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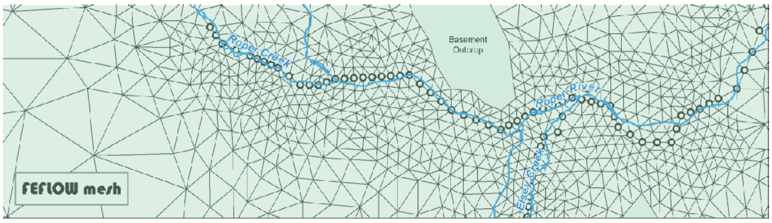
Gulf Water Study

Integrated Surface - Groundwater Model of the Roper River Catchment

Part A: Coupled Surface – Groundwater Model



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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 A - Coupled Surface – Groundwater model

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Technical Report No. 15/2009D

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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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Executive 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 Water 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 an indication of possible impacts on groundwater dependent ecosystems due to development. This information will help in long term decision making and identify the areas where further study is required. The model also provides quantitative information, through the ability to undertake scenario modelling, that will ensure that the current and planned regional water uses remain within sustainable limits.

The identification of sources of dry season water in the catchment will enable property planning and development opportunities by station managers.

A groundwater model encompassing the two major aquifer systems providing baseflow to the Roper River and its' tributaries has been developed. However, the current version of the module used to couple the surface water and groundwater models (IFMMIKE11) does not appear to support the separate meshes used to model the two aquifer systems in a single model. It is anticipated that this limitation will be rectified in future iterations of the model development. As there is little development in the Dook Creek Formation at the present time and in the foreseeable future, the need for a fully distributed groundwater model is not a priority and the historic dry season groundwater flows are adequately simulated using the MIKE11 groundwater module.

Key findings

Key finding

There is a limited amount of data for water resource accounting.

A key constraint to this project lies in the limited amount of data both spatially and temporally for groundwater level and reliable streamflow data.

Establishing rating curve relationships for streamflow has been difficult and there is low confidence in the data at some sites especially for high stage heights and flows. Suitably representative groundwater monitoring bores are also scant, but are adequate for the purposes of this modelling exercise. Synthetic climate data was also required to develop the coupled model of the catchment.

Improvements in the physical representation of the surface water model will come from further surveying of the river to define channel geometry especially with respect to in river storages.

Key finding

Current records of groundwater levels and river flow are biased towards a period of higher levels and flows due to above average rainfall

Surface water and groundwater model calibration relies heavily on streamflow data from the 1970s and 1980s. Only a few locations have streamflow data extending back to the 1950s and a data set through to the present, due to closures of gauging stations in recent years. The groundwater model is calibrated using groundwater levels from the last 5 years.

Climatic records and predicted flows generated by the coupled surface – groundwater model indicate that the past 30 - 35 years of data has been influenced by above average rainfall. Given that records of river flows generally exist for varying periods during the past 40 – 45 years it is expected that the measured records are biased to this wetter period. Care should be taken when using the limited available data to base management decisions.

Key finding

There are few perennial reaches in the Roper River catchment and these are of high ecological importance.

The high evaporation rates, the distribution of regional aquifers and the long dry season mean that there are few reaches of the Roper River that flow year-round and consequently these are of high importance. Critically, the sections of the river that flows through the dry season are sustained through localised groundwater discharge, i.e. discharge occurs where streams incise outcrops of the aquifers. These localised points of discharge are few and the risk of impact from development is high. In these environments, ecosystems have adapted to streamflow conditions that are rainfall dependent in the wet season and groundwater-dependent in the dry season.

Key finding

Groundwater recharge is complex. Further work is required to quantify recharge rates and distribution.

Groundwater recharge rates are variable across the landscape, and depend on soil type, vegetation and topography as well as rainfall amount and other climate variables. The complex interplay between these parameters means there is not a direct relationship between groundwater recharge rates and rainfall amount. There are also complex pathways for water infiltration to water tables. The large areas of carbonate aquifers across the west and north of the Roper River catchment have developed karst features where sinkholes and macro-pores are important channels for water to penetrate the ground. Rivers may also recharge groundwaters during the wet months when river stage heights are greater than groundwater levels. Further investigations into the distribution and quantification of these mechanisms and applying this information to more processed based distributed models will enable improved quantification of the recharge to the carbonate aquifers.

Key finding

Groundwater travels much slower than surface water, hence responses to any change will be measured in years, not months.

Groundwater takes considerably longer than surface waters to move through the landscape. The slower flow times of groundwater compared to surface water means that groundwater-fed rivers can continue to flow during the dry. However, any downstream consequences of groundwater extraction may not be realised for many years. The impact of changing the extraction regime for the Cambrian Limestone at Mataranka, for example, could take 50 or more years for the consequences to be felt at the Red Lily Lagoon Wetland, nearly 40 km downstream. It follows that groundwater models require adequate time-series data (generally >10 years) for calibration if they are to be predictive.

Key finding

The current distribution of extraction bores is likely to have greatest impact on the section upstream of the gauging station in the Elsey National Park.

The majority of extraction which could impact on the flow regime of the Roper River are located in the area around Mataranka. Current extraction totals 3 508 ML/yr (9 611.0 m^3/d or 111 L/s) distributed over 27 bores. Modelling indicates that the current distribution of extraction in the Mataranka area is likely to have greatest impact on the section of the Roper River upstream of the gauging station G9030176 in the Elsey National Park.

Key finding

Cease to flow at the Red Rock gauging station historically was a relatively common occurrence.

Cease to flow at the end of the non-tidal section of the Roper River is a relatively common occurrence based on the modelled discharge at Red Rock for the period 1900 – 1967, with 42 of the 67 years experiencing cease to flow conditions. This is in contrast to the following 34 year period from 1967 – 2008 where only 6 years were predicted where the Roper River ceased to flow at Red Rock.

It must be noted that reductions in the flow in the spring section of the Roper River will result in further reduction in flow downstream in the losing section of the river. Reduced flows could impact not only on the environment but the downstream users reliant on dry season flows necessary for domestic use and watering livestock.

Acknowledgments

This project was funded by the Australian Government Water Smart Australia Program and the NT Government – Department of Natural Resources Environment, The Arts and Sport.

1 Introduction

1.1 Background

The Gulf Water Study is a three year project funded jointly by the Australian Government Water Smart Australia Program and the Northern Territory Government. The Water 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.

Effective management of ecosystems requires a sound knowledge of its characteristics and the interrelationship between elements of the hydrologic cycle. In tropical northern NT with its Wet and Dry seasons, groundwater plays a key role in ecosystem survival by the provision of water to wetlands and rivers throughout the Dry season. Therefore there is a high priority to identify groundwater discharges that sustain flows which maintain groundwater dependent ecosystems. Groundwater behaviour and response remain as a major knowledge gap.

A major aquifer in the Top End of Australia is the Cambrian Limestone aquifer system formed in the Wiso, Georgina and Daly Basins. It represents the source of the majority of the baseflow to the Roper River. The Cambrian limestone also provides baseflow to the Katherine, Flora, Daly and Douglas Rivers of the Daly River catchment.

The aquifer system formed in the Mesoproterozoic aged Dook Creek Formation also provides baseflow to the major tributaries of the Roper River namely Flying Fox Creek, the Mainoru River and the Wilton River. The Dook Creek Formation also provides dry season baseflow to rivers outside of the Roper River catchment including the Goyder and Blythe Rivers. The Goyder River supplies the Arafura Swamp, a nationally significant wetland (Environment Australia, 2001).

Proposed horticultural development of groundwater from the Cambrian Limestone aquifer at the head waters of the Roper River in the area around Mataranka could represent a threat to the environmental flow regime and identified cultural needs of the Roper River particularly in low flow periods.

While perennial rivers may be of particular interest to horticultural investors and developers, these rivers support ecological communities that are dependent upon the quantity, quality and timing of these groundwater flows. Because most rivers in northern Australia are ephemeral, these perennial rivers have high ecological significance. Any extraction of groundwater from these systems will most likely result in a reduction in streamflow at some point in time. The impacts of these reductions and whether those impacts are acceptable is a key management question (Petheram and Bristow, 2008).

There is also the issue of 'double accounting', which arises when surface water assessments and groundwater assessments are conducted independently and a discrepancy may arise from the interactions between groundwater and surface water.

In an attempt to examine and inform some of the management issues with respect to water resource allocation an integrated surface – groundwater modelling approach is adopted. This report documents an ambitious attempt at developing such an integrated surface – groundwater model of the Roper River. The surface water model includes the entire Roper River catchment with emphasis on the branches identified as having dry season flows. The groundwater model includes the entire Cambrian Limestone aquifer system, with an emphasis on the area surrounding Mataranka and the head waters of the Roper River. The model also includes a preliminary model of the entire aquifer system developed in the Dook Creek Formation.

1.2 Objectives

The specific objectives of the Gulf Water Study are identified in the schedule of the Funding Agreement. Items specific to the Roper River integrated modelling study are:

- provide data on groundwater and surface water and their interrelationship into further studies on the connective environment and dependent ecological processes;
- provide baseline data for catchment management;
- identify areas where groundwater dependent ecosystems within the Roper River catchment exist;
- develop an integrated surface water and groundwater model that incorporates the important components of the Roper River surface water system, specifically the evapotranspirational losses signifying groundwater dependence and a groundwater model of the two major aquifer systems providing dry season baseflow;
- determine long term annual catchment water balances of surface water and groundwater to inform water allocation planning;
- explicitly model the exchange fluxes between groundwater and surface water mainly to address the issue of 'double accounting' and hence obtain a true estimate of the water resources of the surface and groundwater systems.
- provide a predictive model which can show the potential effects on water resources from climate change;

- identify where potential impacts on water resources may result from major developments;
- provide a tool to enable assessment of development impact with respect to pumping scenarios and their effects on the dry season flows in the Roper River (ie during periods when base flows are lowest).

1.3 Methodology

Why do we need to use integrated surface – groundwater models to examine catchment scale water resources?

Firstly models designed for surface water have unaccounted gains / losses built into their calibration, surface – groundwater exchange fluxes are only a component of these. Consequently the surface–groundwater flux can only be estimated correctly by a groundwater model. Groundwater models generate fluxes from the groundwater system. However, rivers are complex head boundaries for the groundwater model and the surface – groundwater flux is dependent on the stage height in the river and the groundwater level in the aquifer.

Secondly there is the issue of ‘double accounting’ which arises when surface water assessments and groundwater assessments are conducted independently and discrepancy may arise where there are interactions between surface water and groundwater (Brodie et al., 2007; Evans, 2007; Rassam and Werner, 2008).

Studies such as those conducted for the Murray Darling Basin Sustainable Yields Project (Rassam et al., 2008) employed an iterative process to simulate the interaction between surface water/ groundwater (ModFlow) models. This methodology requires water levels from the surface water model to be manually passed to the groundwater model to provide heads to the river boundary conditions and the resulting groundwater discharge flux exported back to the surface water model to examine changes to the river flows. This methodology is time consuming and depending on the situation could require several iterations to enable convergence between stage height and resulting groundwater flux.

In this study the methodology used to develop the coupled surface water – groundwater model was based on the modelling of the Daly River (URS, 2008). The surface water component is represented using the MIKE11 1D channel flow modelling software (DHI, 2008). The groundwater component is represented using the FEFLOW finite element saturated flow modelling software (Diersch, 2008). The coupling of the models involves passing groundwater discharge at the end of each time step calculated by FEFLOW to the MIKE11 model as a baseflow boundary condition at the H-Points via the coupling module IFMMIKE11 (Monninkhoff, 2005). MIKE11 calculates the river discharge and water levels up to the end of the FEFLOW timestep and the actual water levels at the H-Points are passed back to the coupled FEFLOW transfer boundary nodes ready for the next FEFLOW timestep. This approach is essentially the same as the iterative approach described above. However, this process occurs at a timestep scale, rather than waiting until the end of each model run. It is believed that the direct coupling between the surface water and groundwater models overcomes some of the shortcomings of the iterative approach as water levels and fluxes are dynamically linked. For example the process is automatic and no manual transfer of data between models is required. The FEFLOW – MIKE11 combination has also resulted in an adaptive timestep such that if the solution at a timestep does not converge within the error tolerences set, then the timestep in the FEFLOW model is reduced to decrease the error, and the MIKE11 timestep is also reduced accordingly.

The development of the coupled model involved the following steps:

- Conceptual model development;
- Development of a MIKE11 surface water model;
- Calibration of the MIKE11 surface water model to observed discharges and stage heights;
- Removal of the baseflow component of the calculated surface water flow;
- Development of a FEFLOW steady state groundwater flow model;
- Calibration of the FEFLOW steady state model using Parallel PEST (Doherty, 2004);
- Extension of the calibrated steady state model to the transient domain in the study area;
- Calibration of the groundwater model to the available hydrologic data including rainfall / recharge data, water level hydrographs, streamflow data and pumping data;
- Coupling of the MIKE11 model and the FEFLOW model using the module IFMMIKE11;
- Sensitivity analysis of the calibrated model to determine what are the key assumptions which have a significant impact on the model;

Both methodologies assume that the surface water flow components can be adequately resolved as to enable the baseflow to be separated from the runoff (refer **Figure 1**). The example provided has been generated from the rainfall-runoff model NAM. NAM assumes that the baseflow component is independent of the head gradient between the river and the aquifer and is only related to the recharge. Using a more realistic conceptualisation it would be expected that during the wet season the baseflow is reduced as the stage height in the river increases at a greater rate than the groundwater levels and can become reversed if the river level exceeds the groundwater level. The coupled model enables the modelling of this dynamic interaction between surface and groundwater heads.

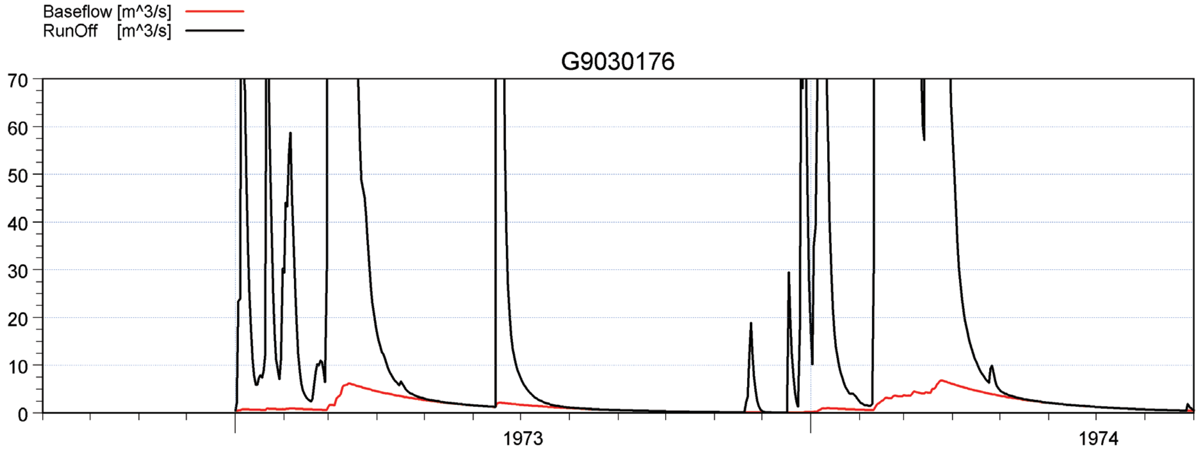


Figure 1 Example of river discharge indicating the total runoff and baseflow components. It should be noted that during the wet season flows the baseflow is probably reduced as the stage height in the river increases and can become reversed if the river level exceeds the groundwater level.

Fine grids are required in modelling for two main reasons:

- to represent physical mechanisms which only operate at a relatively small scale, such as surface groundwater interaction at wetlands or rivers, which is particularly relevant to integrated surface groundwater modelling
- to reduce numerical errors potentially inherent with larger grid spacings (eg. in areas of rapidly changing hydraulic gradients; and when undertaking solute transport and/or particle tracking).

(Middlemis, 2004)

1.4 Report structure

This report presents the development of a coupled surface – groundwater model of the Roper River and the results generated from a simulation based on the historic climate. The coupled model is a combination of two separately developed models representing the surface water system and the groundwater system. The report is separated into three components and consists of:

Part A – Coupled model

Part B – MIKE11 surface water model

Part C – FEFLOW groundwater model

2 Site Characterisation

2.1 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 2**).

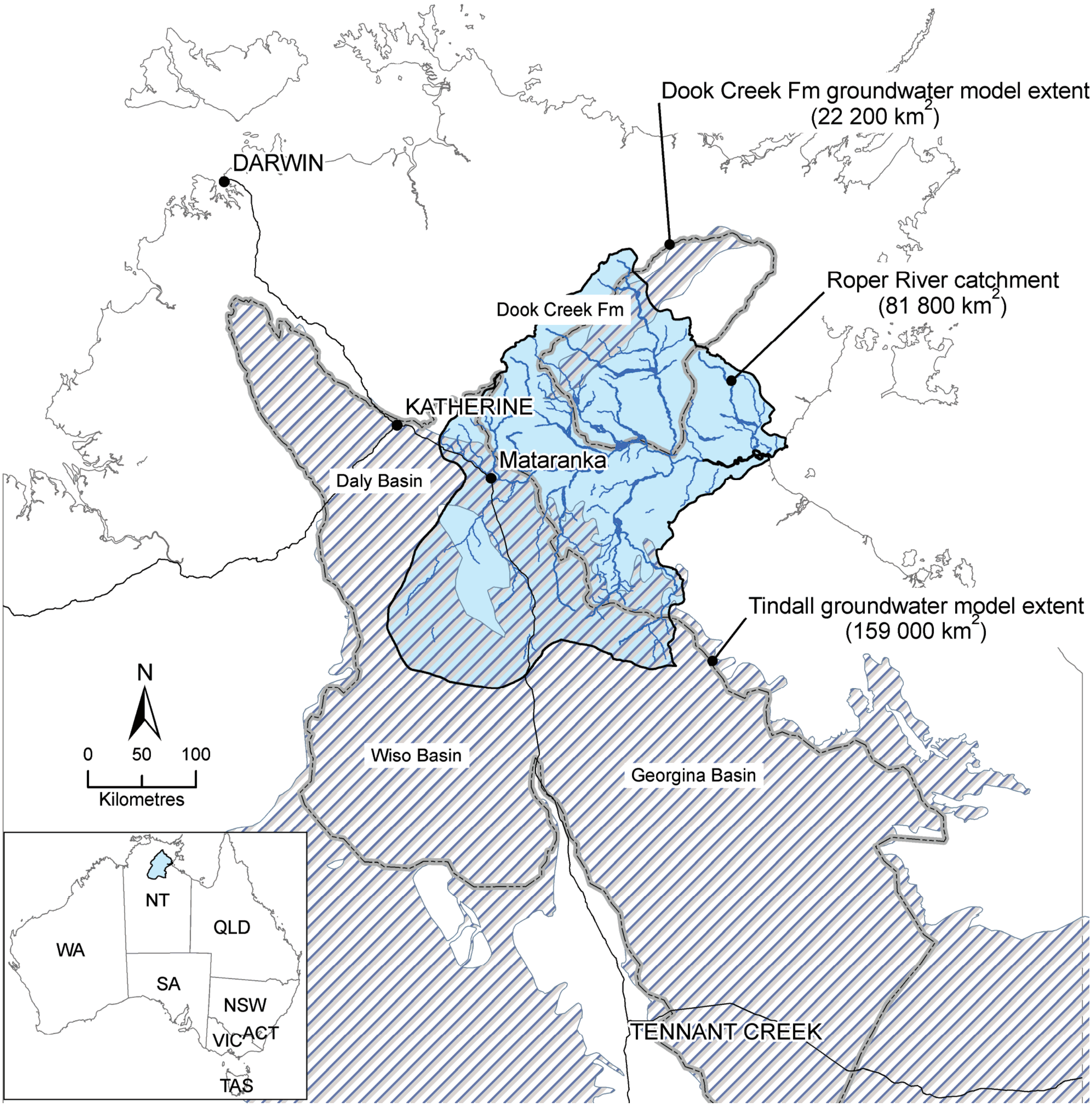


Figure 2 Location of the Roper River catchment with respect to the major groundwater basins (grey hatched regions). The extent of the groundwater models are provided for reference (grey line).

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 2**). The baseflow to the Roper River near Mataranka is dependent on groundwater fed from the Cambrian Limestone in the Daly Basin, the northern Wiso Basin and the northern Georgina Basin. The dry season flows in the northern tributaries are dependant on groundwater from the Dook Creek Formation.

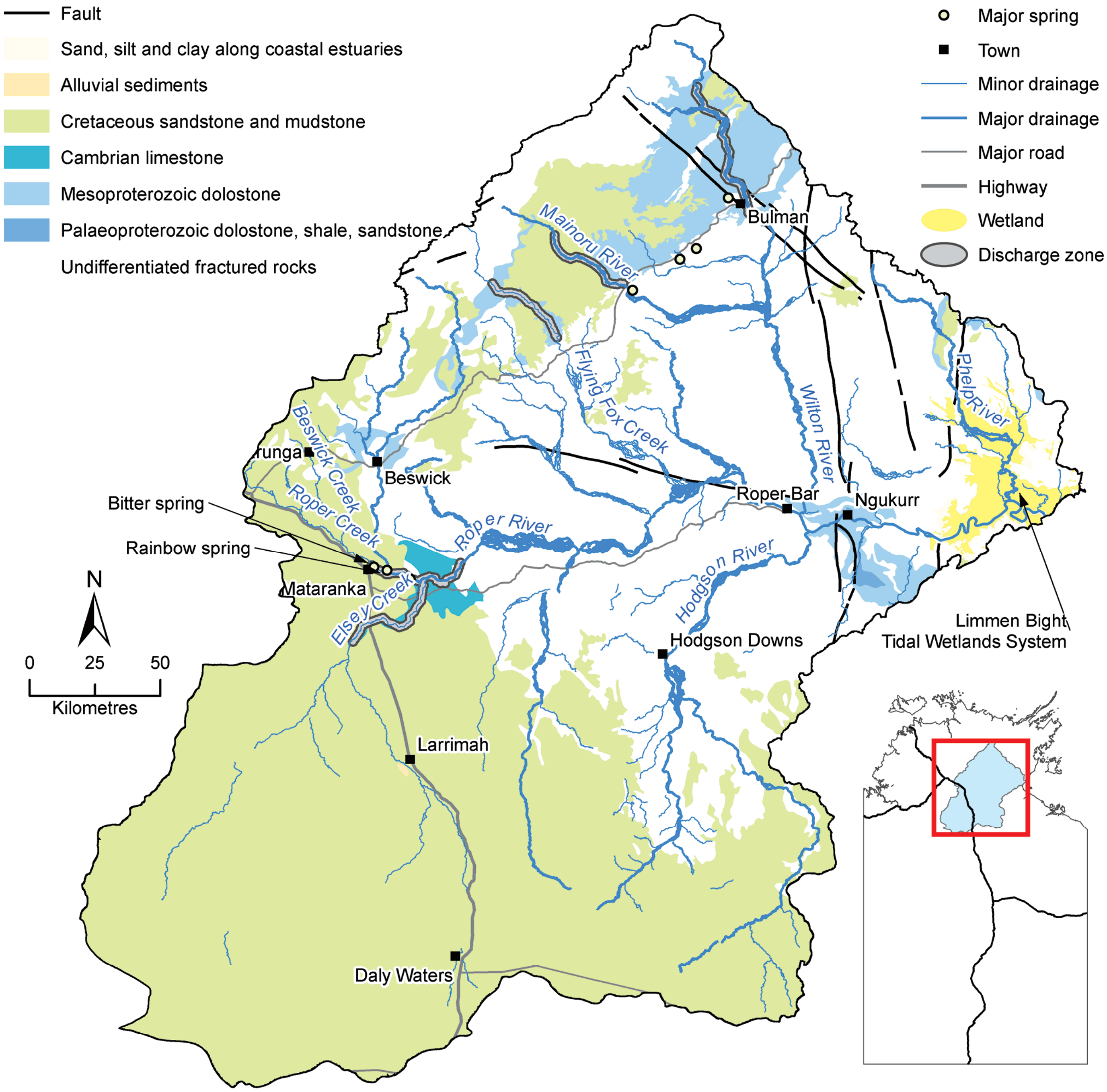


Figure 3 Overview of the Roper River catchment identifying the surface geology and areas where surface - groundwater interactions occur.

The catchment forms part of the drainage system known as the Gulf Fall and has an area of 82 000 km^2. The study area is drained by ten rivers and three major creeks, some of which are also perennial these are: the Roper, Phelp, 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 silicified sandstone. The middle section of Roper River is very braided resulting in high evapotranspirational losses with the increased surface area as the river flow is diverted into multiple channels. The Roper River flows generally in an easterly direction, although the geology and structures in the catchment influences the direction of the drainage systems. The normal tidal limit of the Roper River is at Roper Bar Crossing (shown on **Figure 3**). From this crossing, the Roper River traverses the alluvial coastal plain eastward for 145 km before entering the Gulf of Carpentaria.

Downstream of the Roper Bar, the Roper River is tidal, however, a large section of the river is usually 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 10^6 m^2 assuming an average evaporation rate of 6 mm/d a total of 84 000 m^3/d or 0.97 m^3/s.

The importance of the freshwater inflow to the tidal section of the Roper River during the dry season has not been investigated. During a bathymetric survey of the Roper River flows in and out of the estuary were measured at approximately ±200 m^3/s (NTG, unpublished data). Water quality profiles along the estuary indicate that the system is very well mixed.

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 (including Bitter Spring and Rainbow Spring) which is a good example of tropical springs and associated permanent pools and is one of the best known in the Northern Territory.

2.2 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 4** 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 4**). In the dry season from May to September, less than 10 mm of rainfall may be expected in any month. **Figure 4** 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).

The evaporation is high throughout the year with the average annual rate for the period 1961 to 1990 between 2400 – 2800 mm (http://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). 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.

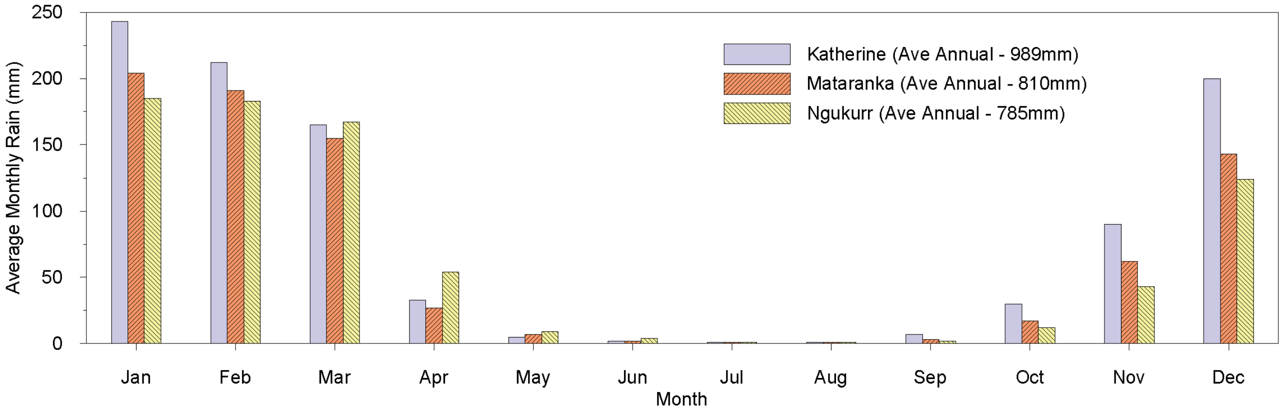


Figure 4 Average monthly rainfall for Mataranka, Ngukurr and Katherine. Source (Clewett et al., 2003)

2.2.1 Long Term Rainfall Trends

The average rainfall for the study area is approximately 989 mm based on the Katherine record from 1885 – 2008. The Katherine data from 1900 – 2008 has been utilised in this instance primarily because it has less gaps and almost 20 years more record than other sites in the region. The average annual rainfall at Mataranka is 810 mm for the period 1917 – 2008. The annual rainfall at Katherine and Mataranka over the period 1900 – 2008 is presented in **Figure 5**. Included on the plot are the rainfall residual mass curves for both rainfall stations.

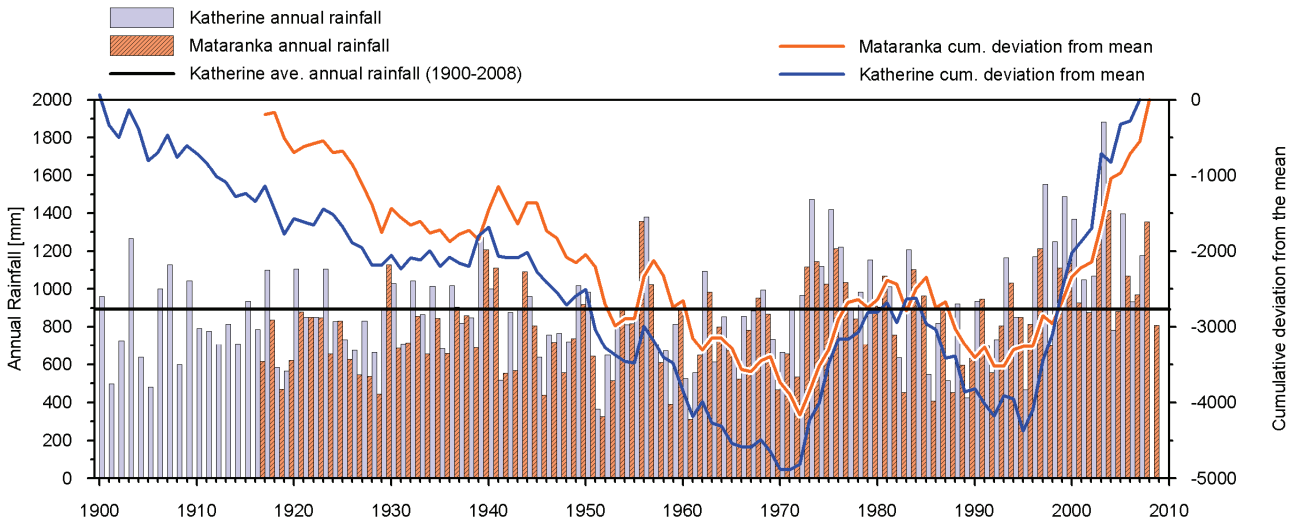


Figure 5 Annual rainfall at Katherine for the period 1900 – 2008 and Mataranka for the period 1917 – 2008 and the rainfall residual mass curves for Katherine (blue trace) and Mataranka (orange trace) demonstrating trends in rainfall.

The rainfall 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 (Crapper et al., 1997).

Key finding

The Roper River catchment has had below average rainfall for approximately 70 – 75% of the 108.8 years of the record. Consequently the current records of river flow are biased towards a period of higher flows.

The rainfall and rainfall residual mass curves for Katherine and Mataranka are quite similar reflecting their close proximity (~100 km). It can be seen that for the period 1900 – 1973 the annual rainfall is generally below average with the mass residual curve consistently declining. Within this there is a period during the late 1920s to the early 1940s with average annual rainfall. The trend from 1996 – present shows a period of well above average rainfall (approximately 350 mm/yr above the average). Based on rainfall residual mass curves the Roper River catchment has had below average rainfall for approximately 70 – 75% of the 108.8 years of the record.

2.3 Water Usage

The town of Mataranka (pop. 276 in 2006) is located near the Roper River's headwaters where major tributaries - the Waterhouse River, Roper Creek (also known as Little Roper River) and Elsey Creek converge. The PowerWater Corporation sources Mataranka's water supply from bores drilled into the Cambrian Limestone aquifer and is currently licensed for 95 ML/yr (260 kL/d or ~3 L/s). Parks and Wildlife (NRETAS) currently extract surface water from the Roper River at locations along the river within Elsey National Park and hold extraction entitlements of 72 ML/yr (197 m^3/d or ~2 L/s).

Within the Roper River catchment there are several small towns and communities, of which Mataranka is the regional centre. Others towns and communities include: Barunga, Beswick, Bulman, Daly Waters, Larrimah, Hodgson Downs, Roper Bar and Ngukurr. Ngukurr, a major aboriginal community (pop. approx. 1000 in 2003), is located on the Roper River's north bank some 40 kilometres inland from the Gulf of Carpentaria.

Entitlements for horticulture currently are 3220 ML/yr (8820 kL/d or ~100 L/s) and comprise the majority of licensed extraction in the region.

The land use over the catchment area is largely pastoral, although many parts remain undeveloped. There are currently no large surface water storages on the Roper River or its tributaries, although the Roper River provides water for stock and domestic uses on pastoral properties and the community of Ngukurr relies on the freshwater stored in the large pool which extends approximately 30 kilometres downstream of the Roper Bar (Knapton et al., 2005).

Surface water extraction from rivers and creeks occurs for stock and domestic purposes within the Roper River catchment. Where greater volumes of surface waters are needed for irrigation, commercial or mining purposes, 'Water Extraction Licences' are required. These extraction licences are issued by the Controller of Waters under the *NT Water Act (1992)* and managed by the Department of Natural Resources, Environment, the Arts and Sport.

2.4 Groundwater Dependent Ecosystems

SKM, (2001) identify six levels of dependency of groundwater dependent ecosystems (GDE's). However, all regimes involve:

- the level or pressure of the groundwater
- the discharge flux of groundwater from an aquifer
- the quality of the groundwater

Figure 6 demonstrates how the distribution of vegetation can be controlled by the availability of groundwater where aquifers exist. Where the water table approaches the surface a greater density of vegetation is evident and can often be identified using remote sensing products such as MODIS normalised difference vegetation index (NDVI).

Based on the criteria above the perennial sections of the rivers and the springs identified in the Roper River catchment by Zaar (2003 a & b) and George (2001 a, b & c) could be classified as groundwater dependent. The prominent areas identified as being potential GDEs are presented below.

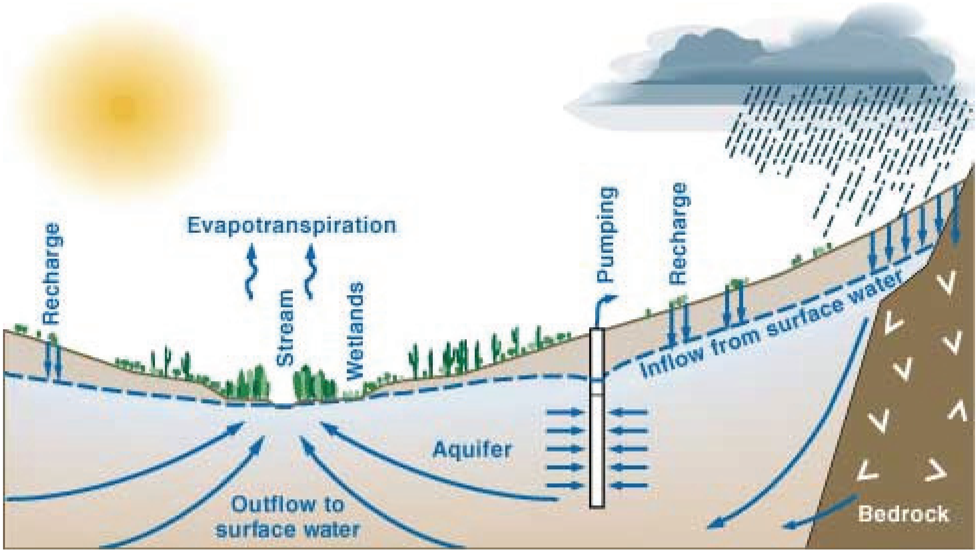


Figure 6 Diagram demonstrating recharge, throughflow and discharge via evapotranspiration.

2.4.1 Elsey National Park

The perennial nature of the spring-fed Roper River; the floristic diversity and restricted range of the riparian vegetation; and the representation of "tufa" formations have been identified as important natural resources within Elsey National Park. The Mataranka Thermal Pools, located within Elsey National Park, are maintained by permanent thermal springs. The pools are fringed mainly by *Livistona rigida*, although Pandanus and *Melaleuca* spp. also occur. The *Livistona rigida* palm community has a restricted distribution in the Top End Region and, as such, is considered a special community (Faulks, 2001).

Water use studies along the riparian zone of the Daly River identified that *Melaleuca argentea* W. Fitzg and *Barringtonia acutangula* (L.) Gaertn. appeared to be obligate phreatophytes as they used groundwater almost exclusively and were associated with riverbanks and lower terraces with shallow (<5 m) water tables (O'Grady et al., 2001). Mapping of the distribution of *Melaleuca sp*. for the northern portion of the Northern Territory has been completed at 1:100 000 scale based on air-photo interpretation and field surveys (Brocklehurst and Van Kerckhof, 1994).

2.4.2 Red Lily Lagoon / 57 Mile Waterhole

The Red Lily Lagoon is an area of riparian vegetation associated with wetlands along a 20 km braided section of the Roper River immediately downstream of the major groundwater discharge zone from the Cambrian Limestone aquifer. It is estimated that ~1 m^3/s is used as ET from the Red Lily Lagoon.

2.4.3 Flying Fox Creek

The head waters of the Flying Fox Creek are sourced from groundwater via springs and discharge from the Dook Creek aquifer along the creeks upstream of the Central Arnhem Highway.

2.4.4 Mainoru River

The head waters of the Mainoru River and downstream of Top Spring are sourced from groundwater via springs and discharge from the Dook Creek aquifer along the river upstream of the Central Arnhem Highway. Considerable evapotranspirational losses occur immediately downstream of the Central Arnhem Highway. It is estimated that ~0.6 m^3/s is used as ET from the 15 km section of the Mainoru River downstream of Top Spring.

2.4.5 Wilton River

Major perennial discharges within the Wilton River catchment occur along the Wilton River and at discrete springs including Lindsay Spring, White Rock Spring, Weemol Spring and Mt Catt Spring springs (Zaar, 2006). Locally these areas would be considered GDEs.

2.4.6 Riparian vegetation

Based on the broad criteria identified by SKM (2001), much of the riparian vegetation along the fringes of the Roper Rivers and tributaries which derive flow from the regional aquifers would be classified as groundwater dependent ecosystems as their source during the dry season is derived solely from groundwater. Riparian lands occupy only a small proportion of the landscape but they frequently have a much higher species richness and abundance of animal life than adjacent habitats. A broad-scale survey of bird distribution in riparian vegetation centred on the mid-reach of rivers with permanent freshwater pools (that is, the Roper, Wilton, Mainoru, Hodgson, Arnold and Waterhouse Rivers and Flying Fox Creek within the Roper River catchment), (Woinarski et al., 2000), found that despite their relatively small total extent, riparian areas were extremely important for birds. The study concluded that the bird fauna of riparian areas is distinct from that of the surrounding savannas, and this was especially so in lower rainfall areas. Species richness and the total abundance of birds was greater in the riparian zones than in non-riparian zones especially where they contained more extensive cover of rainforest plants and *Melaleuca*, (Woinarski et al., 2000).

In these environments, ecosystems have adapted to streamflow conditions that are rainfall dependent in the wet season and groundwater-dependent in the dry season.

2.5 Previous Water Resources Studies within the Roper River catchment

2.5.1 General

Since its' conception in the 1950's the Water Resources group has been involved with groundwater and surface water assessment and monitoring in the Roper River catchment. Brief summaries of some of the more relevant reports to this study are presented below:

Knapton *et al*., (2005) present the investigations conducted in 2002 to obtain the bathymetry and water chemistry of the Roper River estuary, downstream of Roper Bar. Coincident with this work, a related study was undertaken and the results were reported in "Inferring Groundwater Inflow to the Roper River (N.T.) from Environmental Tracers" Cook, (2002).

Jolly, *et al.*, (2004) discussed the water resources of the Tindall Limestone aquifer to the south of the Roper River. The report indicates the variation in discharge from the aquifer and likely volumes and location of recharge. It also identifies the losses along the length of the river due to evaporation and transpiration and the need to examine the methodology for determining water allocations within the Roper River catchment.

Faulks, (2001) titled "*An assessment of the Physical and Ecological Condition of the Roper River and its' Major Tributaries*" provides a "snap shot" of the riverine health of the Roper River and provides a comprehensive bibliography of the land and vegetation resources of the catchment. Although this report is not a water resources based study, much of the collected data is relevant to the hydrologic study of low flows in the Roper, especially the comprehensive collection of river channel cross-sections.

Monograph 15 is a compilation of the mapping work undertaken by Messel on the tidal waterways in northern Australia. Surveys of the waterways were made using the University of Sydney's 125 ton, 21 m long draught research vessel, the Harry Messel, designed and built for estuarine studies in northern Australia. The Roper River was charted in 1979 and is fully presented in Monograph 15 (Messel et al., 1982).

During 1980 and 1986 two major water quality surveys were conducted along the Roper River and it tributaries the report documenting the results is titled: 'Baseflow Water Quality Surveys in Rivers in the Northern Territory, Volume 11 – Roper, Wilton and Hodgson Rivers' (Field, 1988).

The water resources of the Sturt Plateau region, comprising 23 properties and land trust areas over 30,000 km^2, was studied between 1997 and 2000 (Yin Foo & Matthews, 2001) The study produced Water Resources Development Maps and Explanatory Notes (Yin Foo, 2000a, b, c, d) at pastoral property scale. The maps and commentary notes are intended for use by the individual property owners to assist them with planning the future development of their property.

'1:250,000 Hydrogeology Map – Sturt Plateau Region' (Yin Foo & Matthews, 2000). This map covers the entire Sturt Plateau region at 1:250,000 scale and provides a regional indication of groundwater prospects (ie. aquifer type, anticipated yield, likelihood for success).

Local studies of the groundwater resources within the Roper River catchment focusing on community water supplies have also been completed. **Table 1** presents the available reports on community water supply investigations completed within the Roper River catchment by the Water Resources Division.

Table 1 **Reports completed by the Water Resources Division focused on community water supplies within the Roper River catchment.**

Report No.	Report Title	Author	Resource	Electronic Resource No.
11/58D	Beswick Station - report on water resources	P. Augustine	GW	WRD58011
08/83D	Beswick Water Supply - Investigation of Ground Water Resources 1982	D. Yin Foo	GW	WRD83008
10/83D	Preliminary Appraisal of the Hydrogeology of the North Mataranka Area	H. Qureshi	GW	WRD83010
94/83D	Groundwater investigation Mount Catt for the Department Community Development	D. Karp	GW	WRD83094
88/84D	Bore Completion Report, Bulman Outstation	D. Karp	GW	WRD84088
20/85D	Barunga, Bulman, Lajamanu, Ngukurr Investigations for Water and Sewerage Services 1985	K. Stevens	GW	WRD85020
42/89D	Bulman Community Groundwater Resources Evaluation	M. N. Verma	GW	WRD89042
37/91D	Beswick Water Supply: An Assessment of Available Data	D. Yin Foo	GW	WRD91037
57/91D	Bulman Groundwater Resource Evaluation	M.Verma, P.Rowston	GW	WRD91057
40/92D	Barunga (Bamyili) Water Resource Evaluation.	P. Tyson	GW	WRD92040
64/93D	Bore completion report. Beswick Water Supply	J. Mann and D. Yin Foo	GW	WRD93064
28/2002D	Ngukurr, Review of Water Supply Source Options	P Jolly	GW/SW	WRD02028

Note: GW – groundwater focused report, SW – surface water focused report.

Regional investigations which included portions of the Roper River catchment have been completed by the Water Resources Division (refer **Table 2**). The regional studies typically produce water resources maps at a scale of 1:250,000 and provides an explanation of the groundwater and surface water resources. The groundwater resources have been classified according to the supply potential and the surface water resources have been classified according to the minimum river flow recorded at the end of the dry season (ranging from rivers that are ephemeral, to rivers with a flow of more than 100L/sec). (George, 2001a; George, 2001b; George, 2001c) describes the water resources of the Katherine region and south west Arnhem Land 1999-2001. (Zaar, 2003a; Zaar, 2003b; Zaar and Tien, 2003) describes the water resources of western Arnhem Land. The study provides information on the connectivity of surface – groundwater resources in the northern Roper River catchment including the catchments of the Mainoru River and Wilton River.

Table 2 Regional water resources studies completed by the Water Resources Division which include the Roper River catchment.

Report No.	Report Title	Author	Resource	Electronic Resource No.
28/2001D	Water Resources of the Katherine Region and South West Arnhem Land	D. George	GW/SW	
31/2001D	Water Resources of the Katherine Region and South West Arnhem Land – Appendices	D. George	GW/SW	
32/2001D	Water Resources of the Katherine Region and South West Arnhem Land – Technical Data	D. George	GW/SW	
34/2003D	Water Resources of West Arnhem Land	U. Zaar	GW/SW	WRD03034
35/2003D	Water Resources of West Arnhem Land – Technical Data	U. Zaar and T. Tien	GW/SW	WRD03035
36/2003D	Water Resources of West Arnhem Land – Aboriginal Knowledge	U. Zaar	GW/SW	WRD03036

Note: GW – groundwater focused report, SW – surface water focused report.

2.5.2 Surface water modelling

Only a single surface water modelling study is known to have been conducted in the Roper River catchment. A flood study of the upper Roper River was conducted in 2001 (Connell Wagner Pty Ltd, 2001). The objectives of the study were to a) perform a flood risk analysis for the Beswick Community on the Waterhouse River and b) establish a model for use in flood warning for the communities of Beswick, Mataranka Resort. Djilkminggan and Elsey Station. The study used the MIKE11 surface water modelling package with boundary condition discharge hydrographs generated by the rainfall / runoff model URBS (Carroll, 1994).

2.5.3 Groundwater modelling

Several groundwater modelling studies have been completed on the Cambrian Limestone aquifer. Water Studies developed a detailed model centred on the unconfined occurrence of the Tindall Limestone in the area of the Katherine River (Water Studies, 2001). The objective of the model was to determine the effects of pumping in the Venn Horticultural sub-division on groundwater levels and flows in the Katherine River.

Puhalovich, (2005) developed a model based on the modelling work by Water Studies. The model was extended to the south east to include the groundwater divide between the Katherine and Roper River and the discharge zones at the Roper River. It incorporated the contribution to the Tindall aquifer from the inflows from the Cretaceous aquifers in the vicinity of the head waters of the King River using general head boundary conditions.

Knapton (2006) documents the development of a 2D finite element model designed to simulate flows primarily for the Katherine River, however, it encompassed the known extent of the Tindall Limestone and incorporated the discharge from the aquifer to the Daly, Douglas, Flora and Roper Rivers.

URS (2008) extended the model to include the upper carbonate sequence (Oolloo dolostone) to model baseflow to the Daly River. The groundwater model was coupled to a surface water model of the Daly River developed by DHI (URS, 2008).

No known modelling has been undertaken for the Dook Creek Formation.

3 Available Data

Available data for the study site used to develop the surface – groundwater model include:

- synthetically derived SILO climatic data (Queensland Dept of Natural Resources and Mines, 2009);
- groundwater levels from observation bores from the Water Resources database (Water Resources, 2009).
- manually gauged river discharge from the Water Resources database (Water Resources, 2009).
- drainage polylines (Geoscience Australia, 2003)
- vegetation mapping and remote sensing (MODIS images)
- digital surface geology maps (NTGS, 2006)
- borehole stratigraphy
- SRTM digital terrain model (Farr et al., 2007)

3.1 Climate data

The rainfall and evaporation data were required to model the rainfall – runoff input for the surface water model and recharge input for the groundwater model. The inconsistent periods and poor coverage of the available rainfall and evaporation data resulted in the need to use synthetically derived data from the SILO data drill (Queensland Dept of Natural Resources and Mines, 2009) and (Jeffrey et al., 2001).

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, that is, 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.

Rainfall and evaporation data were obtained for 10 sites within the Roper River catchment area.

3.2 Streamflow data

Streamflow data is predominantly 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. River flow hydrographs were employed in the development and calibration of both the surface water and groundwater models.

3.2.1 Manual gaugings

Manually gauged river flows within the Roper River catchment were used in the calibration of both the surface water and groundwater models. Manual gaugings were employed to calibrate the groundwater model due to the fact that they are:

- taken mostly during the dry season thus representing groundwater baseflow
- generally more accurate at low flows especially where tufa deposition occurs

Two sites on the Roper River with multiple measurements of discharge from the Cambrian aquifer are G9030013 (Roper River - Elsey Homestead) and G9030176 (Roper River - Downstream Mataranka Homestead). During this study sites along other sections of the Roper River were also collected. Sites measuring discharge from the Cambrian Limestone to other rivers in the Daly Basin were also employed in the calibration process and included G8140301 (Katherine River - Galloping Jacks), G8140044 (Flora River) and G8145107 (Douglas River).

G9030123 (Roper River – Moroak Station) was used to calibrate the evapotranspirational losses from the Red Lilly Lagoon (refer to **section 2.1.4** of Part B of this report).

In the Roper River catchment G9030108 (Flying Fox Creek), G9030074 (Mainoru River) and G9030003 (Wilton River) were used to calibrate the Dook Creek Formation component of the groundwater model. G8240002 on the Blythe River and G8250002 on the Goyder River were also used to calibrate the component of the groundwater model outside of the Roper River catchment refer to Part C.

3.2.2 Surface water stage heights

River stage height hydrographs were employed in determining the roughness coefficients of the river branches during the calibration of the surface water model. For more details refer to Part B of this report.

3.2.3 Continuous discharge hydrographs

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).

Continuous discharge hydrographs with useable record lengths are available for 9 sites within the Roper River catchment. Continuous discharge hydrographs were used in the calibration of the rainfall / runoff model (NAM) and the MIKE11 model.

3.3 Cross-sections

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 database (Water Resources, 2009);
- Top End Water Ways projects documented by Faulks (2001);

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

Cross-sections have been determined for the low flow conditions and generally only extend to the river bank. This means that during wet season flows, the calculated flow in the river is confined to the banks of the river and does not simulate flooding conditions onto the surrounding flood plain.

To improve the physical representation of the channels and the flood plain further survey work and the inclusion of detailed DTM data should be collected.

3.4 Groundwater levels

Groundwater levels were obtained from the Water Resources groundwater database Hydstra (Water Resources, 2009). Levels were supplemented by non recorded water levels in driller bore statements and Reports eg (Sanders, 1993). Based on this information 55 bores drilled into the Cambrian Limestone have one or more water levels recorded and 9 have been drilled into the Dook Creek formation. Of the 55 bores 16 are within 100 kilometres of the head waters of the Roper River, the majority of these bores have been drilled recently and have a relatively short groundwater level record. Bore collars have generally been located using GPS, in some cases their height has also been determined to less than a metre using differential GPS. Where the bores hae not been surveyed the SRTM was used to estimate the bore collar elevation. Refer to Part C of this report for further information about groundwater level data.

3.5 Groundwater extraction data

The 2008 pumping entitlements in the Mataranka area are 3 508 ML/yr (9 611.0 m^3/d or 111 L/s) distributed over 27 bores. There are also 3 surface water extraction licences totalling 72 ML/yr (197 m^3/d or 2.3 L/s).

3.6 Geological data

Digital surface geology data is available from Geoscience Australia at 1:1 000 000 scale for the entire Northern Territory (Liu, 2007). This data provided controls on the extents of the aquifers, the confining units and the overlying Cretaceous units. Cross-sections from the 1:250 000 geological mapping series were used to constrain the layer geometry, particularly for the Dook Creek Formation.

Stratigraphic data are available for many of the water bores and all of the diamond drillholes completed by the NTGS. The stratigraphic information including the downhole geophysical logs provided controls on the depth to the base of the Cambrian Limestone aquifer (Tickell, 2005). Contours of the depth to the base of the Cambrian Limestone (Tindall Limestone) in the Daly Basin have been determined based on this stratigraphic information (Tickell, 2005).

3.7 Vegetation mapping and remote sensing data

Vegetation mapping and remote sensing techniques were employed to identify the areas where dense perennial vegetation occurs - these areas may be indicative of the presence of GDEs. The 1:100,000 vegetation mapping of Melaleuca spp completed for the Northern Territory (Brocklehurst and Van Kerckhof, 1994). The species were grouped according to their structure and habitat.

Normalised difference vegetation index images from the NASA/GSFC, MODIS Rapid Response image gallery (http://rapidfire.sci.gsfc.nasa.gov/subsets/?subset=Australia2) were used to asses the locations of high NDVI values indicative of areas where water is not a limiting factor on plant growth.

3.8 Data gaps and required further information

- The gauging site G9030013, which represents the discharge from the Cambrian Limestone to the Roper River, is several kilometres upstream of the contact between the Tindall Limestone and the fractured basement rocks to the east. The relative contribution and variation in the flow along this section of the Roper River is currently unknown.
- Groundwater level monitoring data in the Dook Creek Formation

- Groundwater level monitoring bores in the Cambrian Limestone (RN031483, RN029091 and RN029012) require reinstating or inclusion into the NRETAS monitoring network.
- Available cross-sections have been determined for the low flow conditions (ie. within bank), These cross-sections need to be extended to enable the modelling of wet season flows that overtop the banks of the river.
- Continuous flow data for the major rivers with groundwater discharging from the Dook Creek Formation. Rating tables for stations up to the maximum stage height.
- Mapping of the Cretaceous aged Mullaman Beds to distinguish areas where the basal sandstone outcrops will improve the understanding of recharge distribution.
- Better resolution of structure within the Daly Basin to clarify the flow regime between the Flora River and Katherine River (ie. north and south of the basin).

4 Conceptual Model

4.1 Overview

The hydrologic cycle - A portion of runoff enters rivers in valleys in the landscape, with streamflow moving water towards the oceans. Not all runoff flows into rivers. Much of it infiltrates or soaks into the soil. Some of the infiltrated water is transpired by plants or evaporated directly from the soil. The water that infiltrates below the root zone drains deep into the ground and replenishes groundwater stored in aquifers, which if present can store huge amounts of groundwater for long periods of time. A simplified separation of the components of the streamflow based on the hydrologic cycle are described below and represented diagrammatically in **Figure 7**.

- Overland flow – is that water which travels over the ground surface to a drainage channel and the principal contributor to the peak discharge from a storm event.
- Interflow – is that surface water that infiltrates the surface layer and moves laterally beneath the surface to a channel.
- Baseflow – is the flow component contributed to the channel by groundwater. Groundwater occurs from surface-water infiltration to the water table and then moving laterally to the channel through the aquifer. Such water moves much more slowly than direct runoff or interflow.

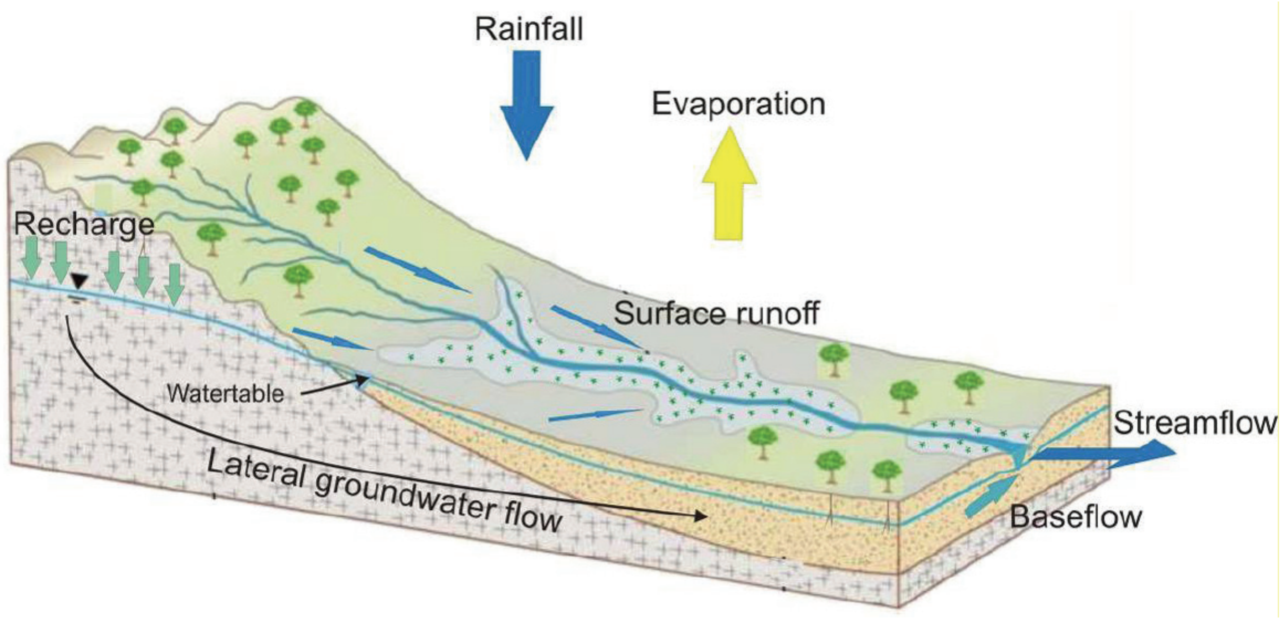


Figure 7 Schematic representation of catchment processes. Source (Petheram and Bristow, 2008)

4.2 Surface Water System

The Roper River starts as the 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 (Yin Foo and Matthews, 2001), which is located in the south-western section of the catchment. Flying Fox Creek flows into the non-tidal portion of the Roper River upstream of Roper Bar. The Wilton River flows in to the tidal section of the Roper River downstream of Roper Bar.

The Roper River flows generally in an easterly direction, although the geology of the catchment influences the direction of the drainage systems. The middle section of Roper River has many areas along its length that are braided with multiple channels and have large evapotranspirational losses associated with them. Large areas along the Roper River are subject to inundation during the wet season. The normal tidal limit of the Roper River is at Roper Bar Crossing (shown on Figure 3). 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.

Except for the areas where groundwater discharges to the Roper River, the river is a losing system with flow decreasing downstream.

4.3 Groundwater Systems

4.3.1 Hydrogeology

There are two major groundwater systems present in the Roper River catchment:

- The older Mesoproterozoic dolostones of the McArthur Basin. In the Roper River catchment this unit is called the Dook Creek Formation. Overlying the Dook Creek Formation is the Limmen Sandstone, which forms a confining unit.
- The younger Cambrian Limestone units of the Daly Basin, Wiso Basin and Georgina Basin. Within the Roper River catchment this unit is referred to as the Tindall Limestone.

Early Cretaceous rocks of the Dunmarra Basin overlie much of the region and obscures the contact between the basins.

Table 3 Major hydrogeological units in the study area.

Unit name	Age	Lithology	Hydrologic type	Comment
Dook Creek Formation	Mesoproterozoic	Dolostone	Karstic aquifer	Aquifer with major discharge
Limmen Sandstone	Mesoproterozoic	Sandstone	Confining aquiclude	Overlies and confines the Dook creek Formation
Antrim Plateau Volcanics	Middle Cambrian	Basalt	Hydrologic basement	Underlies the Tindall Limestone.
Tindall Limestone and equivalents	Middle Cambrian	Limestone	Karstic aquifer	Aquifer with major discharge
Jinduckin Formation and equivalents	Early Ordivician	Shale, sandstone and dolostone	Confining aquitard	Overlies and confines the Tindall Limestone
Mullaman Beds	Early Cretaceous	Claystone and basal sandstone		Overlies large protions of the Tindall and Dook Creek and reduces the amount of recharge

4.3.2 Recharge

Key finding

Groundwater recharge is complex. Further work is required to quantify recharge and its distribution.

Groundwater recharge rates are variable across the landscape, and depend on soil type, vegetation and topography as well as rainfall amount and other climate variables. The complex interplay between these parameters means there is not a direct relationship between groundwater recharge rates and rainfall amount. There are also complex pathways for water infiltration to water tables. Recharge leads to the rise in groundwater levels and an increase in discharge to the rivers and at the springs. Recharge in the model domain is thought to be via four predominant mechanisms.

- direct recharge where water is added to the groundwater in excess of soil moisture deficits and evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone, it is thought that this is the dominant mechanism in areas with Cretaceous cover;
- macro-pores where precipitation is preferentially 'channeled' through the unsaturated zone and has a limited interaction with the unsaturated zone;
- localised indirect recharge where surface water can be channeled into karstic features such as dolines (sinkholes), this is a poorly understood component of recharge;
- river recharge when the stage height of the river exceeds the adjacent groundwater level in the aquifer. This is thought to be a minor component of the overall water budget.

Limited study of recharge of regions with outcropping carbonates in the Daly River catchment, an area with similar hydrogeological characteristics to the study area, indicate it is dominated by macro-pore and local indirect recharge (Wilson et al., 2006). Water balance and hydrograph analysis have estimated the recharge in outcropping areas of carbonate is approximately 120-140 mm/yr and in areas of Cretaceous cover it is estimated at 40-50 mm/yr (Jolly, 2002). Calibration of the groundwater models concur with these values (Knapton, 2006). Estimates of recharge based on total river discharge indicates a value of between 8 and 32 mm/yr (refer to Part C of this report).

The decadal changes in the discharge to the Roper River suggest that the recharge input to the groundwater is relatively close to the discharge area. This is because the discharge from localised systems fluctuate more widely whereas discharge from larger scale systems is much steadier ie there is buffering present from the storage in the large groundwater system (Dahl and Nilsson, 2005).

4.3.3 Discharge

During the dry season the groundwater levels decline as groundwater is either transpired or discharged to wetlands or rivers where it evaporates or is discharged to the sea.

Natural groundwater discharge is thought to be via 3 dominant mechanisms. Major discharges occur along the Roper River as it intercepts groundwater flow from the northern Georgina Basin. The groundwater from the Cambrian Limestone discharges along the bed of the river (eg Bitter Springs) and via discrete springs (eg, Rainbow Spring and Fig Tree Spring).

Diffuse discharge occurs in the Elsey National Park where the basement approaches the surface forcing groundwater levels above the ground surface (Jolly et al., 2004; Tickell, 2005).

Within the Roper River catchment the Dook Creek Formation discharges to the Flying Fox Creek, Mainoru River and the Wilton River where they intersect the dolostone aquifer, several discrete springs have also been mapped (eg Weemol Spring). Discrete springs occur where fractures in the Limmen Sandstone allow groundwater to flow to the surface under pressure (eg Lindsay Spring, White Rock Spring and Top Spring). Outside of the Roper River catchment the Dook Creek Formation also discharges to Guyuyu Creek in the Blyth River catchment and to the Goyder River and a number of its tributaries in the Goyder River catchment (refer **Figure 8**).

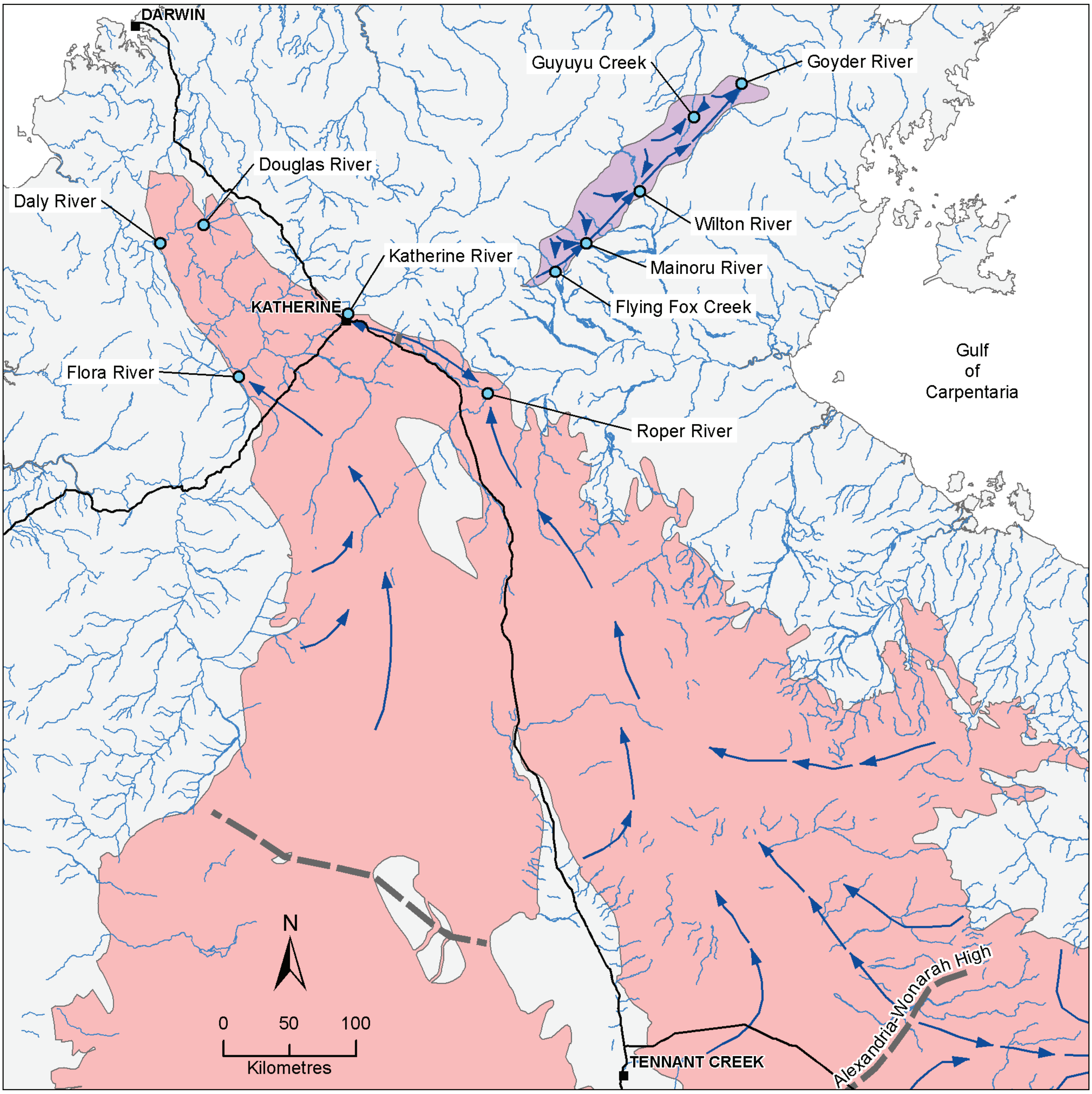


Figure 8 Regional groundwater flow in the Cambrian Limestone aquifer and Dook Creek Formation modified from Tickell (2003).

4.3.4 Regional groundwater flow

Groundwater flow within the Cambrian Limestone aquifer system is predominantly from the Alexandria - Wonarah Basement High (Kruse, 2003) in the central Georgina Basin to the major rivers in the Daly Basin to the north. Locally flow is directed to the major discharge areas identified above such as the Roper River (refer **Figure 8**). Estimates from groundwater levels (Tickell, 2003) indicate low gradients of approximately 0.0001 in the Georgina Basin.

Throughflow from the Georgina Basin is expected to be of the order of 200-300 L/s based on recharge estimates and Darcian flow estimates using transmissivity and groundwater gradients refer to Part C of this report.

Locally the groundwater flow in the Dook Creek dolostone is from the topographically high areas towards the discharge areas along the rivers and at discrete springs. The regional scale groundwater flow is from the topographically high areas in the south west to the topographically lower areas to the north east.

5 Model Development

In any modelling exercise the there will always be latitude for further improvement. Models are designed to imitate the important components of the system and are a tool to help understand the system function. All models are based on available data, where data is limited, incomplete or non-existent, assumptions are often made.

5.1 Surface water model

The surface water model of the study area was developed using MIKE11 (DHI, 2007). A summary of the model is presented below. For a detailed account of the model development is documented in Part B of this report.

5.1.1 Model geometry

In MIKE11 a network configuration depicts the rivers and floodplains as a system of interconnected branches. Water 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 geometry / topography and boundary conditions, which can include man-made features.

The initial data required for establishing the MIKE11 model are:

- the river reaches
- the cross-section data depicting the river channel. The MIKE11 model encompasses the entire Roper River catchment (refer Figure 10).
- boundary conditions at the open ends of the model

The Roper River setup comprises a main river branch with several tributaries feeding into the main river. Boundary conditions are defined as inflow hydrographs on all upstream boundaries, along specified reaches and at the downstream tidal boundary at the sea.

5.1.2 Boundary conditions

MIKE11 requires input at the open ends of the model. Hydrographs generated with the rainfall/runoff model (NAM) are used as input into the model's upstream open boundaries, whilst the downstream boundaries were modelled using an average tidal value.

The conceptual NAM model treats each catchment as a single unit, allowing some of the model parameters to be evaluated from physical catchment data. NAM calculates the water balance for each sub-catchment and includes the actual evapotranspiration and the runoff components overland flow, interflow and baseflow (see **Figure 9**).

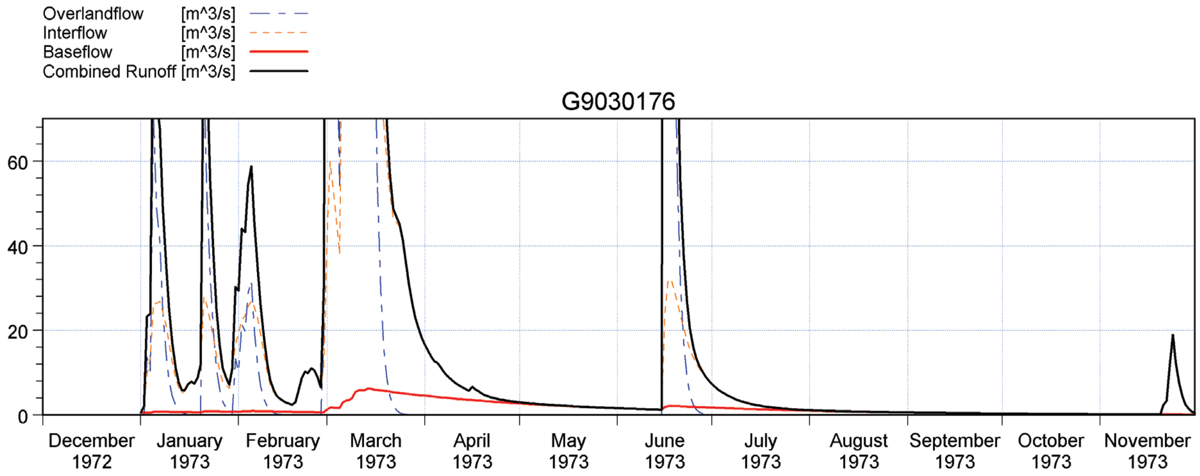


Figure 9 Example of the components of runoff generated using the rainfall runoff model (NAM).

The NAM parameters were calibrated to ensure that the recorded channel discharge estimates within the river system were simulated adequately. The simulated MIKE11 water levels were then calibrated to recorded levels by adjustment of the channel roughness parameter (Manning's 'n'). The channel roughness was modified longitudinally down the river system.

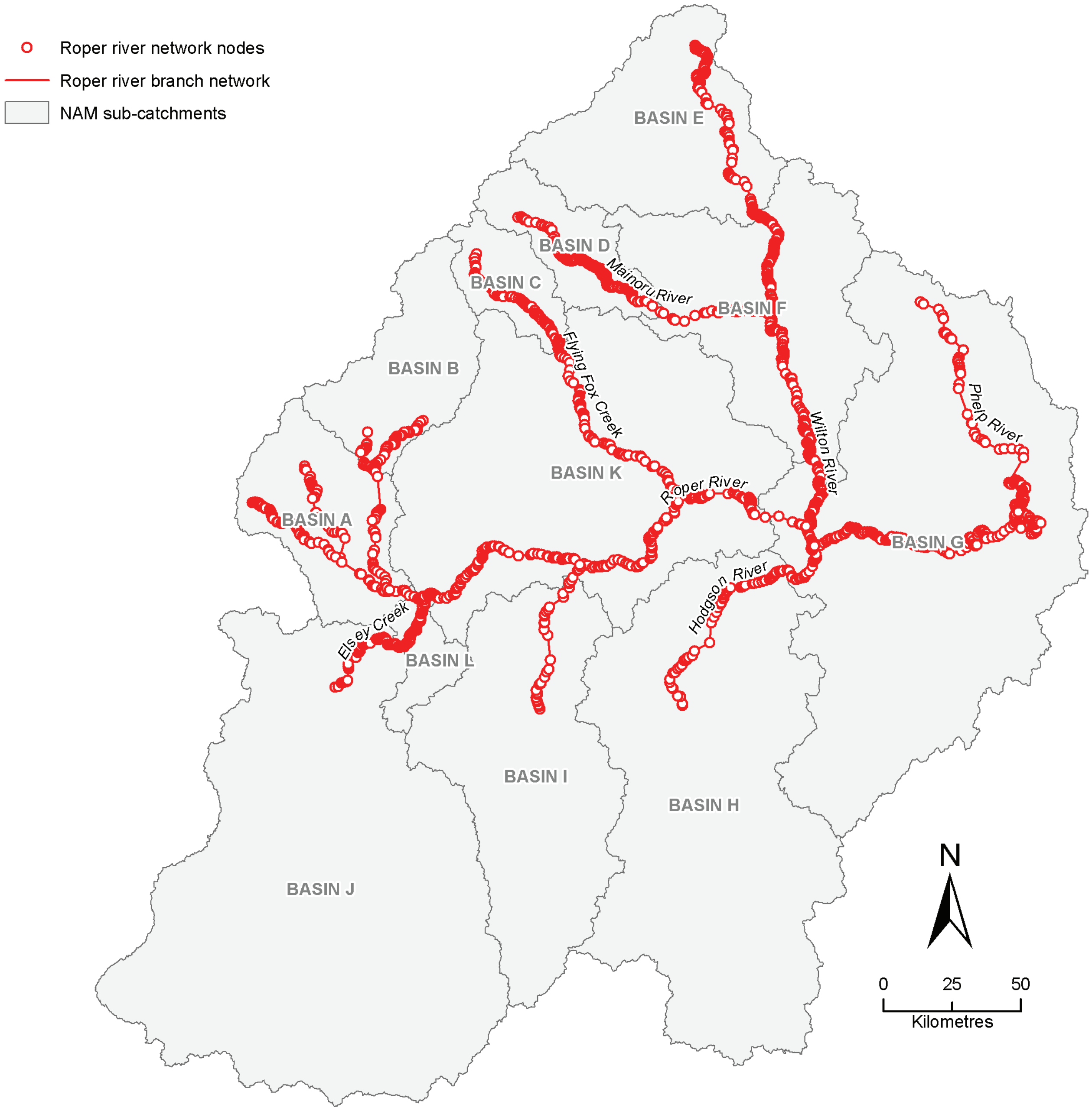


Figure 10 Roper River MIKE11 river network showing river branches and grid points.

5.2 Groundwater model

The groundwater model of the study area was developed using FEFLOW (Diersch, 2008). A summary of the model is presented below. For a detailed account of the groundwater model development refer to Part C of this report.

A groundwater model of the Cambrian Limestone of the Georgina, Wiso and Daly Basins was developed based on the conceptual hydrogeological model proposed by Water Studies, (2001) and refined by Puhalovich, (2005) and Knapton (2006). The groundwater model of the Cambrian Limestone is represented with a redeveloped and re-calibrated version of an existing FEFLOW numerical groundwater flow model (Knapton, 2006). A groundwater model of the Dook Creek formation was also developed to provide baseflow to the northern tributaries of the Roper River.

The Cambrian Limestone component of the FEFLOW groundwater model encompasses an area of approximately 159 000 km^2 and includes the entire extent of the Tindall Limestone in the Daly Basin and its' equivalents in the northern Wiso Basin, northern Georgina Basin (refer **Figure 2**). The outer boundary of the model is considered no-flow.

The Dook Creek component of the FEFLOW groundwater model encompasses an area of approximately 22 220 km^2 and incorporates the entire extent of the unconfined areas of the Dook Creek Formation (refer **Figure 2**) and includes the catchments of the Flying Fox Creek, Mainoru River, Wilton River, Guyuyu Creek and Goyder Rivers.

The groundwater system is unconfined to the north-west of the Central Arnhem Highway and confined to the south-east. The extent of the confined region of the model was arbitrarily defined using the sub-catchments of the rivers which source flows from the Dook Creek Formation. This assumption may prove to be inadequate.

Both of the major aquifers in the Roper River basin are karstic and are dominated by secondary porosity / permeability due to chemical weathering. The system has been modelled as an equivalent porous media using calibrated regional aquifer parameters to reproduce the regional groundwater levels and observed discharge to the rivers. Areas of preferential recharge / discharge are simulated by adjusting the transfer in / out parameters.

As identified in **section 4.3.2** the dominant recharge mechanism in the areas of outcropping Cambrian Limestone and Dook Creek dolostone is via preferential pathways. However, this mechanism is not well understood and poorly represented numerically. The recharge was therefore estimated as diffuse recharge using a simple soil moisture deficit model using rainfall and estimated evapotranspiration. It has been found that this methodology has not quantified the increase in recharge during wetter periods in the rainfall record when compared to groundwater level hydrographs and gauged flows. Recent estimates of recharge have been determined using MIKE SHE® which enables a more process based estimate of recharge to be calculated including an estimate of by-pass flow. Recharge is also expected during periods when the river stage height is greater than the groundwater level adjacent to the river where the river overlies the aquifers and the model simulates this process.

Recharge is applied to the model according to recharge zones. Each recharge zone was determined primarily from the surficial geology. The input recharge for this study was generated from the MIKE SHE modelling and scaled during the groundwater model calibration process to reproduce observed water levels and discharge.

Distribution of hydraulic parameters hydraulic conductivity, storage coefficient and transfer in /out were determined by inverse modelling using the PEST code (Doherty, 2004).

The model was calibrated to match observed groundwater discharge and groundwater levels in monitoring bores in the area of the Tindall Limestone.

5.2.1 Model geometry

The boundary of the model was based on the geologically mapped extent of the Tindall Limestone and its' equivalents, the geological extent of the Dook Creek formation and an arbitrary extent where the Dook Creek Formation is confined by the overlying units.

During the development of the groundwater model the following items were also considered:

- Location of nodes corresponding to discharge to rivers that could be used to integrate a MIKE11 surface water model of the Roper River.

The resulting mesh (**Figure 11a**) has 49 540 elements and 38 559 nodes.

The elevations of the three slices used SRTM data for the surface elevation. The base of the Tindall Limestone was defined from geological logs and top of Tindall Limestone was assumed to be approximately 150 metres above the base (Tickell, 2005). **Figure 11b** shows a cutaway view of the 3D finite element mesh for the Tindall Limestone component of the model.

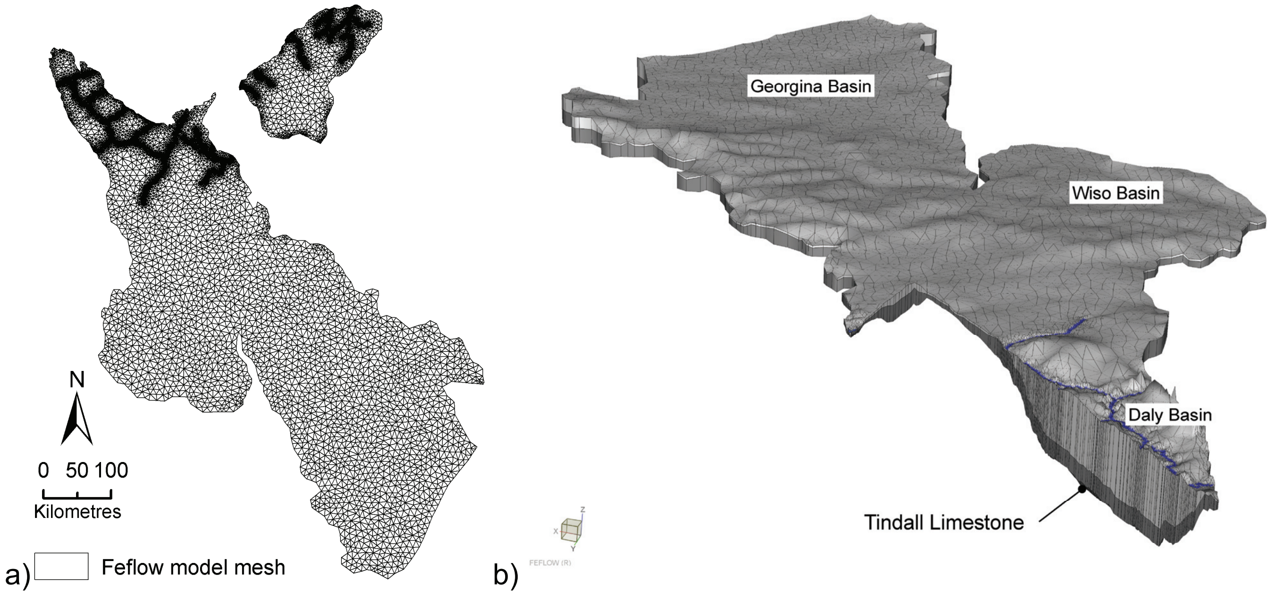


Figure 11 a) Plan view of the finite element mesh used in the FEFLOW model b) 3D view (looking south) of the Tindall Limestone component of the FEFLOW model with cutaway along the axis of the Daly Basin to Mataranka.

5.2.2 Boundary Conditions

The groundwater model includes the follow boundary conditions:

- Transfer boundary conditions – these define the interaction between the rivers and the groundwater system
- Constant head boundary conditions were used to define discrete springs discharging from the Dook Creek Formation through the Limmen Sandstone.
- Well boundary conditions – simulates extraction for stock and domestic and horticultural use
- Areal fluxes representing recharge and evapotranspirational losses are applied at the top slice of the model.

5.2.3 Steady state recharge distribution for the groundwater model

The steady state recharge for the groundwater model was generated based on the geology and recharge estimates and used pilot points (Doherty, 2003) to produce the spatial distribution. The recharge distribution was optimised using Parallel PEST (Doherty, 2004).

5.2.4 1D recharge modelling using MIKE SHE

The MIKE SHE (DHI, 2008) process based model was employed to simulate recharge for the groundwater model. The MIKE SHE two layer water balance option was used to simulate the unsaturated zone.

Inputs to the model include climate data (precipitation and evaporation), the characterisation of the vegetation cover and the physical soil properties. The vegetation is described in terms of leaf area index (LAI) and root depth. The soil properties include a constant infiltration capacity and the soil moisture contents at the wilting point, field capacity and saturation and macro pore bypass constants. Input climatic data is consistent for both the NAM (MIKE11) and MIKE SHE models.

MIKE SHE uses a simplified ET model that is used in the Two-Layer UZ/ET model. The Two-Layer UZ/ET model divides the unsaturated zone into a root zone, from which ET can occur and a zone below the root zone, where ET does not occur. The Simplified ET module considers the entire unsaturated zone to consist of two layers representing average conditions in the unsaturated zone (DHI, 2008).

The outputs from the MIKE SHE model are estimates of the actual evapotranspiration and the groundwater recharge.

Groundwater recharge rates are variable across the landscape, and depend on soil type, vegetation and topography as well as rainfall amount and other climate variables. The complex interplay between these parameters means there is not a direct correlation between groundwater recharge rates and rainfall amount. There are also complex pathways for water infiltration to water tables, via sinkholes or dissolution hollows, for example, and these may change in importance through the year and from year to year. Rivers may recharge groundwaters during the wet months, whilst discharging groundwater may maintain river flow during the dry months. The large areas of carbonate aquifers across the west and north of the Roper River have developed karst features and sinkholes and dissolution features are important channels for water to penetrate the ground. Further investigations into the understanding and quantification of these mechanisms and applying this information to more processed based distributed models such as MIKE SHE will enable quantification of the recharge to the carbonate aquifers.

More details of the MIKE SHE recharge model setup and calibration results are presented in Part C of this report.

5.2.5 Groundwater model calibration

The FEFLOW model was calibrated using inversion implemented with Parallel PEST (Doherty, 2004) and the pilot points method (Doherty, 2003). The use of Parallel PEST required the development of several utilities to generate and read model outputs (river discharge from group observation fluxes and heads from output '.dar' files) and update the model parameter distributions using the PEST generated pilot points. The spatial distribution of the hydraulic parameters for hydraulic conductivity, storage coefficient and transfer in /out were determined during the calibration process. The objective function was derived from estimated average groundwater levels at 52 sites, gauged groundwater discharges at 7 sites and regularisation functions for the parameter distributions. The calibrated steady state groundwater heads and discharges are presented in **Figure 12a,** and a plan view of the modelled heads are presented in **Figure 12b**. The steady state heads were used as initial heads in the transient groundwater model.

5.2.6 Initial water levels

All models need to start from a user-defined initial condition. A hydrologically stable initial condition minimises any potential numerical problems that are likely to occur during the execution of the model. The most stable initial condition that can be used in modelling is steady state; under this condition, fluxes into and out of the model domain are equal and no water is taken from or added to aquifer storage.

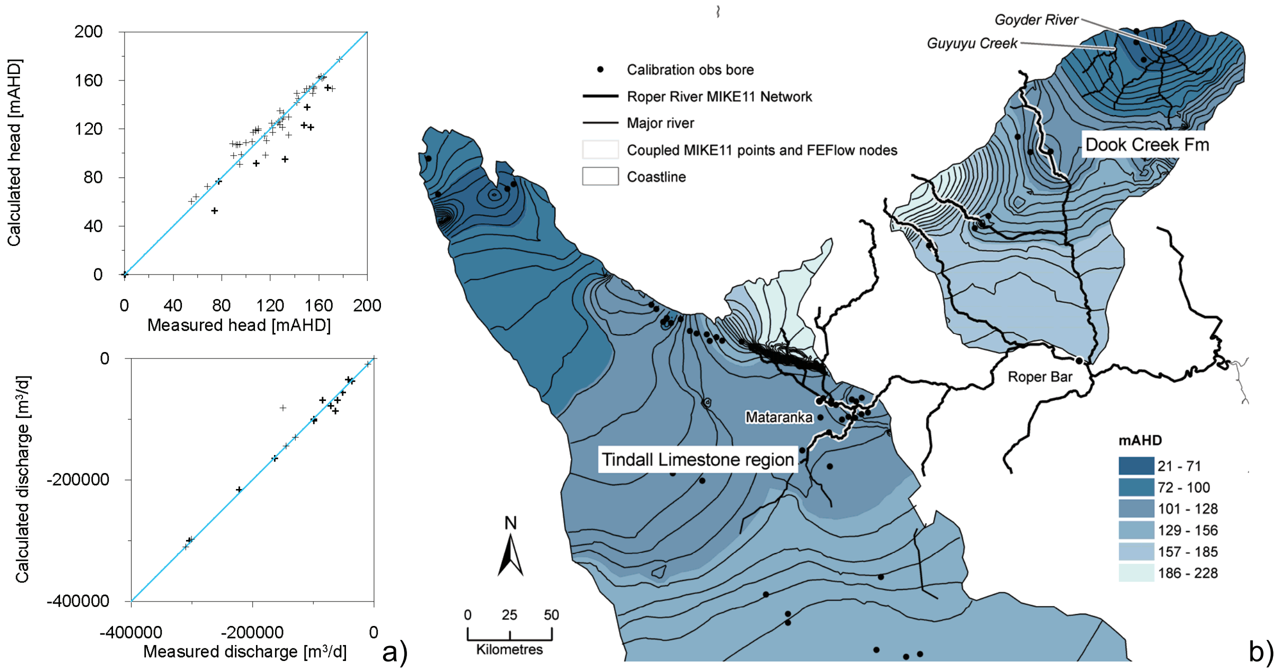


Figure 12 a) Steady state calibration results of measured vs observed heads and measured and observed discharge (-ve values represent water leaving the model domain) and b) Calibrated steady state groundwater heads in the Roper River catchment. Steady state heads were used as initial heads in the transient model.

6 Coupled Groundwater / Surface Water Model

Groundwater / surface water interaction along the rivers occurs where the MIKE11 model is patched to the FEFLOW model. Groundwater and surface water are highly connected in regions where the highly permeable karstic limetstone / dolostone occurs.

The current understanding of the interaction between the river and aquifer is poor and it is assumed that both the transfer rate in and the transfer rate out are equal. Schematically the locations of the areas where the groundwater and surface water models interact are presented in **Figure 13**.

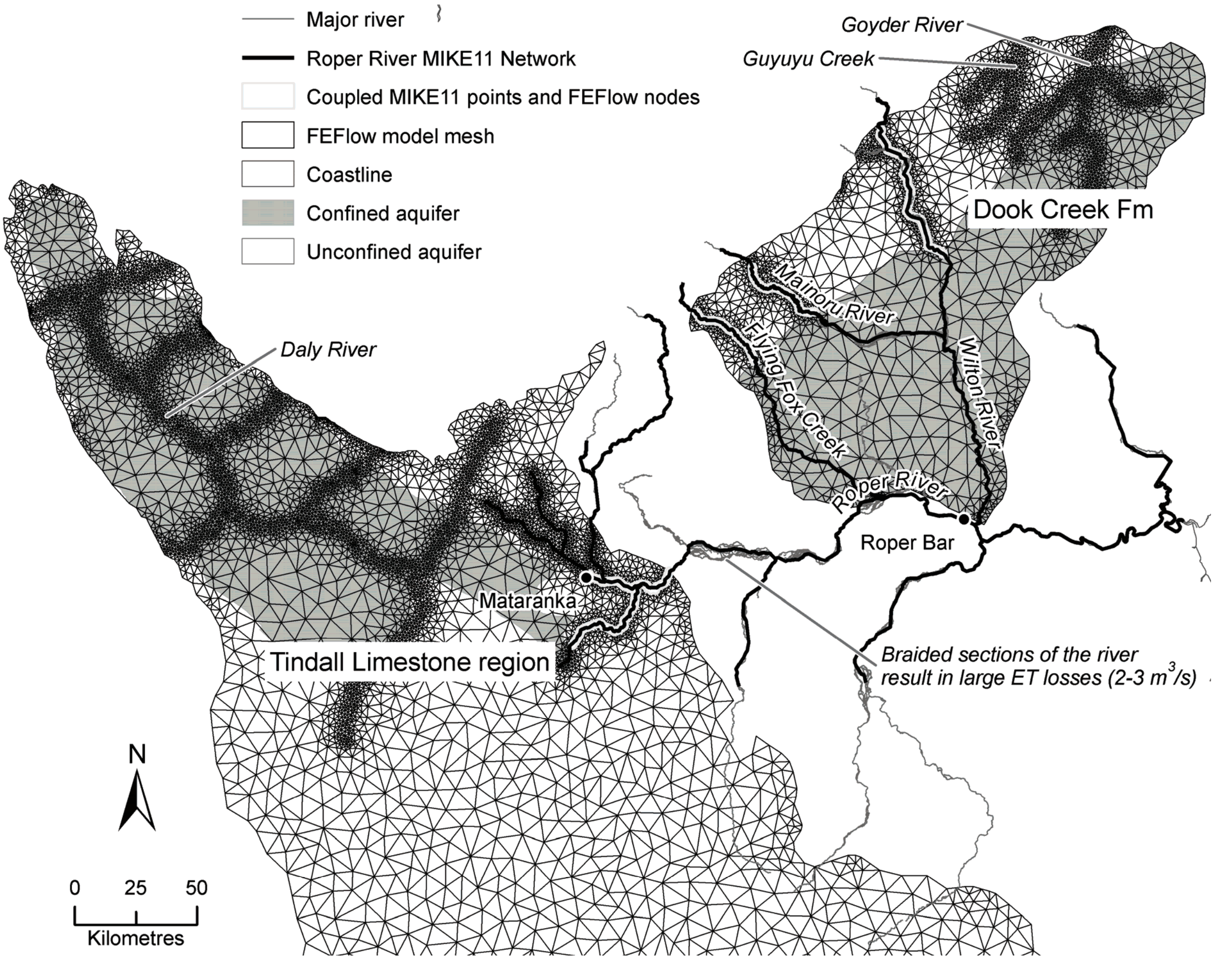


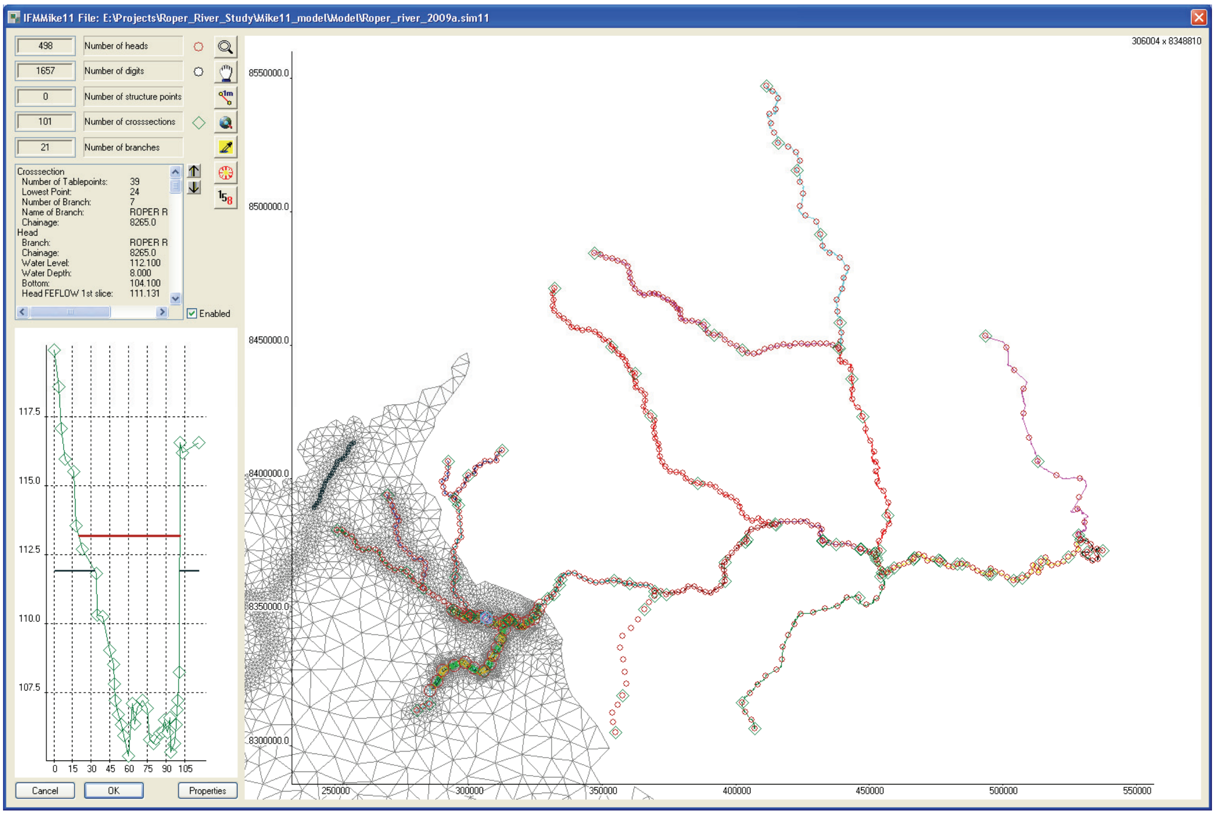
Figure 13 Groundwater model extents with respect to the Roper River catchment

Patches between the MIKE11 channels and the FEFLOW transfer boundary conditions are automatically determined by the IFMMIKE11 module using a user defined search radius refer **Figure 14**. Refer to Part B of this report documenting the Roper River MIKE11 model setup (Knapton, 2009).

Currently only the Cambrian Limestone component of the groundwater model is active in the coupled model. The Dook Creek Formation groundwater component of the simulation is provided by the NAM inputs to MIKE11.

The current version of IFMMIKE11 has not been run successfully using the two separate FEFLOW aquifer systems in the single model. This has resulted in the coupled model being run with only the Cambrian Limestone component active. The Dook Creek Formation groundwater component of the simulation is provided by the NAM inputs to MIKE11 for the Flying Fox Creek, Mainoru River and Wilton River.

Evapotranspiration from the riparian zone is estimated at approximately 6 mm/day. Although ET has been considered in the FEFLOW model, evapotranspiration is also removed from the river via the coupled MIKE11 model using daily pan evaporation scaled to simulate the losses measured at 6 sites along the length of the rivers.



IFMMike11 File: E:\Projects\Roper_River_Study\Mike11_model\Model\Roper_river_2009a.sim11

498 Number of heads
1657 Number of digits
0 Number of structure points
101 Number of crosssections
21 Number of branches

Crosssection
Number of Tablepoints: 39
Lowest Point: 24
Number of Branch: 7
Name of Branch: ROPER R
Chainage: 8265.0
Head
Branch: ROPER R
Chainage: 8265.0
Water Level: 112.100
Water Depth: 8.000
Bottom: 104.100
Head FEFLOW 1st slice: 111.131

☑ Enabled

Figure 14 IFMMIKE11 module showing FEFLOW mesh and BCs and MIKE11 river network with crossections and patched FEFLOW nodes and MIKE11 grid points.

6.1 IFMMIKE11 settings

During the coupling of the MIKE11 model and the FEFLOW model the settings for the IFMMIKE11 module were adjusted to provide a stable model with the most efficient run times.

The time step for the FEFLOW model is constrained to a maximum of 10 days. The MIKE11 model has a maximum time step of 30 minutes. The MIKE11 results are stored every 48 time steps, which means flow is recorded daily for much of the model run.

Where streams are naturally ephemeral or have become intermittent in flow due to excessive diversion and groundwater extraction. it is important to introduce a mechanism by which the boundary condition can be activated and de-activated to allow recharge of the aquifer only when they flow. IFMMIKE11 enables this by disabling the FEFLOW transfer boundary conditions if the water depth in the river channel falls below a specified threshold.

It has been found that the setting “Show Logfile” enables the MIKE11 log file to be displayed at the end of a simulation - it also displays statistics on the flux leaving the FEFLOW model and the status of the FEFLOW boundary conditions.

Table 4 IFMMike11 module settings

FEFLOW / MIKE11 Patching	Option	Setting
	Patch option	Both: Aut. & Obs. Groups
	Snap Dist. [m]	5000
Initial Timestep		
	Relative to Timestep FEFLOW (0-1)	0.25
	Absolute maximum of Timestep [min.]	1
General Settings		
	Show Logfile	Yes
	All Results	Yes
	Exclude Dry H-Points	Yes
	Wmin [cm]	10
Timestep Control Mike11		Variable
Variable Timestep Control		
	Decrease dT at dH [m]	0.15
	Increase dT at dH [m]	0.02
	In / Decrease dT with factor (0.01-0.99)	0.66
	Min dT [Min.]	0.0001
	Max dT [Min.]	30

7 Modelling Results

7.1 *Historic (1900 – 2008) model results*

The model was run using the historic climatic conditions from 01/01/1900 to 01/09/2008 and compared to the observed data. There is particular emphasis on the discharge at the stations Downstream Mataranka Homestead (G9030176), Roper River at Elsey Homestead (G9030013) and Red Rock (G9030250). The discharge at each of these sites is presented below:

7.1.1 G9030176

The simulated discharge at MIKE11 chainage 7372 and measured discharge and gauged flows at Downstream Mataranka Homestead (G9030176) are presented in **Figure 15**. Predicted dry season flows appear to be within 10-20% of the gauged value. This is approximately within the error associated with the collection of the manual gaugings. The simulated discharge appears to be slightly underestimated compared to the continuous record, however, the manual gaugings suggest that the measured discharge is being slightly overestimated.

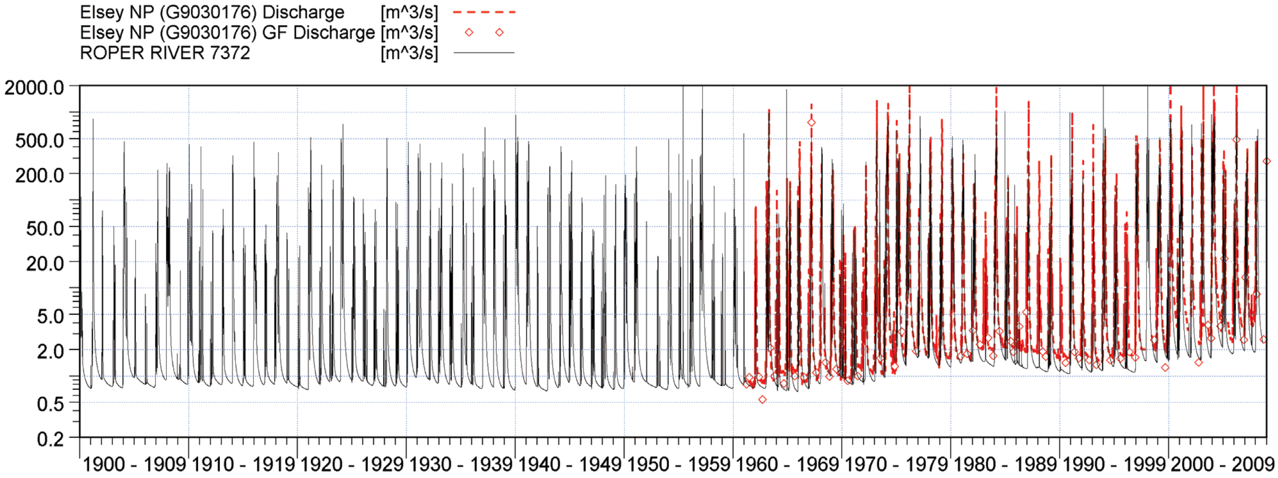


Figure 15 Comparison of simulated and observed discharges at Downstream Mataranka Homestead (G9030176)

7.1.2 G9030013

The comparison of the simulated discharge at MIKE11 chainage 22352 and gauged flows at G9030013 are presented in **Figure 16**. The simulated low flows show reasonable agreement with the manual readings with the majority within 10% of each other, which is within the expected error associated with the gauged discharge measurements.

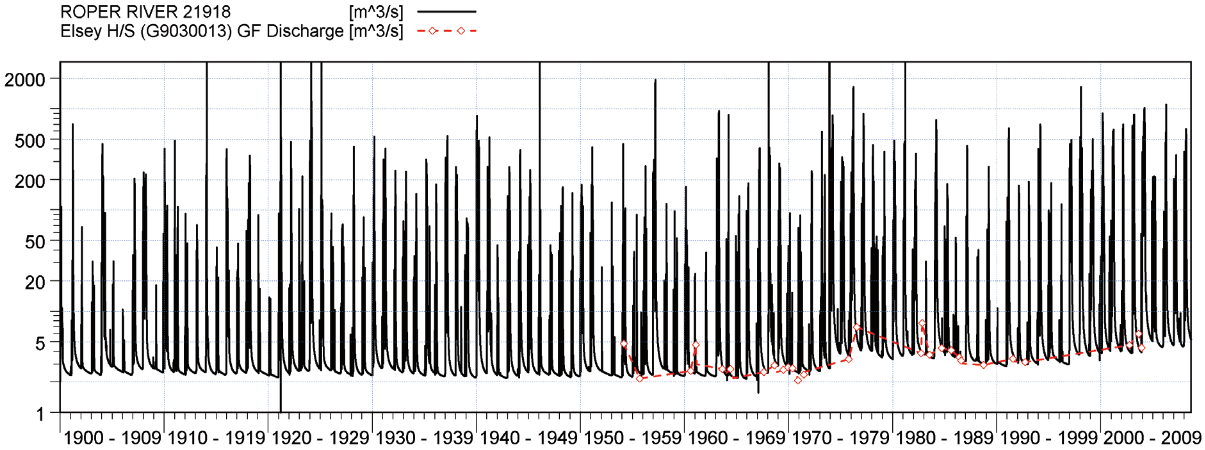


Figure 16 Comparison of simulated and observed discharges at Elsey Homestead (G9030013)

7.1.3 G9030123

The simulated discharge at MIKE11 chainage 74751 and measured discharge and gauged flows at Moroak (G9030123) are presented in **Figure 17**. The difference between the observed flows at G9030013 and G9030123 is primarily due to ET losses as the river flows through Red Lily Lagoon. Although this site does not have a continuous record, the comparison of the simulated flows and the gauged indicate reasonable agreement. However, there are a couple of readings in the mid-late 1960's which are between 0.5 - 0.7 m^3/s below those predicted. No explanation can be provided for the discrepancy, given that the discharges at both Elsey Homestead and Red Rock are not overestimated for the same period (refer **section 7.1.2** and **section 7.1.4**).

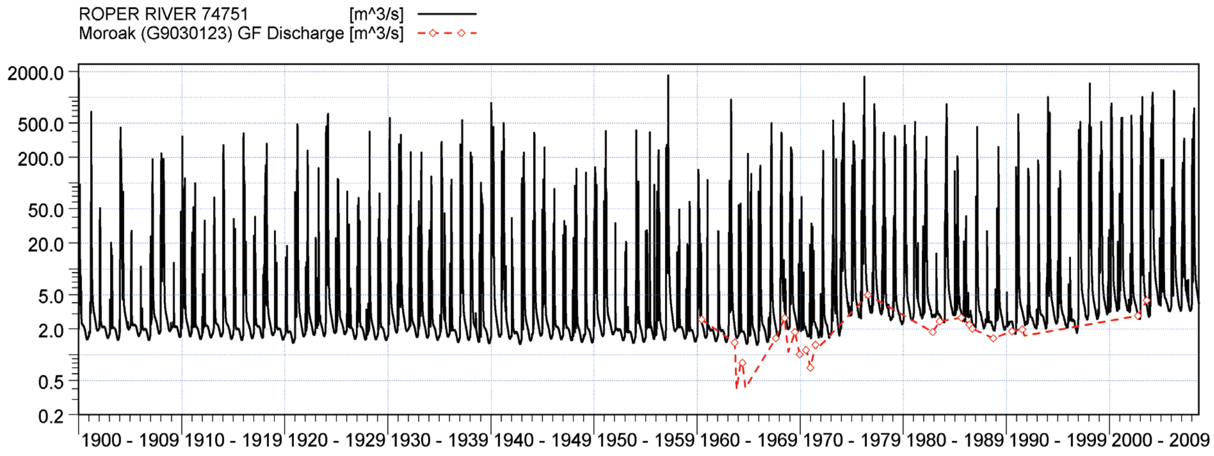


Figure 17 Comparison of simulated and observed discharges at Moroak (G9030123)

7.1.4 G9030250

The simulated discharge at MIKE11 chainage 183575 metres and measured discharge and gauged flows at Red Rock (G9030250) are presented in **Figure 18**. The declining flow towards the end of the dry season is due to the increasing evaporative demand during the lead up to the wet season.

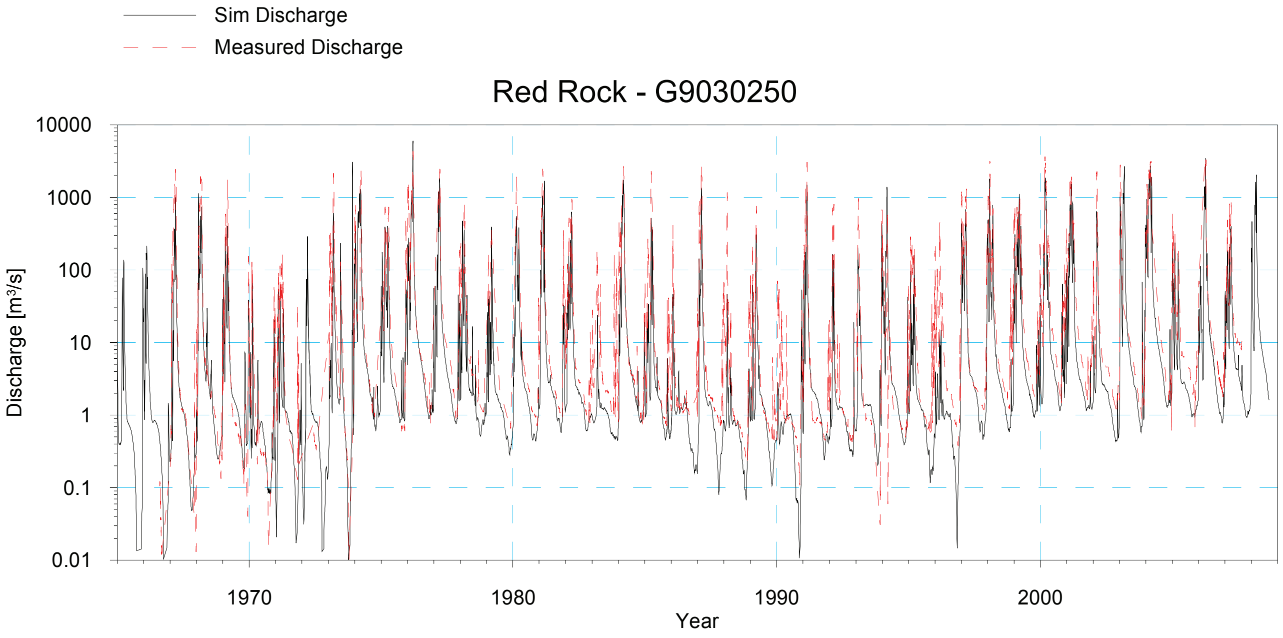


Figure 18 Comparison of simulated and observed discharges at Red Rock (G9030250) from 1966 - 2008

7.2 *Water Balances*

7.2.1 Average Annual Recharge

Over the 108.8 year simulation period the total recharge in the Mataranka Water Allocation Planning reporting area is 13 828 GL. This equates to approximately 127 GL/yr, the reporting region has an area of $5.571\text{x}10^9$ m^2 which means the average recharge rate over the area is 22.8 mm/yr or 0.0624 mm/d.

7.2.2 Average Annual Discharge

The average annual discharge at G9030013 for the period 1900 – 2008 is 652.3 GL/yr. The average annual discharge at G9030250 for the period 1900 – 2008 is estimated at 973.8 GL/yr. For the period where records are available at G9030250 (1966 – 2009) the average annual discharge is estimated at 1748.9 GL/yr. This is approximately double the long term average annual discharge, suggesting that the current period of record is biased towards a higher flow regime.

7.2.3 Groundwater discharge

The average annual groundwater discharge to the river from the Cambrain Limestone aquifer for the period 1900 – 2008 is estimated at 106.8 GL/yr which is approximately 11% of the total runoff measured at G9030250.

7.3 *Historic cease to flow at Red Rock for the period 1900 - 2008*

7.3.1 Historic flow duration

Another way of examining the flow dynamics and a rapid assessment of the effects of development at sites along the length of the river is using a flow duration curve. Flow duration or flow exceedance curves represent the percentage of time a specified discharge is equalled or exceeded. Exceedance curves were generated for the gauge sites at G9030013 (Elsey Homestead) and G9030250 (Red Rock) for the period 1900 – 2008. The curve for G9030013 indicates that under historic climatic conditions the river always exceeds 2 m^3/s, and that for 95% of the time exceeds 2.3 m^3/s. The curve for G9030250, however, indicates that the river ceased to flow approximately 5% of the time over the same period. For an average year this equates to about 18 days per year where cease to flow would occur.

Years where water quality at Ngukurr has been affected by salt water incursion have probably been due to a combination of low wet season flows and cease to flow at Red Rock.

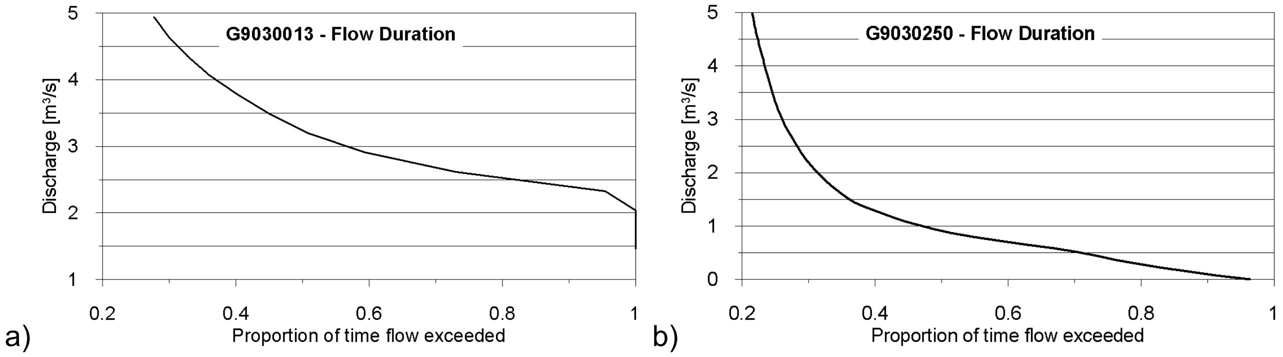


Figure 19 Flow duration curve for a) G9030013 and b) G9030250

7.3.2 Predicted cease to flow at Red Rock

Cease to flow (CTF) at Red Rock is of interest for the downstream users including the community of Ngukurr. It has been assumed that the CTF for the model occurs below 0.02 m^3/s (or 20 L/s).

Key finding

Cease to flow at the Red Rock gauging station historically was a relatively common occurrence.

Visual inspection of the discharge at Red Rock (**Figure 20**) indicates that cease to flow was a relatively common occurrence for the period 1900 – 1967 with 42 of the 73 years experiencing cease to flow conditions. This is in contrast to the following 34 year period from 1967 – 2008 where only 6 years were predicted where the Roper River ceased to flow at Red Rock.

Examination of the rainfall data (refer **Figure 5**) supports the model results with consistent below average rainfall persisting from 1900 -1973.

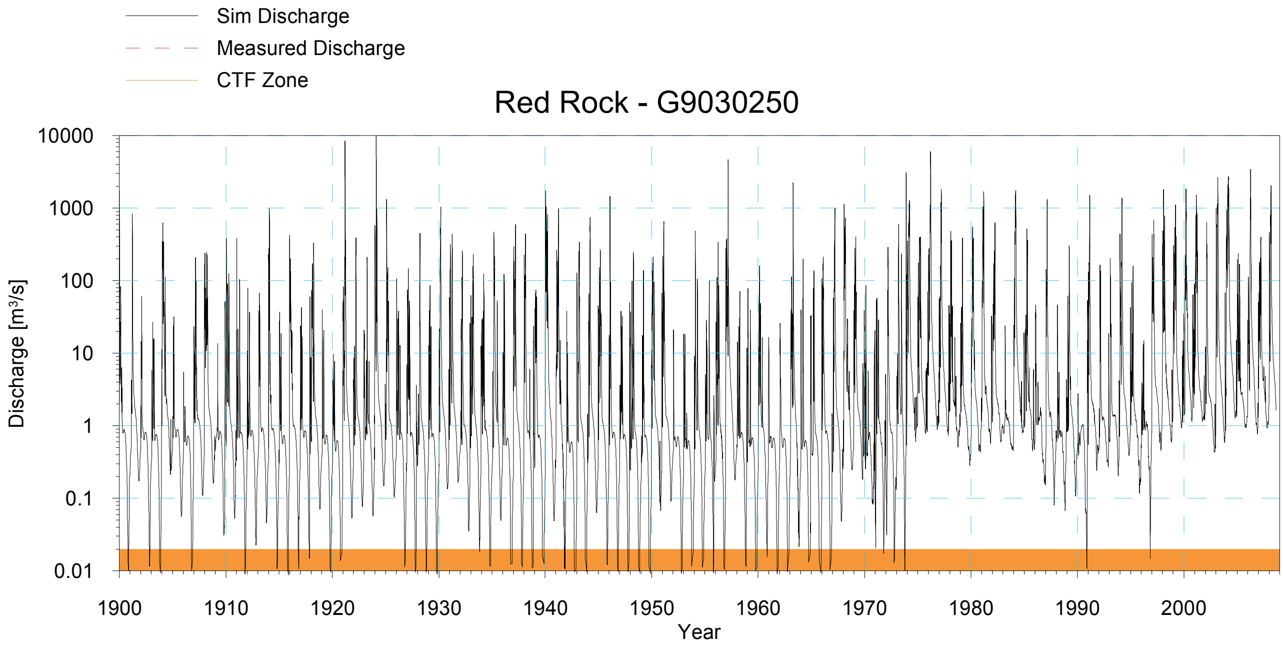


Figure 20 Predicted discharge hydrograph at Red Rock for the period 1900 – 2008 based on the integrated surface water / groundwater model. Cease to flow events (assumed to occur at flows less than 0.02 m^3/s) are predominantly in the period before flow gaugings have been measured.

7.3.3 Implications from the predicted cease to flow record

Currently the model provides an understanding of the flow dynamics along the length of the Roper River and its' tributaries, however, the deep perennial pools which contain large storages are poorly defined. Given that historically, cease to flow at Red Rock (G9030250) appears to be a relatively common occurrence and with extraction from the Cambrian Limestone aquifer likely to make cease to flow more common, then it is likely that downstream users will be reliant on these resources. It is recommended that the understanding of the water stored in the many large perennial pools is improved. The physical representation of these pools in the surface water model will come from further surveying of the river to define channel geometry.

7.4 Scenario Modelling

7.4.1 Modelled pumping scenarios

The pumping entitlements in the Mataranka Water Allocation Planning zone remain to be determined by the Mataranka Water Advisory Committee at the time of writing. However, a hypothetical scenario with an extraction equating to approximately 29 400 ML/yr is examined by modelling for the purposes of this report (Future Scenario). This is compared to the no-pumping scenario (Historic Scenario). Both scenarios are run over a 108.8 year timeframe (ie. from 1/1/1900 to 31/8/2008).

7.4.2 Water balances

The accumulated mass for areal fluxes and boundary condition fluxes into and out of the model domain for the reporting region were extracted for the two modelled scenarios. The total imbalance of the water budget for the two scenarios was also extracted. The total accumulated mass extracted at wells over the 108.8 year scenario using the Future Scenario was 3.150x10^9 m^3 or 3150 GL. The difference in total accumulated mass out of the model domain between the Future and Historical Scenarios is 2.029x10^9 m^3 or 2029 GL (**Figure 22**). Given that there is no increase in recharge, and induced recharge from the river is only 5.00x10^7 m^3 or 50 GL (**Figure 21**), the imbalance represents either a loss of water from storage or an increase in flow into the reporting area from outside.

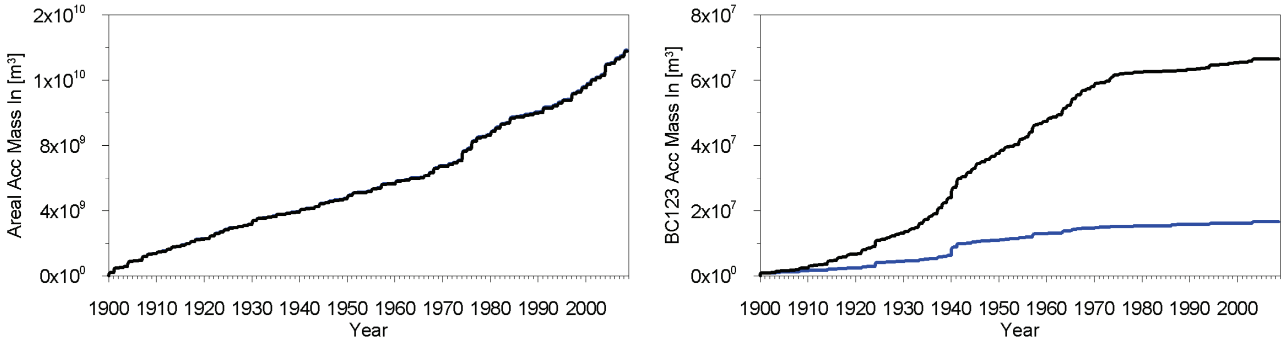


Figure 21 Accumulated mass in to the model domain from areal fluxes (recharge) and BC types 1,2 and 3.

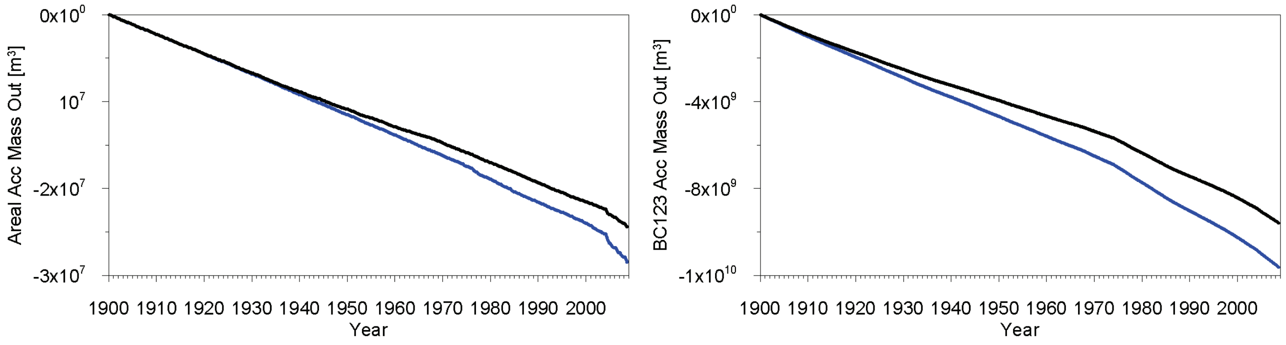


Figure 22 Accumulated mass out of the model domain from areal fluxes (ET) and BC types 1,2 and 3.

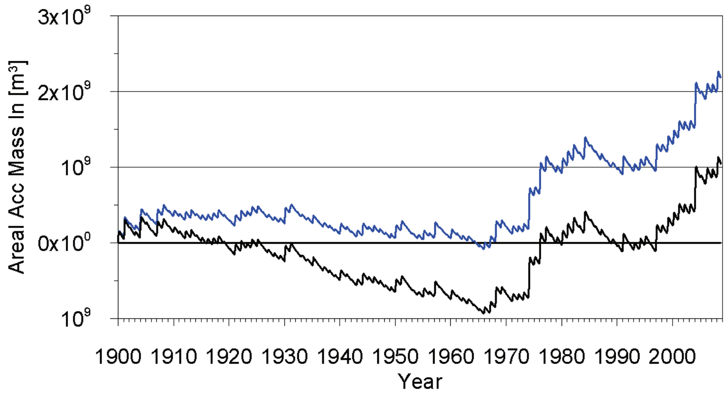


Figure 23 Accumulated mass imbalance, depicting the differences between inflows and outflow to the reporting area. The imbalance indicates the change in storage within the reporting area. The proposed scenario shows a final deficit of approximately $1.14x10^9m^3$ or 1140 GL from the historic imbalance.

The water budget imbalance indicates differences between inflows and outflow to the reporting area. The imbalance suggests that there is a change in storage within the reporting area. The proposed scenario shows a final deficit of approximately $1.14x10^9m^3$ or 1140 GL from the historic imbalance and that the process appears to reach dynamic equilibrium after approximately 50 years. This is because groundwater takes considerably longer than surface waters to move through the landscape. The slower flow times of groundwater compared to surface water means both that groundwater-fed rivers can continue to flow during the dry, but also that any downstream consequences of groundwater extraction may not be realised for many years. For the Future Scenario above, it can be expected that the impact of changing an extraction regime for the Cambrian Limestone at Mataranka, could take 50 or more years for the full consequences to be felt at the Red Lily Lagoon Wetland, nearly 40 km downstream.

Key finding

Groundwater travels much slower than surface water, hence responses to any change will be measured in years, not months.

Water levels in close proximity to the pumping bores indicate a decline of approximately 3 - 4 metres below the historic water levels (**Figure 24**). The reduced water levels are a direct consequence of the imbalance identified above.

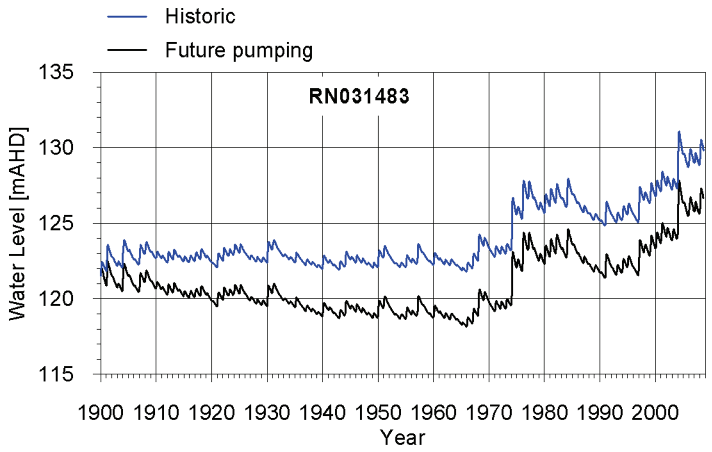


Figure 24 Simulated groundwater levels for the historic and hypothetical future scenarios

7.4.3 Flow duration curves

Exceedance curves were determined for the gauge sites at G9030013 (Elsey Homestead) and G9030250 (Red Rock) for the period 1900 – 2008. The curve for G9030013 indicates that under proposed pumping entitlements the river will 1.6 m^3/s, and that for 95% of the time exceeds 1.8 m^3/s. The curve for G9030250, however, indicates that the river ceased to flow approximately 20% of the time over the same period. For an average year this equates to about 73 days per year where cease to flow would occur.

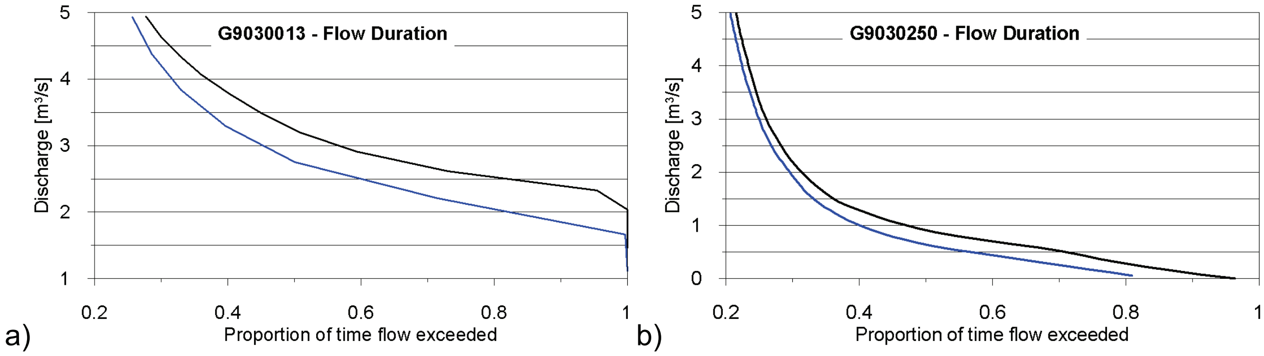


Figure 25 Flow duration curves under the historic conditions and hypothetical future pumping entitlements for a) G9030013 and b) G9030250.

8 Conclusions

The study has:

- Utilised the available data and provided further baseline information about groundwater levels and groundwater discharge data suitable for catchment management,
- Identified areas where groundwater dependent ecosystems within the Roper River catchment are likely to exist,
- Provided data on groundwater and surface water and their interrelationship into further studies on the connective environment and dependent ecological processes,

- Identified where potential impacts on water resources may result from major developments, namely the Cambrian Limestone aquifer in the area around Mataranka and the head waters of the Roper River,
- Developed an integrated surface water model and the groundwater model that incorporates the important components of the Roper River surface water system and evapotranspirational losses signifying groundwater dependence and a groundwater model of the two major aquifer systems providing dry season baseflow,
- Determined long term annual catchment water balances of surface water and groundwater to inform water allocation planning,
- Explicitly modelled the exchange fluxes between groundwater and surface water mainly to address the issue of 'double accounting' and hence obtain a true estimate of the water resources of the surface and groundwater systems,
- Provided a tool to enable assessment of development for allocation planning with respect to pumping scenarios and their effects on the dry season flows in the Roper River (ie. during periods when base flows are lowest),
- And provided a predictive model which can show the potential effects on water resources from climate change and to inform environmental water provisions for the Roper River catchment.

Of particular note is that historically, cease to flow conditions appear to have been a relatively common occurrence prior to the mid-1970's. With possible development (ie. extraction) from the Cambrian Limestone aquifer, the cease to flow condition is indicated to become more common.

9 Recommendations

Currently the model provides an understanding of the flow dynamics along the length of the Roper River and its' tributaries. However, the deep perennial pools which contain large storages are poorly defined. Given that historically cease to flow appears to be a relatively common occurrence and with extraction from the Cambrian Limestone aquifer likely to make cease to flow more common, then it is likely that downstream users will be reliant on these resources. It is suggested that the understanding of the water stored in the many large perennial pools is improved. The physical representation of these pools in the surface water model will come from further surveying of the river to define channel geometry.

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