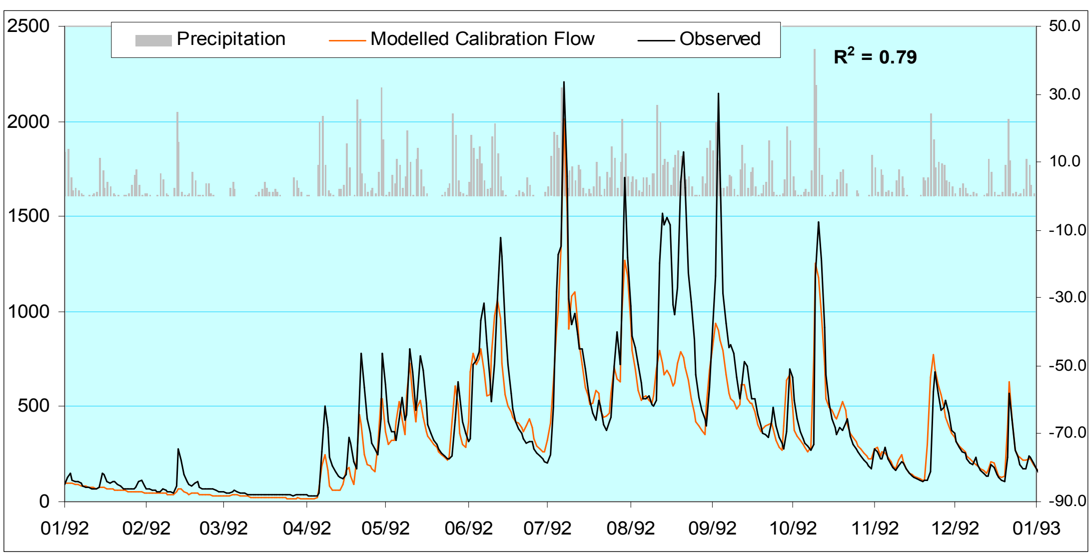

Figure 4-4 Daily time series comparison (ML/d) – upper Hellyer River - Good fit.

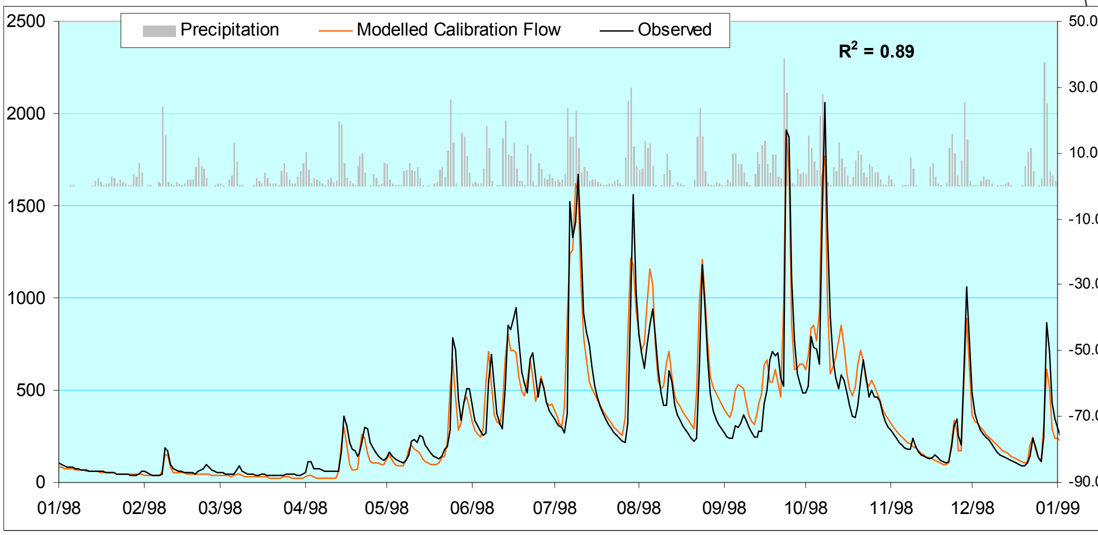

Figure 4-5 Daily time series comparison (ML/d) – upper Hellyer River– Good fit.

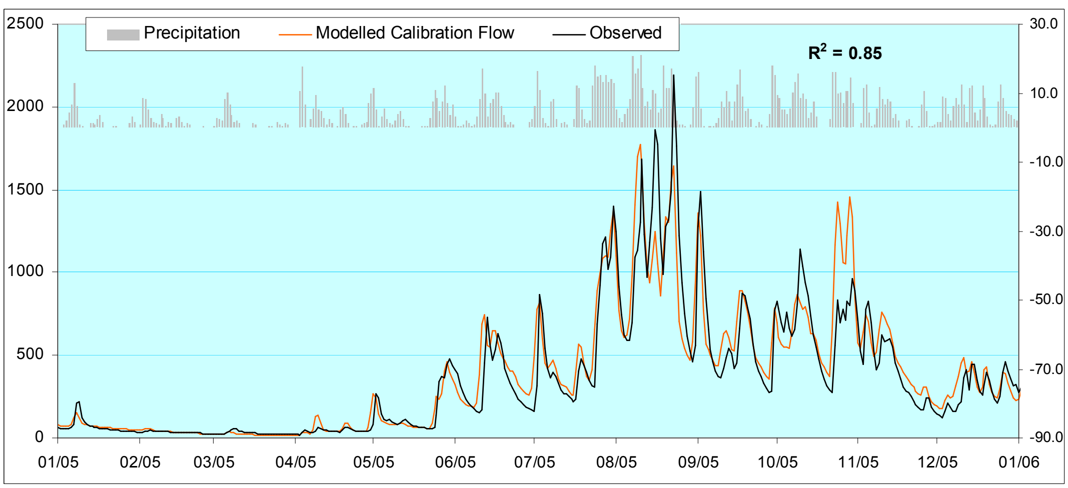

Figure 4-6 Daily time series comparison (ML/d) – upper Hellyer River– Good fit.

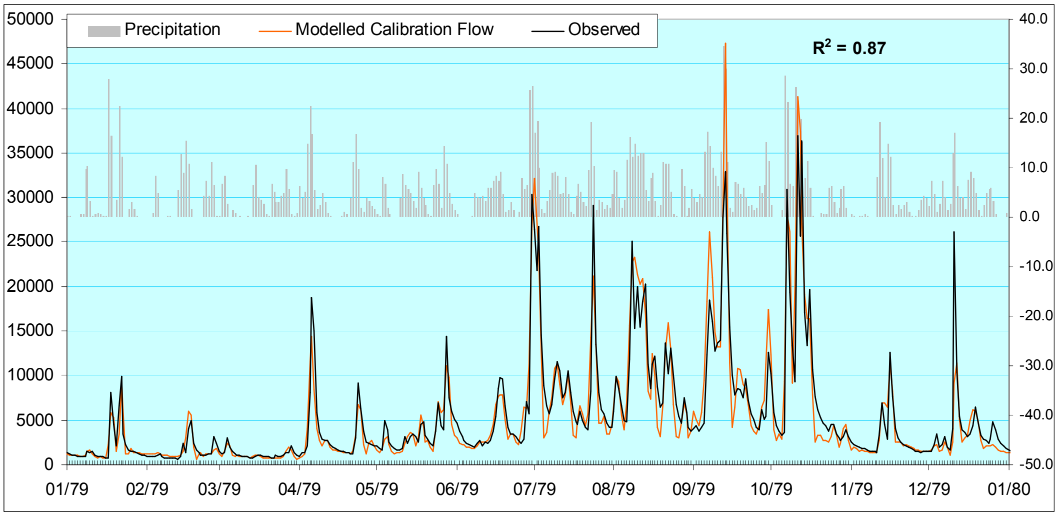

Figure 4-7 Daily time series comparison (ML/d) –Arthur River - Good fit.

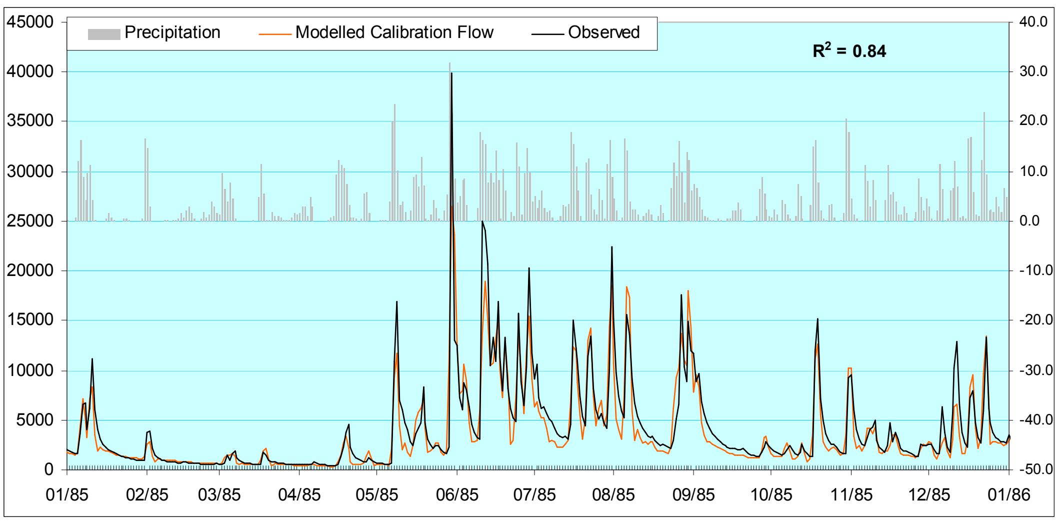

Figure 4-8 Daily time series comparison (ML/d) – Arthur River– Good fit.

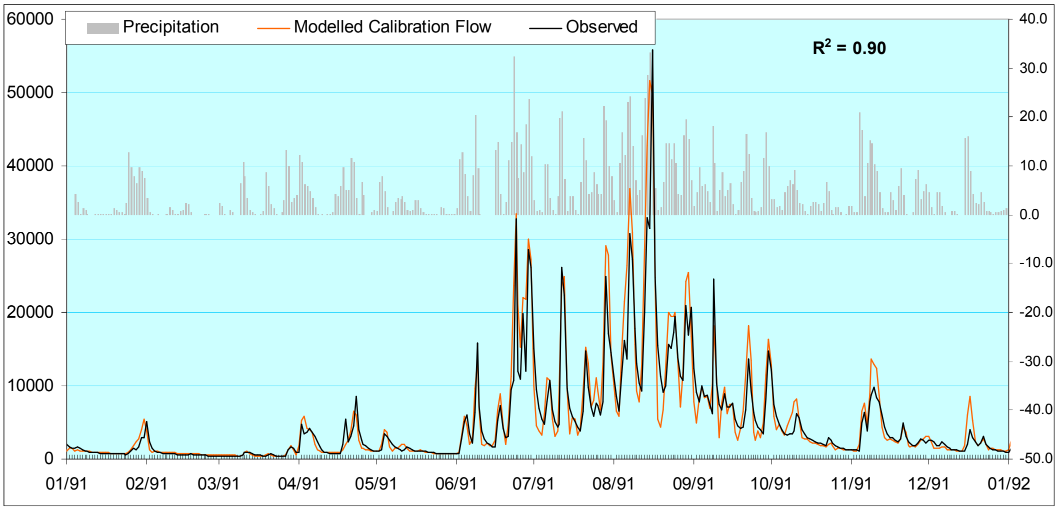

Figure 4-9 Daily time series comparison (ML/d) – Arthur River– Good fit.

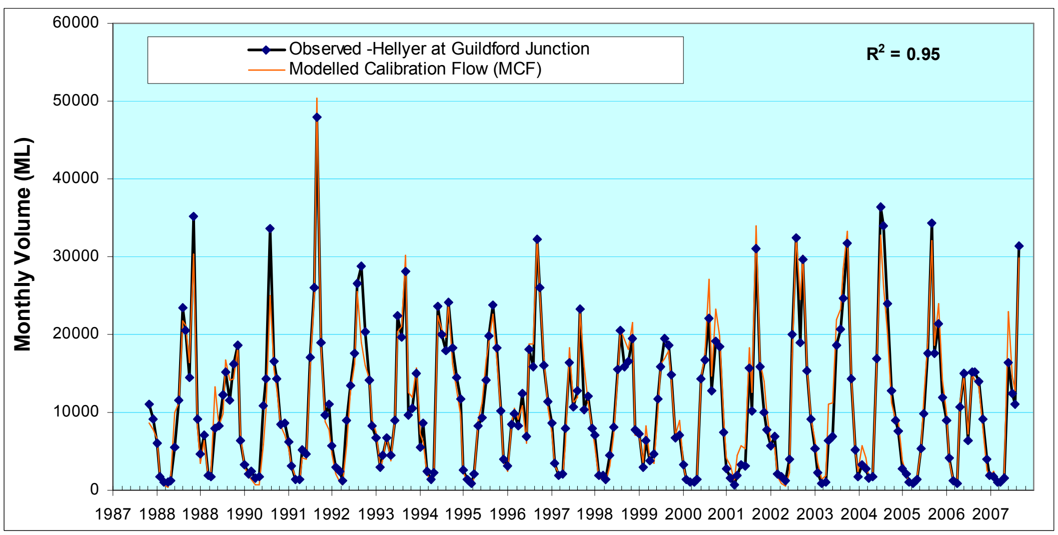

Figure 4-10 Monthly time series comparison – volume (ML) Hellyer River at Guildford Junction

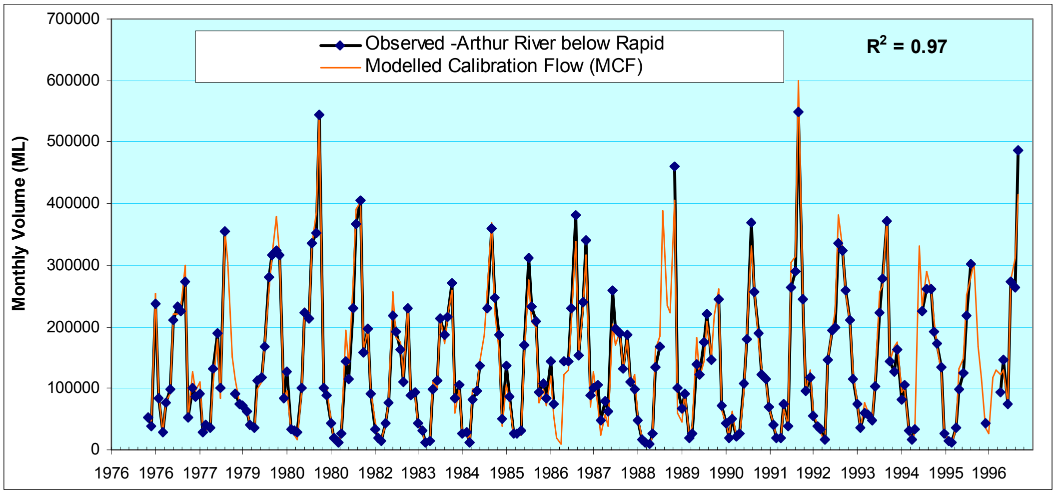

Figure 4-11 Monthly time series comparison – volume (ML) Arthur River below Rapid River

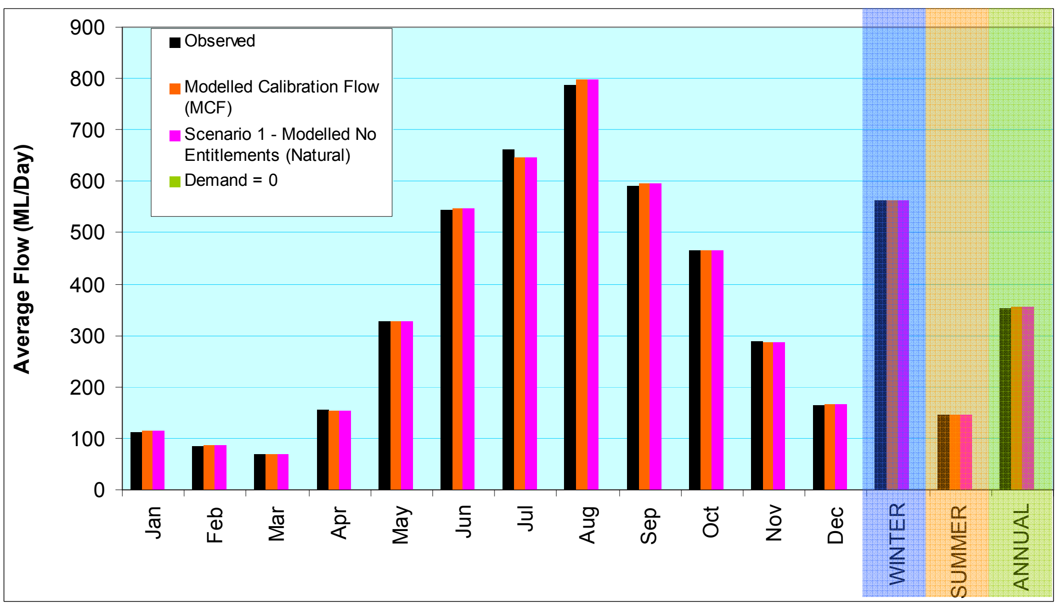

Figure 4-12 Long term average monthly, seasonal and annual comparison plot for Hellyer River at Guildford Junction

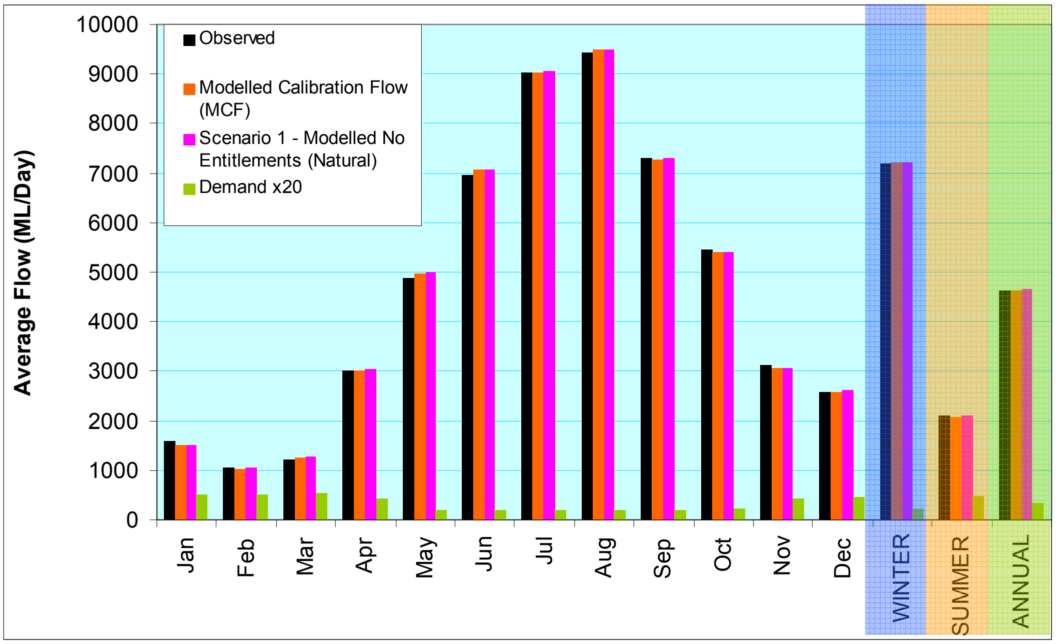

Figure 4-13 Long term average monthly, seasonal and annual comparison plot for Arthur River below Rapid River

Table 4.6 Long term average monthly, seasonal and annual comparisons

HELLYER RIVER AT GUILDFORD JUNCTION				
MONTH	Observed	Modelled-Calibration Flow (MCF)	Scenario 1 "Modelled -- No Entitlements (Natural)"	Demand
Jan	112.97	113.96	113.96	0.00
Feb	84.73	86.28	86.28	0.00
Mar	68.13	68.93	68.93	0.00
Apr	155.67	153.92	153.92	0.00
May	326.65	327.94	327.94	0.00
Jun	545.41	547.49	547.49	0.00
Jul	662.13	646.61	646.61	0.00
Aug	787.25	797.06	797.06	0.00
Sep	590.65	594.96	594.96	0.00
Oct	464.68	465.15	465.15	0.00
Nov	288.23	286.65	286.65	0.00
Dec	162.91	165.39	165.39	0.00
WINTER	562.79	563.20	563.20	0.00
SUMMER	145.44	145.86	145.86	0.00
ANNUAL	354.12	354.53	354.53	0.00
ARTHUR RIVER BELOW RAPID RIVER.				
MONTH	Observed	Modelled-Calibration Flow (MCF)	Scenario 1 "Modelled -- No Entitlements (Natural)"	Demand [1]
Jan	1597.69	1496.31	1517.38	25.65
Feb	1058.82	1028.84	1048.63	25.59
Mar	1225.12	1250.92	1272.26	26.93
Apr	3015.14	3014.27	3039.36	21.67
May	4881.49	4971.96	4988.09	10.61
Jun	6966.21	7073.28	7084.92	10.61
Jul	9036.82	9046.64	9056.34	10.61
Aug	9443.88	9476.84	9487.11	10.61
Sep	7288.73	7277.57	7288.51	10.59
Oct	5443.49	5388.47	5400.42	10.95
Nov	3112.45	3057.24	3077.26	21.06
Dec	2598.70	2584.07	2604.11	22.13
WINTER	7176.77	7205.79	7217.56	10.66
SUMMER	2101.32	2071.94	2093.17	23.84
ANNUAL	4639.05	4638.87	4655.37	17.25
WINTER from May to Oct, **SUMMER** from Nov - Apr.				

[1] The demand value includes all extraction potential upstream of calibration site with a 50% time period reduction factor applied.

4.4.1 Factors affecting the reliability of the model calibration.

Regardless of the effort undertaken to prepare and calibrate a model, there are always factors which will limit the accuracy of the output. In preparation of this model the most significant limitations identified, that will affect the calibration accuracy are:

1. The assumption that water entitlements are taken at a constant rate for each month. Historically the actual extraction from the river would be much more variable than this and possess too many levels of complexity to be accurately represented in a model.

2. The current quantity of water extracted from the catchment is unknown. Although DPIW have provided water licence information (WIMS July 2007) and estimates of extractions in excess of these licences, these may not represent the true quantity of water extracted. No comprehensive continuous water use data is currently available.

3. The quality of the observed flow data (ratings and water level readings) used in the calibration may not be reliable for all periods. Even for sites where reliable data and ratings has been established the actual flow may still be significantly different to the observed (recorded) data, due to the inherent difficulties in recording accurate height data and rating it to flow. These errors typically increase in periods of low and high flows.

4. Misrepresentation of the catchment precipitation. This is due to insufficient rainfall gauge information in and around the catchment. Despite the Data DRILL's good coverage of grid locations, the development of this grid information would still rely considerably on the availability of measured rainfall information in the region. This would also be the case with the evaporation data, which will have a smaller impact on the calibration.

5. The daily average timestep of the model may smooth out rainfall temporal patterns and have an effect on the peak flows. For example, intense rainfall events falling in a few hours will be represented as a daily average rainfall, accordingly reducing the peak flow.

6. The model does not explicitly account for changes in vegetation and terrain within individual sub-catchments. Effects due to vegetation and terrain are accounted for on catchment average basis, using the global AWBM fit parameters. Therefore individual sub-catchment run-off may not be accurately represented by the model's

global fit parameters. To account for this a much more detailed and complex model would be required.

7. Catchment freezing and snowmelt in the upper catchment, during the winter months, may affect the flow regime and this has not been specifically handled within this model.

8. The simple operating rules and assumptions used to model the catchment modification (Transfers from Talbots Lagoon) cannot capture the complexities of operation that occur in reality.

9. The precipitation and evaporation for each sub-catchment is calculated using an inverse distance gauge weighting. The catchment topography changes significantly within this catchment and the precipitation and evaporation in some sub-catchments may not be accurately represented using the inverse distance weighting methodology. However, due to the complexities involved with accounting for localised topography effects and general lack of long term climate data within these areas, no adjustment to the current methodology has been undertaken.

10. The catchment contains coastal areas dominated by flat terrain. It is likely that the flow in these sub-catchments will experience the effects of backwater, especially in periods of high flow and near estuaries. The adopted model does not account for this effect and therefore stream routing between catchments is likely to be misrepresented, especially within modelled daily outputs. To accurately account for backwater effects a hydraulic model that utilises the Saint Venant equations for natural rivers would be required and this has not been undertaken as part of this project.

4.4.2 Model Accuracy - Model Fit Statistics

The following section is an additional assessment of how reliably the model predicts flow at the calibration site.

One of the most common measures of comparison between two sets of data is the coefficient of determination (R^2). If two data sets are defined as x and y, R^2 is the variance in y attributable to the variance in x. A high R^2 value indicates that x and y vary evenly together – that is, the two data sets have a good correlation. In this case x and y are observed flow and modelled calibration flow. So for the catchment model, R^2 indicates how much the modelled calibration flow changes as observed flow changes. Table 4.7 shows the R^2 values between observed and modelled daily and monthly flows, as well as the proportional difference (%) between long-term (20 years) observed and modelled calibration flow.

Table 4.7 Model Fit Statistics

Measure of Fit	Hellyer River at Guildford Junction (Site 61)	Arthur River below Rapid River (Site 159)
Daily coefficient of determination (R^2 Value)	0.85	0.86
Monthly coefficient of determination (R^2 Value)	0.95	0.97
Difference in observed and estimated long term annual average flow	+0.12%	0.00%

As previously mentioned the focus of the calibration process was to obtain a good correlation between monthly long term volumes (and flows) and lesser priority was given to daily correlations. However without a good simulation of daily flows, a good simulation of monthly flows would be difficult to achieve. A target R^2 of 0.70 (or greater) was set for the daily flows and a target of R^2 of 0.85 (or greater) was set for monthly flows. It was deemed that these were acceptable targets considering the model limitations and potentials sources of error (refer to 4.4.1). A summary of comparative qualitative and statistical fit descriptions are provided in the following Table.

Table 4.8 R^2 Fit Description

Qualitative Fit Description	Daily R^2	Monthly R^2
Poor	$R^2 < 0.65$	$R^2 < 0.8$
Fair	$0.65 \geq R^2 > 0.70$	$0.8 \geq R^2 > 0.85$
Good	$R^2 \geq 0.70$	$R^2 \geq 0.85$

It should be noted that although the R^2 value is a good indicator of correlation fit it was only used as a tool, to assist in visually fitting the hydrographs. One of the major limitations is that minor differences in the timing of hydrograph events can significantly affect the R^2 value, although in practice a good calibration has been achieved.

Another indicator on the reliability of the calibration fit is the proportional difference between observed data and the modelled calibration flow (MCF), measured by percent

(%). The proportional difference for the daily flows and monthly volumes were calculated and are presented in Figure 4-14 to Figure 4-17 in the form of a duration curve. These graphs show the percentage of time that a value is less than a specified bound. For example in Figure 4-14, for the *All Record* trace, 90% of the time the difference between the MCF and observed flow is less than 60%. Similarly in Figure 4-15, for the *All Record* trace, 40% of the time the difference between the MCF monthly volume and observed volume is less than 10%.

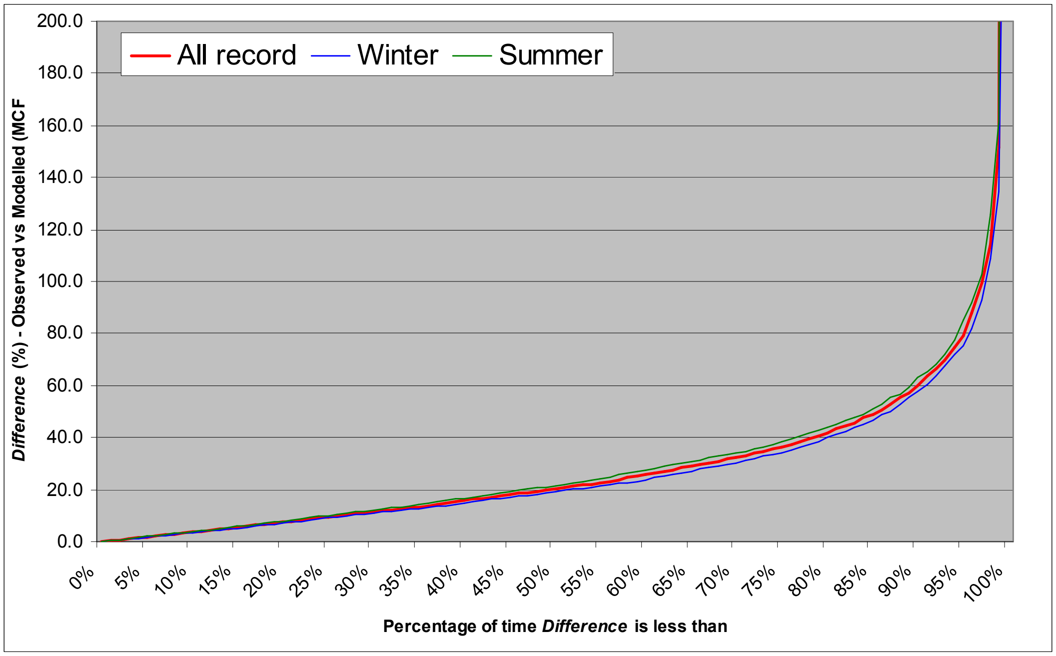

Figure 4-14 Hellyer River at Guildford Junction Duration Curve – Daily flow percentage difference

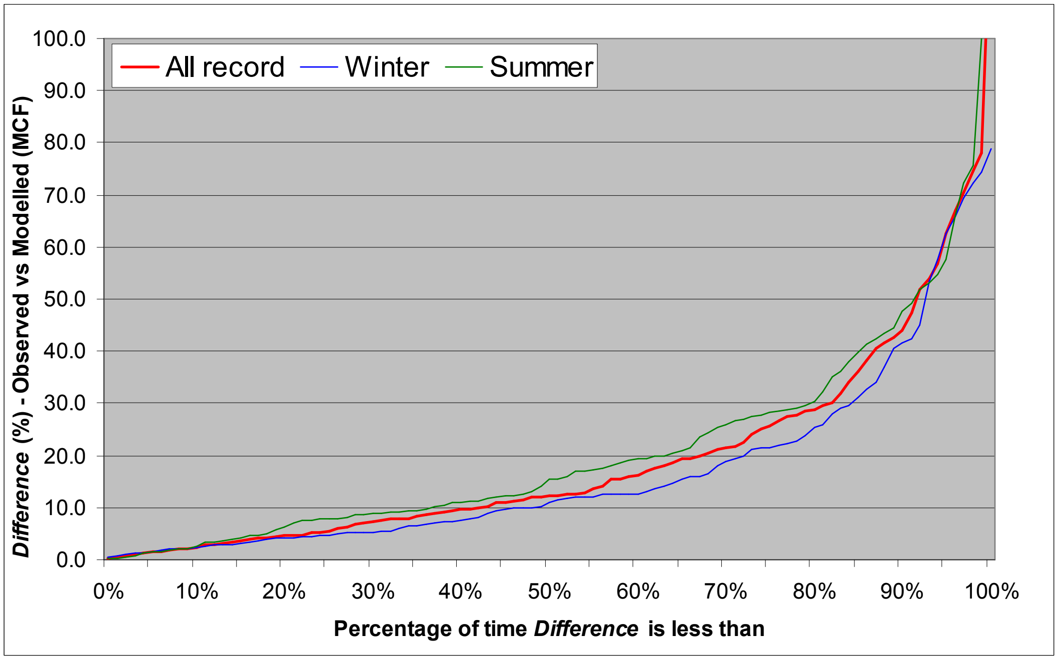

Figure 4-15 Hellyer River at Guildford Junction Duration Curve – Monthly volume percentage difference

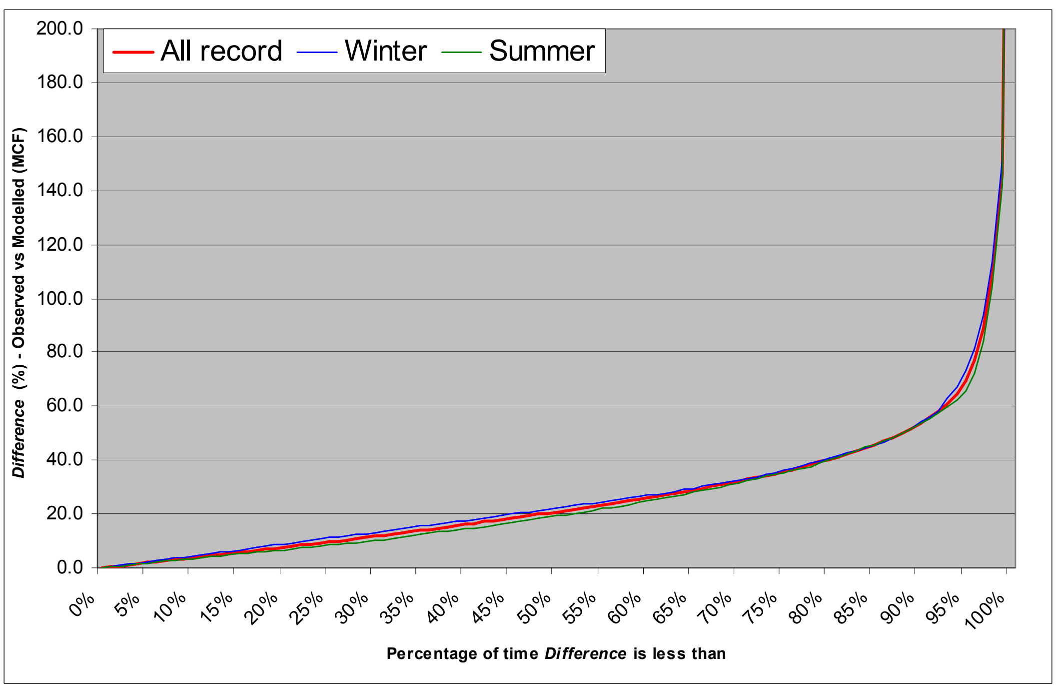

Figure 4-16 Arthur River below Rapid River Duration Curve – Daily flow percentage difference

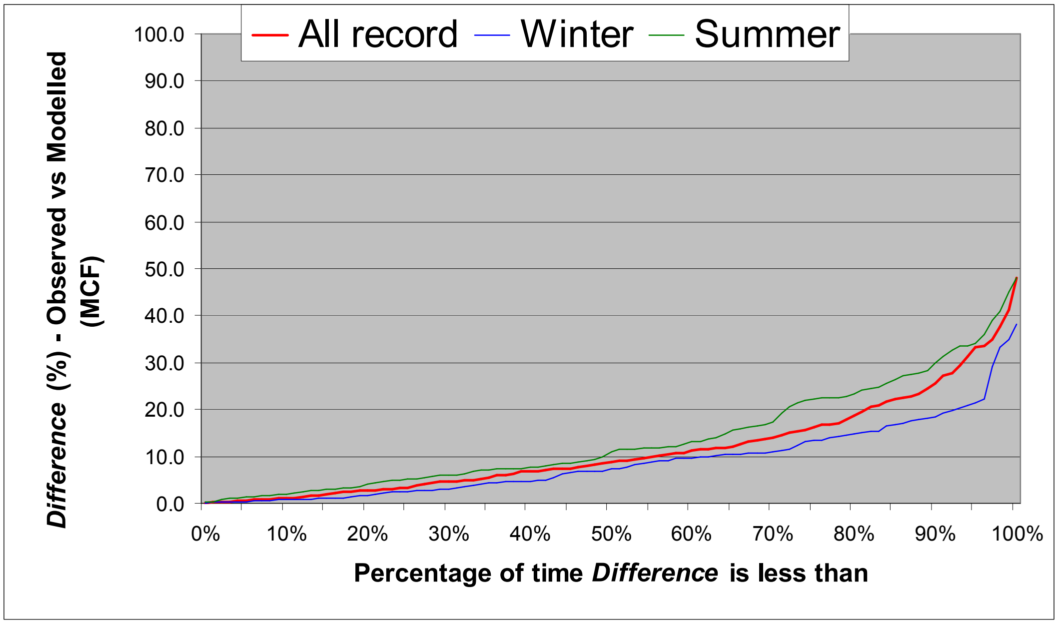

Figure 4-17 Arthur River below Rapid River Duration Curve – Monthly volume percentage difference

Although these duration curves are an indicator of the reliability of the modelled data, they also have their limitations and should be used in conjunction with a visual assessment of the hydrograph fit in determining calibration reliability. One of the major limitations is that in periods of low flow, the percentage difference between observed and modelled can be large although the value is not significant. For example, a 1ML/day difference, would show as a 200% difference if the observed flow was 0.5 ML/day. The duration curve graphs show three traces, the *Summer*[2], the *Winter*[3] and *All Record*. The higher values, caused by the larger proportion of low flows, can be clearly seen in the *Summer* trace.

4.4.3 Model accuracy across the catchment

The model has been calibrated to provide a good simulation for monthly and seasonal volumes at the calibration site. Calibration sites are typically selected low in the catchment to represent as much of the catchment as possible. How the reliability of this calibration translates to other specific locations within the catchment is difficult to accurately assess, however on average it would be expected that the model calibration would translate well to other locations within the catchment. The accuracy of the model in predicting monthly volumes at other locations has been analysed for five river

[2] Summer period = Nov to April.

[3] Winter period = May to Oct.

catchments modelled as part of this project. The results of this assessment are summarised in Appendix A. These analyses suggest that on average the models predict volumes well across the catchment.

The fit of the hydrograph shape (daily flows) is expected to be more site specific and therefore it is predicted that the calibration fit of these will deteriorate as the catchment area decreases.

In the Arthur catchment there were no additional gauging sites identified which can be used to assess the calibration fit at alternative sub-catchments.

In the absence of alternative observed data, the model's ability to predict flow volumes at different sites was ascertained by extrapolating flow data recorded at the calibration site. It was assumed that streamflow volume increased by the same proportion as catchment area. Thus if a calibration site has a subcatchment area A and a flow volume of Q_A, and another site in the catchment has a subcatchment area B and a flow volume of Q_B, then

$$Q_B = Q_A.(B/A)$$

This assumption is crude, as it ignores rainfall variability and variability in water extractions within the catchment, and therefore it will not definitively demonstrate a model's performance throughout the catchment. However, after discussion with DPIW, the method was included as a basic overview of the model's ability to predict flow volumes throughout the catchment.

Five sub-catchments were selected across the catchment.

Comparison of scaled observed site and sub-catchment SC1_k

SC1_k represents the last subcatchment of the Hellyer River before its confluence with the Arthur River. The area ratios of sub-catchment SC1_k to the observed data from both site 61 and site 159 were calculated to be 328%, and 22 %, respectively. The observed monthly volumes at the calibration site were multiplied by this ratio in order to calculate a proxy 'observed' record at the catchment outflow. The results are shown in the following plot (Figure 4-18) and considering the uncertainties in this methodology, the results appear good.

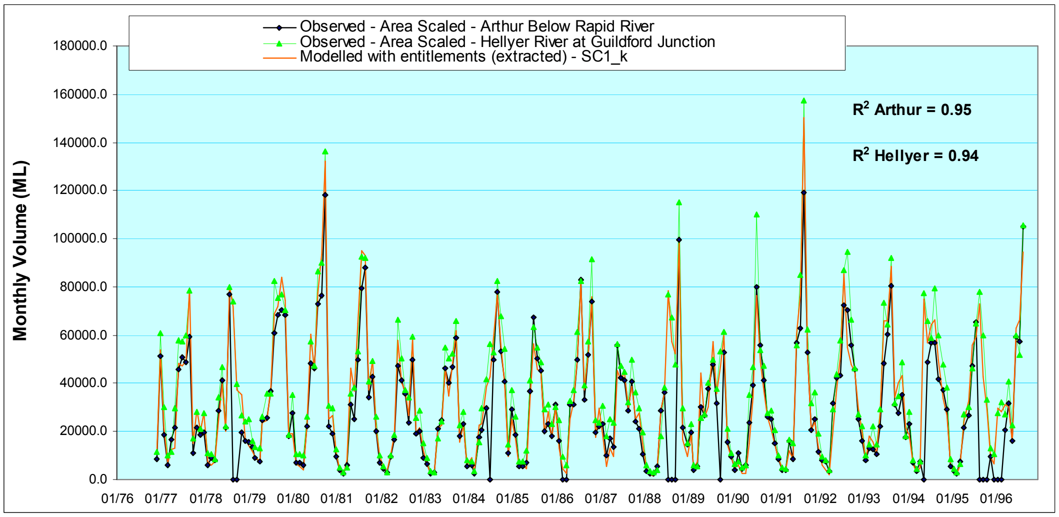

Figure 4-18 Time Series of Monthly Volumes- SC1_k

Comparison of scaled observed site and sub-catchment SC1_u

SC1_u represents the last subcatchment of the Arthur River before it discharges into the Indian Ocean. The area ratio of sub-catchment SC1_u to the observed data (site 159) was calculated to be 161 %. The observed monthly volumes at the calibration site were multiplied by this ratio in order to calculate a proxy 'observed' record at the catchment outflow. The results are shown in Figure 4-19 and considering the uncertainties in this methodology, the results appear good.

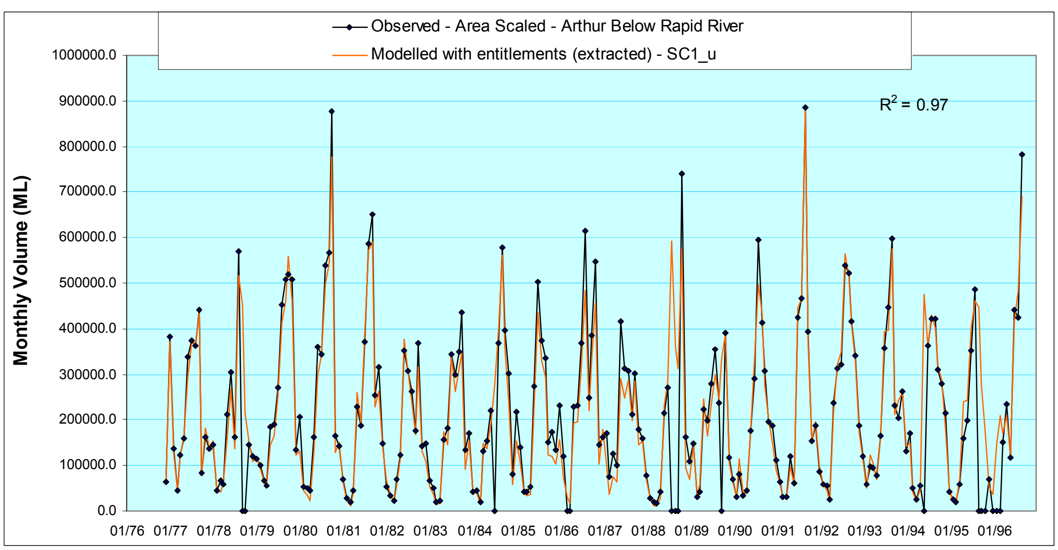

Figure 4-19 Time Series of Monthly Volumes- SC1_u

Comparison of scaled observed site and sub-catchment SC15_d

SC15_d represents the middle of the Rapid catchment. The area ratio of sub-catchment SC15_d to the observed data (site 159) was calculated to be 9.1 %. The observed monthly volumes at the calibration site were multiplied by this ratio in order to calculate a proxy 'observed' record at the catchment outflow. The results are shown in Figure 4-20. The results are shown in the following plot and considering the uncertainties in this methodology, the results appear good.

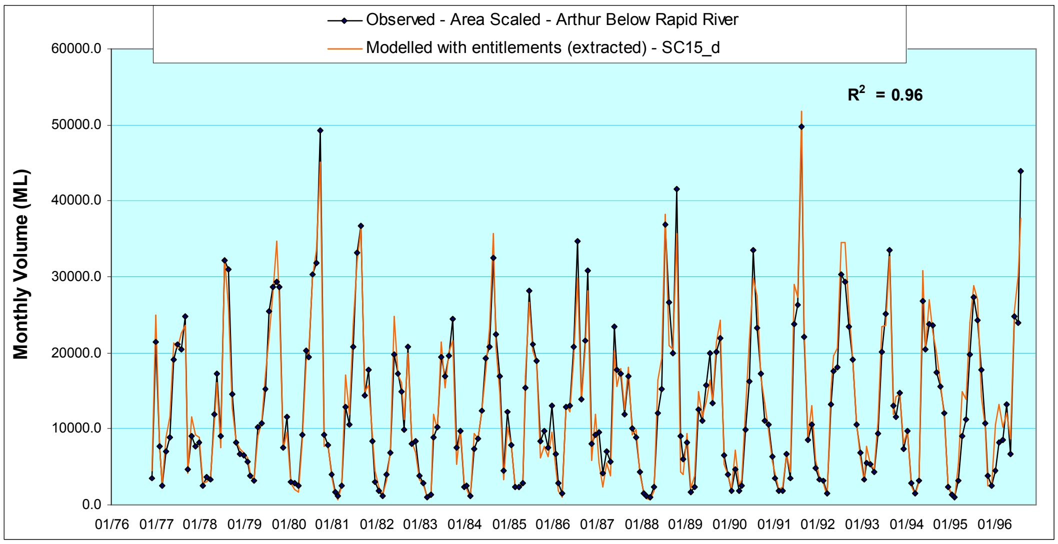

Figure 4-20 Time Series of Monthly Volumes- SC15_d

Comparison of scaled observed site and sub-catchment SC15_h

SC15_h represents the lower sub-catchment of the Rapid River. The area ratio of sub-catchment SC15_h to the observed data (site 159) was calculated to be 20 %. The observed monthly volumes at the calibration site were multiplied by this ratio in order to calculate a proxy 'observed' record at the catchment outflow. The results are shown in Figure 4-21. The results are shown in the following plot and considering the uncertainties in this methodology, the results appear good.

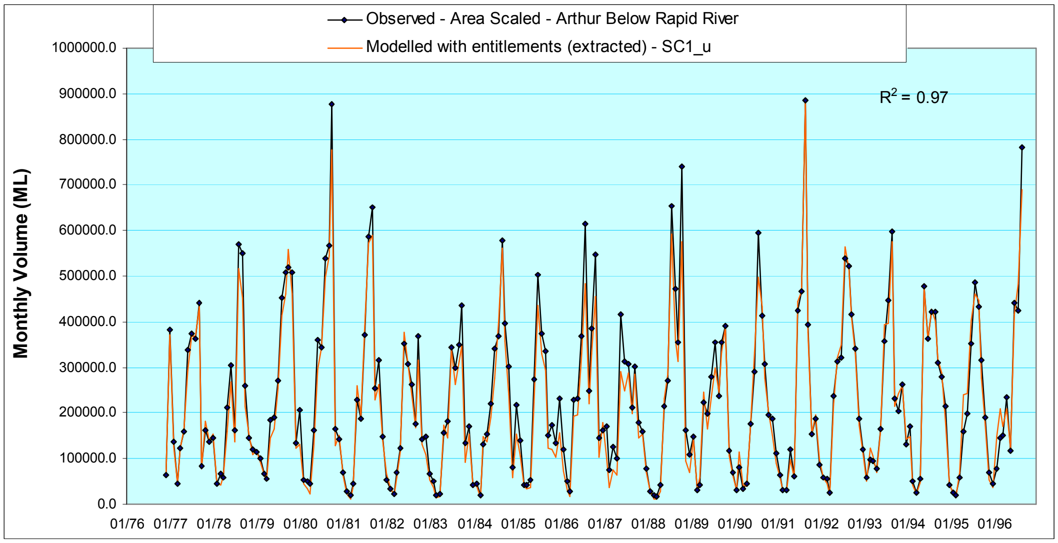

Figure 4-21 Time Series of Monthly Volumes- SC15_h

5. MODEL RESULTS

The completed model and user interface allows data for three catchment demand scenarios to be generated:

- Scenario 1 – No entitlements (Natural Flow);
- Scenario 2 – with Entitlements (with water entitlements extracted);
- Scenario 3 - Environmental Flows and Entitlements (Water entitlements extracted, however low priority entitlements are limited by an environmental flow threshold).

For each of the three scenarios, daily flow sequence, daily flow duration curves, and indices of hydrological disturbance can be produced at any sub-catchment location.

For information on the use of the user interface refer to the *Operating Manual for the NAP Region Hydrological Models* (Hydro Tasmania 2004).

Outputs of daily flow duration curves and indices of hydrological disturbance at the model calibration sites are presented below and in the following section. The outputs are a comparison of scenario 1 (No entitlements - Natural) and scenario 3 (environmental flows and entitlements) for the period 01/01/1961 to 01/01/2008 (the period since the commissioning of Talbots Lagoon). Results have been produced at the two calibration sites, Arthur River below Rapid River (site 159) and Hellyer at Guildford Junction (site 61).

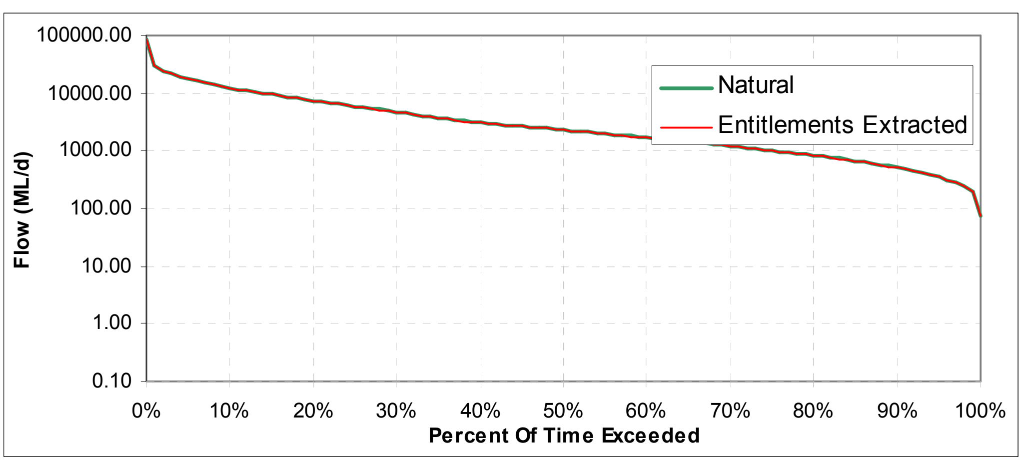

Figure 5-1 Daily Duration Curve – Arthur River below Rapid River

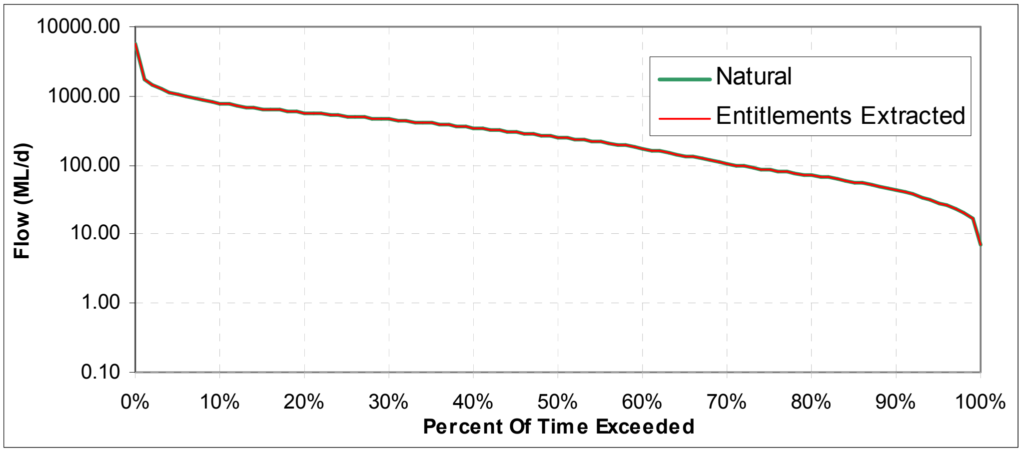

Figure 5-2 Daily Duration Curve – Hellyer River at Guildford Junction

5.1.1 Indices of hydrological disturbance

The calculation of the modeled flow estimates were used to calculate indices of hydrological disturbance. These indices include:

- Index of Mean Annual Flow
- Index of Flow Duration Curve Difference
- Index of Seasonal Amplitude
- Index of Seasonal Periodicity
- Hydrological Disturbance Index

The indices were calculated using the formulas stated in the Natural Resource Management (NRM) Monitoring and Evaluation Framework developed by SKM for the Murray-Darling Basin (MDBC 08/04).

The following table shows the Hydrological Disturbance Indices at 3 locations within the catchment, comparing scenario 1 (No entitlements - Natural) and scenario 3 (environmental flows and entitlements) for period 01/01/1961 to 01/01/2008 (the period in which Talbots Lagoon has been in operation). Three sites in addition to the two calibration sites have been selected to give an indication of the variability of the indices of hydrological disturbance across the catchment.

Table 5.1 Hydrological Disturbance Indices

Disturbance Indices	undisturbed (natural flow)	SC1_q Arthur River b/l Rapid	SC1_c Hellyer at Guildford Junction	SC1_k (Low in Hellyer Catchment)	SC1_u (Bottom of Arthur Catchment)	SC3_a (Talbots Lagoon)
Index of Mean Annual Flow, A	1.00	1.00	1.00	1.00	1.00	0.97
Index of Flow Duration Curve Difference, M	1.00	1.00	1.00	0.99	0.99	0.86
Index of Seasonal Amplitude, SA	1.00	0.99	1.00	0.99	0.99	0.84
Index of Seasonal Periodicity, SP	1.00	1.00	1.00	1.00	1.00	0.92
Hydrological Disturbance Index, HDI	**1.00**	**1.00**	**1.00**	**0.99**	**0.99**	**0.88**

Hydrological Disturbance Index: This provides an indication of the hydrological disturbance to the river's natural flow regime. A value of 1 represents no hydrological disturbance, while a value approaching 0 represents extreme hydrological disturbance.

Index of Mean Annual Flow: This provides a measure of the difference in total flow volume between current and natural conditions. It is calculated as the ratio of the current and natural mean annual flow volumes and assumes that increases and reductions in mean annual flow have equivalent impacts on habitat condition.

Index of Flow Duration Curve Difference: The difference from 1 of the proportional flow deviation. Annual flow duration curves are derived from monthly data, with the index being calculated over 100 percentile points. A measure of the overall difference between current and natural monthly flow duration curves. All flow diverted would give a score of 0.

Index of Seasonal Amplitude: This index compares the difference in magnitude between the yearly high and low flow events under current and natural conditions. It is defined as the average of two current to natural ratios. Firstly, that of the highest monthly flows, and secondly, that of the lowest monthly flows based on calendar month means.

Index of Seasonal Periodicity: This is a measure of the shift in the maximum flow month and the minimum flow month between natural and current conditions. The numerical value of the month with the highest mean monthly flow and the numerical value of the month with the lowest mean monthly flow are calculated for both current and natural conditions. Then the absolute difference between the maximum flow months and the minimum flow months are calculated. The sum of these two values is then divided by the number of months in a year to get a percentage of a year. This percentage is then subtracted from 1 to give a value range between 0 and 1. For example a shift of 12 months would have an index of zero, a shift of 6 months would have an index of 0.5 and no shift would have an index of 1.

6. FLOOD FREQUENCY ANALYSIS

Two flood frequency plots have been developed for the Arthur Catchment, one at the Hellyer at Guildford Junction site (site 61) and one at Arthur below Rapid site (site 159). The plots shown below in Figure 6-1 and Figure 6-2 consists of three traces:

1. Observed data. The annual maxima for this trace have been developed from continuous measured data at the site giving a better representation of the flood peak than the modelled daily average maxima. At the Hellyer at Guildford Junction site (site 61) and Arthur below Rapid site (site 159) site in total 39 and 85 annual maxima values were available, respectively, for these flood frequency analyses. The confidence limits on the plots represent the level of certainty of this observed dataset.

2. Modelled data (Scenario 3 - Environmental Flows & Entitlements) – same period as observed data. Note that the modelled annual maxima have been determined from a daily average flow dataset and accordingly do not represent the instantaneous flood maximum.

3. Modelled data (Scenario 3 - Environmental Flows & Entitlements) – whole period of record. Note that the modelled annual maxima have been determined from a daily average flow dataset and the period of record analysed is from 1900 to 2008.

The difference between flood peak frequency derived from recorded continuous flow data and flood peak frequency derived from modelled daily average flow can be obtained by comparing the first two traces as these relate to the same time period.

However, it should be noted that during the calibration process the highest priority was to achieve the best volume match between modelled and observed. As a result, the matching of flood peaks during calibration was of a lesser priority. Also the modelled flood peaks are based on daily (total) rainfall and accordingly these lack the temporal refinement to produce peaky outputs. That is, flood events are usually based on high intensity rainfall and this is not accurately captured using models and rainfall run on a daily time step.

These two factors do affect the accuracy of the modelled flood peaks used in the development of these flood frequency curves.

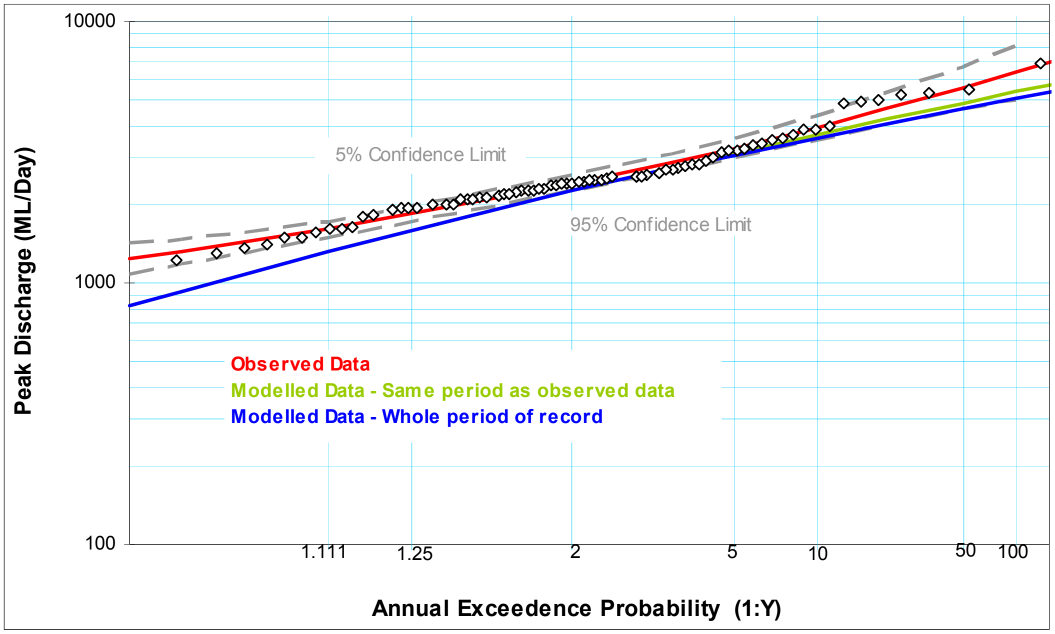

Figure 6-1 Modelled and Observed Flood Frequency Plot – Hellyer at Guildford Junction

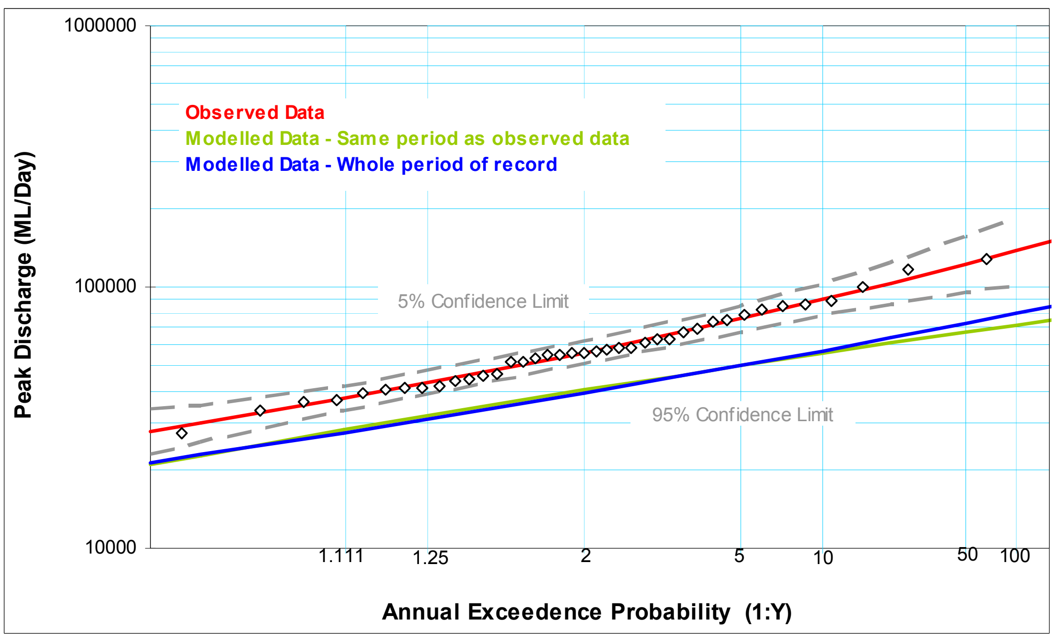

Figure 6-2 Modelled and Observed Flood Frequency Plot – Arthur River below Rapid

7. REFERENCES

Boughton, W.C. and Chiew, F.,(2003) Calibrations of the AWBM for use on Ungauged Catchments

CatchmentSIM Homepage www.toolkit.net.au/catchsim/ , December 2006

QNRM Silo (Drill Data) Homepage www.nrm.qld.gov.au/silo , January 2005

Hydrology Theme Summary of Pilot Audit Technical Report – Sustainable Rivers Audit. MDBC Publication 08/04.

National Land and Water Resources Audit (NLWRA) www.audit.ea.gov.au/anra/water/; January 2005.

Hydro Tasmania internal report, (2004) South Esk River Catchment Above Macquarie River, Impact of Water Entitlements on Water and Hydro Power Yield.

Hydro Tasmania, (2005), NAP Region Hydrological Model, North Esk Catchment.

Hydro Tasmania (2004). Operating Manual for the NAP region Hydrological Models. Hydro Report 118783 – Report -015, 17 September 2004.

Neal B, Nathan RJ, Schreider S, & Jakeman AJ. 2002, Identifying the separate impact of farm dams and land use changes on catchment yield. Aust J of Water Resources, IEAust,; 5(2):165-176.

Parkyn R & Wilson D, (1997): Real-Time Modelling of the Tributary Inflows to ECNZ's Waikato Storages. 24th Hydrology & Water Resources Symposium Proceedings IEAust, Auckland NZ 1997.

SKM (2003) Estimating Available Water in Catchments in Catchments Using Sustainable Diversion Limits. Farm Dam Surface Area and Volume relationship, report to DSE, Draft B October 2003

SKM (2005) Development and Application of a Flow Stress Ranking Procedure, report to Department of Sustainability and Environment, Victoria.

State of the Environment Report, Tasmania, Volume 1 Conditions & Trends 1996. State of Environment Unit, Lands Information Services, DELM.

Trebilcock, D. (2007) DPIW Surface Water Models: Emu Catchment. Hydro Tasmania Consulting Report prepared for DPIW. Doc. No. WR 2007/021

7.1 Personal Communications

Graham, B. Section Head, Ecohydrology, Water Assessment, DPIW. Jan-Feb 2008.

8. GLOSSARY

Coefficient of determination (R^2): One of the most common measures of comparison between two sets of data is the coefficient of determination (R^2). If two data sets are defined as x and y, R^2 is the variance in y attributable to the variance in x. A high R^2 value indicates that x and y vary together – that is, the two data sets have a good correlation.

High priority entitlements: Water entitlements with an assigned Surety 1 to 3.

Low priority entitlements: Water entitlements with an assigned Surety 4 to 8.

Modelled – No entitlements (Natural): The TimeStudio surface water model run in a natural state. That is, all references to water entitlements have been set to zero. Additionally any manmade structures such as dams, power stations and diversions have been omitted and the modelled flow is routed, uncontrolled through the catchment. This is also referred to as Scenario 1.

Modelled – No entitlements (Modified): The TimeStudio surface water model run with no water entitlements extracted. That is, all references to water entitlements have been set to zero. Where human structures are identified that significantly affect the flow regime, such as large dams, power stations and diversions, the TimeStudio model contains custom code to estimate the flow effect on the downstream subareas. This custom code takes effect from the completion date of the structure. Where there are no significant human structures in the catchment or the model is run before the completion of these structures this model will produce the same output as "Modelled – No entitlements (Natural)". This option is not available within the user interface and is one of several inputs used to derive a modelled flow specifically for calibration purposes. It is also referred to as MNEM in Section 4.4.

Modelled – with entitlements (extracted): The TimeStudio surface water model with water entitlements removed from the catchment flow. Where human structures are identified within a catchment that significantly affect the flow regime, such as large dams, power stations and diversions, the TimeStudio model contains custom code to estimate the flow effect on the downstream sub-catchments. This custom code takes effect from the completion date of the structure. This is also referred to as Scenario 2.

Modelled – environmental flows and entitlements (extracted): The TimeStudio surface water model with water entitlements removed. However, low priority entitlements are only removed when sub-catchment flow exceeds a specified environmental threshold. Where manmade structures are identified within a catchment, such as dams, power stations and diversions the TimeStudio model contains code to estimate the flow effect on the downstream subcatchments, commencing on the completion date of the structure. This is also referred to as Scenario 3.

Time Period Reduction Factor (TPRF): A reduction factor applied to current levels of water extracted from a catchment. The TPRF was applied to satisfy the assumption that the amount of water extracted from Tasmanian catchments (e.g. for agriculture) has increased over time. The TPRF was calculated by a method developed in the Tasmanian State of the Environment report. This states that water demand has increased by an average of 6% annually over the last 4 decades. This factor is applied to current water entitlements to provide a simple estimate of water entitlements historically. However, following discussions with DPIW the TPRF was capped at 50% of the current extractions if the mid year of the calibration period was earlier than 1995.

Water entitlements: This refers generally to the potential water extraction from the catchment. Included are licensed extractions documented in WIMS (July 2007) estimates of additional unlicensed extractions and estimates of unlicensed farm dams. Unless specified otherwise, Hydro Tasmania dams and diversions are not included.

WIMS (July 2007): The Department Primary Industries and Water, Water Information Management System, updated to July 2007.

APPENDIX A

This appendix investigates the reliability of the catchment models at predicting river flow throughout the catchment. One of the difficulties in assessing model reliability is the lack of observed data, as there is often only one reliable gauging site within the catchment. Five catchments that do have more than one gauging site and concurrent periods of record were selected and investigated with the results presented in Table A-1. The analysis undertaken is outlined below.

- The relationship between catchment area of the calibration site (primary site) and the secondary site was determined. Good variability is represented within this selection, with the secondary site catchment area ranging between 6.6% and 41.5% of the calibration site.

- The catchment area relationship was used to derive a time series at the secondary site based on scaled observed data from the calibration site. This was used in subsequent analysis to assess the suggestion that an area scaled time series, derived from a primary site was a good representation of sub-catchment flow in the absence of a secondary gauging site.

- For concurrent periods, estimated monthly volumes (ML) were extracted at both the calibration site and the secondary site.

- R^2 values were calculated on the following data sets for concurrent periods:

    - Correlation A: The correlation between the *calibration site observed data* and *calibration site modelled data*. This provides a baseline value at the calibration site for comparison against the other correlations.

    - Correlation B: The correlation between the *calibration site observed data* (which has been reduced by area) and *secondary site observed data*. This shows the relationship of area scaled estimates as a predictor of sub-catchment flows, in this case by comparison with a secondary gauge.

    - Correlation C: The correlation between the *calibration site observed data* (which has been reduced by area) and *secondary site modelled data*. This compares modelled data with an area scaled data set derived from observed data. This has been done because in the absence of a gauging site, observed data from another site is often assumed as a good indication of flow within the sub-catchment (Correlation B addresses this assumption). Where this assumption is applied, this correlation provides a statistical comparison of the models ability to predict comparable volumes to that of an area scaled estimate.

- Correlation D: The correlation between the *secondary site observed data* and *secondary site modelled data*. This has been done to assess how well the calibration undertaken at the primary site directly translates to other sub-catchments within the model.

The catchment model has been calibrated to provide a good fit for monthly and seasonal volumes at the calibration site. Calibration sites are typically selected low in the catchment to represent as much of the catchment as possible. Therefore the calibration fit parameters on average are expected to translate well to other sub-catchments. However, where individual sub-catchments vary significantly in terrain or vegetation or rainfall compared to the catchment average, errors are expected to be greater. The analysis undertaken in this section appears to confirm that the models perform acceptably and the conclusions of this analysis are summarised below:

1. Four of the five catchments studied showed fair to good R^2 values between observed and modelled data at the secondary site. (Correlation D).

2. The George secondary site was the worst performing in the study with a fair R^2 value of 0.83. It is expected that this is due to localised changes in terrain, vegetation and/or rainfall. This is a known limitation of the model and is therefore expected in some cases.

3. Scaling the calibration site observed data by area to derive a data set at another location is not recommended. Area scaled data does not consistently outperform the model at predicting flow/volumes within catchment. It is demonstrated that the model does (in the majority of cases) a good job of directly predicting the flow/volumes within catchment.

Time Series plots of the monthly volumes in megalitres for the five catchments studied in this section are shown in Figure A-1 to Figure A-5. These plots show that generally the calibration fit at the primary site translates well as a direct model output at other locations within the catchment, when modelling monthly volumes.

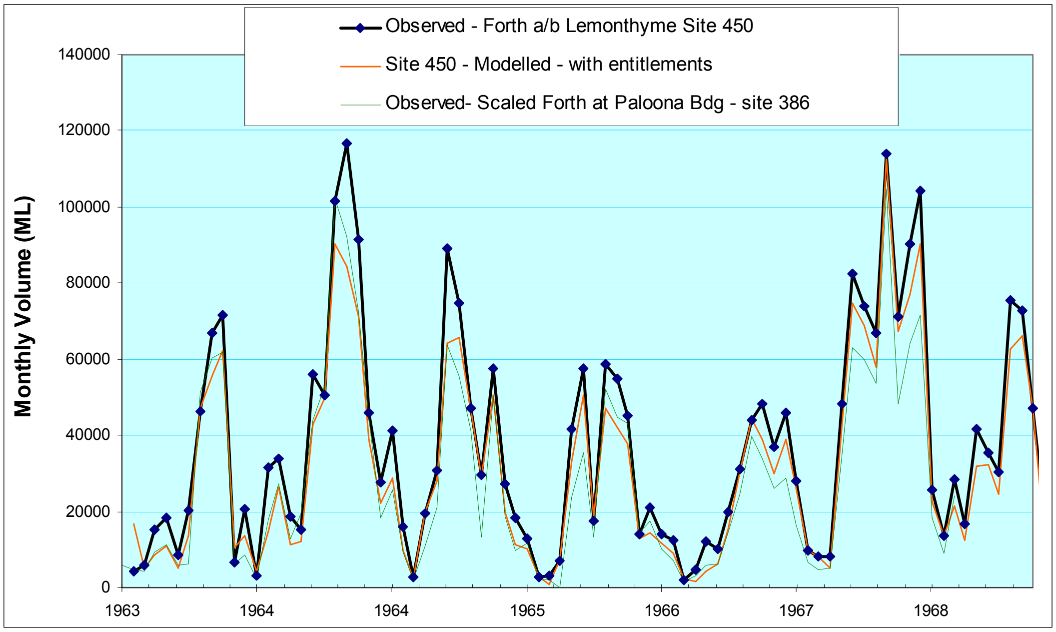

Figure A-1 Forth catchment – monthly volumes at secondary site.

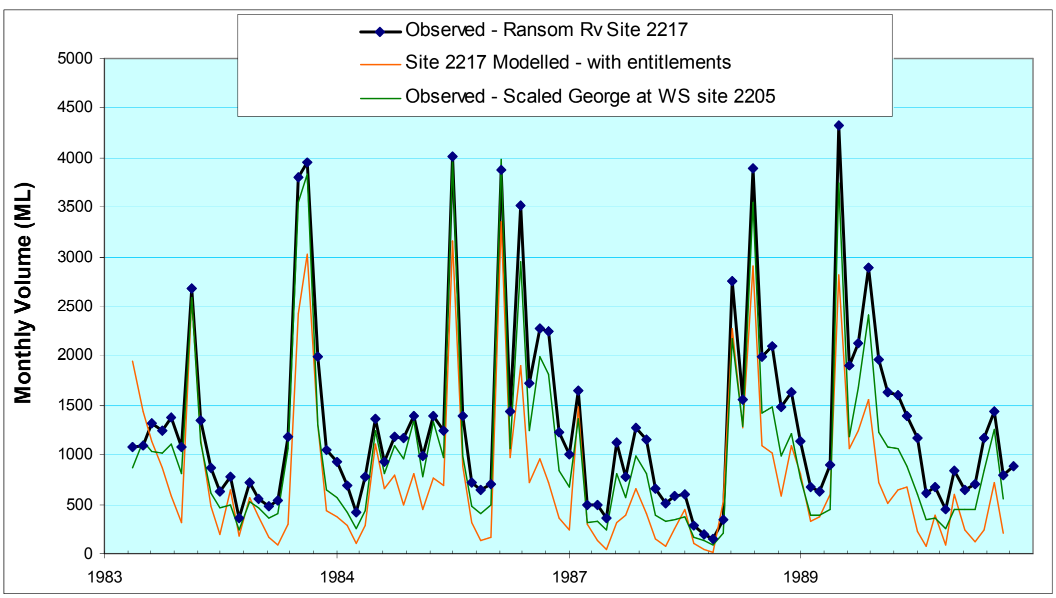

Figure A-2 George catchment – monthly volumes at secondary site.

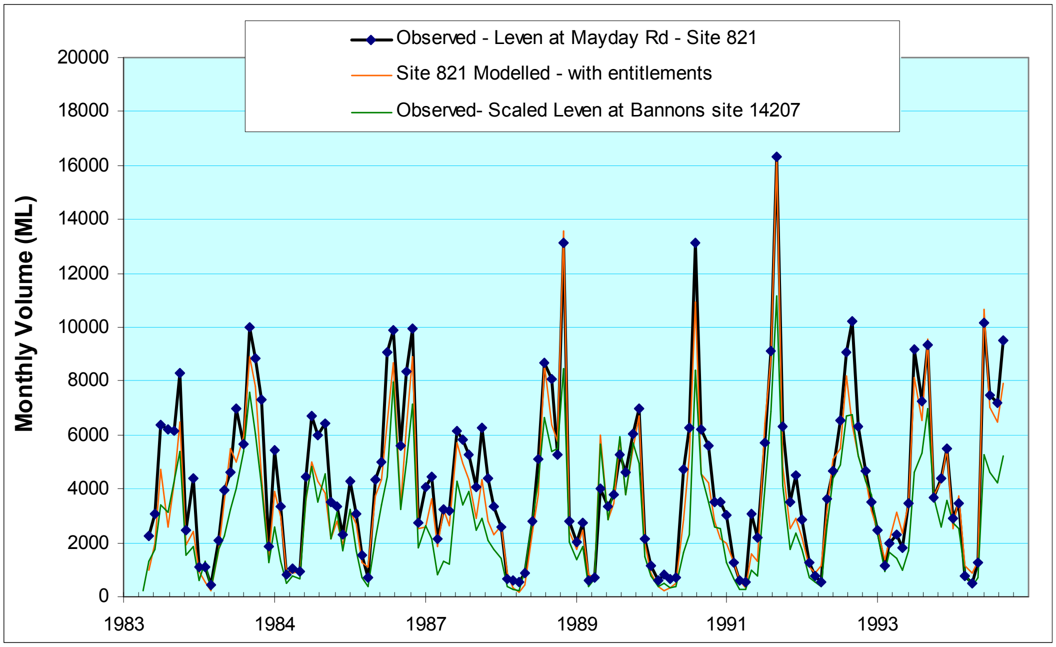

Figure A-3 Leven catchment – monthly volumes at secondary site.

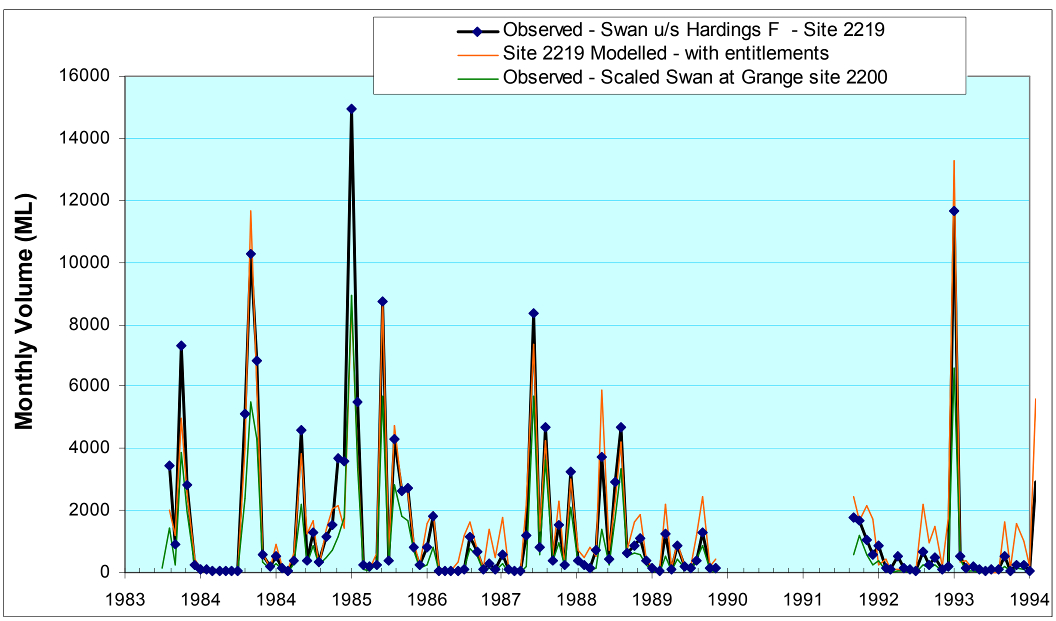

Figure A-4 Swan catchment – monthly volumes at secondary site.

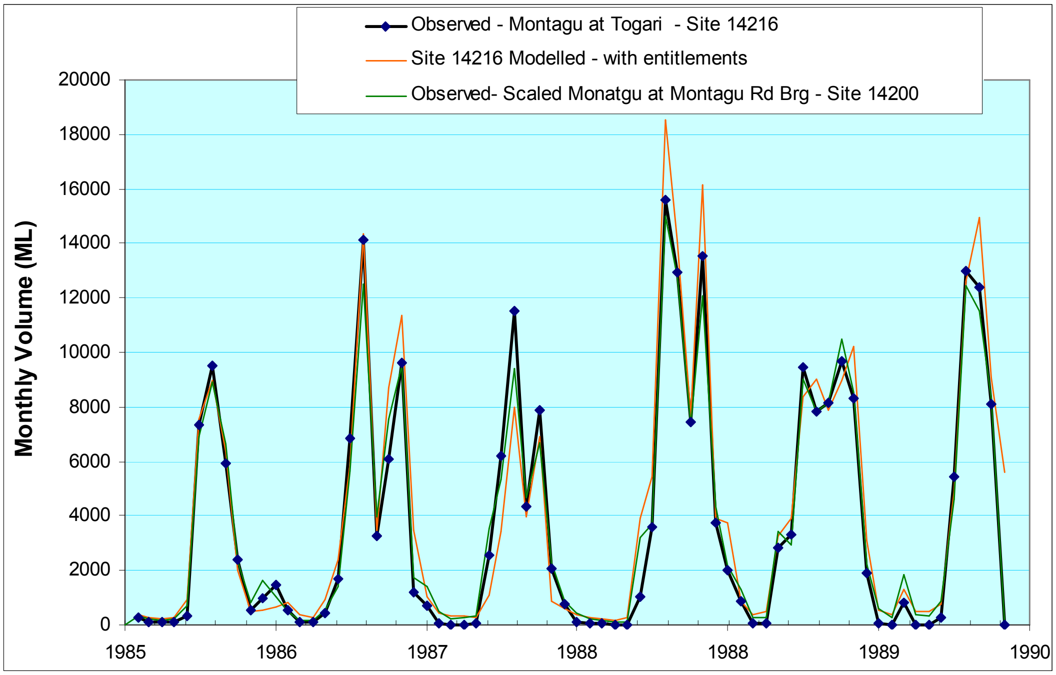

Figure A-5 Montagu catchment – monthly volumes at secondary site.

Table A-1 Model performance at secondary sites

Catchment	Calibration Site Primary Site				Secondary Site				Correlation A	Correlation B	Correlation C	Correlation D
Name	Site Name & No.	Sub-Catchment Location	Catchment Area Km^2	Concurrent data periods used in this analysis	Site Name & No.	Sub-Catchment Location	Catchment Area Km^2	Catchment area factor (compared with calibration site)	Monthly ML R^2 Value Calibration site observed vs Calibration site modelled	Monthly ML R^2 Value Secondary site observed vs Calibration site observed (scaled)	Monthly ML R^2 Value Calibration site observed(scaled) vs Modelled	Monthly ML R^2 Value Secondary site observed vs Modelled
Forth	Forth at Paloona Bridge – Site 386	SC33	1079.6	01/01/1963 to 01/03/1969	Forth River above Lemonthyme – site 450	SC31	310.2	0.2873	0.97	0.95	0.95	0.97
George	George River at SH WS – Site 2205	SC2	397.9	01/03/1983 to 01/10/1990	Ranson Rv at Sweet Hill – Site 2217	SC3	26.1	0.0656	0.91	0.96	0.86	0.83
Leven	Leven at Bannons Bridge – Site14207	SC4	496.4	01/04/1983 to 01/09/1994	Leven at Mayday Rd – site 821	SC6	37.5	0.0755	0.93	0.87	0.88	0.92
Swan	Swan River at Grange – Site 2200	SC20	465.9	01/07/1983 to 01/10/1996	Swan River u/s Hardings Falls – site 2219	SC4	35.6	0.0764	0.92	0.95	0.82	0.85
Montagu	Montagu at Montagu Rd Brdge – Site 14200	SC3	325.9	01/01/1985 to 01/01/1990	Montagu at Togari – Site 14216	SC2	135.4	0.4155	0.98	0.98	0.95	0.94