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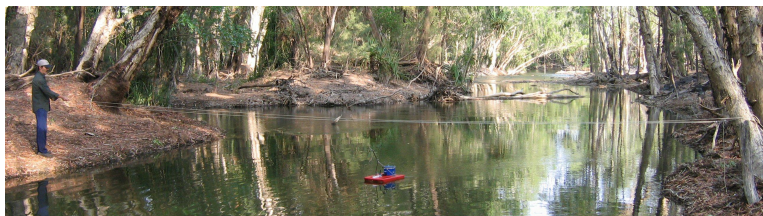
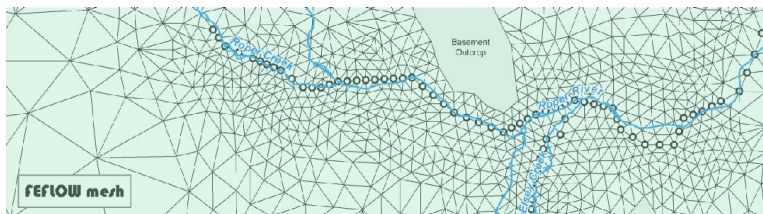
A Territory Government initiative

Gulf Water Study

Integrated Surface - Groundwater

Model of the Roper River Catchment

Part B: MIKE11 Surface Water Model



Australian Government
Water Smart Australia

Department of Natural Resources, Environment, The Arts & Sport

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Gulf Water Study

**An integrated surface – groundwater model
of the Roper River Catchment, Northern Territory**

Part B – MIKE11 Surface Water Model

Author:

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Department of **Natural Resources, Environment, The Arts & Sport**

Technical Report No. 31/2009D

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Cover Image: top to bottom: Anthony Knapton at Bitter Springs, FEFLOW Mesh and Flow Gauging on the Roper River

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Summary

The Gulf Water Study is a three year project funded jointly by the Australian Government's Water Smart Australia Program and the Northern Territory Government. The Smart Australia Program aims to accelerate the development and uptake of smart technologies and practices in water use across Australia.

Water reform through the Australian Government National Water Commission's National Water Initiative (NWI) has established that environmental water provisions should be made prior to allocating to other consumptive uses. This has proven difficult in Southern Australia with its history of urban and rural developments. There is an opportunity here in the tropical north to do it smart. We can obtain the knowledge on environmental water provisions before allocation.

A key outcome of the Gulf Water Study is the development of an integrated surface – groundwater model of the Roper River. The integrated model of the Roper River will provide water allocation planners with quantitative information on the water resources and identifies likely groundwater dependent ecosystems. This information will help in long term decision making and identify the areas where further study is required. The integrated model also provides quantitative information, through the ability to undertake scenario modelling, that will ensure that the current and planned regional water development remain within ecologically sustainable limits.

A numerical hydrologic model to simulate surface water flows of the Roper River and its' tributaries has been developed. The model has been developed with particular emphasis on the dry season flows associated with groundwater discharge from regional aquifers.

A working surface water model of the Roper River has been developed with the MIKE suite of software. The model has been designed to examine low flows with the capacity to couple to a suitable groundwater model. Historic flows have been calculated using historic climate data from 1900 - 2009.

Typically the available streamflow data is from the 1970s and 1980s, with only a few locations having streamflow data extending back to the 1950s. There is also a reduced data set through to the present due to closures of gauging stations in recent years. The relatively short period of flow record is often compounded by unreliable rating tables for higher flow events, therefore calibration of the rainfall-runoff model has been difficult and is probably unreliable for high stage heights and flows for some rivers.

Currently there are limitations with the cross-section data including the elevation accuracy, the length of cross-sections beyond the river bank and general coverage of cross-section data, particularly at river branch junctions.

The numerous pools along the length of the Roper River need to be defined to estimate storage, further cross-section surveys will provide this information.

NAM calibration indicates Upper Roper River (Basin A), Flying Fox Creek (Basin C), Mainoru River (Basin D), Wilton River (Basin E), Upper Roper River (Basin L) and to a lesser extent the Waterhouse River (Basin B) demonstrate baseflow due to groundwater discharge. Roper River estuary (Basin G), Hodgson / Arnold River (Basin H), Strangways River (Basin I) and Elsey Creek (Basin J) do not exhibit baseflow.

This report documents an attempt at modelling the entire Roper River catchment using the MIKE11 river modeling software (DHI, 2007).

1 Introduction

The purpose of this study is to develop a hydrologic model to simulate surface water flows of the Roper River with particular emphasis on the dry season flows associated with groundwater discharge from regional aquifers.

The hydrologic assessment of the Roper River is based on the application of a numerical model using the 1-D MIKE11 unsteady channel flow model developed by the Danish Hydrologic Institute (DHI, 2007).

The MIKE11 model is a quasi two-dimensional unsteady flow model used for simulating flows in rivers, estuaries, drainage networks and other water bodies. The model solves both branched and looped networks and can simulate hydraulic structures such as culverts and bridges. The model computational scheme can be applied to vertically homogeneous flow conditions extending from steep river flows to tidally influenced estuaries.

MIKE11 requires input at the open ends of the model. Hydrographs generated from rainfall – runoff modelling with NAM are used as input into the model's upstream open boundaries, whilst the downstream boundaries were modelled using tidal data. Evaporational losses have been included in the model to simulate the observed losses due to evapotranspiration from riparian vegetation and the free water surface of the river.

1.1 Location

The study is centred on the Roper River catchment approximately 400 km to the south east of Darwin in the Northern Territory of Australia refer **Figure 1**.

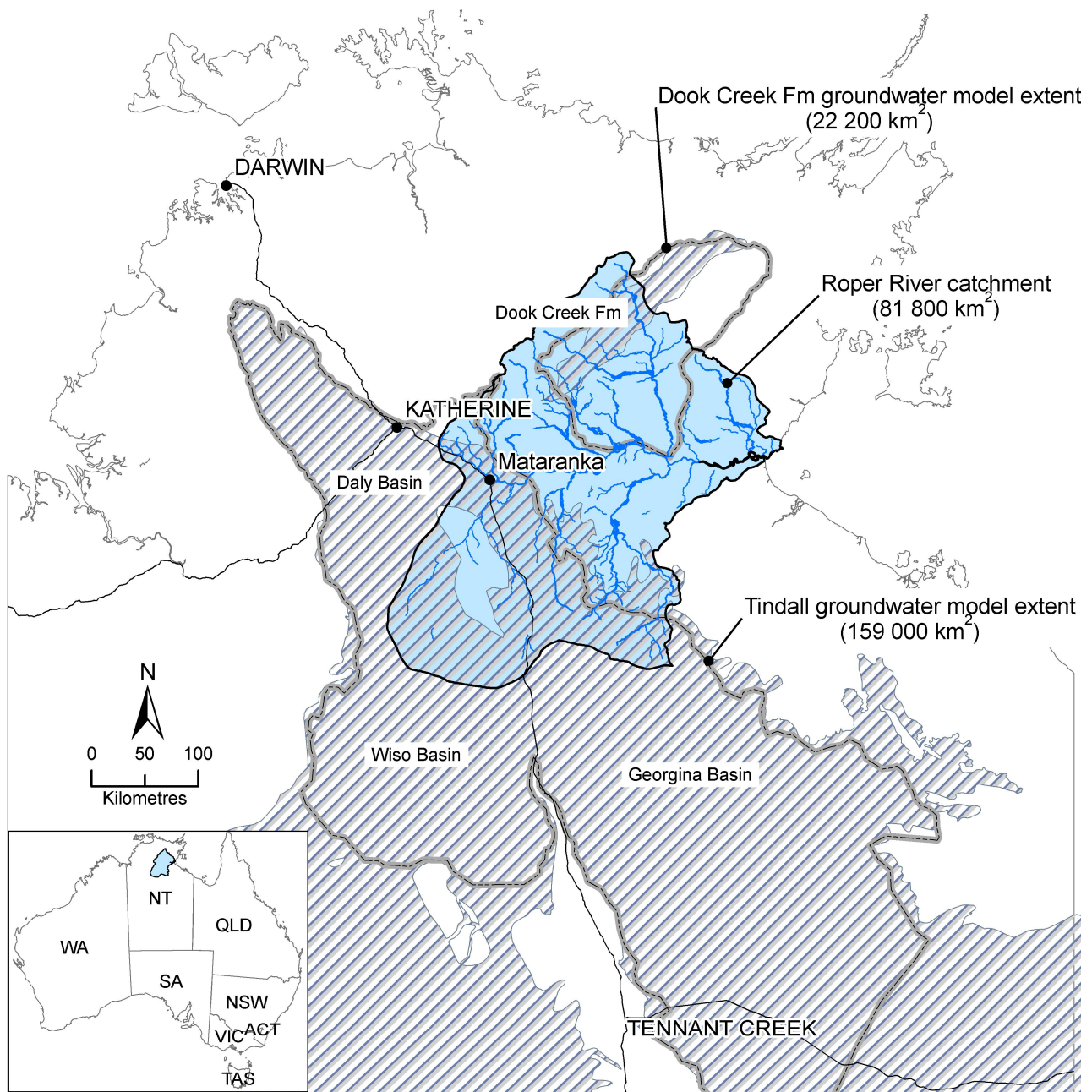


Figure 1 Location of the Roper River catchment underlain by geology to demonstrate areas with aquifers supplying baseflow to the river.

1.2 Climate

The climate of the region based on the Köppen Geiger classification (Peel et al., 2007) the northern half of the catchment is classified as tropical ('wet-dry tropics') and the southern half of the catchment is semi-arid.

As typical of the wet-dry tropical climate, the rainfall in terms of quantity and timing, is highly variable within and across years. There is a slight variation in pattern indicated by the rainfall at Mataranka (inland) and Ngukurr (on the Gulf of Carpentaria). The mean monthly rainfall for each of these centres on **Figure 2** indicates that the catchment area experiences extremes of high rainfall during the wet season between October and April and the near absence of rainfall in the intervening dry season. Average annual rainfall is 989 mm, 810 mm and 785 mm for Katherine,

Mataranka and Ngukurr respectively. However, the rainfall pattern is less attenuated towards the coast where more than 50 mm is received at Ngukurr in April, compared to about half this amount further inland (refer **Figure 2**). In the dry season from May to September, less than 10 mm of rainfall may be expected in any month. **Figure 2** presents summary data for Katherine (DR014903) for the period 1900 – 2009, Mataranka (DR014610) for the period 1917 – 2009 and Ngukurr (DR014609) for the period 1910 – 2009 (Clewett et al., 2003).

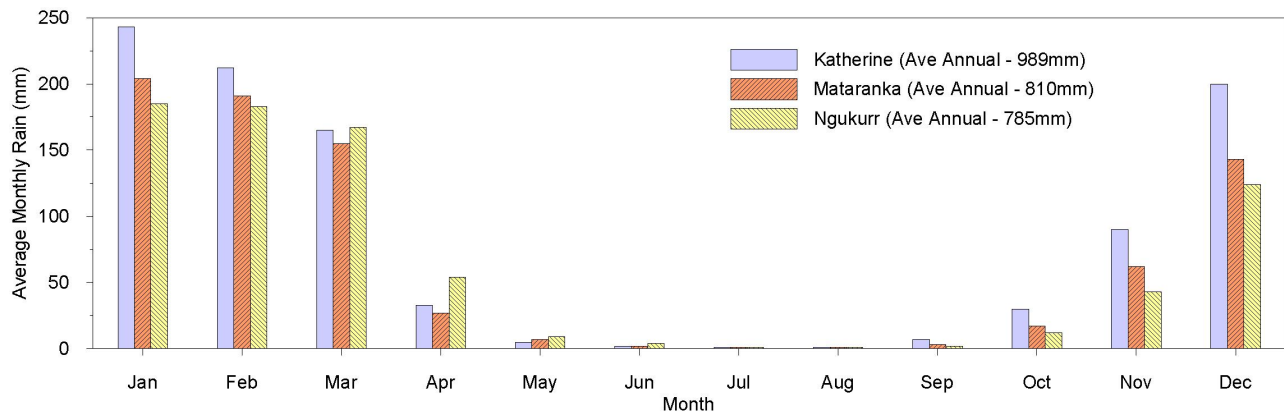


Figure 2 Average monthly rainfall for Mataranka, Ngukurr and Katherine. Source (Clewett et al., 2003)

The evaporation is high throughout the year with the average annual rate for the period 1961 to 1990 between 2400 – 2800mm (www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp) and potential evapotranspiration (PET) rates are consequently very high with the average annual PET for the period 1961 to 1990 between 1800 – 2100 mm (http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp?maptype=3&period=an).

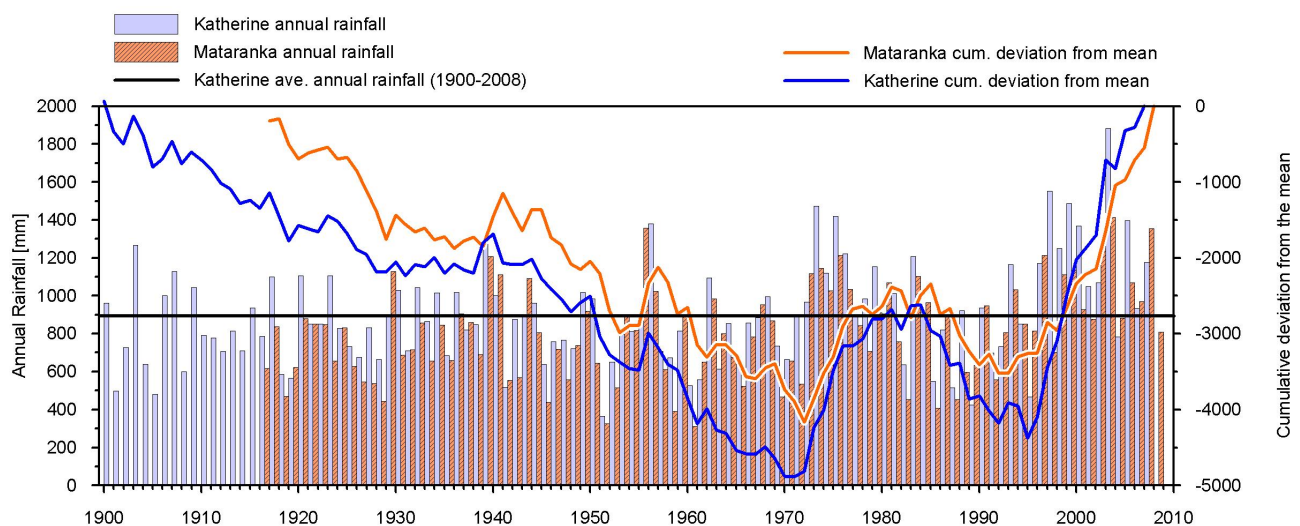


Figure 3 Annual rainfall at Katherine for the period 1900 – 2008 and Mataranka for the period 1917 – 2008 and the rainfall residual mass curves for Katherine (blue trace) and Mataranka (orange trace) demonstrating trends in rainfall.

During a few months in the wet season rainfall exceeds potential evapotranspiration and this drives seasonal streamflow. Climatically, on an annual basis, rainfall is insufficient to meet evaporative demand and the landscape may be described as water-limited.

The residual mass technique or cumulative difference from the mean reveals trends in the rainfall data. Declining trends indicate that rainfall is less than the long term average, rising trends indicate that rainfall is above the long term average. The actual values are not particularly useful, it is the slope that is important. It can be seen that for the period 1900 – 1973 the annual rainfall is generally below average. Within this there is a period during the late 1920s to the early 1940s with average annual rainfall (Figure 3).

1.3 Methodology

The MIKE11 model developed for this study is based on the methodology as below to construct and calibrate the MIKE11 model of the Daly River (URS, 2008).

- Digitisation of sub-catchments based on the digital terrain model and the locations of current and historic gauging stations
- Generate rainfall and evaporation data for the basins using the Thiessen method (Thiessen, 1911) and available climatic data;
- Development of a rainfall – runoff model for upstream boundary conditions;
- Development of the MIKE11 river branch network using the digital terrain model and shape files of the Roper River drainage;
- Add relevant and available cross sections to the river network;
- Conduct hydraulic roughness calibration for reaches of the river where discharge and stage height data are available.

2 Description of the Roper River

The study area includes the catchment of the Roper River and its tributaries. The Roper River is a large, perennial flowing river located in the wet / dry tropics of the Northern Territory of Australia (refer **Figure 1**). The catchment forms part of the drainage system known as the Gulf Fall and has an area of 82 000 km². The study area is drained by ten rivers and three major creeks, some of which are also perennial. These are: the Roper, Phelps, Hodgson, Arnold, Wilton, Mainoru, Jalboi, Strangways, Chambers and Waterhouse Rivers, and Maiwok, Flying Fox and Elsey Creeks. The Roper River starts as Roper Creek (also called Little Roper River) and becomes the Roper River downstream of the Waterhouse River junction near Mataranka. The Elsey Creek system drains the large Sturt Plateau region, which is located in the south-western section of the catchment. The Arnhem Land Plateau and the Wilton River Plateau are located in the northern section of the catchment, and consist predominantly of siliceous sandstone. The Roper River flows generally in an easterly direction, although the geology of the catchment influences the direction of the

drainage systems. This middle section of Roper River is also very braided and flow is often in multiple channels. The normal tidal limit of the Roper River is at Roper Bar Crossing (shown on **Figure 4**). From this crossing, the Roper River traverses the alluvial coastal plain eastward for 145 km before entering the Gulf of Carpentaria. There are currently no large surface water storages on the Roper River or its tributaries.

There are two important wetlands identified within the Roper River Catchment (Environment Australia, 2001). They are: (i) the Limmen Bight (Port Roper) Tidal Wetlands System, which is the second-largest area of saline coastal flats in the Northern Territory and is a good example of a system of tidal wetlands (intertidal mud flats, saline coastal flats and estuaries), with a high volume of freshwater inflow, typical of the Gulf of Carpentaria coast; and (ii) the Mataranka Thermal Pools which is a good example of tropical springs and associated permanent pools (one of the best known in the Northern Territory).

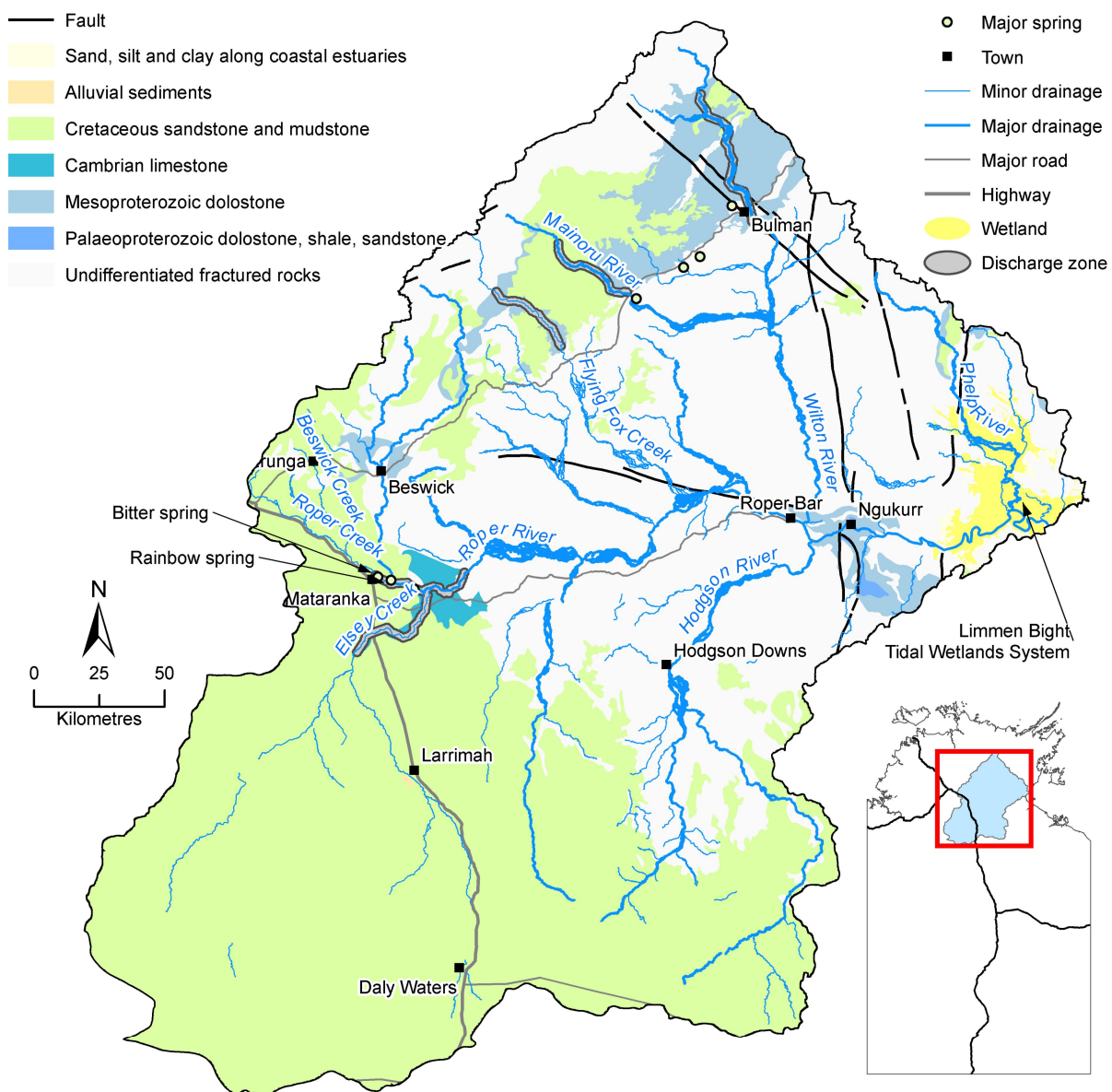


Figure 4 Overview of the Roper River depicting the major tributaries, towns and major geological features including the areas where major groundwater discharge occurs.

2.1 Discharge characteristics

The Roper River is one of the few rivers in northern Australia that exhibits perennial flows. The Roper River is characterised by a four month wet season with significant runoff and an eight month dry season with negligible surface runoff.

The highest mean monthly discharge along the Roper River occurs in March and ranges from 215 GL or 83 m³/s downstream of Mataranka Homestead – aka Elsey NP (G9030176) to 1 100 GL or 424 m³/s at Red Rock (G9030250). The lowest mean monthly discharge along Roper River occurs in September and October and ranges from less than 1.5 m³/s downstream of Mataranka Homestead and 3.5 m³/s at Red Rock (refer **Figure 5**). It should be noted that cease to flow has been observed at Red Rock (refer to **section 2.3**).

The average annual discharge of the non-tidal section of the river is based on flows at Red Rock gauging station (G9030250). The average annual discharge 11/08/1966 to 06/01/2009 at this point was 3 289 GL (NRETAS, 2009).

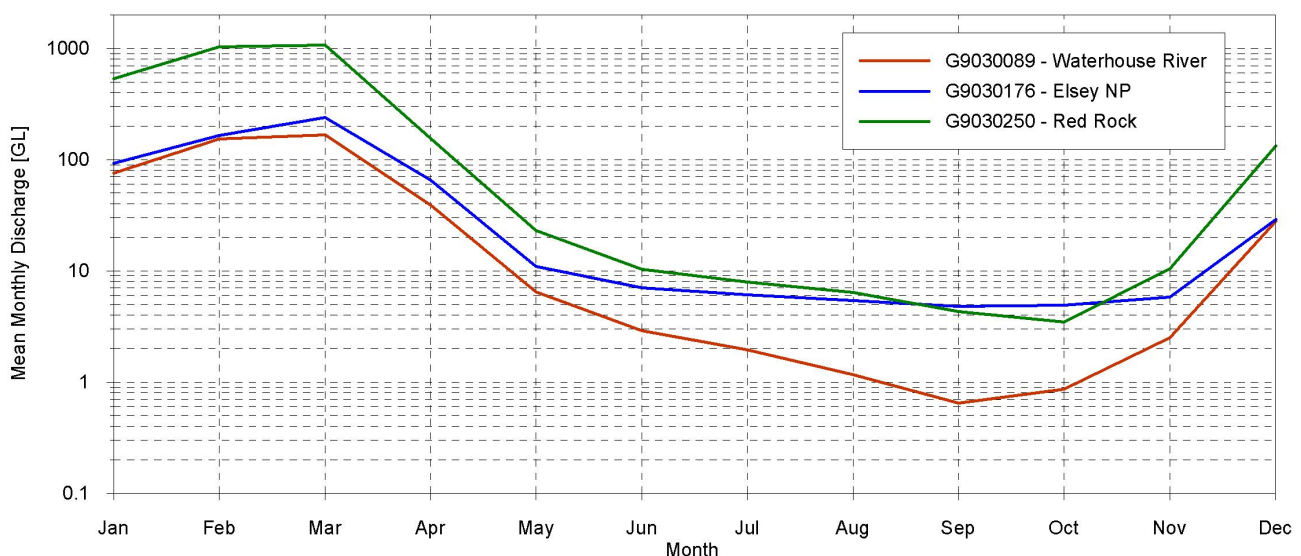


Figure 5 Mean monthly discharge for the Waterhouse River and the Roper River D/S Mataranka Homestead (G9030176) and Red Rock GS (G9030250).

2.2 Baseflow

During the dry season, aquifers within the Roper River catchment provide approximately 3-4 m³/s discharge through the river bed and springs as baseflow. In the wet-dry tropics groundwater inflow must be greater than evaporative demand to sustain a year round flow. The baseflow of the Roper River is sourced at its' headwaters where the river intersects the aquifers of the Cambrian aged Tindall Limestone near Mataranka (refer **Figure 4**). The headwaters of the northern tributaries source baseflow from the Dook Creek Formation. No further contributions occur downstream (refer **Figure 4**). The southern catchments of the Hodgson, Strangways and Elsey Creek provide little or no baseflow during the dry season. This is due to the underlying geology.

2.3 Cease to Flow at Red Rock

Mean monthly discharge for Red Rock is 3 – 4 m³/s based on the continuous record at the site, however, there have been times when the river has ceased to flow. Cease to flow at Red Rock (G9030250) has been observed 19 times during the period that streamflow gaugings have been conducted at the site (**Table 1**). All recorded cease to flows occurred prior to 1973/74.

Table 1 Documented cease to flow for the Roper River at Red Rock gauging station (after Zaar, 2009).

Year	Total Annual Rainfall (mm)	Minimum Flow (cumecs)	Month in which flow ceased	Data source
1951/1952	290	0	N/A	Inferred by historical account (Cole 1968)
1952/1953	616	0	N/A	Inferred from very low flow at G9030013
1953/1954	814	0	June	G9030250 F34, G9030012 F42
1954/1955	797	0	July	G9030012 F6, F42
1955/1956	1073	0	June	G9030250 F34, G9030012 F42
1956/1957	1403	0	April	G9030250 F34, G9030012 F42
1957/1958	606	0	September	G9030250 F34, G9030012 F42
1958/1959	403	0	June	G9030250 F34, G9030012 F42
1959/1960	694	0	August	G9030250 F34, G9030012 F42
1960/1961	516	0	March	G9030250 F34, G9030012 F42
1961/1962	606	0	March	G9030250 F34, G9030012 F42
1962/1963	1038	0	N/A	G9030012 F32, F42
1963/1964	509	0	July	G9030250 F34
1964/1965	832	0	August	G9030250 F34
1965/1966	649	0	September	G9030250 F9, F34
1966/1967	834	0	September	G9030250 F19, Moretti 1992
1967/1968	873	0.133		G9030250 Gaugings and water level record
1968/1969	719	0.04		G9030250 Gaugings and water level record
1969/1970	665	0	September	G9030250 F58, 59. Moretti 1992.
1970/1971	739	0	October	G9030250 Gaugings and water level record
1971/1972	690	N/A		N/A
1972/1973	912	0	October	G9030250 Gaugings and water level record. Moretti 1992.
1973/1974	1173	0.09		G9030250 Gaugings and water level record
1974/1975	1014	0.57		G9030250 Gaugings and water level record
1975/1976	1336	1.3		G9030250 Gaugings and water level record

2.4 Evapotranspirational losses

ET losses are a considerable component of the dry season water budget. Based on differences at common measurement times at the gauging stations G9030013 and G9030250 approximately 2 – 3 cumecs is used via evapotranspirational processes along the river.

The main sources of evaporatranspiration losses are the direct evaporation from surface water, evaporation from the soil close to the river and via transpiration of riparian vegetation along the length of the rivers. Typically riparian vegetation only occurs as a relatively thin strip close to the river, however, in some places the open water surface is substantially greater - for example at Red Lily Lagoon and downstream of Top Spring (refer **Figure 77**).

Regression analysis ($y = mx + b$) was applied between adjacent gauging stations to determine the losses over the respective lengths of river. Where m is the slope of the regression and b is the y intercept when $x = 0$. The ' m ' term describes how the flows at each site relate to each other. That

is if the losses at low flows are greater than or less than losses at higher flows. The 'b' term or offset describes the loss of discharge between the two sites ie. what is the lowest flow at the upstream gauge site that will result in a cease to flow (CTF) at the relevant downstream gauge site. To determine the rate at which the downstream gauge will CTF in very dry times the equation is re-arranged to $x = (y - b) / m$ or $x_{U/S} = b/m$ as $y = 0$. It can be seen that G9030013 gains 1.43 cumecs downstream of G9030176. Conversely the river loses flow between G9030013 and the next downstream station G9030123. A minimum flow of approximately 1.34 cumecs at G9030013 is required to maintain flow at G9030123. The total loss between G9030013 and G9030250 is 2.025 cumecs.

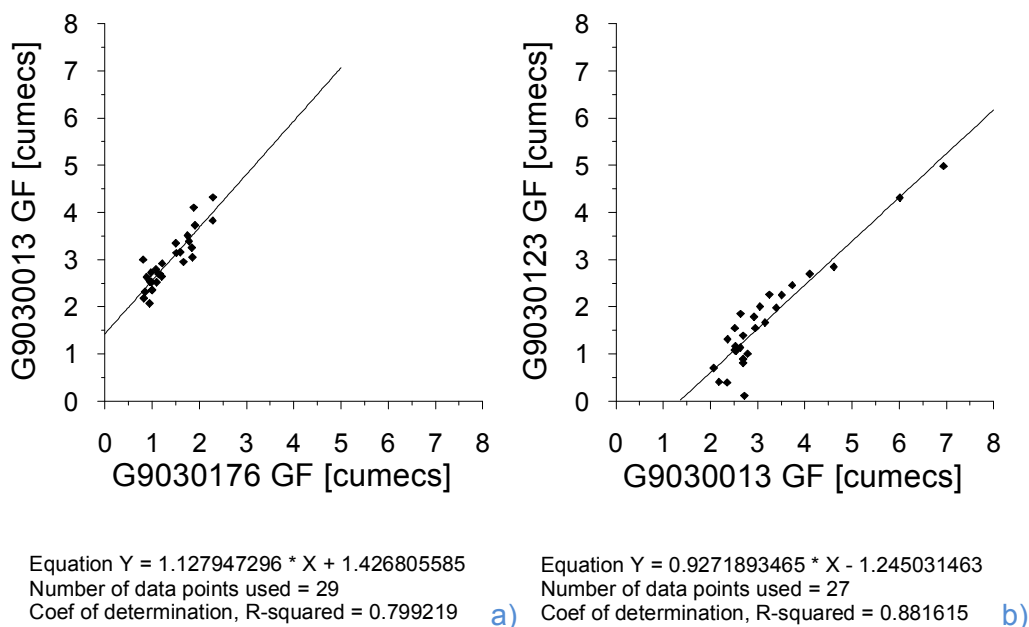


Figure 6 a) Regression between D/S Mataranka Homestead (G9030176) and Elsey Homestead (G9030013) and b) regression between Elsey Homestead (G9030013) and Moroak Station (G9030123).

The area contributing to the ET losses at Red Lily Lagoon on the Roper River is of the order of between 15×10^6 and 22.5×10^6 square metres (15×10^3 metres x $1-2 \times 10^3$ metres) (refer to **Figure 7**). Assuming an ET of the order reported in the Daly River for riparian vegetation of approximately 0.004 m/day (O'Grady et al, 2002) this would mean a loss of between 60,000 – 120,000 m³/d or 0.7 – 1.4 m³/s. This is of the order of loss observed between gauge sites at Elsey Homestead and Moroak Station (refer **Figure 6**).

Similarly for the area down stream of Top Spring in the Mainoru River catchment (refer **Figure 7**). The riparian zone extends for approximately 18,000 metres and is 400 metres wide. Assuming the same ET rate of 0.004 m/d, it can be expected that approximately 28,800 m³/d or 0.3 m³/s is lost through ET.

For the remaining length of the Roper River upstream of Roper Bar it is assumed that the combination of riparian zone and open water is between 100 and 200 metres, This results in a

loss of 400 and 800 m³/d/km of river or 56 000 – 112 000 m³/day (650 – 1.29 m³/s) for the entire 140 km length of the river.

This equates to a range of 1.35 – 2.69 cumecs total loss of flow between G9030013 and G9030250.

Downstream of the Roper Bar, the Roper River is tidal, however, a large section of the river is fresh water. During years of particularly low base flow the river is susceptible to salt water incursion. It is suspected that this occurs when the inflows are not sufficient to replenish the water lost to evaporation. It is estimated that the surface area of the water body downstream of Roper Bar to the saltwater interface is 14 x 10⁶ m² assuming an evaporation rate of 6 mm/d.

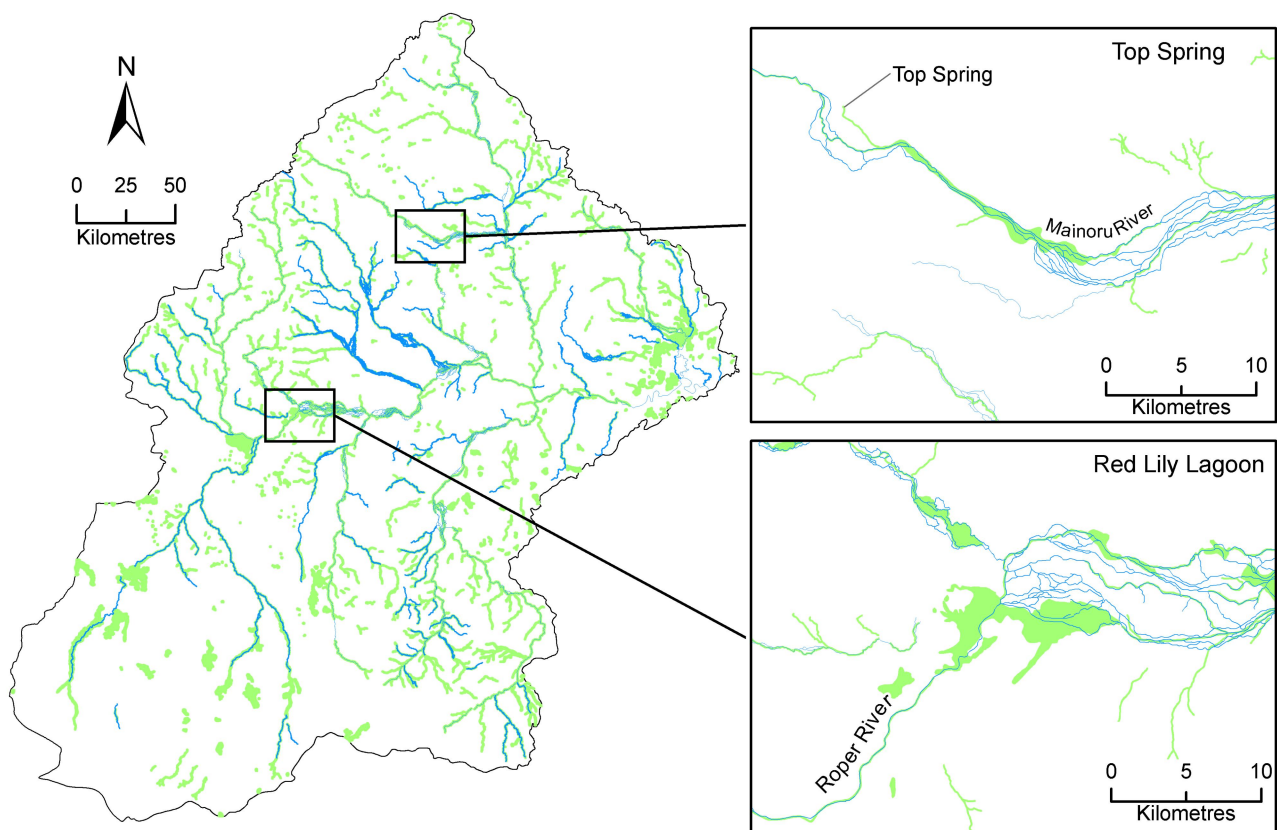


Figure 7 Locations of areas where considerable ET losses occur in the Roper catchment.

3 Available Data

Available data for the surface water component of the study include:

- synthetically derived SILO climatic data (Queensland Dept of Natural Resources and Mines, 2009)
- Flow record from stations in the catchment (Water Resources, 2009) as shown in Appendix A on Figures 21 to 30
- manually gauged river discharge from the Water Resources database (Water Resources, 2009).
- drainage polylines (Geoscience Australia, 2003)

- geological mapping (NTGS, 2006)

Cross-sections utilised in the development of the MIKE11 model of the Roper River are available from two sources:

- the Water Resources gauging station cross-sections database (Water Resources, 2009);
- Top End Water Ways project documented by Faulks (2001);

The cross-sections required a height datum to be estimated as no survey control was available at the time of collection.

3.1 Climatic data

3.1.1 SILO data drill

There are significant inconsistent periods of record and poor spatial coverage in rainfall and evaporation data for the Roper catchment. This has necessitated the use of synthetically derived data from the SILO data drill (Queensland Dept of Natural Resources and Mines, 2009) and (Jeffrey et al., 2001).

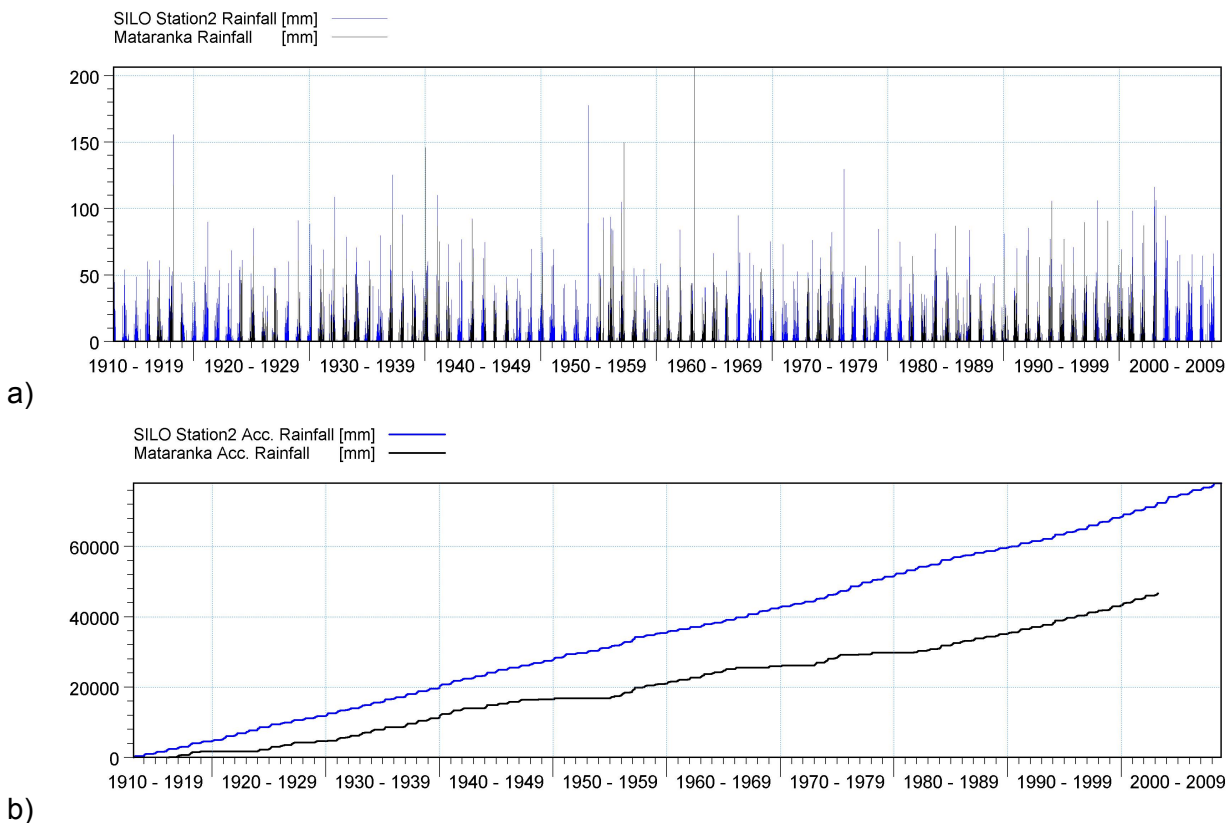


Figure 8 a) Comparison of the monthly rainfall at Mataranka and the equivalent SILO data drill site b) Comparison of the accumulated rainfall at Mataranka and the equivalent SILO data drill site. The periods where rainfall data exists for the Mataranka station parallel the SILO data indicating that the overall rainfall budget is consistent.

The SILO data drill accesses grids of data derived by interpolating the Bureau of Meteorology's station records. Interpolations are calculated by splining and kriging techniques. The data in the SILO data drill are all synthetic; there are no original meteorological station data left in the calculated grid fields. However, the SILO data drill does have the advantage of being available for

any set of coordinates in Australia. A direct comparison of the observed and synthesised Mataranka rainfall dataset by Zaar (2009) indicates there is close correlation.

Interpolated evaporation surfaces have been computed using data recorded from class A pans which measure potential evaporation. Observational data prior to 1970 have not been interpolated because various measuring devices were in use before 1970, resulting in inconsistent and unreliable data.

To demonstrate that the SILO data is a viable proxy for the observed data a comparison the rainfall data for Mataranka Store (DR014610) and the equivalent SILO derived data for Station 2 are presented in a cumulative plot in **Figure 8a** and **Figure 8b** respectively. The accumulated rainfall at the two sites on initial impression look dissimilar, however, this is due to the numerous periods during the actual record with no data. Periods where there is data the SILO and actual rainfall data are parallel indicating similar rainfall amounts are being reported.

Rainfall and evaporation data were obtained for 10 sites within the Roper River catchment area. **Figure 9** depicts the locations of the SILO data drill sites.

3.2 Stream gauging data

Continuous discharges are determined where a continuous stage height recorder has enough manual gaugings to provide a stage height vs discharge rating table. The development and use of a rating table are based on the following assumptions:

- Stable bed or channel cross-section
- No changes in structures downstream of gauge sites (eg tufa dams).

Streamflow gauging stations are or have been located at 22 locations within the Roper region. Twelve of these gauging stations are either: flood warning stations and measure stage height only, or have less than ten years of measured data.

Typically the streamflow data is from the 1970s and 1980s, with only a few locations having streamflow data extending back to the 1950s and a reduced data set through to the present due to closures of gauging stations in recent years. Discharge hydrographs (based on stage height records converted to flows using available rating tables) are available for 9 sub-catchments in the Roper River area (refer Table 2, **Figure 12**).

The quality of each site is subject to the number of gaugings and the maximum stage height used in the site rating table. Two of the sites have only low flow data making the development of a rating table difficult for higher flow events and therefore calibration of the rainfall-runoff model difficult and unreliable for high stage heights and flows.

Linear and log plots of continuous discharge at the gauge sites are presented in Appendix A.

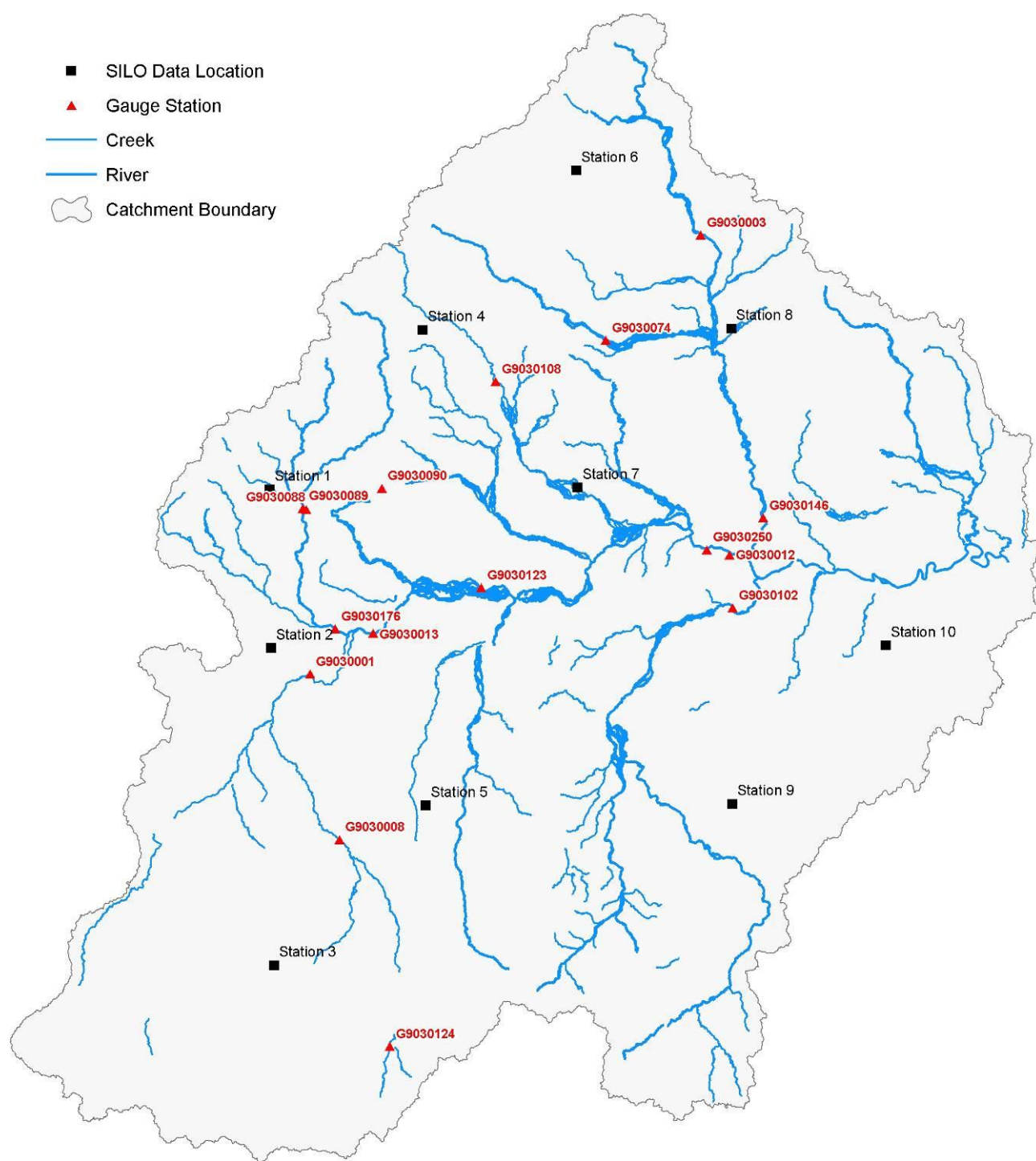


Figure 9 Locations of SILO data drill sites and available gauging station data.

Table 2 Record periods for Roper River gauge stations

Station	Start Date	End Date	Missing [days]	Max SH [m above datum]	Max GH [m above datum]	Basin(s)
G9030001	17/02/1967	01/07/2007	10467	6.635	6.081	J
G9030003	02/09/1967	22/06/1978	787	12.385	3.054	E
G9030013	11/09/1953	31/03/1974	1029	7.86	0.381	A, B, J & L
G9030089	26/11/1972	14/07/2007	1962	9.603	9.030	B
G9030102	16/01/1965	24/04/1986	4725	10.987	2.295	H
G9030108	11/08/1966	12/11/1986	1192	4.225	1.946	C
G9030146	24/08/1963	11/07/1986	1897	7.83	1.11	D,E & F
G9030176	29/06/1961	05/02/2008	1059	8.67	4.953	A & B
G9030250	11/08/1966	26/08/2007	2193	18.482	16.386	A, B, C, I, J, K & L

NOTE: SH = Stage Height and GH = Gauge Height

3.2.1 Correction of discharge data

It was found that the rating tables for G9030108 and G9030146 did not generate satisfactory discharge records from the available stage height data.

In the case of G9030108 (Flying Fox Creek) it was interpreted that the bed level of the river had changed during the period of record and this had affected the calculated low flows. An approach similar to that outlined by Connell Wagner, (2001) was employed to estimate the rating curve using the Manning discharge equation and the channel parameters m (bed gradient), Manning ' n ' and hydraulic radius generated from the calculation of the wetted perimeter and wetted area of the channel cross-section at the site.

$$V = R^{2/3} \cdot S_f^{1/2} / n$$

where

R is the hydraulic radius defined as the wetted area / wetted perimeter (metres)

S_f is the friction slope (dimensionless)

n is Manning roughness coefficient (refer 3)

Table 3 Typical Manning roughness coefficients for natural channels (Chow et al., 1988).

Natural stream Channel	Manning roughness coefficient
Clean, straight stream	0.030
Clean, winding stream	0.040
Winding with weeds and pools	0.050
With heavy brush and timber	0.100

Figure 10 presents the results of the adjustment of the rating table for G9030108 at Flying Fox Creek. Generally the observed discharge (dotted red trace) does not correspond to the manually gauged data (blue circles). The correction applied to the stage height data has produced a discharge record (black trace) which is more consistent with the gauged data.

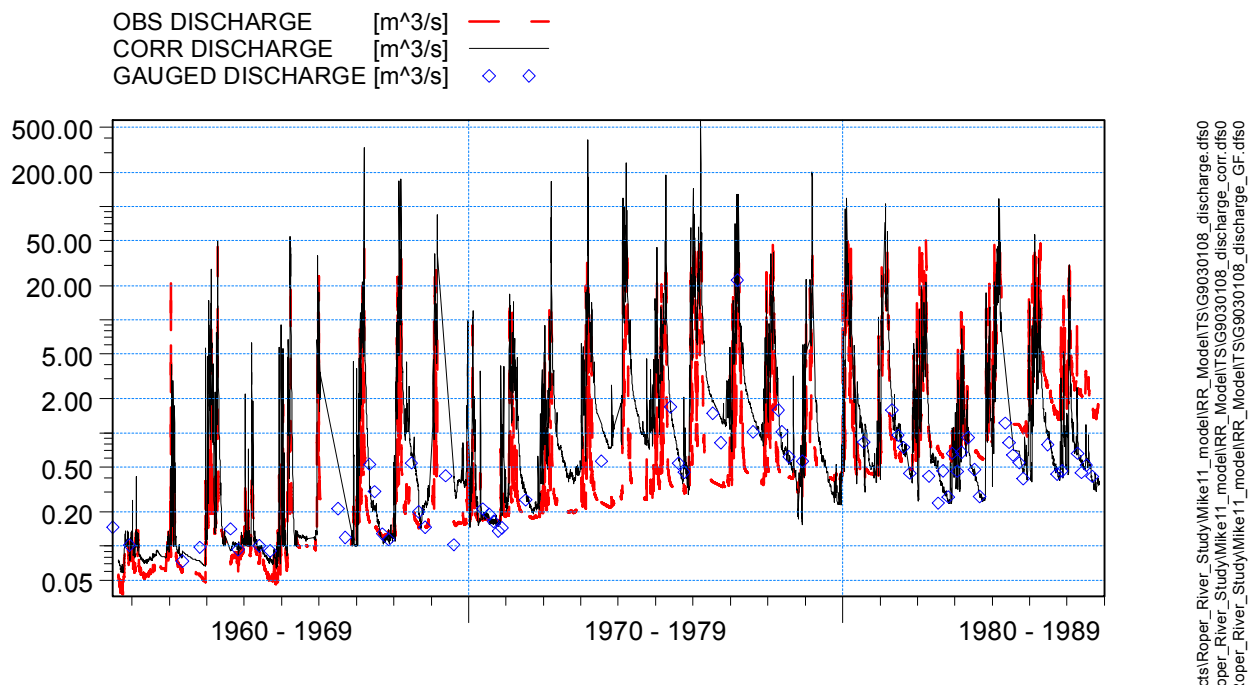


Figure 10 Corrected flows for G9030108 calculated from the historic rating table (red dotted trace), gauged flows (blue circles) and corrected flows (black trace).

In the case of G9030146 it is thought that the rating table over estimates the discharge at stage heights greater than 1.1 metres. To overcome this problem the rating table was again calculated using the Manning discharge equation and the available cross-section data.

3.3 Cross-section data

Cross-sections utilised in the development of the MIKE11 model of the Roper River are available from 2 sources:

- the Water Resources gauging station cross-sections database (Water Resources, 2009);
- Top End Water Ways project (Faulks, 2001);

The cross-sections required a spatial datum to be estimated as no survey ties were available at the time of collection.

Cross-sections only describe the channel up to the levee bank. Cross-section surveys should include up to at least 100 metres of the floodplain.

Recent as yet unreleased detailed DTM information could be used in the future to supplement the cross-sections if found to be suitable.

3.4 SRTM Digital Terrain Model

The Shuttle Radar Topography Mission (SRTM) digital terrain model (Farr et al., 2007) is available for the entire Northern Territory. The DTM is used to determine sub-catchments based on the locations of the gauging stations in the catchment. Unfortunately in areas where there is

considerable vegetation cover (eg the riparian zones along rivers) the DTM reflects this and depending on the type of vegetation can produce elevations up to 15 metres above the actual ground level.

3.5 Data gaps

A number of areas where data was deficient was identified as below:

- Continuous flow record for gauging stations for the major rivers with regard to groundwater discharging from the Dook Creek Formation.
- Rating tables for stations up to the maximum stage height.
- Limitations with respect to the channel dynamics in the braided sections of the river. This impacts on estimates of the year to year ET losses.

4 MIKE11 Model

4.1 A general description of the MIKE11 model

MIKE11 is a popular proprietary software application for the simulation of flows, water quality and sediment transport in rivers, channels and other water bodies. The model allows for the inclusion of inflows from sources such as groundwater and can incorporate surface water pumping.

The reason for using the MIKE11 package was primarily because it enabled direct coupling to the finite element groundwater modeling software FEFLOW (Diersch, 2008), which has been adopted by the NRETAS to model groundwater resources.

In MIKE11 a network configuration depicts the rivers and floodplains as a system of interconnected branches. Flood levels and discharges (h and Q) are calculated at alternating points along the river branches as a function of time. It operates on the basic information from the river and floodplain topography, to include man-made features and boundary conditions.

The simulation engine of the MIKE11 software is the hydrodynamic (HD) module. The HD module uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries (DHI, 2005). The computational scheme is applicable for vertically homogeneous flow conditions extending from steep river flows to tidal influenced estuaries.

MIKE 11HD, when using the fully dynamic wave description, solves the equations of conservation of continuity and momentum (known as the 'Saint Venant' equations). The solution to the equations is based on the following assumptions:

- The water is incompressible and homogeneous (i.e. negligible variation in density)
- The bottom slope is small, thus the cosine of the angle it makes with the horizontal may be taken as 1

- The wave lengths are large compared to the water depth, assuming that the flow everywhere can be assumed to flow parallel to the bottom (i.e. vertical accelerations can be neglected and a hydrostatic pressure variation in the vertical direction can be assumed)
- The flow is sub-critical (super-critical flow is modeled in MIKE11, however more restrictive conditions are applied)

The equations used are:

Equation 1 Continuity

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q$$

Equation 2 Momentum

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(a \frac{Q^2}{A} \right)}{\partial x} + gA \frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0$$

Where

- Q: discharge, (m³/s)
- A: flow area, (m²)
- q: lateral inflow, (m²/s)
- h: stage above datum, (m)
- C: Chezy resistance coefficient, (m^{1/2}/s)
- R: hydraulic or resistance radius, (m)
- I: momentum distribution coefficient

The four terms in the momentum equation (**Equation 2**) are local acceleration, convective acceleration, pressure, and friction (Source: MIKE11 online help).

The system has been used in numerous engineering studies around the world - recent applications in the Northern Territory include the assessment of flows in the Daly River (URS, 2008) and flood analysis of the Keep River Plain (KBR, 2005).

4.2 MIKE11 model development

The steps involved in the model development were:

- Digitisation of sub-catchments based on the terrain model and the locations of current and historic gauging stations
- Development of a rainfall – runoff model (NAM - Nedbør-Afstrømnings-Model meaning precipitation-runoff-model)
- Development of the MIKE11 river branch network
- Add relevant and available cross sections

- Conduct hydraulic roughness calibration

The following sections describe the model set-up, the data inputs and the calibration process.

4.3 Sub-catchment definitions

A total of 12 sub-catchments have been defined for the Roper River based on the locations of gauging stations with available flow data. Sub-catchment boundaries were generated using the ArcGIS hydrology tools with the flow direction derived from the 3 second SRTM digital terrain model and the locations of gauging stations defining the pour points.

Catchment definitions were developed using ArcGIS hydrologic tools (ESRI, 2006). The hydrologic tools allow for the identification and removal of sinks by filling depressions, determination of flow direction, calculation of flow accumulation, delineation of watersheds, and creation of stream networks. **Figure 11** depicts the results of each of the processes used to generate the sub-catchments.

The Fill function is used to create a depressionless DTM.

The Flow Direction function takes a DTM as input and outputs a raster showing the direction of flow out of each cell. There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight direction (D8) flow model and follows an approach presented in Jensen and Domingue (1988). The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell. If the maximum descent to several cells is the same, the neighborhood is enlarged until the steepest descent is found. When a direction of steepest descent is found, the output cell is coded with the value representing that direction.

The Flow Accumulation function calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. Cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. Cells with a flow accumulation of zero are local topographic highs and may be used to identify ridges or surface water divides.

A watershed is the upslope area contributing flow to a given location. Such an area is also referred to as a basin, catchment, sub-watershed, or contributing area. A sub-watershed is simply part of a larger watershed. Watersheds can be delineated from a DTM by computing the flow direction and using it in the Watershed function. The Watershed function uses a raster of flow direction to determine contributing area and pour points as the locations at where the water flows out of an area. The pour points used to determine the sub-catchments were based on the current and historic gauging station sites snapped to the adjacent cell of highest accumulation.

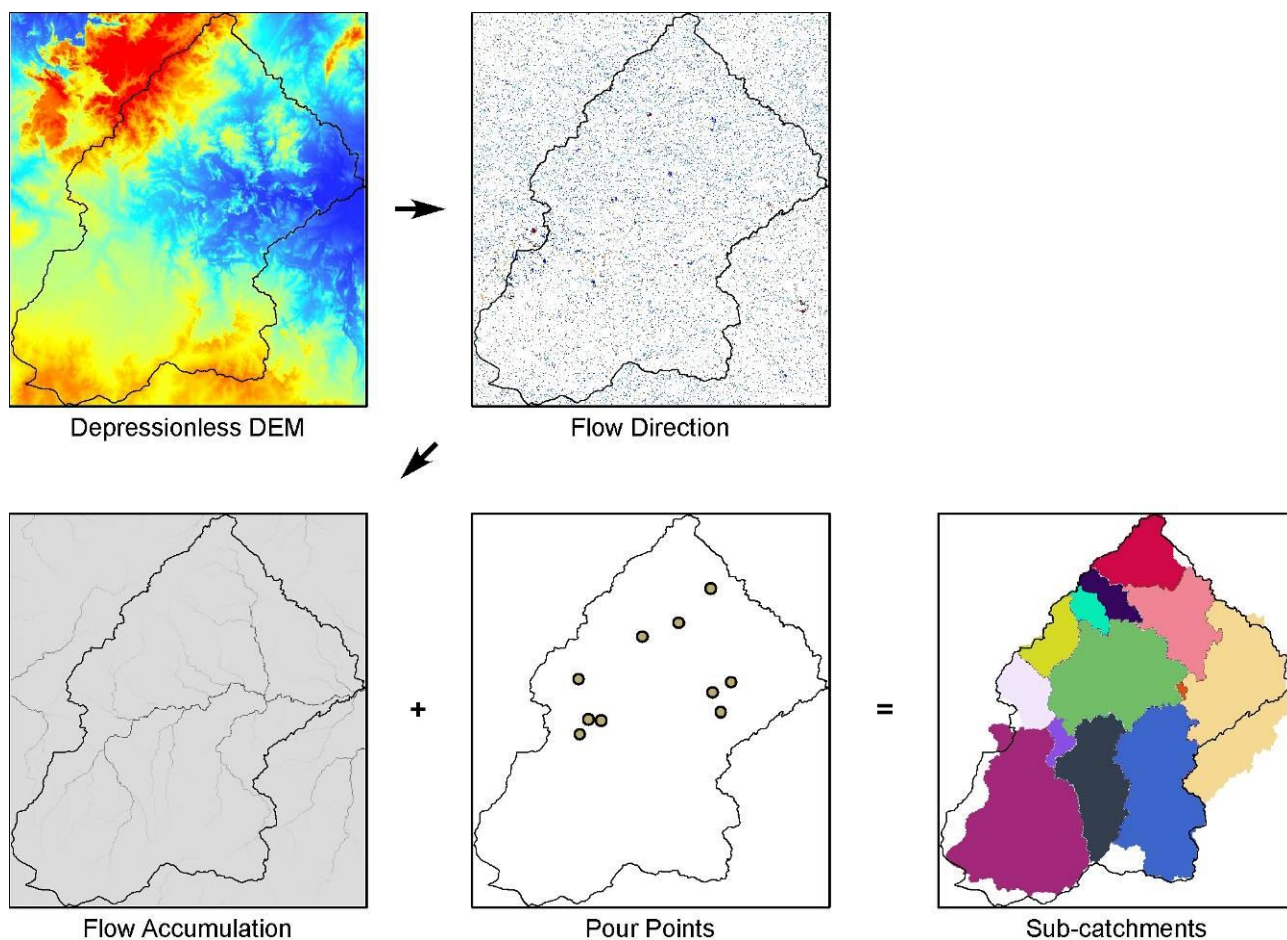


Figure 11 Process used to generate the sub-catchment of the Roper River from the SRTM and gauge stations.

The resulting sub-catchment features generated using this processes are presented in **Figure 12**. It should be noted that there is considerable difference between the catchment for Basin G and the catchment determined by the AWRC (1987). The cause of the poorly resolved catchment boundary is due to the low topographic gradients in the area.

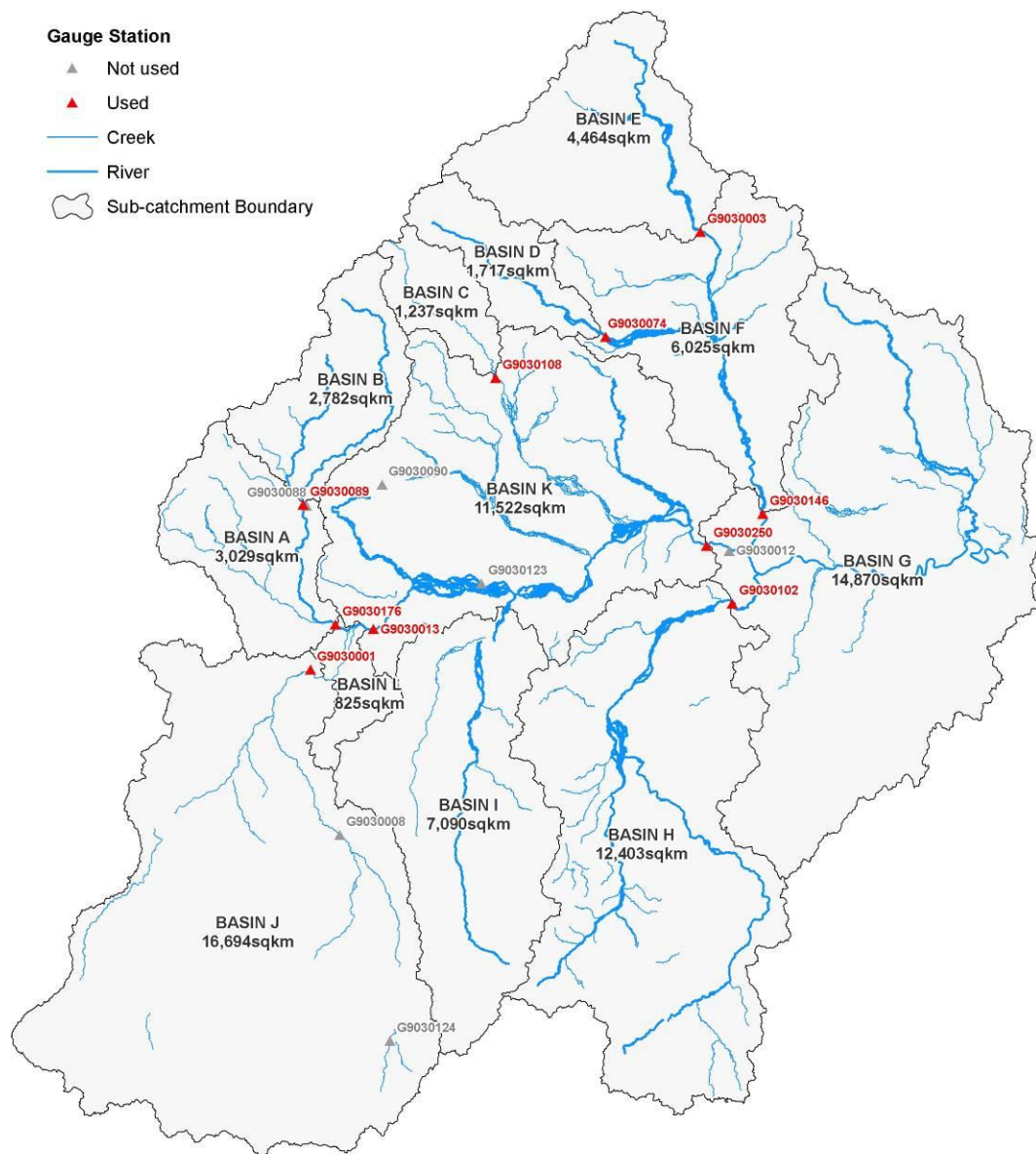


Figure 12 Sub-catchments used to determine rainfall runoff for the Roper River catchment. Gauge stations used in the calibration process are labeled in red.

4.4 Rainfall / runoff modeling (NAM)

Rainfall / runoff modeling was required to produce surface water runoff inflow at the sub-catchment scale for the boundary conditions defined in the MIKE11 model.

4.4.1 Model inputs

The inputs to the NAM model are rainfall and evaporation data, which in this case were from the SILO data drill. The mean area weights or proportion of rainfall (or evaporation) that a station contributes to each of the sub-catchments was determined using the Thiessen method (Thiessen, 1911). The mean area weights were based on the locations of each of the SILO stations and the centroid of each sub-catchment, the mean area weights resulting from the analysis are presented in **Table 4**.

Table 4 Mean area weights used to generate the rainfall and evaporation time series for each of the sub-catchments.

Station No.	1	2	3	4	5	6	7	8	9	10
BASIN A	0.646	0.354	-	-	-	-	-	-	-	-
BASIN B	0.476	-	-	0.524	-	-	-	-	-	-
BASIN C	-	-	-	1.000	-	-	-	-	-	-
BASIN D	-	-	-	0.616	-	0.351	0.003	0.030	-	-
BASIN E	-	-	-	-	-	0.967	-	0.033	-	-
BASIN F	-	-	-	-	-	0.115	0.015	0.864	-	0.007
BASIN G	-	-	-	-	-	-	0.022	0.207	0.134	0.637
BASIN H	-	-	-	-	0.144	-	0.074	-	0.766	0.016
BASIN I	-	0.014	0.066	-	0.887	-	0.033	-	-	-
BASIN J	-	0.179	0.747	-	0.074	-	-	-	-	-
BASIN K	0.112	0.097	-	0.134	-	-	0.639	0.017	-	-
BASIN L	-	0.701	-	-	0.299	-	-	-	-	-

- indicates that the station does not contribute to the sub-catchment.

4.4.2 NAM rainfall runoff model structure

NAM is a lumped parameter model based on physical structures and equations used with semi-empirical equations. The conceptual structure of the NAM model is presented in **Figure 13**. Each catchment is treated as a single unit and the parameters and variables represent average values for the entire catchment. As a result some of the model parameters can be evaluated from physical catchment data, however, the final parameter estimation must be performed against time series hydrological data. The available flow data can be a major limitation to the calibration results.

NAM uses soil moisture accounting to simulate the water balance within the catchment. Soil moisture storage is increased by rainfall and reduced by evaporation and by flow of water out of the storage. The size and relative wetness of the storage then determines the depth of rainfall absorbed, actual evapotranspiration, and the amount of water moving vertically or laterally out of the store.

Rainfall in excess of that absorbed becomes runoff and is transformed through an empirical unit hydrograph or similar device. Lateral water movements from the soil moisture stores are superimposed on this runoff to give streamflow.

$$\text{Overland Flow} + \text{Interflow} + \text{Baseflow} = \text{Precipitation} - \text{Evapotranspiration} - \Delta S$$

The meteorological input data required for the NAM model are precipitation and potential evapotranspiration (PET). In this instance the PET was substituted with pan evaporation. The calibration process corrected for the over estimation of PET using the pan evaporation.

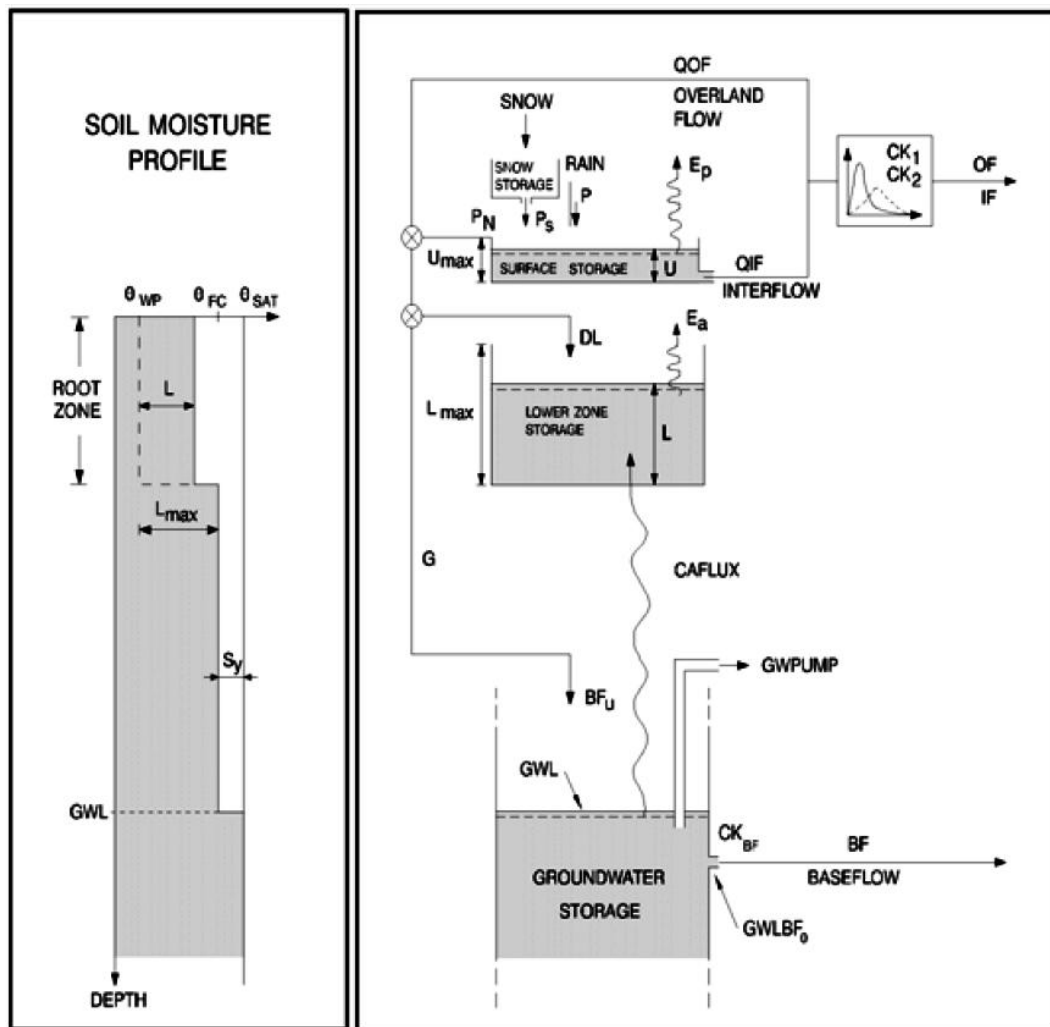


Figure 13 Conceptual NAM model structure source (DHI, 2007).

4.4.3 NAM Parameters

9 base parameters are required to generate runoff. These parameters and their relevance to the model are presented below:

- **Umax** Maximum water content in surface storage [mm]. The surface storage is moisture intercepted on the vegetation, surface depression storage and a few centimeters of the uppermost soil. The amount of water, U , in the surface storage is continuously diminishing by evaporation and interflow leakage. U_{max} denotes the upper limit of the amount of water in the surface storage. Typically U_{max} values are between 10 – 20 mm. If the maximum storage is reached, some of the excess water, P_N , will enter the streams as overland flow and the remainder is infiltrated into the lower zone groundwater storage. In dry periods, the amount of net rainfall that must occur before any overland flow occurs can be used to estimate U_{max} .
- **Lmax** Maximum water content in the root zone storage [mm]. This can be interpreted as the maximum soil moisture content in the root zone available for vegetation transpiration. Since the actual evapotranspiration is highly dependent on the water content of the surface and root zone storages, U_{max} and L_{max} are the primary parameters to be changed in order to adjust the

water balance in the simulations. As a rule, $U_{max} = 0.1L_{max}$ can be used unless special catchment characteristics or hydrograph behaviour indicate otherwise.

- **CQOF** Overland flow runoff coefficient. CQOF is dimensionless with values between 0 and 1. This parameter determines the fraction of excess rainfall that generates overland flow. The excess rainfall that does not contribute to overland flow becomes infiltration. Physically, in a lumped manner, it reflects the infiltration and also to some extent the recharge conditions. Small values of CQOF are expected for a flat catchment having coarse, sandy soils and a large unsaturated zone, whereas large CQOF-values are expected for catchments having low, permeable soils such as clay or bare rocks.
- **CKIF** Time constant for interflow [hours]. This determines the rate at which surface water (U) drains into interflow storage. Physical interpretation of the interflow is difficult. Since interflow is seldom the dominant streamflow component, CKIF is not, in general, a very important parameter. Usually, CKIF-values are in the range 500-1000 hours.
- **CK12** Time constant for routing interflow and overland flow [hours]. This time constant determines the shape of the hydrograph for the overland flow and interflow components. The value of CK12 depends on the size of the catchment and how fast it responds to rainfall. Typical values are in the range 3-48 hours. The time constant can be inferred from calibration on peak events. If the simulated peak discharges are too low or arriving too late, decreasing CK12 may correct this, and vice versa.
- **TOF** Root zone threshold value for overland flow. No overland flow occurs until the relative moisture content of the lower zone storage (L) is above this threshold value.
- **TIF** Root zone threshold value for interflow. As for TOF, except applicable to interflow.
- **CKBF** Baseflow time constant. This determines the shape of the baseflow hydrograph.

If the recession analysis indicates that the shape of the hydrograph changes to a slower recession after a certain time, an additional (lower) groundwater storage can be added to improve the description of the baseflow.

- **TG** Root zone threshold value for groundwater recharge. The root zone threshold value for groundwater recharge (TG) determines the relative value of the moisture content in the root zone (L/L_{max}) above which groundwater recharge is generated. The main impact of increasing TG is less recharge to the groundwater storage. Threshold values typically range between 0 and 70% of L_{max} and the maximum value is 0.99.

4.5 Calibration

Typical calibration of each catchment would require that each upstream gauge information is subtracted from the downstream gauge to determine the contribution from the downstream catchment. The poor amount of overlap and the discontinuous nature of the time series available

for the Roper River meant that this method was not considered a viable option. Instead the upstream gauge was calibrated and then the combined upstream and downstream NAM results (refer to **Table 5**) were compared to the available gauge data of the downstream station.

Table 5 Catchment definitions and relevant gauge station used to calibrate the NAM rainfall runoff model

BASIN ID	Model Type	Area [km ²]	Relevant Gauge Station
BASIN A	NAM	3029.3	-
BASIN B	NAM	2781.6	G9030089
BASIN C	NAM	1236.8	G9030108
BASIN D	NAM	1716.6	No flow data
BASIN E	NAM	4463.8	G9030003
BASIN F	NAM	6024.5	-
BASIN G	NAM	14869.5	-
BASIN H	NAM	12403.2	G9030102
BASIN I	NAM	7090.3	No flow data
BASIN J	NAM	16694.2	G9030001
BASIN K	NAM	11521.9	-
BASIN L	NAM	825.1	-
BASIN A COMBINED	Combined A & B	5810.9	G9030176
BASIN F COMBINED	Combined D, E & F	12204.8	G9030146
BASIN K COMBINED	Combined A, B, C, I, J, K & L	55582.3	G9030250
BASIN L COMBINED	Combined A, B, J & L	23330.2	G9030013

The calibration was initially performed for catchments where gauging data existed starting from the upstream end. Hydrological parameters were determined from manual calibration to the observed discharge measurements. For the calibration of catchments downstream of another, the combined runoff of the catchments was used to compare to the observed outflow. For ungauged catchments, the NAM parameters were transposed from nearby catchments that were considered similar.

The surface-rootzone parameters employed in the NAM model are presented in **Table 6** and the groundwater parameters determined from calibration are presented in **Table 7**.

Appendix B presents the calibration plots for each of the gauged catchments showing times series comparisons between measurements and model predictions for runoff (m³/s) and accumulated runoff (m³).

The flow at Red Rock (G9030250) has considerable losses due to ET. To take this into account 2.5 cumecs was added to the recorded discharge during the calibration process.

Basin A and Basin L have C_{klow} parameters which are an order of magnitude greater than the other sub-catchments. The long time constants reflect the size of the groundwater system discharging into these sections of the river and the associated volume in storage.

Table 6 NAM surface-rootzone parameters derived from rainfall runoff calibration process.

Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF
BASIN A	26	620	0.8	290	45	0.05	0.35
BASIN B	25	540	0.9	270	25	0.05	0.35
BASIN C	22	720	0.65	310	25	0.01	0.6
BASIN D	25	720	0.5	310	25	0.01	0.6
BASIN E	13	380	0.75	500	35	0.01	0.3
BASIN F	23	600	0.7	400	45	0.6	0.9
BASIN G	25	550	0.85	400	50	0.5	0.7
BASIN H	15	300	0.87	500	30	0.01	0.4
BASIN I	20	550	0.6	500	40	0.3	0.5
BASIN J	26	995	0.12	990	60.9	0.12	0.104
BASIN K	25	650	0.6	550	35	0.4	0.7
BASIN L	15	550	0.15	500	35	0.05	0.2

Table 7 NAM groundwater parameters derived from rainfall runoff calibration process.

Name	TG	CKBF	Cqlow	Cklow
BASIN A	0.18	400	70	80000
BASIN B	0.215	210	17	1400
BASIN C	0.2	380	30	5700
BASIN D	0.2	380	45	5700
BASIN E	0.32	250	13	1750
BASIN F	0.99	40	-	-
BASIN G	0.99	500	-	-
BASIN H	0.35	180	80	180
BASIN I	0.99	150	-	-
BASIN J	0.6	200	60	10000
BASIN K	0.65	50	25	900
BASIN L	0	500	99	100000

4.5.1 Rainfall / runoff modeling water balances

An assessment of the proportion of rainfall that generates runoff in each of the sub-catchments of the Roper River for the period from 01/01/1900 to 01/09/2008 or 108.8 years was made. **Table 8** presents the components of the rainfall / runoff relationship for each of the sub-catchments. Plot of the accumulated flow for the period of record against simulated results for each Basin is presented in Appendix B – Figures 31 to 39.

4.5.2 Groundwater / surface water connectivity

Based on the NAM calibration results, the extent to which the catchments have groundwater baseflow can be assessed and an estimate of the level of groundwater / surface water connectivity can be assigned to each sub-catchment (refer to **Table 7**). Basin A, Basin C, Basin D, Basin E and Basin L have considerable baseflow components indicating that groundwater is in connection with the surface water, whereas Basin B and Basin K have minor baseflow components which typically do not extend over the entire dry season.

In the case of Basin B, the groundwater component is indicative of contributions from Cretaceous

Table 8 NAM rainfall / runoff mean annual discharge components

Catchment	Area km ²	Q-obs [GL/yr]	Q-sim [GL/yr]	Rainfall [GL/yr]	PotEvap [GL/yr]	ActEvap [GL/yr]	Recharge [GL/yr]	OF [GL/yr]	IF [GL/yr]	BF [GL/yr]
BASIN A	3029.3	-	245.1	2610.0	7155.0	2354.2	81.9	160.7	12.3	72.1
BASIN B	2781.64	184.9	304.9	2556.2	6358.2	2257.9	78.6	207.5	18.8	78.6
BASIN C	1236.77	31.3	110.5	1166.5	2771.2	1055.1	38.5	72.1	0.1	38.3
BASIN D	1716.57	-	130.9	1634.9	3824.4	1502.6	56.7	74.3	0.2	56.3
BASIN E	4463.78	-	696.7	4352.3	9834.8	3671.5	173.7	486.4	36.5	173.8
BASIN F	6024.5	-	57.4	5157.2	13611.9	5096.7	0.5	55.9	1.0	0.5
BASIN G	14869.50	-	198.3	11196.8	35714.8	10994.6	0.0	184.2	14.1	0.0
BASIN H	12403.20	1044.0	1048.0	8735.5	31030.0	7687.4	171.9	849.3	26.8	171.9
BASIN I	7090.27	-	134.7	5271.7	17740.2	5135.6	0.0	122.6	12.1	0.0
BASIN J	16694.20	98.3	57.5	11657.9	42430.8	11589.3	0.6	29.4	27.5	0.6
BASIN K	11521.90	-	153.3	9422.9	27192.4	9264.1	26.7	122.6	4.0	26.7
BASIN L	825.07	-	65.5	650.1	2011.3	579.1	59.8	8.0	2.9	54.5
BASIN A COMBINED	5810.94	500.7	550.0	5166.2	13513.2	4612.2	160.5	368.2	31.1	150.7
BASIN F COMBINED	12204.80	1565.0	885.0	11144.4	27271.1	10270.8	230.9	616.7	37.7	230.5
BASIN L COMBINED	23330.20	-	673.0	17474.2	57955.3	16780.6	221.0	405.6	61.5	205.9
BASIN K COMBINED	55582.30	2269.0	2119.5	33335.3	105659.0	32235.3	286.1	723.0	77.6	270.9

Q-obs taken from Faulks 2001 based on average annual data from Hysdstra extracted in 2001.

Q-sim period is 108.8 years (01/01/1900 – 01/09/2008)

aged sediments in the Upper Waterhouse River. This assessment is supported by the chemistry of the river water with an EC of less than 100 and pH of less than 7 which is typical of waters from those sediments.

The other sub-catchments Basin F, Basin G, Basin H and Basin I are interpreted as having no baseflow.

NAM calibration indicates Basin A, Basin C, Basin D, Basin E, Basin L and to a lesser extent Basin B demonstrate baseflow due to groundwater discharge.

Basin G, Basin H, Basin I and Basin J do not exhibit baseflow.

4.5.3 Discussion

Generally, the simulated and observed instantaneous discharge hydrographs show a reasonable match, although the accumulated discharge for some of the stations show some discrepancy. Typically the reason for the discrepancy is due to periods of record when the station is not operating and stage height data (and thus the derived flow record) is missing.

Basin F Combined (Wilton River – G9030146) refer to **Figure 35**. It is apparent from examining the discharge hydrograph that sections of the wet season flow are missing. This would result in

considerable reduced measured flow at this station. It is likely that the simulated wet season flows for this site are unreliable. The dry season flows display the distinctive effects of ET loss, the NAM results which do not take the ET losses along the river channel into account are therefore overestimating the dry season flows. This effect is corrected in the MIKE11 model where ET losses can be specified along each river branch.

Basin K Combined (Red Rock – G9030250) refer to **Figure 39**. The accumulated discharge which reflects the overall water balance is relatively consistent, with the exception of the last 3 years, where from 2004 – 2008 the gauging station was not operational for large parts of the wet season. This has resulted in the observed discharge being under reported. The low flows show the distinctive recession related to ET loss. The NAM model does not include this loss component.

4.6 MIKE11 river network

The co-ordinate system used in this study is the Map Grid of Australia 1994 Zone 53 (better known as MGA94). MGA94 is based on the Universal Transverse Mercator (UTM) projection system using the GDA94 datum as reference.

The Roper River setup comprises a main river branch with several smaller tributaries feeding into the main river. The Roper River network was digitised based on the 1:250,000 drainage shapefile sourced from Geoscience Australia (2003). The rivers that were traced include: Roper River, Waterhouse River, Wilton River, Elsey Creek, Flying Fox Creek, Mainoru River, Hodson River, Hodgson River, and Strangways River.

The mapped drainage was found to be more complex than that encountered during the dry season and the data was simplified by reducing the number of channels along each river branch to a single channel and reducing the sampling along each channel to greater than 1000 metres using the ArcGIS simplify tool. The resultant river branch network was refined by removing extraneous branches. Rivers that were considered ephemeral (eg Strangways) were truncated arbitrarily to approximately 20 km upstream of the relevant gauging station.

Chambers River, Maiwok Creek and the Arnold River were removed from the river network as there is no gauging data to provide a basis for calibration of these branches.

The modified network and the original mapped river channels are presented in **Figure 14**. The river branch network is recorded in the MIKE11 network file (Roper_river_2009.nwk11).

Each cross section used is defined in the MIKE11 cross section file and are recorded based on River Branch Name, Topo ID and Chainage. Each cross section has a cross section ID - the cross-section ID's are derived from the site IDs used by Faulks (2001).

Generally the data recorded at each of the cross-sections is only to the top of the bank and does not include the river floodplain. Given the nature of the river this would highly constrain the discharge to a very small width and result in extremely high calculated stage heights.

Additional cross-sections were copied from adjacent locations of the same river branch where required. This was particularly necessary at the junctions between river branches.

Currently there are limitations with the available cross-section data including the elevation accuracy, the length of cross-sections beyond the river bank and general coverage of cross-section data, particularly at river branch junctions.

The numerous pools along the length of the Roper River need to be defined to estimate storage, further cross-section surveys will provide this information.

4.8 MIKE11 boundary conditions

Boundary conditions are defined as inflow hydrographs on all upstream boundaries, along distributed boundaries and at the downstream tidal boundary at sea. The downstream boundary is defined by applying measured (simulated) water levels covering a large number of tidal periods.

Four types of boundary condition have been utilised in the model.

- Inflow at the start of each of the branches
- Distributed inflow where groundwater inflows were anticipated
- Distributed outflow
- Outflow at the estuary end of the Roper River a constant water level BC was employed to simulate the mean tidal level.

4.8.1 The open boundary

An Open Boundary can be specified at the free upstream and downstream ends of the model domain. When the Open option is selected in a Boundary Description cell, a branch name and chainage are also needed in order to identify the location of the boundary. An Open boundary condition has the following valid Boundary Types:

Inflow is specified when a time-varying or constant flow hydrograph condition is required;

Water Level is specified when a time-varying or constant water level condition is required;

$Q-h$ is specified when the relationship between the discharge and the water level is known ie a rating table is available.

4.8.2 The point source boundary

The Point Source boundary condition is used at locations within the model domain where time-varying or constant lateral inflows (or outflows) occur. Point source BCs were used to simulate discrete spring inflows. These are listed in Table 9.

Table 9 Point source boundary conditions located at springs.

Boundary Description	Boundary Type	Branch Name	Chainage [metres]	TS Type	Value
Point Source	Inflow	Roper Creek	59401.63	Constant	0.8
Point Source	Inflow	Waterhouse River	145995.90	Constant	0.8
Point Source	Inflow	Roper River	8191.61	Constant	0.8
Point Source	Inflow	Elsey Creek	61280.89	Constant	0.8

4.8.3 The distributed source boundary

The Distributed Source boundary condition is used along river reaches within the model domain where time-varying or constant lateral distributed inflows need to be specified (eg groundwater discharge), or where meteorological boundaries apply (eg evaporation). The distributed source BC are where the external patches with groundwater models are defined. These are listed in Table 10.

The following Distributed Source Boundary Types were employed:

Inflow is specified when a time-varying or constant lateral inflow condition (for the HD model) is required. The inflow will be divided equally between each computational h-point lying in the specified chainage range;

Evaporation is specified in river reaches where loss of water by evaporation affects the water balance (HD model). Evaporation can also be specified globally.

Table 10 Boundary conditions applied to free river branch ends.

Boundary Description	Boundary Type	Branch Name	Chainage from [metres]	Chainage to [metres]
Open	Inflow	Strangways River	0	0
Open	Inflow	Beswick Creek	0	0
Open	Inflow	Waterhouse River (West Branch)	0	0
Open	Inflow	Waterhouse River	0	0
Open	Inflow	Top Spring	0	0
Open	Inflow	Roper Creek	0	0
Open	Inflow	Phelp River	0	0
Open	Inflow	Elsey Creek	0	0
Distributed Source	Inflow	Mainoru River	0	82788
Distributed Source	Inflow	Flying Fox Creek	0	52902
Distributed Source	Inflow	Wilton River	0	83936
Open	Inflow	Mainoru River	0	0
Open	Inflow	Wilton River	0	0
Open	Inflow	Hodgson River	0	0
Distributed Source	Inflow	Roper River	6479	20046

Distributed Source	Inflow	Flying Fox Creek	53000	117069
Distributed Source	Inflow	Roper River	0	5837
Distributed Source	Inflow	Phelp River	0	114000
Distributed Source	Inflow	Roper River	182374	331000
Distributed Source	Evaporation	Roper River	38038	56703
Distributed Source	Evaporation	Roper River	182273	331000
Distributed Source	Evaporation	Flying Fox Creek	53000	117069
Open	Inflow	Flying Fox Creek	0	0

4.9 MIKE11 settings

4.9.1 HD Settings

Values for three of the HD tabs were adjusted to improve the model calibration and stability:

- Initial conditions for the global water levels and discharge were set using trial and error to provide stable conditions for the model startup, this was especially needed for the integrated model. The global water depth was set at 8 metres and the discharge at 2 m³/s.
- Bed resistance was set globally to 0.05 and specific branches were adjusted to fit the available stage height data. The distribution of bed resistance is discussed further below under model calibration in **section 5.1**.
- The HD wave approximation was set to High Order Fully Dynamic. Other approximations were also trialled, however, the fully dynamic approximation proved to be the most stable and resulted in only a marginal increase in run times.

4.9.2 MIKE11.ini settings

The MIKE11.ini-file offers a possibility of changing settings within the calculation part of MIKE11 by adjusting values of below listed environment variables.

WL_EXCEEDANCE_FACTOR=40

QZERO_METHOD=ON

5 Model Calibration

5.1 Hydraulic roughness

Hydraulic roughness (Manning 'n') was globally set at 0.05. The resulting stage heights along sections of the river were found to be considerably overestimated and the roughness value was increased to adjust the flow characteristics. Table 11 presents the branches, chainages and Manning 'n' value determined during calibration.

Table 11 Bed resistance of branches of the Roper River.

Branch	Chainage from [metres]	Chainage to [metres]	Manning 'n'
Roper River	152700	192360	0.05
Flying Fox Creek	0	147090	0.06
Roper River	8231	20085	0.09
Beswick Creek	0	44117	0.07
Elsy Creek	0	63744	0.07
Roper Creek	0	66308	0.06

5.2 Evapotranspiration losses

Section 2.4 identified that approximately $2.5 \text{ m}^3/\text{s}$ is lost between the point at which groundwater discharge from the Tindall Limestone stops downstream of G9030013 and the gauging station at Red Rock (G9030250). The hydrograph at G9030250 shows a distinctive decline in flows during the dry season this expected to be due to increasing ET losses from the dry season to the wet season. The ET losses were initially represented using the average annual evaporation rate of 6 mm/d , however, the observed discharge at Red Rock were not well represented. Average monthly evaporation was used which improved the dry season recession match. Finally a daily evaporation rate (Basin K) was applied and produced the best match.

The scaled daily evaporation for Basin K was used to represent the ET losses along the Roper River, Flying Fox Creek and the Wilton River. During calibration the scale factor in the Boundary Condition Editor was adjusted to match the observed differences between flows at gauge sites along each river. The calibrated scaling factor for the section of river between G9030013 and G9030123 representing Red Lily Lagoon is 22, the scaling factor for the section of river between G9030123 and G9030250 is 18. The section of Flying Fox Creek downstream of the gauging station used a scale factor of 33. The final calibrated discharge at Red Rock for the period of available flow record is presented in **Figure 15**.

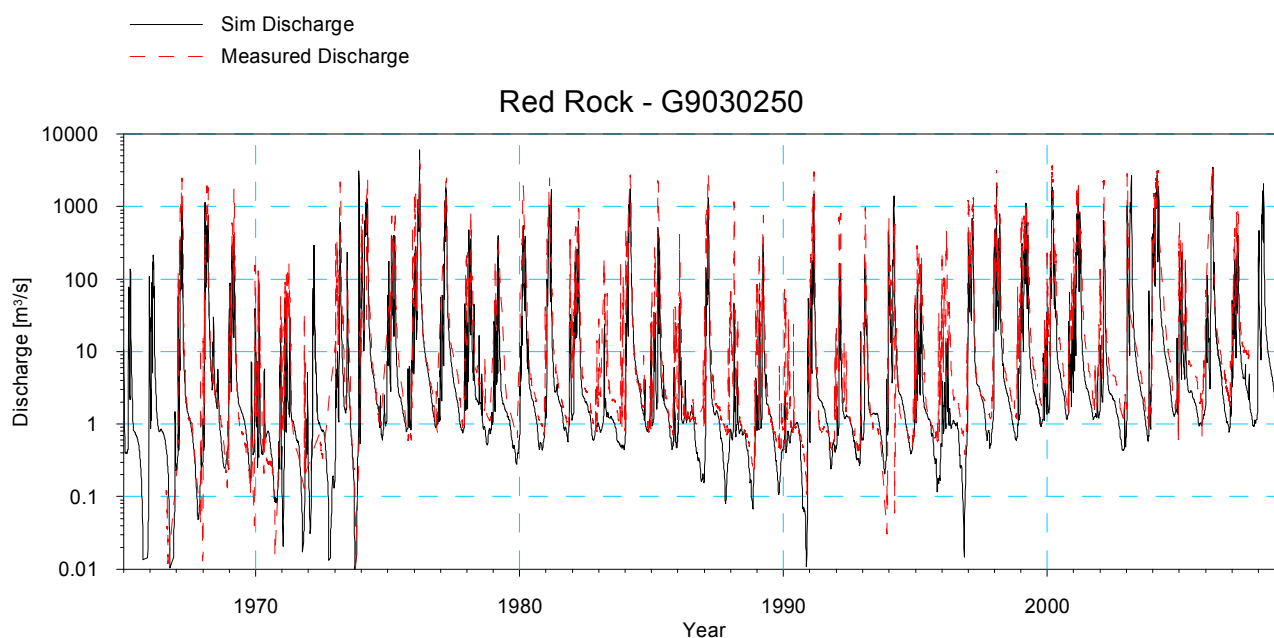


Figure 15 Calibrated discharge at Red Rock (G9030250) using the MIKE11 model with NAM rainfall/runoff and scaled evaporation to simulate ET losses along the length of the Roper River.

6 Modelling Results

6.1 Stage Height and Discharge Hydrographs

The simulated discharge from the MIKE11 model are presented below for key sites along the Roper River.

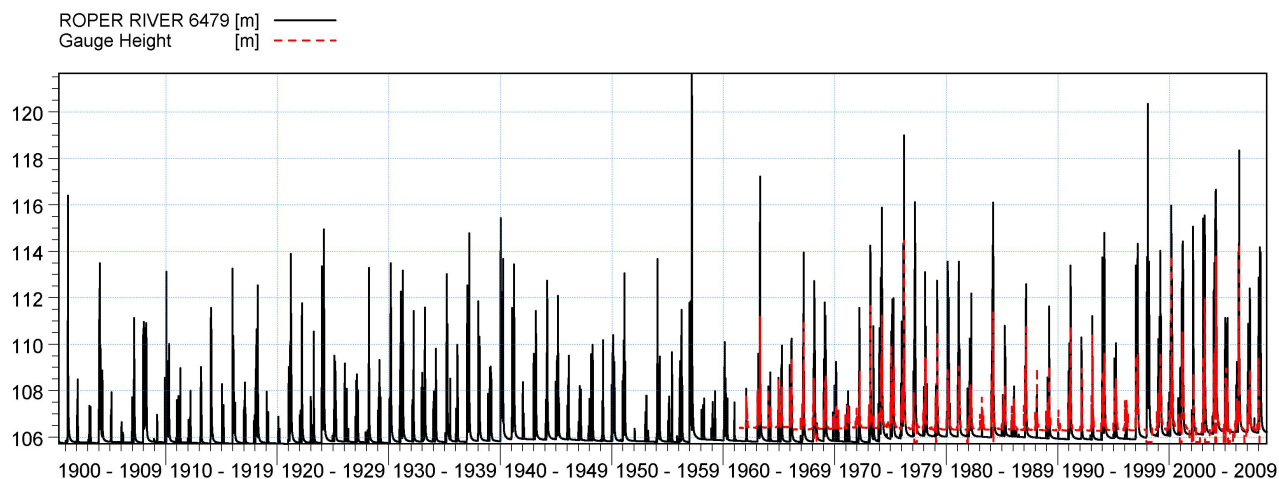


Figure 16 Simulated and measured gauge height at D/S Mataranka Homestead (G9030176)

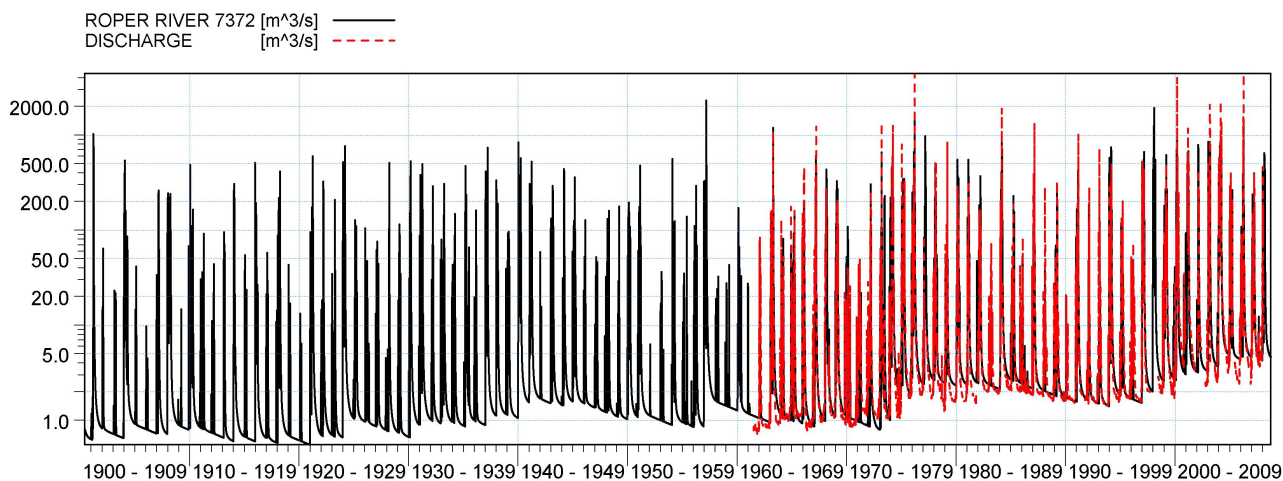


Figure 17 Simulated and measured gauge discharge at D/S Mataranka Homestead (G9030176)

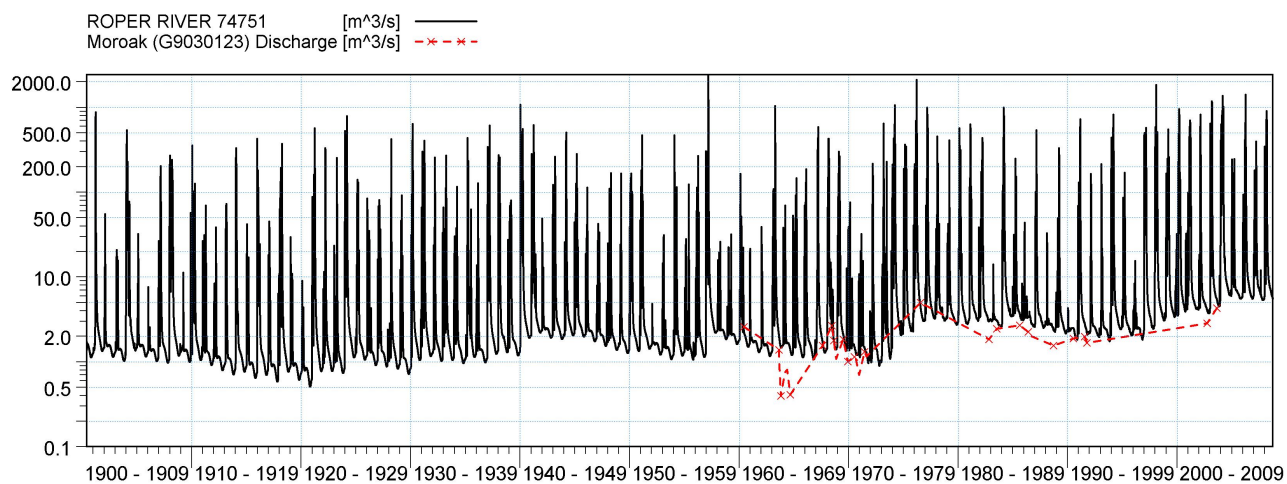


Figure 18 Simulated and measured discharge at Moroak (G9030123).

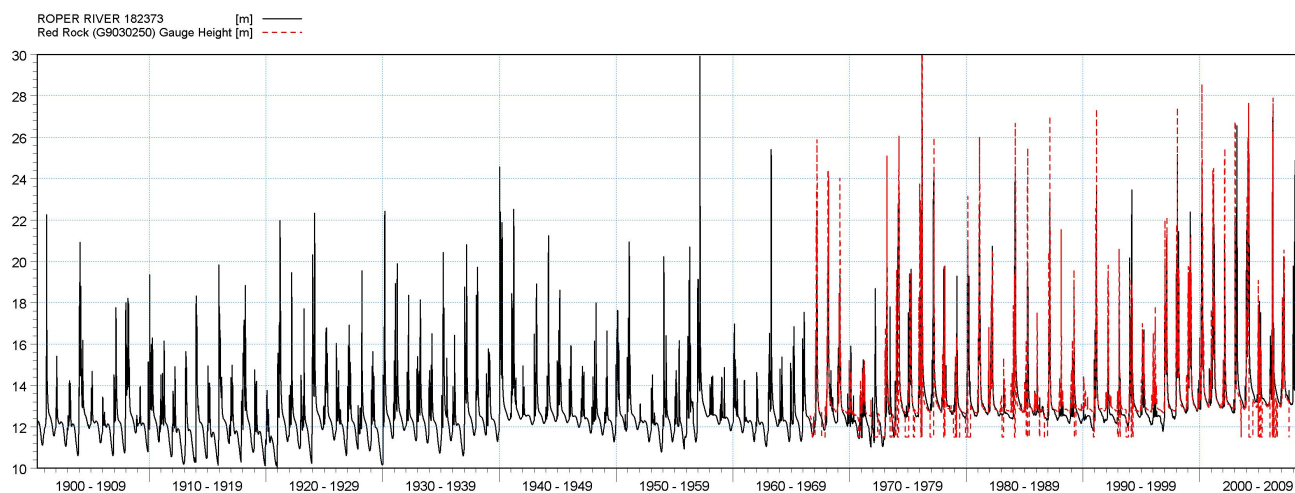


Figure 19 Calibrated gauge height for Red Rock (G9030250).

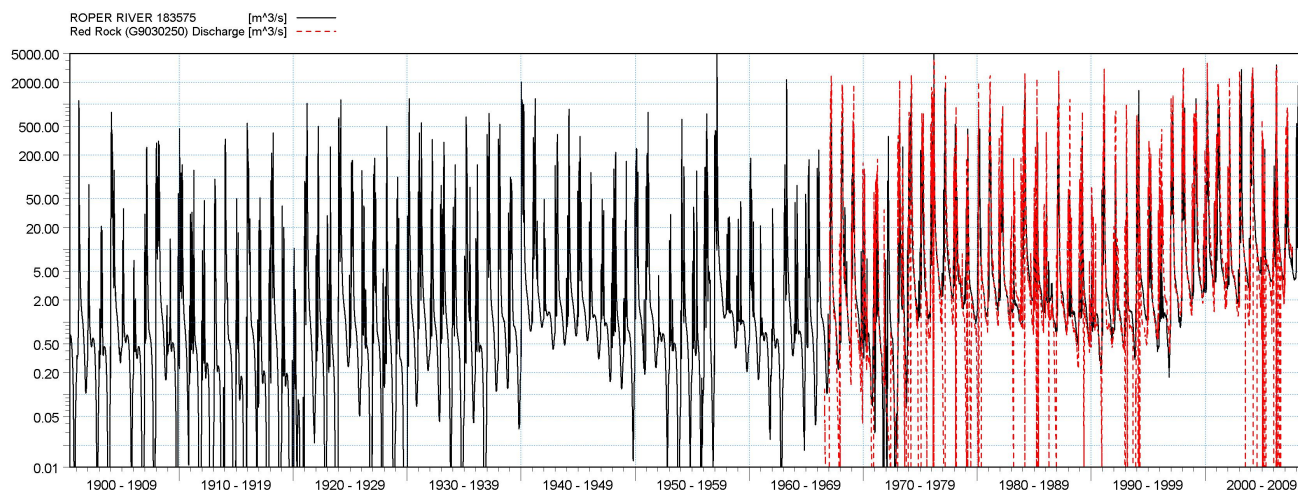


Figure 20 Calibrated discharge for Red Rock (G9030250). Simulated discharge (black trace and observed discharge (red dashed trace).

7 Conclusions

A working surface water model of the Roper River has been developed with the MIKE suite of software. The model has been designed to examine low flows with the capacity to couple to a suitable groundwater model. Historic flows have been calculated using historic climate data from 1900 – 2009 (refer Figures 20, 21 and 23).

Typically the available streamflow data is from the 1970s and 1980s, with only a few locations having streamflow data extending back to the 1950s. There is also a reduced data set through to the present due to closures of gauging stations in recent years. The relatively short period of flow record is often compounded by unreliable rating tables for higher flow events, therefore calibration of the rainfall-runoff model has been difficult and is probably unreliable for high stage heights and flows for some rivers.

Currently there are limitations with the cross-section data including the elevation accuracy, the length of cross-sections beyond the river bank and general coverage of cross-section data, particularly at river branch junctions.

The numerous pools along the length of the Roper River need to be defined to estimate storage, further cross-section surveys will provide this information.

In terms of the further understanding of the river's springfed flow regime and possible future management requirement to maintain flows to downstream ecosystems, a monitoring control needs to be established at the end of the spring section. This should be implemented as a continuous gauging station for which the preferred site is currently indicated to be near Red Lily Lagoon.

NAM calibration indicates Upper Roper River (Basin A), Flying Fox Creek (Basin C), Mainoru River (Basin D), Wilton River (Basin E), Upper Roper River (Basin L) and to a lesser extent the Waterhouse River (Basin B) demonstrate baseflow due to groundwater discharge. Roper River estuary (Basin G), Hodgson / Arnold River (Basin H), Strangways River (Basin I) and Elsey Creek (Basin J) do not exhibit baseflow.

Evapotranspiration is indicated to represent a significant proportion of the water balance for this system. The nature of the braided and open water sections of the river and lengthy run of the river towards its mouth manifest in losses in excess of 2.5 m³/s. In terms of this modelling exercise, significant gains can be made to the model's predictive capacity if these losses can be better quantified.

The hydrodynamic nature of the pool section of the Roper River downstream of Roper Bar and its response to allocated flows warrants further study. The long term quality of water within this pool is highly dependent on the upstream flows that are maintained to it.

8 Recommendations

It is recommended that the further work below is conducted:

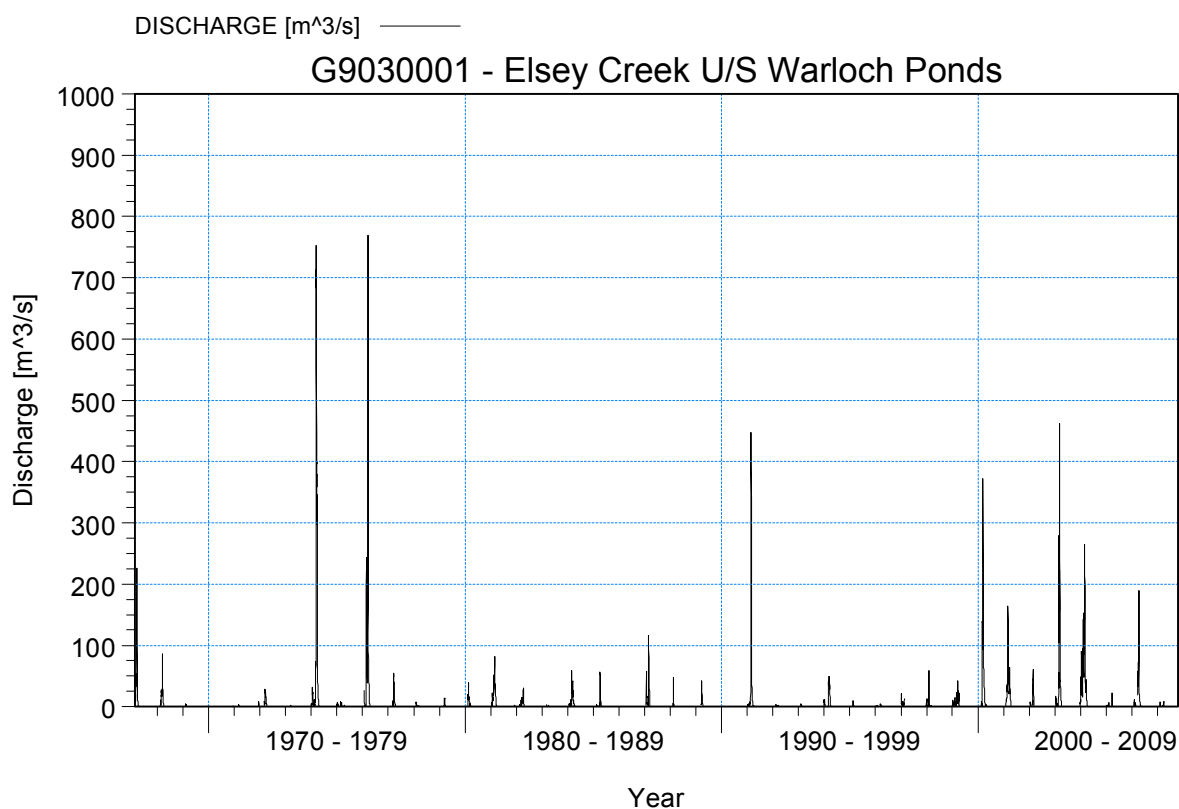
- Elevation survey of gauge sites and available cross-sections of the rivers,
- Improve cross-section and bathymetric coverage of the river particularly at important areas of groundwater interaction and at the junctions between branches
- Seek more detail in the overbank portion of the river cross-sections
- Maintain the current gauging station network and construct a new station at the end of the spring discharge section near Red Lily Lagoon
- Undertake further study to better quantify the system's evapotranspiration losses.
- Undertake hydrodynamic and water quality modelling of the pool downstream of Roper Bar to predict water quality changes due to water allocation at Mataranka.

9 References

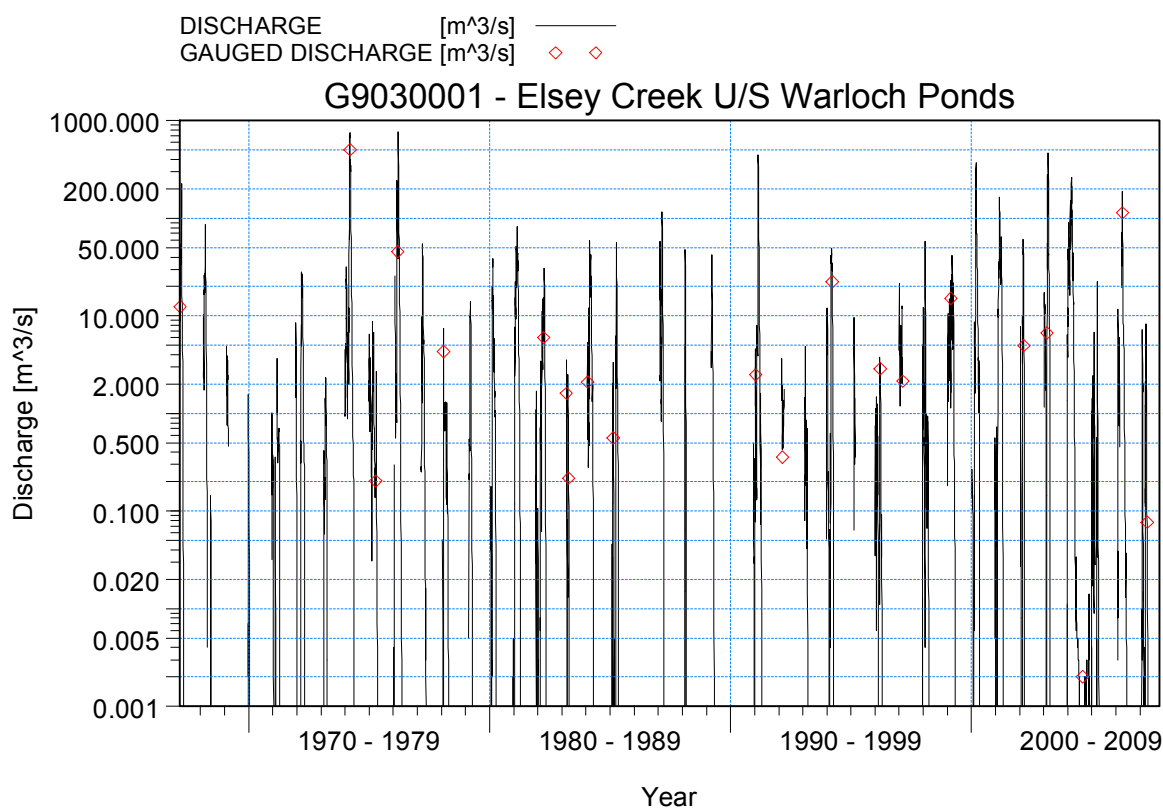
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10 APPENDIX A – Observed Runoff Plots



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Figure 21 G9030001 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for Elsey Creek at Warloch Ponds.

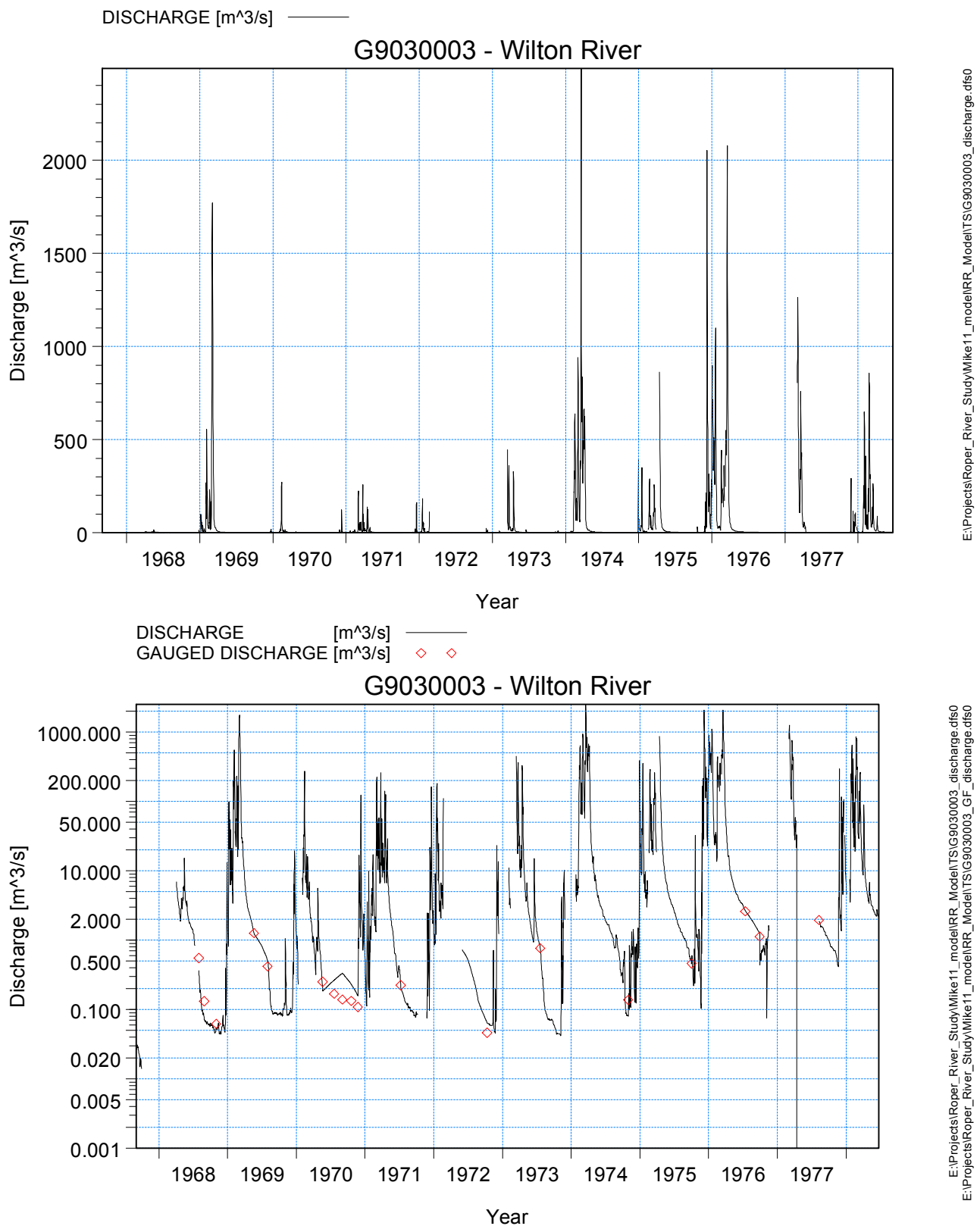


Figure 22 G9030003 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for the Wilton River at Quallari Waterhole.

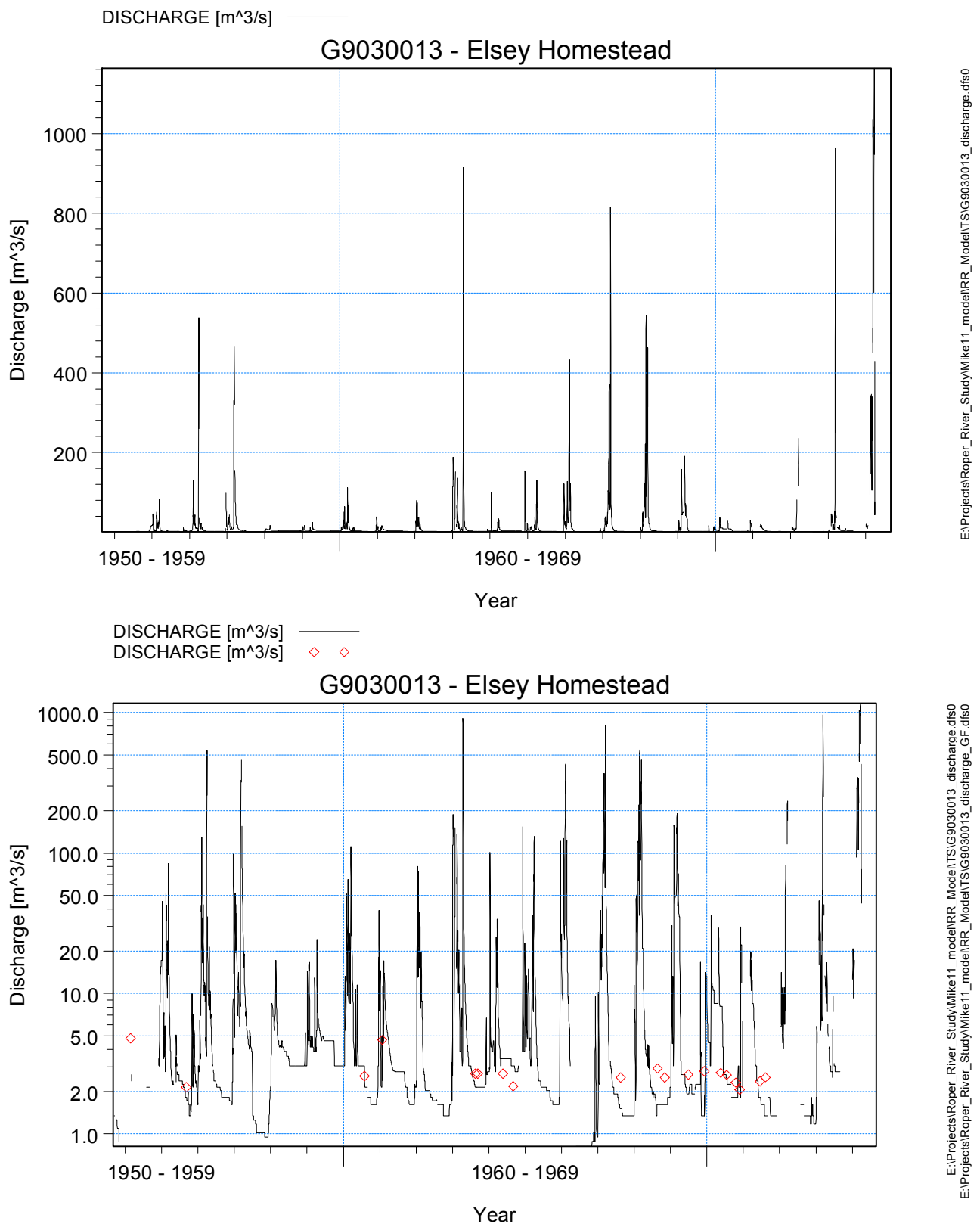
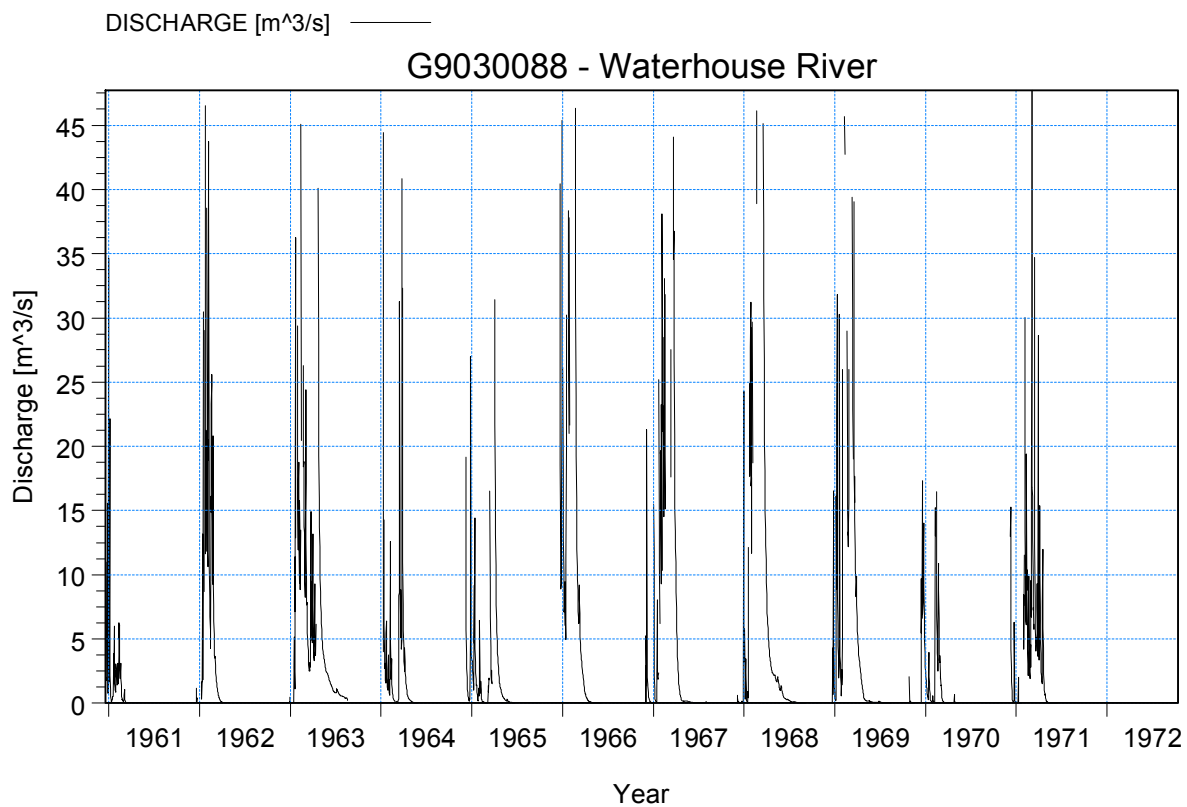
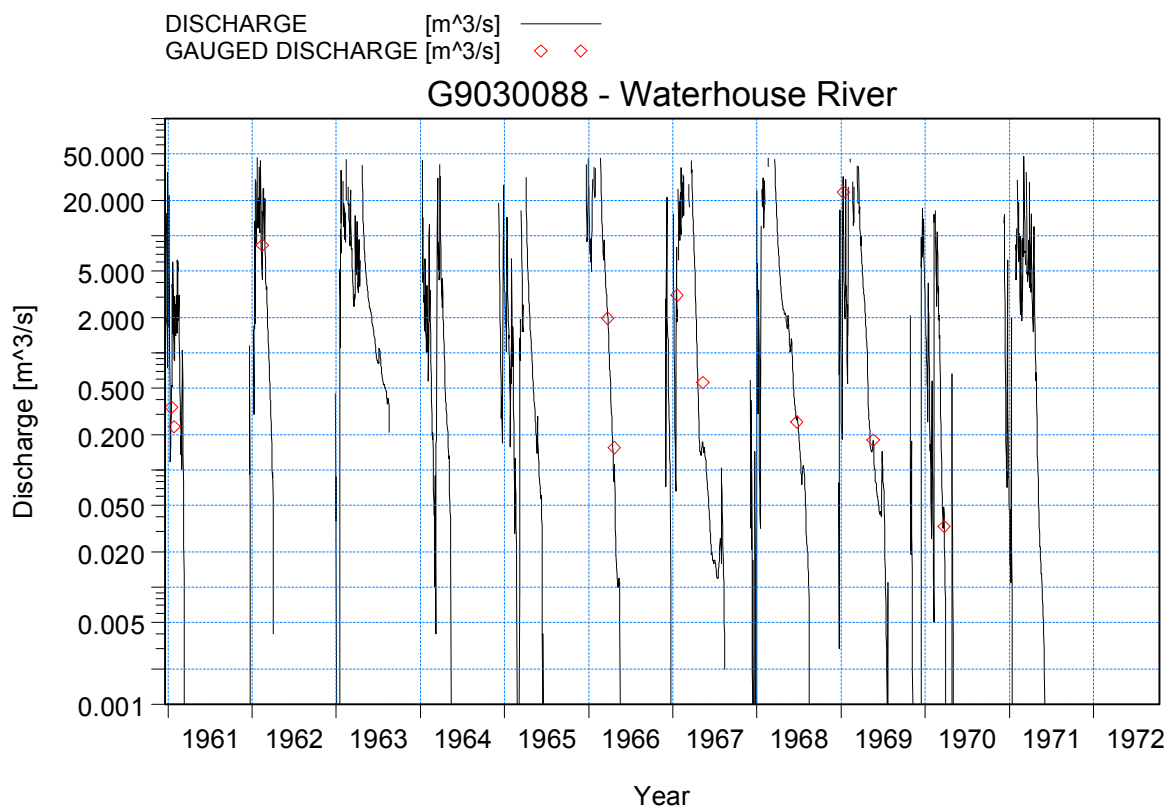


Figure 23 G9030003 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for the Roper River at Elsey Homestead.

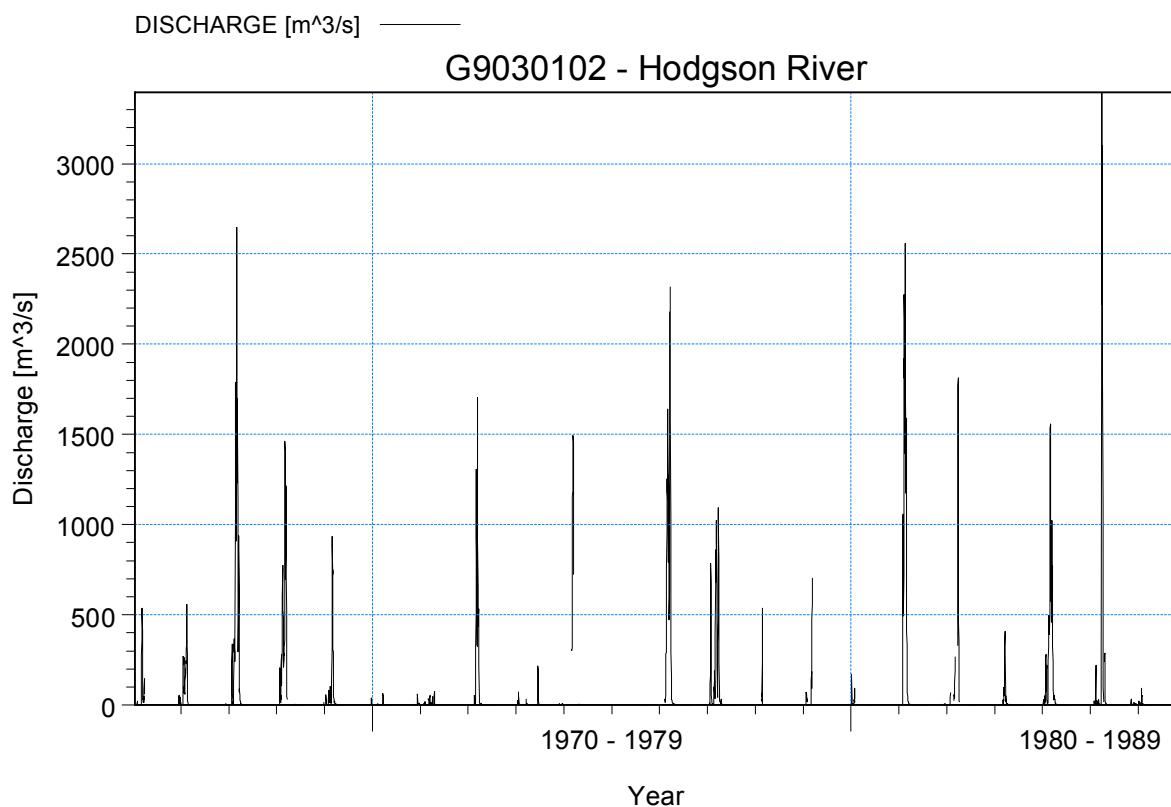


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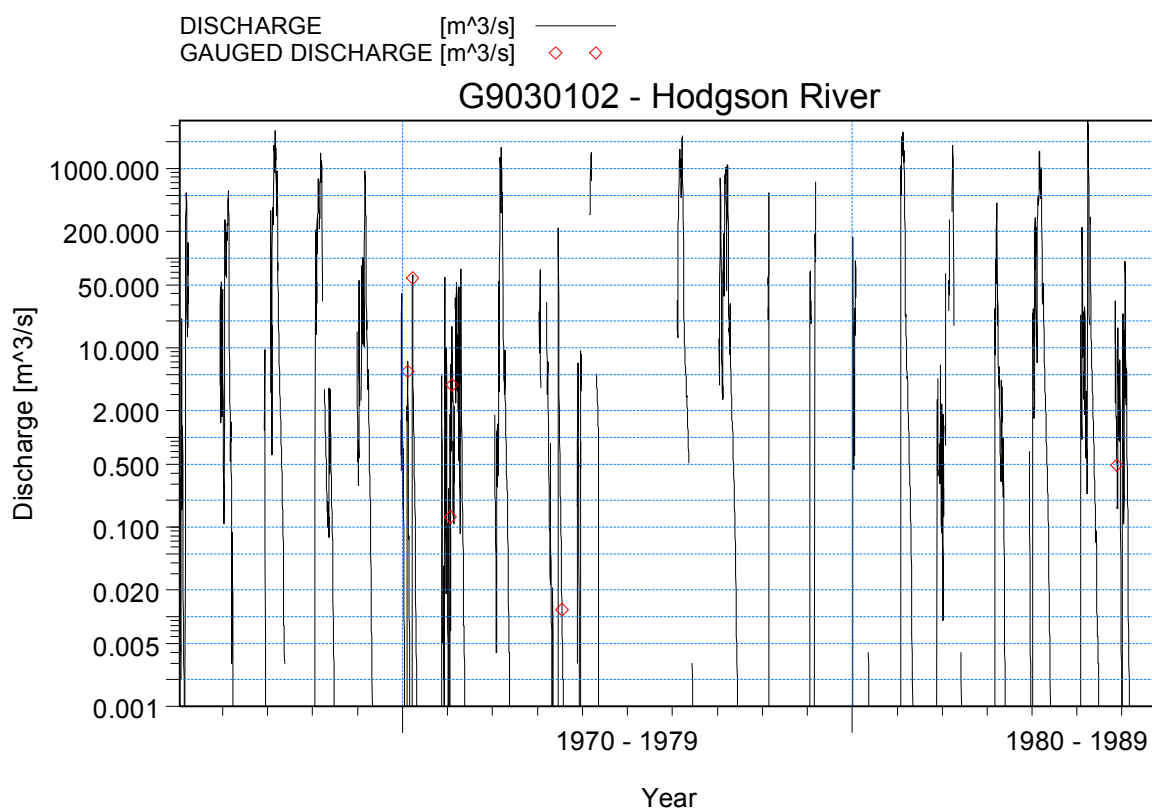


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Figure 24 G9030088 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for the Waterhouse River.

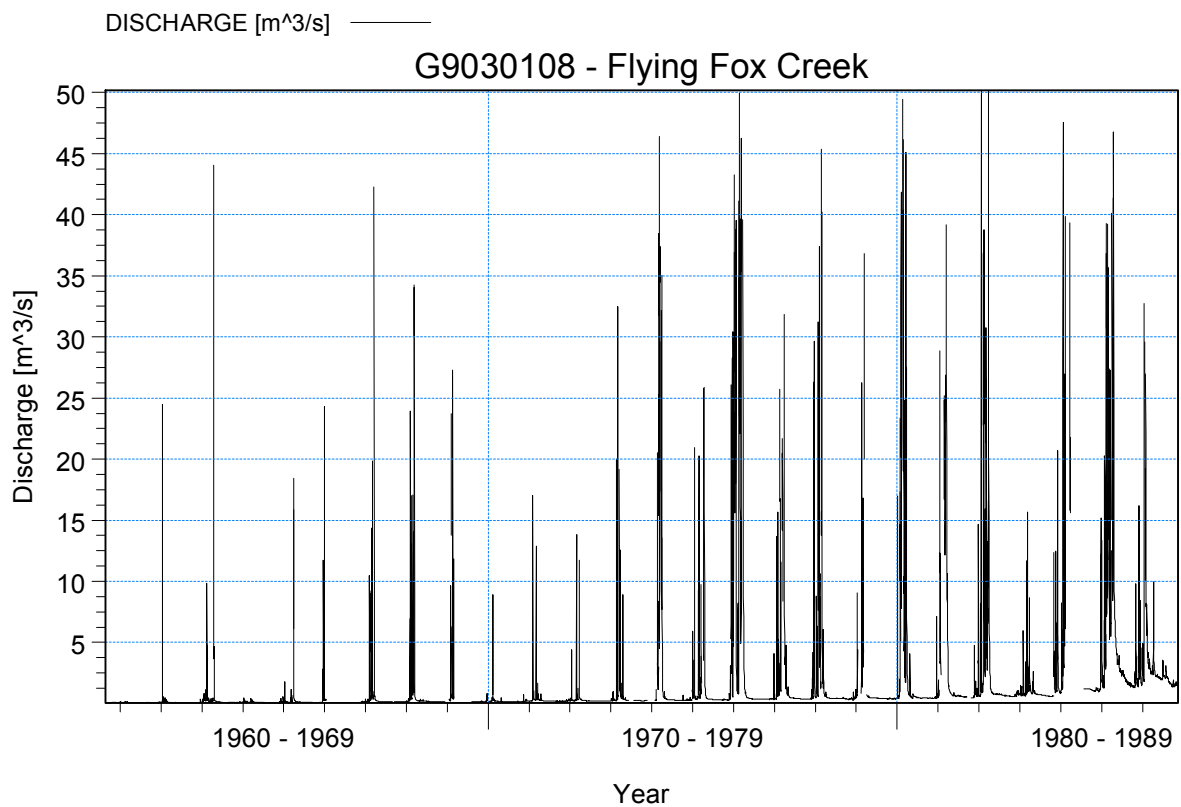


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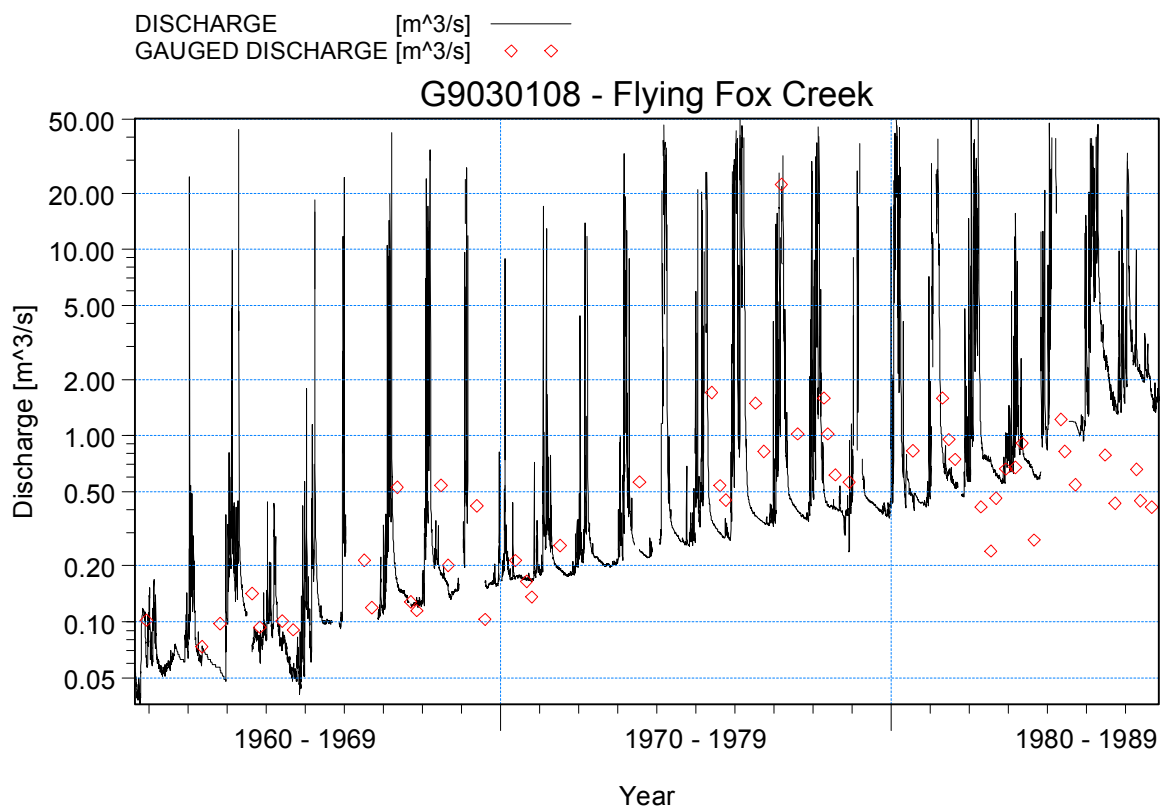


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Figure 25 G9030102 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for Hodgson River.

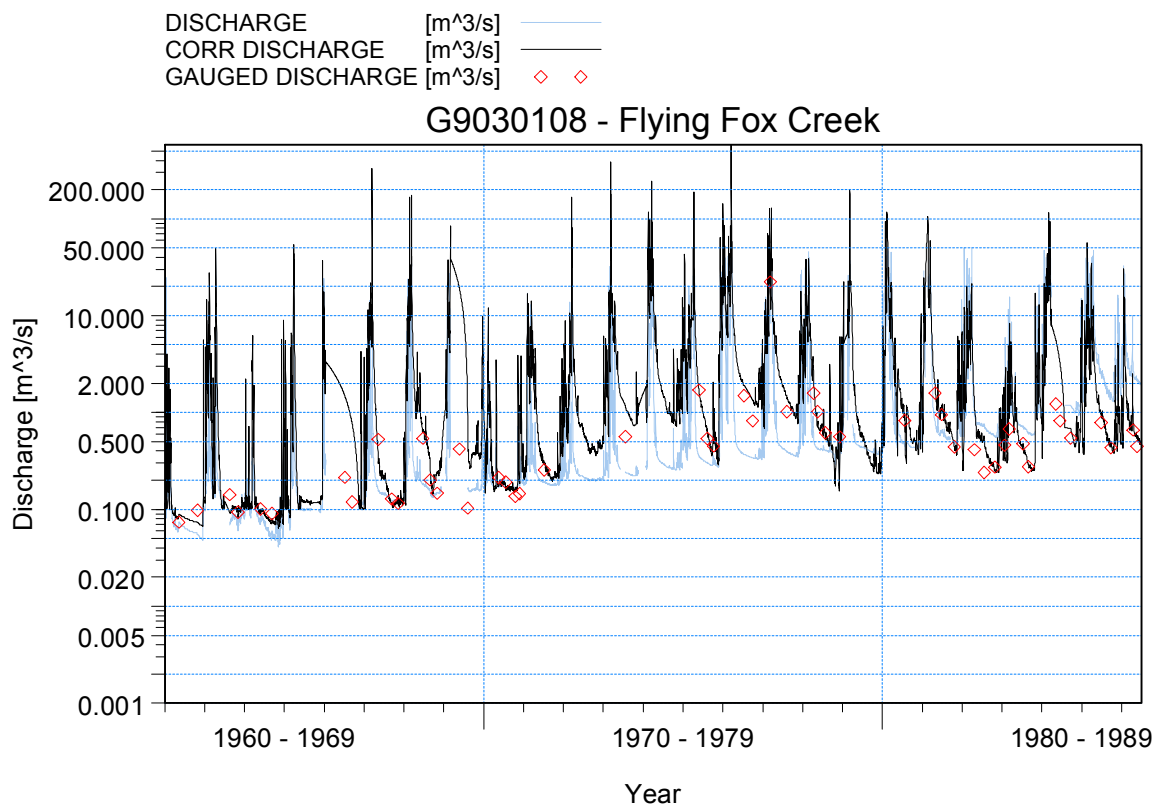


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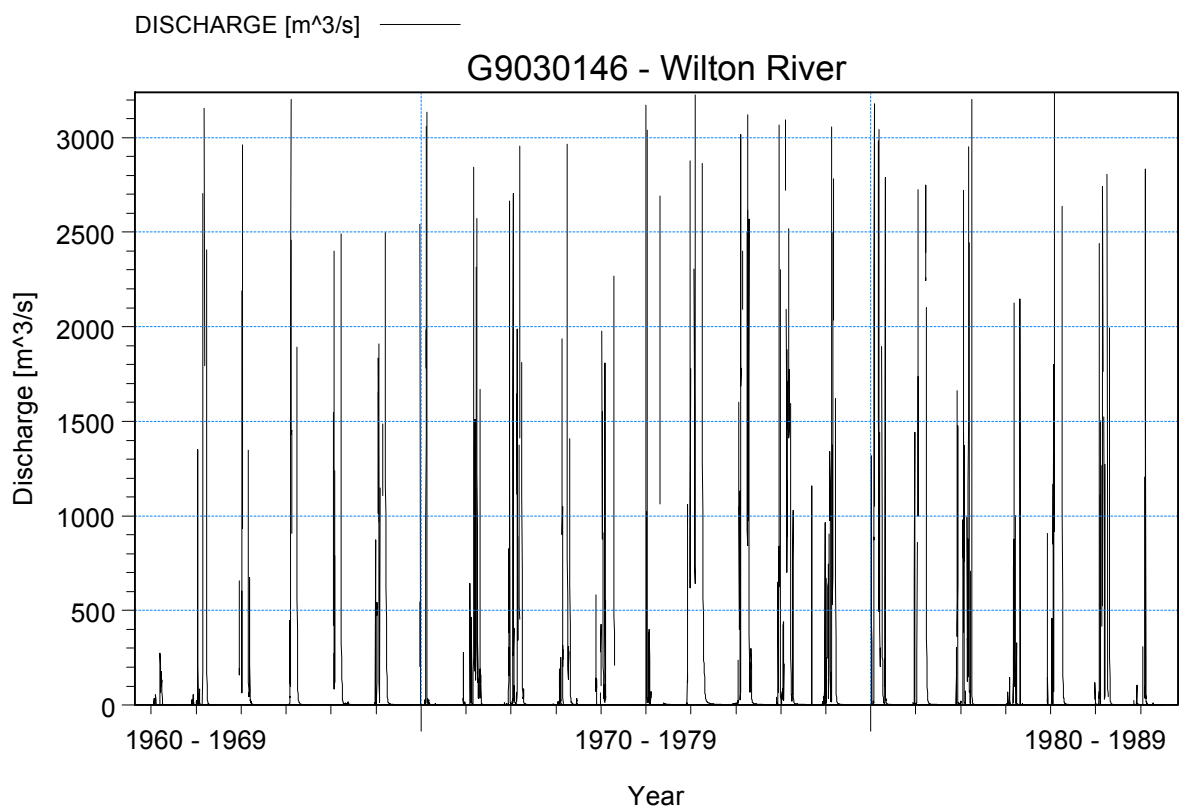
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Figure 26 G9030108 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for Flying Fox Creek.

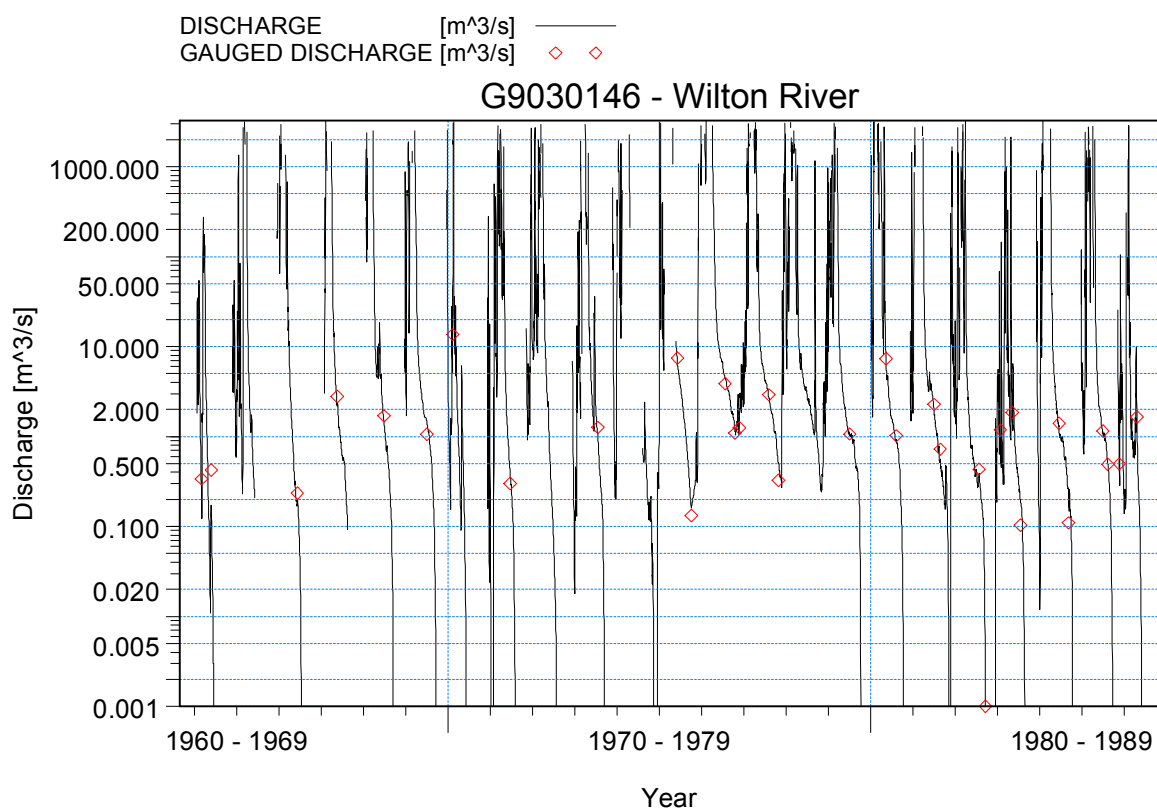


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Figure 27 **Corrected discharge hydrograph for G9030108 – Flying Fox Creek.**



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Figure 28 G9030146 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for the lower Wilton River.

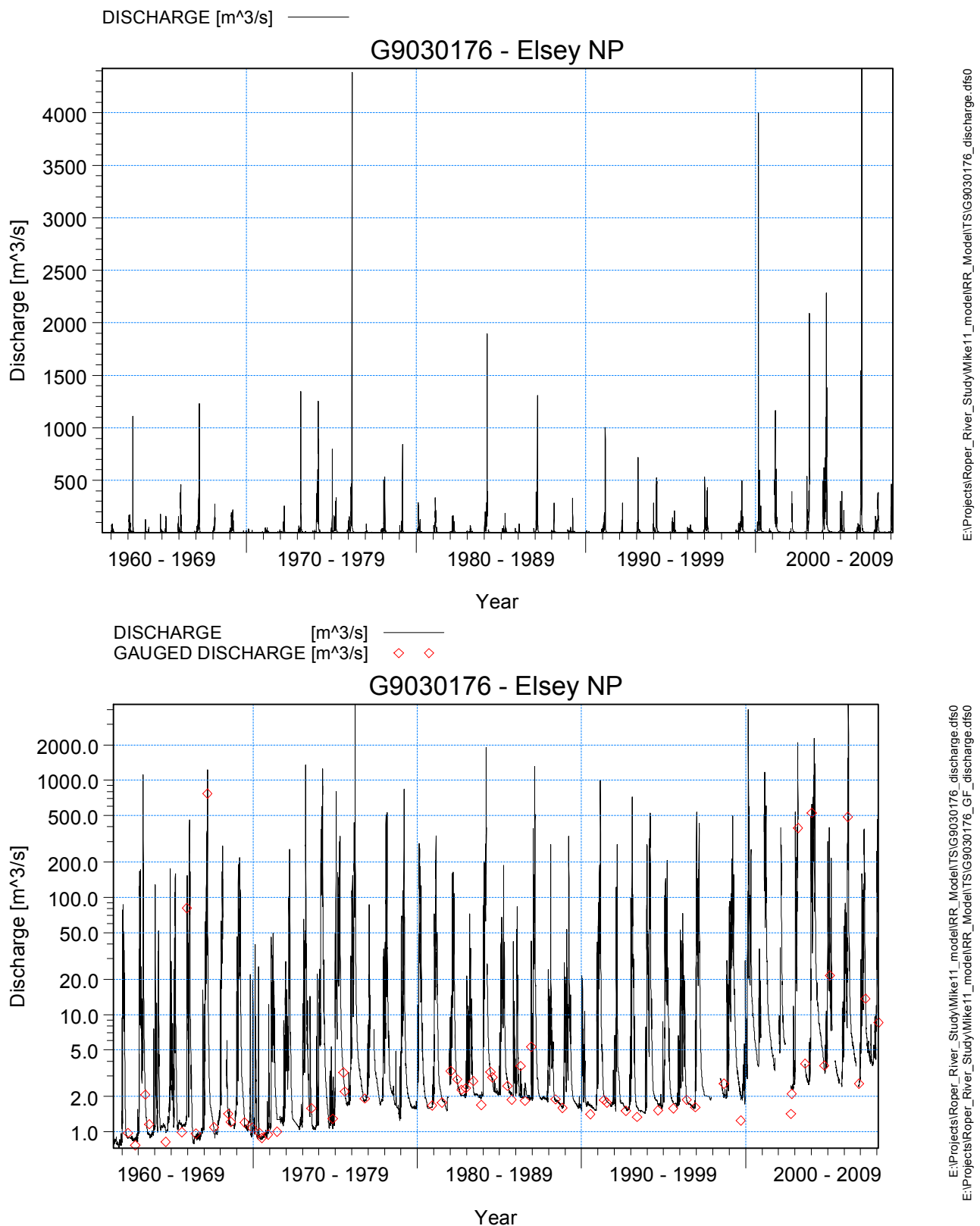


Figure 29 G9030176 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for the Roper River at the D/S Mataranka Homestead.

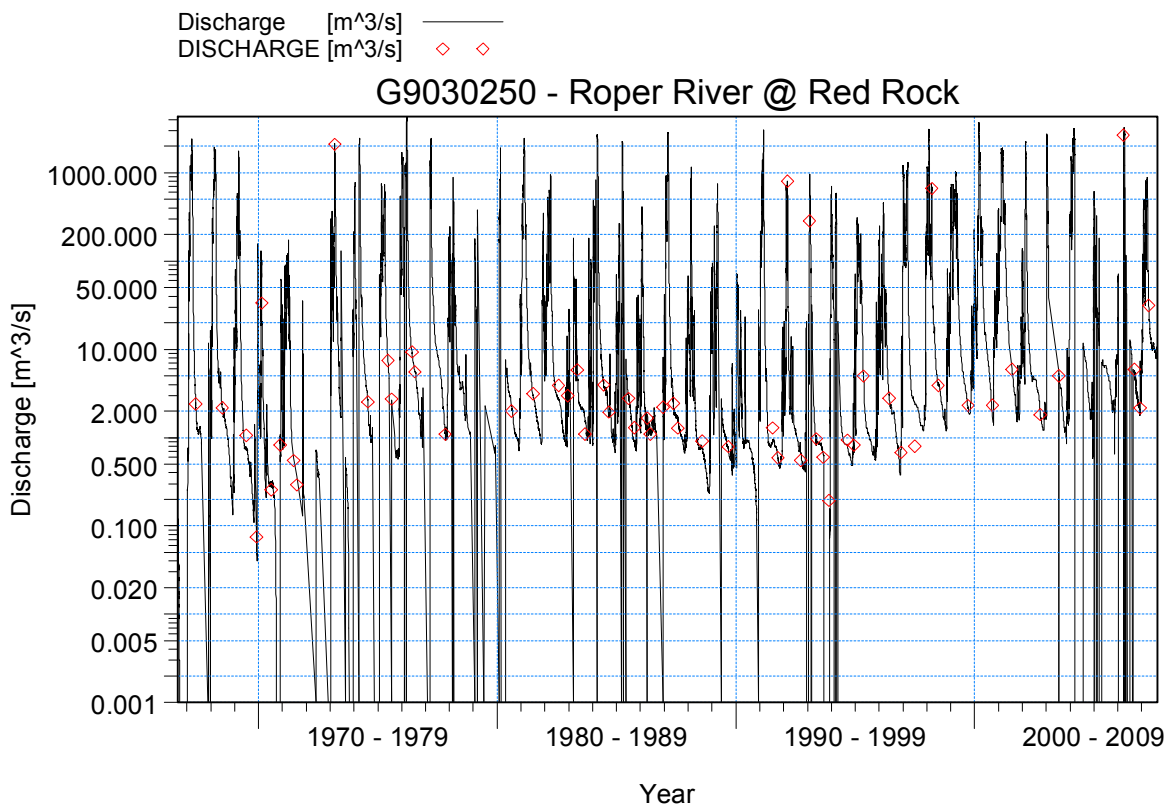
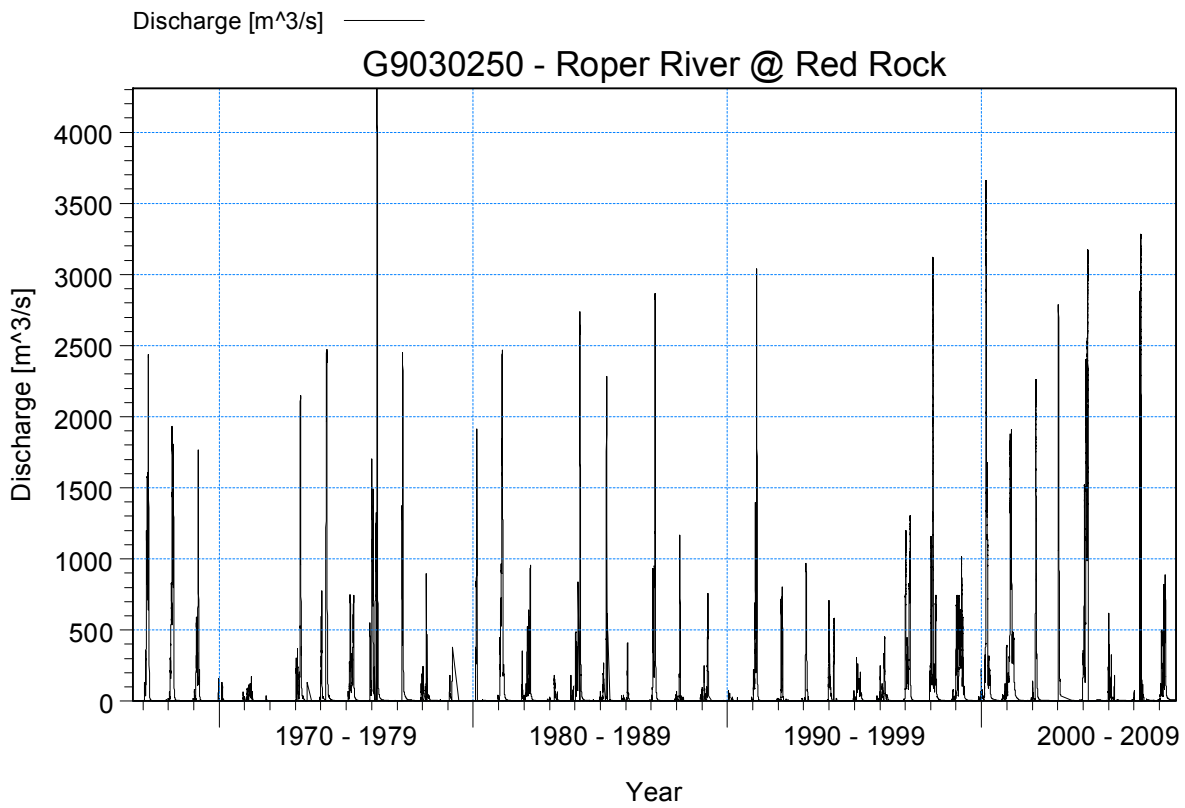
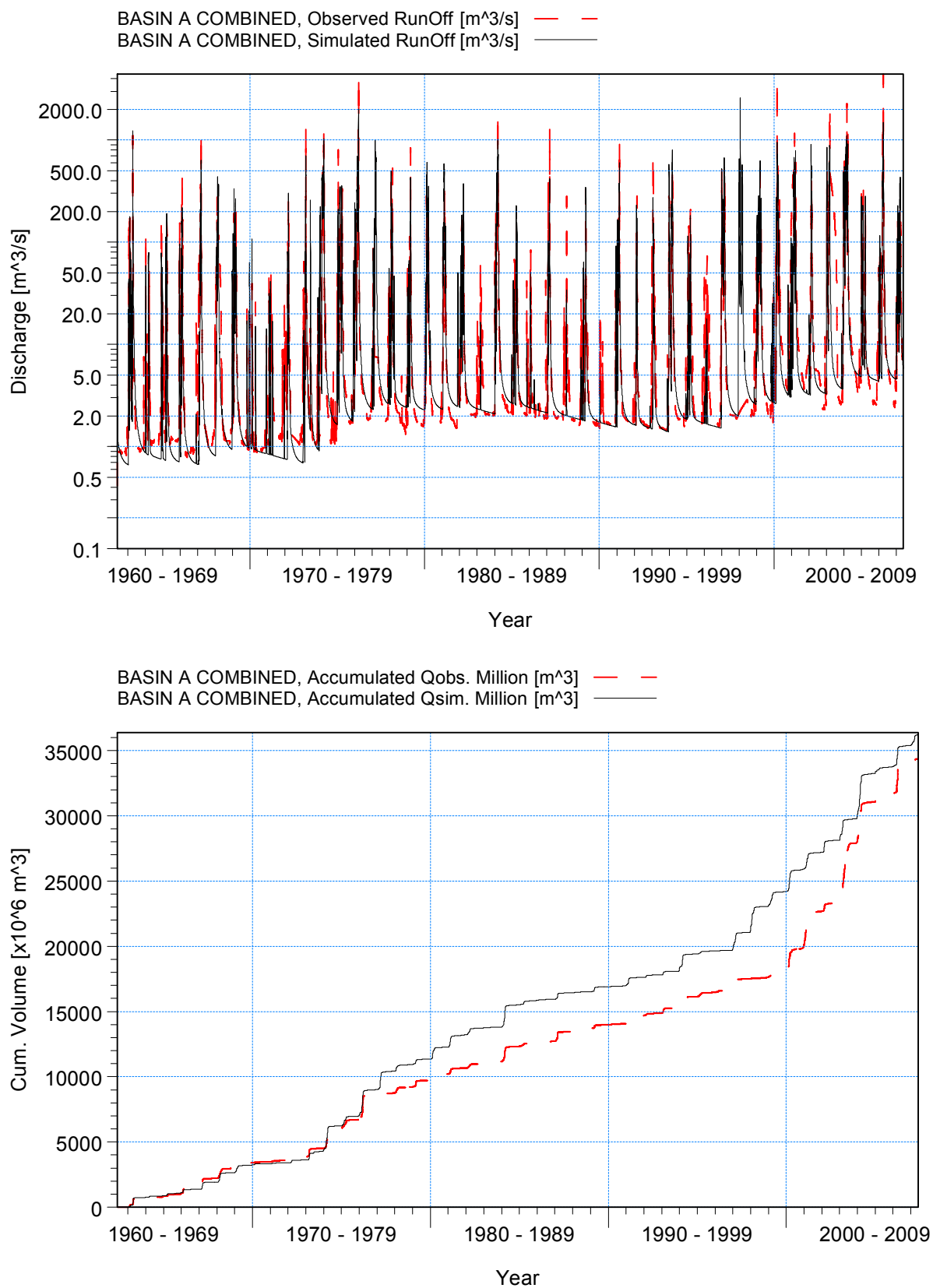


Figure 30 G9030250 discharge hydrograph (black trace) compared with manual gauged flows (red markers) for the Roper River at Red Rock.

11 APPENDIX B – Runoff Calibration Plots



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Figure 31 Basin A Combined (Waterhouse and upper Roper River) runoff calibration results.

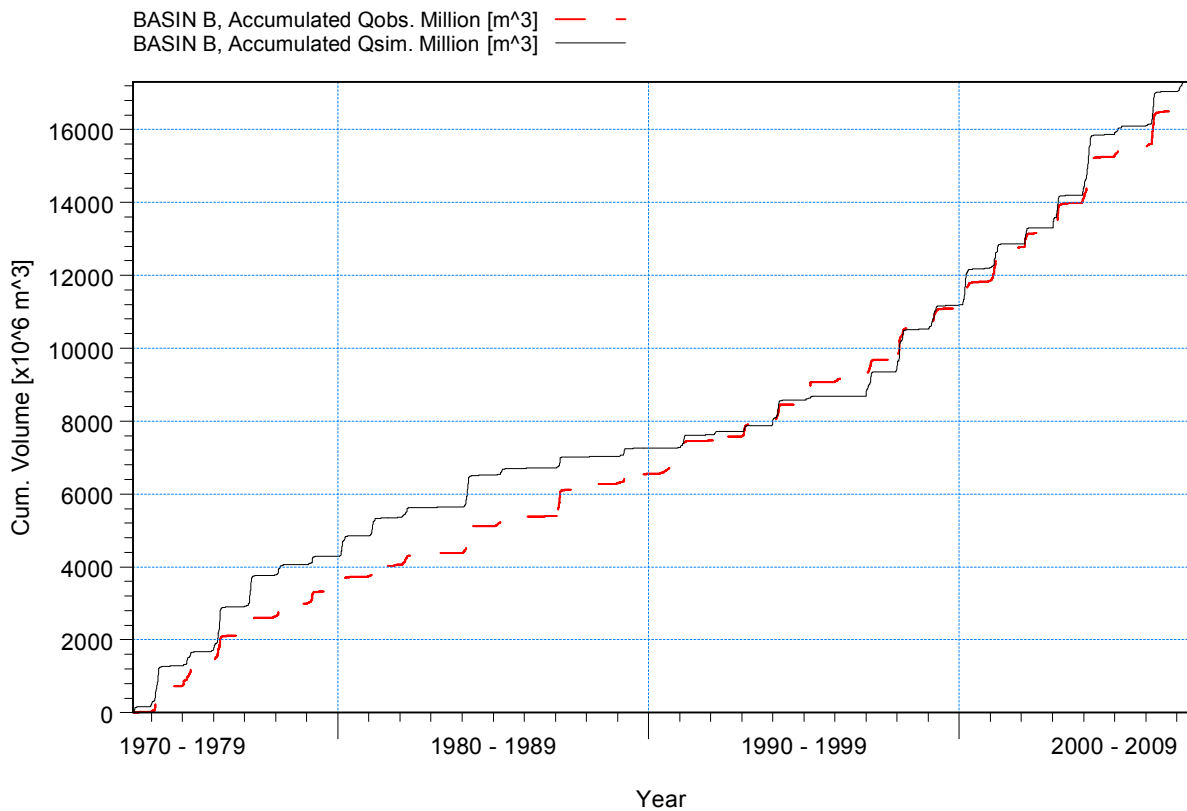
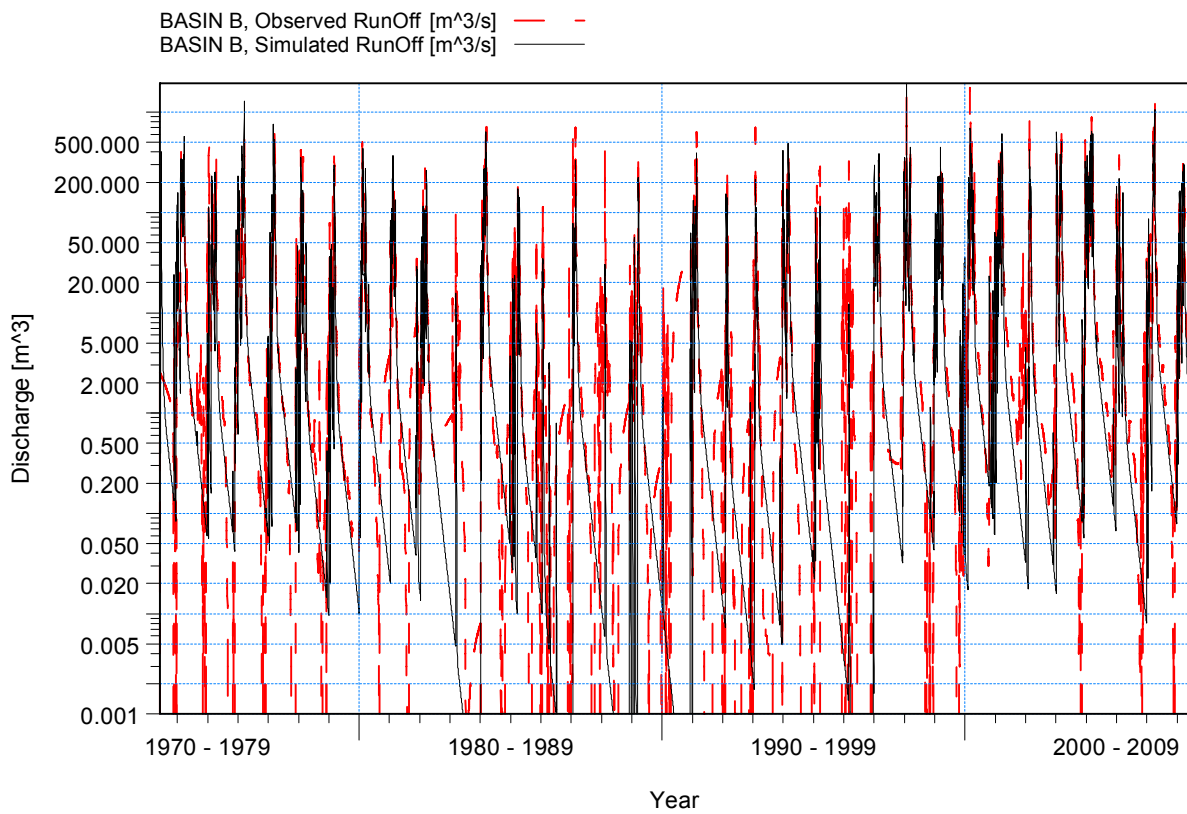
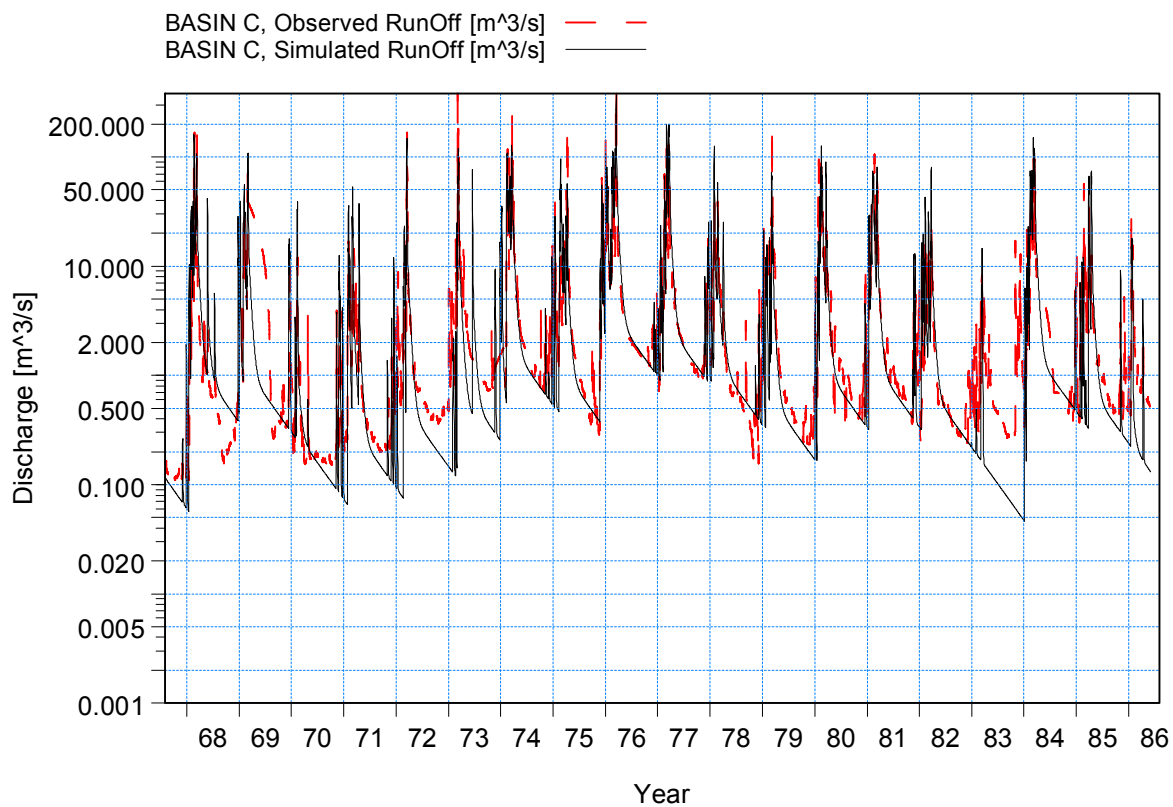
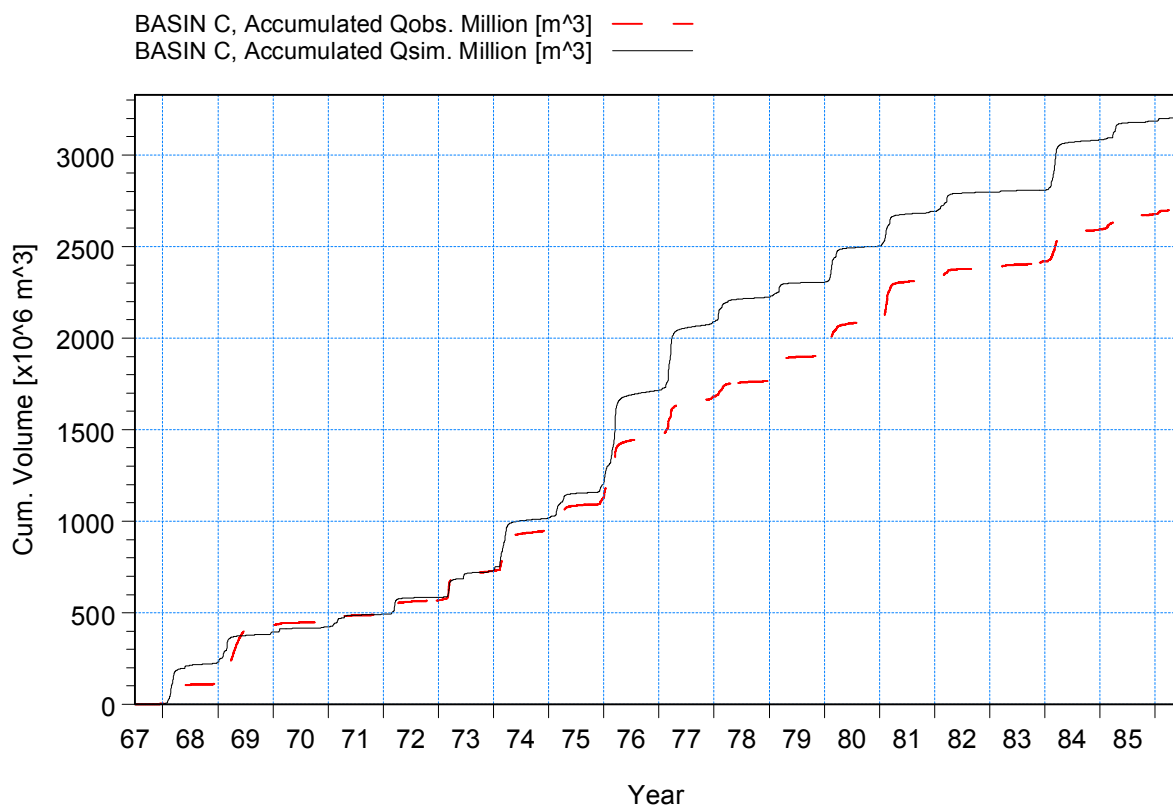


Figure 32 Basin B (Waterhouse River) runoff calibration.

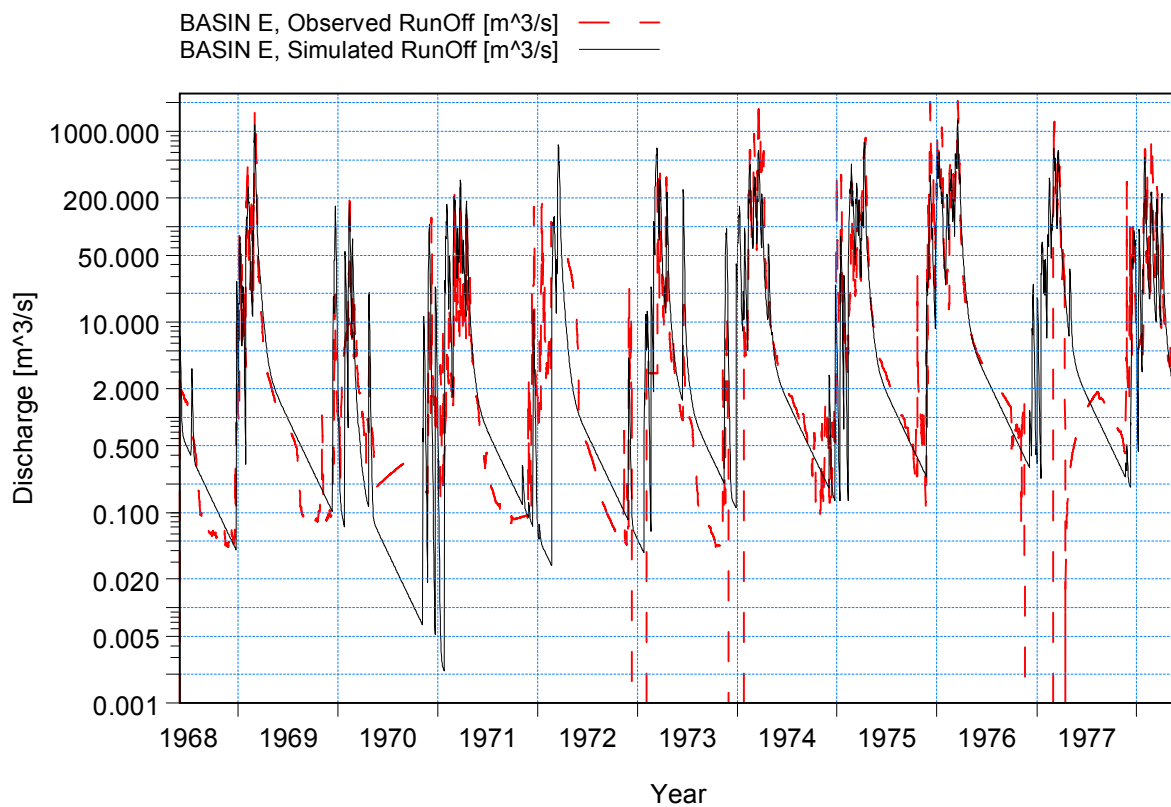


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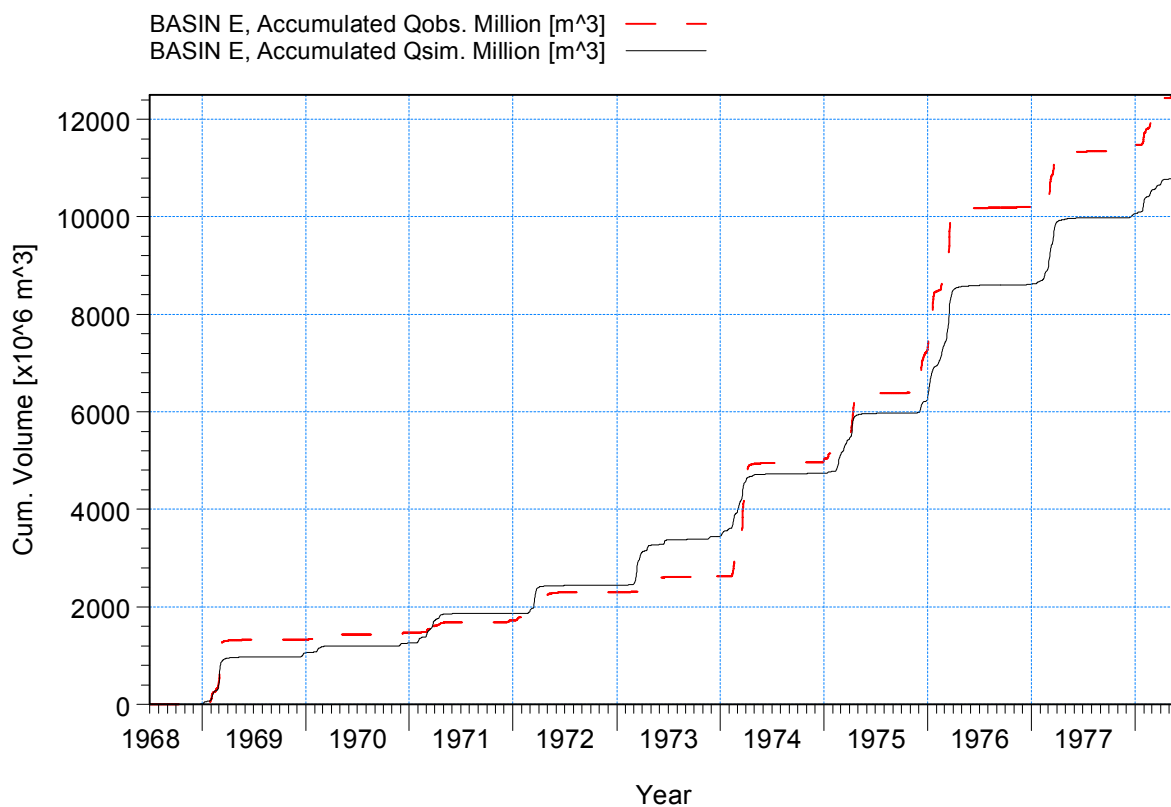


E:\Projects\Roper_River_Study\Mike11_model\IRR_Model\RRcalibration\BASIN C.dfs0

Figure 33 Basin C (Flying Fox Creek) runoff calibration.

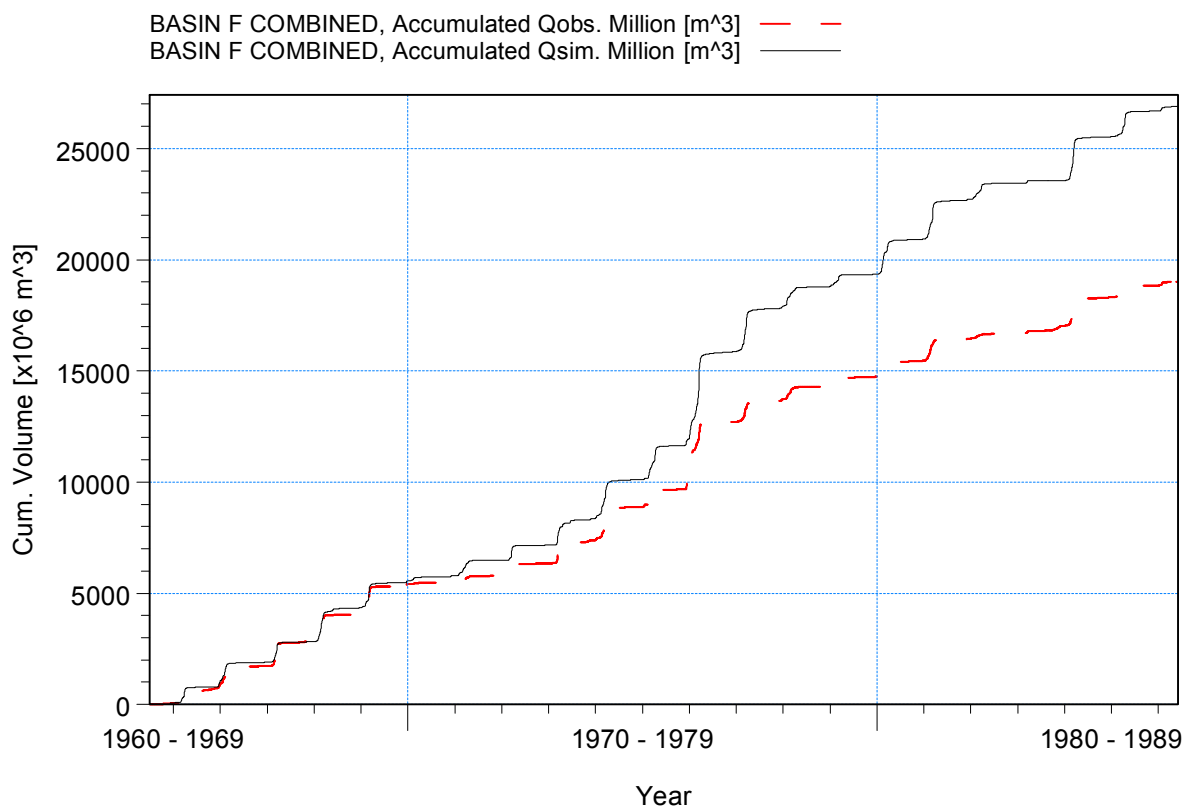
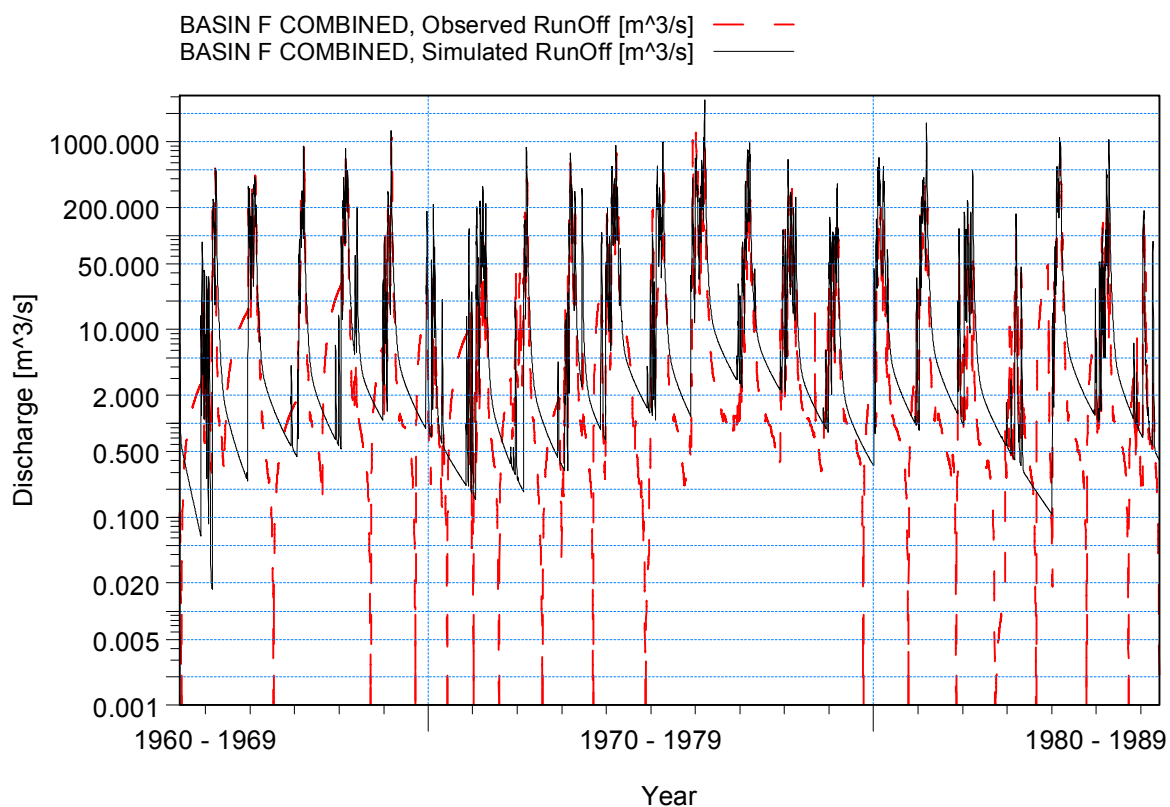


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Figure 34 Basin E (upper Wilton River) runoff calibration.



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 E:\Projects\Roper_River_Study\Mike11_model\IRR_Model\IRRcalibration\BASIN F COMBINED.dfs0

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Figure 35 Basin F Combined (Wilton River – G9030146) runoff calibration.

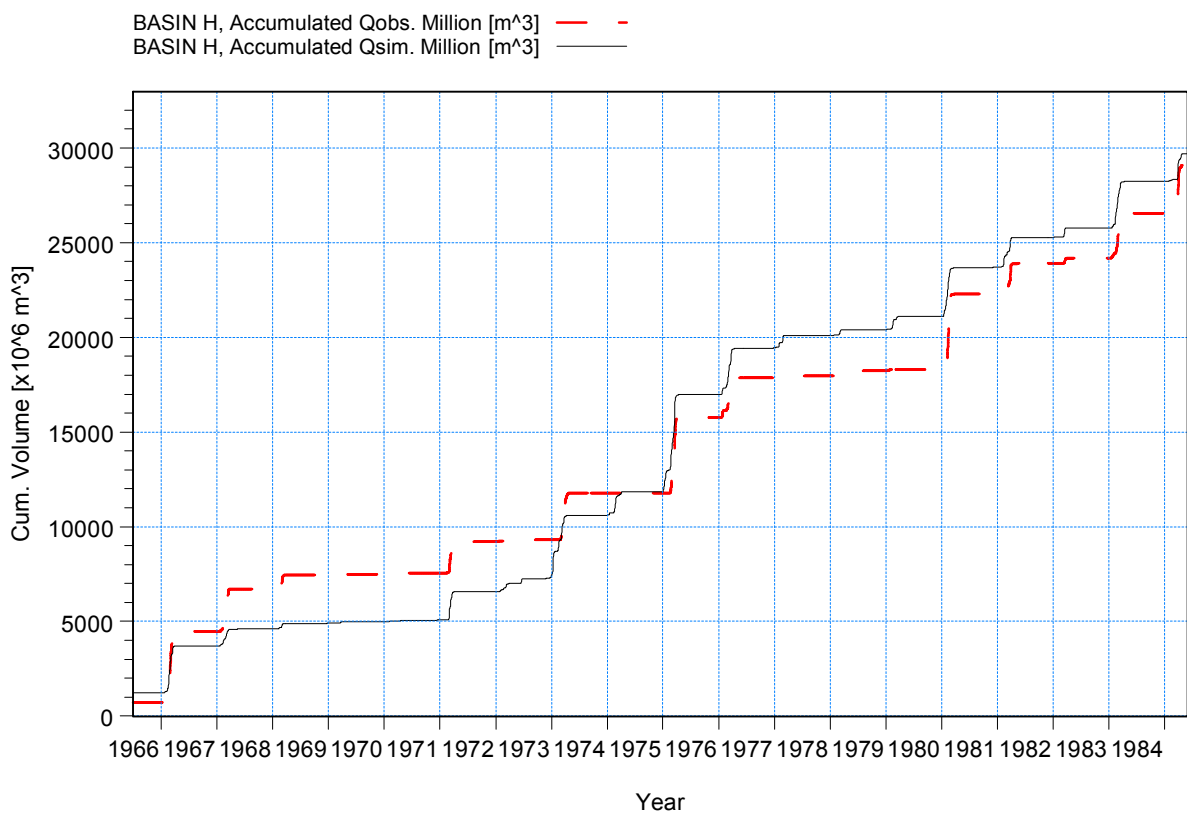
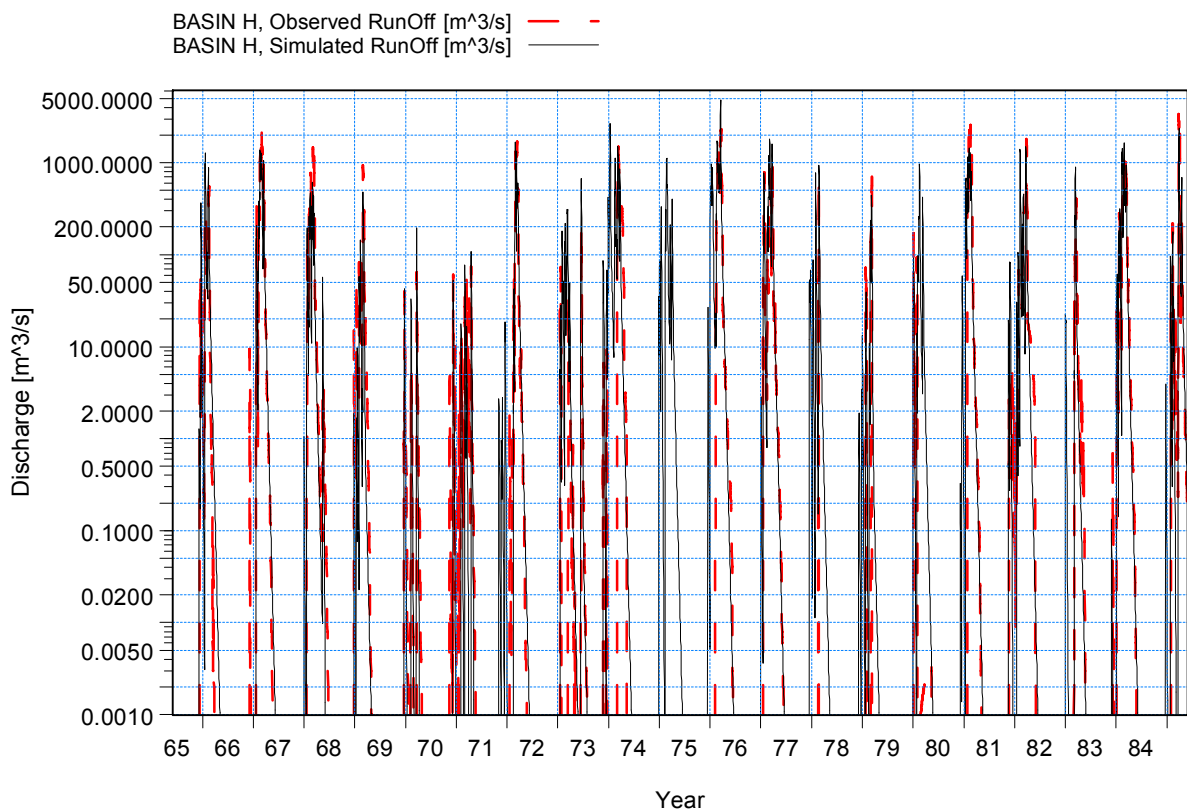
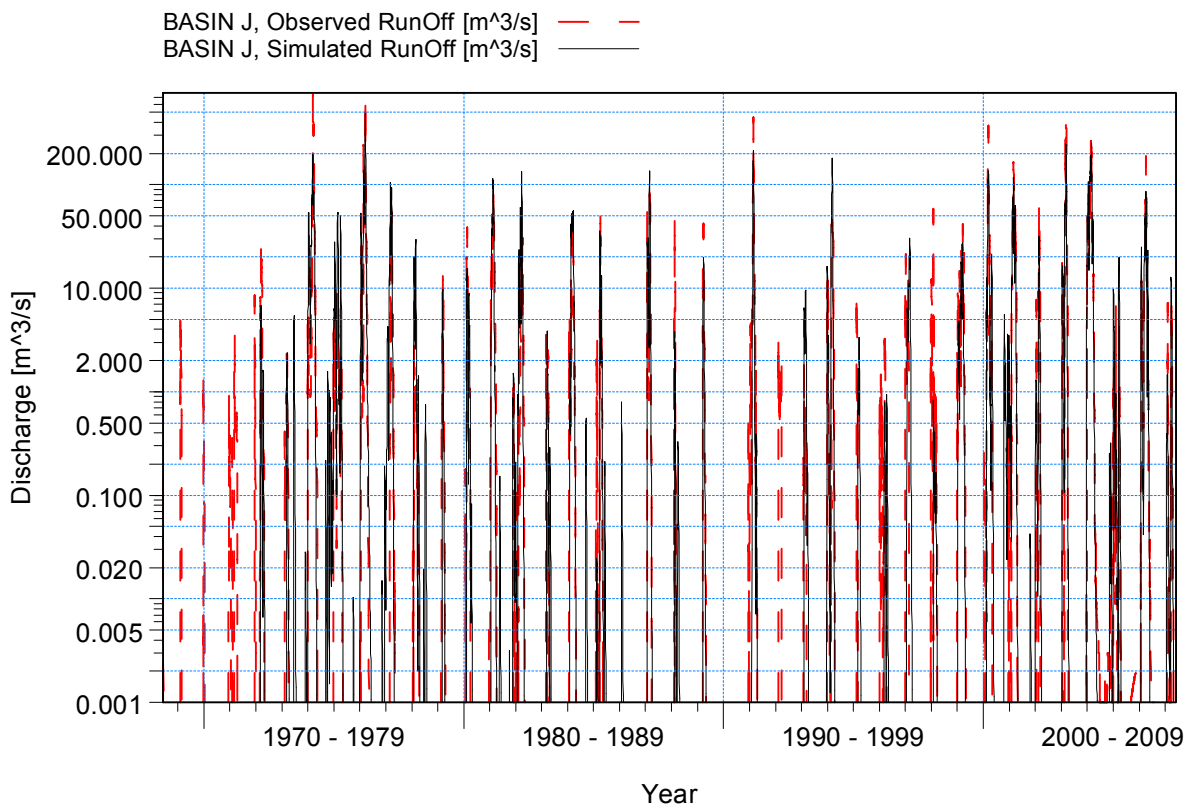
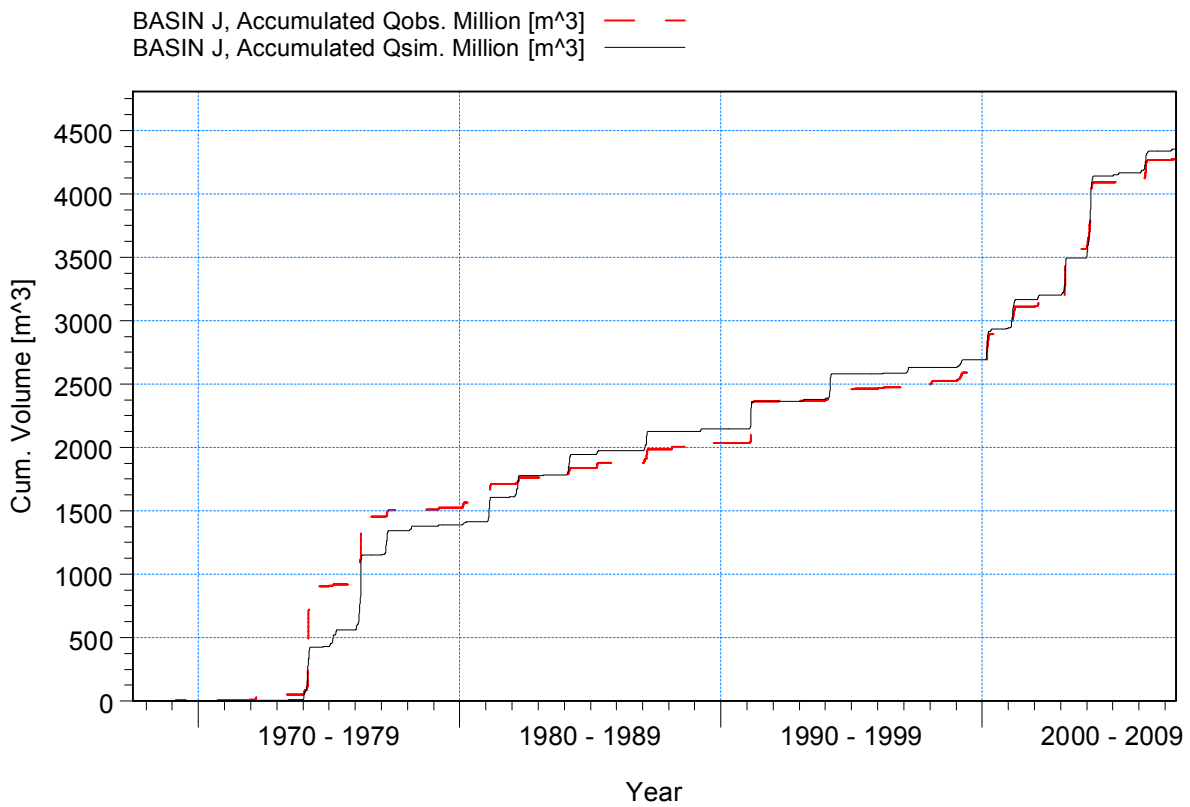


Figure 36 Basin H (Hodgson River) runoff calibration.



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Figure 37 Basin J (Elsey Creek) runoff calibration.

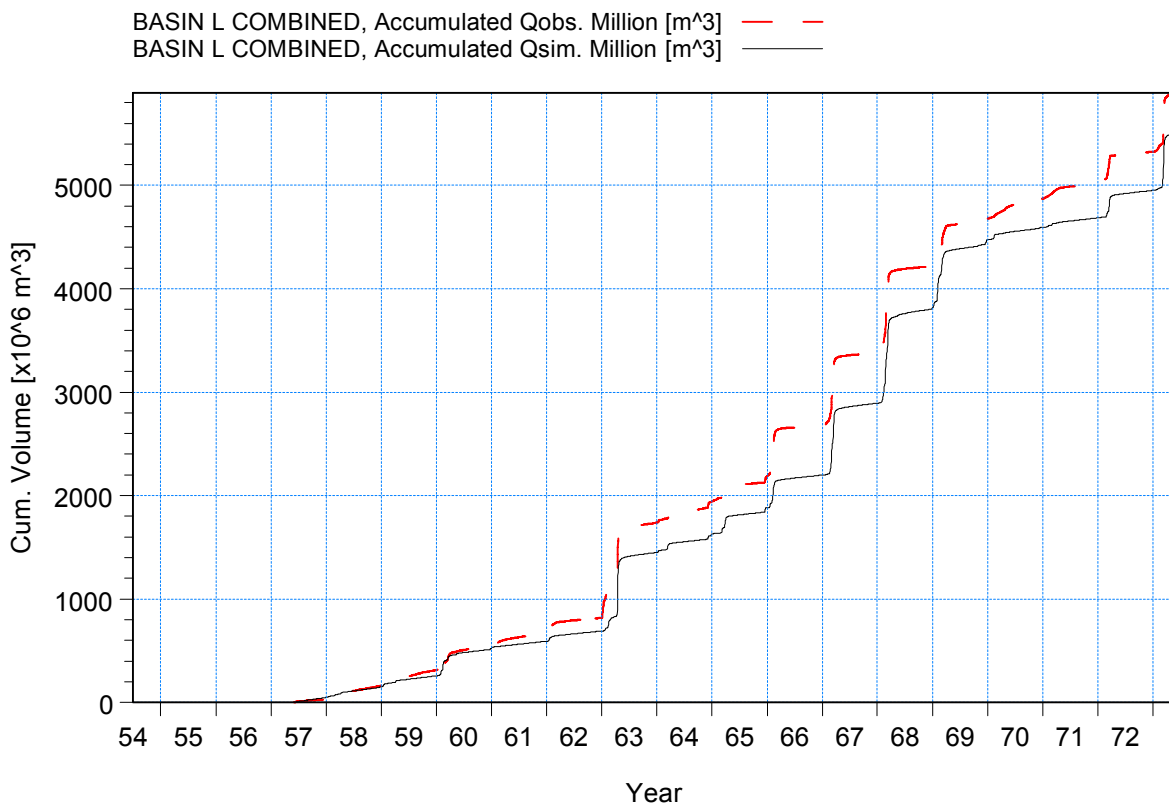
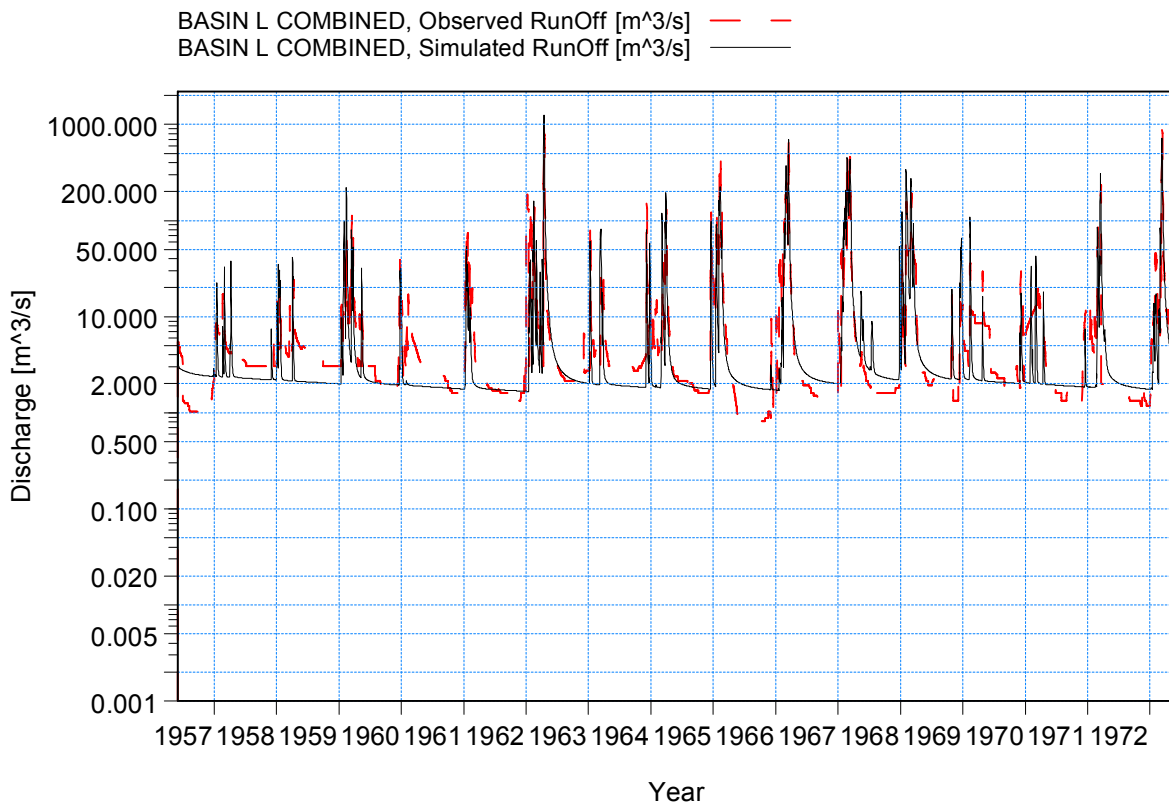
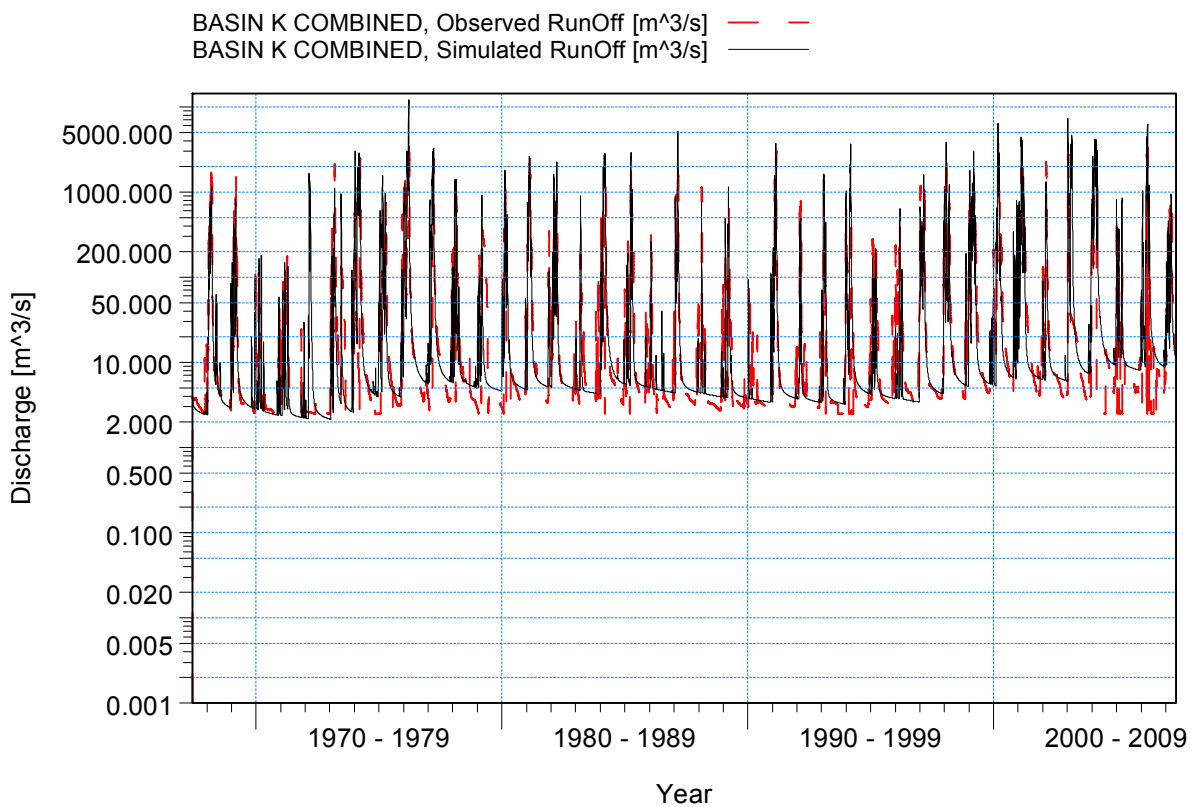
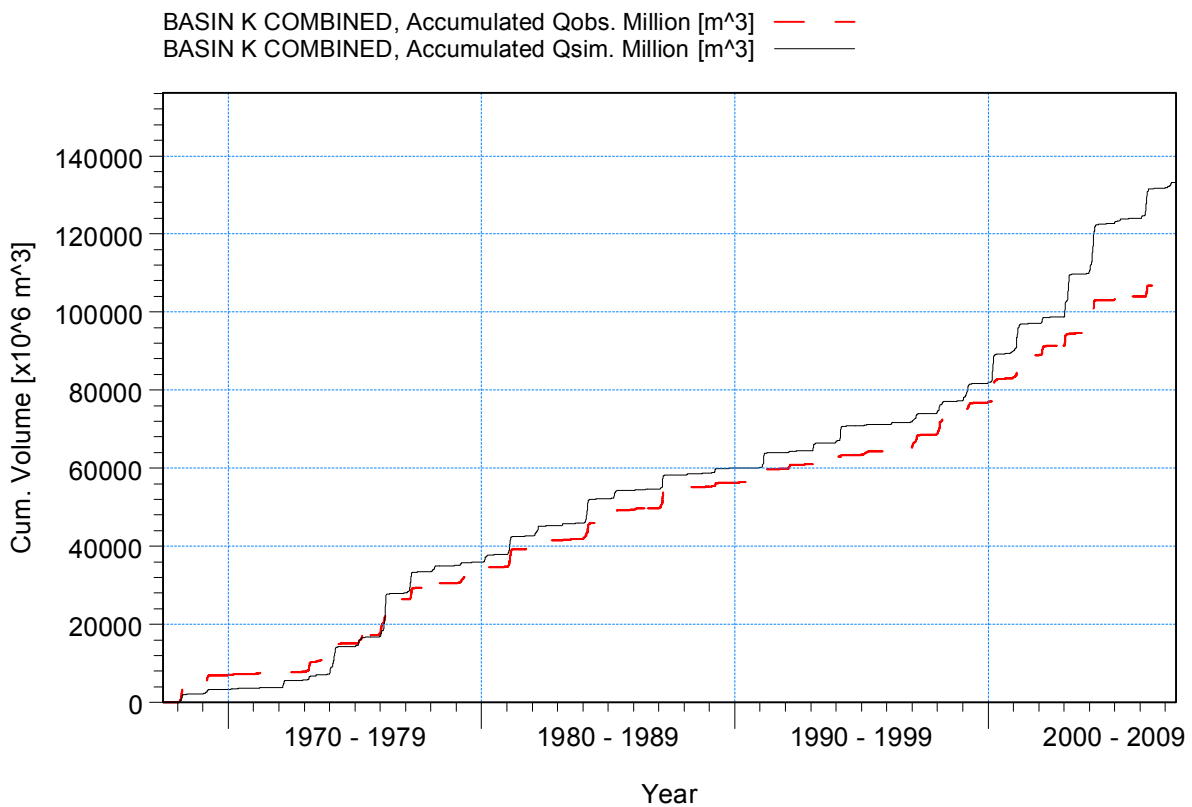


Figure 38 Basin L (Roper River) runoff calibration.



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Figure 39 Basin K Combined calibrated runoff for the Roper River at Red Rock. Observed flows have been increased by 2.5 cumecks to simulate observed losses along the river from Elsey Homestead to Roper Bar.