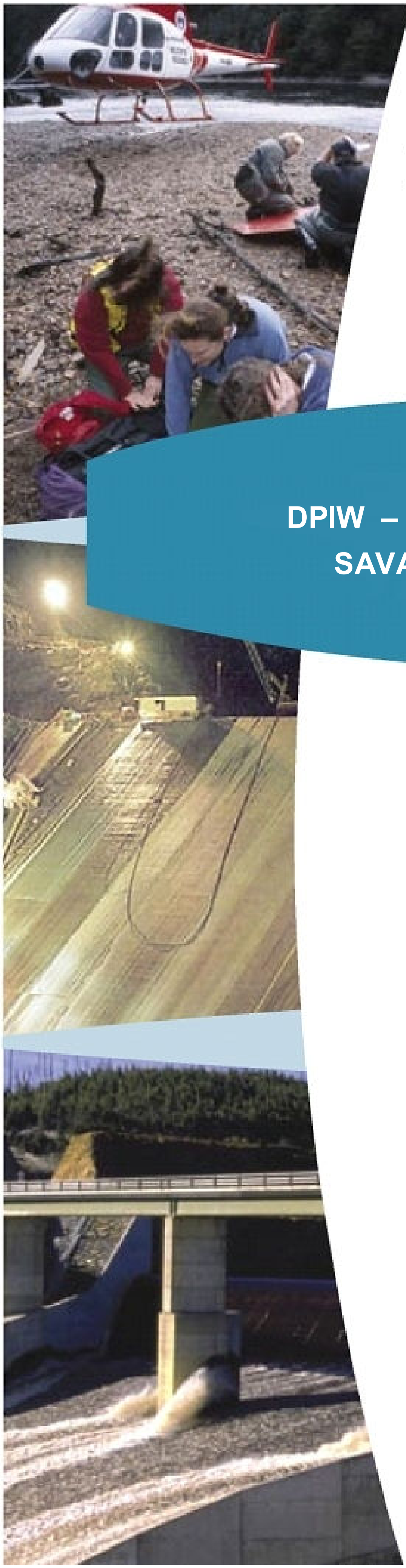

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SAVAGE RIVER CATCHMENT

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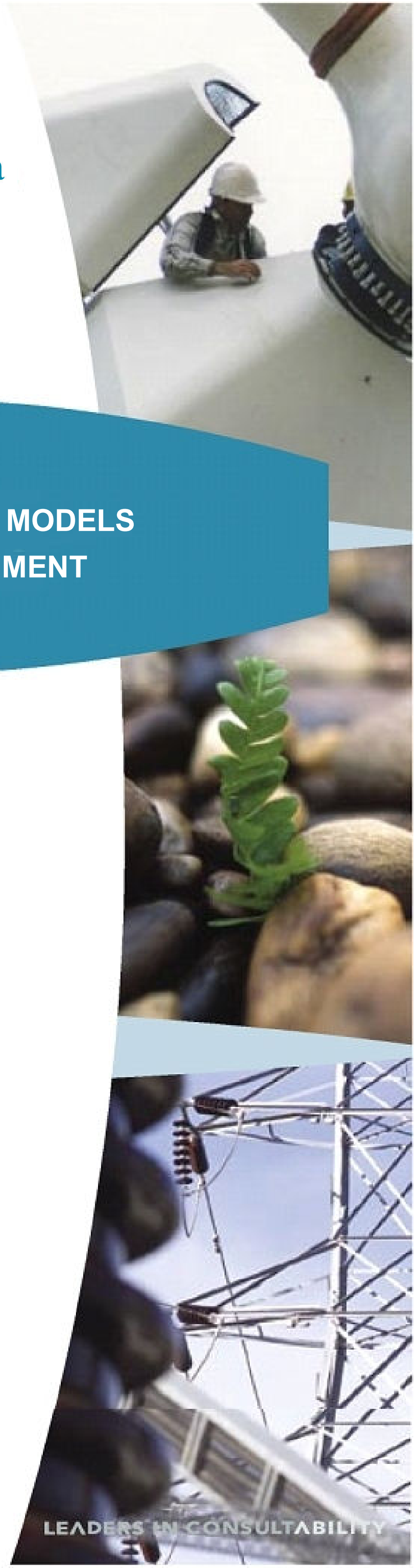

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EXECUTIVE SUMMARY

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 Savage River catchment.

A model was developed for the Savage River catchment 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 modelling 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 Savage River catchment;
- 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 Savage River drains a 305 km^2 catchment in western Tasmania, discharging into the Pieman River near the west coast. The Savage River flows south west from the 650 m high Baretop Ridge, which bounds the catchment's north-west. The catchment is characterised by steep topography and undisturbed native forest. The Savage River falls within the Tarkine Wilderness, one of the largest remaining temperate rainforests on earth.

The northern west coast of Tasmania is one of the wettest regions in Australia, and the Savage catchment is subject to consistently high rainfall. Average annual rainfall in the catchment ranges between 1800 and 2200 mm.

The Savage catchment is completely free of agricultural or silvicultural activities, and is almost entirely covered by native forest managed for preservation (including the Savage River National Park). The catchment is not entirely free from human impact: the large, open-cut Savage River Mine has operated in the catchment since the 1960s. The area in the immediate vicinity of the mine has been cleared, and a large dam has been constructed on Main Creek, the major tributary of the Savage River, to store mine tailings (the subcatchments affected are SC1_j and SC17_a in Figure 2-1). There are no known diversions out of or into the catchment of significant size, and no extraction permit for this storage. Hence the tailings dam on Main Creek has not been treated specially in this model.

The mine operators have a permit to extract 8400 ML from the Savage River, and this is the only registered extraction permitted in the entire catchment on the Water Information Management System database (WIMS July 2007).

For modelling purposes, the Savage River catchment was divided into 47 subareas. The delineation of these areas and the assumed stream routing network is shown in Figure 2-1.

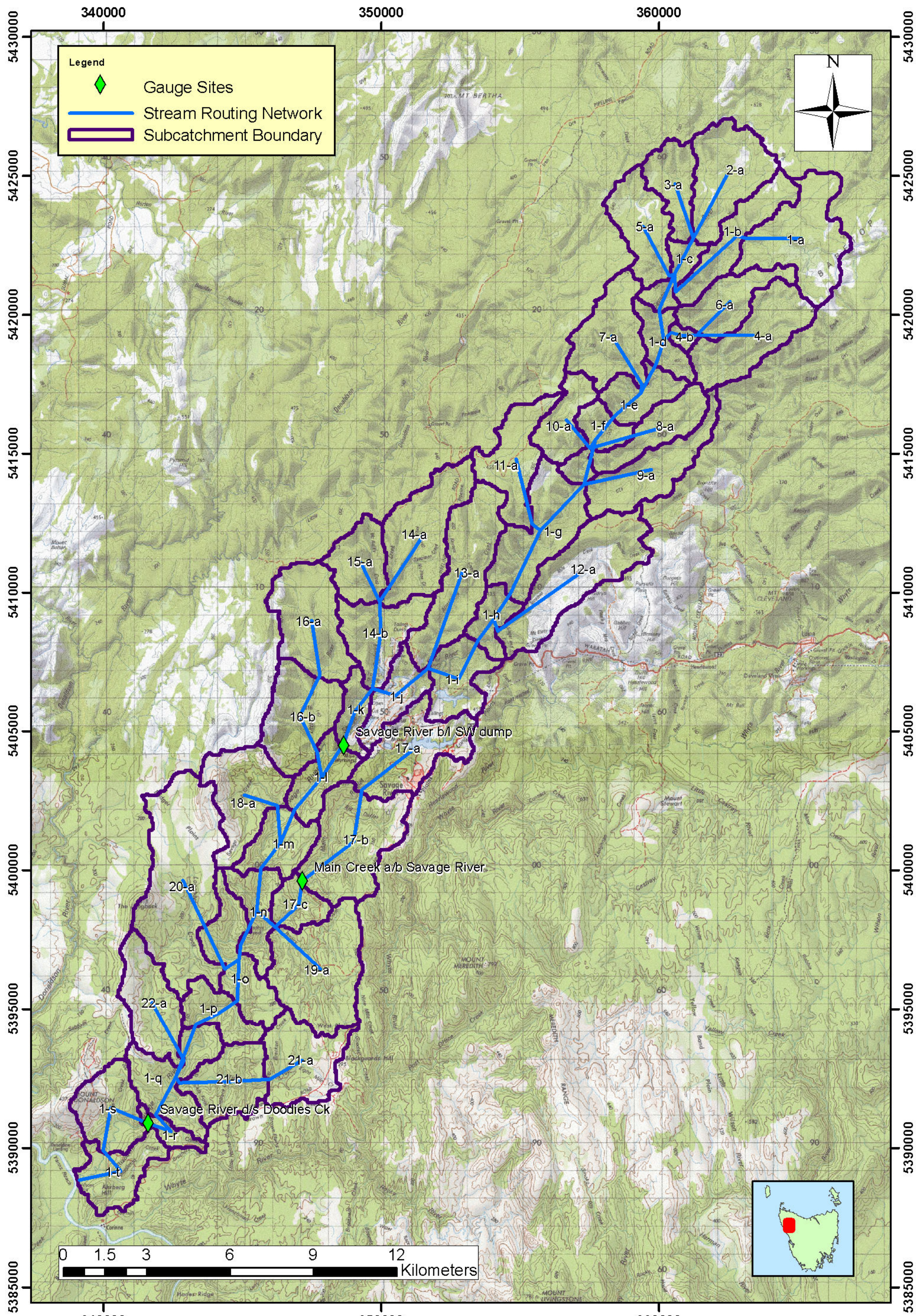

Figure 2-1 Sub-catchment boundaries

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, are 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 Savage 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 Savage 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.

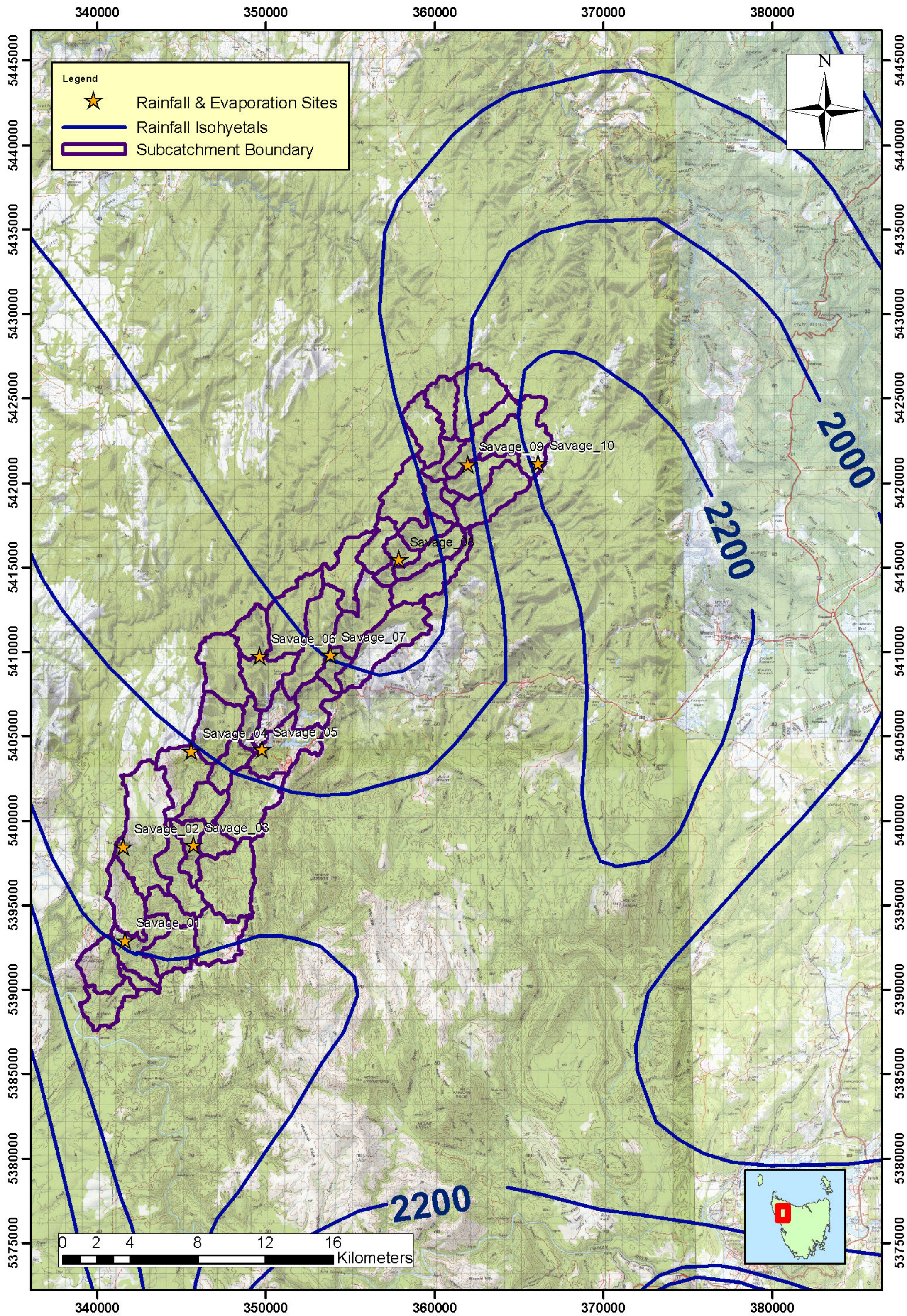

Figure 3-1 Climate Drill site locations

Table 3.1 Data Drill site locations

Site	Latitude	Longitude
Savage_01	-41:36:00	145:06:00
Savage_02	-41:33:00	145:06:00
Savage_03	-41:33:00	145:09:00
Savage_04	-41:30:00	145:09:00
Savage_05	-41:30:00	145:12:00
Savage_06	-41:27:00	145:12:00
Savage_07	-41:27:00	145:15:00
Savage_08	-41:24:00	145:18:00
Savage_09	-41:21:00	145:21:00
Savage_10	-41:21:00	145:24:00

3.4 Comparison of Data Drill rainfall and site gauges

As rainfall data is a critical input to the modelling 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.

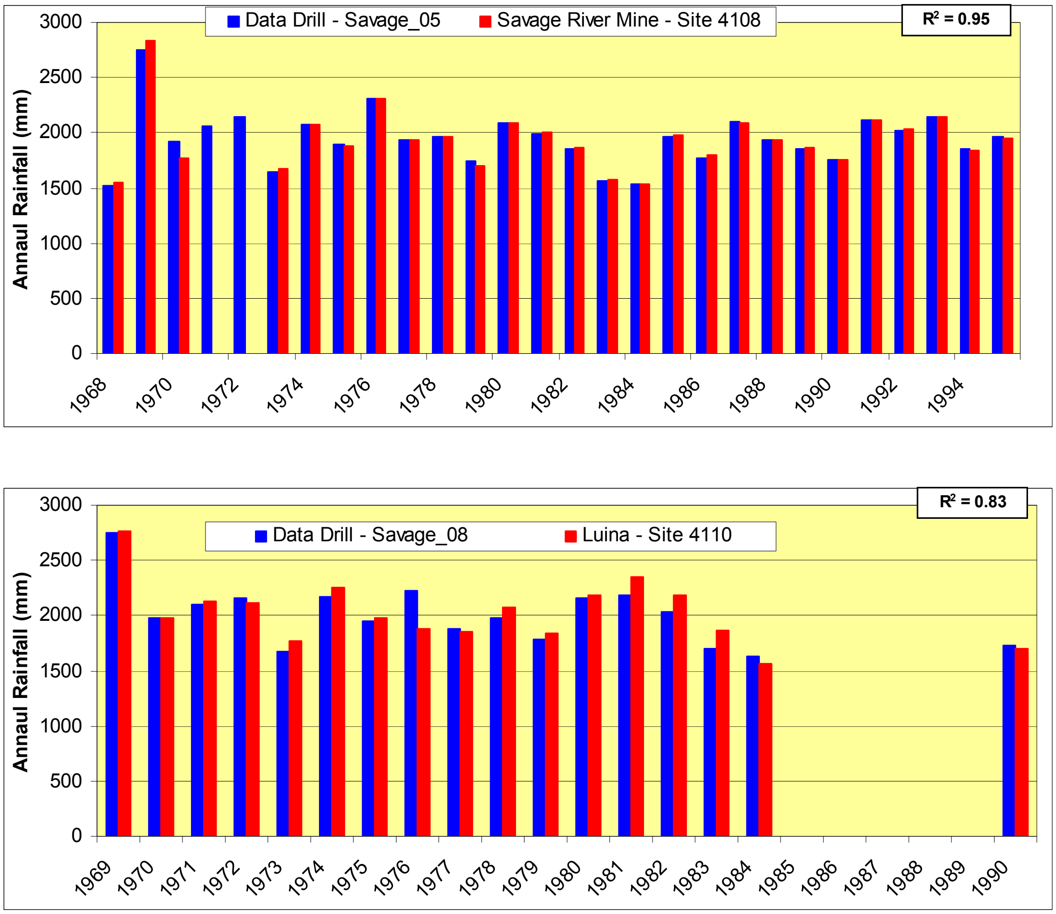

Figure 3-2 Rainfall and Data Drill comparisons

3.5 Streamflow data

Selecting a site suitable for model calibration was difficult for this catchment. Although there were a significant number of DPIW and Hydro Tasmania sites within this catchment there were few with significant periods of record, complete flow ratings and at representative locations in the catchment. Savage River downstream of Doodies Creek (site 10202) had the longest flow record and was located near the catchment's outflow and hence was identified as the main calibration site. As site 10202 had only 10 years of record, it was augmented with the record from Savage River above Doodies Creek (site 2035), which had flow records from an independent 5-year period. Site 2035 is only 400 m upstream of site 10202 and drains only a fractionally smaller catchment area. The record from site 2035 was area-scaled (by a factor of 1.00505) to synthesise a longer record at 10202. This lengthened record was used to calibrate the model. Several other sites were suitable to test the model at different locations. All sites used for calibration and verification of the model are given in the following table.

Table 3.2 Potential calibration sites

Site Name	Site No.	Sub-catchment Location	Period of Record	Easting	Northing	Comments
Savage River downstream of Doodies Creek	10202	SC1_r	19/4/1979 to 25/09/1990	427450	5392900	Low in catchment Longest record in catchment
Savage River above Doodies Creek	2035	SC1_q	13/01/1998 to 25/03/2004	341750	539110	400 m upstream of site 10202
Main Creek above Savage River	2034	SC17_b	16/12/1997 to 8/06/200	350380	5406400	Major Tributary of the Savage River
Savage River below South West Dump	2031	SC1_k	14/01/1998 to 02/03/2005	348550	5404300	Represents flow of approximately half the catchment

Investigations of the rating histories and qualities contained on the Hydro Tasmania's archives for site 10202 indicate that the record appears to be based on a natural control with 3 ratings covering the whole period of record. The record at site 2035 is covered by 1 rating for its entire length. Data at both sites appears to be reliable during the period of interest.

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 modelling 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

There were no unassigned entitlements (Surety = 0) identified for inclusion in this surface water model.

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 modelling 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. For other DPIW surface water models 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. However, with the exception of the Savage River mine there is no other human interference in this catchment and DPIW indicated that no unlicenced extractions were to be accounted for in this catchment. Similarly, no estimates were made for unlicenced storages (small farm dams). A survey of DPIW aerial photographs (dates unknown) confirmed there were no dams in this catchment other than those related to the Savage River Mine.

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.

3.6.1 Estimation of unlicensed (small) farm dams

As there was no agriculture or urban development in this catchment, it was expected there would be no unlicenced dams present. DPIW aerial photographs covered the entirety of this catchment, and a survey of these photographs confirmed that no unlicenced dams were present.

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	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_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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
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	-
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	-
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	-
SC5_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	-
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	-
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	-
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	-
SC14_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_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_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	-
SC17_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_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	-
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	-
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	-
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	-
Total	-	-	-	-	-	-	-	-	-	-	-	-	-

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	713.42	644.38	713.42	690.41	713.42	690.41	713.42	713.42	690.41	713.4	690.4	713.4	**8,400**
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	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_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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
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	-
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	-
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	-
SC5_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	-
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	-
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	-
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	-
SC14_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_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_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	-
SC17_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_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	-
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	-
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	-
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	-
Total	**713**	**644**	**713**	**690**	**713**	**690**	**713**	**713**	**690**	**713**	**690**	**713**	**8,400**

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	713.42	644.38	713.42	690.41	713.42	690.41	713.42	713.42	690.41	713.4	690.4	713.4	**8,400**
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	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_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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
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	-
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	-
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	-
SC5_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	-
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	-
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	-
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	-
SC14_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_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_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	-
SC17_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_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	-
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	-
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	-
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	-
Total	**713**	**644**	**713**	**690**	**713**	**690**	**713**	**713**	**690**	**713**	**690**	**713**	**8,400**

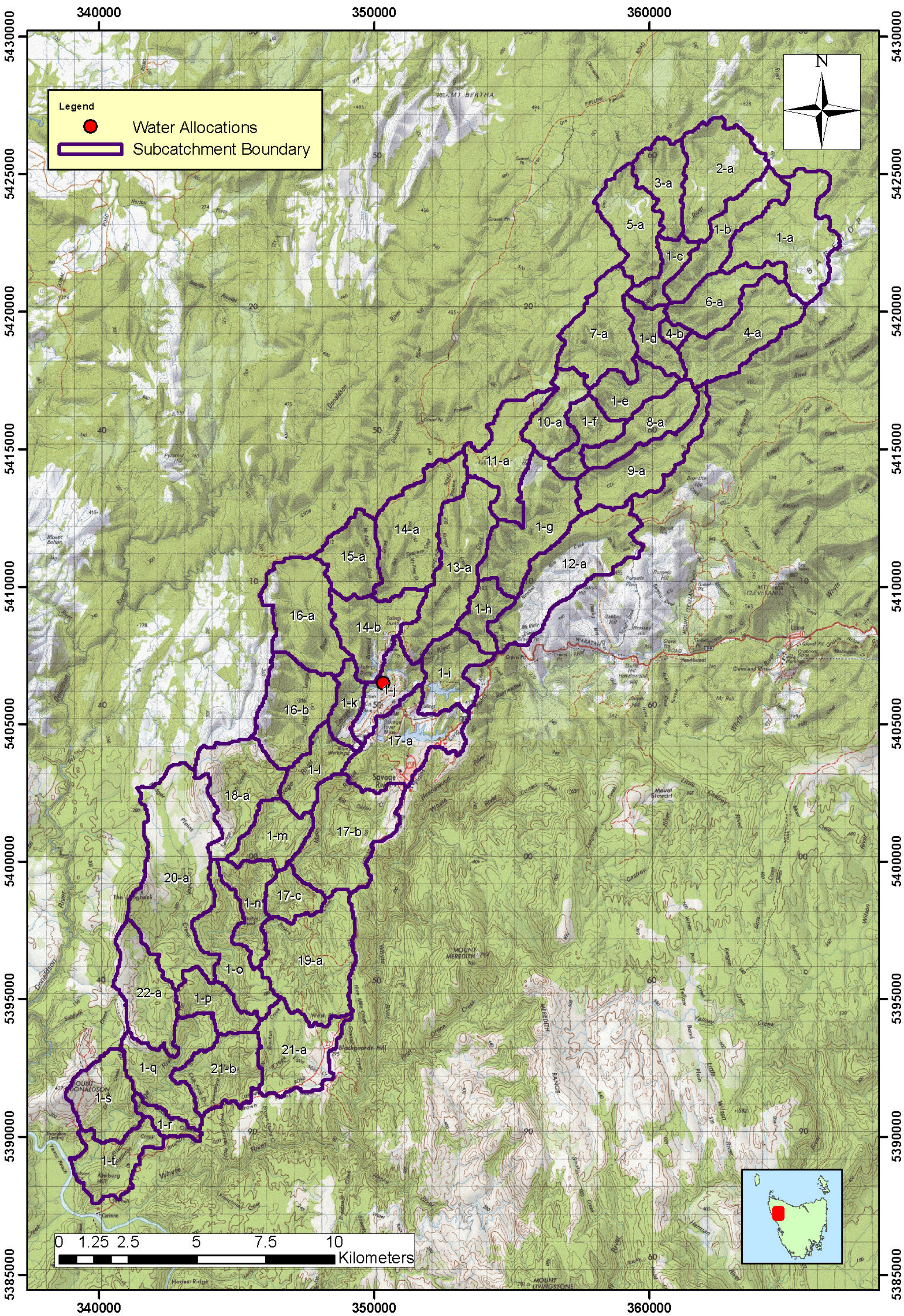

Figure 3-3 WIMS Water allocations

3.7 Environmental flows

One of the modelling scenarios (Scenario 3) was to account for environmental flows within the catchment. DPIW advised, that for the Savage 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 01/01/2008.

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 3.5 Environmental flows

	Sub-Catchment Area (km^2)	Environmental Flow (ML/d) Per Month at each sub-Catchment												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
SC1_a	**10.6**	12.2	6.3	7.4	20.7	36.6	40.5	48.6	59.0	48.9	32.3	27.3	17.2	**29.7**
SC1_b	**6.0**	18.5	9.9	11.3	31.9	55.2	60.6	73.5	90.1	75.0	49.2	42.0	26.3	**45.3**
SC1_c	**2.6**	41.3	22.9	25.8	72.4	123.4	136.4	167.9	203.8	170.4	112.7	95.6	60.1	**102.7**
SC1_d	**3.2**	59.5	33.3	37.4	104.1	177.6	195.7	243.0	294.6	245.9	163.6	138.3	87.0	**148.3**
SC1_e	**3.9**	70.9	40.3	45.1	123.5	210.4	235.7	288.0	352.5	293.9	196.7	165.9	105.0	**177.3**
SC1_f	**3.5**	82.8	47.8	53.3	143.8	243.9	280.7	339.0	414.0	345.2	231.5	195.7	123.1	**208.4**
SC1_g	**9.1**	103.9	60.4	67.8	179.1	302.7	362.8	434.4	519.6	431.2	293.7	248.9	158.2	**263.5**
SC1_h	**2.9**	116.6	68.7	76.8	200.0	334.9	413.3	490.3	582.9	475.7	332.1	276.2	179.4	**295.6**
SC1_i	**5.2**	121.7	72.2	80.5	208.0	346.9	437.1	511.5	607.2	491.0	346.3	284.9	187.5	**307.9**
SC1_j	**4.1**	133.8	81.3	90.5	231.8	382.2	491.4	570.7	674.9	540.7	386.5	310.3	209.6	**342.0**
SC1_k	**2.7**	157.6	98.8	110.1	289.1	454.8	586.2	679.6	803.8	637.8	458.3	357.8	248.8	**406.9**
SC1_l	**4.3**	178.6	114.4	127.2	331.7	510.1	671.5	772.1	909.6	718.3	516.8	402.1	280.0	**461.1**
SC1_m	**4.6**	190.7	123.4	134.1	354.3	534.9	726.4	822.4	967.3	765.8	548.0	427.3	298.0	**491.1**
SC1_n	**4.3**	228.0	150.0	162.5	422.6	619.2	862.9	979.6	1136	915.0	655.5	493.5	352.9	**581.4**
SC1_o	**6.9**	252.4	167.2	176.6	466.6	664.7	947.2	1077.7	1234	1005	723.5	527.0	388.8	**636.4**
SC1_p	**3.8**	256.5	170.3	173.0	473.8	668.2	969.5	1091.3	1259	1014	735.0	532.2	394.6	**644.8**
SC1_q	**7.0**	284.3	190.9	191.9	523.2	728.3	1058.4	1201.6	1368	1098	814.6	575.7	435.9	**705.9**
SC1_r	**1.5**	286.8	192.4	188.2	526.2	725.1	1068.4	1206.1	1377	1100	819.7	579.4	438.0	**708.9**
SC1_s	**6.0**	293.1	197.0	192.7	536.2	733.6	1087.0	1229.0	1400	1116	838.3	591.3	446.7	**721.7**
SC1_t	**5.3**	298.8	199.8	195.9	544.9	739.1	1104.2	1248	1420	1129	854.0	601.5	453.9	**732.4**
SC2_a	**8.7**	9.3	5.1	5.8	16.2	28.1	32.0	38.0	45.9	38.5	25.0	21.3	13.5	**23.2**
SC3_a	**4.6**	4.5	2.6	2.9	7.9	13.7	16.2	19.1	22.6	19.2	12.5	10.7	6.8	**11.6**
SC4_a	**8.4**	8.9	4.9	5.5	15.6	26.8	30.7	36.6	43.8	37.0	23.9	20.4	12.9	**22.2**
SC4_b	**0.7**	15.0	8.4	9.3	26.2	44.9	50.5	61.8	74.4	62.3	41.2	34.9	22.0	**37.6**
SC5_a	**6.3**	6.3	3.6	4.0	10.9	19.0	22.4	26.5	31.3	26.6	17.4	14.8	9.4	**16.0**
SC6_a	**5.3**	5.4	3.1	3.3	9.4	16.2	19.0	22.5	26.7	22.6	14.7	12.5	7.9	**13.6**
SC7_a	**7.9**	7.6	4.3	5.0	13.5	22.9	28.0	32.5	38.0	32.7	21.6	18.1	11.6	**19.6**
SC8_a	**5.0**	4.6	2.7	3.1	8.5	13.9	18.3	20.6	23.6	20.5	13.8	10.9	7.3	**12.3**
SC9_a	**7.2**	6.6	3.9	4.5	12.2	19.6	26.4	29.4	33.5	29.2	19.8	15.2	10.5	**17.6**
SC10_a	**4.2**	3.8	2.3	2.6	7.1	11.3	15.3	17.0	19.4	16.9	11.5	8.8	6.1	**10.2**
SC11_a	**6.8**	6.1	3.7	4.2	11.3	17.6	25.1	27.3	30.6	26.6	18.5	13.9	9.8	**16.2**
SC12_a	**11.5**	10.1	6.3	7.4	18.7	28.4	42.0	46.1	50.0	43.2	31.1	22.8	16.4	**26.9**
SC13_a	**10.4**	9.1	6.0	7.1	17.4	25.8	37.4	42.1	45.6	38.5	28.4	19.9	15.0	**24.4**
SC14_a	**10.1**	9.6	6.5	7.7	19.3	28.3	38.3	43.3	49.1	40.8	29.2	20.9	15.6	**25.7**
SC14_b	**6.5**	22.6	15.0	17.5	44.2	65.9	83.1	97.1	113.0	91.9	64.6	47.2	35.5	**58.1**
SC15_a	**5.1**	5.9	3.7	4.3	11.3	16.6	20.5	23.3	27.6	22.7	15.5	11.7	8.7	**14.3**
SC16_a	**9.0**	10.0	6.5	7.4	19.4	27.3	35.5	40.4	46.7	38.9	26.9	20.1	15.1	**24.5**
SC16_b	**8.2**	17.7	11.7	13.3	35.1	46.6	64.1	74.4	82.8	69.9	49.7	36.3	27.4	**44.1**
SC17_a	**8.8**	8.2	5.5	6.2	15.0	21.5	31.8	36.1	38.1	33.2	23.9	16.9	13.7	**20.8**
SC17_b	**11.1**	18.8	12.5	13.9	34.1	46.5	70.1	81.8	85.2	72.0	54.1	38.3	30.3	**46.5**
SC17_c	**2.9**	21.6	14.3	15.9	39.0	51.7	78.6	93.5	97.7	80.4	62.8	44.0	34.4	**52.8**
SC18_a	**8.1**	7.8	4.9	5.6	14.4	17.8	28.9	32.3	33.2	29.1	21.6	15.3	11.9	**18.6**
SC19_a	**12.0**	11.7	7.2	8.8	20.7	25.4	42.6	48.2	47.6	42.5	32.1	23.0	17.3	**27.3**
SC20_a	**17.9**	17.4	11.0	13.2	30.9	38.5	63.6	72.7	71.0	62.3	47.3	35.2	26.2	**40.8**
SC21_a	**7.6**	7.5	4.7	5.6	12.9	16.1	27.0	30.7	29.7	26.4	20.2	14.8	11.2	**17.2**
SC21_b	**6.2**	13.7	8.8	10.4	23.3	29.4	48.1	54.9	53.9	46.5	36.7	26.8	21.1	**31.1**
SC22_a	**6.9**	6.9	4.3	5.2	11.6	15.0	24.2	27.5	26.7	23.4	18.1	13.2	10.5	**15.5**

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 modelling 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 rainfall and evaporation is 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.

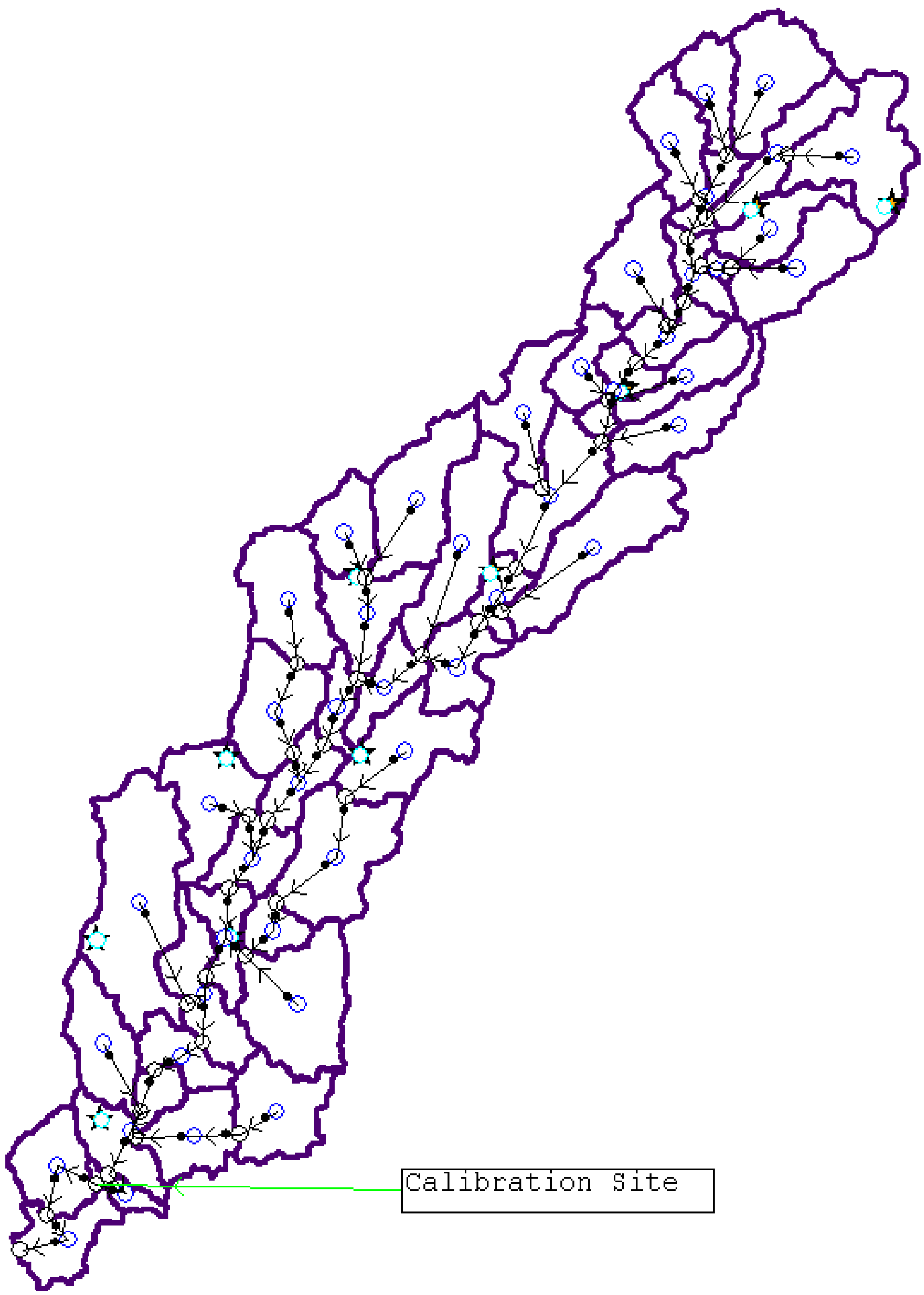

Figure 4-1 Hydstra Model schematic

4.3 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 4.1 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.

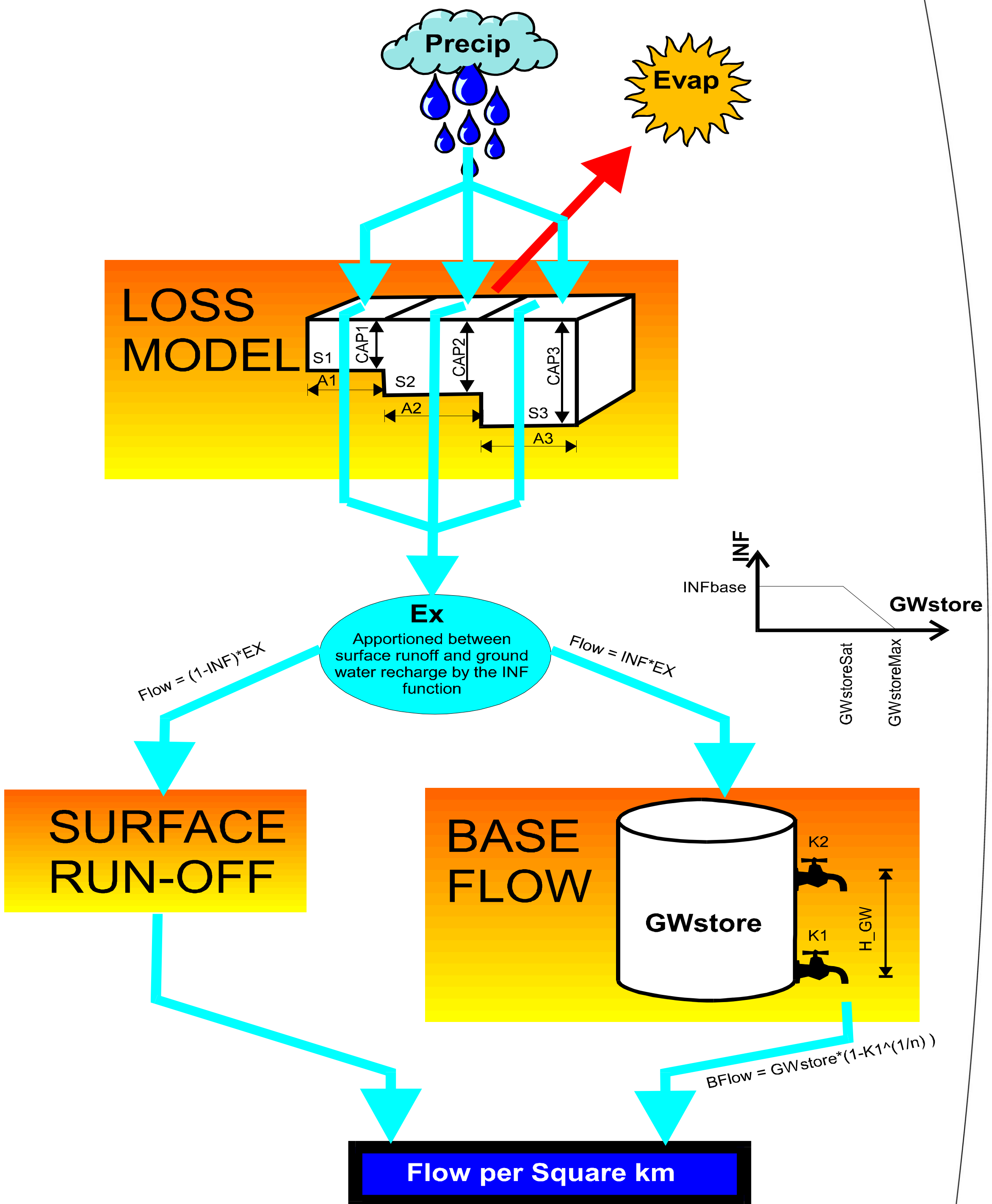

Figure 4-2 Two Tap Australian Water Balance Model schematic

4.3.1 Channel Routing

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

$$S = K.Q^n$$

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 (ML/day)

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 4.2 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

Generally catchments with steeper topography and faster flowing rivers have less channel lag (i.e. lower alpha values) than flatter catchments. The Savage River drains a steep catchment, and the alpha value was adjusted accordingly.

4.4 Model Calibration

Calibration was achieved by adjusting catchment parameters so that the modelled 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 modelled calibration flow (MCF) to the observed flow record. The MCF can be described as:

MCF = MNEM - (WE)

Where:

MCF = Modelled Calibration Flow

MNEM = Modelled - No Entitlements (Modified). *

WE = Water Entitlements

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

In the Savage River catchment, data from the period 21/04/1979 to 24/03/2004 was selected at Savage River downstream of Doodies Creek (site 10202) for calibration. As noted in section 3.5, this site record only extends from 21/04/1979 to 25/09/1990, but has been augmented with scaled flows from Savage River above Doodies Creek (site 2035) from 13/01/1998 to 24/03/2004. Thus the calibration period, while running from 1979 – 2004, only contains approximately 15 years of observed flow data.

In other DPIW surface water models, water entitlements included in the calibration model have been adjusted to the time period of calibration by applying a Time Period Reduction Factor (TPRF). This is essentially to account for historically lower agricultural and urban demand for water. As there has never been water extracted for agricultural or urban purposes in the Savage River catchment, no TPRF has been applied here.

The model was calibrated to the observed flow as stated in the formula MCF = MNEM - (WE). 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 the water entitlement is extracted at a constant daily flow for each month. For each daily time step of the model if water entitlements cannot be met, the modelled 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 4.4 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 4.3. 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 4.3 Adopted Calibration parameters

PARAMETER	VALUE	PARAMETER	VALUE
INFBase	0.5	CapAve Jan	5
K1	0.95	CapAve Feb	7
K2	0.94	CapAve Mar	10
GWstoreSat	45	CapAve Apr	15
GWstoreMax	65	CapAve May	25
H_GW	60	CapAve Jun	37
EvapScaleF	1	CapAve July	51
Alpha	2.6	CapAve Aug	57
n	0.8	CapAve Sept	51
		CapAve Oct	25
		CapAve Nov	9
		CapAve Dec	5

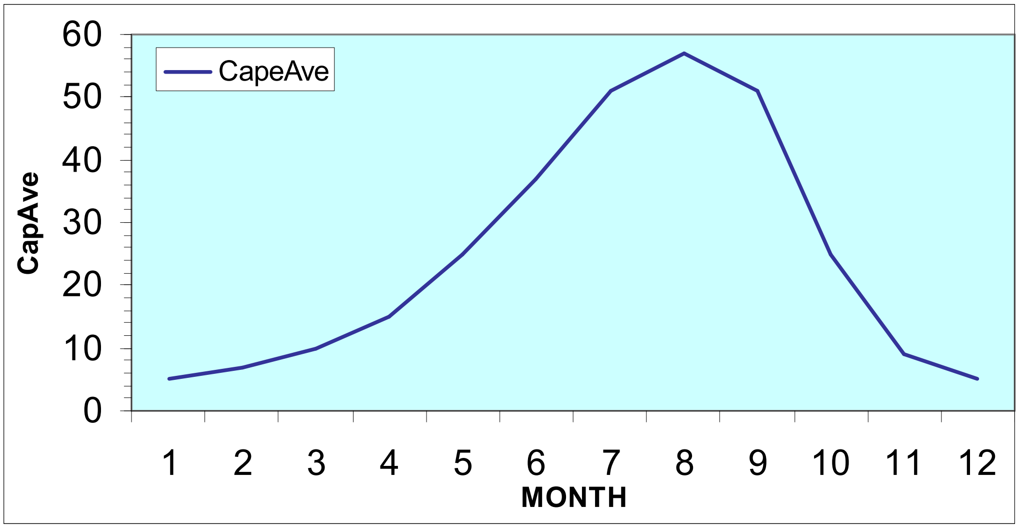

Figure 4-3 Monthly Variation of CapAve parameter

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 location.

Daily time series plots of three discrete calendar years (Figure 4-4 to Figure 4-6) have been displayed for the calibration location, 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. Overall the correlation and fit is very good, although R^2 was generally higher in the latter portion of the calibration period (1998-2004), when the observed record was derived from Savage above Doodies Creek (site 2035; R^2 = 0.85) than for the earlier portion of the observed record (1979-1990), when the record came from Savage downstream of Doodies creek (site 10202; R^2 = 0.80). It is assumed this is due to the reliability of the different ratings applied at these sites.

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.

The monthly time series, over the period of calibration, are plotted in Figure 4-7 and overall shows a good comparison between Modelled Calibration Flow and observed totals at the calibration location.

The monthly, seasonal and annual volume balances for the whole period of calibration record are presented in Figure 4-8 and Table 4.4 and show excellent correlation and fit. The demand values shown represent the adopted total water entitlements upstream of the calibration location, which have been multiplied by 5 for plotting purposes. The demand has been included to provide a general indication of the relative amount of water being extracted from the river.

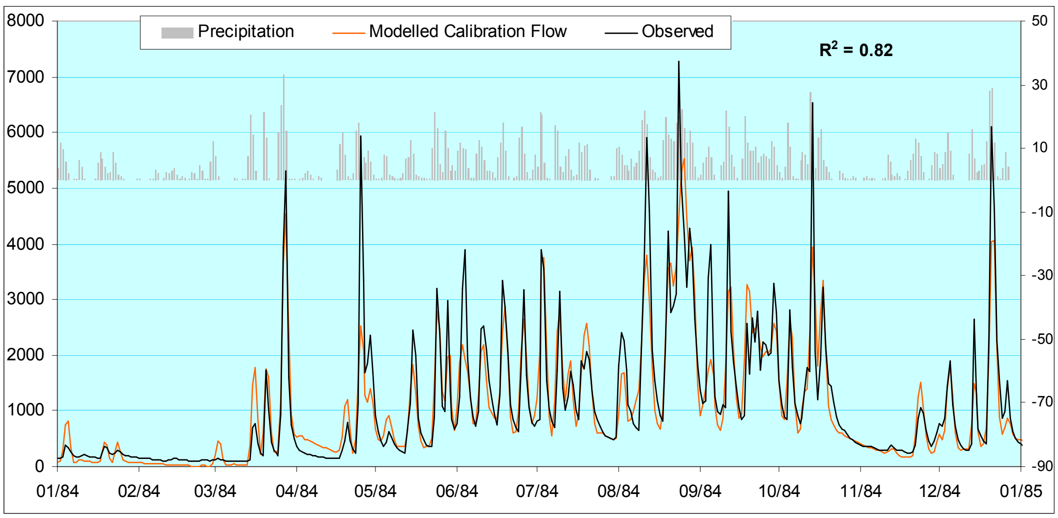

Figure 4-4 Daily time series comparison (ML/d) – Savage River - Good fit.

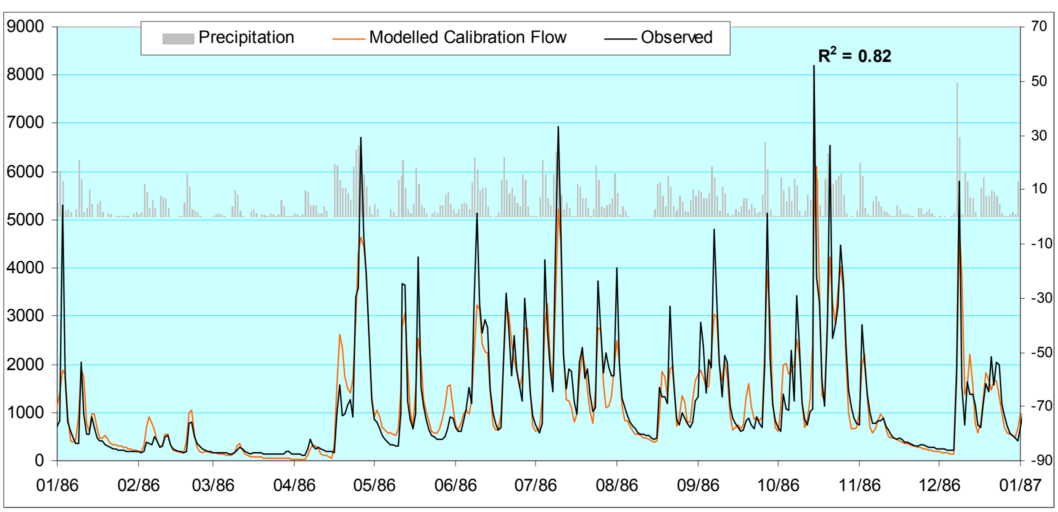

Figure 4-5 Daily time series comparison (ML/d) – Savage River – Good fit.

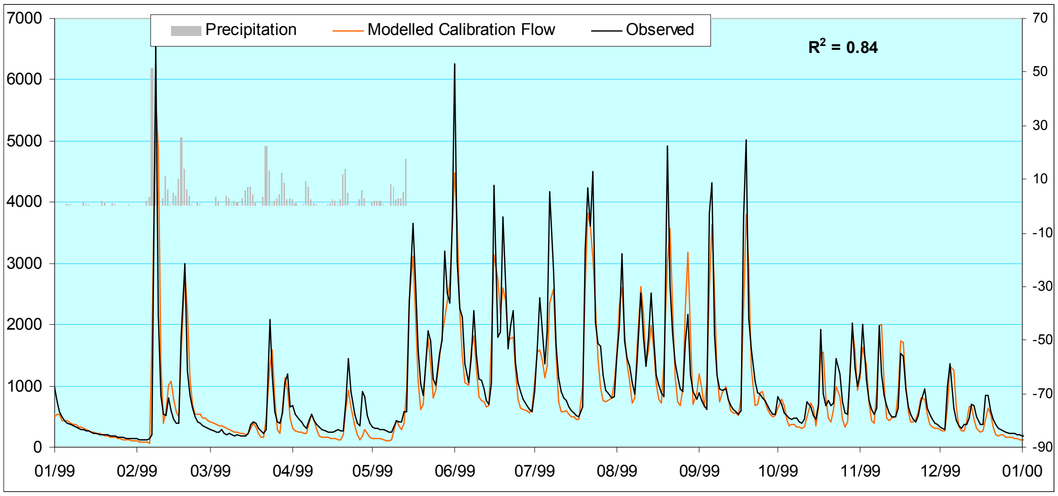

Figure 4-6 Daily time series comparison (ML/d) – Savage River – Good fit.

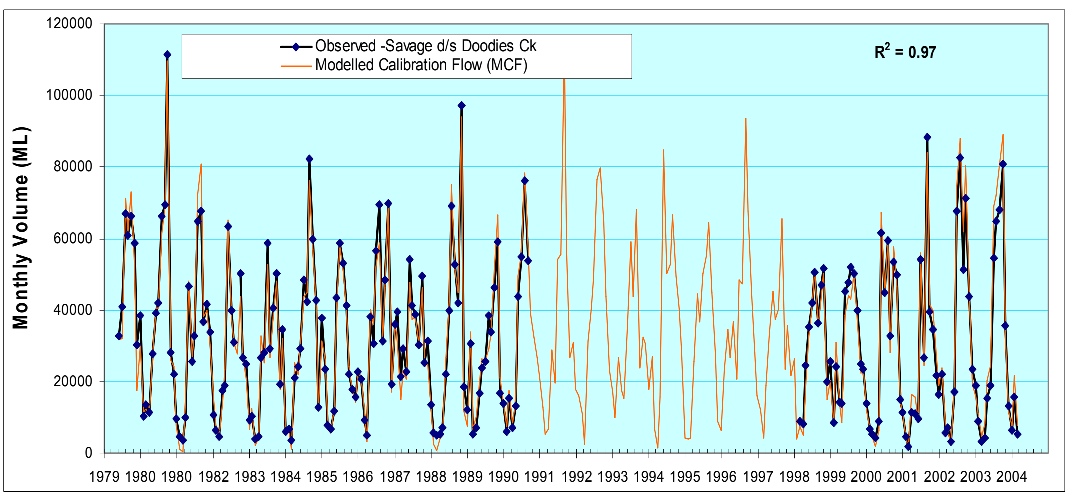

Figure 4-7 Monthly time series comparison – volume (ML)

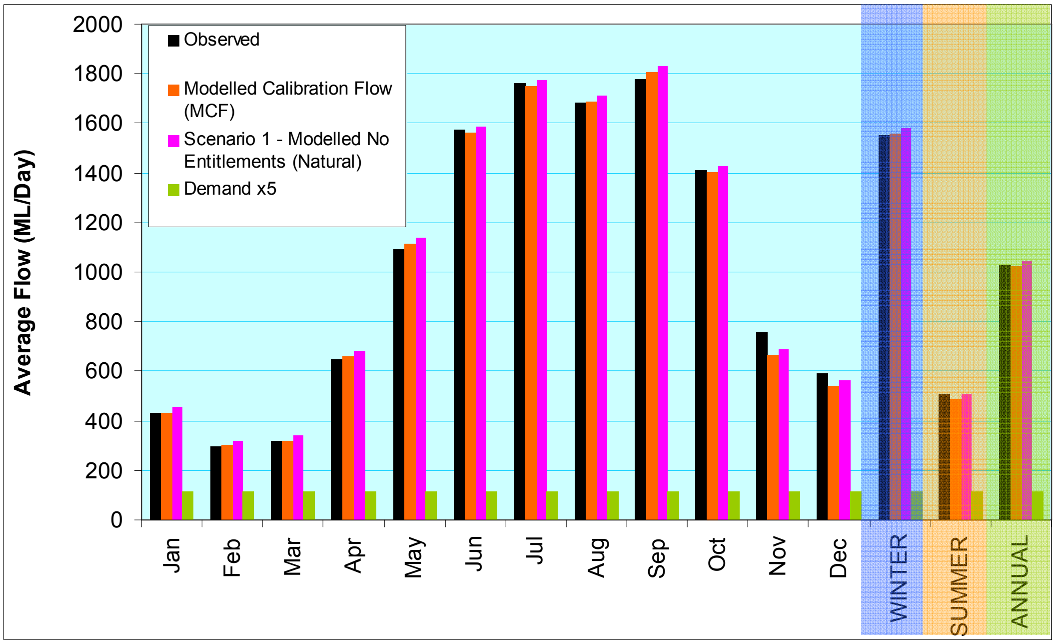

Figure 4-8 Long term average monthly, seasonal and annual comparison plot

Table 4.4 Long term average monthly, seasonal and annual comparisons

MONTH	Observed	Modelled-Calibration Flow (MCF)	Scenario 1 "Modelled -- No Entitlements (Natural)"	Demand[1]
Jan	429.96	434.15	457.04	23.01
Feb	296.27	299.14	320.87	23.01
Mar	318.99	320.64	342.58	23.01
Apr	649.46	659.08	681.48	23.01
May	1092.39	1111.67	1134.78	23.01
Jun	1572.93	1562.78	1585.82	23.01
Jul	1762.92	1752.28	1775.26	23.01
Aug	1684.02	1686.39	1709.38	23.01
Sep	1776.25	1806.01	1829.02	23.01
Oct	1410.01	1404.96	1427.93	23.01
Nov	754.04	663.83	686.71	23.01
Dec	591.63	538.99	561.94	23.01
WINTER	1549.75	1554.01	1577.03	23.01
SUMMER	506.72	485.97	508.44	23.01
ANNUAL	1028.24	1019.99	1042.74	23.01
WINTER from May to Oct, **SUMMER** from Nov to Apr.				

[1] The demand value includes all extraction potential upstream of the calibration site.

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. The precipitation and evaporation for each sub-catchment is calculated using an inverse distance gauge weighting. Topography varies 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.

8. Approximately one third of the Savage catchment is underlain by Karst formations. As this rock type is often associated with subsurface flow, there may be subterranean inter-catchment water transfers (both into and out of the catchment) of unknown quantity. This model assumes that all the water reaching the river originates from rainfall falling within the catchment, and does not explicitly account for any subterranean losses.

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 4.5 shows the R^2 values between observed and modelled daily and monthly flows, as well as the proportional difference (%) between long-term (15 years) observed and modelled calibration flow.

Table 4.5 Model Fit Statistics

Measure of Fit	Savage River d/s Doodies Ck. (Site 10202)
Daily coefficient of determination (R^2 Value)	0.82
Monthly coefficient of determination (R^2 Value)	0.97
Difference in observed and estimated long term annual average flow	-0.80%

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 4.6 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 4-9 and Figure 4-10 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 4-9, for the *All Record* trace, 70 % of the time the difference between the MCF and observed flow is less than 40 %. Similarly in Figure 4-10, for the *All Record* trace, 80 % of the time the difference between the MCF monthly volume and observed volume is less than 20 %.

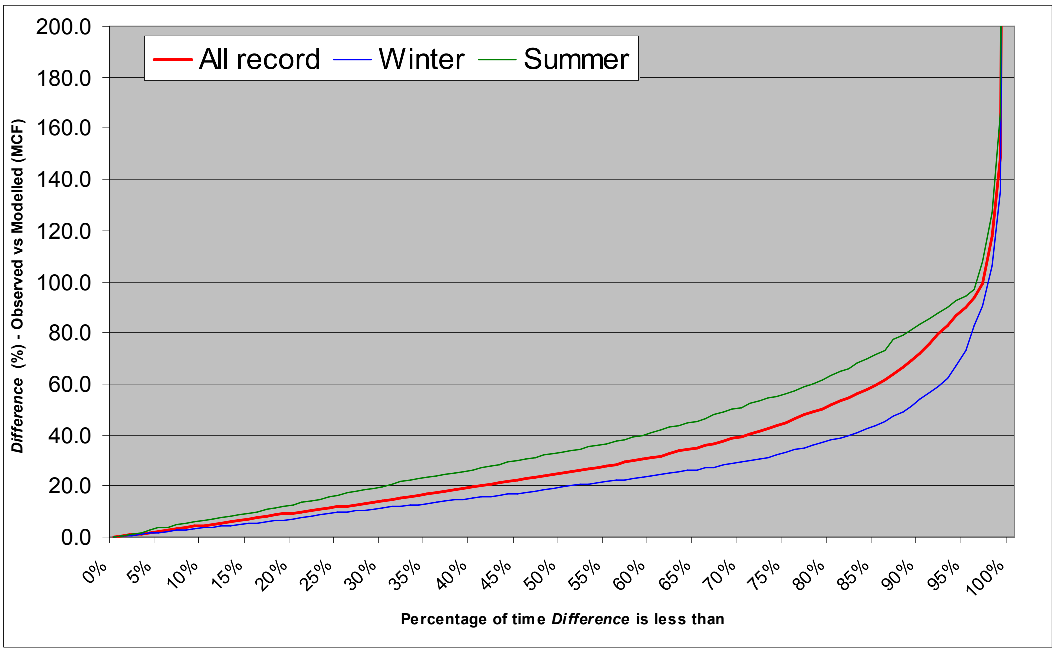

Figure 4-9 Duration Curve – Daily flow percentage difference

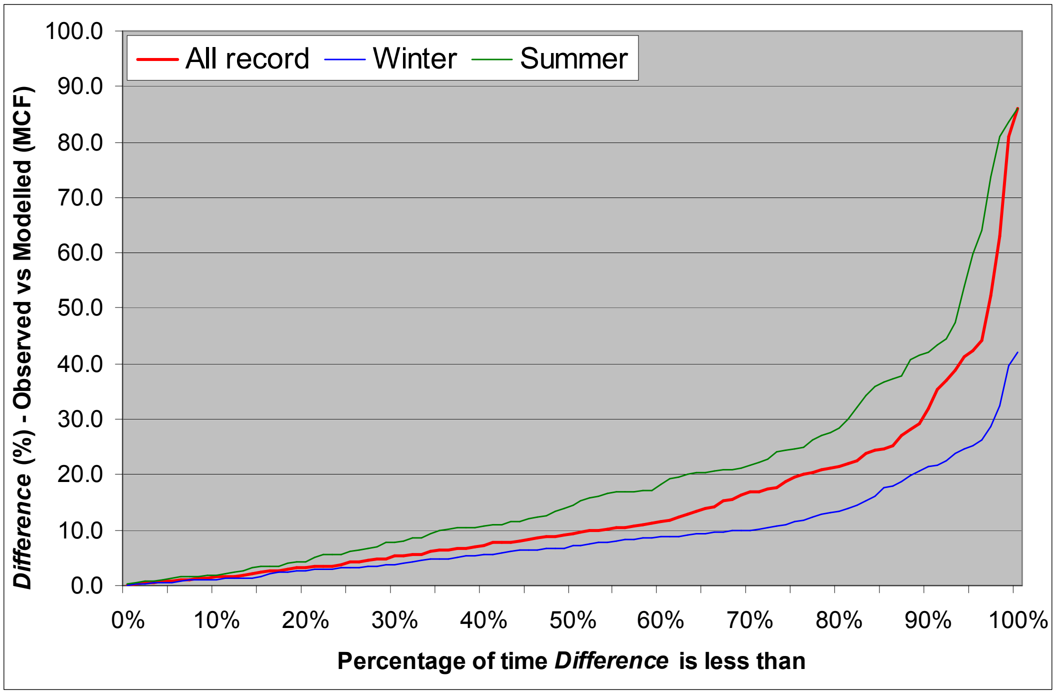

Figure 4-10 Duration Curve – Monthly volume percentage difference

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

[2] Summer period = Nov to April.

[3] Winter period = May to Oct.

in predicting monthly volumes at other locations has been analysed for five river 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 Savage catchment there are two other gauging sites which can be used to assess the calibration fit at alternative locations. Plots of the monthly times series volumes and the corresponding R^2 values are shown in Figure 4-11 and Figure 4-12. Figure 4-11 shows that the correlation between modelled and observed volumes at the Savage River d/s SW Dump site is comparable with that of the calibration site. While the coefficient of determination for Main Creek given in Figure 4-12 is still ‘good’, modelled flows are generally lower than observed flows. This may be due to two reasons: 1) Savage River Mine has a large tailings dam at the top of the Main Creek catchment, which has not been specifically accounted for in this model but which may affect flows; 2) other unknown mining impacts on river flows.

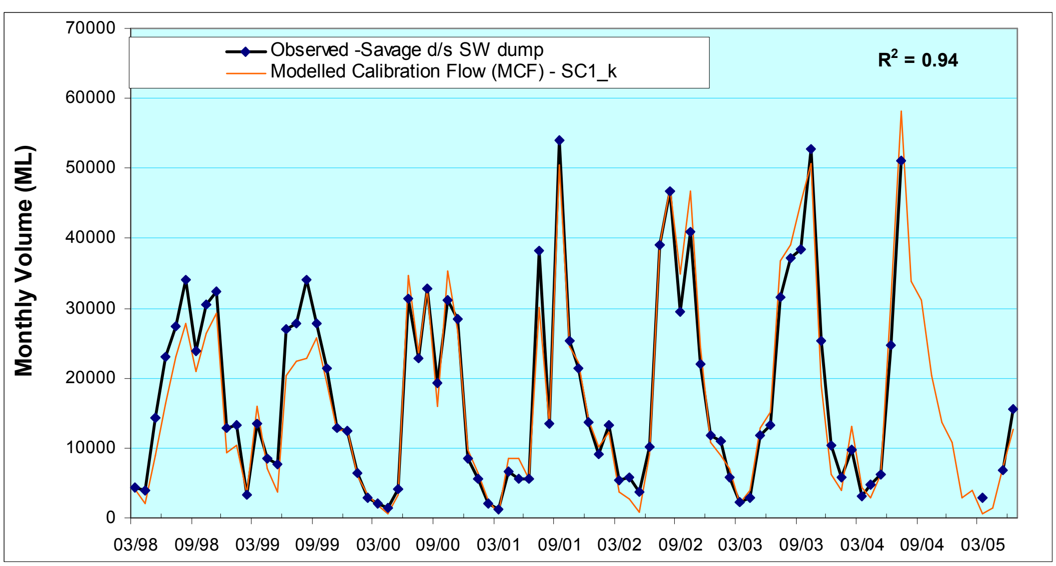

Figure 4-11 Time Series of Monthly Volumes- Site 2031

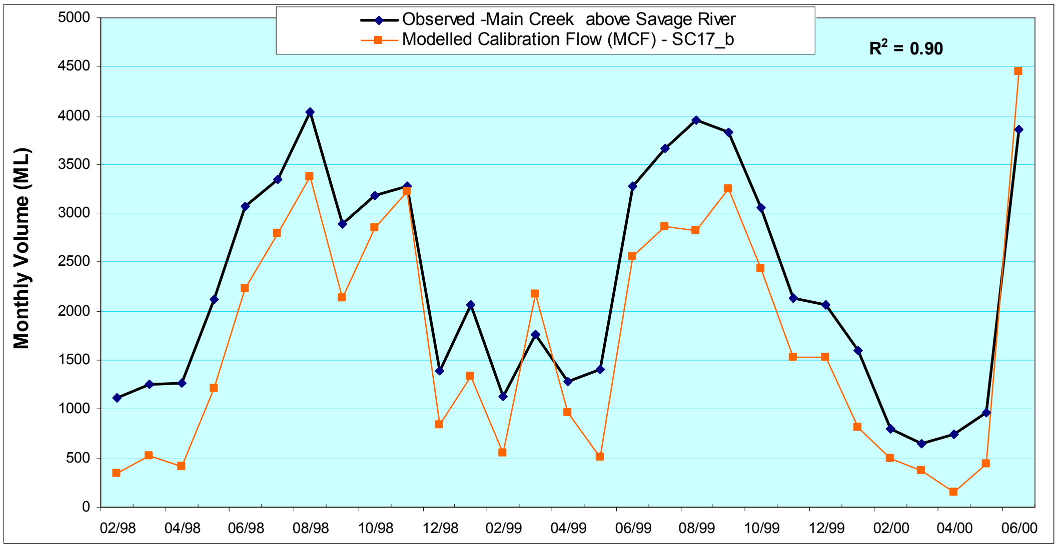

Figure 4-12 Time Series of Monthly Volumes- Site 2034

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 period 01/01/1900 to 01/01/2008. Results have been produced at the calibrations site, Savage River downstream of Doodies Creek, site 10202. Due to the low level of extraction from the Savage River, both traces plot very close together.

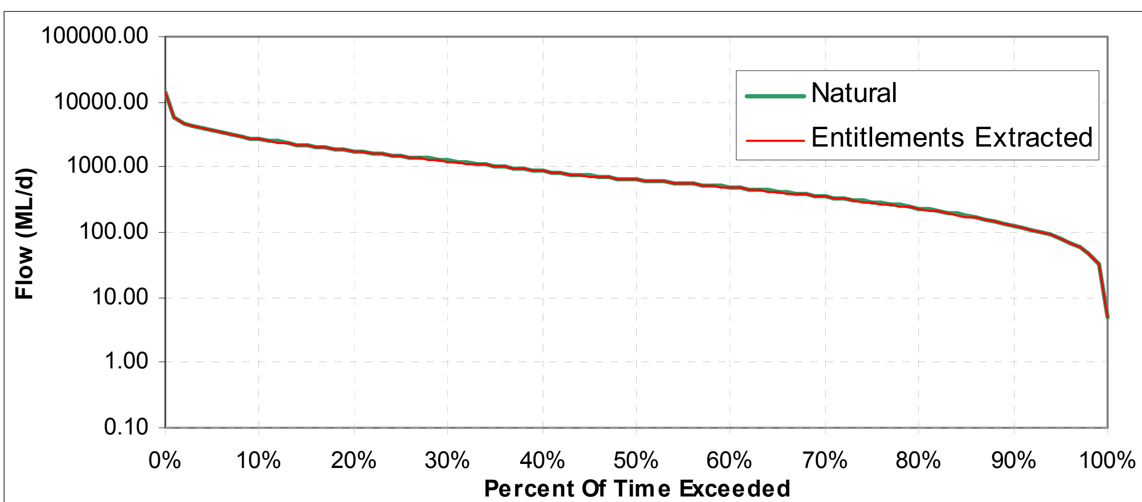

Figure 5-1 Daily Duration Curve

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 01/01/1900 to 01/01/2008. Two sites in addition to the calibration site 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_r Savage River d/s Doodies Creek	SC1_j (Mid catchment)	SC1_f (High in catchment)
Index of Mean Annual Flow, A	1.00	0.99	0.98	1.0
Index of Flow Duration Curve Difference, M	1.00	0.99	0.98	1.0
Index of Seasonal Amplitude, SA	1.00	0.98	0.97	1.0
Index of Seasonal Periodicity, SP	1.00	1.00	1.00	1.0
Hydrological Disturbance Index, HDI	**1.00**	**0.99**	**0.98**	**1.0**

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

A flood frequency plot has been developed at the Savage River downstream of Doodies Creek (site 10202). The plot shown below in Figure 6-1 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 Savage River downstream of Doodies Creek site in total 10[4] annual maxima values were available for this flood frequency analysis. 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 does 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 affect the accuracy of the modelled flood peaks used in the development of this flood frequency curve.

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[4] 10 years of data is considered the minimum period required for production of a flood frequency curve.

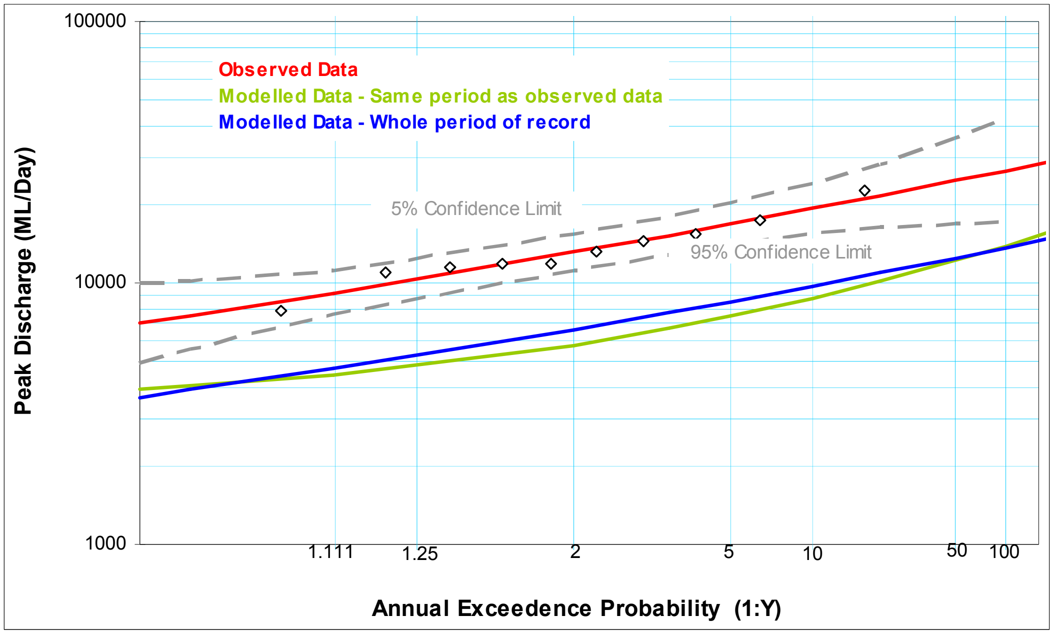

Figure 6-1 Modelled and Observed Flood Frequency Plot - Savage River d/s Doodies Creek

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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 man made 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 man made 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 out perform 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.

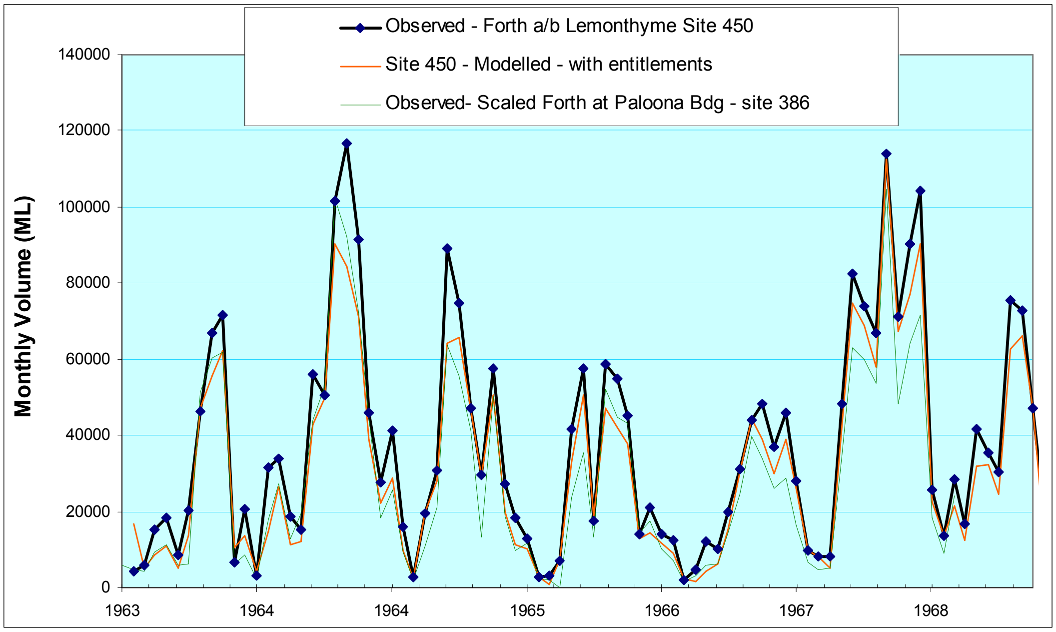

Figure A-1 Forth catchment – monthly volumes at secondary site.

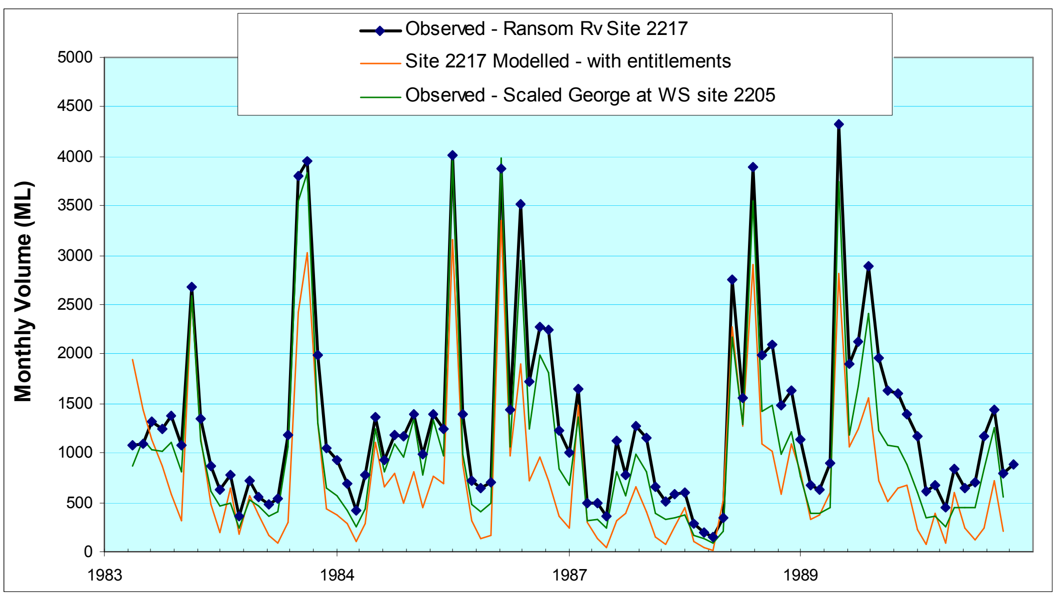

Figure A-2 George catchment – monthly volumes at secondary site.

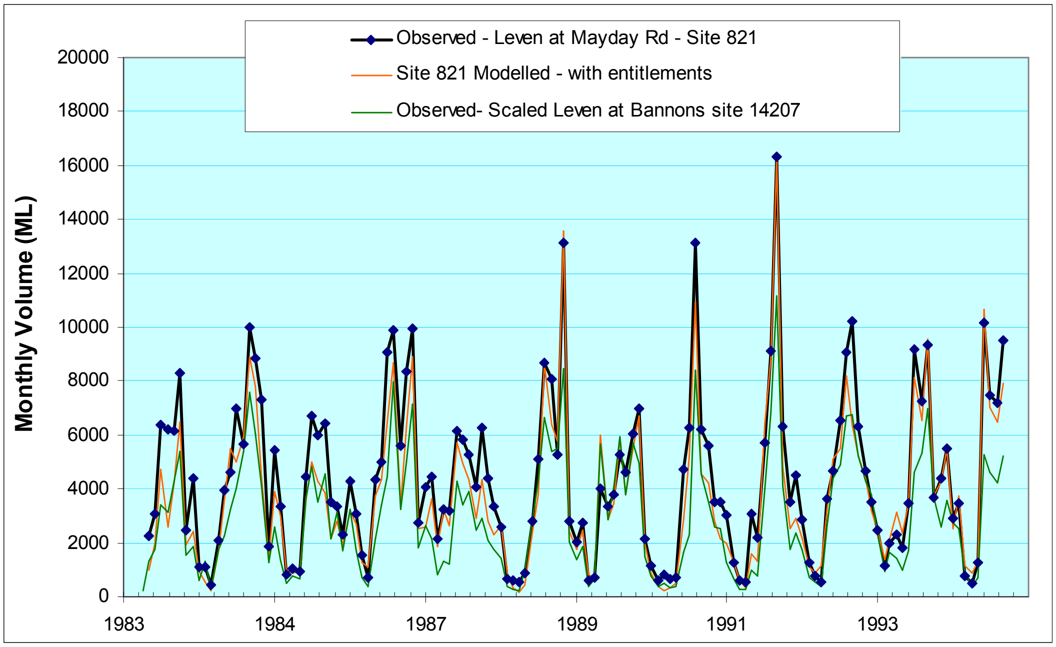

Figure A-3 Leven catchment – monthly volumes at secondary site.

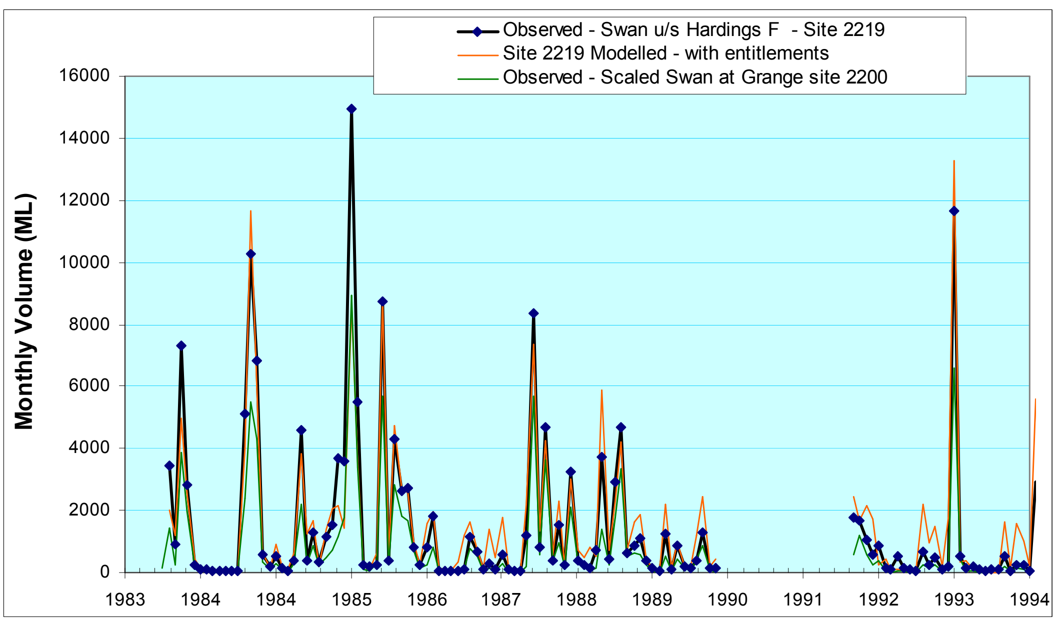

Figure A-4 Swan catchment – monthly volumes at secondary site.

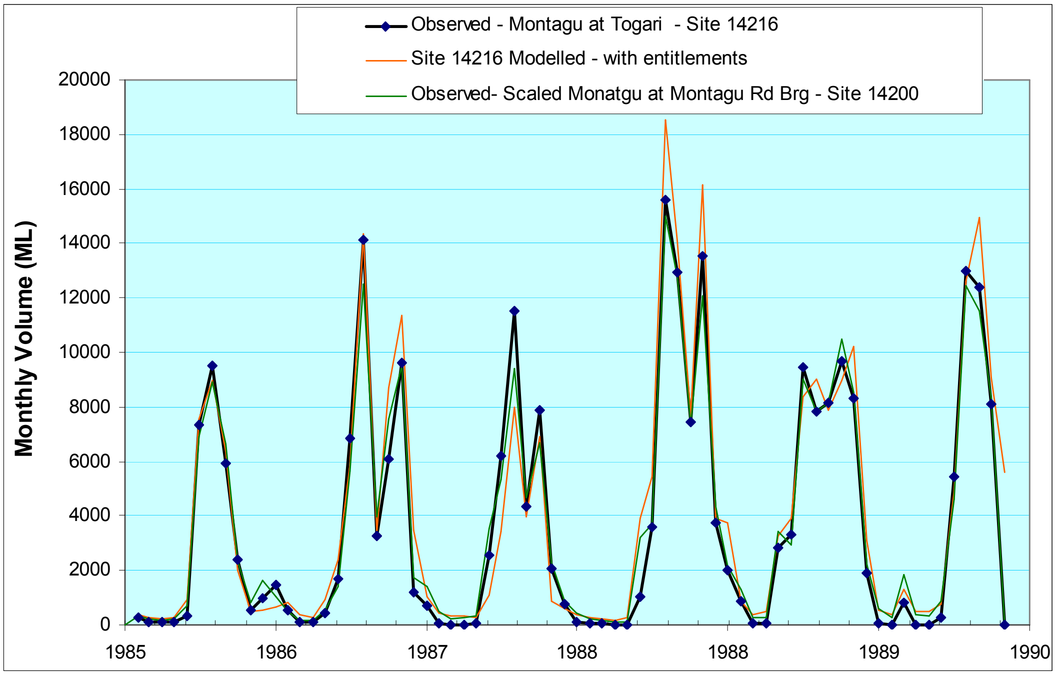

Figure A-5 Montagu catchment – monthly volumes at secondary site.

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	Ransom 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